# Fermipy Documentation

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CHAPTER 1

# Introduction

This is the Fermipy documentation page. Fermipy is a python package that facilitates analysis of data from the Large Area Telescope (LAT) with the Fermi Science Tools. For more information about the Fermi mission and the LAT instrument please refer to the Fermi Science Support Center.

The Fermipy package is built on the pyLikelihood interface of the Fermi Science Tools and provides a set of high-level tools for performing common analysis tasks:

- Data and model preparation with the gt-tools (gtselect, gtmktime, etc.).
- Extracting a spectral energy distribution (SED) of a source.
- Generating TS and residual maps for a region of interest.
- Finding new source candidates.
- Localizing a source or fitting its spatial extension.

Fermipy uses a configuration-file driven workflow in which the analysis parameters (data selection, IRFs, and ROI model) are defined in a YAML configuration file. Analysis is executed through a python script that calls the methods of `GTAnalysis` to perform different analysis operations.

For instructions on installing Fermipy see the *Installation* page. For a short introduction to using Fermipy see the *Quickstart Guide*.

## 1.1 Getting Help

If you have questions about using Fermipy please open a GitHub Issue or email the Fermipy developers.

## 1.2 Acknowledging Fermipy

To acknowledge Fermipy in a publication please cite Wood et al. 2017.

## 1.3 Documentation Contents

### 1.3.1 Installation

**Note:** From version 1.0.1 fermipy is only compatible with fermitools version 2 or later, and with python version 3.7 or higher. If you are using an earlier version, you will need to download and install the latest version from the FSSC.

These instructions will install fermipy as well as it's dependecies.

#### Conda-based installation

The recommended way to install fermipy and the fermitools by using conda.

Conda properly handles a rather complicated set of interdependencies between fermipy, the fermitools and packages they depend on.

```
$ conda create --name fermipy -c conda-forge -c fermi fermipy
```

#### Installing from source

If you want to install fermipy from source you can use the environment.yml file to install the dependecies. Installing from source can be useful if you want to make your own modifications to the fermipy source code. Note that non-developers are recommended to install a tagged release of fermipy following the *Conda-based installation* instructions above.

To set up a conda environment with the dependencies

```
$ git clone https://github.com/fermiPy/fermipy.git
$ cd fermipy
$ conda create --name fermipy -f environment.yml
```

To install the latest commit in the master branch run `setup.py install` from the root directory:

```
# Install the latest commit
$ git checkout master
$ python setup.py install
```

A useful option if you are doing active code development is to install your working copy of the package. This will create an installation in your python distribution that is linked to the copy of the code in your local repository. This allows you to run with any local modifications without having to reinstall the package each time you make a change. To install your working copy of fermipy run with the `develop` argument:

```
# Install a link to your source code installation
$ python setup.py develop
```

You can later remove the link to your working copy by running the same command with the `--uninstall` flag:

```
# Install a link to your source code installation
$ python setup.py develop --uninstall
```

Specific release tags can be installed by running `git checkout` before running the installation command:

```
# Checkout a specific release tag
$ git checkout X.X.X
$ python setup.py install
```

To see the list of available release tags run `git tag`.

#### The diffuse emission models

Starting with fermipy version 0.19.0, we are using the diffuse and istoropic emission model from the fermitools-data package rather than including them in fermipy. However, for working on older analyses created with earlier version of fermipy you can set the FERMI_DIFFUSE_DIR environmental variable to point at a directory that include the version of the models that you wish to use.

#### Upgrading

By default installing fermipy with `pip` or `conda` will get the latest tagged released available on the PyPi package respository. You can check your currently installed version of fermipy with `pip show`:

```
$ pip show fermipy
```

or `conda info`:

```
$ conda info fermipy
```

To upgrade your fermipy installation to the latest version run the pip installation command with `--upgrade --no-deps` (remember to also include the `--user` option if you're running at SLAC):

```
$ pip install fermipy --upgrade --no-deps
Collecting fermipy
Installing collected packages: fermipy
  Found existing installation: fermipy 0.6.6
    Uninstalling fermipy-0.6.6:
      Successfully uninstalled fermipy-0.6.6
Successfully installed fermipy-0.6.7
```

If you installed fermipy with `conda` the equivalent command is:

```
$ conda update fermipy
```

### 1.3.2 Quickstart Guide

This page walks through the steps to setup and perform a basic spectral analysis of a source. For additional fermipy tutorials see the *IPython Notebook Tutorials*. To more easily follow along with this example a directory containing pre-generated input files (FT1, source maps, etc.) is available from the following link:

```
$ curl -OL https://raw.githubusercontent.com/fermiPy/fermipy-extras/master/data/
↪mkn421.tar.gz
$ tar xzf mkn421.tar.gz
$ cd mkn421
```

### Creating a Configuration File

The first step is to compose a configuration file that defines the data selection and analysis parameters. Complete documentation on the configuration file and available options is given in the *Configuration* page. fermiPy uses the YAML format for its configuration files. The configuration file has a hierarchical organization that groups related parameters into separate dictionaries. In this example we will compose a configuration file for a SOURCE-class analysis of Markarian 421 with FRONT+BACK event types (evtype=3):

```
data:
  evfile : ft1.lst
  scfile : ft2.fits
  ltcube : ltcube.fits

binning:
  roiwidth   : 10.0
  binsz      : 0.1
  binsperdec : 8

selection :
  emin : 100
  emax : 316227.76
  zmax    : 90
  evclass : 128
  evtype  : 3
  tmin    : 239557414
  tmax    : 428903014
  filter  : null
  target : 'mkn421'

gtlike:
  edisp : True
  irfs : 'P8R2_SOURCE_V6'
  edisp_disable : ['isodiff','galdiff']

model:
  src_roiwidth : 15.0
  galdiff  : '$FERMI_DIFFUSE_DIR/gll_iem_v06.fits'
  isodiff  : 'iso_P8R2_SOURCE_V6_v06.txt'
  catalogs : ['3FGL']
```

The *data* section defines the input data set and spacecraft file for the analysis. Here `evfile` points to a list of FT1 files that encompass the chosen ROI, energy range, and time selection. The parameters in the *binning* section define the dimensions of the ROI and the spatial and energy bin size. The *selection* section defines parameters related to the data selection (energy range, zmax cut, and event class/type). The `target` parameter in this section defines the ROI center to have the same coordinates as the given source. The *model* section defines parameters related to the ROI model definition (diffuse templates, point sources).

Fermipy gives the user the option to combine multiple data selections into a joint likelihood with the *components* section. The components section contains a list of dictionaries with the same hierarchy as the root analysis configuration. Each element of the list defines the analysis parameters for an independent sub-selection of the data. Any parameters not defined within the component dictionary default to the value defined in the root configuration. The following example shows the *components* section that could be appended to the previous configuration to define a joint analysis with four PSF event types:

```
components:
  - { selection : { evtype : 4  } } # PSF0
  - { selection : { evtype : 8  } } # PSF1
```

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```
  - { selection : { evtype : 16 } } # PSF2
  - { selection : { evtype : 32 } } # PSF3
```

Any configuration parameter can be changed with this mechanism. The following example is a configuration in which a different zmax selection and isotropic template is used for each of the four PSF event types:

```
components:
  - model: {isodiff: isotropic_source_psf0_4years_P8V3.txt}
    selection: {evtype: 4, zmax: 70}
  - model: {isodiff: isotropic_source_psf1_4years_P8V3.txt}
    selection: {evtype: 8, zmax: 75}
  - model: {isodiff: isotropic_source_psf2_4years_P8V3.txt}
    selection: {evtype: 16, zmax: 85}
  - model: {isodiff: isotropic_source_psf3_4years_P8V3.txt}
    selection: {evtype: 32, zmax: 90}
```

### Creating an Analysis Script

Once the configuration file has been composed, the analysis is executed by creating an instance of `GTAnalysis` with the configuration file as its argument and calling its analysis methods. `GTAnalysis` serves as a wrapper over the underlying pyLikelihood classes and provides methods to fix/free parameters, add/remove sources from the model, and perform a fit to the ROI. For a complete documentation of the available methods you can refer to the *fermipy package* page.

In the following python examples we show how to initialize and run a basic analysis of a source. First we instantiate a `GTAnalysis` object with the path to the configuration file and run `setup()`.

```
from fermipy.gtanalysis import GTAnalysis

gta = GTAnalysis('config.yaml',logging={'verbosity' : 3})
gta.setup()
```

The `setup()` method performs the data preparation and response calculations needed for the analysis (selecting the data, creating counts and exposure maps, etc.). Depending on the data selection and binning of the analysis this will often be the slowest step in the analysis sequence. The output of `setup()` is cached in the analysis working directory so subsequent calls to `setup()` will run much faster.

Before running any other analysis methods it is recommended to first run `optimize()`:

```
gta.optimize()
```

This will loop over all model components in the ROI and fit their normalization and spectral shape parameters. This method also computes the TS of all sources which can be useful for identifying weak sources that could be fixed or removed from the model. We can check the results of the optimization step by calling `print_roi()`:

```
gta.print_roi()
```

By default all models parameters are initially fixed. The `free_source()` and `free_sources()` methods can be use to free or fix parameters of the model. In the following example we free the normalization of catalog sources within 3 deg of the ROI center and free the galactic and isotropic components by name.

```
# Free Normalization of all Sources within 3 deg of ROI center
gta.free_sources(distance=3.0,pars='norm')
```

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```
# Free all parameters of isotropic and galactic diffuse components
gta.free_source('galdiff')
gta.free_source('isodiff')
```

The `minmax_ts` and `minmax_npred` arguments to `free_sources()` can be used to free or fixed sources on the basis of their current TS or Npred values:

```
# Free sources with TS > 10
gta.free_sources(minmax_ts=[10,None],pars='norm')

# Fix sources with TS < 10
gta.free_sources(minmax_ts=[None,10],free=False,pars='norm')

# Fix sources with 10 < Npred < 100
gta.free_sources(minmax_npred=[10,100],free=False,pars='norm')
```

When passing a source name argument both case and whitespace are ignored. When using a FITS catalog file a source can also be referred to by any of its associations. When using the 3FGL catalog, the following calls are equivalent ways of freeing the parameters of Mkn 421:

```
# These calls are equivalent
gta.free_source('mkn421')
gta.free_source('Mkn 421')
gta.free_source('3FGL J1104.4+3812')
gta.free_source('3fglj1104.4+3812')
```

After freeing parameters of the model we can execute a fit by calling `fit()`. The will maximize the likelihood with respect to the model parameters that are currently free.

```
gta.fit()
```

After the fitting is complete we can write the current state of the model with `write_roi`:

```
gta.write_roi('fit_model')
```

This will write several output files including an XML model file and an ROI dictionary file. The names of all output files will be prepended with the `prefix` argument to `write_roi()`.

Once we have optimized our model for the ROI we can use the `residmap()` and `tsmap()` methods to assess the fit quality and look for new sources.

```
# Dictionary defining the spatial/spectral parameters of the test source
model = {'SpatialModel' : 'PointSource', 'Index' : 2.0,
         'SpectrumType' : 'PowerLaw'}

# Both methods return a dictionary with the maps
m0 = gta.residmap('fit_model', model=model, make_plots=True)
m1 = gta.tsmap('fit_model', model=model, make_plots=True)
```

More documentation on these methods is available in the *TS Map* and *Residual Map* pages.

By default, calls to `fit()` will execute a global spectral fit over the entire energy range of the analysis. To extract a bin-by-bin flux spectrum (i.e. a SED) you can call `sed()` method with the name of the source:

```
gta.sed('mkn421', make_plots=True)
```

More information about `sed()` method can be found in the *SED Analysis* page.

### Extracting Analysis Results

Results of the analysis can be extracted from the dictionary file written by `write_roi()`. This method writes information about the current state of the analysis to a python dictionary. More documentation on the contents of the output file are available in the *Output File* page.

By default the output dictionary is written to a file in the numpy format and can be loaded from a python session after your analysis is complete. The following demonstrates how to load the analysis dictionary that was written to *fit_model.npy* in the Mkn421 analysis example:

```
>>> # Load analysis dictionary from a npy file
>>> import np
>>> c = np.load('fit_model.npy').flat[0]
>>> list(c.keys())
['roi', 'config', 'sources', 'version']
```

The output dictionary contains the following top-level elements:

Table 1: File Dictionary

| Key | Description | |
|---|---|---|
| `roi` | `dict` | A dictionary containing information about the ROI as a whole. |
| `sources` | `dict` | A dictionary containing information about individual sources in the model (diffuse and point-like). Each element of this dictionary maps to a single source in the ROI model. |
| `config` | `dict` | The configuration dictionary of the `GTAnalysis` instance. |
| `version` | `str` | The version of the Fermipy package that was used to run the analysis. This is automatically generated from the git release tag. |

Each source dictionary collects the properties of the given source (TS, NPred, best-fit parameters, etc.) computed up to that point in the analysis.

```
>>> list(c['sources'].keys())
['3FGL J1032.7+3735',
'3FGL J1033.2+4116',
...
'3FGL J1145.8+4425',
'galdiff',
'isodiff']
>>> c['sources']['3FGL J1104.4+3812']['ts']
87455.9709683
>>> c['sources']['3FGL J1104.4+3812']['npred']
31583.7166495
```

Information about individual sources in the ROI is also saved to a catalog FITS file with the same string prefix as the dictionary file. This file can be loaded with the `astropy.io.fits` or `astropy.table.Table` interface:

```
>>> # Load the source catalog file
>>> from astropy.table import Table
>>> tab = Table.read('fit_model.fits')
>>> tab[['name','class','ts','npred','flux']]
    name       class       ts           npred                    flux [2]
                                                              1 / (cm2 s)
----------------- ----- -------------- ------------- --------------------------------
 ↪-----
3FGL J1104.4+3812   BLL   87455.9709683 31583.7166495 2.20746290445e-07 .. 1.
 ↪67062058528e-09
3FGL J1109.6+3734   bll    42.34511826 93.7971922425  5.90635786943e-10 .. 3.
 ↪6620894143e-10
```

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```
...
3FGL J1136.4+3405  fsrq  4.78089819776 261.427034151 1.86805869704e-08 .. 8.
↪62638727067e-09
3FGL J1145.8+4425  fsrq  3.78006883967 237.525501441 7.25611442299e-08 .. 3.
↪77056557247e-08
```

The FITS file contains columns for all scalar and vector elements of the source dictionary. Spectral fit parameters are contained in the `param_names`, `param_values`, and `param_errors` columns:

```
>>> tab[['param_names','param_values','param_errors']][0]
<Row 0 of table
 values=(['Prefactor', 'Index', 'Scale', '', '', ''],
         [2.1301351784512767e-11, -1.7716399431228638, 1187.1300048828125, nan, nan,␣
↪nan],
         [1.6126233510314277e-13, nan, nan, nan, nan, nan])
 dtype=[('param_names', 'S32', (6,)),
        ('param_values', '>f8', (6,)),
        ('param_errors', '>f8', (6,))]>
```

### Reloading from a Previous State

One can reload an analysis instance that was saved with `write_roi()` by calling either the `create()` or `load_roi()` methods. The `create()` method can be used to construct an entirely new instance of `GTAnalysis` from a previously saved results file:

```
from fermipy.gtanalysis import GTAnalysis
gta = GTAnalysis.create('fit_model.npy')

# Continue running analysis starting from the previously saved
# state
gta.fit()
```

where the argument is the path to an output file produced with `write_roi()`. This function will instantiate a new analysis object, run the `setup()` method, and load the state of the model parameters at the time that `write_roi()` was called.

The `load_roi()` method can be used to reload a previous state of the analysis to an existing instance of `GTAnalysis`.

```
from fermipy.gtanalysis import GTAnalysis

gta = GTAnalysis('config.yaml')
gta.setup()

gta.write_roi('prefit_model')

# Fit a source
gta.free_source('mkn421')
gta.fit()

# Restore the analysis to its prior state before the fit of mkn421
# was executed
gta.load_roi('prefit_model')
```

Using `load_roi()` is generally faster than `create()` when an analysis instance already exists.

#### IPython Notebook Tutorials

Additional tutorials with more detailed examples are available as IPython notebooks in the notebooks directory of the fermipy-extra respository. These notebooks can be browsed as static web pages or run interactively by downloading the fermipy-extra repository and running `jupyter notebook` in the notebooks directory:

```
$ git clone https://github.com/fermiPy/fermipy-extra.git
$ cd fermipy-extra/notebooks
$ jupyter notebook index.ipynb
```

Note that this will require you to have both ipython and jupyter installed in your python environment. These can be installed in a conda- or pip-based installation as follows:

```
# Install with conda
$ conda install ipython jupyter

# Install with pip
$ pip install ipython jupyter
```

One can also run the notebooks from a docker container following the dockerinstall instructions:

```
$ git clone https://github.com/fermiPy/fermipy-extra.git
$ cd fermipy-extra
$ docker pull fermipy/fermipy
$ docker run -it --rm -p 8888:8888 -v $PWD:/workdir -w /workdir fermipy/fermipy
```

After launching the notebook server, paste the URL that appears into your web browser and navigate to the *notebooks* directory.

### 1.3.3 Configuration

This page describes the configuration management scheme used within the Fermipy package and documents the configuration parameters that can be set in the configuration file.

#### Class Configuration

Classes in the Fermipy package own a configuration state dictionary that is initialized when the class instance is created. Elements of the configuration dictionary can be scalars (str, int, float) or dictionaries containing groups of parameters. The settings in this dictionary are used to control the runtime behavior of the class.

When creating a class instance, the configuration is initialized by passing either a configuration dictionary or configuration file path to the class constructor. Keyword arguments can be passed to the constructor to override configuration parameters in the input dictionary. In the following example the *config* dictionary defines values for the parameters *emin* and *emax*. By passing a dictionary for the *selection* keyword argument, the value of *emax* in the keyword argument (10000) overrides the value of *emax* in the input dictionary.

```
config = {
'selection' : { 'emin' : 100,
                'emax' : 1000 }
}

gta = GTAnalysis(config,selection={'emax' : 10000})
```

The first argument can also be the path to a YAML configuration file rather than a dictionary:

```
gta = GTAnalysis('config.yaml',selection={'emax' : 10000})
```

### Configuration File

Fermipy uses YAML files to read and write its configuration in a persistent format. The configuration file has a hierarchical structure that groups parameters into dictionaries that are keyed to a section name (*data*, *binning*, etc.).

Listing 1: Sample Configuration

```
data:
  evfile : ft1.lst
  scfile : ft2.fits
  ltcube : ltcube.fits

binning:
  roiwidth   : 10.0
  binsz      : 0.1
  binsperdec : 8

selection :
  emin : 100
  emax : 316227.76
  zmax    : 90
  evclass : 128
  evtype  : 3
  tmin    : 239557414
  tmax    : 428903014
  filter  : null
  target : 'mkn421'

gtlike:
  edisp : True
  edisp_bins : -1
  irfs : 'P8R3_SOURCE_V2'
  edisp_disable : ['isodiff','galdiff']

model:
  src_roiwidth : 15.0
  galdiff  : '$FERMI_DIFFUSE_DIR/gll_iem_v07.fits'
  isodiff  : 'iso_P8R3_SOURCE_V2_v1.txt'
  catalogs : ['4FGL']
```

The configuration file has the same structure as the configuration dictionary such that one can read/write configurations using the load/dump methods of the yaml module :

```
import yaml
# Load a configuration
config = yaml.load(open('config.yaml'))
# Update a parameter and write a new configuration
config['selection']['emin'] = 1000.
yaml.dump(config, open('new_config.yaml','w'))
```

Most of the configuration parameters are optional and if not set explicitly in the configuration file will be set to a default value. The parameters that can be set in each section are described below.

### binning

Options in the *binning* section control the spatial and spectral binning of the data.

Listing 2: Sample *binning* Configuration

```
binning:

  # Binning
  roiwidth   : 10.0
  npix       : null
  binsz      : 0.1 # spatial bin size in deg
  binsperdec : 8   # nb energy bins per decade
  projtype   : WCS
```

Table 2: *binning* Options

| Option | Default | Description |
|---|---|---|
| binsperdec | 8 | Number of energy bins per decade. |
| binsz | 0.1 | Spatial bin size in degrees. |
| coordsys | CEL | Coordinate system of the spatial projection (CEL or GAL). |
| enumbins | None | Number of energy bins. If none this will be inferred from energy range and binsperdec parameter. |
| hpx_ebin | True | Include energy binning |
| hpx_order | 10 | Order of the map (int between 0 and 12, included) |
| hpx_ordering_scheme | RING | HEALPix Ordering Scheme |
| npix | None | Number of pixels in the x and y direction. If none then this will be set from roiwidth and binsz. |
| proj | AIT | Spatial projection for WCS mode. |
| projtype | WCS | Projection mode (WCS or HPX). |
| roiwidth | 10.0 | Width of the ROI in degrees. The number of pixels in each spatial dimension will be set from roiwidth / binsz (rounded up). |

### components

The *components* section can be used to define analysis configurations for independent subselections of the data. Each subselection will have its own binned likelihood instance that is combined in a global likelihood function for the ROI (implemented with the SummedLikelihood class in pyLikelihood). The *components* section is optional and when set to null (the default) only a single likelihood component will be created with the parameters of the root analysis configuration.

The component section is defined as a list of dictionaries where each element sets analysis parameters for a different subcomponent of the analysis. The component configurations follow the same structure and accept the same parameters as the root analysis configuration. Parameters not defined in a given element will default to the values set in the root analysis configuration.

The following example illustrates how to define a Front/Back analysis with two components. Files associated to each component will be given a suffix according to their order in the list (e.g. file_00.fits, file_01.fits, etc.).

```
# Component section for Front/Back analysis
  - { selection : { evtype : 1 } } # Front
  - { selection : { evtype : 2 } } # Back
```

### data

The *data* section defines the input data files for the analysis (FT1, FT2, and livetime cube). `evfile` and `scfile` can either be individual files or group of files. The optional `ltcube` option can be used to choose a pre-generated livetime cube. If `ltcube` is null a livetime cube will be generated at runtime with `gtltcube`.

Listing 3: Sample *data* Configuration

```
data :
  evfile : ft1.lst
  scfile : ft2.fits
  ltcube : null
```

Table 3: *data* Options

| Option | Default | Description |
|---|---|---|
| `cacheft1` | True | Cache FT1 files when performing binned analysis. If false then only the counts cube is retained. |
| `evfile` | None | Path to FT1 file or list of FT1 files. |
| `ltcube` | None | Path to livetime cube. If none a livetime cube will be generated with `gtmktime`. |
| `scfile` | None | Path to FT2 (spacecraft) file. |

### extension

The options in *extension* control the default behavior of the `extension` method. For more information about using this method see the *Extension Fitting* page.

Table 4: *extension* Options

| Option | Default | Description |
|---|---|---|
| fit_ebin | False | Perform a fit for the angular extension in each analysis energy bin. |
| fit_position | False | Perform a simultaneous fit to the source position and extension. |
| fix_shape | False | Fix spectral shape parameters of the source of interest. If True then only the normalization parameter will be fit. |
| free_background | False | Leave background parameters free when performing the fit. If True then any parameters that are currently free in the model will be fit simultaneously with the source of interest. |
| free_radius | None | Free normalizations of background sources within this angular distance in degrees from the source of interest. If None then no sources will be freed. |
| make_plots | False | Generate diagnostic plots. |
| make_tsmap | True | Make a TS map for the source of interest. |
| psf_scale_fn | None | Tuple of two vectors (logE,f) defining an energy-dependent PSF scaling function that will be applied when building spatial models for the source of interest. The tuple (logE,f) defines the fractional corrections f at the sequence of energies logE = log10(E/MeV) where f=0 corresponds to no correction. The correction function f(E) is evaluated by linearly interpolating the fractional correction factors f in log(E). The corrected PSF is given by P'(x;E) = P(x/(1+f(E));E) where x is the angular separation. |
| save_model_map | False | Save model counts cubes for the best-fit model of extension. |
| spatial_model | RadialGaussian | Spatial model that will be used to test the sourceextension. The spatial scale parameter of the model will be set such that the 68% containment radius of the model is equal to the width parameter. |
| sqrt_ts_threshold | None | Threshold on sqrt(TS_ext) that will be applied when update is True. If None then nothreshold is applied. |
| tsmap_fitter | tsmap | Set the method for generating the TS map. Valid options are tsmap or tscube. |
| update | False | Update this source with the best-fit model for spatial extension if TS_ext > tsext_threshold. |
| width | None | Sequence of values in degrees for the likelihood scan over spatial extension (68% containment radius). If this argument is None then the scan points will be determined from width_min/width_max/width_nstep. |
| width_max | 1.0 | Maximum value in degrees for the likelihood scan over spatial extent. |
| width_min | 0.01 | Minimum value in degrees for the likelihood scan over spatial extent. |
| width_nstep | 21 | Number of scan points between width_min and width_max. Scan points will be spaced evenly on a logarithmic scale between width_min and width_max. |
| write_fits | True | Write the output to a FITS file. |
| write_npy | True | Write the output dictionary to a numpy file. |

### fileio

The *fileio* section collects options related to file bookkeeping. The outdir option sets the root directory of the analysis instance where all output files will be written. If outdir is null then the output directory will be automatically set to the directory in which the configuration file is located. Enabling the usescratch option will stage all output data files to a temporary scratch directory created under scratchdir.

Listing 4: Sample *fileio* Configuration

```
fileio:
   outdir : null
   logfile : null
   usescratch : False
   scratchdir  : '/scratch'
```

Table 5: *fileio* Options

| Option | Default | Description |
|---|---|---|
| logfile | None | Path to log file. If None then log will be written to fermipy.log. |
| outdir | None | Path of the output directory. If none this will default to the directory containing the configuration file. |
| outdir_regex | ['.fits$', '.fit$', '.xml$', 'srcmap', 'bexpmap', 'wmap'] | Stage files to the output directory that match at least one of the regular expressions in this list. This option only takes effect when usescratch is True. |
| savefits | True | Save intermediate FITS files. |
| scratchdir | /scratch | Path to the scratch directory. If usescratch is True then a temporary working directory will be created under this directory. |
| usescratch | False | Run analysis in a temporary working directory under scratchdir. |
| workdir | None | Path to the working directory. |
| workdir_regex | ['.fits$', '.fit$', '.xml$', 'srcmap', 'bexpmap', 'wmap'] | Stage files to the working directory that match at least one of the regular expressions in this list. This option only takes effect when usescratch is True. |

### gtlike

Options in the *gtlike* section control the setup of the likelihood analysis include the IRF name (irfs). The edisp_bin option has been recently added to implement the latest handling of the energy dispersion (see FSSC for further details).

Table 6: *gtlike* Options

| Option | Default | Description |
|---|---|---|
| bexpmap | None | |
| bexpmap_base | None | Set the basline all-sky expoure map file. This will be used to generate a scaled source map. |
| bexpmap_roi | None | |
| bexpmap_roi_base | None | Set the basline ROI expoure map file. This will be used to generate a scaled source map. |
| convolve | True | |
| edisp | True | Enable the correction for energy dispersion. |
| edisp_bins | -1 | Number of bins to use for energy correction. |
| edisp_disable | None | Provide a list of sources for which the edisp correction should be disabled. |
| expscale | None | Exposure correction that is applied to all sources in the analysis component. This correction is superseded by src_expscale if it is defined for a source. |
| irfs | None | Set the IRF string. |
| llscan_npts | 20 | Number of evaluation points to use when performing a likelihood scan. |
| minbinsz | 0.05 | Set the minimum bin size used for resampling diffuse maps. |
| resample | True | |
| rfactor | 2 | |
| src_expscale | None | Dictionary of exposure corrections for individual sources keyed to source name. The exposure for a given source will be scaled by this value. A value of 1.0 corresponds to the nominal exposure. |
| srcmap | None | Set the source maps file. When defined this file will be used instead of the local source maps file. |
| srcmap_base | None | Set the baseline source maps file. This will be used to generate a scaled source map. |
| use_external_srcmap | False | Use an external precomputed source map file. |
| use_scaled_srcmap | False | Generate source map by scaling an external srcmap file. |
| wmap | None | Likelihood weights map. |

### lightcurve

The options in *lightcurve* control the default behavior of the `lightcurve` method. For more information about using this method see the *Light Curves* page.

Table 7: *lightcurve* Options

| Option | Default | Description |
|---|---|---|
| `binsz` | 86400.0 | Set the lightcurve bin size in seconds. |
| `free_background` | False | Leave background parameters free when performing the fit. If True then any parameters that are currently free in the model will be fit simultaneously with the source of interest. |
| `free_params` | None | Set the parameters of the source of interest that will be re-fit in each time bin. If this list is empty then all parameters will be freed. |
| `free_radius` | None | Free normalizations of background sources within this angular distance in degrees from the source of interest. If None then no sources will be freed. |
| `free_sources` | None | List of sources to be freed. These sources will be added to the list of sources satisfying the free_radius selection. |
| `make_plots` | False | Generate diagnostic plots. |
| `max_free_sources` | 5 | Maximum number of sources that will be fit simultaneously with the source of interest. |
| `multithread` | False | Split the calculation across number of processes set by nthread option. |
| `nbins` | None | Set the number of lightcurve bins. The total time range will be evenly split into this number of time bins. |
| `nthread` | None | Number of processes to create when multithread is True. If None then one process will be created for each available core. |
| `outdir` | None | Store all data in this directory (e.g. "30days"). If None then use current directory. |
| `save_bin_data` | True | Save analysis directories for individual time bins. If False then only the analysis results table will be saved. |
| `shape_ts_threshold` | 16.0 | Set the TS threshold at which shape parameters of sources will be freed. If a source is detected with TS less than this value then its shape parameters will be fixed to values derived from the analysis of the full time range. |
| `systematic` | 0.02 | Systematic correction factor for TS:subscript:`var`. See Sect. 3.6 in 2FGL for details. |
| `time_bins` | None | Set the lightcurve bin edge sequence in MET. This option takes precedence over binsz and nbins. |
| `use_local_ltcube` | True | Generate a fast LT cube. |
| `use_scaled_srcmap` | False | Generate approximate source maps for each time bin by scaling the current source maps by the exposure ratio with respect to that time bin. |
| `write_fits` | True | Write the output to a FITS file. |
| `write_npy` | True | Write the output dictionary to a numpy file. |

### model

The *model* section collects options that control the inclusion of point-source and diffuse components in the model. `galdiff` and `isodiff` set the templates for the Galactic IEM and isotropic diffuse respectively. `catalogs` defines a list of catalogs that will be merged to form a master analysis catalog from which sources will be drawn. Valid entries in this list can be FITS files or XML model files. `sources` can be used to insert additional point-source or extended components beyond those defined in the master catalog. `src_radius` and `src_roiwidth` set the maximum distance from the ROI center at which sources in the master catalog will be included in the ROI model.

Listing 5: Sample *model* Configuration

```
model :
```

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```
# Diffuse components
galdiff  : '$FERMI_DIR/refdata/fermi/galdiffuse/gll_iem_v06.fits'
isodiff  : '$FERMI_DIR/refdata/fermi/galdiffuse/iso_P8R2_SOURCE_V6_v06.txt'

# List of catalogs to be used in the model.
catalogs :
  - '3FGL'
  - 'extra_sources.xml'

sources :
  - { 'name' : 'SourceA', 'ra' : 60.0, 'dec' : 30.0, 'SpectrumType' : PowerLaw }
  - { 'name' : 'SourceB', 'ra' : 58.0, 'dec' : 35.0, 'SpectrumType' : PowerLaw }

# Include catalog sources within this distance from the ROI center
src_radius  : null

# Include catalog sources within a box of width roisrc.
src_roiwidth : 15.0
```

Table 8: *model* Options

| Option | Default | Description |
|---|---|---|
| assoc_xmatch_columns | ['3FGL_Name'] | Choose a set of association columns on which to cross-match catalogs. |
| catalogs | None | |
| diffuse | None | |
| diffuse_dirs | None | |
| diffuse_templates | None | |
| extdir | None | Set a directory that will be searched for extended source FITS templates. Template files in this directory will take precendence over catalog source templates with the same name. |
| extract_diffuse | False | Extract a copy of all mapcube components centered on the ROI. |
| galdiff | None | Set the path to one or more galactic IEM mapcubes. A separate component will be generated for each item in this list. |
| isodiff | None | Set the path to one or more isotropic templates. A separate component will be generated for each item in this list. |
| limbdiff | None | |
| merge_sources | True | Merge properties of sources that appear in multiple source catalogs. If merge_sources=false then subsequent sources with the same name will be ignored. |
| sources | None | |
| src_radius | None | Radius of circular region in degrees centered on the ROI that selects sources for inclusion in the model. If this parameter is none then no selection is applied. This selection is ORed with the src_roiwidth selection. |
| src_radius_roi | None | Half-width of src_roiwidth selection. This parameter can be used in lieu of src_roiwidth. |
| src_roiwidth | None | Width of square region in degrees centered on the ROI that selects sources for inclusion in the model. If this parameter is none then no selection is applied. This selection will be ORed with the src_radius selection. |

### optimizer

Table 9: *optimizer* Options

| Option | Default | Description |
|---|---|---|
| init_lambda | 0.0001 | Initial value of damping parameter for step size calculation when using the NEWTON fitter. A value of zero disables damping. |
| max_iter | 100 | Maximum number of iterations for the Newtons method fitter. |
| min_fit_quality | 2 | Set the minimum fit quality. |
| optimizer | MINUIT | Set the optimization algorithm to use when maximizing the likelihood function. |
| retries | 3 | Set the number of times to retry the fit when the fit quality is less than min_fit_quality. |
| tol | 0.001 | Set the optimizer tolerance. |
| verbosity | 0 | |

### plotting

Table 10: *plotting* Options

| Option | Default | Description |
|---|---|---|
| catalogs | None | |
| cmap | magma | Set the colormap for 2D plots. |
| cmap_resid | RdBu_r | Set the colormap for 2D residual plots. |
| figsize | [8.0, 6.0] | Set the default figure size. |
| format | png | |
| graticule_radii | None | Define a list of radii at which circular graticules will be drawn. |
| interactive | False | Enable interactive mode. If True then plots will be drawn after each plotting command. |
| label_ts_threshold | 0.0 | TS threshold for labeling sources in sky maps. If None then no sources will be labeled. |
| loge_bounds | None | |

### residmap

The options in *residmap* control the default behavior of the residmap method. For more information about using this method see the *Residual Map* page.

Table 11: *residmap* Options

| Option | Default | Description |
|---|---|---|
| exclude | None | List of sources that will be removed from the model when computing the residual map. |
| loge_bounds | None | Restrict the analysis to an energy range (emin,emax) in log10(E/MeV) that is a subset of the analysis energy range. By default the full analysis energy range will be used. If either emin/emax are None then only an upper/lower bound on the energy range wil be applied. |
| make_plots | False | Generate diagnostic plots. |
| model | None | Dictionary defining the spatial/spectral properties of the test source. If model is None the test source will be a PointSource with an Index 2 power-law spectrum. |
| use_weights | False | Used weighted version of maps in making plots. |
| write_fits | True | Write the output to a FITS file. |
| write_npy | True | Write the output dictionary to a numpy file. |

### roiopt

The options in *roiopt* control the default behavior of the `optimize` method. For more information about using this method see the *ROI Optimization and Fitting* page.

Table 12: *roiopt* Options

| Option | Default | Description |
|---|---|---|
| `max_free_sources` | 5 | Maximum number of sources that will be fit simultaneously in the first optimization step. |
| `npred_frac` | 0.95 | |
| `npred_threshold` | 1.0 | |
| `shape_ts_threshold` | 25.0 | Threshold on source TS used for determining the sources that will be fit in the third optimization step. |
| `skip` | None | List of str source names to skip while optimizing. |

### sed

The options in *sed* control the default behavior of the `sed` method. For more information about using this method see the *SED Analysis* page.

Table 13: *sed* Options

| Option | Default | Description |
|---|---|---|
| `bin_index` | 2.0 | Spectral index that will be use when fitting the energy distribution within an energy bin. |
| `cov_scale` | 3.0 | Scale factor that sets the strength of the prior on nuisance parameters that are free. Setting this to None disables the prior. |
| `free_background` | False | Leave background parameters free when performing the fit. If True then any parameters that are currently free in the model will be fit simultaneously with the source of interest. |
| `free_params` | None | Set the parameters of the source of interest that will be freed when performing the global fit. By default all parameters will be freed. |
| `free_radius` | None | Free normalizations of background sources within this angular distance in degrees from the source of interest. If None then no sources will be freed. |
| `make_plots` | False | Generate diagnostic plots. |
| `ul_confidence` | 0.95 | Confidence level for flux upper limit. |
| `use_local_index` | False | Use a power-law approximation to the shape of the global spectrum in each bin. If this is false then a constant index set to `bin_index` will be used. |
| `write_fits` | True | Write the output to a FITS file. |
| `write_npy` | True | Write the output dictionary to a numpy file. |

### selection

The *selection* section collects parameters related to the data selection and target definition. The majority of the parameters in this section are arguments to *gtselect* and *gtmktime*. The ROI center can be set with the *target* parameter by providing the name of a source defined in one of the input catalogs (defined in the *model* section). Alternatively the ROI center can be defined by giving explicit sky coordinates with *ra* and *dec* or *glon* and *glat*.

```
selection:

  # gtselect parameters
  emin    : 100
  emax    : 100000
  zmax    : 90
```

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```
  evclass : 128
  evtype  : 3
  tmin    : 239557414
  tmax    : 428903014

  # gtmktime parameters
  filter : 'DATA_QUAL>0 && LAT_CONFIG==1'
  roicut : 'no'

  # Set the ROI center to the coordinates of this source
  target : 'mkn421'
```

Table 14: *selection* Options

| Option | Default | Description |
|---|---|---|
| convtype | None | Conversion type selection. |
| dec | None | |
| emax | None | Maximum Energy (MeV) |
| emin | None | Minimum Energy (MeV) |
| evclass | None | Event class selection. |
| evtype | None | Event type selection. |
| filter | None | Filter string for gtmktime selection. |
| glat | None | |
| glon | None | |
| logemax | None | Maximum Energy (log10(MeV)) |
| logemin | None | Minimum Energy (log10(MeV)) |
| phasemax | None | Maximum pulsar phase |
| phasemin | None | Minimum pulsar phase |
| ra | None | |
| radius | None | Radius of data selection. If none this will be automatically set from the ROI size. |
| roicut | no | |
| target | None | Choose an object on which to center the ROI. This option takes precendence over ra/dec or glon/glat. |
| tmax | None | Maximum time (MET). |
| tmin | None | Minimum time (MET). |
| zmax | None | Maximum zenith angle. |

### sourcefind

The options in *sourcefind* control the default behavior of the `find_sources` method. For more information about using this method see the *Source Finding* page.

Table 15: *sourcefind* Options

| Option | Default | Description |
|---|---|---|
| free_parame | None | |
| max_iter | 5 | Maximum number of source finding iterations. The source finder will continue adding sources until no additional peaks are found or the number of iterations exceeds this number. |
| min_separation | 1.0 | Minimum separation in degrees between sources detected in each iteration. The source finder will look for the maximum peak in the TS map within a circular region of this radius. |
| model | None | Dictionary defining the spatial/spectral properties of the test source. If model is None the test source will be a PointSource with an Index 2 power-law spectrum. |
| multithread | False | Split the calculation across number of processes set by nthread option. |
| nthread | None | Number of processes to create when multithread is True. If None then one process will be created for each available core. |
| sources_per_iter | 4 | Maximum number of sources that will be added in each iteration. If the number of detected peaks in a given iteration is larger than this number, only the N peaks with the largest TS will be used as seeds for the current iteration. |
| sqrt_ts_threshold | 5.0 | Source threshold in sqrt(TS). Only peaks with sqrt(TS) exceeding this threshold will be used as seeds for new sources. |
| tsmap_fitmap | tsmap | Set the method for generating the TS map. Valid options are tsmap or tscube. |

### tsmap

The options in *tsmap* control the default behavior of the `tsmap` method. For more information about using this method see the *TS Map* page.

Table 16: *tsmap* Options

| Option | Default | Description |
|---|---|---|
| exclude | None | List of sources that will be removed from the model when computing the TS map. |
| loge_bounds | None | Restrict the analysis to an energy range (emin,emax) in log10(E/MeV) that is a subset of the analysis energy range. By default the full analysis energy range will be used. If either emin/emax are None then only an upper/lower bound on the energy range wil be applied. |
| make_plots | False | Generate diagnostic plots. |
| max_kernel_radius | 3.0 | Set the maximum radius of the test source kernel. Using a smaller value will speed up the TS calculation at the loss of accuracy. |
| model | None | Dictionary defining the spatial/spectral properties of the test source. If model is None the test source will be a PointSource with an Index 2 power-law spectrum. |
| multithread | False | Split the calculation across number of processes set by nthread option. |
| nthread | None | Number of processes to create when multithread is True. If None then one process will be created for each available core. |
| write_fits | True | Write the output to a FITS file. |
| write_npy | True | Write the output dictionary to a numpy file. |

### tscube

The options in *tscube* control the default behavior of the `tscube` method. For more information about using this method see the *TS Cube* page.

Table 17: *tscube* Options

| Option | Default | Description |
|---|---|---|
| cov_scale | 1.0 | Scale factor to apply to broadband fitting cov. matrix in bin-by-bin fits ( < 0 -> fixed ) |
| cov_scale_bb | -1.0 | Scale factor to apply to global fitting cov. matrix in broadband fits. ( < 0 -> no prior ) |
| do_sed | True | Compute the energy bin-by-bin fits |
| exclude | None | List of sources that will be removed from the model when computing the TS map. |
| init_lambda | 0 | Initial value of damping parameter for newton step size calculation. A value of zero disables damping. |
| max_iter | 30 | Maximum number of iterations for the Newtons method fitter. |
| model | None | Dictionary defining the spatial/spectral properties of the test source. If model is None the test source will be a PointSource with an Index 2 power-law spectrum. |
| nnorm | 10 | Number of points in the likelihood v. normalization scan |
| norm_sigma | 5.0 | Number of sigma to use for the scan range |
| remake_test_source | False | If true, recomputes the test source image (otherwise just shifts it) |
| st_scan_level | 0 | Level to which to do ST-based fitting (for testing) |
| tol | 0.001 | Critetia for fit convergence (estimated vertical distance to min < tol ) |
| tol_type | 0 | Absoulte (0) or relative (1) criteria for convergence. |

### 1.3.4 Output File

The current state of the ROI can be written at any point by calling `write_roi`.

