# Fermipy Documentation

***Release 0.1.0***

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Contents

CHAPTER 1

# Introduction

This is the fermiPy documentation page. fermiPy is a set of python modules and scripts that automate analysis with the Fermi Science Tools. fermipy provides a configuration-file driven workflow in which the analysis parameters (data selection, IRFs, and ROI model) are defined in a user-specified YAML file. The analysis is controlled with a set of python classes that provide methods to execute various analysis tasks. For instruction on installing fermiPy see the *Installation* page. For a short introduction to using fermiPy see the *Quickstart Guide*.

## 1.1 Documentation Contents

### 1.1.1 Installation

**Note:** fermiPy is only compatible with ST v10r0p5 or later. If you are using an earlier version, it is recommended to download and install the latest version from the FSSC.

These instructions assume that you already have a local installation of the Fermi STs. Instructions for downloading and installing the STs are provided through the FSSC. If you are running at SLAC you can follow the *Running at SLAC* instructions. For Unix/Linux users we currently recommend following the *Installing with Anaconda Python* instructions. For OSX users we recommend following the *Installing with pip* instructions.

#### Installing with pip

These instructions cover installation with the `pip` package management tool. This method will install fermipy and its dependencies into the python distribution that comes with the Fermi Science Tools. First verify that you're running the python from the Science Tools

```
$ which python
```

If this doesn't point to the python in your Science Tools install (i.e. it returns /usr/bin/python or /usr/local/bin/python) then the Science Tools are not properly setup.

Before starting the installation process, you will need to determine whether you have setuptools and pip installed in your local python environment. You may need to install these packages if you are running with the binary version of the Fermi Science Tools distributed by the FSSC. The following command will install both packages in your local environment:

```
$ curl https://bootstrap.pypa.io/get-pip.py | python -
```

Check if pip is correctly installed:

```
$ which pip
```

Once again, if this isn't the pip in the Science Tools, something went wrong. Now install fermipy by running

```
$ pip install fermipy
```

To run the ipython notebook examples you will also need to install jupyter notebook:

```
$ pip install jupyter
```

Finally, check that fermipy imports:

```
$ python
Python 2.7.8 (default, Aug 20 2015, 11:36:15)
[GCC 4.2.1 Compatible Apple LLVM 6.0 (clang-600.0.56)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> from fermipy.gtanalysis import GTAnalysis
>>> help(GTAnalysis)
```

### Installing with Anaconda Python

**Note:** The following instructions have only been verified to work with binary Linux distributions of the Fermi STs. If you are using OSX or you have installed the STs from source you should follow the *Installing with pip* thread above.

These instructions cover how to use fermipy with a new or existing conda python installation. These instructions assume that you have already downloaded and installed the Fermi STs from the FSSC and you have set the `FERMI_DIR` environment variable to point to the location of this installation.

The `condainstall.sh` script can be used to install fermipy into an existing conda python installation or to create a minimal conda installation from scratch. In either case download and run the `condainstall.sh` installation script from the fermipy repository:

```
$ curl -OL https://raw.githubusercontent.com/fermiPy/fermipy/master/condainstall.sh
$ bash condainstall.sh
```

If you do not already have anaconda python installed on your system this script will create a new installation under `$HOME/miniconda`. If you already have conda installed and the `conda` command is in your path the script will use your existing installation. The script will create a separate environment for your fermipy installation called *fermi-env*.

Once fermipy is installed you can initialize the fermi environment by running `condasetup.sh`:

```
$ curl -OL https://raw.githubusercontent.com/fermiPy/fermipy/master/condasetup.sh
$ source condasetup.sh
```

This will both activate the *fermi-env* environment and set up your shell environment to run the Fermi Science Tools. The *fermi-env* python environment can be exited by running:

```
$ source deactivate
```

### Running at SLAC

This section provides specific installation instructions for running in the SLAC computing environment. First download and source the `slacsetup.sh` script:

```
$ wget https://raw.githubusercontent.com/fermiPy/fermipy/master/slacsetup.sh -O slacsetup.sh
$ source slacsetup.sh
```

To initialize the ST environment run the `slacsetup` function:

```
$ slacsetup
```

This will setup your `GLAST_EXT` path and source the setup script for one of the pre-built ST installations (the current default is 10-01-01). To manually override the ST version you can optionally provide the release tag as an argument to `slacsetup`:

```
$ slacsetup 10-XX-XX
```

Because users don't have write access to the ST python installation all pip commands that install or uninstall packages must be executed with the `--user` flag. After initializing the STs environment, install fermipy with pip:

```
$ pip install fermipy --user
```

This will install fermipy in `$HOME/.local`. You can verify that the installation has succeeded by importing *GTAnalysis*:

```
$ python
Python 2.7.8 |Anaconda 2.1.0 (64-bit)| (default, Aug 21 2014, 18:22:21)
[GCC 4.4.7 20120313 (Red Hat 4.4.7-1)] on linux2
Type "help", "copyright", "credits" or "license" for more information.
Anaconda is brought to you by Continuum Analytics.
Please check out: http://continuum.io/thanks and https://binstar.org
>>> from fermipy.gtanalysis import GTAnalysis
```

### Upgrading

By default installing fermipy with `pip` 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
---
Metadata-Version: 2.0
Name: fermipy
Version: 0.6.7
Summary: A Python package for analysis of Fermi-LAT data
Home-page: https://github.com/fermiPy/fermipy
Author: The Fermipy developers
Author-email: fermipy.developers@gmail.com
License: BSD
Location: /home/vagrant/miniconda/envs/fermi-env/lib/python2.7/site-packages
Requires: wcsaxes, astropy, matplotlib, healpy, scipy, numpy, pyyaml
```

To upgrade your fermipy installation to the latest version run the pip installation command with `--upgrade --no-deps`:

```
$ 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
```

### Building from Source

These instructions describe how to install fermipy from its git source code repository. This is necessary if you want to locally develop fermipy or you want to use features in a development version of the fermipy code. Note that for non-expert users it is recommended to install fermipy with `pip` following the instructions above. First clone the fermipy repository:

```
$ git clone https://github.com/fermiPy/fermipy.git
$ cd fermipy
```

To install the head of the master branch run `setup.py install` from the root of the source tree:

```
# Install the latest version
$ git checkout master
$ python setup.py install --user
```

A useful option if you are doing active code development is to install your working copy as the local installation. This can be done by running `setup.py develop`:

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

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 --user --uninstall
```

You also have the option of installing a previous release tag. To see the list of release tags use `git tag`:

```
$ git tag
0.4.0
0.5.0
0.5.1
0.5.2
0.5.3
0.5.4
0.6.0
0.6.1
```

To install a specific release tag, run `git checkout` with the tag name followed by `setup.py install`:

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

### Issues

If you get an error about importing matplotlib (specifically something about the macosx backend) you might change your default backend to get it working. The customizing matplotlib page details the instructions to modify your default matplotlibrc file (you can pick GTK or WX as an alternative). Specifically the `TkAgg` and `macosx` backends currently do not work on OSX if you upgrade matplotlib to the version required by fermipy. To get around this issue you can enable the `Agg` backend at runtime:

```
>>> import matplotlib
>>> matplotlib.use('Agg')
```

However this backend does not support interactive plotting.

In some cases the setup.py script will fail to properly install the fermipy package dependecies. If installation fails you can try running a forced upgrade of these packages with `pip install --upgrade`:

```
$ pip install --upgrade --user numpy matplotlib scipy astropy pyyaml healpy wcsaxes ipython jupyter
```

### 1.1.2 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 section on *IPython Notebook Tutorials*.

#### 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 structure in which sets of related options are grouped into sections. The following example is 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

binning:
  roiwidth   : 10.0
  binsz      : 0.1
  binsperdec : 8

selection :
  emin : 100
  emax : 100000
  zmax    : 90
  evclass : 128
  evtype  : 3
  target : 'mkn421'
  tmin    : 239557414
  tmax    : 428903014
  filter  : null

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

Any configuration parameter can be changed with this mechanism. The following example shows how to define a different zmax selection and isotropic template 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')

# 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 template
model = {'SpatialModel' : 'PointSource', 'Index' : 2.0,
         'SpectrumType' ; 'PowerLaw'}

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

More documentation about these methods is available in the *Source Detection* page.

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')
```

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 the current ROI model to both an XML model file and a results dictionary. The results dictionary is written in both npy and yaml formats and can be loaded from a python session after your analysis is complete. The following example demonstrates how to load the dictionary from either format:

```
>>> # Load from yaml
>>> import yaml
>>> c = yaml.load(open('fit_model.yaml'))
>>>
>>> # Load from npy
>>> import np
>>> c = np.load('fit_model.npy').flat[0]
>>>
>>> print c.keys()
['roi', 'config', 'sources']
```

The output dictionary contains the following top-level elements:

**roi** A dictionary containing information about the ROI as a whole.

**config** The configuration dictionary of the *GTAnalysis* instance.

**sources** A dictionary containing information for individual sources in the model (diffuse and point-like). Each element of this dictionary maps to a single source in the ROI model.

**version** The version of the fermiPy package that was used to run this analysis. This will automatically be 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.

```
>>> print c['sources'].keys()
['3FGL J0954.2+4913',
 '3FGL J0957.4+4728',
 '3FGL J1006.7+3453',

 ...

 '3FGL J1153.4+4932',
 '3FGL J1159.5+2914',
 '3FGL J1203.2+3847',
 '3FGL J1209.4+4119',
 'galdiff',
 'isodiff']
```

### 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 fermipy examples are available as IPython notebooks in the notebooks directory of the fermipy respository. To run any of the notebooks, download the fermipy repository and run `jupyter notebook` followed by the notebook name:

```
git clone https://github.com/fermiPy/fermipy.git
cd fermipy/notebooks
jupyter notebook PG\ 1553+113.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
```

### 1.1.3 Configuration

This page describes the configuration management scheme used within the fermiPy package and the documents the analysis options that can be controlled with the configuration file.

### Class Configuration

Classes in the fermiPy package follow a common convention by which the the runtime behavior of a class instance can be controlled. Internally every class instance has a dictionary that defines its configuration state. Elements of this dictionary can be scalars (str, int ,float) or dictionaries defining nested blocks of the configuration.

The class configuration dictionary is set at the time of object creation by passing a dictionary or a path to YAML configuration file to the class constructor. Optional kwargs arguments can be used to override options in the input dictionary. For instance in the following example the *config* dictionary defines values for the parameters *emin* and *emax*. By passing an additional dictionary for the selection block, the value of emax in the kwargs argument (10000) overrides the value of this parameter in the config dictionary.

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

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

Alternatively the config argument can be the path to a YAML configuration file:

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

### Configuration File

fermiPy uses YAML configuration files which define a hierarchy of parameters organized in sections that group sets of related options. The configuration file mirrors the layout of the configuration dictionary. The options 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 1.1: 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
```

Listing 1.2: *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. 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 a sequence of independent subselections of the data. Each subselection will have its own binned likelihood instance that will be combined in a global likelihood likelihood function for the whole ROI (implemented with the SummedLikelihood class in pyLikelihood). This section is optional and when this section is empty (the default) fermiPy will construct a single likelihood with the parameters of the root analysis configuration.

The component section can be defined as either a list or dictionary of dictionary elements where each element sets analysis parameters for a different subcomponent of the analysis. Dictionary elements have the same hierarchy of 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 the a list of dictionaries. In this case files associated to each component will be named according to their order in the list (e.g. file_00.fits, file_01.fits, etc.).

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

This example illustrates how to define the components as a dictionary of dictionaries. In this case the files of a component will be appended with its corresponding key (e.g. file_front.fits, file_back.fits).

```
# Component section for Front/Back analysis with dictionary style
components:
```

```
  front : { selection : { evtype : 1 } } # Front
  back  : { 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 1.3: Sample *data* Configuration

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

Listing 1.4: *data* Options

| Option | Default | Description |
|---|---|---|
| `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 running this method see the *Extension Fitting* page.

Listing 1.5: *extension* Options

| Option | Default | Description |
|---|---|---|
| `fix_background` | False | Fix any background parameters that are currently free in the model when performing the likelihood scan over extension. |
| `save_model_map` | False | |
| `save_templates` | False | |
| `spatial_model` | Gaussian-Source | Spatial model use for extension test. |
| `update` | False | Update the source model with the best-fit spatial extension. |
| `width` | None | Parameter vector for scan over spatial extent. If none then the parameter vector will be set from `width_min`, `width_max`, and `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 steps for the spatial likelihood scan. |

### 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 1.6: Sample *fileio* Configuration

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

Listing 1.7: *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. |
| savefits | True | Save intermediate FITS files. |
| scratchdir | /scratch | Path to the scratch directory. |
| usescratch | False | Run analysis in a temporary directory under scratchdir. |
| workdir | None | Override the working directory. |

#### gtlike

Options in the *gtlike* section control the setup of the likelihood analysis include the IRF name (irfs).

Listing 1.8: *gtlike* Options

| Option | Default | Description |
|---|---|---|
| bexpmap | None | |
| convolve | True | |
| edisp | True | Enable the correction for energy dispersion. |
| edisp_disable | None | Provide a list of sources for which the edisp correction should be disabled. |
| irfs | None | Set the IRF string. |
| minbinsz | 0.05 | Set the minimum bin size used for resampling diffuse maps. |
| resample | True | |
| rfactor | 2 | |
| srcmap | None | |

#### 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 1.9: Sample *model* Configuration