```
>>> gta.write_roi('output.npy')
```

The output file will contain all information about the state of the ROI as calculated up to that point in the analysis including model parameters and measured source characteristics (flux, TS, NPred). An XML model file will also be saved for each analysis component.

The output file can be read with `load`:

```
>>> o = np.load('output.npy').flat[0]
>>> print(o.keys())
['roi', 'config', 'sources','version']
```

The output file is organized in four top-level of dictionaries:

Table 18: File Dictionary

| Key | Type | Description |
|---|---|---|
| roi | dict | A dictionary containing information about the ROI as a whole. |
| sources | dict | A dictionary containing information about individual sources in the model (diffuse and point-like). Each element of this dictionary maps to a single source in the ROI model. |
| config | dict | The configuration dictionary of the `GTAnalysis` instance. |
| version | str | The version of the Fermipy package that was used to run the analysis. This is automatically generated from the git release tag. |

#### ROI Dictionary

#### Source Dictionary

The `sources` dictionary contains one element per source keyed to the source name. The following table lists the elements of the source dictionary and their descriptions.

Table 19: Source Dictionary

| Key | Type | Description |
|---|---|---|
| name | str | Name of the source. |
| Source_Name | str | Name of the source. |
| SpatialModel | str | Spatial model. |
| SpatialWidth | float | Spatial size parameter. |
| SpatialType | str | Spatial type string. This corresponds to the type attribute of the spatialModel component in the XML model. |
| SourceType | str | Source type string (PointSource or DiffuseSource). |
| SpectrumType | str | Spectrum type string. This corresponds to the type attribute of the spectrum component in the XML model (e.g. PowerLaw, LogParabola, etc.). |
| Spatial_Filename | str | Path to spatial template associated to this source. |
| SpectrumFile | str | Path to file associated to the spectral model of this source. |
| correlation | dict | Dictionary of correlation coefficients. |
| model_counts | ndarray | Vector of predicted counts for this source in each analysis energy bin. |
| model_counts_wt | ndarray | Vector of predicted counts for this source in each analysis energy bin. |
| sed | dict | Output of SED analysis. See *SED Analysis* for more information. |
| ra | float | Right ascension of the source (deg). |
| dec | float | Declination of the source (deg). |
| glon | float | Galactic longitude of the source (deg). |
| glat | float | Galactic latitude of the source (deg). |
| ra_err | float | Std. deviation of positional uncertainty in right ascension (deg). |
| dec_err | float | Std. deviation of positional uncertainty in declination (deg). |
| glon_err | float | Std. deviation of positional uncertainty in galactic longitude (deg). |
| glat_err | float | Std. deviation of positional uncertainty in galactic latitude (deg). |
| pos_err | float | 1-sigma positional uncertainty (deg). |
| pos_r68 | float | 68% positional uncertainty (deg). |
| pos_r95 | float | 95% positional uncertainty (deg). |
| pos_r99 | float | 99% positional uncertainty (deg). |
| pos_err_semimajor | float | 1-sigma uncertainty (deg) along major axis of uncertainty ellipse. |
| pos_err_semiminor | float | 1-sigma uncertainty (deg) along minor axis of uncertainty ellipse. |
| pos_angle | float | Position angle of uncertainty ellipse with respect to major axis. |
| pos_gal_cov | ndarray | Covariance matrix of positional uncertainties in local projection in galactic coordinates. |
| pos_gal_corr | ndarray | Correlation matrix of positional uncertainties in local projection in galactic coordinates. |
| pos_cel_cov | ndarray | Covariance matrix of positional uncertainties in local projection in celestial coordinates. |
| pos_cel_corr | ndarray | Correlation matrix of positional uncertainties in local projection in celestial coordinates. |
| offset_ra | float | Right ascension offset from ROI center in local celestial projection (deg). |
| offset_dec | float | Declination offset from ROI center in local celestial projection (deg). |
| offset_glon | float | Galactic longitude offset from ROI center in local galactic projection (deg). |
| offset_glat | float | Galactic latitude offset from ROI center in local galactic projection (deg). |
| offset_roi_edge | float | Distance from the edge of the ROI (deg). Negative (positive) values indicate locations inside (outside) the ROI. |
| offset | float | Angular offset from ROI center (deg). |
| param_names | ndarray | Names of spectral parameters. |
| param_values | ndarray | Spectral parameter values. |
| param_errors | ndarray | Spectral parameters errors. |
| ts | float | Source test statistic. |
| loglike | float | Log-likelihood of the model evaluated at the best-fit normalization of the source. |
| loglike_scan | ndarray | Log-likelihood values for scan of source normalization. |
| dloglike_scan | ndarray | Delta Log-likelihood values for scan of source normalization. |

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Table 19 – continued from previous page

| Key | Type | Description |
|---|---|---|
| eflux_scan | ndarray | Energy flux values for scan of source normalization. |
| flux_scan | ndarray | Flux values for scan of source normalization. |
| norm_scan | ndarray | Normalization parameters values for scan of source normalization. |
| npred | float | Number of predicted counts from this source integrated over the analysis energy range. |
| npred_wt | float | Number of predicted counts from this source integrated over the analysis energy range. |
| pivot_energy | float | Decorrelation energy in MeV. |
| flux | float | Photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range |
| flux100 | float | Photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV. |
| flux1000 | float | Photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV. |
| flux10000 | float | Photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV. |
| flux_err | float | Photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range |
| flux100_err | float | Photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV. |
| flux1000_err | float | Photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV. |
| flux10000_err | float | Photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV. |
| flux_ul95 | float | 95% CL upper limit on the photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range |
| flux100_ul95 | float | 95% CL upper limit on the photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV. |
| flux1000_ul95 | float | 95% CL upper limit on the photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV. |
| flux10000_ul95 | float | 95% CL upper limit on the photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV. |
| eflux | float | Energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range |
| eflux100 | float | Energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV. |
| eflux1000 | float | Energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV. |
| eflux10000 | float | Energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV. |
| eflux_err | float | Energy flux uncertainty ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range |
| eflux100_err | float | Energy flux uncertainty ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV. |
| eflux1000_err | float | Energy flux uncertainty ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV. |
| eflux10000_err | float | Energy flux uncertainty ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV. |
| eflux_ul95 | float | 95% CL upper limit on the energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range |
| eflux100_ul95 | float | 95% CL upper limit on the energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV. |
| eflux1000_ul95 | float | 95% CL upper limit on the energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV. |
| eflux10000_ul95 | float | 95% CL upper limit on the energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV. |
| dnde | float | Differential photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at the pivot energy. |
| dnde100 | float | Differential photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 100 MeV. |
| dnde1000 | float | Differential photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 1 GeV. |
| dnde10000 | float | Differential photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 10 GeV. |
| dnde_err | float | Differential photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at the pivot energy. |
| dnde100_err | float | Differential photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 100 MeV. |
| dnde1000_err | float | Differential photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 1 GeV. |
| dnde10000_err | float | Differential photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 10 GeV. |
| dnde_index | float | Logarithmic slope of the differential photon spectrum evaluated at the pivot energy. |
| dnde100_index | float | Logarithmic slope of the differential photon spectrum evaluated at 100 MeV. |
| dnde1000_index | float | Logarithmic slope of the differential photon spectrum evaluated evaluated at 1 GeV. |
| dnde10000_index | float | Logarithmic slope of the differential photon spectrum evaluated at 10 GeV. |

### 1.3.5 ROI Optimization and Fitting

Source fitting with fermipy is generally performed with the `optimize` and `fit` methods.

#### Fitting

`fit` is a wrapper on the pyLikelihood fit method and performs a likelihood fit of all free parameters of the model. This method can be used to manually optimize of the model by calling it after freeing one or more source parameters. The following example demonstrates the commands that would be used to fit the normalizations of all sources within 3 deg of the ROI center:

```
>>> gta.free_sources(distance=2.0,pars='norm')
>>> gta.print_params(True)
 idx parname                   value     error       min       max     scale free
--------------------------------------------------------------------------------
3FGL J1104.4+3812
  18 Prefactor                 1.77         0     1e-05       100     1e-11    *
3FGL J1109.6+3734
  24 Prefactor                 0.33         0     1e-05       100     1e-14    *
galdiff
  52 Prefactor                    1         0       0.1        10         1    *
isodiff
  55 Normalization                1         0     0.001     1e+03         1    *
>>> o = gta.fit()
2016-04-19 14:07:55 INFO     GTAnalysis.fit(): Starting fit.
2016-04-19 14:08:56 INFO     GTAnalysis.fit(): Fit returned successfully.
2016-04-19 14:08:56 INFO     GTAnalysis.fit(): Fit Quality: 3 LogLike:   -77279.869␣
↪DeltaLogLike:      501.128
>>> gta.print_params(True)
2016-04-19 14:10:02 INFO     GTAnalysis.print_params():
 idx parname                   value     error       min       max     scale free
--------------------------------------------------------------------------------
3FGL J1104.4+3812
  18 Prefactor                 2.13    0.0161     1e-05       100     1e-11    *
3FGL J1109.6+3734
  24 Prefactor                0.342    0.0904     1e-05       100     1e-14    *
galdiff
  52 Prefactor                0.897    0.0231       0.1        10         1    *
isodiff
  55 Normalization             1.15     0.016     0.001     1e+03         1    *
```

By default `fit` will repeat the fit until a fit quality of 3 is obtained. After the fit returns all sources with free parameters will have their properties (flux, TS, NPred, etc.) updated in the `ROIModel` instance. The return value of the method is a dictionary containing the following diagnostic information about the fit:

Table 20: *fit* Output Dictionary

| Key | Type | Description |
|---|---|---|
| edm | float | Estimated distance to maximum of log-likelihood function. |
| fit_status | int | Optimizer return code (0 = ok). |
| fit_quality | int | Fit quality parameter for MINUIT and NEWMINUIT optimizers (3 - Full accurate covariance matrix, 2 - Full matrix, but forced positive-definite (i.e. not accurate), 1 - Diagonal approximation only, not accurate, 0 - Error matrix not calculated at all) |
| covariance | ndarray | Covariance matrix between free parameters of the fit. |
| correlation | ndarray | Correlation matrix between free parameters of the fit. |
| dloglike | float | Improvement in log-likehood value. |
| loglike | float | Post-fit log-likehood value. |
| values | ndarray | Vector of best-fit parameter values (unscaled). |
| errors | ndarray | Vector of parameter errors (unscaled). |
| config | dict | Copy of input configuration to this method. |

The `fit` also accepts keyword arguments which can be used to configure its behavior at runtime:

```
>>> o = gta.fit(min_fit_quality=2,optimizer='NEWMINUIT',reoptimize=True)
```

#### Reference/API

#### ROI Optimization

The `optimize` method performs an automatic optimization of the ROI by fitting all sources with an iterative strategy.

```
>>> o = gta.optimize()
```

It is generally good practice to run this method once at the start of your analysis to ensure that all parameters are close to their global likelihood maxima.

Table 21: *optimization* Output Dictionary

| Key | Type | Description |
|---|---|---|
| loglike0 | float | Pre-optimization log-likelihood value. |
| loglike1 | float | Post-optimization log-likelihood value. |
| dloglike | float | Improvement in log-likehood value. |
| config | dict | Copy of input configuration to this method. |

#### Reference/API

### 1.3.6 Customizing the Model

The ROIModel class is responsible for managing the source and diffuse components in the ROI. Configuration of the model is controlled with the *model* block of YAML configuration file.

#### Configuring Diffuse Components

The simplest configuration uses a single file for the galactic and isotropic diffuse components. By default the galactic diffuse and isotropic components will be named *galdiff* and *isodiff* respectively. An alias for each component will

also be created with the name of the mapcube or file spectrum. For instance the galactic diffuse can be referred to as *galdiff* or *gll_iem_v06* in the following example.

```
model:
  src_roiwidth : 10.0
  galdiff  : '$FERMI_DIFFUSE_DIR/gll_iem_v06.fits'
  isodiff  : '$FERMI_DIFFUSE_DIR/isotropic_source_4years_P8V3.txt'
  catalogs : ['gll_psc_v14.fit']
```

To define two or more galactic diffuse components you can optionally define the *galdiff* and *isodiff* parameters as lists. A separate component will be generated for each element in the list with the name *galdiffXX* or *isodiffXX* where *XX* is an integer position in the list.

```
model:
  galdiff  :
    - '$FERMI_DIFFUSE_DIR/diffuse_component0.fits'
    - '$FERMI_DIFFUSE_DIR/diffuse_component1.fits'
```

To explicitly set the name of a component you can define any element as a dictionary containing *name* and *file* fields:

```
model:
  galdiff  :
    - { 'name' : 'component0', 'file' : '$FERMI_DIFFUSE_DIR/diffuse_component0.fits' }
    - { 'name' : 'component1', 'file' : '$FERMI_DIFFUSE_DIR/diffuse_component1.fits' }
```

### Configuring Source Components

The list of sources for inclusion in the ROI model is set by defining a list of catalogs with the *catalogs* parameter. Catalog files can be in either XML or FITS format. Sources from the catalogs in this list that satisfy either the *src_roiwidth* or *src_radius* selections are added to the ROI model. If a source is defined in multiple catalogs the source definition from the last file in the catalogs list takes precedence.

```
model:

  src_radius: 5.0
  src_roiwidth: 10.0
  catalogs :
    - 'gll_psc_v16.fit'
    - 'extra_sources.xml'
```

Individual sources can also be defined within the configuration file with the *sources* parameter. This parameter contains a list of dictionaries that defines the spatial and spectral parameters of each source. The keys of the source dictionary map to the spectral and spatial source properties as they would be defined in the XML model file.

```
model:
  sources  :
    - { name: 'SourceA', glon : 120.0, glat : -3.0,
     SpectrumType : 'PowerLaw', Index : 2.0, Scale : 1000, Prefactor : !!float 1e-11,
     SpatialModel: 'PointSource' }
    - { name: 'SourceB', glon : 122.0, glat : -3.0,
     SpectrumType : 'LogParabola', norm : !!float 1E-11, Scale : 1000, beta : 0.0,
     SpatialModel: 'PointSource' }
```

For parameters defined as scalars, the scale and value properties will be assigned automatically from the input value. To set these manually a parameter can also be initialized with a dictionary that explicitly sets the value and scale properties:

```
model:
  sources  :
    - { name: 'SourceA', glon : 120.0, glat : -3.0,
        SpectrumType : 'PowerLaw', Index : 2.0, Scale : 1000,
        Prefactor : { value : 1.0, scale : !!float 1e-11, free : '0' },
        SpatialModel: 'PointSource' }
```

### Spatial Models

Fermipy supports four spatial models which are defined with the `SpatialModel` property:

- PointSource : A point source (SkyDirFunction).
- RadialGaussian : A symmetric 2D Gaussian with width parameter 'Sigma'.
- RadialDisk : A symmetric 2D Disk with radius 'Radius'.
- SpatialMap : An arbitrary 2D shape with morphology defined by a FITS template.

The spatial extension of RadialDisk and RadialGaussian can be controlled with the `SpatialWidth` parameter which sets the 68% containment radius in degrees. Note for ST releases prior to 11-01-01, RadialDisk and RadialGaussian sources will be represented with the `SpatialMap` type.

```
model:
  sources  :
    - { name: 'PointSource', glon : 120.0, glat : 0.0,
     SpectrumType : 'PowerLaw', Index : 2.0, Scale : 1000, Prefactor : !!float 1e-11,
     SpatialModel: 'PointSource' }
    - { name: 'DiskSource', glon : 120.0, glat : 0.0,
     SpectrumType : 'PowerLaw', Index : 2.0, Scale : 1000, Prefactor : !!float 1e-11,
     SpatialModel: 'RadialDisk', SpatialWidth: 1.0 }
    - { name: 'GaussSource', glon : 120.0, glat : 0.0,
     SpectrumType : 'PowerLaw', Index : 2.0, Scale : 1000, Prefactor : !!float 1e-11,
     SpatialModel: 'RadialGaussian', SpatialWidth: 1.0 }
    - { name: 'MapSource', glon : 120.0, glat : 0.0,
     SpectrumType : 'PowerLaw', Index : 2.0, Scale : 1000, Prefactor : !!float 1e-11,
     SpatialModel: 'SpatialMap', Spatial_Filename : 'template.fits' }
```

### Editing the Model at Runtime

The model can be manually editing at runtime with the `add_source()` and `delete_source()` methods. Sources should be added after calling `setup()` as shown in the following example.

```
from fermipy.gtanalysis import GTAnalysis

gta = GTAnalysis('config.yaml',logging={'verbosity' : 3})
gta.setup()

# Remove isodiff from the model
gta.delete_source('isodiff')

# Add SourceA to the model
gta.add_source('SourceA',{ 'glon' : 120.0, 'glat' : -3.0,
               'SpectrumType' : 'PowerLaw', 'Index' : 2.0,
               'Scale' : 1000, 'Prefactor' : 1e-11,
               'SpatialModel' : 'PointSource' })
```

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```
# Add SourceB to the model
gta.add_source('SourceB',{ 'glon' : 121.0, 'glat' : -2.0,
                  'SpectrumType' : 'PowerLaw', 'Index' : 2.0,
                  'Scale' : 1000, 'Prefactor' : 1e-11,
                  'SpatialModel' : 'PointSource' })
```

Sources added after calling `setup()` will be created dynamically through the pyLikelihood object creation mechanism.

## 1.3.7 Developer Notes

### Adding a spectral model

One of the most common changes to the underlying fermitools code is to add a new spectral model. To be able to use that model in fermipy will require a few changes, depending on how exactly you would like you use the model.

1. At a minimum, the model, and default values and bounds for the parameters need to be added to `fermipy/data/models.yaml`
2. If you want to be able to use functions that free the source-shape parameters, fit the SED, you will want to modify the `norm_parameters` and `shape_parameters` blocks at the top of the `fermipy/gtanalysis.py` file to include the new spectral model.
3. If you want to be able to include the spectral model in an xml 'catalog' of sources that you use to define an ROI, you will have to update the `spectral_pars_from_catalog` and `get_catalog_dict` functions in `fermipy/roi_model.py` to include the spectral model.
4. If the spectral model is included in a new source catalog, and you want to support that catalog, see the section below on supporting new catalogs.
5. If you want to use the spectral to do more complicated things, like vectorizing call to evalute the spectrum because you are using it in sensitivity studies, then you will have to add it the the `fermipy/spectrum.py` file. That is pretty much expert territory.

### Supporting a new catalog

To support a new catalog will require some changes in the `fermipy/catalog.py` file. In short

1. Define a class to manage the catalog. This will have to handle converting the parameters in the FITS file to the format that fermipy expects. It should inherit from the `Catalog` class.
2. Update the `Catalog.create` function to have a hook to create a class of the correct type.
3. For now we are also maintaining the catalog files in the `fermipy/data/catalogs` area, so the catalog files should be added to that area.

### Creating a New Release

The following are steps for creating a new release:

1. Update the Changelog page (in `docs/changelog.rst`) with notes for the release and commit those changes.
2. Update documentation tables by running `make_tables.py` inside the `docs` subdirectory and commit any resulting changes to the configuration table files under `docs/config`.

3. Checkout `master` and ensure that you have pulled all commits from origin.
4. Create the release tag and push it to GitHub.

```
$ git tag -a XX.YY.ZZ -m ""
$ git push --tags
```

5. Upload the release to pypi.

```
$ python setup.py sdist upload -r pypi
```

6. Create a new release on conda-forge by opening a PR on the fermipy-feedstock repo. There is a fork of `fermipy-feedstock` in the fermipy organization that you can use for this purpose. Edit `recipe/meta.yaml` by entering the new package version and updating the sha256 hash to the value copied from the pypi download page. Update the package dependencies as necessary in the `run` section of `requirements`. Verify that `entry_points` contains the desired set of command-line scripts. Generally this section should match the contents `entry_points` in `setup.py`. Before merging the PR confirm that all tests have successfully passed.

### 1.3.8 Advanced Analysis Methods

This page documents some of the more advanced methods and features available in Fermipy:

- *TS Map*: Generate a test statistic (TS) map for a new source centered at each spatial bin in the ROI.
- *TS Cube*: Generate a TS map using the `gttscube` ST application. In addition to generating a TS map this method can also extract a test source likelihood profile as a function of energy and position over the whole ROI.
- *Residual Map*: Generate a residual map by evaluating the difference between smoothed data and model maps (residual) at each spatial bin in the ROI.
- *Source Finding*: Find new sources using an iterative source-finding algorithim. Adds new sources to the ROI by looking for peaks in the TS map.
- *SED Analysis*: Extract the spectral energy distribution of a source with the `sed` method. This method fits the source amplitude in a sequence of energy bins.
- *Light Curves*: Extract the lightcurve of a source with the `lightcurve` method. This method fits the source amplitude in a sequence of time bins.
- *Extension Fitting*: Fit the angular extension of a source with the `extension` method.
- *Source Localization*: Find the best-fit position of a source with the `localize` method.
- *Phased Analysis*: Instructions for performing a phased-selected analysis.
- *Sensitivity Tools*: Scripts and classes for estimating sensitivity.

#### SED Analysis

The `sed()` method computes a spectral energy distribution (SED) by performing independent fits for the flux normalization of a source in bins of energy. The normalization in each bin is fit using a power-law spectral parameterization with a fixed index. The value of this index can be set with the `bin_index` parameter or allowed to vary over the energy range according to the local slope of the global spectral model (with the `use_local_index` parameter).

The `free_background`, `free_radius`, and `cov_scale` parameters control how nuisance parameters are dealt with in the fit. By default the method will fix the parameters of background components ROI when fitting the source normalization in each energy bin (`free_background=False`). Setting `free_background=True` will profile the normalizations of all background components that were free when the method was executed. In order to minimize

overfitting, background normalization parameters are constrained with priors taken from the global fit. The strength of the priors is controlled with the `cov_scale` parameter. A larger (smaller) value of `cov_scale` applies a weaker (stronger) constraint on the background amplitude. Setting `cov_scale=None` performs an unconstrained fit without priors.

### Examples

The `sed()` method is executed by passing the name of a source in the ROI as a single argument. Additional keyword argument can also be provided to override the default configuration of the method:

```
# Run analysis with default energy binning
sed = gta.sed('sourceA')

# Override the energy binning and the assumed power-law index
# within the bin
sed = gta.sed('sourceA', loge_bins=[2.0,2.5,3.0,3.5,4.0,4.5,5.0], bin_index=2.3)

# Profile background normalization parameters with prior scale of 5.0
sed = gta.sed('sourceA', free_background=True, cov_scale=5.0)
```

By default the method will use the energy bins of the underlying analysis. The `loge_bins` keyword argument can be used to override the default binning with the restriction that the SED energy bins must align with the analysis bins. The bins used in the analysis can be found with `gta.log_energies`. For example if in the analysis 8 energy bins per decade are considered and you want to make the SED in 4 bins per decade you can specify `loge_bins=gta.log_energies[::2]`.

The return value of `sed()` is a dictionary with the results of the analysis. The following example shows how to extract values from the output dictionary and load the SED data from the output FITS file:

```
# Get the sed results from the return argument
sed = gta.sed('sourceA', outfile='sed.fits')

# Print the SED flux values
print(sed['flux'])

# Reload the SED table from the output FITS file
from astropy.table import Table
sed_tab = Table.read('sed.fits')
```

The contents of the FITS file and output dictionary are documented in *SED FITS File* and *SED Dictionary*.

### SED FITS File

The following table describes the contents of the FITS file written by `sed()`. The `SED` HDU uses that data format specification for SEDs documented here.

Table 22: *sed* Output Dictionary

| HDU | Column Name | Description |
|---|---|---|
| SED | e_min | Lower edges of SED energy bins (MeV). |
| SED | e_ref | Upper edges of SED energy bins (MeV). |
| SED | e_max | Centers of SED energy bins (MeV). |
| SED | ref_dnde_e_min | Differential flux of the reference model evaluated at the lower bin edge ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) |
| SED | ref_dnde_e_max | Differential flux of the reference model evaluated at the upper bin edge ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) |
| SED | ref_flux | Flux of the reference model in each bin ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$). |
| SED | ref_eflux | Energy flux of the reference model in each bin ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$). |
| SED | ref_dnde | Differential flux of the reference model evaluated at the bin center ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) |
| SED | ref_npred | Number of predicted counts in the reference model in each bin. |
| SED | norm | Normalization in each bin in units of the reference model. |
| SED | norm_err | Symmetric error on the normalization in each bin in units of the reference model. |
| SED | norm_errn | Lower 1-sigma error on the normalization in each bin in units of the reference model. |
| SED | norm_errp | Upper 1-sigma error on the normalization in each bin in units of the reference model. |
| SED | norm_UL | Upper limit on the normalization in each bin in units of the reference model. |
| SED | loglike | Log-likelihood value of the model for the best-fit amplitude. |
| SED | norm_scan | Array of NxM normalization values for the profile likelihood scan in N energy bins and M scan points. A row-wise multiplication with any of ref columns can be used to convert this matrix to the respective unit. |
| SED | dloglike_scan | Array of NxM delta-loglikelihood values for the profile likelihood scan in N energy bins and M scan points. |
| MODEL_FLUX | Energy | Energies at which the spectral band is evaluated (MeV). |
| MODEL_FLUX | dnde | Central value of spectral band ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$). |
| MODEL_FLUX | dnde_lo | Lower 1-sigma bound of spectral band ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$). |
| MODEL_FLUX | dnde_hi | Upper 1-sigma bound of spectral band ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$). |
| MODEL_FLUX | dnde_err | Symmetric error of spectral band ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$). |
| MODEL_FLUX | dnde_ferr | Fractional width of spectral band. |
| PARAMS | name | Name of the parameter. |
| PARAMS | value | Value of the parameter. |
| PARAMS | error | 1-sigma parameter error (nan indicates that the parameter was not included in the fit). |
| PARAMS | covariance | Covariance matrix among free parameters. |
| PARAMS | correlation | Correlation matrix among free parameters. |

### SED Dictionary

The following table describes the contents of the `sed()` output dictionary:

Table 23: *sed* Output Dictionary

| Key | Type | Description |
|---|---|---|
| loge_min | ndarray | Lower edges of SED energy bins (log10(E/MeV)). |
| loge_max | ndarray | Upper edges of SED energy bins (log10(E/MeV)). |
| loge_ctr | ndarray | Centers of SED energy bins (log10(E/MeV)). |
| loge_ref | ndarray | Reference energies of SED energy bins (log10(E/MeV)). |
| e_min | ndarray | Lower edges of SED energy bins (MeV). |
| e_max | ndarray | Upper edges of SED energy bins (MeV). |
| e_ctr | ndarray | Centers of SED energy bins (MeV). |
| e_ref | ndarray | Reference energies of SED energy bins (MeV). |

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Table 23 – continued from previous page

| Key | Type | Description |
|---|---|---|
| ref_flux | ndarray | Flux of the reference model in each bin ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$). |
| ref_eflux | ndarray | Energy flux of the reference model in each bin ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$). |
| ref_dnde | ndarray | Differential flux of the reference model evaluated at the bin center ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) |
| ref_dnde_min | ndarray | Differential flux of the reference model evaluated at the lower bin edge ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) |
| ref_dnde_max | ndarray | Differential flux of the reference model evaluated at the upper bin edge ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) |
| ref_e2dnde | ndarray | E^2 x the differential flux of the reference model evaluated at the bin center ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) |
| ref_npred | ndarray | Number of predicted counts in the reference model in each bin. |
| norm | ndarray | Normalization in each bin in units of the reference model. |
| flux | ndarray | Flux in each bin ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$). |
| eflux | ndarray | Energy flux in each bin ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$). |
| dnde | ndarray | Differential flux in each bin ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$). |
| e2dnde | ndarray | E^2 x the differential flux in each bin ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$). |
| dnde_err | ndarray | 1-sigma error on dnde evaluated from likelihood curvature. |
| dnde_err_lo | ndarray | Lower 1-sigma error on dnde evaluated from the profile likelihood (MINOS errors). |
| dnde_err_hi | ndarray | Upper 1-sigma error on dnde evaluated from the profile likelihood (MINOS errors). |
| dnde_ul95 | ndarray | 95% CL upper limit on dnde evaluated from the profile likelihood (MINOS errors). |
| dnde_ul | ndarray | Upper limit on dnde evaluated from the profile likelihood using a CL = `ul_confidence`. |
| e2dnde_err | ndarray | 1-sigma error on e2dnde evaluated from likelihood curvature. |
| e2dnde_err_lo | ndarray | Lower 1-sigma error on e2dnde evaluated from the profile likelihood (MINOS errors). |
| e2dnde_err_hi | ndarray | Upper 1-sigma error on e2dnde evaluated from the profile likelihood (MINOS errors). |
| e2dnde_ul95 | ndarray | 95% CL upper limit on e2dnde evaluated from the profile likelihood (MINOS errors). |
| e2dnde_ul | ndarray | Upper limit on e2dnde evaluated from the profile likelihood using a CL = `ul_confidence`. |
| ts | ndarray | Test statistic. |
| loglike | ndarray | Log-likelihood of model for the best-fit amplitude. |
| npred | ndarray | Number of model counts. |
| fit_quality | ndarray | Fit quality parameter for MINUIT and NEWMINUIT optimizers (3 - Full accurate covariance matrix, 2 - Full matrix, but forced positive-definite (i.e. not accurate), 1 - Diagonal approximation only, not accurate, 0 - Error matrix not calculated at all). |
| fit_status | ndarray | Fit status parameter (0=ok). |
| index | ndarray | Spectral index of the power-law model used to fit this bin. |
| norm_scan | ndarray | Array of NxM normalization values for the profile likelihood scan in N energy bins and M scan points. A row-wise multiplication with any of `ref` columns can be used to convert this matrix to the respective unit. |
| dloglike_scan | ndarray | Array of NxM delta-loglikelihood values for the profile likelihood scan in N energy bins and M scan points. |
| loglike_scan | ndarray | Array of NxM loglikelihood values for the profile likelihood scan in N energy bins and M scan points. |
| param_covariance | ndarray | Covariance matrix for the best-fit spectral parameters of the source. |
| param_names | ndarray | Array of names for the parameters in the global spectral parameterization of this source. |
| param_values | ndarray | Array of parameter values. |
| param_errors | ndarray | Array of parameter errors. |
| model_flux | dict | Dictionary containing the differential flux uncertainty band of the best-fit global spectral parameterization for the source. |
| config | dict | Copy of input configuration to this method. |

### Configuration

The default configuration of the method is controlled with the *sed* section of the configuration file. The default configuration can be overriden by passing the option as a *kwargs* argument to the method.

Table 24: *sed* Options

| Option | Default | Description |
|---|---|---|
| bin_index | 2.0 | Spectral index that will be use when fitting the energy distribution within an energy bin. |
| cov_scale | 3.0 | Scale factor that sets the strength of the prior on nuisance parameters that are free. Setting this to None disables the prior. |
| free_background | False | Leave background parameters free when performing the fit. If True then any parameters that are currently free in the model will be fit simultaneously with the source of interest. |
| free_params | None | Set the parameters of the source of interest that will be freed when performing the global fit. By default all parameters will be freed. |
| free_radius | None | Free normalizations of background sources within this angular distance in degrees from the source of interest. If None then no sources will be freed. |
| make_plots | False | Generate diagnostic plots. |
| ul_confidence | 0.95 | Confidence level for flux upper limit. |
| use_local_index | False | Use a power-law approximation to the shape of the global spectrum in each bin. If this is false then a constant index set to bin_index will be used. |
| write_fits | True | Write the output to a FITS file. |
| write_npy | True | Write the output dictionary to a numpy file. |

### Reference/API

### Light Curves

`lightcurve()` fits the charateristics of a source (flux, TS, etc.) in a sequence of time bins. This method uses the data selection and model of a baseline analysis (e.g. the full mission) and is therefore restricted to analyzing time bins that are encompassed by the time selection of the baseline analysis. In general when using this method it is recommended to use a baseline time selection of at least several years or more to ensure the best characterization of background sources in the ROI.

When fitting a time bin the method will initialize the model to the current parameters of the baseline analysis. The parameters to be refit in each time bin may be controlled with `free_background`, `free_sources`, `free_radius`, `free_params`, and `shape_ts_threshold` options.

### Examples

```
# Generate a lightcurve with two bins
lc = gta.lightcurve('sourceA', nbins=2)

# Generate a lightcurve with 1-week binning
lc = gta.lightcurve('sourceA', binsz=86400.*7.0)

# Generate a lightcurve freeing sources within 3 deg of the source
# of interest
lc = gta.lightcurve('sourceA', binsz=86400.*7.0, free_radius=3.0)

# Generate a lightcurve with arbitrary MET binning
```

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```
lc = gta.lightcurve('sourceA', time_bins=[239557414,242187214,250076614],
                    free_radius=3.0)
```

### Optimizing Computation Speed

By default the `lightcurve` method will run an end-to-end analysis in each time bin using the same processing steps as the baseline analysis. Depending on the data selection and ROI size each time bin may take 10-15 minutes to process. There are several options which can be used to reduce the lightcurve computation time. The `multithread` option splits the analysis of time bins across multiple cores:

```
# Split lightcurve across all available cores
lc = gta.lightcurve('sourceA', nbins=2, multithread=True)

# split lightcurve across 2 cores
lc = gta.lightcurve('sourceA', nbins=2, multithread=True, nthread=2)
```

Note that when using the `multithread` option in a computing cluster environment one should reserve the appropriate number of cores when submitting the job.

The `use_scaled_srcmap` option generates an approximate source map for each time bin by scaling the source map of the baseline analysis by the relative exposure.

```
# Enable scaled source map
lc = gta.lightcurve('sourceA', nbins=2, use_scaled_srcmap=True)
```

Enabling this option can speed up the lightcurve calculation by at least a factor of 2 or 3 at the cost of slightly reduced accuracy in the model evaluation. For point-source analysis on medium to long timescales (days to years) the additional systematic uncertainty incurred by using scaled source maps should be no more than 1-2%. For analysis of diffuse sources or short time scales (< day) one should verify the systematic uncertainty is less than the systematic uncertainty of the IRFs.

### Output

The following tables describe the contents of the method output:

Table 25: *lightcurve* Output

| Key | Type | Description |
|---|---|---|
| `name` | `str` | Name of Source, |
| `tmin` | `ndarray` | Lower edge of time bin in MET. |
| `tmax` | `ndarray` | Upper edge of time bin in MET. |
| `fit_success` | `ndarray` | Did the likelihood fit converge? True if yes. |
| `config` | `dict` | Copy of the input configuration to this method. |
| `ts_var` | `float` | TS of variability. Should be distributed as $\chi^2$ with $n-1$ degrees of freedom, where $n$ is the number of time bins. |

Table 26: *lightcurve* Source Output

| Key | Type | Description |
|---|---|---|
| `param_names` | `ndarray` | Names of spectral parameters. |
| `param_values` | `ndarray` | Spectral parameter values. |

Continued on next page

Table 26 – continued from previous page

| Key | Type | Description |
|---|---|---|
| param_errors | ndarray | Spectral parameters errors. |
| ts | float | Source test statistic. |
| loglike | float | Log-likelihood of the model evaluated at the best-fit normalization of the source. |
| loglike_scan | ndarray | Log-likelihood values for scan of source normalization. |
| dloglike_scan | ndarray | Delta Log-likelihood values for scan of source normalization. |
| eflux_scan | ndarray | Energy flux values for scan of source normalization. |
| flux_scan | ndarray | Flux values for scan of source normalization. |
| norm_scan | ndarray | Normalization parameters values for scan of source normalization. |
| npred | float | Number of predicted counts from this source integrated over the analysis energy range. |
| npred_wt | float | Number of predicted counts from this source integrated over the analysis energy range. |
| pivot_energy | float | Decorrelation energy in MeV. |
| flux | float | Photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range |
| flux100 | float | Photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV. |
| flux1000 | float | Photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV. |
| flux10000 | float | Photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV. |
| flux_err | float | Photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range |
| flux100_err | float | Photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV. |
| flux1000_err | float | Photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV. |
| flux10000_err | float | Photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV. |
| flux_ul95 | float | 95% CL upper limit on the photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range |
| flux100_ul95 | float | 95% CL upper limit on the photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV. |
| flux1000_ul95 | float | 95% CL upper limit on the photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV. |
| flux10000_ul95 | float | 95% CL upper limit on the photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV. |
| eflux | float | Energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range |
| eflux100 | float | Energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV. |
| eflux1000 | float | Energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV. |
| eflux10000 | float | Energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV. |
| eflux_err | float | Energy flux uncertainty ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range |
| eflux100_err | float | Energy flux uncertainty ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV. |
| eflux1000_err | float | Energy flux uncertainty ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV. |
| eflux10000_err | float | Energy flux uncertainty ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV. |
| eflux_ul95 | float | 95% CL upper limit on the energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range |
| eflux100_ul95 | float | 95% CL upper limit on the energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV. |
| eflux1000_ul95 | float | 95% CL upper limit on the energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV. |
| eflux10000_ul95 | float | 95% CL upper limit on the energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV. |
| dnde | float | Differential photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at the pivot energy. |
| dnde100 | float | Differential photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 100 MeV. |
| dnde1000 | float | Differential photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 1 GeV. |
| dnde10000 | float | Differential photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 10 GeV. |
| dnde_err | float | Differential photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at the pivot energy. |
| dnde100_err | float | Differential photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 100 MeV. |
| dnde1000_err | float | Differential photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 1 GeV. |
| dnde10000_err | float | Differential photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 10 GeV. |
| dnde_index | float | Logarithmic slope of the differential photon spectrum evaluated at the pivot energy. |
| dnde100_index | float | Logarithmic slope of the differential photon spectrum evaluated at 100 MeV. |

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Table 26 – continued from previous page

| Key | Type | Description |
|---|---|---|
| dnde1000_index | | Logarithmic slope of the differential photon spectrum evaluated evaluated at 1 GeV. |
| dnde10000_index | | Logarithmic slope of the differential photon spectrum evaluated at 10 GeV. |

### Reference/API

### Extension Fitting

The `extension()` method executes a source extension analysis for a given source by computing a likelihood ratio test with respect to the no-extension (point-source) hypothesis and a best-fit model for extension. The best-fit extension is found by performing a likelihood profile scan over the source width (68% containment) and fitting for the extension that maximizes the model likelihood. Currently this method supports two models for extension: a 2D Gaussian (*RadialGaussian*) or a 2D disk (*RadialDisk*).

At runtime the default settings for the extension analysis can be overriden by passing one or more *kwargs* when executing `extension()`:

```
# Run extension fit of sourceA with default settings
>>> gta.extension('sourceA')

# Override default spatial model
>>> gta.extension('sourceA', spatial_model='RadialDisk')
```

By default the method will fix all background parameters before performing the extension fit. One can leave background parameters free by setting `free_background=True`:

```
# Free a nearby source that maybe be partially degenerate with the
# source of interest.  The normalization of SourceB will be refit
# when testing the extension of sourceA
gta.free_norm('sourceB')
gta.extension('sourceA', free_background=True)

# Fix all background parameters when testing the extension
# of sourceA
gta.extension('sourceA', free_background=False)

# Free normalizations of sources within 2 degrees of sourceA
gta.extension('sourceA', free_radius=2.0)
```

The results of the extension analysis are written to a dictionary which is the return value of the extension method.