```
model :

  # 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
```

Listing 1.10: *model* Options

| Option | Default | Description |
|---|---|---|
| assoc_xmatch_col | ['3FGL_Name'] | Choose a set of association columns on which to cross-match catalogs. |
| catalogs | None | |
| diffuse | None | |
| extdir | Extended_archive_v15 | |
| extract_diffuse | False | Extract a copy of all mapcube components centered on the ROI. |
| galdiff | None | Set the galactic IEM mapcube. |
| isodiff | None | Set the isotropic template. |
| 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 | Set the maximum distance for inclusion of sources in the ROI model. Selects all sources within a circle of this radius centered on the ROI. If none then no selection is applied. This selection will be ORed with sources passing the cut on src_roiwidth. |
| src_radius_roi | None | Half-width of the ROI selection. This parameter can be used in lieu of src_roiwidth. |
| src_roiwidth | None | Select sources within a box of RxR centered on the ROI. If none then no cut is applied. |

### optimizer

Listing 1.11: *optimizer* Options

| Option | Default | Description |
|---|---|---|
| min_fit_quality | 3 | 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 | 0.0001 | Set the optimizer tolerance. |
| verbosity | 0 | |

### plotting

Listing 1.12: *plotting* Options

| Option | Default | Description |
|---|---|---|
| `catalogs` | None | |
| `cmap` | ds9_b | Set the colormap for 2D plots. |
| `erange` | None | |
| `format` | png | |
| `graticule_radii` | None | Define a list of radii at which circular graticules will be drawn. |

### sed

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

Listing 1.13: *sed* Options

| Option | Default | Description |
|---|---|---|
| `bin_index` | 2.0 | Spectral index that will be use when fitting the energy distribution within an energy bin. |
| `fix_background` | True | Fix background parameters when fitting the source flux in each energy bin. |
| `ul_confidence` | 0.95 | Confidence level for upper limit calculation. |
| `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. |

### 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
  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'
```

Listing 1.14: *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)) |
| 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

Listing 1.15: *sourcefind* Options

| Option | Default | Description |
|---|---|---|
| max_iter | 3 | Set the number of search iterations. |
| min_separation | 1.0 | Set the minimum separation in deg for sources added in each iteration. |
| model | None | Set the source model dictionary. By default the test source will be a PointSource with an Index 2 power-law specturm. |
| sources_per_iter | 3 | |
| sqrt_ts_threshold | 5.0 | Set the threshold on sqrt(TS). |
| tsmap_fitter | tsmap | Set the method for generating the TS map. |

### tsmap

Listing 1.16: *tsmap* Options

| Option | Default | Description |
|---|---|---|
| erange | None | Lower and upper energy bounds in log10(E/MeV). By default the calculation will be performed over the full analysis energy range. |
| max_kernel_radius | 3.0 | |
| model | None | Dictionary defining the properties of the test source. |
| multithread | False | |

#### tscube

Listing 1.17: *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 |
| max_iter | 30 | Maximum number of iterations for the Newtons method fitter. |
| model | None | Dictionary defining the properties of the test source. By default the test source will be a PointSource with an Index 2 power-law specturm. |
| 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. |

### 1.1.4 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_v14.fit'
    - 'extra_sources.xml'
```

Sources in addition to those in the catalog file can be defined with the *sources* parameter. This parameter contains a list of dictionaries that define the parameters of individual sources. 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 alternatively 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' }
```

fermiPy supports three types of pre-defined spatial templates which can be defined by setting the SpatialModel property: PointSource (the default), DiskSource, and GaussianSource. The spatial extension of DiskSource and GaussianSource can be controlled with the *SpatialWidth* parameter which defines respectively the radius or 68% containment radius in degrees. Note that sources with the DiskSource and GaussianSource spatial property can only be defined with the *sources* parameter.

```
model:
  sources  :
    - { name: 'MyDiskSource', glon : 120.0, glat : 0.0,
     SpectrumType : 'PowerLaw', Index : 2.0, Scale : 1000, Prefactor : !!float 1e-11,
     SpatialModel: 'DiskSource', SpatialWidth: 1.0 }
    - { name: 'MyGaussSource', glon : 120.0, glat : 0.0,
     SpectrumType : 'PowerLaw', Index : 2.0, Scale : 1000, Prefactor : !!float 1e-11,
     SpatialModel: 'GaussianSource', SpatialWidth: 1.0 }
```

### Editing the Model at Runtime

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

```
from fermipy.gtanalysis import GTAnalysis

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

# 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' })

gta.setup()

# 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 before calling *setup()* will be appended to the XML model definition. Sources added after calling *setup()* will be created dynamically through the pyLikelihood object creation mechanism.

## 1.1.5 Advanced Analysis Methods

fermipy provides several advanced analysis methods that are documented in the following pages:

### SED Analysis

The *sed()* method can be used to compute a spectral energy distribution (SED) for a source by fitting the source flux normalization in a sequence of energy bins. The normalization in each bin is fit independently using a power-law spectrum 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). By default this method will fix the parameters of all background components in the ROI. To leave background parameters free in the fit set `fix_background` to True.

The default configuration of *sed()* is defined in the *sed* section of the configuration file:

Listing 1.18: *sed* Options

| Option | Default | Description |
|---|---|---|
| `bin_index` | 2.0 | Spectral index that will be use when fitting the energy distribution within an energy bin. |
| `fix_background` | True | Fix background parameters when fitting the source flux in each energy bin. |
| `ul_confidence` | 0.95 | Confidence level for upper limit calculation. |
| `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. |

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 for the SED
>>> sed = gta.sed('sourceA',energies=[2.0,2.5,3.0,3.5,4.0,4.5,5.0], bin_index=2)
```

By default the method will use the energy bins of the underlying analysis. The `energies` keyword argument can be used to override the default binning with the restriction that the SED energy bins most align with the analysis bins.