```
ext = gta.extension('sourceA', write_npy=True, write_fits=True)
```

The contents of the output dictionary are given in the following table:

Table 27: *extension* Output Dictionary

| Key | Type | Description |
|---|---|---|
| name | str | Name of source. |
| file | str | Name of output FITS file. |
| config | dict | Copy of the input configuration to this method. |
| width | ndarray | Vector of width (intrinsic 68% containment radius) values (deg). |
| dloglike | ndarray | Delta-log-likelihood values for each point in the profile likelihood scan. |
| loglike | ndarray | Log-likelihood values for each point in the scan over the spatial extension. |

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Table 27 – continued from previous page

| Key | Type | Description |
|---|---|---|
| loglike_ptsrc | float | Log-Likelihood value of the best-fit point-source model. |
| loglike_extf | float | Log-Likelihood of the best-fit extended source model. |
| loglike_init | float | Log-Likelihood of model before extension fit. |
| loglike_base | float | Log-Likelihood of model after initial spectral fit. |
| ext | float | Best-fit extension (68% containment radius) (deg). |
| ext_err_hi | float | Upper (1-sigma) error on the best-fit extension (deg). |
| ext_err_lo | float | Lower (1-sigma) error on the best-fit extension (deg). |
| ext_err | float | Symmetric (1-sigma) error on the best-fit extension (deg). |
| ext_ul95 | float | 95% CL upper limit on the spatial extension (deg). |
| ts_ext | float | Test statistic for the extension hypothesis. |
| ebin_e_min | ndarray | |
| ebin_e_ctr | ndarray | |
| ebin_e_max | ndarray | |
| ebin_ext | ndarray | Best-fit extension as measured in each energy bin (intrinsic 68% containment radius) (deg). |
| ebin_ext_err | ndarray | Symmetric (1-sigma) error on best-fit extension in each energy bin (deg). |
| ebin_ext_err_hi | ndarray | Upper (1-sigma) error on best-fit extension in each energy bin (deg). |
| ebin_ext_err_lo | ndarray | Lower (1-sigma) error on best-fit extension in each energy bin (deg). |
| ebin_ext_ul95 | ndarray | 95% CL upper limit on best-fit extension in each energy bin (deg). |
| ebin_ts_ext | ndarray | Test statistic for extension hypothesis in each energy bin. |
| ebin_dloglike | ndarray | Delta-log-likelihood values for scan over the spatial extension in each energy bin. |
| ebin_loglike | ndarray | Log-likelihood values for scan over the spatial extension in each energy bin. |
| ebin_loglike_ptsrc | ndarray | Log-Likelihood value of the best-fit point-source model in each energy bin. |
| ebin_loglike_ext | ndarray | Log-Likelihood value of the best-fit extended source model in each energy bin. |
| ra | float | Right ascension of best-fit position (deg). |
| dec | float | Declination of best-fit position (deg). |
| glon | float | Galactic Longitude of best-fit position (deg). |
| glat | float | Galactic Latitude of best-fit position (deg). |
| ra_err | float | Std. deviation of positional uncertainty in right ascension (deg). |
| dec_err | float | Std. deviation of positional uncertainty in declination (deg). |
| glon_err | float | Std. deviation of positional uncertainty in galactic longitude (deg). |
| glat_err | float | Std. deviation of positional uncertainty in galactic latitude (deg). |
| pos_offset | float | Angular offset (deg) between the old and new (localized) source positions. |
| pos_err | float | 1-sigma positional uncertainty (deg). |
| pos_r68 | float | 68% positional uncertainty (deg). |
| pos_r95 | float | 95% positional uncertainty (deg). |
| pos_r99 | float | 99% positional uncertainty (deg). |
| pos_err_semimajor | float | 1-sigma uncertainty (deg) along major axis of uncertainty ellipse. |
| pos_err_semiminor | float | 1-sigma uncertainty (deg) along minor axis of uncertainty ellipse. |
| pos_angle | float | Position angle of uncertainty ellipse with respect to major axis. |
| tsmap | *Map* | |
| ptsrc_tot_map | *Map* | |
| ptsrc_src_map | *Map* | |
| ptsrc_bkg_map | *Map* | |
| ext_tot_map | *Map* | |
| ext_src_map | *Map* | |
| ext_bkg_map | *Map* | |
| source_fit | dict | Dictionary with parameters of the best-fit extended source model. |

### Configuration

The default configuration of the method is controlled with the *extension* section of the configuration file. The default configuration can be overriden by passing the option as a *kwargs* argument to the method.

Table 28: *extension* Options

| Option | Default | Description |
|---|---|---|
| fit_ebin | False | Perform a fit for the angular extension in each analysis energy bin. |
| fit_position | False | Perform a simultaneous fit to the source position and extension. |
| fix_shape | False | Fix spectral shape parameters of the source of interest. If True then only the normalization parameter will be fit. |
| free_background | False | Leave background parameters free when performing the fit. If True then any parameters that are currently free in the model will be fit simultaneously with the source of interest. |
| free_radius | None | Free normalizations of background sources within this angular distance in degrees from the source of interest. If None then no sources will be freed. |
| make_plots | False | Generate diagnostic plots. |
| make_tsmap | True | Make a TS map for the source of interest. |
| psf_scale_fn | None | Tuple of two vectors (logE,f) defining an energy-dependent PSF scaling function that will be applied when building spatial models for the source of interest. The tuple (logE,f) defines the fractional corrections f at the sequence of energies logE = log10(E/MeV) where f=0 corresponds to no correction. The correction function f(E) is evaluated by linearly interpolating the fractional correction factors f in log(E). The corrected PSF is given by P'(x;E) = P(x/(1+f(E));E) where x is the angular separation. |
| save_model_map | False | Save model counts cubes for the best-fit model of extension. |
| spatial_model | RadialGaussian | Spatial model that will be used to test the sourceextension. The spatial scale parameter of the model will be set such that the 68% containment radius of the model is equal to the width parameter. |
| sqrt_ts_threshold | None | Threshold on sqrt(TS_ext) that will be applied when update is True. If None then nothreshold is applied. |
| tsmap_fitter | tsmap | Set the method for generating the TS map. Valid options are tsmap or tscube. |
| update | False | Update this source with the best-fit model for spatial extension if TS_ext > tsext_threshold. |
| width | None | Sequence of values in degrees for the likelihood scan over spatial extension (68% containment radius). If this argument is None then the scan points will be determined from width_min/width_max/width_nstep. |
| width_max | 1.0 | Maximum value in degrees for the likelihood scan over spatial extent. |
| width_min | 0.01 | Minimum value in degrees for the likelihood scan over spatial extent. |
| width_nstep | 21 | Number of scan points between width_min and width_max. Scan points will be spaced evenly on a logarithmic scale between width_min and width_max. |
| write_fits | True | Write the output to a FITS file. |
| write_npy | True | Write the output dictionary to a numpy file. |

### Reference/API

### TS Map

tsmap() generates a test statistic (TS) map for an additional source component centered at each spatial bin in the ROI. The methodology is similar to that of the gttsmap ST application but with the following approximations:

- Evaluation of the likelihood is limited to pixels in the vicinity of the test source position.
- The background model is fixed when fitting the test source amplitude.

*TS Cube* is a related method that can also be used to generate TS maps as well as cubes (TS vs. position and energy).

For each spatial bin the method calculates the maximum likelihood test statistic given by

$$\mathrm{TS} = 2\sum_k \ln L(\mu,\theta|n_k) - \ln L(0,\theta|n_k)$$

where the summation index $k$ runs over both spatial and energy bins, $\mu$ is the test source normalization parameter, and $\theta$ represents the parameters of the background model. The likelihood fitting implementation used by `tsmap()` only fits the test source normalization ($\mu$). Shape parameters of the test source and parameters of background components are fixed to their current values.

### Examples

The spatial and spectral properties of the convolution kernel are defined with the `model` dictionary argument. The `model` dictionary format is the same as accepted by `add_source()`.

```
# Generate TS map for a power-law point source with Index=2.0
model = {'Index' : 2.0, 'SpatialModel' : 'PointSource'}
maps = gta.tsmap('fit1',model=model)

# Generate TS map for a power-law point source with Index=2.0 and
# restricting the analysis to E > 3.16 GeV
model = {'Index' : 2.0, 'SpatialModel' : 'PointSource'}
maps = gta.tsmap('fit1_emin35',model=model,erange=[3.5,None])

# Generate TS maps for a power-law point source with Index=1.5, 2.0, and 2.5
model={'SpatialModel' : 'PointSource'}
maps = []
for index in [1.5,2.0,2.5]:
    model['Index'] = index
    maps += [gta.tsmap('fit1',model=model)]
```

The `multithread` option can be enabled to split the calculation across all available cores:

```
maps = gta.tsmap('fit1',model=model,multithread=True)
```

Note that care should be taken when using this option in an environment where the number of cores per process is restricted such as a batch farm.

`tsmap()` returns a `maps` dictionary containing *Map* representations of the TS and predicted counts (NPred) of the best-fit test source at each position.

```
model = {'Index' : 2.0, 'SpatialModel' : 'PointSource'}
maps = gta.tsmap('fit1',model=model)
print('TS at Pixel (50,50): ',maps['ts'].counts[50,50])
```

The contents of the output dictionary are given in the following table.

| Key | Type | Description |
|---|---|---|
| amplitude | *Map* | Best-fit test source amplitude expressed in terms of the spectral prefactor. |
| npred | *Map* | Best-fit test source amplitude expressed in terms of the total model counts (Npred). |
| ts | *Map* | Test source TS (twice the logLike difference between null and alternate hypothese). |
| sqrt_ts | *Map* | Square-root of the test source TS. |
| file | str | Path to a FITS file containing the maps (TS, etc.) generated by this method. |
| src_dict | dict | Dictionary defining the properties of the test source. |

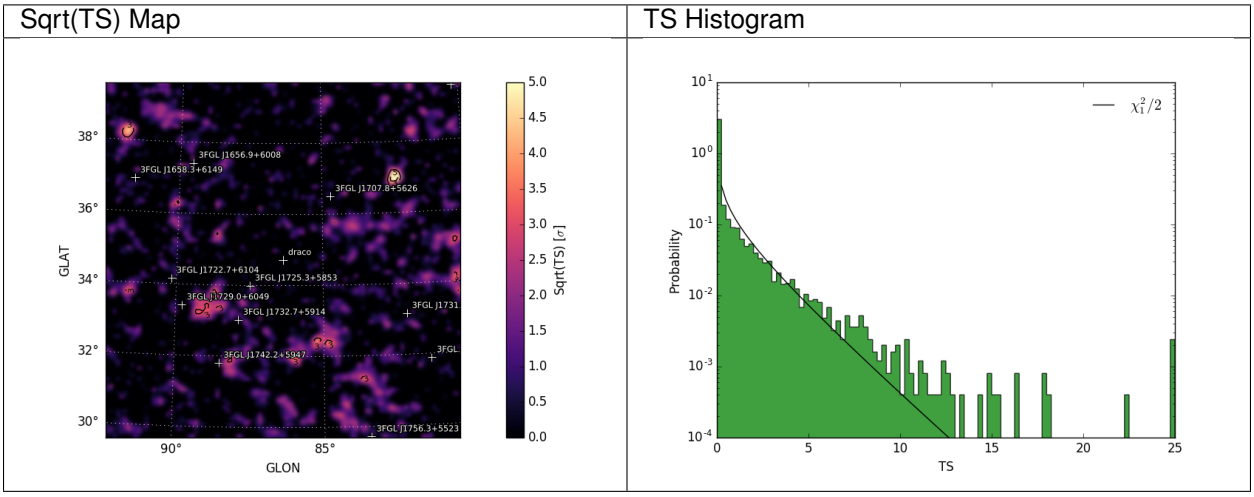
The `write_fits` and `write_npy` options can used to write the output to a FITS or numpy file. All output files are prepended with the `prefix` argument.

Diagnostic plots can be generated by setting `make_plots=True` or by passing the output dictionary to *`make_residmap_plots`*:

```
maps = gta.tsmap('fit1',model=model, make_plots=True)
gta.plotter.make_tsmap_plots(maps, roi=gta.roi)
```

This will generate the following plots:

- `tsmap_sqrt_ts` : Map of sqrt(TS) values. The color map is truncated at 5 sigma with isocontours at 2 sigma intervals indicating values above this threshold.
- `tsmap_npred` : Map of best-fit source amplitude in counts.
- `tsmap_ts_hist` : Histogram of TS values for all points in the map. Overplotted is the reference distribution for chi-squared with one degree of freedom (expectation from Chernoff's theorem).




## Configuration

The default configuration of the method is controlled with the *tsmap* section of the configuration file. The default configuration can be overriden by passing the option as a *kwargs* argument to the method.

Table 29: *tsmap* Options

| Option | Default | Description |
|---|---|---|
| exclude | None | List of sources that will be removed from the model when computing the TS map. |
| loge_bounds | None | Restrict the analysis to an energy range (emin,emax) in log10(E/MeV) that is a subset of the analysis energy range. By default the full analysis energy range will be used. If either emin/emax are None then only an upper/lower bound on the energy range wil be applied. |
| make_plots | False | Generate diagnostic plots. |
| max_kernel_radius | 3.0 | Set the maximum radius of the test source kernel. Using a smaller value will speed up the TS calculation at the loss of accuracy. |
| model | None | Dictionary defining the spatial/spectral properties of the test source. If model is None the test source will be a PointSource with an Index 2 power-law spectrum. |
| multithread | False | Split the calculation across number of processes set by nthread option. |
| nthread | None | Number of processes to create when multithread is True. If None then one process will be created for each available core. |
| write_fits | True | Write the output to a FITS file. |
| write_npy | True | Write the output dictionary to a numpy file. |

### Reference/API

### TS Cube

**Warning:** This method requires Fermi Science Tools version 11-04-00 or later.

`tscube()` can be used generate both test statistic (TS) maps and bin-by-bin scans of the test source likelihood as a function of spatial pixel and energy bin (likelihood cubes). The implemention is based on the `gttscube` ST application which uses an efficient newton optimization algorithm for fitting the test source at each pixel in the ROI.

The TS map output has the same format as TS maps produced by `tsmap()` (see *TS Map* for further details). However while `tsmap()` fixes the background model, `tscube()` can also fit background normalization parameters when scanning the test source likelihood. This method makes no approximations in the evaluation of the likelihood and may be somewhat slower than `tsmap()` depending on the ROI dimensions and energy bounds.

For each spatial bin the method calculates the maximum likelihood test statistic given by

$$\mathrm{TS} = 2\sum_k \ln L(\mu,\hat{\theta}|n_k) - \ln L(0,\hat{\hat{\theta}}|n_k)$$

where the summation index $k$ runs over both spatial and energy bins, $\mu$ is the test source normalization parameter, and $\theta$ represents the parameters of the background model. Normalization parameters of the background model are refit at every test source position if they are free in the model. All other spectral parameters (indices etc.) are kept fixed.

### Examples

The method is executed by providing a `model` dictionary argument that defines the spectrum and spatial morphology of the test source:

```
# Generate TS cube for a power-law point source with Index=2.0
model = {'Index' : 2.0, 'SpatialModel' : 'PointSource'}
cube = gta.tscube('fit1',model=model)
```

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```
# Generate TS cube for a power-law point source with Index=2.0 and
# restricting the analysis to E > 3.16 GeV
model = {'Index' : 2.0, 'SpatialModel' : 'PointSource'}
cube = gta.tscube('fit1_emin35',model=model,erange=[3.5,None])

# Generate TS cubes for a power-law point source with Index=1.5, 2.0, and 2.5
model={'SpatialModel' : 'PointSource'}
cubes = []
for index in [1.5,2.0,2.5]:
    model['Index'] = index
    cubes += [gta.tsmap('fit1',model=model)]
```

In addition to generating a TS map, this method can also extract a test source likelihood profile as a function of energy at every position in the ROI (likelihood cube). This information is saved to the `SCANDATA` HDU of the output FITS file:

```
from astropy.table import Table
cube = gta.tscube('fit1',model=model, do_sed=True)
tab_scan = Table.read(cube['file'],'SCANDATA')
tab_ebounds = Table.read(cube['file'],'EBOUNDS')

eflux_scan = tab_ebounds['REF_EFLUX'][None,:,None]*tab_scan['norm_scan']

# Plot likelihood for pixel 400 and energy bin 2
plt.plot(eflux_scan[400,2],tab_scan['dloglike_scan'][400,2])
```

The likelihood profile cube can be used to evaluate the likelihood for a test source with an arbitrary spectral model at any position in the ROI. The *TSCube* and *CastroData* classes can be used to analyze a TS cube:

```
from fermipy.castro import TSCube
tscube = TSCube.create_from_fits('tscube.fits')
cd = tscube.castroData_from_ipix(400)

# Fit the likelihoods at pixel 400 with different spectral models
cd.test_spectra()
```

### Configuration

The default configuration of the method is controlled with the *tscube* section of the configuration file. The default configuration can be overriden by passing the option as a *kwargs* argument to the method.

Table 30: *tscube* Options

| Option | Default | Description |
|---|---|---|
| cov_scale | 1.0 | Scale factor to apply to broadband fitting cov. matrix in bin-by-bin fits ( < 0 -> fixed ) |
| cov_scale_bb | 1.0 | Scale factor to apply to global fitting cov. matrix in broadband fits. ( < 0 -> no prior ) |
| do_sed | True | Compute the energy bin-by-bin fits |
| exclude | None | List of sources that will be removed from the model when computing the TS map. |
| init_lambda | 0 | Initial value of damping parameter for newton step size calculation. A value of zero disables damping. |
| max_iter | 30 | Maximum number of iterations for the Newtons method fitter. |
| model | None | Dictionary defining the spatial/spectral properties of the test source. If model is None the test source will be a PointSource with an Index 2 power-law spectrum. |
| nnorm | 10 | Number of points in the likelihood v. normalization scan |
| norm_sigma | 5.0 | Number of sigma to use for the scan range |
| remake_test_source | False | If true, recomputes the test source image (otherwise just shifts it) |
| st_scan_level | 0 | Level to which to do ST-based fitting (for testing) |
| tol | 0.001 | Critetia for fit convergence (estimated vertical distance to min < tol ) |
| tol_type | 0 | Absoulte (0) or relative (1) criteria for convergence. |

### Reference/API

### Residual Map

`residmap()` calculates the residual between smoothed data and model maps. Whereas a TS map is only sensitive to positive deviations with respect to the model, `residmap()` is sensitive to both positive and negative residuals and therefore can be useful for assessing the model goodness-of-fit. The significance of the data/model residual at map position $(i, j)$ is given by

$$\sigma_{ij}^2 = 2\mathrm{sgn}(\tilde{n}_{ij} - \tilde{m}_{ij}) \left(\ln L_P(\tilde{n}_{ij}, \tilde{n}_{ij}) - \ln L_P(\tilde{n}_{ij}, \tilde{m}_{ij})\right)$$

$$\text{with} \quad \tilde{m}_{ij} = \sum_k (m_k * f_k)_{ij} \quad \tilde{n}_{ij} = \sum_k (n_k * f_k)_{ij} \quad \ln L_P(n, m) = n \ln(m) - m$$

where $n_\mathrm{k}$ and $m_\mathrm{k}$ are the data and model maps at energy plane $k$ and $f_\mathrm{k}$ is the convolution kernel. The convolution kernel is proportional to the counts expectation at a given pixel and normalized such that

$$f_{ijk} = s_{ijk} \left( \sum_{ijk} s_{ijk}^2 \right)^{-1}$$

where $s$ is the expectation counts cube for a pure signal normalized to one.

### Examples

The spatial and spectral properties of the convolution kernel are defined with the `model` dictionary argument. All source models are supported as well as a gaussian kernel (defined by setting *SpatialModel* to *Gaussian*).

```
# Generate residual map for a Gaussian kernel with Index=2.0 and
# radius (R_68) of 0.3 degrees
model = {'Index' : 2.0,
         'SpatialModel' : 'Gaussian', 'SpatialWidth' : 0.3 }
maps = gta.residmap('fit1',model=model)
```

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```
# Generate residual map for a power-law point source with Index=2.0 for
# E > 3.16 GeV
model = {'Index' : 2.0, 'SpatialModel' : 'PointSource'}
maps = gta.residmap('fit1_emin35',model=model,loge_bounds=[3.5,None])

# Generate residual maps for a power-law point source with Index=1.5, 2.0, and 2.5
model={'SpatialModel' : 'PointSource'}
maps = []
for index in [1.5,2.0,2.5]:
    model['Index'] = index
    maps += [gta.residmap('fit1',model=model)]
```

`residmap()` returns a `maps` dictionary containing *Map* representations of the residual significance and amplitude as well as the smoothed data and model maps. The contents of the output dictionary are described in the following table.

| Key | Type | Description |
|---|---|---|
| sigma | *Map* | Residual significance in sigma. |
| excess | *Map* | Residual amplitude in counts. |
| data | *Map* | Smoothed counts map. |
| model | *Map* | Smoothed model map. |
| files | dict | File paths of the FITS image files generated by this method. |
| src_dict | dict | Source dictionary with the properties of the convolution kernel. |

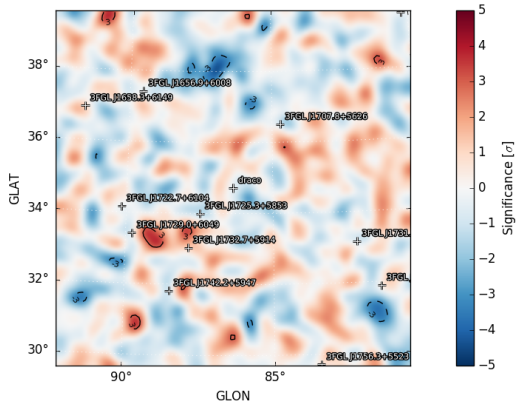
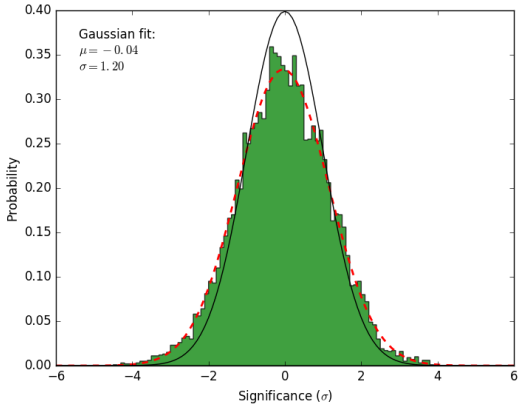
The `write_fits` and `write_npy` options can used to write the output to a FITS or numpy file. All output files are prepended with the `prefix` argument.

Diagnostic plots can be generated by setting `make_plots=True` or by passing the output dictionary to *make_residmap_plots*:

```
maps = gta.residmap('fit1',model=model, make_plots=True)
gta.plotter.make_residmap_plots(maps, roi=gta.roi)
```

This will generate the following plots:

- `residmap_excess` : Smoothed excess map (data-model).
- `residmap_data` : Smoothed data map.
- `residmap_model` : Smoothed model map.
- `residmap_sigma` : Map of residual significance. The color map is truncated at -5 and 5 sigma with labeled isocontours at 2 sigma intervals indicating values outside of this range.
- `residmap_sigma_hist` : Histogram of significance values for all points in the map. Overplotted are distributions for the best-fit Gaussian and a unit Gaussian.

| Residual Significance Map | Significance Histogram |
|---|---|
|  |  |



## Configuration

The default configuration of the method is controlled with the *residmap* section of the configuration file. The default configuration can be overriden by passing the option as a *kwargs* argument to the method.

Table 31: *residmap* Options

| Option | Default | Description |
|---|---|---|
| `exclude` | None | List of sources that will be removed from the model when computing the residual map. |
| `loge_bounds` | None | Restrict the analysis to an energy range (emin,emax) in log10(E/MeV) that is a subset of the analysis energy range. By default the full analysis energy range will be used. If either emin/emax are None then only an upper/lower bound on the energy range wil be applied. |
| `make_plots` | False | Generate diagnostic plots. |
| `model` | None | Dictionary defining the spatial/spectral properties of the test source. If model is None the test source will be a PointSource with an Index 2 power-law spectrum. |
| `use_weights` | False | Used weighted version of maps in making plots. |
| `write_fits` | True | Write the output to a FITS file. |
| `write_npy` | True | Write the output dictionary to a numpy file. |

## Reference/API

## Source Finding

`find_sources()` is an iterative source-finding algorithm that uses peak detection on a TS map to find new source candidates. The procedure for adding new sources at each iteration is as follows:

- Generate a TS map for the test source model defined with the `model` argument.
- Identify peaks with sqrt(TS) > `sqrt_ts_threshold` and an angular distance of at least `min_separation` from a higher amplitude peak in the map.
- Order the peaks by TS and add a source at each peak starting from the highest TS peak. Set the source position by fitting a 2D parabola to the log-likelihood surface around the peak maximum. After adding each source, re-fit its spectral parameters.
- Add sources at the N highest peaks up to N = `sources_per_iter`.

Source finding is repeated up to `max_iter` iterations or until no peaks are found in a given iteration. Sources found by the method are added to the model and given designations *PS JXXXX.X+XXXX* according to their position in celestial coordinates.

### Examples

```
model = {'Index' : 2.0, 'SpatialModel' : 'PointSource'}
srcs = gta.find_sources(model=model, sqrt_ts_threshold=5.0,
                        min_separation=0.5)
```

The method for generating the TS maps can be controlled with the `tsmap_fitter` option. TS maps can be generated with either `tsmap()` or `tscube()`.

### Reference/API

### Source Localization

The `localize()` method can be used to spatially localize a source. Localization is performed by scanning the likelihood surface in source position in a local patch around the nominal source position. The fit to the source position proceeds in two iterations:

- **TS Map Scan**: Obtain a first estimate of the source position by generating a likelihood map of the region using the `tsmap` method. In this step all background parameters are fixed to their nominal values. The size of the search region used for this step is set with the `dtheta_max` parameter.
- **Likelihood Scan**: Refine the position of the source by performing a scan of the likelihood surface in a box centered on the best-fit position found in the first iteration. The size of the search region is set to encompass the 99% positional uncertainty contour. This method uses a full likelihood fit at each point in the likelihood scan and will re-fit all free parameters of the model.

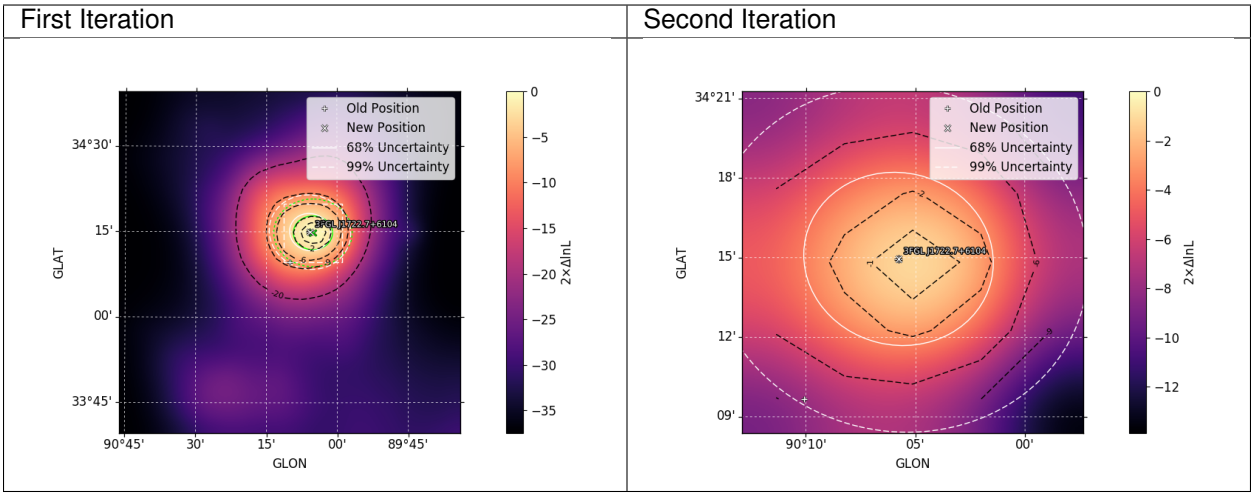
If a peak is found in the search region and the positional fit succeeds, the method will update the position of the source in the model to the new best-fit position.

### Examples

The localization method is executed by passing the name of a source as its argument. The method returns a python dictionary with the best-fit source position and localization errors and also saves the same information to FITS and numpy files.

```
>>> loc = gta.localize('3FGL J1722.7+6104', make_plots=True)
>>> print(loc['ra'],loc['dec'],loc['pos_r68'],loc['pos_r95'])
(260.53164555483784, 61.04493807148745, 0.14384100879403075, 0.23213050350030126)
```

When running with `make_plots=True` the method will save a diagnostic plot to the working directory with a visualization of the localization contours. The green and white contours show the uncertainty ellipse derived from the first and second iterations of the positional scan.




The default configuration for the localization analysis can be overriden by supplying one or more *kwargs*:

```
# Localize the source and update its properties in the model
# with the localized position
>>> o = gta.extension('3FGL J1722.7+6104', update=True)
```

By default all background parameters will be fixed when the positional fit is performed. One can choose to free background parameters with the `free_background` and `free_radius` options:

```
# Free a nearby source that may be be partially degenerate with the
# source of interest
gta.free_norm('sourceB')
gta.localize('3FGL J1722.7+6104', free_background=True)

# Free normalizations of background sources within a certain
# distance of the source of interest
gta.localize('3FGL J1722.7+6104', free_radius=1.0)
```

The contents of the output dictionary are described in the following table:

Table 32: *localize* Output

| Key | Type | Description |
|---|---|---|
| name | str | Name of source. |
| file | str | Name of output FITS file. |
| config | dict | Copy of the input configuration to this method. |
| ra | float | Right ascension of best-fit position (deg). |
| dec | float | Declination of best-fit position (deg). |
| glon | float | Galactic Longitude of best-fit position (deg). |
| glat | float | Galactic Latitude of best-fit position (deg). |
| xpix | float | Longitude pixel coordinate of best-fit position. |
| ypix | float | Latitude pixel coordinate of best-fit position. |
| deltax | float | Longitude offset from old position (deg). |
| deltay | float | Latitude offset from old position (deg). |
| skydir | SkyCoord | |
| ra_prelo | float | Right ascension of pre-localization position (deg). |
| dec_prelo | float | Declination of pre-localization position (deg). |

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Table 32 – continued from previous page

| Key | Type | Description |
|---|---|---|
| glon_preloc | float | Galactic Longitude of pre-localization position (deg). |
| glat_preloc | float | Galactic Latitude of pre-localization position (deg). |
| ra_err | float | Std. deviation of positional uncertainty in right ascension (deg). |
| dec_err | float | Std. deviation of positional uncertainty in declination (deg). |
| glon_err | float | Std. deviation of positional uncertainty in galactic longitude (deg). |
| glat_err | float | Std. deviation of positional uncertainty in galactic latitude (deg). |
| pos_offset | float | Angular offset (deg) between the old and new (localized) source positions. |
| pos_err | float | 1-sigma positional uncertainty (deg). |
| pos_r68 | float | 68% positional uncertainty (deg). |
| pos_r95 | float | 95% positional uncertainty (deg). |
| pos_r99 | float | 99% positional uncertainty (deg). |
| pos_err_semimajor | float | 1-sigma uncertainty (deg) along major axis of uncertainty ellipse. |
| pos_err_semiminor | float | 1-sigma uncertainty (deg) along minor axis of uncertainty ellipse. |
| pos_angle | float | Position angle of uncertainty ellipse with respect to major axis. |
| pos_ecc | float | Eccentricity of uncertainty ellipse defined as sqrt(1-b**2/a**2). |
| pos_ecc2 | float | Eccentricity of uncertainty ellipse defined as sqrt(a**2/b**2-1). |
| pos_gal_cov | ndarray | Covariance matrix of positional uncertainties in local projection in galactic coordinates. |
| pos_gal_corr | ndarray | Correlation matrix of positional uncertainties in local projection in galactic coordinates. |
| pos_cel_cov | ndarray | Covariance matrix of positional uncertainties in local projection in celestial coordinates. |
| pos_cel_corr | ndarray | Correlation matrix of positional uncertainties in local projection in celestial coordinates. |
| tsmap | *Map* | |
| tsmap_peak | *Map* | |
| loglike_init | float | Log-Likelihood of model before localization. |
| loglike_base | float | Log-Likelihood of model after initial spectral fit. |
| loglike_loc | float | Log-Likelihood of model after localization. |
| dloglike_loc | float | Difference in log-likelihood before and after localization. |
| fit_success | bool | |
| fit_inbounds | bool | |
| fit_init | dict | |
| fit_scan | dict | |

### Configuration

Table 33: *localize* Options

| Option | Default | Description |
|---|---|---|
| dtheta_max | 0.5 | Half-width of the search region in degrees used for the first pass of the localization search. |
| fix_shape | False | Fix spectral shape parameters of the source of interest. If True then only the normalization parameter will be fit. |
| free_background | False | Leave background parameters free when performing the fit. If True then any parameters that are currently free in the model will be fit simultaneously with the source of interest. |
| free_radius | None | Free normalizations of background sources within this angular distance in degrees from the source of interest. If None then no sources will be freed. |
| make_plots | False | Generate diagnostic plots. |
| nstep | 5 | Number of steps in longitude/latitude that will be taken when refining the source position. The bounds of the scan range are set to the 99% positional uncertainty as determined from the TS map peak fit. The total number of sampling points will be nstep**2. |
| tsmap_fitmethod | tsmap | Set the method for generating the TS map. Valid options are tsmap or tscube. |
| update | True | Update the source model with the best-fit position. |
| write_fits | True | Write the output to a FITS file. |
| write_npy | True | Write the output dictionary to a numpy file. |

### Reference/API

### Phased Analysis

Fermipy provides several options to support analysis with selections on pulsar phase. The following examples assume that you already have a phased FT1 file that contains a PULSE_PHASE column with the pulsar phase for each event.

The following examples illustrates the settings for the *gtlike* and *selection* sections of the configuration file that would be used for a single-component ON- or OFF-phase analysis:

```
selection :
  emin : 100
  emax : 316227.76
  zmax    : 90
  evclass : 128
  evtype  : 3
  tmin    : 239557414
  tmax    : 428903014
  target : '3FGL J0534.5+2201p'
  phasemin : 0.68
  phasemax : 1.00

gtlike :
  edisp : True
  irfs : 'P8R2_SOURCE_V6'
  edisp_disable : ['isodiff','galdiff']
  expscale : 0.32
```

The `gtlike.expscale` parameter defines the correction that should be applied to the nominal exposure to account for the phase selection defined by `selection.phasemin` and `selection.phasemax`. Normally this should be set to the size of the phase selection interval.

To perform a joint analysis of multiple phase selections you can use the *components* section to define separate ON- and OFF-phase components:

```
components:
  - selection : {phasemin : 0.68, phasemax: 1.0}
    gtlike    : {expscale : 0.32, src_expscale : {'3FGL J0534.5+2201p':0.0}}
  - selection : {phasemin : 0.0 , phasemax: 0.68}
    gtlike    : {expscale : 0.68, src_expscale : {'3FGL J0534.5+2201p':1.0}}
```

The `src_expscale` parameter can be used to define an exposure correction for indvidual sources. In this example it is used to zero the pulsar component for the OFF-phase selection.

### Sensitivity Tools

The `fermipy-flux-sensitivity` script calculates the LAT flux threshold for a gamma-ray source in bins of energy (differential sensitivity) and integrated over the full LAT energy range (integral sensitivity). The source flux threshold is the flux at which the median TS of a source (twice the likelihood ratio of the best-fit model with and without the source) equals a certain value. Primary inputs to this script are the livetime cube (output of `gtltcube`) and the model cube for the galactic diffuse background. The `obs_time_yr` option can be used to rescale the livetime cube to a shorter or longer observation time.

```
$ fermipy-flux-sensitivity --glon=30 --glat=30 --output=lat_sensitivity.fits \
--ltcube=ltcube.fits --galdiff=gll_iem_v06.fits --event_class=P8R2_SOURCE_V6 \
--ts_thresh=25.0 --min_counts=10.0
```

If no livetime cube is provided then the sensitivity will be computed assuming an "ideal" survey-mode operation with uniform exposure over the whole sky and no Earth obscuration or deadtime. By default the flux sensitivity will be calculated for a TS threshold of 25 and at least 3 counts.

A map of sensitivity with WCS or HEALPix pixelization can be generated by setting the `map_type` argument to either `wcs` or `hpx`:

```
# Generate a WCS sensitivity map of 50 x 50 deg centered at (glon,glat) = (30,30)
$ fermipy-flux-sensitivity  --glon=30 --glat=30 --output=lat_sensitivity_map.fits \
--ltcube=ltcube.fits --galdiff=gll_iem_v06.fits --event_class=P8R2_SOURCE_V6 \
--map_type=wcs --wcs_npix=100 --wcs_cdelt=0.5 --wcs_proj=AIT

# Generate a HPX sensitivity map of nside=16
$ fermipy-flux-sensitivity  --output=lat_sensitivity_map.fits \
--ltcube=ltcube.fits --galdiff=gll_iem_v06.fits --event_class=P8R2_SOURCE_V6 \
--map_type=hpx --hpx_nside=16
```

The integral and differential sensitivity maps will be written to the `MAP_INT_FLUX` and `MAP_DIFF_FLUX` extensions respectively.

By default the flux sensitivity will be computed for a point-source morphology. The assumed source morphology can be changed with the `spatial_model` and `spatial_size` parameters:

It is possible to choose among PowerLaw, LogParabola and PLSuperExpCutoff SED shapes using the option `sedshape`.

```
# Generate the sensitivity to a source with a 2D gaussian morphology
# and a 68% containment radius of 1 deg located at longitude 30deg and
# latitude 30 deg and with a PLSuperExpCutoff SED with index 2.0 and
# cutoff energy 10 GeV
$ fermipy-flux-sensitivity --output=lat_sensitivity_map.fits \
--ltcube=ltcube.fits --galdiff=gll_iem_v06.fits --event_class=P8R2_SOURCE_V6 \
--spatial_model=RadialGaussian --spatial_size=1.0 --glon=30 --glat=30
--sedshape=PLSuperExpCutoff --index=2.0 --cutoff=1e4
```

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```
# Generate the sensitivity map in healpix with nside 128 of a point source with
# LogParabola SED and with spectral index 2.0 and curvature index beta=0.50
# between 1 and 10 GeV
$ fermipy-flux-sensitivity --output=lat_sensitivity_map.fits \
--ltcube=ltcube.fits --galdiff=gll_iem_v06.fits --event_class=P8R2_SOURCE_V6 \
--spatial_model=PointSource --sedshape=LogParabola --index=2.0 --beta=0.50 \
--hpx_nside=128 --map_type=hpx --emin=1000 --emax=10000
```

The output FITS file set with the `output` option contains the following tables. Note that `MAP` tables are only generated when the `map_type` argument is set.

- `DIFF_FLUX` : Differential flux sensitivity for a gamma-ray source at sky posititon set by `glon` and `glat`.
- `INT_FLUX` : Integral flux sensitivity evaluated for PowerLaw sources with spectral indices between 1.0 and 5.0 at sky posititon set by `glon` and `glat`. Columns starting with `ebin` contain the source amplitude vs. energy bin.
- `MAP_DIFF_FLUX` : Sky cube with differential flux threshold vs. sky position and energy.
- `MAP_DIFF_NPRED` : Sky cube with counts amplitude (NPred) of a source at the detection threshold vs. position and energy.
- `MAP_INT_FLUX` : Sky map with integral flux threshold vs. sky position. Integral sensitivity will be computed for a PowerLaw source with index equal to the `index` parameter.
- `MAP_INT_NPRED` : Sky map with counts amplitude (NPred) of a source at the detection threshold vs. sky position.

The output file can be read using the `Table` module:

```
from astropy.table import Table

tab = Table.read('lat_sensitivity.fits','DIFF_FLUX')
print(tab['e_min'], tab['e_max'], tab['flux'])
tab = Table.read('lat_sensitivity.fits','INT_FLUX')
print(tab['index'], tab['flux'])
```

### 1.3.9 Validation Tools

This page documents LAT validation tools.

#### Merit Skimmer

The `fermipy-merit-skimmer` script can be used to create skimmed Merit files (either MC or data) and serves as a replacement for the web-based merit skimmer tool. The script accepts as input a sequence of Merit file paths or lists of Merit file paths which can be either local (nfs) or xrootd.

```
$ fermipy-merit-skimmer merit_list.txt --output=merit.root --selection='FswGamFilter'␣
↪\
--aliases=aliases.yaml

$ fermipy-merit-skimmer merit_list.txt --output=merit-clean.root \
--selection='FswGamFilter && CLEAN' --aliases=EvtClassDefs_P8R2.xml
```

where merit_list.txt is a text file with one path per line. The --selection option sets the selection that will be applied when filtering events in each file. The --output option sets the path to the output merit file. The --aliases option can be used to load an alias file (set of key/value cut expression pairs). This option can accept either a YAML alias file or an XML event class definition file. The following illustrates the YAML alias file format:

```
FswGamFilter : FswGamState == 0
TracksCutFilter : FswGamState == 0 && TkrNumTracks > 0
CalEnergyFilter : FswGamState == 0 && CalEnergyRaw > 0
```

One can restrict the set of output branches with the --branches option which accepts an alias file or a YAML file containing a list of branch names. In the former case all branch names used in the given alias set will be extracted and added to the list of output branches.

```
$ fermipy-merit-skimmer merit_list.txt --output=merit.root --selection='FswGamFilter'␣
↪\
--aliases=EvtClassDefs_P8R2.xml --branches=EvtClassDefs_P8R2.xml
```

One can split the skimming task into separate batch jobs by running with the --batch option. This will subdivide task into N jobs when N is the number of files in the list divided by --files_per_job. The name of the output ROOT file of each job will be appended with the index of the job in the sequence (e.g. skim_000.root, skim_001.root, etc.). The --time and --resources options can be used to set the LSF wallclock time and resource flags.

```
$ fermipy-merit-skimmer merit_list.txt --output=merit.root --selection='SOURCE &&␣
↪FRONT' \
--branches=EvtClassDefs_P8R2.xml --files_per_job=1000 --batch --aliases=EvtClassDefs_
↪P8R2.xml
```

When skimming MC files it can be useful to extract the jobinfo for tracking the number of thrown events. The --extra_trees option can be used to copy one or more trees to the output file in addition to the Merit Tuple:

```
$ fermipy-merit-skimmer merit_list.txt --output=merit.root --extra_trees=jobinfo
```

### 1.3.10 fermipy package

#### fermipy.config module

**class** fermipy.config.**ConfigManager**

Bases: object

**classmethod create**(*configfile*)

Create a configuration dictionary from a yaml config file. This function will first populate the dictionary with defaults taken from pre-defined configuration files. The configuration dictionary is then updated with the user-defined configuration file. Any settings defined by the user will take precedence over the default settings.

**static load**(*path*)

**class** fermipy.config.**ConfigSchema**(*options=None*, ***kwargs*)

Bases: object

Class encapsulating a configuration schema.