The output of the SED analysis are written to a dictionary which is the return argument of the SED method. The output dictionary is also saved to the `sed` dictionary of the *Source* instance which is written to the output file generated by *write_roi()*. The following example shows how the output dictionary can be captured from either from the method return value or later accessed from the *ROIModel* instance:

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

# Get the sed results from the source object
>>> sed = gta.roi['sourceA']
```

The contents of the output dictionary are described below:

Listing 1.19: *sed* Output Dictionary

| Key | Type | Description |
|---|---|---|
| Npred | ndarray | Number of model counts. |
| config | dict | Copy of the input parameters to this method. |
| dfde | ndarray | Differential flux in each bin (MeV^{-1} cm^{-2} s^{-1}). |
| dfde_err | ndarray | 1-sigma error on dfde evaluated from likelihood curvature. |
| dfde_err_hi | ndarray | Upper 1-sigma error on dfde evaluated from the profile likelihood (MINOS errors). |
| dfde_err_lo | ndarray | Lower 1-sigma error on dfde evaluated from the profile likelihood (MINOS errors). |
| dfde_ul | ndarray | Upper limit on dfde evaluated from the profile likelihood using a CL = ul_confidence. |
| dfde_ul95 | ndarray | 95% CL upper limit on dfde evaluated from the profile likelihood (MINOS errors). |
| e2dfde | ndarray | E^2 x the differential flux in each bin (MeV^{-1} cm^{-2} s^{-1}). |
| e2dfde_err | ndarray | 1-sigma error on e2dfde evaluated from likelihood curvature. |
| e2dfde_err_hi | ndarray | Upper 1-sigma error on e2dfde evaluated from the profile likelihood (MINOS errors). |
| e2dfde_err_lo | ndarray | Lower 1-sigma error on e2dfde evaluated from the profile likelihood (MINOS errors). |
| e2dfde_ul | ndarray | Upper limit on e2dfde evaluated from the profile likelihood using a CL = ul_confidence. |
| e2dfde_ul95 | ndarray | 95% CL upper limit on e2dfde evaluated from the profile likelihood (MINOS errors). |
| ecenter | ndarray | Centers of SED energy bins (log10(E/MeV)). |
| eflux | ndarray | Energy flux in each bin (MeV cm^{-2} s^{-1}). |
| emax | ndarray | Upper edges of SED energy bins (log10(E/MeV)). |
| emin | ndarray | Lower edges of SED energy bins (log10(E/MeV)). |
| fit_quality | ndarray | Fit quality parameter. |
| flux | ndarray | Flux in each bin (cm^{-2} s^{-1}). |
| index | ndarray | Spectral index of the power-law model used to fit this bin. |
| lnlprofile | dict | Likelihood scan for each energy bin. |
| ts | ndarray | Test statistic. |

#### Reference/API

GTAnalysis.**sed**(*name*, *profile=True*, *energies=None*, ***kwargs*)

Generate an SED for a source. This function will fit the normalization of a given source in each energy bin.

**Parameters**

- **name** (*str*) – Source name.
- **profile** (*bool*) – Profile the likelihood in each energy bin.
- **energies** (ndarray) – Sequence of energies in log10(E/MeV) defining the edges of the energy bins. If this argument is None then the analysis energy bins will be used. The energies in this sequence must align with the bin edges of the underyling analysis instance.
- **bin_index** (*float*) – Spectral index that will be use when fitting the energy distribution within an energy bin.
- **use_local_index** (*bool*) – 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.

- **fix_background** (*bool*) – Fix background components when fitting the flux normalization in each energy bin. If fix_background=False then all background parameters that are currently free in the fit will be profiled. By default fix_background=True.
- **ul_confidence** (*float*) – Set the confidence level that will be used for the calculation of flux upper limits in each energy bin.

**Returns** **sed** – This dictionary is also saved to the 'sed' dictionary of the *Source* instance.

**Return type** dict Dictionary containing output of the SED analysis.

### 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 evaluated by a likelihood profile scan over the source width. Currently this method supports two models for extension: a 2D Gaussian (*GaussianSource*) or a 2D disk (*DiskSource*).

The default configuration of *extension()* is defined in the *extension* section of the configuration file:

Listing 1.20: *extension* Options

| Option | Default | Description |
|---|---|---|
| fix_background | False | Fix any background parameters that are currently free in the model when performing the likelihood scan over extension. |
| save_model_map | False | |
| save_templates | False | |
| spatial_model | GaussianSource | Spatial model use for extension test. |
| update | False | Update the source model with the best-fit spatial extension. |
| width | None | Parameter vector for scan over spatial extent. If none then the parameter vector will be set from width_min, width_max, and 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 steps for the spatial likelihood scan. |

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='DiskSource')
```

By default the extension method will profile over any background parameters that were free when the method was executed. One can optionally fix all background parameters with the *fix_background* parameter:

```
# Free a nearby source that maybe be partially degenerate with the
# source of interest
gta.free_norm('sourceB')

# Normalization of SourceB will be refit when testing the extension
# of sourceA
gta.extension('sourceA')

# Fix all background parameters when testing the extension
```

```
# of sourceA
gta.extension('sourceA',fix_background=True)
```

The results of the extension analysis are written to a dictionary which is the return value of the extension method. This dictionary is also written to the *extension* dictionary of the corresponding source and will also be saved in the output file generated by *write_roi()*.

```
ext = gta.extension('sourceA')

ext = gta.roi['sourceA']
```

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

| Key | Description |
|---|---|
| dlogLike | Sequence of delta-log-likelihood values for each point in the profile likelihood scan. |
| logLike | Sequence of likelihood values for each point in the scan over the spatial extension. |
| logLike_ptsrc | Log-Likelihood value of the best-fit point-source model. |
| logLike_base | Log-Likelihood value of the baseline model. |
| ext | Best-fit extension in degrees. |
| ext_err_hi | Upper (1 sigma) error on the best-fit extension in degrees. |
| ext_err_lo | Lower (1 sigma) error on the best-fit extension in degrees. |
| ext_err | Symmetric (1 sigma) error on the best-fit extension in degrees. |
| ext_ul95 | 95% CL upper limit on the extension in degrees. |
| width | List of width parameters. |
| ts_ext | Test statistic for the extension hypothesis. |
| source_fit | Dictionary with parameters of the best-fit extended source model. |
| config | Copy of the input parameters to this method. |

#### Reference/API

GTAnalysis.**extension**(*name*, ***kwargs*)

Test this source for spatial extension with the likelihood ratio method (TS_ext). This method will substitute an extended spatial model for the given source and perform a one-dimensional scan of the spatial extension parameter over the range specified with the width parameters. The 1-D profile likelihood is then used to compute the best-fit value, upper limit, and TS for extension. Any background parameters that are free will also be simultaneously profiled in the likelihood scan.