**add_option**(*name*, *default_value*, *helpstr=''*, *otype=None*)

**add_section**(*name*, *section*)

**create_config**(*config=None*, *validate=True*, ***kwargs*)

**items**()

**class** fermipy.config.**Configurable**(*config*, ***kwargs*)
Bases: object

The base class provides common facilities like loading and saving configuration state.

**config**
Return the configuration dictionary of this class.

**configdir**

**configure**(*config*, ***kwargs*)

**classmethod get_config**()
Return a default configuration dictionary for this class.

**print_config**(*logger*, *loglevel=None*)

**schema**
Return the configuration schema of this class.

**write_config**(*outfile*)
Write the configuration dictionary to an output file.

fermipy.config.**cast_config**(*config*, *defaults*)

fermipy.config.**create_default_config**(*schema*)
Create a configuration dictionary from a schema dictionary. The schema defines the valid configuration keys and their default values. Each element of schema should be a tuple/list containing (default value,docstring,type) or a dict containing a nested schema.

fermipy.config.**update_from_schema**(*cfg*, *cfgin*, *schema*)
Update configuration dictionary cfg with the contents of cfgin using the schema dictionary to determine the valid input keys.

**Parameters**

- **cfg** (*dict*) – Configuration dictionary to be updated.
- **cfgin** (*dict*) – New configuration dictionary that will be merged with cfg.
- **schema** (*dict*) – Configuration schema defining the valid configuration keys and their types.

**Returns** cfgout

**Return type** dict

fermipy.config.**validate_config**(*config*, *defaults*, *section=None*)

fermipy.config.**validate_from_schema**(*cfg*, *schema*, *section=None*)

fermipy.config.**validate_option**(*opt_name*, *opt_val*, *schema_type*)

### fermipy.defaults module

fermipy.defaults.**make_attrs_class**(*typename*, *d*)

fermipy.defaults.**make_default_dict**(*d*)

fermipy.defaults.**make_default_tuple**(*d*)

### fermipy.gtanalysis module

### fermipy.logger module

**class** fermipy.logger.**Logger**
Bases: object

This class provides helper functions which facilitate creating instances of the built-in logger class.

**static configure**(*name*, *logfile*, *loglevel=10*)
Create a python logger instance and configure it.

**Parameters**

- **name** (*str*) – Logger name.
- **logfile** (*str*) – Path to the log file.
- **loglevel** (*int*) – Default log level for STDOUT.

**static setup**(*config=None*, *logfile=None*)
This method sets up the default configuration of the logger. Once this method is called all subsequent instances Logger instances will inherit this configuration.

**class** fermipy.logger.**StreamLogger**(*name='stdout'*, *logfile=None*, *quiet=True*)
Bases: object

File-like object to log stdout/stderr using the logging module.

**close**()

**flush**()

**write**(*msg*, *level=10*)

fermipy.logger.**log_level**(*level*)
This is a function that returns a python like level from a HEASOFT like level.

### fermipy.roi_model module

**class** fermipy.roi_model.**CompositeSource**(*name*, *data*)
Bases: *fermipy.roi_model.Model*

**diffuse**

**nested_sources**

**write_xml**(*root*)

**class** fermipy.roi_model.**IsoSource**(*name*, *data*)
Bases: *fermipy.roi_model.Model*

**diffuse**

**filefunction**

**write_xml**(*root*, ***kwargs*)

**class** fermipy.roi_model.**MapCubeSource**(*name*, *data*)
Bases: *fermipy.roi_model.Model*

**diffuse**

**mapcube**

**write_xml**(*root*, ***kwargs*)

**class** fermipy.roi_model.**Model**(*name*, *data*)
Bases: object

Base class for point-like and diffuse source components. This class is a container for spectral and spatial parameters as well as other source properties such as TS, Npred, and location within the ROI.

**add_name**(*name*)

**add_to_table**(*tab*)

**assoc**

**check_cuts**(*cuts*)

**static create_from_dict**(*src_dict*, *roi_skydir=None*, *rescale=False*)

**data**

**get_catalog_dict**()

**get_norm**()

**is_free**
returns True if any of the spectral model parameters is set to free, else False

**items**()

**name**

**names**

**params**

**psf_scale_fn**

**set_name**(*name*, *names=None*)

**set_psf_scale_fn**(*fn*)

**set_spectral_pars**(*spectral_pars*)

**spatial_pars**

**spectral_pars**

**update_data**(*d*)

**update_from_source**(*src*)

**update_spectral_pars**(*spectral_pars*)

**class** fermipy.roi_model.**ROIModel**(*config=None*, ***kwargs*)
Bases: *fermipy.config.Configurable*

This class is responsible for managing the ROI model (both sources and diffuse components). Source catalogs can be read from either FITS or XML files. Individual components are represented by instances of *Model* and can be accessed by name using the bracket operator.

- Create an ROI with all 3FGL sources and print a summary of its contents:

```
>>> skydir = astropy.coordinates.SkyCoord(0.0,0.0,unit='deg')
>>> roi = ROIModel({'catalogs' : ['3FGL'],'src_roiwidth' : 10.0},
↪skydir=skydir)
>>> print(roi)
name                SpatialModel   SpectrumType     offset        ts
↪ npred
```

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```
------------------------------------------------------------------------
↪------
3FGL J2357.3-0150   PointSource    PowerLaw          1.956       nan
↪    0.0
3FGL J0006.2+0135   PointSource    PowerLaw          2.232       nan
↪    0.0
3FGL J0016.3-0013   PointSource    PowerLaw          4.084       nan
↪    0.0
3FGL J0014.3-0455   PointSource    PowerLaw          6.085       nan
↪    0.0
```

- Print a summary of an individual source

```
>>> print(roi['3FGL J0006.2+0135'])
Name            : 3FGL J0006.2+0135
Associations    : ['3FGL J0006.2+0135']
RA/DEC          :      1.572/     1.585
GLON/GLAT       :    100.400/   -59.297
TS              : nan
Npred           : nan
Flux            :       nan +/-      nan
EnergyFlux      :       nan +/-      nan
SpatialModel    : PointSource
SpectrumType    : PowerLaw
Spectral Parameters
Index           :         -2 +/-        nan
Scale           :       1000 +/-        nan
Prefactor       :      1e-12 +/-        nan
```

- Get the SkyCoord for a source

```
>>> dir = roi['SourceA'].skydir
```

- Loop over all sources and print their names

```
>>> for s in roi.sources: print(s.name)
3FGL J2357.3-0150
3FGL J0006.2+0135
3FGL J0016.3-0013
3FGL J0014.3-0455
```

**clear**()
Clear the contents of the ROI.

**copy_source**(*name*)

**classmethod create**(*selection*, *config*, ***kwargs*)
Create an ROIModel instance.

**create_diffuse_srcs**(*config*)

**classmethod create_from_position**(*skydir*, *config*, ***kwargs*)
Create an ROIModel instance centered on a sky direction.

**Parameters**

- **skydir** (SkyCoord) – Sky direction on which the ROI will be centered.
- **config** (*dict*) – Model configuration dictionary.

**classmethod create_from_roi_data**(*datafile*)
Create an ROI model.

**classmethod create_from_source**(*name*, *config*, ***kwargs*)
Create an ROI centered on the given source.

**create_param_table**()

**classmethod create_roi_from_ft1**(*ft1file*, *config*)
Create an ROI model by extracting the sources coordinates form an FT1 file.

**create_source**(*name*, *src_dict*, *build_index=True*, *merge_sources=True*, *rescale=True*)
Add a new source to the ROI model from a dictionary or an existing source object.

**Parameters**

- **name** (*str*) –
- **src_dict** (dict or *Source*) –

**Returns** src

**Return type** *Source*

**create_source_table**()

**create_table**(*names=None*)
Create an astropy Table object with the contents of the ROI model.

**defaults = {'assoc_xmatch_columns': (['3FGL_Name'], 'Choose a set of association colu**

**delete_sources**(*srcs*)

**diffuse_sources**

**extdir**

**geom**

**get_nearby_sources**(*name*, *distance*, *min_dist=None*, *square=False*)

**get_source_by_name**(*name*)
Return a single source in the ROI with the given name. The input name string can match any of the strings in the names property of the source object. Case and whitespace are ignored when matching name strings. If no sources are found or multiple sources then an exception is thrown.

**Parameters** **name** (*str*) – Name string.

**Returns** **srcs** – A source object.

**Return type** *Model*

**get_sources**(*skydir=None*, *distance=None*, *cuts=None*, *minmax_ts=None*, *minmax_npred=None*, *exclude=None*, *square=False*, *coordsys='CEL'*, *names=None*)
Retrieve list of source objects satisfying the following selections:

- **Angular separation from skydir or ROI center (if** `skydir` is None) less than `distance`.
- Cuts on source properties defined in `cuts` list.
- TS and Npred in range specified by `minmax_ts` and `minmax_npred`.
- Name matching a value in `names`

Sources can be excluded from the selection by adding their name to the `exclude` list.

**Returns** **srcs** – List of source objects.

**Return type** list

**get_sources_by_name**(*name*)
Return a list of sources in the ROI matching the given name. The input name string can match any of the strings in the names property of the source object. Case and whitespace are ignored when matching name strings.

**Parameters** **name** (*str*) –

**Returns** **srcs** – A list of *Model* objects.

**Return type** list

**get_sources_by_position**(*skydir*, *dist*, *min_dist=None*, *square=False*, *coordsys='CEL'*)
Retrieve sources within a certain angular distance of a sky coordinate. This function supports two types of geometric selections: circular (square=False) and square (square=True). The circular selection finds all sources with a given angular distance of the target position. The square selection finds sources within an ROI-like region of size R x R where R = 2 x dist.

**Parameters**

- **skydir** (SkyCoord) – Sky direction with respect to which the selection will be applied.
- **dist** (*float*) – Maximum distance in degrees from the sky coordinate.
- **square** (*bool*) – Choose whether to apply a circular or square selection.
- **coordsys** (*str*) – Coordinate system to use when applying a selection with square=True.

**get_sources_by_property**(*pname*, *pmin*, *pmax=None*)

**has_source**(*name*)

**load**(***kwargs*)
Load both point source and diffuse components.

**load_diffuse_srcs**()

**load_existing_catalog**(*cat*, ***kwargs*)
Load sources from an existing catalog object.

**Parameters** **cat** (Catalog) – Catalog object.

**load_fits_catalog**(*name*, ***kwargs*)
Load sources from a FITS catalog file.

**Parameters** **name** (*str*) – Catalog name or path to a catalog FITS file.

**load_source**(*src*, *build_index=True*, *merge_sources=True*, ***kwargs*)
Load a single source.

**Parameters**

- **src** (*Source*) – Source object that will be added to the ROI.
- **merge_sources** (*bool*) – When a source matches an existing source in the model update that source with the properties of the new source.
- **build_index** (*bool*) – Re-make the source index after loading this source.

**load_sources**(*sources*)
Delete all sources in the ROI and load the input source list.

**load_xml** (*xmlfile*, ***kwargs*)
Load sources from an XML file.

**match_source** (*src*)
Look for source or sources in the model that match the given source. Sources are matched by name and any association columns defined in the assoc_xmatch_columns parameter.

**point_sources**

**set_geom** (*geom*)

**skydir**
Return the sky direction corresponding to the center of the ROI.

**sources**

**src_name_cols = ['Source_Name', 'ASSOC', 'ASSOC1', 'ASSOC2', 'ASSOC_GAM', '1FHL_Name',**

**to_ds9** (*free='box'*, *fixed='cross'*, *frame='fk5'*, *color='green'*, *header=True*)
Returns a list of ds9 region definitions :param free: one of the supported ds9 point symbols, used for free sources, see here: http://ds9.si.edu/doc/ref/region.html :type free: bool :param fixed: as free but for fixed sources :type fixed: bool :param frame: typically fk5, more to be implemented :type frame: str :param color: color used for symbols (only ds9 compatible colors) :type color: str :param header: if True, will prepend a global header line. :type header: bool

**Returns lines** – list of regions (and header if requested)

**Return type** list

**write_ds9region** (*region*, **args*, ***kwargs*)
Create a ds9 compatible region file from the ROI.

It calls the *to_ds9* method and write the result to the region file. Only the file name is required. All other parameters will be forwarded to the *to_ds9* method, see the documentation of that method for all accepted parameters and options. :param region: name of the region file (string) :type region: str

**write_fits** (*fitsfile*)
Write the ROI model to a FITS file.

**write_xml** (*xmlfile*, *config=None*)
Save the ROI model as an XML file.

**class** fermipy.roi_model.**Source** (*name*, *data*, *radec=None*)
Bases: *fermipy.roi_model.Model*

Class representation of a source (non-diffuse) model component. A source object serves as a container for the properties of that source (position, spatial/spectral parameters, TS, etc.) as derived in the current analysis. Most properties of a source object can be accessed with the bracket operator:

# Return the TS of this source >>> src['ts']

# Get a skycoord representation of the source position >>> src.skydir

**associations**

**classmethod create_from_dict** (*src_dict*, *roi_skydir=None*, *rescale=False*)
Create a source object from a python dictionary.

**Parameters src_dict** (*dict*) – Dictionary defining the properties of the source.

**static create_from_xml** (*root*, *extdir=None*)
Create a Source object from an XML node.

**Parameters**

- **root** (Element) – XML node containing the source.
- **extdir** (*str*) – Path to the extended source archive.

**classmethod create_from_xmlfile**(*xmlfile*, *extdir=None*)
Create a Source object from an XML file.

**Parameters**

- **xmlfile** (*str*) – Path to XML file.
- **extdir** (*str*) – Path to the extended source archive.

**data**

**diffuse**

**extended**

**radec**

**separation**(*src*)

**set_position**(*skydir*)
Set the position of the source.

**Parameters** **skydir** (SkyCoord) –

**set_radec**(*ra*, *dec*)

**set_roi_direction**(*roidir*)

**set_roi_geom**(*geom*)

**set_spatial_model**(*spatial_model*, *spatial_pars*)

**skydir**
Return a SkyCoord representation of the source position.

**Returns** **skydir**

**Return type** SkyCoord

**update_data**(*d*)

**write_xml**(*root*)
Write this source to an XML node.

fermipy.roi_model.**create_source_table**(*scan_shape*)
Create an empty source table.

**Returns** **tab**

**Return type** Table

fermipy.roi_model.**get_dist_to_edge**(*skydir*, *lon*, *lat*, *width*, *coordsys='CEL'*)

fermipy.roi_model.**get_linear_dist**(*skydir*, *lon*, *lat*, *coordsys='CEL'*)

fermipy.roi_model.**get_skydir_distance_mask**(*src_skydir*, *skydir*, *dist*, *min_dist=None*, *square=False*, *coordsys='CEL'*)
Retrieve sources within a certain angular distance of an (ra,dec) coordinate. This function supports two types of geometric selections: circular (square=False) and square (square=True). The circular selection finds all sources with a given angular distance of the target position. The square selection finds sources within an ROI-like region of size R x R where R = 2 x dist.

**Parameters**

- **src_skydir** (SkyCoord) – Array of sky directions.

- **skydir** (SkyCoord) – Sky direction with respect to which the selection will be applied.
- **dist** (*float*) – Maximum distance in degrees from the sky coordinate.
- **square** (*bool*) – Choose whether to apply a circular or square selection.
- **coordsys** (*str*) – Coordinate system to use when applying a selection with square=True.

fermipy.roi_model.**get_true_params_dict**(*pars_dict*)

fermipy.roi_model.**spatial_pars_from_catalog**(*cat*)

fermipy.roi_model.**spectral_pars_from_catalog**(*cat*)
Create spectral parameters from 3FGL catalog columns.

### fermipy.utils module

fermipy.utils.**angle_to_cartesian**(*lon*, *lat*)
Convert spherical coordinates to cartesian unit vectors.

fermipy.utils.**apply_minmax_selection**(*val*, *val_minmax*)

fermipy.utils.**arg_to_list**(*arg*)

fermipy.utils.**center_to_edge**(*center*)

fermipy.utils.**collect_dirs**(*path*, *max_depth=1*, *followlinks=True*)
Recursively find directories under the given path.

fermipy.utils.**convolve2d_disk**(*fn*, *r*, *sig*, *nstep=200*)
Evaluate the convolution f'(r) = f(r) * g(r) where f(r) is azimuthally symmetric function in two dimensions and g is a step function given by:

g(r) = H(1-r/s)

**Parameters**

- **fn** (*function*) – Input function that takes a single radial coordinate parameter.
- **r** (ndarray) – Array of points at which the convolution is to be evaluated.
- **sig** (*float*) – Radius parameter of the step function.
- **nstep** (*int*) – Number of sampling point for numeric integration.

fermipy.utils.**convolve2d_gauss**(*fn*, *r*, *sig*, *nstep=200*)
Evaluate the convolution f'(r) = f(r) * g(r) where f(r) is azimuthally symmetric function in two dimensions and g is a 2D gaussian with standard deviation s given by:

g(r) = 1/(2*pi*s^2) Exp[-r^2/(2*s^2)]

**Parameters**

- **fn** (*function*) – Input function that takes a single radial coordinate parameter.
- **r** (ndarray) – Array of points at which the convolution is to be evaluated.
- **sig** (*float*) – Width parameter of the gaussian.
- **nstep** (*int*) – Number of sampling point for numeric integration.

fermipy.utils.**cov_to_correlation**(*cov*)
Compute the correlation matrix given the covariance matrix.

**Parameters** **cov** (ndarray) – N x N matrix of covariances among N parameters.

**Returns** **corr** – N x N matrix of correlations among N parameters.

**Return type** ndarray

fermipy.utils.**create_dict**(*d0*, ***kwargs*)

fermipy.utils.**create_hpx_disk_region_string**(*skyDir*, *coordsys*, *radius*, *inclusive=0*)

fermipy.utils.**create_kernel_function_lookup**(*psf*, *fn*, *sigma*, *egy*, *dtheta*, *psf_scale_fn*)

fermipy.utils.**create_model_name**(*src*)
Generate a name for a source object given its spatial/spectral properties.

**Parameters** **src** (*Source*) – A source object.

**Returns** **name** – A source name.

**Return type** str

fermipy.utils.**create_radial_spline**(*psf*, *fn*, *sigma*, *egy*, *dtheta*, *psf_scale_fn*)

fermipy.utils.**create_source_name**(*skydir*, *floor=True*, *prefix='PS'*)

fermipy.utils.**create_xml_element**(*root*, *name*, *attrib*)

fermipy.utils.**decode_list**(*input_list*, *key_map*)

fermipy.utils.**dot_prod**(*xyz0*, *xyz1*)
Compute the dot product between two cartesian vectors where the second dimension contains the vector components.

fermipy.utils.**edge_to_center**(*edges*)

fermipy.utils.**edge_to_width**(*edges*)

fermipy.utils.**ellipse_to_cov**(*sigma_maj*, *sigma_min*, *theta*)
Compute the covariance matrix in two variables x and y given the std. deviation along the semi-major and semi-minor axes and the rotation angle of the error ellipse.

**Parameters**

- **sigma_maj** (*float*) – Std. deviation along major axis of error ellipse.
- **sigma_min** (*float*) – Std. deviation along minor axis of error ellipse.
- **theta** (*float*) – Rotation angle in radians from x-axis to ellipse major axis.

fermipy.utils.**eq2gal**(*ra*, *dec*)

fermipy.utils.**eval_radial_kernel**(*psf*, *fn*, *sigma*, *idx*, *dtheta*, *psf_scale_fn*)

fermipy.utils.**extend_array**(*edges*, *binsz*, *lo*, *hi*)
Extend an array to encompass lo and hi values.

fermipy.utils.**find_function_root**(*fn*, *x0*, *xb*, *delta=0.0*, *bounds=None*)
Find the root of a function: f(x)+delta in the interval encompassed by x0 and xb.

**Parameters**

- **fn** (*function*) – Python function.
- **x0** (*float*) – Fixed bound for the root search. This will either be used as the lower or upper bound depending on the relative value of xb.
- **xb** (*float*) – Upper or lower bound for the root search. If a root is not found in the interval [x0,xb]/[xb,x0] this value will be increased/decreased until a change in sign is found.

fermipy.utils.**find_rows_by_string**(*tab, names, colnames=['assoc']*)
Find the rows in a table `tab` that match at least one of the strings in `names`. This method ignores whitespace and case when matching strings.

**Parameters**

- **tab** (astropy.table.Table) – Table that will be searched.
- **names** (*list*) – List of strings.
- **colname** (*str*) – Name of the table column that will be searched for matching string.

**Returns** **mask** – Boolean mask for rows with matching strings.

**Return type** ndarray

fermipy.utils.**fit_parabola**(*z*, *ix*, *iy*, *dpix=3*, *zmin=None*)

Fit a parabola to a 2D numpy array. This function will fit a parabola with the functional form described in *parabola* to a 2D slice of the input array `z`. The fit region encompasses pixels that are within `dpix` of the pixel coordinate (iz,iy) OR that have a value relative to the peak value greater than `zmin`.

**Parameters**

- **z** (ndarray) –
- **ix** (*int*) – X index of center pixel of fit region in array `z`.
- **iy** (*int*) – Y index of center pixel of fit region in array `z`.
- **dpix** (*int*) – Max distance from center pixel of fit region.
- **zmin** (*float*) –

fermipy.utils.**fits_recarray_to_dict**(*table*)

Convert a FITS recarray to a python dictionary.

fermipy.utils.**format_filename**(*outdir*, *basename*, *prefix=None*, *extension=None*)

fermipy.utils.**gal2eq**(*l*, *b*)

fermipy.utils.**get_bounded_slice**(*idx*, *dpix*, *shape*)

fermipy.utils.**get_parameter_limits**(*xval*, *loglike*, *cl_limit=0.95*, *cl_err=0.68269*, *tol=0.01*, *bounds=None*)

Compute upper/lower limits, peak position, and 1-sigma errors from a 1-D likelihood function. This function uses the delta-loglikelihood method to evaluate parameter limits by searching for the point at which the change in the log-likelihood value with respect to the maximum equals a specific value. A cubic spline fit to the log-likelihood values is used to improve the accuracy of the calculation.

**Parameters**

- **xval** (ndarray) – Array of parameter values.
- **loglike** (ndarray) – Array of log-likelihood values.
- **cl_limit** (*float*) – Confidence level to use for limit calculation.
- **cl_err** (*float*) – Confidence level to use for two-sided confidence interval calculation.
- **tol** (*float*) – Absolute precision of likelihood values.

**Returns**

- **x0** (*float*) – Coordinate at maximum of likelihood function.
- **err_lo** (*float*) – Lower error for two-sided confidence interval with CL `cl_err`. Corresponds to point (x < x0) at which the log-likelihood falls by a given value with respect to the maximum (0.5 for 1 sigma). Set to nan if the change in the log-likelihood function at the lower bound of the `xval` input array is less than than the value for the given CL.

- **err_hi** (*float*) – Upper error for two-sided confidence interval with CL `cl_err`. Corresponds to point (x > x0) at which the log-likelihood falls by a given value with respect to the maximum (0.5 for 1 sigma). Set to nan if the change in the log-likelihood function at the upper bound of the `xval` input array is less than the value for the given CL.
- **err** (*float*) – Symmetric 1-sigma error. Average of `err_lo` and `err_hi` if both are defined.
- **ll** (*float*) – Lower limit evaluated at confidence level `cl_limit`.
- **ul** (*float*) – Upper limit evaluated at confidence level `cl_limit`.
- **lnlmax** (*float*) – Log-likelihood value at `x0`.

fermipy.utils.**get_region_mask**(*z*, *delta*, *xy=None*)
Get mask of connected region within delta of max(z).

fermipy.utils.**init_matplotlib_backend**(*backend=None*)
This function initializes the matplotlib backend. When no DISPLAY is available the backend is automatically set to 'Agg'.

**Parameters** **backend** (*str*) – matplotlib backend name.

fermipy.utils.**interpolate_function_min**(*x*, *y*)

fermipy.utils.**is_fits_file**(*path*)

fermipy.utils.**isstr**(*s*)
String instance testing method that works under both Python 2.X and 3.X. Returns true if the input is a string.

fermipy.utils.**join_strings**(*strings*, *sep='_'*)

fermipy.utils.**load_data**(*infile*, *workdir=None*)
Load python data structure from either a YAML or numpy file.

fermipy.utils.**load_npy**(*infile*)

fermipy.utils.**load_xml_elements**(*root*, *path*)

fermipy.utils.**load_yaml**(*infile*, ***kwargs*)

fermipy.utils.**lonlat_to_xyz**(*lon*, *lat*)

fermipy.utils.**make_cdisk_kernel**(*psf*, *sigma*, *npix*, *cdelt*, *xpix*, *ypix*, *psf_scale_fn=None*, *normalize=False*)
Make a kernel for a PSF-convolved 2D disk.

**Parameters**

- **psf** (`PSFModel`) –
- **sigma** (*float*) – 68% containment radius in degrees.

fermipy.utils.**make_cgauss_kernel**(*psf*, *sigma*, *npix*, *cdelt*, *xpix*, *ypix*, *psf_scale_fn=None*, *normalize=False*)
Make a kernel for a PSF-convolved 2D gaussian.

**Parameters**

- **psf** (`PSFModel`) –
- **sigma** (*float*) – 68% containment radius in degrees.

fermipy.utils.**make_disk_kernel**(*radius*, *npix=501*, *cdelt=0.01*, *xpix=None*, *ypix=None*)
Make kernel for a 2D disk.

**Parameters** **radius** (*float*) – Disk radius in deg.

fermipy.utils.**make_gaussian_kernel**(*sigma*, *npix=501*, *cdelt=0.01*, *xpix=None*, *ypix=None*)
Make kernel for a 2D gaussian.

**Parameters** **sigma** (*float*) – Standard deviation in degrees.

fermipy.utils.**make_pixel_distance**(*shape*, *xpix=None*, *ypix=None*)
Fill a 2D array with dimensions shape with the distance of each pixel from a reference direction (xpix,ypix) in pixel coordinates. Pixel coordinates are defined such that (0,0) is located at the center of the corner pixel.

fermipy.utils.**make_psf_kernel**(*psf*, *npix*, *cdelt*, *xpix*, *ypix*, *psf_scale_fn=None*, *normalize=False*)
Generate a kernel for a point-source.

**Parameters**

- **psf** (PSFModel) –
- **npix** (*int*) – Number of pixels in X and Y dimensions.
- **cdelt** (*float*) – Pixel size in degrees.

fermipy.utils.**make_radial_kernel**(*psf*, *fn*, *sigma*, *npix*, *cdelt*, *xpix*, *ypix*, *psf_scale_fn=None*, *normalize=False*, *klims=None*, *sparse=False*)
Make a kernel for a general radially symmetric 2D function.

**Parameters**

- **psf** (PSFModel) –
- **fn** (*callable*) – Function that evaluates the kernel at a radial coordinate r.
- **sigma** (*float*) – 68% containment radius in degrees.

fermipy.utils.**match_regex_list**(*patterns*, *string*)
Perform a regex match of a string against a list of patterns. Returns true if the string matches at least one pattern in the list.

fermipy.utils.**memoize**(*obj*)

fermipy.utils.**merge_dict**(*d0*, *d1*, *add_new_keys=False*, *append_arrays=False*)
Recursively merge the contents of python dictionary d0 with the contents of another python dictionary, d1.

**Parameters**

- **d0** (*dict*) – The input dictionary.
- **d1** (*dict*) – Dictionary to be merged with the input dictionary.
- **add_new_keys** (*str*) – Do not skip keys that only exist in d1.
- **append_arrays** (*bool*) – If an element is a numpy array set the value of that element by concatenating the two arrays.

fermipy.utils.**merge_list_of_dicts**(*listofdicts*)

fermipy.utils.**met_to_mjd**(*time*)
“Convert mission elapsed time to mean julian date.

fermipy.utils.**mkdir**(*dir*)

fermipy.utils.**onesided_cl_to_dlnl**(*cl*)
Compute the delta-loglikehood values that corresponds to an upper limit of the given confidence level.

**Parameters** **cl** (*float*) – Confidence level.

**Returns** **dlnl** – Delta-loglikelihood value with respect to the maximum of the likelihood function.

**Return type** float

fermipy.utils.**onesided_dlnl_to_cl**(*dlnl*)
Compute the confidence level that corresponds to an upper limit with a given change in the loglikelihood value.

**Parameters** **dlnl** (*float*) – Delta-loglikelihood value with respect to the maximum of the likelihood function.

**Returns** **cl** – Confidence level.

**Return type** float

fermipy.utils.**overlap_slices**(*large_array_shape*, *small_array_shape*, *position*)
Modified version of overlap_slices.

Get slices for the overlapping part of a small and a large array.

Given a certain position of the center of the small array, with respect to the large array, tuples of slices are returned which can be used to extract, add or subtract the small array at the given position. This function takes care of the correct behavior at the boundaries, where the small array is cut of appropriately.

**Parameters**

- **large_array_shape** (*tuple*) – Shape of the large array.
- **small_array_shape** (*tuple*) – Shape of the small array.
- **position** (*tuple*) – Position of the small array's center, with respect to the large array. Coordinates should be in the same order as the array shape.

**Returns**

- **slices_large** (*tuple of slices*) – Slices in all directions for the large array, such that `large_array[slices_large]` extracts the region of the large array that overlaps with the small array.
- **slices_small** (*slice*) – Slices in all directions for the small array, such that `small_array[slices_small]` extracts the region that is inside the large array.

fermipy.utils.**parabola**(*xy*, *amplitude*, *x0*, *y0*, *sx*, *sy*, *theta*)
Evaluate a 2D parabola given by:

f(x,y) = f_0 - (1/2) * delta^T * R * Sigma * R^T * delta

where

delta = [(x - x_0), (y - y_0)]

and R is the matrix for a 2D rotation by angle heta and Sigma is the covariance matrix:

**Sigma = [[1/sigma_x^2, 0 ],** [0 , 1/sigma_y^2]]

**Parameters**

- **xy** (*tuple*) – Tuple containing x and y arrays for the values at which the parabola will be evaluated.
- **amplitude** (*float*) – Constant offset value.
- **x0** (*float*) – Centroid in x coordinate.
- **y0** (*float*) – Centroid in y coordinate.
- **sx** (*float*) – Standard deviation along first axis (x-axis when theta=0).
- **sy** (*float*) – Standard deviation along second axis (y-axis when theta=0).
- **theta** (*float*) – Rotation angle in radians.

**Returns** **vals** – Values of the parabola evaluated at the points defined in the `xy` input tuple.

**Return type** `ndarray`

`fermipy.utils.`**`path_to_xmlpath`**(*path*)

`fermipy.utils.`**`poly_to_parabola`**(*coeff*)

`fermipy.utils.`**`prettify_xml`**(*elem*)
Return a pretty-printed XML string for the Element.

`fermipy.utils.`**`project`**(*lon0*, *lat0*, *lon1*, *lat1*)
This function performs a stereographic projection on the unit vector (lon1,lat1) with the pole defined at the reference unit vector (lon0,lat0).

`fermipy.utils.`**`rebin_map`**(*k*, *nebin*, *npix*, *rebin*)

`fermipy.utils.`**`resolve_file_path`**(*path*, ***kwargs*)

`fermipy.utils.`**`resolve_file_path_list`**(*pathlist*, *workdir*, *prefix=''*, *randomize=False*)
Resolve the path of each file name in the file `pathlist` and write the updated paths to a new file.

`fermipy.utils.`**`resolve_path`**(*path*, *workdir=None*)

`fermipy.utils.`**`scale_parameter`**(*p*)

`fermipy.utils.`**`separation_cos_angle`**(*lon0*, *lat0*, *lon1*, *lat1*)
Evaluate the cosine of the angular separation between two direction vectors.

`fermipy.utils.`**`split_bin_edges`**(*edges*, *npts=2*)
Subdivide an array of bins by splitting each bin into `npts` subintervals.

**Parameters**

- **`edges`** (`ndarray`) – Bin edge array.
- **`npts`** (*`int`*) – Number of intervals into which each bin will be subdivided.

**Returns** **edges** – Subdivided bin edge array.

**Return type** `ndarray`

`fermipy.utils.`**`strip_suffix`**(*filename*, *suffix*)

`fermipy.utils.`**`sum_bins`**(*x*, *dim*, *npts*)

`fermipy.utils.`**`tolist`**(*x*)
convenience function that takes in a nested structure of lists and dictionaries and converts everything to its base objects. This is useful for dupming a file to yaml.

(a) numpy arrays into python lists

```
>>> type(tolist(np.asarray(123))) == int
True
>>> tolist(np.asarray([1,2,3])) == [1,2,3]
True
```

(b) numpy strings into python strings.

```
>>> tolist([np.asarray('cat')])==['cat']
True
```

(c) an ordered dict to a dict

```
>>> ordered=OrderedDict(a=1, b=2)
>>> type(tolist(ordered)) == dict
True
```

(d) converts unicode to regular strings

```
>>> type(u'a') == str
False
>>> type(tolist(u'a')) == str
True
```

(e) converts numbers & bools in strings to real represntation, (i.e. '123' -> 123)

```
>>> type(tolist(np.asarray('123'))) == int
True
>>> type(tolist('123')) == int
True
>>> tolist('False') == False
True
```

fermipy.utils.**twosided_cl_to_dlnl**(*cl*)

Compute the delta-loglikehood value that corresponds to a two-sided interval of the given confidence level.

**Parameters** **cl** (*float*) – Confidence level.

**Returns** **dlnl** – Delta-loglikelihood value with respect to the maximum of the likelihood function.

**Return type** float

fermipy.utils.**twosided_dlnl_to_cl**(*dlnl*)

Compute the confidence level that corresponds to a two-sided interval with a given change in the loglikelihood value.

**Parameters** **dlnl** (*float*) – Delta-loglikelihood value with respect to the maximum of the likelihood function.

**Returns** **cl** – Confidence level.

**Return type** float

fermipy.utils.**unicode_representer**(*dumper*, *uni*)

fermipy.utils.**unicode_to_str**(*args*)

fermipy.utils.**update_bounds**(*val*, *bounds*)

fermipy.utils.**update_keys**(*input_dict*, *key_map*)

fermipy.utils.**val_to_bin**(*edges*, *x*)

Convert axis coordinate to bin index.

fermipy.utils.**val_to_bin_bounded**(*edges*, *x*)

Convert axis coordinate to bin index.

fermipy.utils.**val_to_edge**(*edges*, *x*)

Convert axis coordinate to bin index.

fermipy.utils.**val_to_pix**(*center*, *x*)

fermipy.utils.**write_yaml**(*o*, *outfile*, ***kwargs*)

fermipy.utils.**xmlpath_to_path**(*path*)

fermipy.utils.**xyz_to_lonlat**(**args*)

### fermipy.plotting module

**class** fermipy.plotting.**AnalysisPlotter**(*config*, ***kwargs*)
Bases: *fermipy.config.Configurable*

**defaults = {'catalogs': (None, '', <class 'list'>), 'cmap': ('magma', 'Set the color**

**make_extension_plots**(*ext*, *roi=None*, ***kwargs*)

**make_localization_plots**(*loc*, *roi=None*, ***kwargs*)

**make_residmap_plots**(*maps*, *roi=None*, ***kwargs*)
Make plots from the output of `residmap`.

**Parameters**

- **maps** (*dict*) – Output dictionary of `residmap`.
- **roi** (*ROIModel*) – ROI Model object. Generate markers at the positions of the sources in this ROI.
- **zoom** (*float*) – Crop the image by this factor. If None then no crop is applied.

**make_roi_plots**(*gta*, *mcube_tot*, ***kwargs*)
Make various diagnostic plots for the 1D and 2D counts/model distributions.

**Parameters** **prefix** (*str*) – Prefix that will be appended to all filenames.

**make_sed_plots**(*sed*, ***kwargs*)

**make_tsmap_plots**(*maps*, *roi=None*, ***kwargs*)
Make plots from the output of `tsmap` or `tscube`. This method generates a 2D sky map for the best-fit test source in sqrt(TS) and Npred.

**Parameters**

- **maps** (*dict*) – Output dictionary of `tsmap` or `tscube`.
- **roi** (*ROIModel*) – ROI Model object. Generate markers at the positions of the sources in this ROI.
- **zoom** (*float*) – Crop the image by this factor. If None then no crop is applied.

**run**(*gta*, *mcube_map*, ***kwargs*)
Make all plots.

**class** fermipy.plotting.**ExtensionPlotter**(*src*, *roi*, *suffix*, *workdir*, *loge_bounds=None*)
Bases: object

**plot**(*iaxis*)

**class** fermipy.plotting.**ImagePlotter**(*img*, *mapping=None*)
Bases: object

**geom**

**plot**(*subplot=111*, *cmap='magma'*, ***kwargs*)

**projtype**

**class** fermipy.plotting.**ROIPlotter**(*data_map*, *hpx2wcs=None*, ***kwargs*)
Bases: *fermipy.config.Configurable*

**classmethod create_from_fits**(*fitsfile*, *roi*, ***kwargs*)

**data**

**defaults = {'catalogs': (None, '', <class 'list'>), 'cmap': ('ds9_b', '', <class 'st**

**draw_circle**(*radius*, ***kwargs*)

**geom**

**static get_data_projection**(*data_map*, *axes*, *iaxis*, *xmin=-1*, *xmax=1*, *loge_bounds=None*)

**map**

**plot**(***kwargs*)

**plot_catalog**(*catalog*)

**plot_projection**(*iaxis*, ***kwargs*)

**plot_roi**(*roi*, ***kwargs*)

**plot_sources**(*skydir*, *labels*, *plot_kwargs*, *text_kwargs*, ***kwargs*)

**proj**

**projtype**

**static setup_projection_axis**(*iaxis*, *loge_bounds=None*)

**zoom**(*zoom*)

**class** fermipy.plotting.**SEDPlotter**(*sed*)

Bases: object

**static get_ylims**(*sed*)

**plot**(*showlnl=False*, ***kwargs*)

**static plot_flux_points**(*sed*, ***kwargs*)

**static plot_lnlscan**(*sed*, ***kwargs*)

**static plot_model**(*model_flux*, ***kwargs*)

**static plot_resid**(*src*, *model_flux*, ***kwargs*)

**static plot_sed**(*sed*, *showlnl=False*, ***kwargs*)

Render a plot of a spectral energy distribution.

**Parameters**

- **showlnl** (*bool*) – Overlay a map of the delta-loglikelihood values vs. flux in each energy bin.
- **cmap** (*str*) – Colormap that will be used for the delta-loglikelihood map.
- **llhcut** (*float*) – Minimum delta-loglikelihood value.
- **ul_ts_threshold** (*float*) – TS threshold that determines whether the MLE or UL is plotted in each energy bin.

**sed**

fermipy.plotting.**annotate**(***kwargs*)

fermipy.plotting.**annotate_name**(*data*, *xy=(0.05, 0.93)*, ***kwargs*)

fermipy.plotting.**get_xerr**(*sed*)

fermipy.plotting.**load_bluered_cmap**()

fermipy.plotting.**load_ds9_cmap**()

fermipy.plotting.**make_counts_spectrum_plot**(*o*, *roi*, *energies*, *imfile*, ***kwargs*)

fermipy.plotting.**make_cube_slice**(*map_in*, *loge_bounds*)
Extract a slice from a map cube object.

fermipy.plotting.**plot_error_ellipse**(*fit*, *xy*, *cdelt*, ***kwargs*)

fermipy.plotting.**plot_markers**(*lon*, *lat*, ***kwargs*)

fermipy.plotting.**truncate_colormap**(*cmap*, *minval=0.0*, *maxval=1.0*, *n=256*)
Function that extracts a subset of a colormap.

### fermipy.sed module

### fermipy.sourcefind module

### fermipy.spectrum module

**class** fermipy.spectrum.**DMFitFunction**(*params*, *chan='bb'*, *jfactor=1e+19*, *tablepath=None*, *dfactor=1e+17*)
Bases: *fermipy.spectrum.SpectralFunction*

Class that evaluates the spectrum for a DM particle of a given mass, channel, cross section, and J-factor. The parameterization is given by:

F(x) = 1 / (8 * pi) * (1/mass^2) * sigmav * J * dN/dE(E,mass,i)

where the `params` array should be defined with:

- params[0] : sigmav (or tau for decay)
- params[1] : mass

Note that this class assumes that mass and J-factor are provided in units of GeV and GeV^2 cm^-5 while energies are defined in MeV.

For decay the D-factor is in uits of GeV cm^-2 s

**ann_channel_names**

**chan**
Return the channel string.

**chan_code**
Return the channel code.

**channel_index_mapping = {1: 8, 2: 6, 3: 3, 4: 1, 5: 2, 6: 7, 7: 4, 8: 5, 9: 0**

**channel_name_mapping = {1: ['e+e-', 'ee'], 2: ['mu+mu-', 'mumu', 'musrc'], 3: ['tau**

**channel_rev_map = {'W+W-': 7, 'W+W-_decay': 107, 'ZZ': 8, 'ZZ_decay': 108, 'bb': 4**

**channel_shortname_mapping = {1: 'ee', 2: 'mumu', 3: 'tautau', 4: 'bb', 5: 'tt', 6**

**static channels**()
Return all available DMFit channel strings

**decay**
Return True if this is a decay spectrum

**decay_channel_names**

**static nparam**()

**set_channel**(*chan*)

**class** fermipy.spectrum.**LogParabola**(*params=None*, *scale=1.0*, *extra_params=None*)
Bases: *fermipy.spectrum.SpectralFunction*

Class that evaluates a function with the parameterization:

F(x) = p_0 * (x/x_s)^(p_1 - p_2*log(x/x_s) )

where x_s is a scale parameter. The `params` array should be defined with:

- params[0] : Prefactor (p_0)
- params[1] : Index (p_1)
- params[2] : Curvature (p_2)

**static nparam**()

**class** fermipy.spectrum.**PLExpCutoff**(*params=None*, *scale=1.0*, *extra_params=None*)
Bases: *fermipy.spectrum.SpectralFunction*

Class that evaluates a function with the parameterization:

F(x) = p_0 * (x/x_s)^(p_1) * exp(- x/p_2 )

where x_s is the scale parameter. The `params` array should be defined with:

- params[0] : Prefactor (p_0)
- params[1] : Index (p_1)
- params[2] : Cutoff (p_2)

**static log_to_params**(*params*)

**static nparam**()

**static params_to_log**(*params*)

**class** fermipy.spectrum.**PLSuperExpCutoff**(*params=None*, *scale=1.0*, *extra_params=None*)
Bases: *fermipy.spectrum.SpectralFunction*

Class that evaluates a function with the parameterization:

F(x) = p_0 * (x/x_s)^(p_1) * exp(-(x/p2)**p3)

where x_s is the scale parameter. The `params` array should be defined with:

- params[0] : Prefactor (p_0)
- params[1] : Index1 (p_1)
- params[2] : Curvature (p_2)
- params[3] : Index2 (p3)

**static log_to_params**(*params*)

**static nparam**()

**static params_to_log**(*params*)

**class** fermipy.spectrum.**PowerLaw**(*params=None*, *scale=1.0*, *extra_params=None*)
Bases: *fermipy.spectrum.SpectralFunction*

Class that evaluates a power-law function with the parameterization:

F(x) = p_0 * (x/x_s)^p_1

where x_s is the scale parameter. The `params` array should be defined with:

- params[0] : Prefactor (p_0)
- params[1] : Index (p_1)

**classmethod eval_eflux**(*emin*, *emax*, *params*, *scale=1.0*, *extra_params=None*)

**static eval_flux**(*emin*, *emax*, *params*, *scale=1.0*, *extra_params=None*)

**classmethod eval_norm**(*scale*, *index*, *emin*, *emax*, *flux*)

**static nparam**()

**class** fermipy.spectrum.**SEDEFluxFunctor**(*sfn*, *emin*, *emax*)
Bases: *fermipy.spectrum.SEDFunctor*

Functor that computes the energy flux of a source in a pre-defined sequence of energy bins.

**class** fermipy.spectrum.**SEDFluxFunctor**(*sfn*, *emin*, *emax*)
Bases: *fermipy.spectrum.SEDFunctor*

Functor that computes the flux of a source in a pre-defined sequence of energy bins.

**class** fermipy.spectrum.**SEDFunctor**(*sfn*, *emin*, *emax*)
Bases: object

Functor object that wraps a *SpectralFunction* and computes the normalization of the model in a sequence of SED energy bins. The evaluation method of this class accepts a single vector for the parameters of the model. This class serves as an object that can be passed to likelihood optimizers.

**emax**

**emin**

**params**

**scale**

**spectral_fn**

**class** fermipy.spectrum.**SpectralFunction**(*params*, *scale=1.0*, *extra_params=None*)
Bases: object

Base class for spectral models. Spectral models inheriting from this class should implement at a minimum an _eval_dnde method which evaluates the differential flux at a given energy.

**classmethod create_eflux_functor**(*emin*, *emax*, *params=None*, *scale=1.0*, *extra_params=None*)

**classmethod create_flux_functor**(*emin*, *emax*, *params=None*, *scale=1.0*, *extra_params=None*)

**classmethod create_from_eflux**(*params*, *emin*, *emax*, *eflux*, *scale=1.0*)
Create a spectral function instance given its energy flux.

**classmethod create_from_flux**(*params*, *emin*, *emax*, *flux*, *scale=1.0*)
Create a spectral function instance given its flux.

**classmethod create_functor**(*spec_type*, *func_type*, *emin*, *emax*, *params=None*, *scale=1.0*, *extra_params=None*)

**dnde**(*x*, *params=None*)
Evaluate differential flux.

**dnde_deriv**(*x*, *params=None*)
Evaluate derivative of the differential flux with respect to E.

**e2dnde**(*x*, *params=None*)
Evaluate E^2 times differential flux.

**e2dnde_deriv**(*x*, *params=None*)
Evaluate derivative of E^2 times differential flux with respect to E.

**ednde**(*x*, *params=None*)
Evaluate E times differential flux.

**ednde_deriv**(*x*, *params=None*)
Evaluate derivative of E times differential flux with respect to E.

**eflux**(*emin*, *emax*, *params=None*)
Evaluate the integral energy flux.

**classmethod eval_dnde**(*x*, *params*, *scale=1.0*, *extra_params=None*)

**classmethod eval_dnde_deriv**(*x*, *params*, *scale=1.0*, *extra_params=None*)

**classmethod eval_e2dnde**(*x*, *params*, *scale=1.0*, *extra_params=None*)

**classmethod eval_e2dnde_deriv**(*x*, *params*, *scale=1.0*, *extra_params=None*)

**classmethod eval_ednde**(*x*, *params*, *scale=1.0*, *extra_params=None*)

**classmethod eval_ednde_deriv**(*x*, *params*, *scale=1.0*, *extra_params=None*)

**classmethod eval_eflux**(*emin*, *emax*, *params*, *scale=1.0*, *extra_params=None*)

**classmethod eval_flux**(*emin*, *emax*, *params*, *scale=1.0*, *extra_params=None*)

**extra_params**
Dictionary containing additional parameters needed for evaluation of the function.

**flux**(*emin*, *emax*, *params=None*)
Evaluate the integral flux.

**log_params**
Return transformed parameter vector in which norm and scale parameters are converted to log10.

**params**
Return parameter vector of the function.

**scale**

fermipy.spectrum.**cast_args**(*x*)

fermipy.spectrum.**cast_params**(*params*)

### fermipy.skymap module

**class** fermipy.skymap.**HpxMap**(*counts*, *hpx*)
Bases: *fermipy.skymap.Map_Base*

Representation of a 2D or 3D counts map using HEALPix.

**convert_to_cached_wcs**(*hpx_in*, *sum_ebins=False*, *normalize=True*)
Make a WCS object and convert HEALPix data into WCS projection

**Parameters**

- **hpx_in** (ndarray) – HEALPix input data
- **sum_ebins** (*bool*) – sum energy bins over energy bins before reprojecting

- **normalize** (*bool*) – True -> perserve integral by splitting HEALPix values between bins
- **(WCS object, np.ndarray() with reprojected data)** (*returns*) –

**classmethod create_from_fits**(*fitsfile*, ***kwargs*)

**classmethod create_from_hdu**(*hdu*, *ebins*)
Creates and returns an HpxMap object from a FITS HDU.

hdu : The FITS ebins : Energy bin edges [optional]

**classmethod create_from_hdulist**(*hdulist*, ***kwargs*)
Creates and returns an HpxMap object from a FITS HDUList

extname : The name of the HDU with the map data ebounds : The name of the HDU with the energy bin data

**create_image_hdu**(*name=None*, ***kwargs*)

**expanded_counts_map**()
return the full counts map

**explicit_counts_map**(*pixels=None*)
return a counts map with explicit index scheme

**Parameters** **pixels** (np.ndarray or None) – If set, grab only those pixels. If none, grab only non-zero pixels

**get_map_values**(*lons*, *lats*, *ibin=None*)
Return the indices in the flat array corresponding to a set of coordinates

**Parameters**

- **lons** (*array-like*) – 'Longitudes' (RA or GLON)
- **lats** (*array-like*) – 'Latitidues' (DEC or GLAT)
- **ibin** (*int or array-like*) – Extract data only for a given energy bin. None -> extract data for all bins

**Returns** **vals** – Values of pixels in the flattened map, np.nan used to flag coords outside of map

**Return type** numpy.ndarray((n))

**get_pixel_indices**(*lats*, *lons*)
Return the indices in the flat array corresponding to a set of coordinates

**get_pixel_skydirs**()
Get a list of sky coordinates for the centers of every pixel.

**hpx**

**interpolate**(*lon*, *lat*, *egy=None*, *interp_log=True*)
Interpolate map values.

**Parameters** **interp_log** (*bool*) – Interpolate the z-coordinate in logspace.

**make_wcs_from_hpx**(*sum_ebins=False*, *proj='CAR'*, *oversample=2*, *normalize=True*)
Make a WCS object and convert HEALPix data into WCS projection

NOTE: this re-calculates the mapping, if you have already calculated the mapping it is much faster to use convert_to_cached_wcs() instead

**Parameters**

- **sum_ebins** (*bool*) – sum energy bins over energy bins before reprojecting

- **proj** (*str*) – WCS-projection
- **oversample** (*int*) – Oversampling factor for WCS map
- **normalize** (*bool*) – True -> perserve integral by splitting HEALPix values between bins
- **(WCS object, np.ndarray() with reprojected data)** (*returns*) –

**sparse_counts_map**()
return a counts map with sparse index scheme

**sum_over_energy**()
Reduce a counts cube to a counts map

**swap_scheme**()

**ud_grade**(*order*, *preserve_counts=False*)

**class** fermipy.skymap.**Map**(*counts*, *wcs*, *ebins=None*)
Bases: *fermipy.skymap.Map_Base*

Representation of a 2D or 3D counts map using WCS.

**classmethod create**(*skydir*, *cdelt*, *npix*, *coordsys='CEL'*, *projection='AIT'*, *ebins=None*, *differential=False*)

**classmethod create_from_fits**(*fitsfile*, ***kwargs*)

**classmethod create_from_hdu**(*hdu*, *wcs*)

**create_image_hdu**(*name=None*, ***kwargs*)

**create_primary_hdu**()

**get_map_values**(*lons*, *lats*, *ibin=None*)
Return the map values corresponding to a set of coordinates.

**Parameters**

- **lons** (*array-like*) – 'Longitudes' (RA or GLON)
- **lats** (*array-like*) – 'Latitidues' (DEC or GLAT)
- **ibin** (*int or array-like*) – Extract data only for a given energy bin. None -> extract data for all bins

**Returns** **vals** – Values of pixels in the flattened map, np.nan used to flag coords outside of map

**Return type** numpy.ndarray((n))

**get_pixel_indices**(*lons*, *lats*, *ibin=None*)
Return the indices in the flat array corresponding to a set of coordinates

**Parameters**

- **lons** (*array-like*) – 'Longitudes' (RA or GLON)
- **lats** (*array-like*) – 'Latitidues' (DEC or GLAT)
- **ibin** (*int or array-like*) – Extract data only for a given energy bin. None -> extract data for all energy bins.

**Returns** **pixcrd** – Pixel indices along each dimension of the map.

**Return type** list

**get_pixel_skydirs**()
Get a list of sky coordinates for the centers of every pixel.

**interpolate**(*lon*, *lat*, *egy=None*)
Return the interpolated map values corresponding to a set of coordinates.

**interpolate_at_skydir**(*skydir*)

**ipix_swap_axes**(*ipix*, *colwise=False*)
Return the transposed pixel index from the pixel xy coordinates

if colwise is True (False) this assumes the original index was in column wise scheme

**ipix_to_xypix**(*ipix*, *colwise=False*)
Return array multi-dimensional pixel indices from flattened index.

**Parameters** **colwise** (*bool*) – Use column-wise pixel indexing.

**npix**

**pix_center**
Return the ROI center in pixel coordinates.

**pix_size**
Return the pixel size along the two image dimensions.

**skydir**
Return the sky coordinate of the image center.

**sum_over_energy**()
Reduce a 3D counts cube to a 2D counts map

**wcs**

**width**
Return the dimensions of the image.

**xypix_to_ipix**(*xypix*, *colwise=False*)
Return the flattened pixel indices from an array multi-dimensional pixel indices.

**Parameters**

- **xypix** (*list*) – List of pixel indices in the order (LON,LAT,ENERGY).
- **colwise** (*bool*) – Use column-wise pixel indexing.

**class** fermipy.skymap.**Map_Base**(*counts*)
Bases: object

Abstract representation of a 2D or 3D counts map.

**counts**

**data**

**get_map_values**(*lons*, *lats*, *ibin=None*)
Return the map values corresponding to a set of coordinates.

**get_pixel_indices**(*lats*, *lons*)
Return the indices in the flat array corresponding to a set of coordinates

**get_pixel_skydirs**()
Get a list of sky coordinates for the centers of every pixel.

**interpolate**(*lon*, *lat*, *egy=None*)
Return the interpolated map values corresponding to a set of coordinates.

**sum_over_energy**()
Reduce a counts cube to a counts map by summing over the energy planes

fermipy.skymap.**coadd_maps**(*geom*, *maps*, *preserve_counts=True*)
Coadd a sequence of Map objects.

fermipy.skymap.**make_coadd_hpx**(*maps*, *hpx*, *shape*, *preserve_counts=True*)

fermipy.skymap.**make_coadd_map**(*maps*, *proj*, *shape*, *preserve_counts=True*)

fermipy.skymap.**make_coadd_wcs**(*maps*, *wcs*, *shape*)

fermipy.skymap.**read_map_from_fits**(*fitsfile*, *extname=None*)

### fermipy.castro module

Utilities for dealing with 'castro data', i.e., 2D table of likelihood values.

Castro data can be tabluated in terms of a variety of variables. The most common example is probably a simple SED, where we have the likelihood as a function of Energy and Energy Flux.

However, we could easily convert to the likelihood as a function of other variables, such as the Flux normalization and the spectral index, or the mass and cross-section of a putative dark matter particle.

**class** fermipy.castro.**CastroData**(*norm_vals*, *nll_vals*, *refSpec*, *norm_type*)
Bases: *fermipy.castro.CastroData_Base*

This class wraps the data needed to make a "Castro" plot, namely the log-likelihood as a function of normalization for a series of energy bins.

**classmethod create_from_fits**(*fitsfile*, *norm_type='eflux'*, *hdu_scan='SCANDATA'*, *hdu_energies='EBOUNDS'*, *irow=None*)
Create a CastroData object from a tscube FITS file.

**Parameters**

- **fitsfile** (*str*) – Name of the fits file
- **norm_type** (*str*) – Type of normalization to use. Valid options are:
  - norm : Normalization w.r.t. to test source
  - flux : Flux of the test source ( ph cm^-2 s^-1 )
  - eflux: Energy Flux of the test source ( MeV cm^-2 s^-1 )
  - npred: Number of predicted photons (Not implemented)
  - dnde : Differential flux of the test source ( ph cm^-2 s^-1 MeV^-1 )
- **hdu_scan** (*str*) – Name of the FITS HDU with the scan data
- **hdu_energies** (*str*) – Name of the FITS HDU with the energy binning and normalization data
- **irow** (*int or None*) – If none, then this assumes that there is a single row in the scan data table Otherwise, this specifies which row of the table to use

**Returns** castro

**Return type** *CastroData*

**classmethod create_from_flux_points**(*txtfile*)
Create a Castro data object from a text file containing a sequence of differential flux points.

**classmethod create_from_sedfile**(*fitsfile*, *norm_type='eflux'*)
Create a CastroData object from an SED fits file

**Parameters**

- **fitsfile** (*str*) – Name of the fits file
- **norm_type** (*str*) – Type of normalization to use, options are:
  - norm : Normalization w.r.t. to test source
  - flux : Flux of the test source ( ph cm^-2 s^-1 )
  - eflux: Energy Flux of the test source ( MeV cm^-2 s^-1 )
  - npred: Number of predicted photons (Not implemented)
  - dnde : Differential flux of the test source ( ph cm^-2 s^-1 MeV^-1 )

**Returns** castro

**Return type** *CastroData*

**classmethod create_from_stack**(*shape*, *components*, *ylims*, *weights=None*)

Combine the log-likelihoods from a number of components.

**Parameters**

- **shape** (*tuple*) – The shape of the return array
- **components** (*[CastroData_Base]*) – The components to be stacked
- **weights** (*array-like*) –

**Returns** castro

**Return type** *CastroData*

**classmethod create_from_tables**(*norm_type='eflux'*, *tab_s='SCANDATA'*, *tab_e='EBOUNDS'*)

Create a CastroData object from two tables

**Parameters**

- **norm_type** (*str*) – Type of normalization to use. Valid options are:
  - norm : Normalization w.r.t. to test source
  - flux : Flux of the test source ( ph cm^-2 s^-1 )
  - eflux: Energy Flux of the test source ( MeV cm^-2 s^-1 )
  - npred: Number of predicted photons (Not implemented)
  - dnde : Differential flux of the test source ( ph cm^-2 s^-1 MeV^-1 )
- **tab_s** (*str*) – table scan data
- **tab_e** (*str*) – table energy binning and normalization data

**Returns** castro

**Return type** *CastroData*

**classmethod create_from_yamlfile**(*yamlfile*)

Create a Castro data object from a yaml file contains the likelihood data.

**create_functor**(*specType*, *initPars=None*, *scale=1000.0*)

Create a functor object that computes normalizations in a sequence of energy bins for a given spectral model.

**Parameters**

- **specType** (*str*) – The type of spectrum to use. This can be a string corresponding to the spectral model class name or a *SpectralFunction* object.

- **initPars** (ndarray) – Arrays of parameter values with which the spectral function will be initialized.
- **scale** (*float*) – The 'pivot energy' or energy scale to use for the spectrum

**Returns** **fn** – A functor object.

**Return type** *SEDFunctor*

**nE**
Return the number of energy bins. This is also the number of x-axis bins.

**refSpec**
Return a *ReferenceSpec* with the spectral data

**spectrum_loglike**(*specType*, *params*, *scale=1000.0*)
return the log-likelihood for a particular spectrum

**Parameters**

- **specTypes** (*str*) – The type of spectrum to try
- **params** (*array-like*) – The spectral parameters
- **scale** (*float*) – The energy scale or 'pivot' energy

**test_spectra**(*spec_types=None*)
Test different spectral types against the SED represented by this CastroData.

**Parameters** **spec_types** (*[str,..]*) – List of spectral types to try

**Returns**

**retDict** – A dictionary of dictionaries. The top level dictionary is keyed by spec_type. The sub-dictionaries each contain:

- "Function" : *SpectralFunction*
- "Result" : tuple with the output of scipy.optimize.fmin
- "Spectrum" : ndarray with best-fit spectral values
- "ScaleEnergy" : float, the 'pivot energy' value
- "TS" : float, the TS for the best-fit spectrum

**Return type** dict

**x_edges**()

**class** fermipy.castro.**CastroData_Base**(*norm_vals*, *nll_vals*, *nll_offsets*, *norm_type*)
Bases: object

This class wraps the data needed to make a "Castro" plot, namely the log-likelihood as a function of normalization.

In this case the x-axes and y-axes are generic Sub-classes can implement particul axes choices (e.g., EFlux v. Energy)

**TS_spectrum**(*spec_vals*)
Calculate and the TS for a given set of spectral values.

**build_lnl_fn**(*normv*, *nllv*)

**build_scandata_table**()
Build an astropy.table.Table object from these data.

**chi2_vals**(*x*)
Compute the difference in the log-likelihood between the MLE in each energy bin and the normalization predicted by a global best-fit model. This array can be summed to get a goodness-of-fit chi2 for the model.

**Parameters** **x** (ndarray) – An array of normalizations derived from a global fit to all energy bins.

**Returns** **chi2_vals** – An array of chi2 values for each energy bin.

**Return type** ndarray

**derivative**(*x*, *der=1*)
Return the derivate of the log-like summed over the energy bins

**Parameters**

- **x** (ndarray) – Array of N x M values
- **der** (*int*) – Order of the derivate

**Returns** **der_val** – Array of negative log-likelihood values.

**Return type** ndarray

**fitNorm_v2**(*specVals*)
Fit the normalization given a set of spectral values that define a spectral shape.

This version uses scipy.optimize.fmin.

**Parameters**

- **specVals** (*an array of (nebin values that define a spectral shape*) –
- **xlims** (*fit limits*) –

**Returns** **norm** – Best-fit normalization value

**Return type** float

**fitNormalization**(*specVals*, *xlims*)
Fit the normalization given a set of spectral values that define a spectral shape

This version is faster, and solves for the root of the derivatvie

**Parameters**

- **specVals** (*an array of (nebin values that define a spectral shape*) –
- **xlims** (*fit limits*) –
- **the best-fit normalization value** (*returns*) –

**fit_spectrum**(*specFunc*, *initPars*, *freePars=None*)
Fit for the free parameters of a spectral function

**Parameters**

- **specFunc** (*SpectralFunction*) – The Spectral Function
- **initPars** (ndarray) – The initial values of the parameters
- **freePars** (ndarray) – Boolean array indicating which parameters should be free in the fit.

**Returns**

- **params** (ndarray) – Best-fit parameters.
- **spec_vals** (ndarray) – The values of the best-fit spectral model in each energy bin.
- **ts_spec** (*float*) – The TS of the best-fit spectrum
- **chi2_vals** (ndarray) – Array of chi-squared values for each energy bin.
- **chi2_spec** (*float*) – Global chi-squared value for the sum of all energy bins.
- **pval_spec** (*float*) – p-value of chi-squared for the best-fit spectrum.

**fn_mles**()
returns the summed likelihood at the maximum likelihood estimate

Note that simply sums the maximum likelihood values at each bin, and does not impose any sort of constrain between bins

**getIntervals**(*alpha*)
Evaluate the two-sided intervals corresponding to a C.L. of (1-alpha)%.

**Parameters** **alpha** (*float*) – limit confidence level.

**Returns**

- **limit_vals_hi** (ndarray) – An array of lower limit values.
- **limit_vals_lo** (ndarray) – An array of upper limit values.

**getLimits**(*alpha*, *upper=True*)
Evaluate the limits corresponding to a C.L. of (1-alpha)%.

**Parameters**

- **alpha** (*float*) – limit confidence level.
- **upper** (*bool*) – upper or lower limits.
- **an array of values, one for each energy bin** (*returns*) –

**mles**()
return the maximum likelihood estimates for each of the energy bins

**nll_null**
Return the negative log-likelihood for the null-hypothesis

**nll_offsets**
Return the offsets in the negative log-likelihoods for each bin

**norm_derivative**(*spec*, *norm*)

**norm_type**
Return the normalization type flag

**nx**
Return the number of profiles

**ny**
Return the number of profiles

**static stack_nll**(*shape*, *components*, *ylims*, *weights=None*)
Combine the log-likelihoods from a number of components.

**Parameters**

- **shape** (*tuple*) – The shape of the return array
- **components** (*CastroData_Base*) – The components to be stacked

- **weights** (*array-like*) –

**Returns**

- **norm_vals** (numpy.ndarray) – N X M array of Normalization values
- **nll_vals** (numpy.ndarray) – N X M array of log-likelihood values
- **nll_offsets** (numpy.ndarray) – N array of maximum log-likelihood values in each bin

**ts_vals**()
returns test statistic values for each energy bin

**x_edges**()

**class** fermipy.castro.**Interpolator**(*x*, *y*)
Bases: object

Helper class for interpolating a 1-D function from a set of tabulated values.

Safely deals with overflows and underflows

**derivative**(*x*, *der=1*)
return the derivative a an array of input values

x : the inputs der : the order of derivative

**x**
return the x values used to construct the split

**xmax**
return the maximum value over which the spline is defined

**xmin**
return the minimum value over which the spline is defined

**y**
return the y values used to construct the split

**class** fermipy.castro.**LnLFn**(*x*, *y*, *norm_type=0*)
Bases: object

Helper class for interpolating a 1-D log-likelihood function from a set of tabulated values.

**TS**()
return the Test Statistic

**fn_mle**()
return the function value at the maximum likelihood estimate

**getDeltaLogLike**(*dlnl*, *upper=True*)
Find the point at which the log-likelihood changes by a given value with respect to its value at the MLE.

**getInterval**(*alpha*)
Evaluate the interval corresponding to a C.L. of (1-alpha)%.

**Parameters** **alpha** (*limit confidence level.*) –

**getLimit**(*alpha*, *upper=True*)
Evaluate the limits corresponding to a C.L. of (1-alpha)%.

**Parameters**

- **alpha** (*limit confidence level.*) –
- **upper** (*upper or lower limits.*) –

**interp**
return the underlying Interpolator object

**mle**()
return the maximum likelihood estimate

This will return the cached value, if it exists

**norm_type**
Return a string specifying the quantity used for the normalization. This isn't actually used in this class, but it is carried so that the class is self-describing. The possible values are open-ended.

**class** fermipy.castro.**ReferenceSpec**(*emin*, *emax*, *ref_dnde*, *ref_flux*, *ref_eflux*, *ref_npred*, *eref=None*)

Bases: object

This class encapsulates data for a reference spectrum.

**Parameters**

- **ne** (int) – Number of energy bins
- **ebins** (ndarray) – Array of bin edges.
- **emin** (ndarray) – Array of lower bin edges.
- **emax** (ndarray) – Array of upper bin edges.
- **bin_widths** (ndarray) – Array of energy bin widths.
- **eref** (ndarray) – Array of reference energies. Typically these are the geometric mean of the energy bins
- **ref_dnde** (ndarray) – Array of differential photon flux values.
- **ref_flux** (ndarray) – Array of integral photon flux values.
- **ref_eflux** (ndarray) – Array of integral energy flux values.
- **ref_npred** (ndarray) – Array of predicted number of photons in each energy bin.

**bin_widths**

**build_ebound_table**()
Build and return an EBOUNDS table with the encapsulated data.

**classmethod create_from_table**(*tab_e*)

**Parameters** **tab_e** (Table) – EBOUNDS table.

**create_functor**(*specType*, *normType*, *initPars=None*, *scale=1000.0*)
Create a functor object that computes normalizations in a sequence of energy bins for a given spectral model.

**Parameters**

- **specType** (*str*) – The type of spectrum to use. This can be a string corresponding to the spectral model class name or a *SpectralFunction* object.
- **normType** (*The type of normalization to use*) –
- **initPars** (ndarray) – Arrays of parameter values with which the spectral function will be initialized.
- **scale** (*float*) – The 'pivot energy' or energy scale to use for the spectrum

**Returns** **fn** – A functor object.

**Return type** *SEDFunctor*

**ebins**

**emax**

**emin**

**eref**

**log_ebins**

**nE**

**ref_dnde**

**ref_eflux**
return the energy flux values

**ref_flux**
return the flux values

**ref_npred**
return the number of predicted events

**class** fermipy.castro.**SpecData**(*ref_spec*, *norm*, *norm_err*)
Bases: *fermipy.castro.ReferenceSpec*

This class encapsulates spectral analysis results (best-fit normalizations, errors, etc.), energy binning, and reference spectrum definition.

**Parameters**

- **norm** (ndarray) –
- **norm_err** (ndarray) –
- **flux** (ndarray) – Array of integral photon flux values.
- **eflux** (ndarray) – Array of integral energy flux values.
- **dnde** (ndarray) – Differential flux values
- **dnde_err** (ndarray) – Uncertainties on differential flux values
- **e2dnde** (ndarray) – Differential flux values scaled by E^2
- **e2dnde_err** (ndarray) – Uncertainties on differential flux values scaled by E^2

**build_spec_table**()

**classmethod create_from_table**(*tab*)

**dnde**

**dnde_err**

**e2dnde**

**e2dnde_err**

**eflux**

**flux**

**norm**

**norm_err**

**class** fermipy.castro.**TSCube**(*tsmap*, *normmap*, *tscube*, *normcube*, *norm_vals*, *nll_vals*, *refSpec*, *norm_type*)

Bases: object

A class wrapping a TSCube, which is a collection of CastroData objects for a set of directions.

This class wraps a combination of:

- Pixel data,
- Pixel x Energy bin data,
- Pixel x Energy Bin x Normalization scan point data

**castroData_from_ipix**(*ipix*, *colwise=False*)
Build a CastroData object for a particular pixel

**castroData_from_pix_xy**(*xy*, *colwise=False*)
Build a CastroData object for a particular pixel

**classmethod create_from_fits**(*fitsfile*, *norm_type='flux'*)
Build a TSCube object from a fits file created by gttscube :param fitsfile: Path to the tscube FITS file. :type fitsfile: str :param norm_type: String specifying the quantity used for the normalization :type norm_type: str

**find_and_refine_peaks**(*threshold*, *min_separation=1.0*, *use_cumul=False*)
Run a simple peak-finding algorithm, and fit the peaks to paraboloids to extract their positions and error ellipses.

**Parameters**

- **threshold** (*float*) – Peak threshold in TS.
- **min_separation** (*float*) – Radius of region size in degrees. Sets the minimum allowable separation between peaks.
- **use_cumul** (*bool*) – If true, used the cumulative TS map (i.e., the TS summed over the energy bins) instead of the TS Map from the fit to and index=2 powerlaw.

**Returns** **peaks** – List of dictionaries containing the location and amplitude of each peak. Output of find_peaks

**Return type** list

**find_sources**(*threshold*, *min_separation=1.0*, *use_cumul=False*, *output_peaks=False*, *output_castro=False*, *output_specInfo=False*, *output_src_dicts=False*, *output_srcs=False*)

**nE**
return the number of energy bins

**nN**
return the number of sample points in each energy bin

**normcube**
return the Cube of the normalization value per pixel / energy bin

**normmap**
return the Map of the Best-fit normalization value

**nvals**
Return the number of values in the tscube

**refSpec**
Return the Spectral Data object

**test_spectra_of_peak** (*peak*, *spec_types=None*)
Test different spectral types against the SED represented by the CastroData corresponding to a single pixel in this TSCube :param spec_types: List of spectral types to try :type spec_types: [str,...]

**Returns**

- **castro** (*CastroData*) – The castro data object for the pixel corresponding to the peak
- **test_dict** (*dict*) – The dictionary returned by *test_spectra*

**ts_cumul**
return the Map of the cumulative TestStatistic value per pixel (summed over energy bin)

**tscube**
return the Cube of the TestStatistic value per pixel / energy bin

**tsmap**
return the Map of the TestStatistic value

fermipy.castro.**build_source_dict** (*src_name*, *peak_dict*, *spec_dict*, *spec_type*)

fermipy.castro.**convert_sed_cols** (*tab*)
Cast SED column names to lowercase.

### fermipy.tsmap module

### fermipy.residmap module

**class** fermipy.residmap.**ResidMapGenerator**
Bases: object

Mixin class for GTAnalysis that generates spatial residual maps from the difference of data and model maps smoothed with a user-defined spatial/spectral template. The map of residual significance can be interpreted in the same way as a TS map (the likelihood of a source at the given location).

**residmap** (*prefix=''*, ***kwargs*)
Generate 2-D spatial residual maps using the current ROI model and the convolution kernel defined with the model argument.

**Parameters**

- **prefix** (*str*) – String that will be prefixed to the output residual map files.
- **{options}** –

**Returns** **maps** – A dictionary containing the Map objects for the residual significance and amplitude.

**Return type** dict

fermipy.residmap.**convolve_map** (*m*, *k*, *cpix*, *threshold=0.001*, *imin=0*, *imax=None*, *wmap=None*)
Perform an energy-dependent convolution on a sequence of 2-D spatial maps.

**Parameters**

- **m** (ndarray) – 3-D map containing a sequence of 2-D spatial maps. First dimension should be energy.
- **k** (ndarray) – 3-D map containing a sequence of convolution kernels (PSF) for each slice in m. This map should have the same dimension as m.
- **cpix** (*list*) – Indices of kernel reference pixel in the two spatial dimensions.
- **threshold** (*float*) – Kernel amplitude

- **imin** (*int*) – Minimum index in energy dimension.
- **imax** (*int*) – Maximum index in energy dimension.
- **wmap** (ndarray) – 3-D map containing a sequence of 2-D spatial maps of weights. First dimension should be energy. This map should have the same dimension as m.

fermipy.residmap.**convolve_map_hpx**(*m*, *k*, *cpix*, *threshold=0.001*, *imin=0*, *imax=None*, *wmap=None*)

Perform an energy-dependent convolution on a sequence of 2-D spatial maps.

**Parameters**

- **m** (ndarray) – 2-D map containing a sequence of 1-D HEALPix maps. First dimension should be energy.
- **k** (ndarray) – 2-D map containing a sequence of convolution kernels (PSF) for each slice in m. This map should have the same dimension as m.
- **threshold** (*float*) – Kernel amplitude
- **imin** (*int*) – Minimum index in energy dimension.
- **imax** (*int*) – Maximum index in energy dimension.
- **wmap** (ndarray) – 2-D map containing a sequence of 1-D HEALPix maps of weights. First dimension should be energy. This map should have the same dimension as m.

fermipy.residmap.**convolve_map_hpx_gauss**(*m*, *sigmas*, *imin=0*, *imax=None*, *wmap=None*)

Perform an energy-dependent convolution on a sequence of 2-D spatial maps.

**Parameters**

- **m** (HpxMap) – 2-D map containing a sequence of 1-D HEALPix maps. First dimension should be energy.
- **sigmas** (ndarray) – 1-D map containing a sequence gaussian widths for smoothing
- **imin** (*int*) – Minimum index in energy dimension.
- **imax** (*int*) – Maximum index in energy dimension.
- **wmap** (ndarray) – 2-D map containing a sequence of 1-D HEALPix maps of weights. First dimension should be energy. This map should have the same dimension as m.

fermipy.residmap.**get_source_kernel**(*gta*, *name*, *kernel=None*)

Get the PDF for the given source.

fermipy.residmap.**poisson_lnl**(*nc*, *mu*)

### fermipy.lightcurve module

### Module contents

fermipy.**get_ft_conda_version**()

Get the version string from conda

fermipy.**get_git_version_fp**()

Get the version string of the ST release.

fermipy.**get_st_version**()

Get the version string of the ST release.

fermipy.**test**(*package=None*, *test_path=None*, *args=None*, *plugins=None*, *verbose=False*, *pastebin=None*, *remote_data=False*, *pep8=False*, *pdb=False*, *coverage=False*, *open_files=False*, ***kwargs*)

Run the tests using py.test. A proper set of arguments is constructed and passed to pytest.main.

**Parameters**

- **package** (*str, optional*) – The name of a specific package to test, e.g. 'io.fits' or 'utils'. If nothing is specified all default tests are run.
- **test_path** (*str, optional*) – Specify location to test by path. May be a single file or directory. Must be specified absolutely or relative to the calling directory.
- **args** (*str, optional*) – Additional arguments to be passed to pytest.main in the `args` keyword argument.
- **plugins** (*list, optional*) – Plugins to be passed to pytest.main in the `plugins` keyword argument.
- **verbose** (*bool, optional*) – Convenience option to turn on verbose output from py.test. Passing True is the same as specifying `'-v'` in `args`.
- **pastebin** (*{'failed','all',None}, optional*) – Convenience option for turning on py.test pastebin output. Set to `'failed'` to upload info for failed tests, or `'all'` to upload info for all tests.
- **remote_data** (*bool, optional*) – Controls whether to run tests marked with @remote_data. These tests use online data and are not run by default. Set to True to run these tests.
- **pep8** (*bool, optional*) – Turn on PEP8 checking via the pytest-pep8 plugin and disable normal tests. Same as specifying `'--pep8 -k pep8'` in `args`.
- **pdb** (*bool, optional*) – Turn on PDB post-mortem analysis for failing tests. Same as specifying `'--pdb'` in `args`.
- **coverage** (*bool, optional*) – Generate a test coverage report. The result will be placed in the directory htmlcov.
- **open_files** (*bool, optional*) – Fail when any tests leave files open. Off by default, because this adds extra run time to the test suite. Works only on platforms with a working `lsof` command.
- **parallel** (*int, optional*) – When provided, run the tests in parallel on the specified number of CPUs. If parallel is negative, it will use the all the cores on the machine. Requires the pytest-xdist plugin installed. Only available when using Astropy 0.3 or later.
- **kwargs** – Any additional keywords passed into this function will be passed on to the astropy test runner. This allows use of test-related functionality implemented in later versions of astropy without explicitly updating the package template.

### 1.3.11 fermipy.jobs subpackage

The fermipy.jobs sub-package is a light-weight, largely standalone, package to manage data analysis pipelines. It allows the user to build up increasingly complex analysis pipelines from single applications that are callable either from inside python or from the unix command line.

#### Subpackage contents

### Link objects

The basic building block of an analysis pipeline is a `Link` object. In general a `Link` is a single application that can be called from the command line.

The fermipy.jobs package imlements five types of `Link` objects, and the idea is that users can make sub-classes to perform the steps of their analysis.

Every link sub-class has a small required header block, for example:

```
class AnalyzeROI(Link):
    """Small class that wraps an analysis script.

    This particular script does baseline fitting of an ROI.
    """
    appname = 'fermipy-analyze-roi'
    linkname_default = 'analyze-roi'
    usage = '%s [options]' % (appname)
    description = "Run analysis of a single ROI"

    default_options = dict(config=defaults.common['config'],
                           roi_baseline=defaults.common['roi_baseline'],
                           make_plots=defaults.common['make_plots'])

    __doc__ += Link.construct_docstring(default_options)
```

The various pieces of the header are:

- appname This is the unix command that will invoke this link.
- linkname_default This is the default name that links of this type will be given when then are put into analysis pipeline.
- usage, description These are passed to the argument parser and used to build the help string.
- default_options This is the set of options and default values for this link
- The __doc__ += Link.construct_docstring(default_options) line ensures that the default options will be included in the class's docstring.

### Link sub-classes

There are five types of `Link` sub-classes implemented here.

- `Link`

  This is the sub-class to use for a user-defined function. In this case in addition to providing the header material above, the sub-class will need to implement the run_analysis() to perform that function.

  ```
  def run_analysis(self, argv):
      """Run this analysis"""
      args = self._parser.parse_args(argv)

      do stuff
  ```

- `Gtlink`

  This is the sub-class to use to invoke a Fermi ScienceTools gt-tool, such as gtsrcmaps or gtexcube2. In this case the user only needs to provide the header content to make the options they want availble to the interface.

- `AppLink`

  This is the sub-class to use to invoke a pre-existing unix command. In this case the user only needs to provide the header content to make the options they want availble to the interface.

- `ScatterGather`

  This is the sub-class to use to send a set of similar jobs to a computing batch farm. In this case the user needs to provide the standard header content and a couple of addtional things. Here is an example:

```
  class AnalyzeROI_SG(ScatterGather):
      """Small class to generate configurations for the `AnalyzeROI`␣
↪class.

      This loops over all the targets defined in the target list.
      """
      appname = 'fermipy-analyze-roi-sg'
      usage = "%s [options]" % (appname)
      description = "Run analyses on a series of ROIs"
      clientclass = AnalyzeROI

      job_time = 1500

      default_options = dict(ttype=defaults.common['ttype'],
                             targetlist=defaults.common['targetlist'],
                             config=defaults.common['config'],
                             roi_baseline=defaults.common['roi_baseline'],
                             make_plots=defaults.common['make_plots'])

      __doc__ += Link.construct_docstring(default_options)

      def build_job_configs(self, args):
          """Hook to build job configurations
          """
          job_configs = {}

          ttype = args['ttype']

          do stuff

          return job_configs


The job_time class parameter should be an estimate of the time the average
job managed by this class will take.  That is used to decided which batch
farm resources to use to run the job, and how often to check from job␣
↪completion.

The user defined function build_job_configs() function should build a␣
↪dictionary of
dictionaries that contains the parameters to use for each instance of the␣
↪command that
will run.  E.g., if you want to analyze a set of 3 ROIs, using different
config files and making different roi_baseline output files, build_job_
↪configs
should return a dictionary of 3 dictionaries, something like this:

.. code-block:: python
```

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```
    job_configs = {"ROI_000000" : {config="ROI_000000/config.yaml",
                                   roi_baseline="baseline",
                                   make_plts=True},
                   "ROI_000000" : {config="ROI_000000/config.yaml",
                                   roi_baseline="baseline",
                                   make_plts=True},
                   "ROI_000000" : {config="ROI_000000/config.yaml",
                                   roi_baseline="baseline",
                                   make_plts=True}}
```

- `Chain`

  This is the sub-class to use to run multiple `Link` objects in sequence.

  For `Chain` sub-classes, in addtion to the standard header material, the user should profile a map_arguments() method that builds up the chain and sets the options of the component `Link` objects using the _set_link() method. Here is an example:

```
def _map_arguments(self, input_dict):
    """Map from the top-level arguments to the arguments provided to
    the indiviudal links """

    config_yaml = input_dict['config']
    config_dict = load_yaml(config_yaml)

    data = config_dict.get('data')
    comp = config_dict.get('comp')
    sourcekeys = config_dict.get('sourcekeys')

    mktimefilter = config_dict.get('mktimefilter')

    self._set_link('expcube2', Gtexpcube2wcs_SG,
                   comp=comp, data=data,
                   mktimefilter=mktimefilter)

    self._set_link('exphpsun', Gtexphpsun_SG,
                   comp=comp, data=data,
                   mktimefilter=mktimefilter)

    self._set_link('suntemp', Gtsuntemp_SG,
                   comp=comp, data=data,
                   mktimefilter=mktimefilter,
                   sourcekeys=sourcekeys)
```

### Using Links and sub-classes in python

The main aspect of the `Link` python interface are:

- Building the `Link` and setting the parameters. By way of example we will build a `Link` of type `AnalyzeROI` and configure it do a standard analysis of the ROI using the file 'config.yaml' write the resulting ROI snapshot to 'baseline' and make the standard validation plots.

```
link = AnalyzeROI.create()
link.update_args(dict(config='config.yaml',
```

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```
                        roi_baseline='baseline',
                        make_plots=True))
```

- Seeing the equivalent command line task

```
link.formatted_command()
```

- Running the `Link`:

```
link.run()
```

- Seeing the status of the `Link`:

```
link.check_job_status()
```

- Seeing the jobs associated to this `Link`:

```
link.jobs
```

- Setting the arguments used to run this `Link`:

```
link.update_args(dict=(option_name=option_value,
                       option_name2=option_value2,
                       ...))
```

### Using fermipy.jobs to analyze multiple ROIS

The fermipy.jobs sub-package includes a few scripts and tools that can be used to parallelize standard analysis of region of interest as well as both positive and negative control tests.

### Overview

This package implements an analysis pipeline to perform as standard analysis on multiple ROIs. This involves a lot of bookkeeping and loops over various things. It is probably easiest to first describe this with a bit of pseudo-code that represents the various analysis steps.

The various loop variable are:

- rosters

  The list of all lists of targets to analyze. This might seem a bit like overkill, but it is a way to allow you to define multiple versions of the same target, e.g., to test different models.

- targets

  The list of all the analysis targets. This is generated by merging all the targets from the input rosters.

- target.profiles

  The list of all the spatial profiles to analyze for a particular targeet. This is generated by finding all the versions of a target from all the input rosters.

- sims

  This is of all the simulation scenarios to analyze. This is provided by the user.

- first, last

The first and last seeds to use the random number genreator (for simulations), or the first and last random directions to use, (for random direction control studies).