**Parameters**

- **name** (*str*) – Source name.
- **spatial_model** (*str*) – Spatial model that will be used when testing extension (e.g. DiskSource, GaussianSource).
- **width_min** (*float*) – Minimum value in degrees for the spatial extension scan.
- **width_max** (*float*) – Maximum value in degrees for the spatial extension scan.
- **width_nstep** (*int*) – Number of scan points between width_min and width_max. Scan points will be spaced evenly on a logarithmic scale between log(width_min) and log(width_max).
- **width** (*array-like*) – Sequence of values in degrees for the spatial extension scan. If this argument is None then the scan points will be determined from width_min/width_max/width_nstep.
- **fix_background** (*bool*) – Fix all background sources when performing the extension fit.

- **update** (*bool*) – Update this source with the best-fit model for spatial extension.
- **save_model_map** (*bool*) – Save model maps for all steps in the likelihood scan.

**Returns** **extension** – Dictionary containing results of the extension analysis. The same dictionary is also saved to the dictionary of this source under 'extension'.

**Return type** dict

### Source Detection

fermipy provides several methods for source detection that can be used to look for unmodeled sources as well as evaluate the fit quality of the model. These methods are

- *TS Map*: *tsmap()* generates a test statistic (TS) map for a new source centered at each spatial bin in the ROI.
- *TS Cube*: *tscube()* generates 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*: *residmap()* generates a residual map by evaluating the difference between smoothed data and model maps (residual) at each spatial bin in the ROI.
- *Source Finding*: *find_sources()* is an iterative source-finding algorithim that adds new sources to the ROI by looking for peaks in the TS map.

Additional information about using each of these methods is provided in the sections below.

#### TS Map

*tsmap()* performs a likelihood ratio test for an additional source at the center of each spatial bin of the ROI. The methodology is similar to that of the gttsmap ST application but with a simplified source fitting implementation that significantly speeds up the calculation. 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. Unlike gttsmap, the likelihood fitting implementation used by *tsmap()* only fits for the normalization of the test source and does not re-fit parameters of the background model. The properties of the test source (spectrum and spatial morphology) are controlled with the model dictionary argument. The syntax for defining the test source properties follows the same conventions as *add_source()* as illustrated in the following examples.

```
# 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)]
```

If running interactively, the `multithread` option can be enabled to split the calculation across all available cores. However it is not recommended to use this option when running in a cluster environment.

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

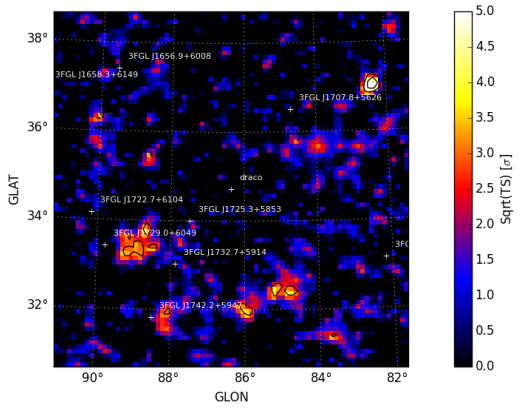
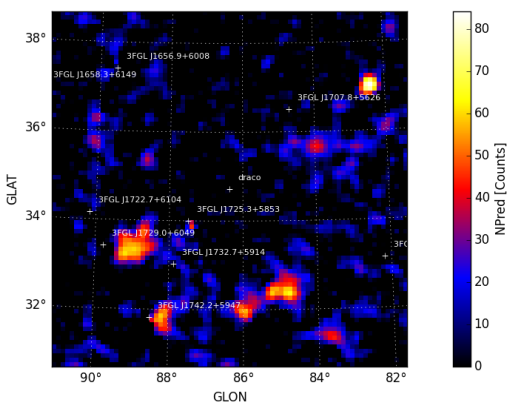
*tsmap()* returns a `maps` dictionary containing *Map* representations of the TS and NPred of the best-fit test source at each position.

```
>>> model = {'Index' : 2.0, 'SpatialModel' : 'PointSource'}
>>> maps = gta.tsmap('fit1',model=model)
>>> print(maps.keys())
[u'file', u'name', u'sqrt_ts', u'ts', u'src_dict', u'npred', u'amplitude']
```

The contents of the output dictionary are described 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. |

Maps are also written as both FITS and rendered image files to the analysis working directory. All output files are prepended with the `prefix` argument. Sample images for `sqrt_ts` and `npred` generated by *tsmap()* are shown below. A colormap threshold for the `sqrt_ts` image is applied at 5 sigma with iscontours at 2 sigma intervals (3,5,7,9, ...) indicating values above this threshold.

| Sqrt(TS) | NPred |
|---|---|
|  |  |



**Reference/API**

`GTAnalysis.`**`tsmap`**(*prefix=''*, ***kwargs*)

Generate a spatial TS map for a source component with properties defined by the `model` argument. The TS map will have the same geometry as the ROI. The output of this method is a dictionary containing *Map* objects with the TS and amplitude of the best-fit test source. By default this method will also save maps to FITS files and render them as image files.

This method uses a simplified likelihood fitting implementation that only fits for the normalization of the test source. Before running this method it is recommended to first optimize the ROI model (e.g. by running

*optimize()*).

**Parameters**

- **prefix** (*str*) – Optional string that will be prepended to all output files (FITS and rendered images).
- **model** (*dict*) – Dictionary defining the properties of the test source.
- **exclude** (*str or list of str*) – Source or sources that will be removed from the model when computing the TS map.
- **erange** (*list*) – 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.
- **max_kernel_radius** (*float*) – Set the maximum radius of the test source kernel. Using a smaller value will speed up the TS calculation at the loss of accuracy. The default value is 3 degrees.
- **make_plots** (*bool*) – Write image files.
- **make_fits** (*bool*) – Write FITS files.

**Returns** **maps** – A dictionary containing the *Map* objects for TS and source amplitude.

**Return type** dict

### Residual Map

*residmap()* calculates the residual between smoothed data and model maps. Whereas *tsmap()* fits for positive excesses with respect to the current 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

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

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

where $n$ and $m$ are the data and model maps and $k$ is the convolution kernel. The spatial and spectral properties of the convolution kernel are defined with the `model` argument. All source models are supported as well as a gaussian kernel (defined by setting *SpatialModel* to *Gaussian*). The following examples illustrate how to run the method with different spatial kernels.