```
# Initialization, prepare the analysis directories and build the list of targets
PrepareTargets(rosters)

# Data analysis

# Loop over targets
for target in targets:
    AnalyzeROI(target)

    for profile in target.profiles:
        AnalyzeSED(target, profile)
        PlotCastro(target, profile)


# Simulation analysis

# Loop over simulation scenarios
for sim in sims:

    # Loop over targets
    for target in targets:
        CopyBaseROI(sim, target)

        for profile in target.profiles:
            SimulateROI(sim, target, profile) # This loops over simulation seeds and
↪produces SEDS
            CollectSED(sim, target, profile)


# Random direction control analysis

# Loop over targets
for target in targets:
    CopyBaseROI(target)
    RandomDirGen(target)

    for profile in target.profiles:
        for seed in range(first, last)
            AnalyzeSED(target, profile, seed)

        CollectSED('random', target, profile)
```

### Master Configuration File

fermipy.jobs uses YAML files to read and write its configuration in a persistent format. The configuration file has a hierarchical structure that groups parameters into dictionaries that are keyed to a section name.

```
:caption: Sample Configuration

ttype: dSphs
rosters : ['test']
spatial_models: ['point']
```

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```
sim_defaults:
    seed : 0
    nsims : 20
    profile : ['point']

sims:
    'null' : {}
    'pl2_1em9' : {}

random: {}

data_plotting:
    plot-castro : {}
```

Options at the top level apply to all parts of the analysis pipeline

Listing 6: Sample *top level* Configuration

```
  # Top level
  ttype : 'dSphs'
  rosters : ['test']
  spatial_models: ['point']
```

- ttype: str Target tpye. This is used for bookkeeping mainly, to give the name of the top-level directory, and to call out specfic configuration files.
- rosters: list List of rosters of targets to analyze. Each roster represents a self-consistent set of targets. Different versions of the same target can be on several different rosters. But no target should appear on a single roster more than once.
- spatial_models: : list List of types of spatial model to use when fitting the DM. Options are * point : A point source

---

**Note:** If multiple rosters include the same target and profile, that target will only be analyzed once, and those results will be re-used when combining each roster.

---

### Simulation configuration

The *sim_defaults*, *sims* and *random* sections can be used to define analysis configurations for control studies with simulations and random sky directions.

Listing 7: Sample *simulation* Configuration

```
sim_defaults:
    seed : 0
    nsims : 20
    profile : point

sims:
    'null' : {}
    'pl2_1em9' : {}

random: {}
```

- sim_defaults : dict This is a dictionary of the parameters to use for simulations. This can be overridden for specific type of simulation.
  - **seed** [int] Random number seed to use for the first simulation
  - **nsims** [int] Number of simulations
  - **profile** [str] Name of the spatial profile to use for simulations. This must match a profile defined in the roster for each target. The 'alias_dict' file can be used to remap longer profile names, or to define a common name for all the profiles in a roster.
- sims : dict This is a dictionary of the simulation scenarious to consider, and of any option overrides for some of those scenarios.

  Each defined simulation needs a 'config/sim_{sim_name}.yaml' to define the injected source to use for that simulation.
- random: dict This is a dictionary of the options to use for random sky direction control studies.

### Plotting configuration

Listing 8: Sample *plotting* Configuration

```
data_plotting:
    plot-castro : {}
```

- data_plotting : dict

  Dictionaries of which types of plots to make for data, simulations and random direction controls. These dictionaries can be used to override the default set of channels for any particular set of plots.

  The various plot types are:
  - plot-castro : SED plots of a particular target, assuming a particular spatial profile.

### Additional Configuration files

In addition to the master configuration file, the pipeline needs a few additional files.

### Fermipy Analysis Configuration Yaml

This is simply a template of the *fermipy* configuration file to be used for the baseline analysis and SED fitting in each ROI. Details of the syntax and options are here _ The actual direction and name of the target source in this file will be over written for each target.

### Profile Alias Configuration Yaml

This is an optional small file that remaps the target profile names to shorter names (without underscores in them). Removing the underscores helps keep the file name fields more logical, and fermipy.jobs generally uses underscores as a field seperator. This also keeps file names shorter, and allows us to use roster with a mixed set of profile versions to do simulations. Here is an example:

```
ackermann2016_photoj_0.6_nfw : ack2016
geringer-sameth2015_nfw : gs2015
```

### Simulation Scenario Configuration Yaml

This file specifies the signal to inject in the analysis (if any). Here is a example, note that everything inside the 'injected_source' tag is in the format that *fermipy* expects to see source defintions.

```
# For positive control tests we with injected source.
# In this case it is a powerlaw specturm
injected_source:
  name : testpl
  source_model :
    SpatialModel : PointSource
    SpectrumType : Powerlaw
  Prefactor :
    value : 1e-9
  index :
    value: 2.
  scale :
    value : 1000.
```

For null simulations, you should include the 'injected_source' tag, but leave it blank

```
# For positive control tests we with injected source.
# In this case it is a DM annihilation spectrum.
injected_source:
```

### Random Direction Control Sample Configuration Yaml

The file define how we select random directions for the random direction control studies. Here is an example:

```
# These are the parameters for the random direction selection
# The algorithm picks points on a grid

# File key for the first direction
seed : 0
# Number of directions to select
nsims : 20

# Step size between grid points (in deg)
step_x : 1.0
step_y : 1.0
# Max distance from ROI center (in deg)
max_x : 3.0
max_y : 3.0
```

### Preparing the analysis areas

The initial setup can be done either by using the `PrepareTargets` link directly from python, or by running the fermipy-prepare-targets executable. This will produce a number of analysis directories and populate them with the needed configuration files.

```
link = PrepareTargets()
link.update_args(dict(ttype=dSphs,
                      rosters=['dsph_roster.yaml'],
```

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```
                      spatial_models=['point'],
                      sims=['null', 'random', 'pl2_1em9']))
link.run()
```

```
fermipy-prepare-targets --ttype dSphs --rosters dsph_roster.yaml --spatial_
↪models point --sims random --sims pl2_1em9 --sims null
```

- Additional Arguments
  - alias_dict [None] Optional path to a file that remaps the target profile name to shorter names.

### Baseline target analysis

The first step of the analysis chain is to perform a baseline re-opimization of each ROI. This is done by using `AnalyzeROI_SG` to run the `AnalyzeROI` link on each ROI in the target list generated by `PrepareTargets`. This can be done directly from python, or from the shell using the fermipy-analyze-roi-sg executable.

```
  link = AnalyzeROI_SG()
  link.update_args(dict(ttype=dSphs,
                        targetlist='dSphs/target_list.yaml'))
  link.run()

.. code-block:: shell

  fermipy-analyze-roi-sg --ttype dSphs --targetlist dSphs/target_list.yaml --config␣
↪config.yaml
```

- Additional Arguments
  - config [‘config.yaml’] Name of the fermipy configuration file to use.
  - roi_baseline [‘fit_baseline’] Prefix to use for the output files from the baseline fit to the ROI
  - make_plots [False] Produce the standard plots for an ROI analysis.

### Target SED analysis

The next step of the analysis chain is to perform extract the SED each spatial profile for each target. This is done by using `AnalyzeSED_SG` to run the `AnalyzeSED` link on each ROI in the target list. This uses the baseline fits as a starting point for the SED fits. This can be done directly from python, or from the shell using the fermipy-analyze-sed-sg executable.

```
  link = AnalyzeSED_SG()
  link.update_args(dict(ttype=dSphs,
                        targetlist='dSphs/target_list.yaml'))
  link.run()

.. code-block:: shell

  fermipy-analyze-sed-sg --ttype dSphs --targetlist dSphs/target_list.yaml --config␣
↪config.yaml
```

- Additional Arguments
  - config [‘config.yaml’] Name of the fermipy configuration file to use.

- roi_baseline ['fit_baseline'] Prefix to use for the output files from the baseline fit to the ROI
- make_plots [False] Produce the standard plots for a SED analysis.
- non_null_src [False] If set to True, the analysis will zero out the source before computing the SED. This is needed for positive control simulations.
- skydirs [None] Optional file with a set of directions to build SEDs for. This is used from random direction control samples.

### Simulated realizations of ROI analysis

This module provides tools to perform simulated realizations of the ROIs. This is done by copying the baseline ROI, using it as a starting point, and simulating realizations of the analysis by throwing Poisson fluctuations on the expected models counts of the ROI and then fitting those simulated data. These simulations are done for each target and can optionally include injecting a signal source. This can be done directly from python, or from the shell using executables. Here is an example of how to generate negative control ("null") simulations. This requires having 'config/sim_null.yaml' consist of just a single empty tag 'injected_source'. To run positive control sample you would just change "null" to, for example "pl2_1em9", where 'config/sim_pl2_1em9.yaml' is the yaml file with the spectral model described above.

```
# Copy the base line ROI
copy_link = CopyBaseROI_SG()
copy_link.update_args(dict(ttype=dSphs,
                           targetlist='dSphs_sim/sim_null/target_list.yaml',
                           sim='null'))
copy_link.run()

# Run simulations of the ROI
sim_link = SimulateROI_SG()
sim_link.update_args(dict(ttype=dSphs,
                          targetlist='dSphs_sim/sim_null/target_list.yaml',
                          sim='null'))
sim_link.run()

# Collect the results of the simulations
col_link = CollectSED_SG()
col_link.update_args(dict(ttype=dSphs,
                          targetlist='dSphs_sim/sim_null/target_list.yaml',
                          sim='null'))
col_link.run()
```

```
fermipy-copy-base-roi-sg --ttype dSphs --targetlist dSphs_sim/sim_null/
↪target_list.yaml --sim null
fermipy-simulate-roi-sg --ttype dSphs --targetlist dSphs_sim/sim_null/target_
↪list.yaml --sim null
fermipy-collect-sed-sg --ttype dSphs --targetlist dSphs_sim/sim_null/target_
↪list.yaml --sim null
```

- Additional Arguments
  - extracopy [] Extra files to copy from basline fit directory.
  - config ['config.yaml'] Name of the fermipy configuration file to use.
  - roi_baseline ['fit_baseline'] Prefix to use for the output files from the baseline fit to the ROI
  - non_null_src [False] If set to True, the analysis will zero out the source before computing the SED. This is needed for positive control simulations.

- do_find_src [False] Do an additional setup of source finding in the ROI.
- sim_profile ['default'] Name of the profile to use to produce the simulations
- nsims [20] Number of simulations to run
- seed [0] Starting random number seed. Also used as in bookkeeping.
- nsims_job [0] Number of simulations per job. 0 means to run all the simulations in a single job.

### Random Direction Control Studies

This module also provides tools to perform analyses of random directions in the ROI as a control sample. This done by copying the baseline ROI, using it as a starting point, and then picked directions away from the center of the ROI and treating them as the target. Here is an example of how to generate random direction control simulations. Defined by having 'config/sim_null.yaml' consist of just a single empty tag 'injected_source'. To run positive control sample you would just change "null" to, for example "pl2_1em9", where 'config/sim_pl2_1em9.yaml' is the yaml file with the spectral model described above.

```
# Copy the base line ROI
copy_link = CopyBaseROI_SG()
copy_link.update_args(dict(ttype=dSphs,
                           targetlist='dSphs_sim/sim_random/target_random.
↪yaml',
                           sim='random'))
copy_link.run()

# Make a set of random directions
dir_link = RandomDirGen_SG()
dir_link.update_args(dict(ttype=dSphs,
                          targetlist='dSphs_sim/sim_random/target_list.yaml',
                          sim='random',
                          rand_config='config/random_dSphs.yaml'))
dir_link.run()

# Construct the SED for each random direction
sed_link = AnalyzeSED_SG()
sed_link.update_args(dict(ttype=dSphs,
                          targetlist='dSphs_sim/sim_random/target_list.yaml',
                          skydirs='skydirs.yaml'))
sed_link.run()

# Collect the results for the random directions
col_link = CollectSED_SG()
col_link.update_args(dict(ttype=dSphs,
                          targetlist='dSphs_sim/sim_random/target_list.yaml',
                          sim='random'))
col_link.run()
```

```
fermipy-copy-base-roi-sg --ttype dSphs --targetlist dSphs_sim/sim_random/
↪target_list.yaml --sim random
fermipy-random-dir-gen-sg --ttype dSphs --targetlist dSphs_sim/sim_random/
↪target_list.yaml --sim random --rand_config config/random_dSphs.yaml
fermipy-analyze-sed-sg --ttype dSphs --targetlist dSphs_sim/sim_random/
↪target_list.yaml --skydirs skydirs.yaml
fermipy-collect-sed-sg --ttype dSphs --targetlist dSphs_sim/sim_random/
↪target_list.yaml --sim random
```

- Additional Arguments
  - extracopy [] Extra files to copy from basline fit directory.
  - config ['config.yaml'] Name of the fermipy configuration file to use.
  - roi_baseline ['fit_baseline'] Prefix to use for the output files from the baseline fit to the ROI
  - non_null_src [False] If set to True, the analysis will zero out the source before computing the SED. This is needed for positive control simulations.
  - do_find_src [False] Do an additional setup of source finding in the ROI.
  - write_full [False Write a full description of all the collected SED results
  - write_summary [False]

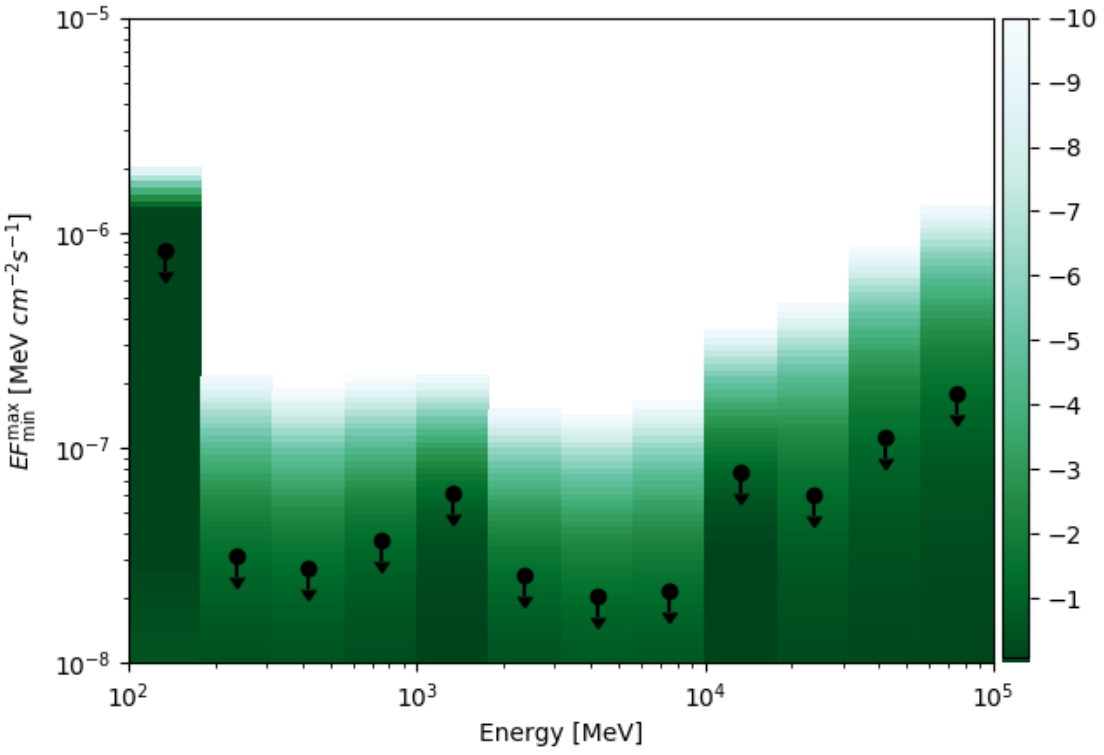
### Plotting Results

The module also includes code to plot the SED for each target. Note that this can also be done with the make_plots=True option in `AnalyzeSED_SG`.

```
link = PlotCastro_SG()
link.update_args(dict(ttype=dSphs,
                      targetlist='dSphs/target_list.yaml'))
link.run()
```