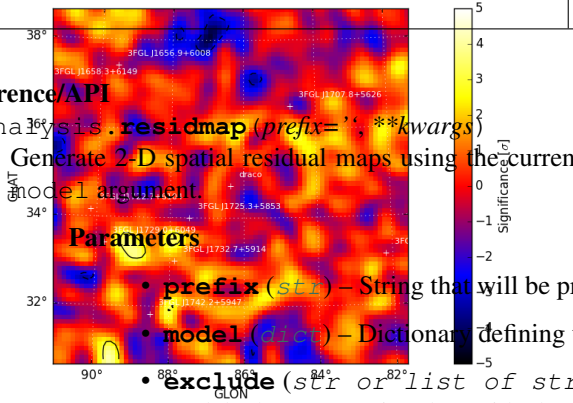
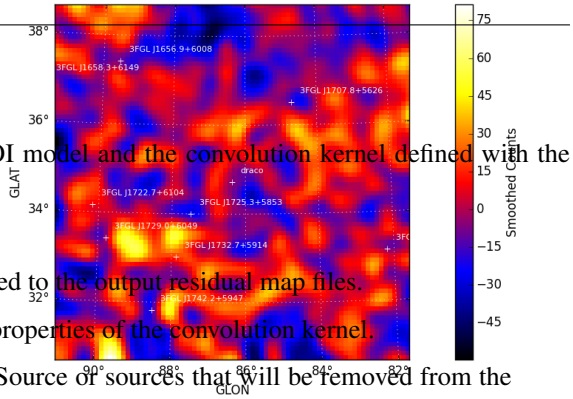
```
# Generate residual map for a Gaussian kernel with Index=2.0 and
# radius (R_68) of 0.3 degrees
model = {'Index' : 2.0,
         'SpatialModel' : 'Gaussian', 'SpatialWidth' : 0.3 }
maps = gta.residmap('fit1',model=model)

# 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,erange=[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. |

Maps are also written as both FITS and rendered image files to the analysis working directory. All output files are prepended with the prefix argument. Sample images for sigma and excess generated by *tsmap()* are shown below. A colormap threshold for the sigma image is applied at both -5 and 5 sigma with iscontours at 2 sigma intervals (-5, -3, 3, 5, 7, 9, ...) indicating values above and below this threshold.

| Sigma | Excess Counts |
|---|---|
|  |  |



**Reference/API**

GTAnalysis.**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.
- **model** (*dict*) – Dictionary defining the properties of the convolution kernel.
- **exclude** (*str or list of str*) – Source or sources that will be removed from the model when computing the residual map.
- **erange** (*list*) – 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** (*bool*) – Write image files.
- **make_fits** (*bool*) – Write FITS files.

**Returns** **maps** – A dictionary containing the *Map* objects for the residual significance and amplitude.

**Return type** dict

### TS Cube

**Warning:** This method is experimental and is not supported by the current public release of the Fermi STs.

GTAnalysis.**tscube**(*prefix=''*, ***kwargs*)

Generate a spatial TS map for a source component with properties defined by the model argument. This method

uses the `gttscube` ST application for source fitting and will simultaneously fit the test source normalization as well as the normalizations of any background components that are currently free. The output of this method is a dictionary containing *Map* objects with the TS and amplitude of the best-fit test source. By default this method will also save maps to FITS files and render them as image files.

**Parameters**

- **prefix** (*str*) – Optional string that will be prepended to all output files (FITS and rendered images).
- **model** (*dict*) – Dictionary defining the properties of the test source.
- **do_sed** (*bool*) – Compute the energy bin-by-bin fits.
- **nnorm** (*int*) – Number of points in the likelihood v. normalization scan.
- **norm_sigma** (*float*) – Number of sigma to use for the scan range.
- **tol** (*float*) – Critetia for fit convergence (estimated vertical distance to min < tol ).
- **tol_type** (*int*) – Absoulte (0) or relative (1) criteria for convergence.
- **max_iter** (*int*) – Maximum number of iterations for the Newton's method fitter
- **remake_test_source** (*bool*) – If true, recomputes the test source image (otherwise just shifts it)
- **st_scan_level** (*int*) –
- **make_plots** (*bool*) – Write image files.
- **make_fits** (*bool*) – Write FITS files.

**Returns** **maps** – A dictionary containing the *Map* objects for TS and source amplitude.

**Return type** dict

### Source Finding

**Warning:** This method is experimental and still under development. API changes are likely to occur in future releases.

*find_sources()* is an iterative source-finding algorithm that uses peak detection on the TS map to find the locations of new sources.

GTAnalysis.**find_sources**(*prefix=''*, ***kwargs*)

An iterative source-finding algorithm.

**Parameters**

- **model** (*dict*) – Dictionary defining the properties of the test source. This is the model that will be used for generating TS maps.
- **sqrt_ts_threshold** (*float*) – Source threshold in sqrt(TS). Only peaks with sqrt(TS) exceeding this threshold will be used as seeds for new sources.
- **min_separation** (*float*) – Minimum separation in degrees of 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.
- **max_iter** (*int*) – 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.

- **sources_per_iter** (*int*) – 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.
- **tsmap_fitter** (*str*) – Set the method used internally for generating TS maps. Valid options:
  - tsmap
  - tscube
- **tsmap** (*dict*) – Keyword arguments dictionary for tsmap method.
- **tscube** (*dict*) – Keyword arguments dictionary for tscube method.

### Source Localization

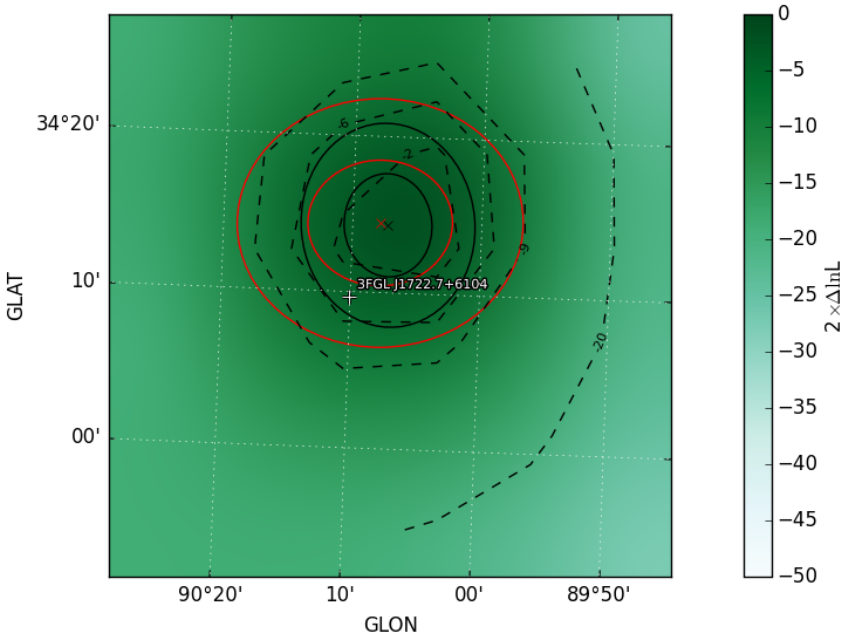
The *localize()* method can be used to spatially localize a source. Localization is performed by scanning the 2D likelihood surface in a local patch around the nominal source position. The current implementation of the localization analysis proceeds in two steps:

- **TS Map Scan**: Obtain a rough estimate of the source position by generating a fast TS Map of the region using the *tsmap* method. In this step all background parameters are fixed to their nominal values.
- **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 with the TS Map method. 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.

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 this information to the *localization* dictionary of the *Source* object.

```
>>> loc = gta.localize('3FGL J1722.7+6104')
>>> print(loc['ra'],loc['dec'],loc['r68'],loc['r95'])
(260.53164555483784, 61.04493807148745, 0.14384100879403075, 0.23213050350030126)
```

By default the method will save a plot to the working directory with a visualization of the localization contours. The black and red contours show the uncertainty ellipse derived from the TS Map and likelihood scan, respectively.




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('sourceA',update=True)
```

The localization method will profile over any background parameters that were free when the method was executed. One can fix all background parameters with the *fix_background* parameter:

```
# Free a nearby source that may be be partially degenerate with the
# source of interest
gta.free_norm('sourceB')
gta.localize('sourceA')
```

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

Listing 1.21: *localize* Output

| Key | Type | Description |
|---|---|---|
| `config` | dict | Copy of the input parameters to this method. |
| `dec` | float | Declination of best-fit position in deg. |
| `glat` | float | Galactic Latitude of best-fit position in deg. |
| `glon` | float | Galactic Longitude of best-fit position in deg. |
| `offset` | float | Angular offset in deg between the current and localized source position. |
| `r68` | float | 68% positional uncertainty in deg. |
| `r95` | float | 95% positional uncertainty in deg. |
| `r99` | float | 99% positional uncertainty in deg. |
| `ra` | float | Right ascension of best-fit position in deg. |
| `sigmax` | float | 1-sigma uncertainty in deg in longitude. |
| `sigmay` | float | 1-sigma uncertainty in deg in latitude. |
| `theta` | float | Position angle of uncertainty ellipse. |
| `xpix` | float | Longitude pixel coordinate of best-fit position. |
| `ypix` | float | Latitude pixel coordinate of best-fit position. |

#### Reference/API

GTAnalysis.**localize**(*name*, ***kwargs*)

Find the best-fit position of a source. Localization is performed in two steps. First a TS map is computed centered on the source with half-width set by dtheta_max. A fit is then performed to the maximum TS peak in this map. The source position is then further refined by scanning the likelihood in the vicinity of the peak found in the first step. The size of the scan region is set to encompass the 99% positional uncertainty contour as determined from the peak fit.

**Parameters**

- **name** (*str*) – Source name.
- **dtheta_max** (*float*) – Maximum offset in RA/DEC in deg from the nominal source position that will be used to define the boundaries of the TS map search region.
- **nstep** (*int*) – 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.
- **fix_background** (*bool*) – Fix background parameters when fitting the source position.
- **update** (*bool*) – Update the model for this source with the best-fit position. If newname=None this will overwrite the existing source map of this source with one corresponding to its new location.
- **newname** (*str*) – Name that will be assigned to the relocalized source when update=True. If newname is None then the existing source name will be used.

**Returns** **localize** – Dictionary containing results of the localization analysis. This dictionary is also saved to the dictionary of this source in 'localize'.

**Return type** dict

### 1.1.6 fermipy package

#### Submodules

#### fermipy.config module

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

Bases: object

**static 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.**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.

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

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

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

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

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

fermipy.config.**create_default_config**(*defaults*)
Create a configuration dictionary from a defaults dictionary. The defaults dictionary defines valid configuration keys with default values and docstrings. Each dictionary element should be a tuple or list containing (default value,docstring,type).

fermipy.config.**validate_config**(*config*, *defaults*, *block='root'*)

### fermipy.defaults module

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

### fermipy.gtanalysis module

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

High-level analysis interface that internally manages a set of analysis component objects. Most of the functionality of the fermiPy package is provided through the methods of this class. The class constructor accepts a dictionary that defines the configuration for the analysis. Keyword arguments provided in **kwargs can be used to override parameter values in the configuration dictionary.

**add_source**(*name*, *src_dict*, *free=False*, *init_source=True*, *save_source_maps=True*, ***kwargs*)
Add a source to the ROI model. This function may be called either before or after setup().

**Parameters**

- **name** (*str*) – Source name.
- **src_dict** (dict or *Source* object) – Dictionary or source object defining the source properties (coordinates, spectral parameters, etc.).
- **free** (*bool*) – Initialize the source with a free normalization parameter.

**cleanup**()

**components**
Return the list of analysis components.

**counts_map**()
Return a *Map* representation of the counts map.

**Returns** map

**Return type** *Map*

**static create**(*infile*, *config=None*)
Create a new instance of GTAnalysis from an analysis output file generated with write_roi. By default the new instance will inherit the configuration of the saved analysis instance. The configuration may be overriden by passing a config file path with the config argument.

**Parameters**

- **infile** (*str*) – Path to the ROI results file.
- **config** (*str*) – Path to a configuration file. This will override the configuration in the ROI results file.

**defaults = {'sourcefind': {'max_iter': (3, 'Set the number of search iterations.', <type 'int'>), 'min_separation': (1.0, 'S**

**delete_source**(*name*, *save_template=True*, *delete_source_map=False*, ***kwargs*)
Delete a source from the model.

**Parameters** **name** (*str*) – Source name.

**Returns** **src** – The deleted source object.

**Return type** *Model*

**delete_sources**(*cuts=None*, *distance=None*, *minmax_ts=None*, *minmax_npred=None*, *square=False*)
Delete sources in the ROI model satisfying the given selection criteria.

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

**Return type** list

**energies**
Return the energy bin edges.

**enumbins**
Return the number of energy bins.

**erange**

**extension**(*name*, ***kwargs*)
Test this source for spatial extension with the likelihood ratio method (TS_ext). This method will substitute an extended spatial model for the given source and perform a one-dimensional scan of the spatial extension parameter over the range specified with the width parameters. The 1-D profile likelihood is then used to compute the best-fit value, upper limit, and TS for extension. Any background parameters that are free will also be simultaneously profiled in the likelihood scan.