```
fermipy-plot-castro-sg --ttype dSphs --targetlist dSphs/target_list.yaml
```

One of the resulting plots would look something like this:



### Module contents

### Link class and trivial sub-classes

**class** fermipy.jobs.link.**Link**(***kwargs*)
Bases: object

A wrapper for a command line application.

This class keeps track for the arguments to pass to the application as well as input and output files.

This can be used either with other *Link* objects to build a Chain, or as standalone wrapper to pass configuration to the application.

Derived classes will need to override the appname and linkname-default class parameters.

**Parameters**

- **appname** (*str*) – Name of the application run by this *Link*
- **linkname_default** (*str*) – Default name for *Link* of this type
- **default_options** (*dict*) – Dictionry with options, defaults, helpstring and types for the parameters associated with the *Link*
- **default_file_args** (*dict*) – Dictionary specifying if particular parameters are associated with input or output files.
- **linkname** (*str*) – Name of this *Link*, used as a key to find it in a Chain.
- **link_prefix** (*str*) – Optional prefix for this *Link*, used to distinguish between similar *Link* objects on different Chain objects.
- **args** (*dict*) – Up-to-date dictionary with the arguments that will be passed to the application
- **_options** (*dict*) – Dictionary with the options that we are allowed to set and default values
- **files** (FileDict) – Object that keeps track of input and output files
- **jobs** (OrderedDict) – Dictionary mapping keys to JobDetails. This contains information about all the batch jobs associated to this *Link*

**appname = 'dummy'**

**arg_names**
Return the list of arg names

**check_input_files**(*return_found=True*, *return_missing=True*)
Check if input files exist.

**Parameters**

- **return_found** (*list*) – A list with the paths of the files that were found.
- **return_missing** (*list*) – A list with the paths of the files that were missing.

**Returns**

- **found** (*list*) – List of the found files, if requested, otherwise None
- **missing** (*list*) – List of the missing files, if requested, otherwise None

**check_job_status**(*key='__top__'*, *fail_running=False*, *fail_pending=False*, *force_check=False*)
Check the status of a particular job

By default this checks the status of the top-level job, but can by made to drill into the sub-jobs.

**Parameters**

- **key** (*str*) – Key associated to the job in question
- **fail_running** (bool) – If True, consider running jobs as failed
- **fail_pending** (bool) – If True, consider pending jobs as failed
- **force_check** (bool) – Drill into status of individual jobs‘ instead of using top level job only

**Returns** **status** – Job status flag

**Return type** JobStatus

**check_jobs_status**(*fail_running=False*, *fail_pending=False*)
Check the status of all the jobs run from this link and return a status flag that summarizes that.

**Parameters**

- **fail_running** (bool) – If True, consider running jobs as failed
- **fail_pending** (bool) – If True, consider pending jobs as failed

**Returns** **status** – Job status flag that summarizes the status of all the jobs,

**Return type** JobStatus

**check_output_files**(*return_found=True*, *return_missing=True*)
Check if output files exist.

**Parameters**

- **return_found** (*list*) – A list with the paths of the files that were found.
- **return_missing** (*list*) – A list with the paths of the files that were missing.

**Returns**

- **found** (*list*) – List of the found files, if requested, otherwise None
- **missing** (*list*) – List of the missing files, if requested, otherwise None

**clean_jobs**(*recursive=False*)
Clean out all of the jobs associated to this link.

For sub-classes, if recursive is True this also clean jobs from any internal *Link*

**clear_jobs**(*recursive=True*)
Clear the self.jobs dictionary that contains information about jobs associated with this *Link*.

For sub-classes, if recursive is True this also clean jobs from any internal *Link*

**command_template**()
Build and return a string that can be used as a template invoking this chain from the command line.

The actual command can be obtainted by using `self.command_template().format(**self.args)`

**static construct_docstring**(*options*)
Construct a docstring for a set of options

**classmethod create**(***kwargs*)
Build and return a *Link*

**default_file_args = {}**

**default_options = {}**

**description = 'Link to run dummy'**

**formatted_command**()
Build and return the formatted command for this *Link*.

This is exactly the command as called from the Unix command line.

**full_linkname**
Return the linkname with the prefix attached This is useful to distinguish between links on different `Chain` objects.

**get_failed_jobs**(*fail_running=False*, *fail_pending=False*)
Return a dictionary with the subset of jobs that are marked as failed

**Parameters**

- **fail_running** (`bool`) – If True, consider running jobs as failed
- **fail_pending** (`bool`) – If True, consider pending jobs as failed

**Returns** **failed_jobs** – Dictionary mapping from job key to `JobDetails` for the failed jobs.

**Return type** dict

**get_jobs**(*recursive=True*)
Return a dictionary with all the jobs

For sub-classes, if recursive is True this will include jobs from any internal *Link*

**linkname_default = 'dummy'**

**classmethod main**()
Hook to run this *Link* from the command line

**missing_input_files**()
Make and return a dictionary of the missing input files.

This returns a dictionary mapping filepath to list of *Link* that use the file as input.

**missing_output_files**()
Make and return a dictionary of the missing output files.

This returns a dictionary mapping filepath to list of links that produce the file as output.

**print_summary**(*stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*, *indent=''*, *recurse_level=2*)
Print a summary of the activity done by this *Link*.

**Parameters**

- **stream** (`file`) – Stream to print to, must have 'write' method.
- **indent** (*str*) – Indentation at start of line
- **recurse_level** (*int*) – Number of recursion levels to print

**classmethod register_class**()
Regsiter this class in the `LinkFactory`

**run**(*stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*, *dry_run=False*, *stage_files=True*, *resubmit_failed=False*)
Runs this *Link*.

This version is intended to be overwritten by sub-classes so as to provide a single function that behaves the same for all version of *Link*

**Parameters**

- **stream** (file) – Stream that this *Link* will print to, Must have 'write' function
- **dry_run** (*bool*) – Print command but do not run it.
- **stage_files** (*bool*) – Copy files to and from scratch staging area.
- **resubmit_failed** (*bool*) – Flag for sub-classes to resubmit failed jobs.

**run_analysis**(*argv*)
Implemented by sub-classes to run a particular analysis

**run_command**(*stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*, *dry_run=False*)
Runs the command for this link. This method can be overridden by sub-classes to invoke a different command

**Parameters**

- **stream** (file) – Stream that this *Link* will print to, Must have 'write' function
- **dry_run** (*bool*) – Print command but do not run it

**Returns** **code** – Return code from sub-process

**Return type** int

**run_with_log**(*dry_run=False*, *stage_files=True*, *resubmit_failed=False*)
Runs this link with output sent to a pre-defined logfile

**Parameters**

- **dry_run** (*bool*) – Print command but do not run it.
- **stage_files** (*bool*) – Copy files to and from scratch staging area.
- **resubmit_failed** (*bool*) – Flag for sub-classes to resubmit failed jobs.

**topkey = '__top__'**

**update_args**(*override_args*)
Update the argument used to invoke the application

Note that this will also update the dictionary of input and output files.

**Parameters** **override_args** (*dict*) – Dictionary of arguments to override the current values

**usage = 'dummy [options]'**

**class** fermipy.jobs.app_link.**AppLink**(***kwargs*)
Bases: *fermipy.jobs.link.Link*

A wrapper for a single fermipy application

This class keeps track for the arguments to pass to the application as well as input and output files.

This can be used either with other Link to build a Chain, or as as standalone wrapper to pass conifguration to the application.

See help for `Link` for additional details

**appname = 'dummy'**

**description = 'Link to run dummy'**

**linkname_default = 'dummy'**

**run_analysis**(*argv*)
Implemented by sub-classes to run a particular analysis

**usage = 'dummy [options]'**

### ScatterGather class

**class** fermipy.jobs.scatter_gather.**ScatterGather**(*link*, ***kwargs*)
Bases: *fermipy.jobs.link.Link*

Class to dispatch several jobs in parallel and collect and merge the results.

Sub-classes will need to generatare configuration for the jobs that they launch.

**Parameters**

- **clientclass** (*type*) – Type of `Link` object managed by this class.
- **job_time** (*int*) – Estimated maximum time it takes to run a job This is used to manage batch farm scheduling and checking for completion.

**appname = 'dummy-sg'**

**build_job_configs**(*args*)
Hook to build job configurations

Sub-class implementation should return:

**job_configs** [dict] Dictionary of dictionaries passed to parallel jobs

**check_status**(*stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*, *check_once=False*, *fail_pending=False*, *fail_running=False*, *no_wait=False*, *do_print=True*, *write_status=False*)
Loop to check on the status of all the jobs in job dict.

**Parameters**

- **stream** (`file`) – Stream that this function will print to, Must have 'write' function.
- **check_once** (*bool*) – Check status once and exit loop.
- **fail_pending** (`bool`) – If True, consider pending jobs as failed
- **fail_running** (`bool`) – If True, consider running jobs as failed
- **no_wait** (*bool*) – Do not sleep before checking jobs.
- **do_print** (*bool*) – Print summary stats.
- **write_status** (*bool*) – Write the status the to log file.

**Returns** **status_vect** – Vector that summarize the number of jobs in various states.

**Return type** `JobStatusVector`

**clean_jobs**(*recursive=False*)
Clean up all the jobs associated with this object.

If recursive is True this also clean jobs dispatch by this object.

**clear_jobs**(*recursive=True*)
Clear the self.jobs dictionary that contains information about jobs associated with this *ScatterGather*

If recursive is True this will include jobs from all internal `Link`

**clientclass = None**

**classmethod create**(***kwargs*)
Build and return a *ScatterGather* object

**default_options = {}**

**default_options_base = {'action': ('run', 'Action to perform', <class 'str'>), 'check**

**default_prefix_logfile = 'scatter'**

**description = 'Run multiple analyses'**

**get_jobs**(*recursive=True*)
Return a dictionary with all the jobs

If recursive is True this will include jobs from all internal `Link`

**job_time = 1500**

**classmethod main**()
Hook for command line interface to sub-classes

**print_failed**(*stream=<_io.TextIOWrapper name='<stderr>' mode='w' encoding='UTF-8'>*)
Print list of the failed jobs

**print_summary**(*stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*, *indent=''*, *recurse_level=2*)
Print a summary of the activity done by this `Link`.

**Parameters**

- **stream** (`file`) – Stream to print to
- **indent** (*str*) – Indentation at start of line
- **recurse_level** (*int*) – Number of recursion levels to print

**print_update**(*stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*, *job_stats=None*)
Print an update about the current number of jobs running

**resubmit**(*stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*, *fail_running=False*, *resubmit_failed=False*)
Function to resubmit failed jobs and collect results

**Parameters**

- **stream** (`file`) – Stream that this function will print to, Must have 'write' function.
- **fail_running** (`bool`) – If True, consider running jobs as failed
- **resubmit_failed** (*bool*) – Resubmit failed jobs.

**Returns** **status_vect** – Vector that summarize the number of jobs in various states.

**Return type** `JobStatusVector`

**run**(*stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*, *dry_run=False*, *stage_files=True*, *resubmit_failed=True*)
Runs this `Link`.

This version is intended to be overwritten by sub-classes so as to provide a single function that behaves the same for all version of `Link`

**Parameters**

- **stream** (`file`) – Stream that this `Link` will print to, Must have 'write' function
- **dry_run** (*bool*) – Print command but do not run it.
- **stage_files** (*bool*) – Copy files to and from scratch staging area.
- **resubmit_failed** (*bool*) – Flag for sub-classes to resubmit failed jobs.

**run_analysis** (*argv*)
Implemented by sub-classes to run a particular analysis

**run_jobs** (*stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>, resubmit_failed=False*)
Function to dipatch jobs and collect results

**Parameters**

- **stream** (`file`) – Stream that this function will print to, Must have 'write' function.
- **resubmit_failed** (*bool*) – Resubmit failed jobs.

**Returns** **status_vect** – Vector that summarize the number of jobs in various states.

**Return type** `JobStatusVector`

**scatter_link**
Return the `Link` object used the scatter phase of processing

**update_args** (*override_args*)
Update the arguments used to invoke the application

Note that this will also update the dictionary of input and output files

**Parameters** **override_args** (*dict*) – dictionary of arguments to override the current values

**usage = 'dummy-sg [options]'**

### Chain class

**class** fermipy.jobs.chain.**Chain** (***kwargs*)
Bases: *fermipy.jobs.link.Link*

An object tying together a series of applications into a single application.

This class keep track of the arguments to pass to the applications as well as input and output files.

Note that this class is itself a `Link`. This allows you to write a python module that implements a chain and also has a __main__ function to allow it to be called from the shell.

**check_links_status** (*fail_running=False, fail_pending=False*)
"Check the status of all the jobs run from the `Link` objects in this *Chain* and return a status flag that summarizes that.

**Parameters**

- **fail_running** (`bool`) – If True, consider running jobs as failed
- **fail_pending** (`bool`) – If True, consider pending jobs as failed

**Returns** **status** – Job status flag that summarizes the status of all the jobs,

**Return type** JobStatus

**clear_jobs**(*recursive=True*)
Clear a dictionary with all the jobs

If recursive is True this will include jobs from all internal Link

**get_jobs**(*recursive=True*)
Return a dictionary with all the jobs

If recursive is True this will include jobs from all internal Link

**linknames**
Return the name of the Link objects owned by this *Chain*

**links**
Return the OrderedDict of Link objects owned by this *Chain*

**load_config**(*configfile*)
Read a config file for the top-level arguemnts

**classmethod main**()
Hook to run this *Chain* from the command line

**missing_input_files**()
Make and return a dictionary of the missing input files.

This returns a dictionary mapping filepath to list of Link that use the file as input.

**missing_output_files**()
Make and return a dictionary of the missing output files.

This returns a dictionary mapping filepath to list of links that produce the file as output.

**print_status**(*indent=''*, *recurse=False*)
Print a summary of the job status for each Link in this *Chain*

**print_summary**(*stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*, *indent=''*, *recurse_level=2*)
Print a summary of the activity done by this *Chain*.

**Parameters**

- **stream** (file) – Stream to print to, must have 'write' method.
- **indent** (*str*) – Indentation at start of line
- **recurse_level** (*int*) – Number of recursion levels to print

**run**(*stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*, *dry_run=False*, *stage_files=True*, *resubmit_failed=False*)
Runs this *Chain*.

**Parameters**

- **stream** (file) – Stream that this Link will print to, Must have 'write' function
- **dry_run** (*bool*) – Print command but do not run it.
- **stage_files** (*bool*) – Copy files to and from scratch staging area.
- **resubmit_failed** (*bool*) – Flag for sub-classes to resubmit failed jobs.

**run_analysis**(*argv*)
Implemented by sub-classes to run a particular analysis

**update_args**(*override_args*)
Update the argument used to invoke the application

Note that this will also update the dictionary of input and output files.

**Parameters** **override_args** (*dict*) – dictionary passed to the links

### High-level analysis classes

These are `Link` sub-classes that implement *fermipy* analyses, or perform tasks related to *fermipy* analyses, such as plotting or collecting results for a set of simulations.

**class** fermipy.jobs.target_analysis.**AnalyzeROI**(**kwargs*)
Bases: *fermipy.jobs.link.Link*

Small class that wraps an analysis script.

This particular script does baseline fitting of an ROI.

**Parameters**

- **make_plots** (*<class 'bool'>*) – Make plots [False]
- **config** (*<class 'str'>*) – Path to fermipy config file. [None]
- **roi_baseline** (*<class 'str'>*) – Key for roi baseline file. [fit_baseline]

**appname = 'fermipy-analyze-roi'**

**default_options = {'config': (None, 'Path to fermipy config file.', <class 'str'>), '**

**description = 'Run analysis of a single ROI'**

**linkname_default = 'analyze-roi'**

**run_analysis**(*argv*)
Run this analysis

**usage = 'fermipy-analyze-roi [options]'**

**class** fermipy.jobs.target_analysis.**AnalyzeSED**(**kwargs*)
Bases: *fermipy.jobs.link.Link*

Small class to wrap an analysis script.

This particular script fits an SED for a target source with respect to the baseline ROI model.

**Parameters**

- **make_plots** (*<class 'bool'>*) – Make plots [False]
- **config** (*<class 'str'>*) – Path to fermipy config file. [None]
- **roi_baseline** (*<class 'str'>*) – Key for roi baseline file. [fit_baseline]
- **non_null_src** (*<class 'bool'>*) – Zero out test source [False]
- **profiles** (*<class 'list'>*) – List of profiles to analyze [[]]
- **skydirs** (*<class 'str'>*) – Yaml file with blank sky directions. [None]

**appname = 'fermipy-analyze-sed'**

**default_options = {'config': (None, 'Path to fermipy config file.', <class 'str'>), '**

**description = 'Extract the SED for a single target'**

**linkname_default = 'analyze-sed'**

**run_analysis**(*argv*)
Run this analysis

**usage = 'fermipy-analyze-sed [options]'**

**class** fermipy.jobs.target_collect.**CollectSED**(***kwargs*)
Bases: *fermipy.jobs.link.Link*

Small class to collect SED results from a series of simulations.

**Parameters**

- **nsims** (*<class 'int'>*) – Number of simulations to run. [20]
- **enumbins** (*<class 'int'>*) – Number of energy bins [12]
- **summaryfile** (*<class 'str'>*) – Path to file with results summaries. [None]
- **sed_file** (*<class 'str'>*) – Path to SED file. [None]
- **config** (*<class 'str'>*) – Path to fermipy config file. [None]
- **dry_run** (*<class 'bool'>*) – Print commands but do not run them. [False]
- **seed** (*<class 'int'>*) – Seed number for first simulation. [0]
- **outfile** (*<class 'str'>*) – Path to output file. [None]

**appname = 'fermipy-collect-sed'**

**collist = [{'unit': 'MeV', 'name': 'e_min'}, {'unit': 'MeV', 'name': 'e_ref'}, {'u**

**default_options = {'config': (None, 'Path to fermipy config file.', <class 'str'>), '**

**description = 'Collect SED results from simulations'**

**linkname_default = 'collect-sed'**

**run_analysis**(*argv*)
Run this analysis

**usage = 'fermipy-collect-sed [options]'**

**class** fermipy.jobs.target_sim.**CopyBaseROI**(***kwargs*)
Bases: *fermipy.jobs.link.Link*

**Small class to copy a baseline ROI to a simulation area** This is useful for parallelizing analysis using the fermipy.jobs module.

**Parameters**

- **sim** (*<class 'str'>*) – Name of the simulation scenario. [None]
- **extracopy** (*<class 'list'>*) – Extra files to copy [[]]
- **roi_baseline** (*<class 'str'>*) – Key for roi baseline file. [fit_baseline]
- **target** (*<class 'str'>*) – Name of analysis target. [None]
- **ttype** (*<class 'str'>*) – Type of target being analyzed. [None]

**appname = 'fermipy-copy-base-roi'**

**classmethod copy_analysis_files**(*orig_dir*, *dest_dir*, *copyfiles*)
Copy a list of files from orig_dir to dest_dir

**classmethod copy_target_dir**(*orig_dir*, *dest_dir*, *roi_baseline*, *extracopy*)
Create and populate directoris for target analysis

**copyfiles = ['srcmap_*.fits', 'ccube.fits', 'ccube_*.fits']**

**default_options = {'extracopy': ([], 'Extra files to copy', <class 'list'>), 'roi_bas**

**description = 'Copy a baseline ROI to a simulation area'**

**linkname_default = 'copy-base-roi'**

**run_analysis**(*argv*)
Run this analysis

**usage = 'fermipy-copy-base-roi [options]'**

**class** fermipy.jobs.target_sim.**RandomDirGen**(***kwargs*)
Bases: *fermipy.jobs.link.Link*

**Small class to generate random sky directions inside an ROI** This is useful for parallelizing analysis using the fermipy.jobs module.

**Parameters**

- **config** (*<class 'str'>*) – Path to fermipy config file. [None]
- **rand_config** (*<class 'str'>*) – Path to config file for genaration random sky dirs [None]
- **outfile** (*<class 'str'>*) – Path to output file. [None]

**appname = 'fermipy-random-dir-gen'**

**default_options = {'config': (None, 'Path to fermipy config file.', <class 'str'>), '**

**description = 'Generate random sky directions in an ROI'**

**linkname_default = 'random-dir-gen'**

**run_analysis**(*argv*)
Run this analysis

**usage = 'fermipy-random-dir-gen [options]'**

**class** fermipy.jobs.target_sim.**SimulateROI**(***kwargs*)
Bases: *fermipy.jobs.link.Link*

**Small class wrap an analysis script.** This is useful for parallelizing analysis using the fermipy.jobs module.

**Parameters**

- **do_find_src** (*<class 'bool'>*) – Add source finding step to simulated realizations [False]
- **nsims** (*<class 'int'>*) – Number of simulations to run. [20]
- **profiles** (*<class 'list'>*) – List of profiles to analyze [[]]
- **sim_profile** (*<class 'str'>*) – Name of the profile to use for simulation. [default]
- **sim** (*<class 'str'>*) – Name of the simulation scenario. [None]
- **config** (*<class 'str'>*) – Path to fermipy config file. [None]

- **non_null_src** (*<class 'bool'>*) – Zero out test source [False]
- **roi_baseline** (*<class 'str'>*) – Key for roi baseline file. [fit_baseline]
- **seed** (*<class 'int'>*) – Seed number for first simulation. [0]

**appname = 'fermipy-simulate-roi'**

**default_options = {'config': (None, 'Path to fermipy config file.', <class 'str'>), '**

**description = 'Run simulated analysis of a single ROI'**

**linkname_default = 'simulate-roi'**

**run_analysis**(*argv*)
Run this analysis

**usage = 'fermipy-simulate-roi [options]'**

**class** fermipy.jobs.target_plotting.**PlotCastro**(***kwargs*)
Bases: *fermipy.jobs.link.Link*

Small class to plot an SED as a 'Castro' plot.

**Parameters**

- **infile** (*<class 'str'>*) – Path to input file. [None]
- **outfile** (*<class 'str'>*) – Path to output file. [None]

**appname = 'fermipy-plot-castro'**

**default_options = {'infile': (None, 'Path to input file.', <class 'str'>), 'outfile':**

**description = 'Plot likelihood v. flux normalization and energy'**

**linkname_default = 'plot-castro'**

**run_analysis**(*argv*)
Run this analysis

**usage = 'fermipy-plot-castro [options]'**

### High-level analysis job dispatch

These are `ScatterGather` sub-classes that invoke the `Link` sub-classes listed above.

**class** fermipy.jobs.target_analysis.**AnalyzeROI_SG**(*link*, ***kwargs*)
Bases: *fermipy.jobs.scatter_gather.ScatterGather*

Small class to generate configurations for the *AnalyzeROI* class.

This loops over all the targets defined in the target list.

**Parameters**

- **make_plots** (*<class 'bool'>*) – Make plots [False]
- **config** (*<class 'str'>*) – Path to fermipy config file. [None]
- **targetlist** (*<class 'str'>*) – Path to the target list. [None]
- **roi_baseline** (*<class 'str'>*) – Key for roi baseline file. [fit_baseline]
- **ttype** (*<class 'str'>*) – Type of target being analyzed. [None]

**appname = 'fermipy-analyze-roi-sg'**

**build_job_configs**(*args*)
Hook to build job configurations

**clientclass**
alias of *AnalyzeROI*

**default_options = {'config': (None, 'Path to fermipy config file.', <class 'str'>), '**

**description = 'Run analyses on a series of ROIs'**

**job_time = 1500**

**usage = 'fermipy-analyze-roi-sg [options]'**

**class** fermipy.jobs.target_analysis.**AnalyzeSED_SG**(*link*, ***kwargs*)
Bases: *fermipy.jobs.scatter_gather.ScatterGather*

Small class to generate configurations for this script

This loops over all the targets defined in the target list, and over all the profiles defined for each target.

**Parameters**

- **make_plots** (*<class 'bool'>*) – Make plots [False]
- **config** (*<class 'str'>*) – Path to fermipy config file. [None]
- **skydirs** (*<class 'str'>*) – Yaml file with blank sky directions. [None]
- **roi_baseline** (*<class 'str'>*) – Key for roi baseline file. [fit_baseline]
- **non_null_src** (*<class 'bool'>*) – Zero out test source [False]
- **targetlist** (*<class 'str'>*) – Path to the target list. [None]
- **ttype** (*<class 'str'>*) – Type of target being analyzed. [None]

**appname = 'fermipy-analyze-sed-sg'**

**build_job_configs**(*args*)
Hook to build job configurations

**clientclass**
alias of *AnalyzeSED*

**default_options = {'config': (None, 'Path to fermipy config file.', <class 'str'>), '**

**description = 'Run analyses on a series of ROIs'**

**job_time = 1500**

**usage = 'fermipy-analyze-sed-sg [options]'**

**class** fermipy.jobs.target_collect.**CollectSED_SG**(*link*, ***kwargs*)
Bases: *fermipy.jobs.scatter_gather.ScatterGather*

Small class to generate configurations for *CollectSED*

This loops over all the targets defined in the target list

**Parameters**

- **nsims** (*<class 'int'>*) – Number of simulations to run. [20]
- **ttype** (*<class 'str'>*) – Type of target being analyzed. [None]

- **sim** (*<class 'str'>*) – Name of the simulation scenario. [None]
- **config** (*<class 'str'>*) – Path to fermipy config file. [None]
- **write_summary** (*<class 'bool'>*) – Write file with summary of collected results [False]
- **seed** (*<class 'int'>*) – Seed number for first simulation. [0]
- **targetlist** (*<class 'str'>*) – Path to the target list. [None]
- **write_full** (*<class 'bool'>*) – Write file with full collected results [False]

**appname = 'fermipy-collect-sed-sg'**

**build_job_configs**(*args*)
Hook to build job configurations

**clientclass**
alias of *CollectSED*

**default_options = {'config': (None, 'Path to fermipy config file.', <class 'str'>), '**

**description = 'Collect SED data from a set of simulations for a series of ROIs'**

**job_time = 120**

**usage = 'fermipy-collect-sed-sg [options]'**

**class** fermipy.jobs.target_sim.**CopyBaseROI_SG**(*link*, ***kwargs*)
Bases: *fermipy.jobs.scatter_gather.ScatterGather*

**Small class to generate configurations for this script** This adds the following arguments:

**Parameters**

- **extracopy** (*<class 'list'>*) – Extra files to copy [[]]
- **sim** (*<class 'str'>*) – Name of the simulation scenario. [None]
- **targetlist** (*<class 'str'>*) – Path to the target list. [None]
- **roi_baseline** (*<class 'str'>*) – Key for roi baseline file. [fit_baseline]
- **ttype** (*<class 'str'>*) – Type of target being analyzed. [None]

**appname = 'fermipy-copy-base-roi-sg'**

**build_job_configs**(*args*)
Hook to build job configurations

**clientclass**
alias of *CopyBaseROI*

**default_options = {'extracopy': ([], 'Extra files to copy', <class 'list'>), 'roi_bas**

**description = 'Run analyses on a series of ROIs'**

**job_time = 60**

**usage = 'fermipy-copy-base-roi-sg [options]'**

**class** fermipy.jobs.target_sim.**RandomDirGen_SG**(*link*, ***kwargs*)
Bases: *fermipy.jobs.scatter_gather.ScatterGather*

**Small class to generate configurations for this script** This adds the following arguments:

**Parameters**

- **sim** (*<class 'str'>*) – Name of the simulation scenario. [None]
- **config** (*<class 'str'>*) – Path to fermipy config file. [None]
- **targetlist** (*<class 'str'>*) – Path to the target list. [None]
- **rand_config** (*<class 'str'>*) – Path to config file for genaration random sky dirs [None]
- **ttype** (*<class 'str'>*) – Type of target being analyzed. [None]

**appname = 'fermipy-random-dir-gen-sg'**

**build_job_configs**(*args*)
Hook to build job configurations

**clientclass**
alias of *RandomDirGen*

**default_options = {'config': (None, 'Path to fermipy config file.', <class 'str'>), '**

**description = 'Run analyses on a series of ROIs'**

**job_time = 60**

**usage = 'fermipy-random-dir-gen-sg [options]'**

**class** fermipy.jobs.target_sim.**SimulateROI_SG**(*link*, ***kwargs*)
Bases: *fermipy.jobs.scatter_gather.ScatterGather*

**Small class to generate configurations for this script** This adds the following arguments:

**Parameters**

- **do_find_src** (*<class 'bool'>*) – Add source finding step to simulated realizations [False]
- **sim_profile** (*<class 'str'>*) – Name of the profile to use for simulation. [default]
- **roi_baseline** (*<class 'str'>*) – Key for roi baseline file. [fit_baseline]
- **config** (*<class 'str'>*) – Path to fermipy config file. [None]
- **nsims** (*<class 'int'>*) – Number of simulations to run. [20]
- **ttype** (*<class 'str'>*) – Type of target being analyzed. [None]
- **sim** (*<class 'str'>*) – Name of the simulation scenario. [None]
- **nsims_job** (*<class 'int'>*) – Number of simulations to run per job. [0]
- **non_null_src** (*<class 'bool'>*) – Zero out test source [False]
- **seed** (*<class 'int'>*) – Seed number for first simulation. [0]
- **targetlist** (*<class 'str'>*) – Path to the target list. [None]

**appname = 'fermipy-simulate-roi-sg'**

**build_job_configs**(*args*)
Hook to build job configurations

**clientclass**
alias of *SimulateROI*

**default_options = {'config': (None, 'Path to fermipy config file.', <class 'str'>), '**

**description = 'Run analyses on a series of ROIs'**

**job_time = 1500**

**usage = 'fermipy-simulate-roi-sg [options]'**

**class** fermipy.jobs.target_plotting.**PlotCastro_SG**(*link*, ***kwargs*)
Bases: *fermipy.jobs.scatter_gather.ScatterGather*

Small class to generate configurations for the *PlotCastro* class.

This loops over all the targets defined in the target list.

**Parameters**

- **targetlist** (*<class 'str'>*) – Path to the target list. [None]
- **ttype** (*<class 'str'>*) – Type of target being analyzed. [None]

**appname = 'fermipy-plot-castro-sg'**

**build_job_configs**(*args*)
Hook to build job configurations

**clientclass**
alias of *PlotCastro*

**default_options = {'targetlist': (None, 'Path to the target list.', <class 'str'>), '**

**description = 'Make castro plots for set of targets'**

**job_time = 60**

**usage = 'fermipy-plot-castro-sg [options]'**

### Batch and System Interfaces

Abstract interface for interactions with system for launching jobs.

**class** fermipy.jobs.sys_interface.**SysInterface**(***kwargs*)
Bases: object

Base class to handle job dispatching interface

**classmethod check_job**(*job_details*)
Check the status of a specfic job

**clean_jobs**(*link*, *job_dict=None*, *clean_all=False*)
Clean up all the jobs associated with this link.

Returns a JobStatus enum

**dispatch_job**(*link*, *key*, *job_archive*, *stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*)
Function to dispatch a single job

**Parameters**

- **link** (Link) – Link object that sendes the job
- **key** (*str*) – Key used to identify this particular job
- **job_archive** (JobArchive) – Archive used to keep track of jobs

- **JobDetails object** (*Returns*) –

**dispatch_job_hook**(*link*, *key*, *job_config*, *logfile*, *stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*)
Hook to dispatch a single job

**string_exited = 'Exited with exit code'**

**string_successful = 'Successfully completed'**
C'tor

**submit_jobs**(*link*, *job_dict=None*, *job_archive=None*, *stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*)
Run the `Link` with all of the items job_dict as input.

If job_dict is None, the job_dict will be take from link.jobs

Returns a `JobStatus` enum

fermipy.jobs.sys_interface.**check_log**(*logfile*, *exited='Exited with exit code'*, *successful='Successfully completed'*)
Check a log file to determine status of LSF job

Often logfile doesn't exist because the job hasn't begun to run. It is unclear what you want to do in that case...

**Parameters**

- **logfile** (*str*) – String with path to logfile
- **exited** (*str*) – Value to check for in existing logfile for exit with failure
- **successful** (*str*) – Value to check for in existing logfile for success
- **str, one of 'Pending', 'Running', 'Done', 'Failed'** (*Returns*) –

fermipy.jobs.sys_interface.**clean_job**(*logfile*, *outfiles*, *dry_run=False*)
Removes log file and files created by failed jobs.

If dry_run is True, print name of files to be removed, but do not remove them.

fermipy.jobs.sys_interface.**remove_file**(*filepath*, *dry_run=False*)
Remove the file at filepath

Catches exception if the file does not exist.

If dry_run is True, print name of file to be removed, but do not remove it.

Implementation of `ScatterGather` class for dealing with LSF batch jobs

**class** fermipy.jobs.native_impl.**NativeInterface**(***kwargs*)
Bases: *fermipy.jobs.sys_interface.SysInterface*

Implmentation of ScatterGather that uses the native system

**dispatch_job_hook**(*link*, *key*, *job_config*, *logfile*, *stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*)
Send a single job to be executed

**Parameters**

- **link** (`fermipy.jobs.chain.Link`) – The link used to invoke the command we are running
- **key** (*str*) – A string that identifies this particular instance of the job
- **job_config** (*dict*) – A dictionrary with the arguments for the job. Used with the self._command_template job template

- **logfile** (*str*) – The logfile for this job, may be used to check for success/ failure

**string_exited = 'Exited with exit code'**

**string_successful = 'Successfully completed'**

**submit_jobs**(*link*, *job_dict=None*, *job_archive=None*, *stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*)
Submit all the jobs in job_dict

fermipy.jobs.native_impl.**get_native_default_args**()
Get the correct set of batch jobs arguments.

Implementation of ScatterGather interface class for dealing with LSF batch jobs at SLAC

**class** fermipy.jobs.slac_impl.**SlacInterface**(***kwargs*)
Bases: *fermipy.jobs.sys_interface.SysInterface*

Implmentation of ScatterGather that uses LSF

**dispatch_job_hook**(*link*, *key*, *job_config*, *logfile*, *stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*)
Send a single job to the LSF batch

**Parameters**

- **link** (fermipy.jobs.chain.Link) – The link used to invoke the command we are running
- **key** (*str*) – A string that identifies this particular instance of the job
- **job_config** (*dict*) – A dictionrary with the arguments for the job. Used with the self._command_template job template
- **logfile** (*str*) – The logfile for this job, may be used to check for success/ failure

**string_exited = 'Exited with exit code'**

**string_successful = 'Successfully completed'**

**submit_jobs**(*link*, *job_dict=None*, *job_archive=None*, *stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*)
Submit all the jobs in job_dict

fermipy.jobs.slac_impl.**build_bsub_command**(*command_template*, *lsf_args*)
Build and return a lsf batch command template

**The structure will be 'bsub -s <key> <value> <command_template>'** where <key> and <value> refer to items in lsf_args

fermipy.jobs.slac_impl.**get_lsf_status**()
Count and print the number of jobs in various LSF states

fermipy.jobs.slac_impl.**get_slac_default_args**(*job_time=1500*)
Create a batch job interface object.

**Parameters** **job_time** (*int*) – Expected max length of the job, in seconds. This is used to select the batch queue and set the job_check_sleep parameter that sets how often we check for job completion.

fermipy.jobs.slac_impl.**make_gpfs_path**(*path*)
Make a gpfs version of a file path. This just puts /gpfs at the beginning instead of /nfs

fermipy.jobs.slac_impl.**make_nfs_path**(*path*)
Make a nfs version of a file path. This just puts /nfs at the beginning instead of /gpfs

Factory module to return the default interace to the batch farm

fermipy.jobs.batch.**get_batch_job_args**(*job_time=1500*)
Get the correct set of batch jobs arguments.

**Parameters** **job_time** (*int*) – Expected max length of the job, in seconds. This is used to select the batch queue and set the job_check_sleep parameter that sets how often we check for job completion.

**Returns** **job_args** – Dictionary of arguments used to submit a batch job

**Return type** dict

fermipy.jobs.batch.**get_batch_job_interface**(*job_time=1500*)
Create a batch job interface object.

**Parameters** **job_time** (*int*) – Expected max length of the job, in seconds. This is used to select the batch queue and set the job_check_sleep parameter that sets how often we check for job completion.

**Returns** **job_interfact** – Object that manages interactions with batch farm

**Return type** SysInterface

### File Archive module

Classes and utilites to keep track of files associated to an analysis.

The main class is *FileArchive*, which keep track of all the files associated to an analysis.

The *FileHandle* helper class encapsulates information on a particular file.

**class** fermipy.jobs.file_archive.**FileArchive**(***kwargs*)
Bases: object

Class that keeps track of the status of files used in an analysis

**Parameters**

- **table_file** (*str*) – Path to the file used to persist this *FileArchive*
- **table** (astropy.table.Table) – Persistent representation of this *FileArchive*
- **cache** (OrderedDict) – Transient representation of this *FileArchive*
- **base_path** (*str*) – Base file path for all files in this *FileArchive*

**base_path**
Return the base file path for all files in this *FileArchive*

**classmethod build_archive**(***kwargs*)
Return the singleton *FileArchive* instance, building it if needed

**cache**
Return the transiet representation of this *FileArchive*

**classmethod get_archive**()
Return the singleton *FileArchive* instance

**get_file_ids**(*file_list*, *creator=None*, *status=0*, *file_dict=None*)
Get or create a list of file ids based on file names

**Parameters**

- **file_list** (*list*) – The paths to the file

- **creatror** (*int*) – A unique key for the job that created these files
- **status** (*FileStatus*) – Enumeration giving current status of files
- **file_dict** (*FileDict*) – Mask giving flags set on this file
- **list of integers** (*Returns*) –

**get_file_paths**(*id_list*)
Get a list of file paths based of a set of ids

**Parameters**

- **id_list** (*list*) – List of integer file keys
- **list of file paths** (*Returns*) –

**get_handle**(*filepath*)
Get the *FileHandle* object associated to a particular file

**register_file**(*filepath*, *creator*, *status=0*, *flags=0*)
Register a file in the archive.

If the file already exists, this raises a KeyError

**Parameters**

- **filepath** (*str*) – The path to the file
- **creatror** (*int*) – A unique key for the job that created this file
- **status** (*FileStatus*) – Enumeration giving current status of file
- **flags** (*FileFlags*) – Enumeration giving flags set on this file
- **FileHandle** (*Returns*) –

**table**
Return the persistent representation of this *FileArchive*

**table_file**
Return the path to the file used to persist this *FileArchive*

**update_file**(*filepath*, *creator*, *status*)
Update a file in the archive

If the file does not exists, this raises a KeyError

**Parameters**

- **filepath** (*str*) – The path to the file
- **creatror** (*int*) – A unique key for the job that created this file
- **status** (*FileStatus*) – Enumeration giving current status of file
- **FileHandle** (*Returns*) –

**update_file_status**()
Update the status of all the files in the archive

**write_table_file**(*table_file=None*)
Write the table to self._table_file

**class** fermipy.jobs.file_archive.**FileDict**(***kwargs*)
Bases: object

Small class to keep track of files used & createed by a link.

**Parameters**

- **file_args** (*dict*) – Dictionary mapping argument to *FileFlags* enum
- **file_dict** (*dict*) – Dictionary mapping file path to *FileFlags* enum

**chain_input_files**
Return a list of the input files needed by this chain.

For Link sub-classes this will return only those files that were not created by any internal Link

**chain_output_files**
Return a list of the all the output files produced by this link.

For Link sub-classes this will return only those files that were not marked as internal files or marked for removal.

**gzip_files**
Return a list of the files compressed by this link.

This returns all files that were explicitly marked for compression.

**input_files**
Return a list of the input files needed by this link.

For Link sub-classes this will return the union of all the input files of each internal Link.

That is to say this will include files produced by one Link in a Chain and used as input to another Link in the Chain

**input_files_to_stage**
Return a list of the input files needed by this link.

For Link sub-classes this will return the union of all the input files of each internal Link.

That is to say this will include files produced by one Link in a Chain and used as input to another Link in the Chain

**internal_files**
Return a list of the intermediate files produced by this link.

This returns all files that were explicitly marked as internal files.

**items**()
Return iterator over self.file_dict

**latch_file_info**(*args*)
Extract the file paths from a set of arguments

**output_files**
Return a list of the output files produced by this link.

For Link sub-classes this will return the union of all the output files of each internal Link.

That is to say this will include files produced by one Link in a Chain and used as input to another Link in the Chain

**output_files_to_stage**
Return a list of the input files needed by this link.

For Link sub-classes this will return the union of all the input files of each internal Link.

That is to say this will include files produced by one Link in a Chain and used as input to another Link in the Chain

**print_chain_summary**(*stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*, *indent=''*)
Print a summary of the files in this file dict.

This version uses chain_input_files and chain_output_files to count the input and output files.

**print_summary**(*stream=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*, *indent=''*)
Print a summary of the files in this file dict.

This version explictly counts the union of all input and output files.

**temp_files**
Return a list of the temporary files produced by this link.

This returns all files that were explicitly marked for removal.

**update**(*file_dict*)
Update self with values from a dictionary mapping file path [str] to *FileFlags* enum

**class** fermipy.jobs.file_archive.**FileFlags**
Bases: object

Bit masks to indicate file types

**gz_mask = 8**

**in_ch_mask = 23**

**in_stage_mask = 33**

**input_mask = 1**

**internal_mask = 16**

**no_flags = 0**

**out_ch_mask = 22**

**out_stage_mask = 34**

**output_mask = 2**

**rm_mask = 4**

**rmint_mask = 20**

**stageable = 32**

**class** fermipy.jobs.file_archive.**FileHandle**(***kwargs*)
Bases: object

Class to keep track of infomration about a file file.

**Parameters**

- **key** (*int*) – Unique id for this particular file
- **creator** (*int*) – Unique id for the job that created this file
- **timestamp** (*int*) – File creation time cast as an int
- **status** (*FileStatus*) – Enum giving current status of file
- **flags** (*FileFlags*) – Mask giving flags set on this file
- **path** (*str*) – Path to file

**append_to_table**(*table*)
Add this instance as a row on a astropy.table.Table

**check_status**(*basepath=None*)
Check on the status of this particular file

**classmethod create_from_row**(*table_row*)
Build and return a *FileHandle* from an astropy.table.row.Row

**classmethod make_dict**(*table*)
Build and return a dict of *FileHandle* from an astropy.table.Table

The dictionary is keyed by FileHandle.key, which is a unique integer for each file

**static make_table**(*file_dict*)
Build and return an astropy.table.Table to store *FileHandle*

**update_table_row**(*table*, *row_idx*)
Update the values in an astropy.table.Table for this instances

**class** fermipy.jobs.file_archive.**FileStageManager**(*scratchdir*, *workdir*)
Bases: object

Small class to deal with staging files to and from a scratch area

**construct_scratch_path**(*dirname*, *basename*)
Construct and return a path in the scratch area.

This will be <self.scratchdir>/<dirname>/<basename>

**static copy_from_scratch**(*file_mapping*, *dry_run=True*)
Copy output files from scratch area

**static copy_to_scratch**(*file_mapping*, *dry_run=True*)
Copy input files to scratch area

**get_scratch_path**(*local_file*)
Construct and return a path in the scratch area from a local file.

**static make_scratch_dirs**(*file_mapping*, *dry_run=True*)
Make any directories need in the scratch area

**map_files**(*local_files*)
Build a dictionary mapping local paths to scratch paths.

**Parameters**

- **local_files** (*list*) – List of filenames to be mapped to scratch area
- **dict** (*Returns*) – Mapping local_file : fullpath of scratch file

**split_local_path**(*local_file*)
Split the local path into a directory name and a file name

If local_file is in self.workdir or a subdirectory of it, the directory will consist of the relative path from workdir.

If local_file is not in self.workdir, directory will be empty.

Returns (dirname, basename)

**class** fermipy.jobs.file_archive.**FileStatus**
Bases: object

Enumeration of file status types

**exists = 2**

**expected = 1**

**missing = 3**

**no_file = 0**

**superseded = 4**

**temp_removed = 5**

fermipy.jobs.file_archive.**get_timestamp**()
Get the current time as an integer

fermipy.jobs.file_archive.**get_unique_match**(*table*, *colname*, *value*)
Get the row matching value for a particular column. If exactly one row matchs, return index of that row, Otherwise raise KeyError.

fermipy.jobs.file_archive.**main_browse**()
Entry point for command line use for browsing a FileArchive

### Job Archive module

Classes and utilites to keep track the various jobs that are running in an analysis pipeline.

The main class is *JobArchive*, which keep track of all the jobs associated to an analysis.

The *JobDetails* helper class encapsulates information on a instance of running a job.

**class** fermipy.jobs.job_archive.**JobArchive**(***kwargs*)
Bases: object

Class that keeps of all the jobs associated to an analysis.

**Parameters**

- **table_file** (*str*) – Path to the file used to persist this *JobArchive*
- **table** (astropy.table.Table) – Persistent representation of this *JobArchive*
- **table_ids** (astropy.table.Table) – Ancillary table with information about file ids
- **file_archive** (FileArchive) – Archive with infomation about all this files used and produced by this analysis

**classmethod build_archive**(***kwargs*)
Return the singleton *JobArchive* instance, building it if needed

**classmethod build_temp_job_archive**()
Build and return a *JobArchive* using defualt locations of persistent files.

**cache**
Return the transiet representation of this *JobArchive*

**file_archive**
Return the FileArchive with infomation about all the files used and produced by this analysis

**classmethod get_archive**()
Return the singleton *JobArchive* instance

**get_details**(*jobname*, *jobkey*)
Get the *JobDetails* associated to a particular job instance

**make_job_details**(*row_idx*)
Create a *JobDetails* from an astropy.table.row.Row

**register_job**(*job_details*)
Register a job in this *JobArchive*

**register_job_from_link**(*link*, *key*, ***kwargs*)
Register a job in the *JobArchive* from a Link object

**register_jobs**(*job_dict*)
Register a bunch of jobs in this archive

**remove_jobs**(*mask*)
Mark all jobs that match a mask as 'removed'

**table**
Return the persistent representation of this *JobArchive*

**table_file**
Return the path to the file used to persist this *JobArchive*

**table_ids**
Return the rpersistent epresentation of the ancillary info of this *JobArchive*

**update_job**(*job_details*)
Update a job in the *JobArchive*

**update_job_status**(*checker_func*)
Update the status of all the jobs in the archive

**write_table_file**(*job_table_file=None*, *file_table_file=None*)
Write the table to self._table_file

**class** fermipy.jobs.job_archive.**JobDetails**(***kwargs*)
Bases: object

A simple structure to keep track of the details of each of the sub-proccess jobs.

**Parameters**

- **dbkey** (*int*) – A unique key to identify this job
- **jobname** (*str*) – A name used to idenfity this job
- **jobkey** (*str*) – A string to identify this instance of the job
- **appname** (*str*) – The executable inovked to run the job
- **logfile** (*str*) – The logfile for this job, may be used to check for success/ failure
- **job_config** (*dict*) – A dictionrary with the arguments for the job
- **parent_id** (*int*) – Unique key identifying the parent job
- **infile_ids** (*list of int*) – Keys to identify input files to this job
- **outfile_ids** (*list of int*) – Keys to identify output files from this job
- **rmfile_ids** (*list of int*) – Keys to identify temporary files removed by this job
- **intfile_ids** (*list of int*) – Keys to identify internal files
- **status** (*int*) – Current job status, one of the enums above

**append_to_tables**(*table*, *table_ids*)
Add this instance as a row on a astropy.table.Table

**check_status_logfile**(*checker_func*)
Check on the status of this particular job using the logfile

**classmethod create_from_row**(*table_row*)
Create a *JobDetails* from an astropy.table.row.Row

**fullkey**
Return the fullkey for this job fullkey = <jobkey>@<jobname>

**get_file_ids**(*file_archive*, *creator=None*, *status=0*)
Fill the file id arrays from the file lists

**Parameters**

- **file_archive** (FileArchive) – Used to look up file ids
- **creator** (*int*) – A unique key for the job that created these file
- **status** (FileStatus) – Enumeration giving current status thse files

**get_file_paths**(*file_archive*, *file_id_array*)
Get the full paths of the files used by this object from the the id arrays

**Parameters**

- **file_archive** (FileArchive) – Used to look up file ids
- **file_id_array** (numpy.array) – Array that remaps the file indexes

**classmethod make_dict**(*table*)
Build a dictionary map int to *JobDetails* from an astropy.table.Table

**static make_fullkey**(*jobname*, *jobkey='__top__'*)
Combine jobname and jobkey to make a unique key fullkey = <jobkey>@<jobname>

**static make_tables**(*job_dict*)
Build and return an astropy.table.Table' to store `JobDetails

**static split_fullkey**(*fullkey*)
Split fullkey to make extract jobname, jobkey fullkey = <jobkey>@<jobname>

**topkey = '__top__'**

**update_table_row**(*table*, *row_idx*)
Add this instance as a row on a astropy.table.Table

**class** fermipy.jobs.job_archive.**JobStatus**
Bases: object

Enumeration of job status types

**done = 5**

**failed = 6**

**no_job = -1**

**not_ready = 1**

**partial_failed = 7**

**pending = 3**

**ready = 2**

**removed = 8**

**running = 4**

**unknown = 0**

**class** fermipy.jobs.job_archive.**JobStatusVector**
Bases: object

Vector that counts the status of jobs and returns an overall status flag based on those

**get_status**()
Return an overall status based on the number of jobs in various states.

**n_done**
Return the number of successfully completed jobs

**n_failed**
Return the number of failed jobs

**n_pending**
Return the number jobs submitted to batch, but not yet running

**n_running**
Return the number of running jobs

**n_total**
Return the total number of jobs

**n_waiting**
Return the number of jobs in various waiting states

**reset**()
Reset the counters

fermipy.jobs.job_archive.**main_browse**()
Entry point for command line use for browsing a JobArchive

### 1.3.12 fermipy.diffuse subpackage

The fermipy.diffuse sub-package is a collection of standalone utilities that allow the user to parallelize the data and template preparation for all-sky analysis.

The tools described here perform a number of functions:

- Making binned counts maps and expousre maps over the whole sky.
- Managing model components for all-sky analysis; including both diffuse emission and point source contributions. This includes make spatial-spectral templates and expected counts maps for various components.
- Building intergrated models for a collection of model components.
- Fitting those models.

#### Overview

This package implements an analysis pipeline prepare data and templates for analysis. This involves a lot of bookkeeping and loops over various things.It is probably easiest to first describe this with a bit of pseudo-code that represents the various analysis steps.

The various loop variables are:

- Input data files

  For practical reasons, the input photon event files (FT1) files are split into monthly files. In the binning step of the analysis we loop over those files.

- binning components

  We split the data into several "binning components" and make seperate binned counts maps for each components. A binning component is defined by energy range and data sub-selection (such as PSF event type and zenith angle cuts).

- Diffuse model components

  The set of all the model components that represent diffuse emission, such as contributions for cosmic ray interactions with

- Catalog model components

  The set of all the catalog sources (both point sources and extended source), merged into a few distinct contributions.

- Diffuse emission model definitions

  A set of user defined models that merge the various model components with specific spectral models.

```
 # Data Binning, prepare the analysis directories and precompute the DM spectra

 # First we loop over all the input input files and split up the
 # data by binning component and bin the data using the command
 # fermipy-split-and-bin-sg, which is equivalent to:
 for file in input_data_files:
     fermipy-split-and-bin(file)

 # Then we loop over the binning components and coadd the binned
 # data from all the input files using the command
 # fermipy-coadd-split-sf, which is equivalent to:
 for comp in binning_components:
     fermipy-coadd-split(comp)

 # We also loop over the binning components and compute the
 # exposure maps for each binning component using the command
 # fermipy-gtexpcube2-sg, which is equivalent to:
 for comp in binned_components:
     gtexpcube2(comp)

 # We loop over the diffuse components that come from GALProp
 # templates and refactor them using the command
 # fermipy-sum-ring-gasmaps-sg, which is equivalent to
 for galprop_comp in diffuse_galprop_components:
    fermipy-coadd(galprop_comp)

# We do a triple loop over all of the diffuse components, all the
# binning components and all the energy bins and convolve the
# emission template with the instrument response using the command
# fermipy-srcmaps-diffuse-sg, which is equivalent to
for diffuse_comp in diffuse_components:
    for binning_comp in binned_components:
        for energy in energy_bins:
             fermipy-srcmap-diffuse(diffuse_comp, binning_comp, energy)

# We then do a double loop over all the diffuse components and all
# the binning components and stack the template maps into single
# files using the command
# fermipy-vstack-diffuse-sg, which is equivalent to
for diffuse_comp in diffuse_components:
```

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```
    for binning_comp in binned_components:
        fermipy-vstack-diffuse(diffuse_comp, binning_comp)

# We then do a double loop over source catalogs and binning
# components and compute the templates for each source using the
# command
# fermipy-srcmaps-catalog-sg, which is equivalent to
for catalog in catalogs:
    for binning_comp in binned_components:
        fermipy-srcmaps-catalog(catalog, binning_comp)

# We then loop over the catalog components (essentially
# sub-sets of catalog sources that we want to merge)
# and merge those sources into templates using the command
# fermipy-merge-srcmaps-sg, which is equivalent to
for catalog_comp in catalog_components:
    for binning_comp in binned_components:
        fermipy-merge-srcmaps(catalog_comp, binning_comp)

# At this point we have a library to template maps for all the
# emision components that we have defined.
# Now we want to define specific models.  We do this
# using the commands
# fermipy-init-model and fermipy-assemble-model-sg, which is equivalent to
for model in models:
    fermipy-assemble-model(model)

# At this point we, for each model under consideration we have an
# analysis directory that is set up for fermipy
```

### Configuration

This section describes the configuration management scheme used within the fermipy.diffuse package and documents the configuration parameters that can be set in the configuration file.

Analysis classes in the dmpipe package all inherit from the `fermipy.jobs.Link` class, which allow user to invoke the class either interactively within python or from the unix command line.

From the command line

```
$ fermipy-srcmaps-diffuse-sg --comp config/binning.yaml --data config/dataset_source.
↪yaml --library models/library.yaml
```

From python there are a number of ways to do it, we recommend this:

```
from fermipy.diffuse.gt_srcmap_partial import SrcmapsDiffuse_SG
link = SrcmapsDiffuse_SG( )
link.update_args(dict(comp='config/binning.yaml', data='config/dataset_source.yaml',
↪library='models/library.yaml'))
link.run()
```

### Top Level Configuration

We use a yaml file to define the top-level analysis parameters.

Listing 9: Sample *top level* Configuration

```
# The binning components
comp : config/binning.yaml
# The dataset
data : config/dataset_source.yaml
# Library with the fitting components
library : models/library.yaml
# Yaml file with the list of models to prepare
models : models/modellist.yaml
# Input FT1 file
ft1file : P8_P305_8years_source_zmax105.lst
# HEALPix order for counts cubes
hpx_order_ccube : 9
# HEALPix order for exposure cubes
hpx_order_expcube : 6
# HEALPix order fitting models
hpx_order_fitting : 7
# Build the XML files for the diffuse emission model components
make_diffuse_comp_xml : True
# Build the XML files for the catalog source model components
make_catalog_comp_xml : True
# Name of the directory for the merged GALProp gasmaps
merged_gasmap_dir : merged_gasmap
# Number of catalog sources per batch job
catalog_nsrc : 500
```

### Binning Configuration

We use a yaml file to define the binning components.

Listing 10: Sample *binning* Configuration

```
coordsys : 'GAL'
E0:
    log_emin : 1.5
    log_emax : 2.0
    enumbins : 2
    zmax : 80.
    psf_types :
        PSF3 :
            hpx_order : 5
E1:
    log_emin : 2.0
    log_emax : 2.5
    enumbins : 2
    zmax : 90.
    psf_types :
        PSF23 :
            hpx_order : 6
E2:
    log_emin : 2.5
    log_emax : 3.0
    enumbins : 3
    zmax : 100.
    psf_types :
```

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```
        PSF123 :
            hpx_order : 8
E3:
    log_emin : 3.0
    log_emax : 6.0
    enumbins : 9
    zmax : 105.
    psf_types :
        PSF0123 :
           hpx_order : 9
```

- **coordsys** ['GAL' or 'CEL'] Coordinate system to use
- **log_emin, log_emax: float** Energy bin boundries in log10(MeV)
- **enumbins: int** Number of energy bins for this binning component
- **zmax** [float] Maximum zenith angle (in degrees) for this binning component
- **psf_types: dict** Sub-dictionary of binning components by PSF event type, PSF3 means PSF event type 3 events only. PSF0123 means all four PSF event types.
- **hpx_order: int** HEALPix order to use for binning. The more familiar nside parameter is nside = 2**order

### Dataset Configuration

We use a yaml file to define the data set we are using. The example below specifies using a pre-defined 8 year dataset, selecting the "SOURCE" event class and using the V2 version of the corresponding IRFs (specifically P8R3_SOURCE_V2).

Listing 11: Sample *dataset* Configuration

```
basedir : '/gpfs/slac/kipac/fs1/u/dmcat/data/flight/diffuse_dev'
data_pass : 'P8'
data_ver : 'P305'
evclass : 'source'
data_time : '8years'
irf_ver : 'V2'
```

The basedir parameter should point at the analysis directory. For the most part the other parameter are using to make the names of the various files produced by the pipeline. The evclass parameter defines the event selection, and the IRF version is defined by a combination of the data_ver, evclass and irf_ver parameters.

### GALProp Rings Configuration

We use a yaml file to define the how we combine GALProp emission templates. The example below specifies how to construct as series of 'merged_CO' rings by combining GALProp intensity template predictions.

Listing 12: Sample *GALProp rings* Configuration

```
galprop_run : 56_LRYusifovXCO5z6R30_QRPD_150_rc_Rs8
ring_limits : [1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13, 15]
diffuse_comp_dict :
    merged_CO : ['pi0_decay_H2R', 'bremss_H2R']
remove_rings : ['merged_CO_7']
```

- **galprop_run** [string] Define the GALProp run to use for this component. This is used to make the filenames for input template maps.
- **ring_limits** [list of int] This specfies how to combine the GALProp rings into a smaller set of rings.
- **diffuse_comp_dict** [dict] This specifies how to make GALProp components into merged components for the diffuse analysis
- **remove_rings: list of str** This allow use to remove certain rings from the model

### Catalog Component Configuration

We use a yaml file to define the how we split up the catalog source components. The example below specifies using the FL8Y source list, and to split out the faint sources (i.e., those with the Signif_Avg value less that 100.), and the extended source, and to keep all the remaining sources (i.e., the bright, pointlike, sources) as individual sources.

Listing 13: Sample *catalog component* Configuration

```
catalog_name : FL8Y
catalog_file : /nfs/slac/kipac/fs1/u/dmcat/ancil/catalogs/official/4FGLp/gll_psc_
↪8year_v4.fit
catalog_extdir : /nfs/slac/kipac/fs1/u/dmcat/ancil/catalogs/official/extended/
↪Extended_archive_v18
catalog_type : FL8Y
rules_dict :
    faint :
        cuts :
            - { cut_var: Signif_Avg, max_val : 100. }
            - mask_extended
    extended :
        cuts :
            - select_extended
    remainder :
        merge : False
```

### Model Component Library

We use a yaml file to define a "library" of model components. The comprises a set of named emission components, and a set one or more versions for each named component. Here is an example library defintion file.

Listing 14: Sample *Model Component Library* Configuration

```
# Catalog Components
FL8Y :
    model_type : catalog
    versions : [v00]
# Diffuse Components
galprop_rings :
    model_type : galprop_rings
    versions : [p8-ref_IC_thin, p8-ref_HI_150, p8-ref_CO_300_mom, p8-ref_dnm_300hp]
dnm_merged:
    model_type : MapCubeSource
   versions : ['like_4y_300K']
gll-iem :
    model_type : MapCubeSource
    versions : [v06]
```

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```
loopI :
    model_type : MapCubeSource
    versions : [haslam]
bubbles :
    model_type : MapCubeSource
    versions : [v00, v01]
iso_map :
    model_type : MapCubeSource
    versions : [P8R3_SOURCE_V2]
patches :
    model_type : MapCubeSource
    versions : [v09]
    selection_dependent : True
    no_psf : True
    edisp_disable : True
unresolved :
    model_type : MapCubeSource
    versions : [strong]
sun-ic :
    model_type : MapCubeSource
    versions : [v2r0, P8R3-v2r0]
    moving : True
    edisp_disable : True
sun-disk :
    model_type : MapCubeSource
    versions : [v3r1, P8R3-v3r1]
    moving : True
    edisp_disable : True
moon :
    model_type : MapCubeSource
    versions : [v3r2, P8R3-v3r2]
    moving : True
    edisp_disable : True
```

- **model_type: 'MapCubeSource' or 'catalog' or 'galprop_rings' or 'SpatialMap'** Specifies how this model should be constructed. See more below in the versions parameters.
- **versions: list of str** Specifies different versions of this model component. How this string is used depend on the model type. for 'MapCubeSource' and 'SpatialMap' sources it is used to construct the expected filename for the intensity template. For 'catalog' and 'galprop_rings' it is used to construct the filename for the yaml file that defines the sub-components for that component.
- moving: bool If true, then will use source-specific livetime cubes to constuct source templates for each zenith angle cut.
- selection_dependent : bool If true, then will used different source templates for each binning component.
- no_psf : bool Turns of PSF convolution for this source. Useful for data-driven components.
- edisp_disable : bool Turns off energy dispersion for the source. Useful for data-driven components.

### Spectral Model Configuration

We use a yaml file to define the spectral models and default parameters. This file is simply a dictionary mapping names to sub-dictionaries defining spectral models and default model parameters.

### Model Defintion

We use a yaml file to define each overall model, which combine library components and spectral models.

Listing 15: Sample *Model Definition* Configuration

```
library : models/library.yaml
spectral_models : models/spectral_models.yaml
sources :
    galprop_rings_p8-ref_IC_thin :
        model_type : galprop_rings
        version : p8-ref_IC_150
        SpectrumType :
            default : Constant_Correction
    galprop_rings-p8-ref_HI_300:
        model_type : galprop_rings
        version : p8-ref_HI_300
        SpectrumType :
            default : Powerlaw_Correction
            merged_HI_2_p8-ref_HI_300 : BinByBin_5
            merged_HI_3_p8-ref_HI_300 : BinByBin_5
            merged_HI_4_p8-ref_HI_300 : BinByBin_9
            merged_HI_5_p8-ref_HI_300 : BinByBin_9
            merged_HI_6_p8-ref_HI_300 : BinByBin_9
            merged_HI_8_p8-ref_HI_300 : BinByBin_5
            merged_HI_9_p8-ref_HI_300 : BinByBin_5
    galprop_rings-p8-ref_CO_300:
        model_type : galprop_rings
        version : p8-ref_CO_300_mom
        SpectrumType :
            default : Powerlaw_Correction
            merged_CO_2_p8-ref_CO_300_mom : BinByBin_5
            merged_CO_3_p8-ref_CO_300_mom : BinByBin_5
            merged_CO_4_p8-ref_CO_300_mom : BinByBin_9
            merged_CO_5_p8-ref_CO_300_mom : BinByBin_9
            merged_CO_6_p8-ref_CO_300_mom : BinByBin_9
            merged_CO_8_p8-ref_CO_300_mom : BinByBin_5
            merged_CO_9_p8-ref_CO_300_mom : BinByBin_5
    dnm_merged :
        version : like_4y_300K
        SpectrumType : BinByBin_5
    iso_map :
        version : P8R3_SOURCE_V2
        SpectrumType : Iso
    sun-disk :
        version : v3r1
        SpectrumType : Constant_Correction
        edisp_disable : True
    sun-ic :
        version : v2r0
        SpectrumType : Constant_Correction
        edisp_disable : True
    moon :
        version : v3r2
        SpectrumType : Constant_Correction
        edisp_disable : True
    patches :
        version : v09
```

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```
        SpectrumType : Patches
        edisp_disable : True
    unresolved :
        version : strong
        SpectrumType : Constant_Correction
    FL8Y :
        model_type : Catalog
        version : v00
        SpectrumType :
            default : Constant_Correction
            FL8Y_v00_remain : Catalog
            FL8Y_v00_faint : BinByBin_9
```

- **model_type: 'MapCubeSource' or 'catalog' or 'galprop_rings' or 'SpatialMap'** Specifies how this model should be constructed. See more below.
- **version: str** Specifies version of this model component.
- edisp_disable : bool Turns off energy dispersion for the source. Useful for data-driven components. Needed for model XML file construction.
- SpectrumType: str or dictionary This specifies the Spectrum type to use for this model component. For 'catalog' and 'galprop_rings' model types it can be a dictionary mapping model sub-components to spectrum types. Note that the spectrum types should be defined in the spectral model configuration described above.

### Examples

### Module contents

### Configuration, binning, default options, etc...

Small helper class to represent the binning used for a single component of a summed likelihood in diffuse analysis

**class** fermipy.diffuse.binning.**Component**(***kwargs*)

Bases: object

Small helper class to represent the binning used for a single component of a summed likelihood in diffuse analysis

**Parameters**

- **log_emin** (*float*) – Log base 10 of minimum energy for this component
- **log_emax** (*float*) – Log base 10 of maximum energy for this component
- **enumbins** (*int*) – Number of energy bins for this component
- **zmax** (*float*) – Maximum zenith angle cube for this component in degrees
- **mktimefilters** (*list*) – Filters for gtmktime.
- **hpx_order** (*int*) – HEALPix order to use for this component
- **coordsys** (*str*) – Coodinate system, 'CEL' or 'GAL'

**classmethod build_from_energy_dict**(*ebin_name*, *input_dict*)

Build a list of components from a dictionary for a single energy range

**classmethod build_from_yamlfile**(*yamlfile*)

Build a list of components from a yaml file

**classmethod build_from_yamlstr**(*yamlstr*)
Build a list of components from a yaml string

**emax**
Maximum energy for this component

**emin**
Minimum energy for this component

**evtype**
Event type bit mask for this component

**make_key**(*format_str*)
Make a key to identify this compoment

format_str is formatted using object __dict__

Analysis framework for all-sky diffuse emission fitting

Handle the naming conventions for composite likelihood analysis

**class** fermipy.diffuse.name_policy.**NameFactory**(***kwargs*)
Bases: object

Helper class to define file names and keys consistently.

**angprofile**(***kwargs*)
return the file name for sun or moon angular profiles

**angprofile_format = 'templates/profile_{sourcekey}.fits'**

**bexpcube**(***kwargs*)
return the name of a binned exposure cube file

**bexpcube_format = 'bexp_cubes/bexcube_{dataset}_{mktime}_{component}_{coordsys}_{irf_v**

**bexpcube_moon**(***kwargs*)
return the name of a binned exposure cube file

**bexpcube_sun**(***kwargs*)
return the name of a binned exposure cube file

**bexpcubemoon_format = 'bexp_cubes/bexcube_{dataset}_{mktime}_{component}_{irf_ver}_moo**

**bexpcubesun_format = 'bexp_cubes/bexcube_{dataset}_{mktime}_{component}_{irf_ver}_sun.**

**catalog_split_yaml**(***kwargs*)
return the name of a catalog split yaml file

**catalog_split_yaml_format = 'models/catalog_{sourcekey}.yaml'**

**ccube**(***kwargs*)
return the name of a counts cube file

**ccube_format = 'counts_cubes/ccube_{dataset}_{mktime}_{component}_{coordsys}.fits'**

**comp_srcmdl_xml**(***kwargs*)
return the name of a source model file

**comp_srcmdl_xml_format = 'analysis/model_{modelkey}/srcmdl_{modelkey}_{component}.xml'**

**component**(***kwargs*)
Return a key that specifies data the sub-selection

**component_format = '{zcut}_{ebin}_{psftype}'**

**dataset**(***kwargs*)
Return a key that specifies the data selection

**dataset_format = '{data_pass}_{data_ver}_{data_time}_{evclass}'**

**diffuse_template**(***kwargs*)
return the file name for other diffuse map templates

**diffuse_template_format = 'templates/template_{sourcekey}.fits'**

**evclassmask**(*evclass_str*)
Get the bitmask for a particular event class

**ft1file**(***kwargs*)
return the name of the input ft1 file list

**ft1file_format = '{dataset}_{zcut}.lst'**

**ft2file**(***kwargs*)
return the name of the input ft2 file list

**ft2file_format = 'ft2_files/ft2_{data_time}.lst'**

**fullpath**(***kwargs*)
Return a full path name for a given file

**fullpath_format = '{basedir}/{localpath}'**

**galprop_gasmap**(***kwargs*)
return the file name for Galprop input gasmaps

**galprop_gasmap_format = 'gasmap/{sourcekey}_{projtype}_{galprop_run}.gz'**

**galprop_ringkey**(***kwargs*)
return the sourcekey for galprop input maps : specifies the component and ring

**galprop_ringkey_format = '{source_name}_{ringkey}'**

**galprop_rings_yaml**(***kwargs*)
return the name of a galprop rings merging yaml file

**galprop_rings_yaml_format = 'models/galprop_rings_{galkey}.yaml'**

**galprop_sourcekey**(***kwargs*)
return the sourcekey for merged galprop maps : specifies the merged component and merging scheme

**galprop_sourcekey_format = '{source_name}_{galpropkey}'**

**generic**(*input_string*, ***kwargs*)
return a generic filename for a given dataset and component

**irf_ver**(***kwargs*)
Get the name of the IRF version

**irfs**(***kwargs*)
Get the name of IFRs associted with a particular dataset

**ltcube**(***kwargs*)
return the name of a livetime cube file

**ltcube_format = 'lt_cubes/ltcube_{data_time}_{mktime}_{zcut}.fits'**

**ltcube_moon**(***kwargs*)
return the name of a livetime cube file

**ltcube_sun** (***kwargs*)
return the name of a livetime cube file

**ltcubemoon_format = 'sunmoon/ltcube_{data_time}_{mktime}_{zcut}_moon.fits'**

**ltcubesun_format = 'sunmoon/ltcube_{data_time}_{mktime}_{zcut}_sun.fits'**

**make_filenames** (***kwargs*)
Make a dictionary of filenames for various types

**master_srcmdl_xml** (***kwargs*)
return the name of a source model file

**master_srcmdl_xml_format = 'analysis/model_{modelkey}/srcmdl_{modelkey}_master.xml'**

**mcube** (***kwargs*)
return the name of a model cube file

**mcube_format = 'model_cubes/mcube_{sourcekey}_{dataset}_{mktime}_{component}_{coordsys**

**merged_gasmap** (***kwargs*)
return the file name for Galprop merged gasmaps

**merged_gasmap_format = 'merged_gasmaps/{sourcekey}_{projtype}.fits'**

**merged_sourcekey** (***kwargs*)
return the sourcekey for merged sets of point sources : specifies the catalog and merging rule

**merged_sourcekey_format = '{catalog}_{rulekey}'**

**merged_srcmaps** (***kwargs*)
return the name of a source map file

**merged_srcmaps_format = 'analysis/model_{modelkey}/srcmaps_{dataset}_{mktime}_{compone**

**mktime** (***kwargs*)
return the name of a selected events ft1file

**mktime_format = 'counts_cubes/mktime_{dataset}_{mktime}_{component}.fits'**

**model_yaml** (***kwargs*)
return the name of a model yaml file

**model_yaml_format = 'models/model_{modelkey}.yaml'**

**nested_srcmdl_xml** (***kwargs*)
return the file name for source model xml files of nested sources

**nested_srcmdl_xml_format = 'srcmdls/{sourcekey}_sources.xml'**

**residual_cr** (***kwargs*)
Return the name of the residual CR analysis output files

**residual_cr_format = 'residual_cr/residual_cr_{dataset}_{mktime}_{component}_{coordsys**

**select** (***kwargs*)
return the name of a selected events ft1file

**select_format = 'counts_cubes/select_{dataset}_{component}.fits'**

**sourcekey** (***kwargs*)
Return a key that specifies the name and version of a source or component

**sourcekey_format = '{source_name}_{source_ver}'**

**spectral_template** (***kwargs*)
return the file name for spectral templates

**spectral_template_format = 'templates/spectral_{sourcekey}.txt'**

**srcmaps**(***kwargs*)
return the name of a source map file

**srcmaps_format = 'srcmaps/srcmaps_{sourcekey}_{dataset}_{mktime}_{component}_{coordsys**

**srcmdl_xml**(***kwargs*)
return the file name for source model xml files

**srcmdl_xml_format = 'srcmdls/{sourcekey}.xml'**

**stamp**(***kwargs*)
Return the path for a stamp file for a scatter gather job

**stamp_format = 'stamps/{linkname}.stamp'**

**template_sunmoon**(***kwargs*)
return the file name for sun or moon template files

**templatesunmoon_format = 'templates/template_{sourcekey}_{zcut}.fits'**

**update_base_dict**(*yamlfile*)
Update the values in baseline dictionary used to resolve names

### Utilities and tools

Classes and utilities that manage spectral model specific to diffuse analyses

**class** fermipy.diffuse.spectral.**SpectralLibrary**(*spectral_dict*)
Bases: object

A small helper class that serves as an alias dictionary for spectral models

**classmethod create_from_yaml**(*yamlfile*)
Create the dictionary for a yaml file

**classmethod create_from_yamlstr**(*yamlstr*)
Create the dictionary for a yaml file

**update**(*spectral_dict*)
Update the dictionary

Small helper class to represent the selection of mktime filters used in the analysis

**class** fermipy.diffuse.timefilter.**MktimeFilterDict**(*aliases*, *selections*)
Bases: object

Small helper class toselection of mktime filters used in the analysis

**static build_from_yamlfile**(*yamlfile*)
Build a list of components from a yaml file

**items**()
Return the itratetor over key, value pairs

**keys**()
Return the iterator over keys

**values**()
Return the itratetor over values

Classes and utilities that create fermipy source objects

**class** fermipy.diffuse.source_factory.**SourceFactory**
Bases: object

Small helper class to build and keep track of sources

**add_sources**(*source_info_dict*)
Add all of the sources in source_info_dict to this factory

**static build_catalog**(***kwargs*)
Build a fermipy.catalog.Catalog object

**Parameters**

- **catalog_type** (*str*) – Specifies catalog type, options include 2FHL | 3FGL | 4FGLP
- **catalog_file** (*str*) – FITS file with catalog tables
- **catalog_extdir** (*str*) – Path to directory with extended source templates

**classmethod copy_selected_sources**(*roi*, *source_names*)
Build and return a *fermipy.roi_model.ROIModel* object by copying selected sources from another such object

**static make_fermipy_roi_model_from_catalogs**(*cataloglist*)
Build and return a fermipy.roi_model.ROIModel object from a list of fermipy.catalog.Catalog objects

**classmethod make_roi**(*sources=None*)
Build and return a *fermipy.roi_model.ROIModel* object from a dict with information about the sources

**source_info_dict**
Return the dictionary of source_info objects used to build sources

**sources**
Return the dictionary of sources

fermipy.diffuse.source_factory.**make_catalog_sources**(*catalog_roi_model*, *source_names*)
Construct and return dictionary of sources that are a subset of sources in catalog_roi_model.

**Parameters**

- **catalog_roi_model** (dict or *fermipy.roi_model.ROIModel*) – Input set of sources
- **source_names** (*list*) – Names of sourcs to extract
- **dict mapping source_name to fermipy.roi_model.Source object** (*Returns*) –

fermipy.diffuse.source_factory.**make_composite_source**(*name*, *spectrum*)
Construct and return a *fermipy.roi_model.CompositeSource* object

fermipy.diffuse.source_factory.**make_isotropic_source**(*name*, *Spectrum_Filename*, *spectrum*)
Construct and return a *fermipy.roi_model.IsoSource* object

fermipy.diffuse.source_factory.**make_mapcube_source**(*name*, *Spatial_Filename*, *spectrum*)
Construct and return a *fermipy.roi_model.MapCubeSource* object

fermipy.diffuse.source_factory.**make_point_source**(*name*, *src_dict*)
Construct and return a *fermipy.roi_model.Source* object

fermipy.diffuse.source_factory.**make_sources**(*comp_key*, *comp_dict*)
Make dictionary mapping component keys to a source or set of sources

**Parameters**

- **comp_key** (*str*) – Key used to access sources
- **comp_dict** (*dict*) – Information used to build sources
- **OrderedDict maping comp_key to fermipy.roi_model.Source** (*return*) –

fermipy.diffuse.source_factory.**make_spatialmap_source**(*name*, *Spatial_Filename*, *spectrum*)
Construct and return a *fermipy.roi_model.Source* object

Prepare data for diffuse all-sky analysis

fermipy.diffuse.utils.**create_inputlist**(*arglist*)
Read lines from a file and makes a list of file names.

Removes whitespace and lines that start with '#' Recursively read all files with the extension '.lst'

fermipy.diffuse.utils.**readlines**(*arg*)
Read lines from a file into a list.

Removes whitespace and lines that start with '#'

### Helper classes to manage model building

**class** fermipy.diffuse.model_component.**ModelComponentInfo**(***kwargs*)
Bases: object

Information about a model component

**Parameters**

- **source_name** (*str*) – The name given to the component, e.g., loop_I or moon
- **source_ver** (*str*) – Key to indentify the model version of the source, e.g., v00
- **sourcekey** (*str*) – Key that identifies this component, e.g., loop_I_v00 or moon_v00
- **model_type** (*str*) – Type of model, 'MapCubeSource' | 'IsoSource' | 'CompositeSource' | 'Catalog' | 'PointSource'
- **srcmdl_name** (*str*) – Name of the xml file with the xml just for this component
- **moving** (*bool*) – Flag for moving sources (i.e., the sun and moon)
- **selection_dependent** (*bool*) – Flag for selection dependent sources (i.e., the residual cosmic ray model)
- **no_psf** (*bool*) – Flag to indicate that we do not smear this component with the PSF
- **components** (*dict*) – Sub-dictionary of *ModelComponentInfo* objects for moving and selection_dependent sources
- **comp_key** (*str*) – Component key for this component of moving and selection_dependent sources

**add_component_info**(*compinfo*)
Add sub-component specific information to a particular data selection

**Parameters** **compinfo** (*ModelComponentInfo* object) – Sub-component being added

**clone_and_merge_sub**(*key*)
Clones self and merges clone with sub-component specific information

**Parameters**

- **key** (*str*) – Key specifying which sub-component
- **ModelComponentInfo object** (*Returns*) –

**get_component_info**(*comp*)
Return the information about sub-component specific to a particular data selection

**Parameters**

- **comp** (binning.Component object) – Specifies the sub-component
- **ModelComponentInfo object** (*Returns*) –

**update**(***kwargs*)
Update data members from keyword arguments

**class** fermipy.diffuse.model_component.**CatalogInfo**(***kwargs*)
Bases: object

Information about a source catalog

**Parameters**

- **catalog_name** (*str*) – The name given to the merged component, e.g., merged_CO or merged_HI
- **catalog_file** (*str*) – Fits file with catalog data
- **catalog_extdir** (*str*) – Directory with extended source templates
- **catalog_type** (*str*) – Identifies the format of the catalog fits file: e.g., '3FGL' or '4FGLP'
- **catalog** (fermipy.catalog.Catalog) – Catalog object
- **roi_model** (*fermipy.roi_model.ROIModel*) – Fermipy object describing all the catalog sources
- **srcmdl_name** (*str*) – Name of xml file with the catalog source model

**update**(***kwargs*)
Update data members from keyword arguments

**class** fermipy.diffuse.model_component.**GalpropMergedRingInfo**(***kwargs*)
Bases: object

Information about a set of Merged Galprop Rings

**Parameters**

- **source_name** (*str*) – The name given to the merged component, e.g., merged_CO or merged_HI
- **ring** (*int*) – The index of the merged ring
- **sourcekey** (*str*) – Key that identifies this component, e.g., merged_CO_1, or merged_HI_3
- **galkey** (*str*) – Key that identifies how to merge the galprop rings, e.g., 'ref'
- **galprop_run** (*str*) – Key that idenfifies the galprop run used to make the input rings
- **files** (*str*) – List of files of the input gasmap files

- **merged_gasmap** (*str*) – Filename for the merged gasmap

**update**(***kwargs*)
Update data members from keyword arguments

**class** fermipy.diffuse.model_component.**ModelComponentInfo**(***kwargs*)
Bases: object

Information about a model component

**Parameters**

- **source_name** (*str*) – The name given to the component, e.g., loop_I or moon
- **source_ver** (*str*) – Key to indentify the model version of the source, e.g., v00
- **sourcekey** (*str*) – Key that identifies this component, e.g., loop_I_v00 or moon_v00
- **model_type** (*str*) – Type of model, 'MapCubeSource' | 'IsoSource' | 'CompositeSource' | 'Catalog' | 'PointSource'
- **srcmdl_name** (*str*) – Name of the xml file with the xml just for this component
- **moving** (*bool*) – Flag for moving sources (i.e., the sun and moon)
- **selection_dependent** (*bool*) – Flag for selection dependent sources (i.e., the residual cosmic ray model)
- **no_psf** (*bool*) – Flag to indicate that we do not smear this component with the PSF
- **components** (*dict*) – Sub-dictionary of *ModelComponentInfo* objects for moving and selection_dependent sources
- **comp_key** (*str*) – Component key for this component of moving and selection_dependent sources

**add_component_info**(*compinfo*)
Add sub-component specific information to a particular data selection

**Parameters** **compinfo** (*ModelComponentInfo* object) – Sub-component being added

**clone_and_merge_sub**(*key*)
Clones self and merges clone with sub-component specific information

**Parameters**

- **key** (*str*) – Key specifying which sub-component
- **ModelComponentInfo object** (*Returns*) –

**get_component_info**(*comp*)
Return the information about sub-component specific to a particular data selection

**Parameters**

- **comp** (binning.Component object) – Specifies the sub-component
- **ModelComponentInfo object** (*Returns*) –

**update**(***kwargs*)
Update data members from keyword arguments

**class** fermipy.diffuse.model_component.**IsoComponentInfo**(***kwargs*)
Bases: *fermipy.diffuse.model_component.ModelComponentInfo*

Information about a model component represented by a IsoSource

**Parameters** **Spectral_Filename** (*str*) – Name of the template file for the spatial model

**class** fermipy.diffuse.model_component.**PointSourceInfo**(***kwargs*)
Bases: *fermipy.diffuse.model_component.ModelComponentInfo*

Information about a model component represented by a PointSource

**class** fermipy.diffuse.model_component.**CompositeSourceInfo**(***kwargs*)
Bases: *fermipy.diffuse.model_component.ModelComponentInfo*

Information about a model component represented by a CompositeSource

**Parameters**

- **source_names** (*list*) – The names of the nested sources
- **catalog_info** (model_component.CatalogInfo or None) – Information about the catalog containing the nested sources
- **roi_model** (*fermipy.roi_model.ROIModel*) – Fermipy object describing the nested sources

**class** fermipy.diffuse.model_component.**CatalogSourcesInfo**(***kwargs*)
Bases: *fermipy.diffuse.model_component.ModelComponentInfo*

Information about a model component consisting of sources from a catalog

**Parameters**

- **source_names** (*list*) – The names of the nested sources
- **catalog_info** (model_component.CatalogInfo or None) – Information about the catalog containing the nested sources
- **roi_model** (*fermipy.roi_model.ROIModel*) – Fermipy object describing the nested sources

**class** fermipy.diffuse.diffuse_src_manager.**GalpropMapManager**(***kwargs*)
Bases: object

Small helper class to keep track of Galprop gasmaps

This keeps track of two types of dictionaries. Both are keyed by: key = {source_name}_{ring}_{galkey}

Where: {source_name} is something like 'merged_C0' {ring} is the ring index {galkey} is a key specifying which version of galprop rings to use.

The two dictionaries are: ring_dict[key] = model_component.GalpropMergedRingInfo diffuse_comp_info_dict[key] ] model_component.ModelComponentInfo

The dictionaries are defined in files called. models/galprop_rings_{galkey}.yaml

**diffuse_comp_info_dicts**(*galkey*)
Return the components info dictionary for a particular galprop key

**galkeys**()
Return the list of galprop keys used

**make_diffuse_comp_info**(*merged_name*, *galkey*)
Make the information about a single merged component

**Parameters**

- **merged_name** (*str*) – The name of the merged component
- **galkey** (*str*) – A short key identifying the galprop parameters
- **Model_component.ModelComponentInfo** (*Returns*) –

**make_diffuse_comp_info_dict** (*galkey*)
Make a dictionary maping from merged component to information about that component

**Parameters** **galkey** (*str*) – A short key identifying the galprop parameters

**make_merged_name** (*source_name*, *galkey*, *fullpath*)
Make the name of a gasmap file for a set of merged rings

**Parameters**

- **source_name** (*str*) – The galprop component, used to define path to gasmap files
- **galkey** (*str*) – A short key identifying the galprop parameters
- **fullpath** (*bool*) – Return the full path name

**make_ring_dict** (*galkey*)
Make a dictionary mapping the merged component names to list of template files

**Parameters**

- **galkey** (*str*) – Unique key for this ring dictionary
- **model_component.GalpropMergedRingInfo** (*Returns*) –

**make_ring_filelist** (*sourcekeys*, *rings*, *galprop_run*)
Make a list of all the template files for a merged component

**Parameters**

- **sourcekeys** (*list-like of str*) – The names of the componenents to merge
- **rings** (*list-like of int*) – The indices of the rings to merge
- **galprop_run** (*str*) – String identifying the galprop parameters

**make_ring_filename** (*source_name*, *ring*, *galprop_run*)
Make the name of a gasmap file for a single ring

**Parameters**

- **source_name** (*str*) – The galprop component, used to define path to gasmap files
- **ring** (*int*) – The ring index
- **galprop_run** (*str*) – String identifying the galprop parameters

**make_xml_name** (*source_name*, *galkey*, *fullpath*)
Make the name of an xml file for a model definition for a set of merged rings

**Parameters**

- **source_name** (*str*) – The galprop component, used to define path to gasmap files
- **galkey** (*str*) – A short key identifying the galprop parameters
- **fullpath** (*bool*) – Return the full path name

**merged_components** (*galkey*)
Return the set of merged components for a particular galprop key

**read_galprop_rings_yaml** (*galkey*)
Read the yaml file for a partiuclar galprop key

**ring_dict** (*galkey*)
Return the ring dictionary for a particular galprop key

**class** fermipy.diffuse.diffuse_src_manager.**DiffuseModelManager**(***kwargs*)
Bases: object

Small helper class to keep track of diffuse component templates

This keeps track of the 'diffuse component infomation' dictionary

This keyed by: key = {source_name}_{source_ver} Where: {source_name} is something like 'loopI' {source_ver} is somthinng like v00

The dictioary is diffuse_comp_info_dict[key] - > model_component.ModelComponentInfo

Note that some components ( those that represent moving sources or are selection depedent ) will have a sub-dictionary of diffuse_comp_info_dict object for each sub-component

The compoents are defined in a file called config/diffuse_components.yaml

**diffuse_comp_info**(*sourcekey*)
Return the Component info associated to a particular key

**make_diffuse_comp_info**(*source_name*, *source_ver*, *diffuse_dict*, *components=None*, *comp_key=None*)
Make a dictionary mapping the merged component names to list of template files

**Parameters**

- **source_name** (*str*) – Name of the source
- **source_ver** (*str*) – Key identifying the version of the source
- **diffuse_dict** (*dict*) – Information about this component
- **comp_key** (*str*) – Used when we need to keep track of sub-components, i.e., for moving and selection dependent sources.
- **model_component.ModelComponentInfo or** (*Returns*) –
- **model_component.IsoComponentInfo** –

**make_diffuse_comp_info_dict**(*diffuse_sources*, *components*)
Make a dictionary maping from diffuse component to information about that component

**Parameters**

- **diffuse_sources** (*dict*) – Dictionary with diffuse source defintions
- **components** (*dict*) – Dictionary with event selection defintions, needed for selection depenedent diffuse components

**Returns ret_dict** – Dictionary mapping sourcekey to model_component.ModelComponentInfo

**Return type** dict

**make_template_name**(*model_type*, *sourcekey*)
Make the name of a template file for particular component

**Parameters**

- **model_type** (*str*) – Type of model to use for this component
- **sourcekey** (*str*) – Key to identify this component
- **filename or None if component does not require a template file** (*Returns*) –

**make_xml_name**(*sourcekey*)
Make the name of an xml file for a model definition of a single component

**Parameters** **sourcekey** (*str*) – Key to identify this component

**static read_diffuse_component_yaml** (*yamlfile*)
Read the yaml file for the diffuse components

**sourcekeys**()
Return the list of source keys

**class** fermipy.diffuse.catalog_src_manager.**CatalogSourceManager**(***kwargs*)
Bases: object

Small helper class to keep track of how we deal with catalog sources

This keeps track of two dictionaries

One of the dictionaries is keyed by catalog name, and contains information about complete catalogs catalog_comp_info_dicts[catalog_name] : model_component.CatalogInfo

The other dictionary is keyed by [{catalog_name}_{split_ver}][{split_key}] Where: {catalog_name} is something like '3FGL' {split_ver} is somthing like 'v00' and specifes how to divide sources in the catalog {split_key} refers to a specific sub-selection of sources

split_comp_info_dicts[splitkey] : model_component.ModelComponentInfo

**build_catalog_info**(*catalog_info*)
Build a CatalogInfo object

**catalog_comp_info_dict**(*catkey*)
Return the roi_model for an entire catalog

**catalog_components**(*catalog_name*, *split_ver*)
Return the set of merged components for a particular split key

**catalogs**()
Return the list of full catalogs used

**make_catalog_comp_info**(*full_cat_info*, *split_key*, *rule_key*, *rule_val*, *sources*)
Make the information about a single merged component

**Parameters**

- **full_cat_info** (_model_component.CatalogInfo) – Information about the full catalog
- **split_key** (*str*) – Key identifying the version of the spliting used
- **rule_key** (*str*) – Key identifying the specific rule for this component
- **rule_val** (*list*) – List of the cuts used to define this component
- **sources** (*list*) – List of the names of the sources in this component
- **CompositeSourceInfo or CatalogSourcesInfo** (*Returns*) –

**make_catalog_comp_info_dict**(*catalog_sources*)
Make the information about the catalog components

**Parameters** **catalog_sources** (*dict*) – Dictionary with catalog source defintions

**Returns**

- **catalog_ret_dict** (*dict*) – Dictionary mapping catalog_name to model_component.CatalogInfo
- **split_ret_dict** (*dict*) – Dictionary mapping sourcekey to model_component.ModelComponentInfo

**read_catalog_info_yaml**(*splitkey*)
Read the yaml file for a particular split key

**split_comp_info**(*catalog_name*, *split_ver*, *split_key*)
Return the info for a particular split key

**split_comp_info_dict**(*catalog_name*, *split_ver*)
Return the information about a particular scheme for how to handle catalog sources

**splitkeys**()
Return the list of catalog split keys used

**class** fermipy.diffuse.model_manager.**ModelComponent**(***kwargs*)
Bases: object

Small helper class to tie a ModelComponentInfo to a spectrum

**class** fermipy.diffuse.model_manager.**ModelInfo**(***kwargs*)
Bases: object

Small helper class to keep track of a single fitting model

**component_names**
Return the list of name of the components

**edisp_disable_list**()
Return the list of source for which energy dispersion should be turned off

**items**()
Return the key, value pairs of model components

**make_model_rois**(*components*, *name_factory*)
Make the fermipy roi_model objects for each of a set of binning components

**make_srcmap_manifest**(*components*, *name_factory*)
Build a yaml file that specfies how to make the srcmap files for a particular model

**Parameters**

- **components** (*list*) – The binning components used in this analysis
- **name_factory** (NameFactory) – Object that handles naming conventions
- **a dictionary that contains information about where to find the** (*Returns*) –
- **maps for each component of the model** (*source*) –

**class** fermipy.diffuse.model_manager.**ModelManager**(***kwargs*)
Bases: object

Small helper class to create fitting models and manager XML files for fermipy

This class contains a 'library', which is a dictionary of all the source components:

specifically it maps:

sourcekey : model_component.ModelComponentInfo

**csm**
Return the CatalogSourceManager

**dmm**
Return the DiffuseModelManager

**static get_sub_comp_info**(*source_info*, *comp*)
Build and return information about a sub-component for a particular selection

**gmm**
Return the GalpropMapManager

**make_fermipy_config_yaml**(*modelkey*, *components*, *data*, ***kwargs*)
Build a fermipy top-level yaml configuration file

**Parameters**

- **modelkey** (*str*) – Key used to identify this particular model
- **components** (*list*) – The binning components used in this analysis
- **data** (*str*) – Path to file containing dataset definition

**make_library**(*diffuse_yaml*, *catalog_yaml*, *binning_yaml*)
Build up the library of all the components

**Parameters**

- **diffuse_yaml** (*str*) – Name of the yaml file with the library of diffuse component definitions
- **catalog_yaml** (*str*) – Name of the yaml file width the library of catalog split definitions
- **binning_yaml** (*str*) – Name of the yaml file with the binning definitions

**make_model_info**(*modelkey*)
Build a dictionary with the information for a particular model.

**Parameters**

- **modelkey** (*str*) – Key used to identify this particular model
- **ModelInfo** (*Return*) –

**make_srcmap_manifest**(*modelkey*, *components*, *data*)
Build a yaml file that specfies how to make the srcmap files for a particular model

**Parameters**

- **modelkey** (*str*) – Key used to identify this particular model
- **components** (*list*) – The binning components used in this analysis
- **data** (*str*) – Path to file containing dataset definition

**read_model_yaml**(*modelkey*)
Read the yaml file for the diffuse components

### Trivial Link Sub-classes

### Standalone Analysis Links

**class** fermipy.diffuse.gt_assemble_model.**InitModel**(***kwargs*)
Bases: *fermipy.jobs.link.Link*

Small class to preprate files fermipy analysis.

Specifically this create the srcmap_manifest and fermipy_config_yaml files

**appname = 'fermipy-init-model'**

**default_options = {'comp': ('config/binning.yaml', 'Path to yaml file defining binnin**

**description = 'Initialize model fitting directory'**

**linkname_default = 'init-model'**

**run_analysis**(*argv*)
Build the manifest for all the models

**usage = 'fermipy-init-model [options]'**

**class** fermipy.diffuse.gt_assemble_model.**AssembleModel**(***kwargs*)
Bases: *fermipy.jobs.link.Link*

Small class to assemple source map files for fermipy analysis.

This is useful for re-merging after parallelizing source map creation.

**static append_hdus**(*hdulist*, *srcmap_file*, *source_names*, *hpx_order*)
Append HEALPix maps to a list

**Parameters**

- **hdulist** (*list*) – The list being appended to
- **srcmap_file** (*str*) – Path to the file containing the HDUs
- **source_names** (*list of str*) – Names of the sources to extract from srcmap_file
- **hpx_order** (*int*) – Maximum order for maps

**appname = 'fermipy-assemble-model'**

**static assemble_component**(*compname*, *compinfo*, *hpx_order*)
Assemble the source map file for one binning component

**Parameters**

- **compname** (*str*) – The key for this component (e.g., E0_PSF3)
- **compinfo** (*dict*) – Information about this component
- **hpx_order** (*int*) – Maximum order for maps

**static copy_ccube**(*ccube*, *outsrcmap*, *hpx_order*)
Copy a counts cube into outsrcmap file reducing the HEALPix order to hpx_order if needed.

**default_options = {'compname': (None, 'Component name.', <class 'str'>), 'hpx_order':**

**description = 'Assemble sourcemaps for model fitting'**

**linkname_default = 'assemble-model'**

**static open_outsrcmap**(*outsrcmap*)
Open and return the outsrcmap file in append mode

**run_analysis**(*argv*)
Assemble the source map file for one binning component FIXME

**usage = 'fermipy-assemble-model [options]'**

### Batch job dispatch classes

**class** fermipy.diffuse.gt_assemble_model.**AssembleModel_SG**(*link*, ***kwargs*)
Bases: *fermipy.jobs.scatter_gather.ScatterGather*

Small class to generate configurations for this script

**Parameters**

- **--compname** (*binning component definition yaml file*) –
- **--data** (*datset definition yaml file*) –
- **--models** (*model definitino yaml file*) –
- **args** (*Names of models to assemble source maps for*) –

**appname = 'fermipy-assemble-model-sg'**

**build_job_configs**(*args*)
Hook to build job configurations

**clientclass**
alias of *AssembleModel*

**default_options = {'comp': ('config/binning.yaml', 'Path to yaml file defining binnin**

**description = 'Copy source maps from the library to a analysis directory'**

**job_time = 300**

**usage = 'fermipy-assemble-model-sg [options]'**

#### Analysis chain classes

**class** fermipy.diffuse.gt_assemble_model.**AssembleModelChain**(***kwargs*)
Bases: *fermipy.jobs.chain.Chain*

Small class to split, apply mktime and bin data according to some user-provided specification

**appname = 'fermipy-assemble-model-chain'**

**default_options = {'comp': ('config/binning.yaml', 'Path to yaml file defining binnin**

**description = 'Run init-model and assemble-model'**

**linkname_default = 'assemble-model-chain'**

**usage = 'fermipy-assemble-model-chain [options]'**

### 1.3.13 Changelog

This page is a changelog for releases of Fermipy. You can also browse releases on Github.

#### 1.0.1 (03/12/2021)

- Switch primaty installation method to conda
- Fixes to work with recent gammapy and yaml releases
- Remove old installation scripts
- Switch to github actions for testing

#### 1.0.0 (10/1/2020)

- First working python3 version, very close to 0.20.0

### 0.20.0 (08/24/2020)

- Upgrade to P8R3_XXX_V3 irfs in testing
- Added improvements to extension fitting and residual maps

### 0.19.0 (03/25/2020)

- Switch installation procedure and to using fermitools-data for diffuse emission models
- Update docs to reflect changers in intallation procedure
- Added new version of 4FGL catalog
- Updated automatic testing to work with 4FGL and new diffuse emisison models

### 0.18.1 (03/10/2020)

- Changes to improve automated builds for testing
- Added documentation for fermipy.jobs and femripy.diffuse modules
- Some changes to support different size pixels in different components
- Added gtpsf and gtdrm support to gtanalysis

### 0.18.0 (10/18/2019)

- Added tools to use new version of energy dispersion from fermitools.
- Changed travis testing and conda scripts to work with conda release of fermitools.

### 0.17.4 (3/13/2019)

- Including 4FGL, interstellar emission model and isotropic templates files.
- Changing catalog.py to use 4FGL catalog
- Minor fixes to target_collect.py, lightcurve.py and gta.simulate()

### 0.17.3 (7/12/2018)

- Added fitting code to fermipy.diffuse module
- Improved fermipy.jobs to deal with analyses with multiple components
- Added capability to plot global minimum in castro plots
- Added spectra for dark matter decay to DMFitFunction
- Added code to split simulations into smaller batch jobs
- Added fixed shape lightcurve to correct TS_var computation

### 0.17.2 (5/30/2018)

- Added lots of documentation for the fermipy.jobs module.
- Minor changes to the fermipy.jobs module to work with the dark matter analysis pipeline (dmpipe).

### 0.17.1 (5/23/2018)

- Patch release to get versioning working with GitHub release system.

### 0.17.0 (5/22/2018)

- The LogParabola, PowerLawSuperExponetial and Dark Matter SEDs have been added to the sensitivity.py script.
- There are a lot of additions to perform a stacking analysis. This can be applied for instance for the search of dark matter with a stacking analysis of Milky Way dSphs, Galaxy Clusters or other galaxies.
- It contains scripts to send jobs to SLAC Batch Farm and collect the results.
- It includes scripts and functions to perform all sky fits.
- It also fixes a few issues with glon and glat in the localization (#225), and the wrong orientation of residual and TS maps (#216)

### 0.16.0 (12/27/2017)

- Improvements and refactoring in the internals of the `lightcurve` method (see #156, #157, #160, #161, #162). Resolve fit stability issues that were arising when the source of interest was not significantly detected in a given time bin. Added options to speed up source map calculation by rescaling source maps (enabled with `use_scaled_srcmap=True`) and split the lightcurve calculation across N cores (enabled with `multithread=True` and `nthread=N`). Add calculation of `TS_var` to test for variability using method from the 2FGL.
- Updates to validation tools. Added MeritSkimmer script (`fermipy-merit-skimmer`) for skimming ROOT merit tuples either locally or on xrootd.

### 0.15.0 (09/05/2017)

- Bug fix related to restoring analysis state for phased analysis (scaled exposure).
- Many improvements and feature additions to senstivity tools (see e.g. #148, #149, and #152).
- Various updates to support DM pipeline package (#146).
- Improve robustness of algorithms for extracting peak and uncertainty ellipse from 2D likelihood surface.
- Added `curvature` method for testing a source for spectral curvature.
- Added `fix_shape` option to `extension` and `localize` to fix spectral shape parameters. Spectral shape parameters of the source of interest are now free by default when localizing or fitting extension.

### 0.14.0 (03/28/2017)

- Refactoring and improvements in `localize` and `extension` (see #124). Cleanup of columns in `localize`. Add new columns for 1-sigma errors projected in CEL and GAL coordinates as well as associated covariance and correlation matrices. Add positional errors when running `extension` with `fit_position=True`.
- Add `free_radius` option to `localize`, `extension`, and `sed`. This can be used to free background sources within a certain distance of the analyzed source.
- Relocalize point-source hypothesis when testing extension of extended sources.
- Improve speed and accuracy of source map calculation (see #123). Exposures are now extracted directly from the exposure map.
- Write analysis configuration to `CONFIG` header keyword of all FITS output files.
- Add `jobs` and `diffuse` submodules (see #120 and #122). These contain functionality for peforming all-sky diffuse analysis and setting up automated analysis pipelines. More detailed documentation on these features to be provided in a future release.

### 0.13.0 (01/16/2017)

- Rewrite LTCube class to add support for fast LT cube generation. The `gtlike.use_local_ltcube` option can be used to enable the python-based LT cube calculation in lieu of `gtltcube`.
- Bug fixes and improvements to lightcurve method (see #102). Python-based LT cube generation is now enabled by default resulting in much faster execution time when generating light curves over long time spans.
- Add `fit_position` option to `extension` that can be used to enable a joint fit of extension and position.
- New scheme for auto-generating parameter docstrings.
- Add new `set_source_morphology` method to update the spatial model of a source at runtime.
- Major refactoring of `extension` and `localize` (see #106 and #110).
- Pulled in many new modules and scripts for diffuse all-sky analysis (see #105).

### 0.12.0 (11/20/2016)

- Add support for phased analysis (#87). `gtlike.expscale` and `gtlike.src_expscale` can be used to apply a constant exposure correction to a whole component or individual sources within a component. See *Phased Analysis* for examples.
- Add script and tools for calculating flux sensitivity (#88 and #95). The `fermipy-flux-sensitivity` script evaluates both the differential and integral flux sensitivity for a given TS threshold and minimum number of detected counts. See *Sensitivity Tools* for examples.
- Add `fermipy-healview` script for generating images of healpix maps and cubes.
- Improvements to HPX-related classes and utilities.
- Refactoring in `irfs` module to support development of new validation tools.
- Improvements to configuration handling to allow parameter validation when updating configuration at runtime.
- Add lightcurve method (#80). See *Light Curves* for documentation.
- Change convention for flux arrays in source object. Values and uncertainties are now stored in separate arrays (e.g. `flux` and `flux_err`).

- Add Docker-based installation instructions. This can be used to run the RHEL6 SLAC ST builds on any machine that supports Docker (e.g. OSX Yosemite or later).
- Adopt changes to column name conventions in SED format. All column names are now lowercase.

### 0.11.0 (08/24/2016)

- Add support for weighted likelihood fits (supported in ST 11-03-00 or later). Weights maps can be specified with the `wmap` parameter in *gtlike*.
- Implemented performance improvements in `tsmap` including switching to newton's method for step-size calculation and masking of empty pixels (see #79).
- Ongoing development and refactoring of classes for dealing with CastroData (binned likelihood profiles).
- Added `reload_sources` method for faster recomputation of source maps.
- Fixed sign error in localization plotting method that gave wrong orientation for error ellipse..
- Refactored classes in *spectrum* and simplified interface for doing spectral fits (see #69).
- Added DMFitFunction spectral model class in *spectrum* (see #66). This uses the same lookup tables as the ST DMFitFunction class but provides a pure python implementation which can be used independently of the STs.

### 0.10.0 (07/03/2016)

- Implement support for more spectral models (DMFitFunction, EblAtten, FileFunction, Gaussian).
- New options (`outdir_regex` and `workdir regex`) for fine-grained control over input/output file staging.
- Add `offset_roi_edge` to source dictionary. Defined as the distance from the source position to the edge of the ROI (< 0 = inside the ROI, > 0 = outside the ROI).
- Add new variables in `fit` output (`edm`, `fit_status`).
- Add new package scripts (`fermipy-collect-sources`, `fermipy-cluster-sources`).
- Various refactoring and improvements in code for dealing with castro data.
- Add `MODEL_FLUX` and `PARAMS` HDUs to SED FITS file. Many new elements added SED output dictionary.
- Support NEWTON fitter with the same interface as MINUIT and NEWMINUIT. Running `fit` with `optimizer` = NEWTON will use the NEWTON fitter where applicable (only free norms) and MINUIT otherwise. The `optimizer` argument to `sed`, `extension`, and `localize` can be used to override the default optimizer at runtime. Note that the NEWTON fitter is only supported by ST releases *after* 11-01-01.

### 0.9.0 (05/25/2016)

- Bug fixes and various refactoring in TSCube and CastroData. Classes for reading and manipulating bin-by-bin likelihoods are now moved to the *castro* module.
- Rationalized naming conventions for energy-related variables. Properties and method arguments with units of the logarithm of the energy now consistently contain `log` in the name.
  - `energies` now returns bin energies in MeV (previously it returned logarithmic energies). `log_energies` can be used to access logarithmic bin energies.
  - Changed `erange` parameter to `loge_bounds` in the methods that accept an energy range.
  - Changed the units of `emin`, `ectr`, and `emax` in the sed output dictionary to MeV.

- Add more columns to the FITS source catalog file generated by `write_roi`. All float and string values in the source dictionary are now automatically included in the FITS file. Parameter values, errors, and names are written to the `param_values`, `param_errors`, and `param_names` vector columns.
- Add package script for dispatching batch jobs to LSF (`fermipy-dispatch`).
- Fixed some bugs related to handling of unicode strings.

### 0.8.0 (05/18/2016)

- Added new variables to source dictionary:
  - Likelihood scan of source normalization (`dloglike_scan`, `eflux_scan`, `flux_scan`).
  - Source localization errors (`pos_sigma`, `pos_sigma_semimajor`, `pos_sigma_semiminor`, `pos_r68`, `pos_r95`, `pos_r99`, `pos_angle`). These are automatically filled when running `localize` or `find_sources`.
- Removed camel-case in some source variable names.
- Add `cacheft1` option to *data* disable caching FT1 files. Cacheing is still enabled by default.
- Support FITS file format for preliminary releases of the 4FGL catalog.
- Add `__future__` statements throughout to ensure forward-compatibility with python3.
- Reorganize utility modules including those for manipulation of WCS and healpix images.
- Various improvements and refactoring in `localize`. This method now moved to the `sourcefind` module.
- Add new global parameter `llscan_pts` in *gtlike* to define the number of likelihood evaluation points.
- Write output of `sed` to a FITS file in the Likelihood SED format. More information about the Likelihood SED format is available on this page.
- Write ROI model to a FITS file when calling `write_roi`. This file contains a BINTABLE with one row per source and uses the same column names as the 3FGL catalog file to describe spectral parameterizations. Note that this file currently only contains a subset of the information available in the numpy output file.
- Reorganize classes and methods in `sed` for manipulating and fitting bin-by-bin likelihoods. Spectral functions moved to a dedicated *`spectrum`* module.
- Write return dictionary to a numpy file in `residmap` and `tsmap`.

CHAPTER 2

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