**Parameters**

- **name** (*str*) – Source name.
- **spatial_model** (*str*) – Spatial model that will be used when testing extension (e.g. DiskSource, GaussianSource).
- **width_min** (*float*) – Minimum value in degrees for the spatial extension scan.
- **width_max** (*float*) – Maximum value in degrees for the spatial extension scan.
- **width_nstep** (*int*) – Number of scan points between width_min and width_max. Scan points will be spaced evenly on a logarithmic scale between log(width_min) and log(width_max).
- **width** (*array-like*) – Sequence of values in degrees for the spatial extension scan. If this argument is None then the scan points will be determined from width_min/width_max/width_nstep.
- **fix_background** (*bool*) – Fix all background sources when performing the extension fit.
- **update** (*bool*) – Update this source with the best-fit model for spatial extension.
- **save_model_map** (*bool*) – Save model maps for all steps in the likelihood scan.

**Returns** **extension** – Dictionary containing results of the extension analysis. The same dictionary is also saved to the dictionary of this source under 'extension'.

**Return type** dict

**find_sources** (*prefix=''*, ***kwargs*)

An iterative source-finding algorithm.

**Parameters**

- **model** (*dict*) – Dictionary defining the properties of the test source. This is the model that will be used for generating TS maps.
- **sqrt_ts_threshold** (*float*) – Source threshold in sqrt(TS). Only peaks with sqrt(TS) exceeding this threshold will be used as seeds for new sources.
- **min_separation** (*float*) – Minimum separation in degrees of 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.
- **max_iter** (*int*) – 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.
- **sources_per_iter** (*int*) – 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.
- **tsmap_fitter** (*str*) – Set the method used internally for generating TS maps. Valid options:
  - tsmap
  - tscube
- **tsmap** (*dict*) – Keyword arguments dictionary for tsmap method.
- **tscube** (*dict*) – Keyword arguments dictionary for tscube method.

**fit** (*update=True*, ***kwargs*)

Run the likelihood optimization. This will execute a fit of all parameters that are currently free in the ROI model and update the charateristics (TS, Npred, etc.) of the corresponding model components. The fit will be repeated N times (set with the retries parameter) until a fit quality of 3 is obtained.

**Parameters**

- **update** (*bool*) – Do not update the ROI model.
- **tol** (*float*) – Set the optimizer tolerance.
- **verbosity** (*int*) – Set the optimizer output level.
- **retries** (*int*) – Set the number of times to rerun the fit when the fit quality is < 3.
- **min_fit_quality** (*int*) – Set the minimum fit quality. If the fit quality is smaller than this value then all model parameters will be restored to their values prior to the fit.
- **reoptimize** (*bool*) – Refit background sources when updating source properties (TS and likelihood profiles).

**Returns** **fit** – Dictionary containing diagnostic information for the fit (fit quality, parameter covariances, etc.).

**Return type** dict

**free_index**(*name*, *free=True*)
Free/Fix index of a source.

**Parameters**

- **name** (*str*) – Source name.
- **free** (*bool*) – Choose whether to free (free=True) or fix (free=False).

**free_norm**(*name*, *free=True*)
Free/Fix normalization of a source.

**Parameters**

- **name** (*str*) – Source name.
- **free** (*bool*) – Choose whether to free (free=True) or fix (free=False).

**free_parameter**(*name*, *par*, *free=True*)

**free_shape**(*name*, *free=True*)
Free/Fix shape parameters of a source.

**Parameters**

- **name** (*str*) – Source name.
- **free** (*bool*) – Choose whether to free (free=True) or fix (free=False).

**free_source**(*name*, *free=True*, *pars=None*)
Free/Fix parameters of a source.

**Parameters**

- **name** (*str*) – Source name.
- **free** (*bool*) – Choose whether to free (free=True) or fix (free=False) source parameters.
- **pars** (*list*) – Set a list of parameters to be freed/fixed for this source. If none then all source parameters will be freed/fixed with the exception of those defined in the skip_pars list.

**free_sources**(*free=True*, *pars=None*, *cuts=None*, *distance=None*, *minmax_ts=None*, *minmax_npred=None*, *square=False*, *exclude_diffuse=False*)
Free or fix sources in the ROI model satisfying the given selection. When multiple selections are defined, the selected sources will be those satisfying the logical AND of all selections (e.g. distance < X && minmax_ts[0] < ts < minmax_ts[1] && ...).

**Parameters**

- **free** (*bool*) – Choose whether to free (free=True) or fix (free=False) source parameters.
- **pars** (*list*) – Set a list of parameters to be freed/fixed for this source. If none then all source parameters will be freed/fixed. If pars='norm' then only normalization parameters will be freed.
- **cuts** (*dict*) – Dictionary of [min,max] selections on source properties.
- **distance** (*float*) – Distance out to which sources should be freed or fixed. If this parameter is none no selection will be applied.
- **minmax_ts** (*list*) – Free sources that have TS in the range [min,max]. If either min or max are None then only a lower (upper) bound will be applied. If this parameter is none no selection will be applied.

- **minmax_npred** (*list*) – Free sources that have Npred in the range [min,max]. If either min or max are None then only a lower (upper) bound will be applied. If this parameter is none no selection will be applied.
- **square** (*bool*) – Switch between applying a circular or square (ROI-like) selection on the maximum projected distance from the ROI center.
- **exclude_diffuse** (*bool*) – Exclude diffuse sources.

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

**Return type** list

**free_sources_by_position** (*free=True*, *pars=None*, *distance=None*, *square=False*)
Free/Fix all sources within a certain distance of the given sky coordinate. By default it will use the ROI center.

**Parameters**

- **free** (*bool*) – Choose whether to free (free=True) or fix (free=False) source parameters.
- **pars** (*list*) – Set a list of parameters to be freed/fixed for this source. If none then all source parameters will be freed/fixed. If pars='norm' then only normalization parameters will be freed.
- **distance** (*float*) – Distance in degrees out to which sources should be freed or fixed. If none then all sources will be selected.
- **square** (*bool*) – Apply a square (ROI-like) selection on the maximum distance in either X or Y in projected cartesian coordinates.

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

**Return type** list

**generate_model** (*model_name=None*)
Generate model maps for all components. model_name should be a unique identifier for the model. If model_name is None then the model maps will be generated using the current parameters of the ROI.

**generate_model_map** (*model_name*, *name=None*)

**Parameters**

- **model_name** (*str*) – String that will be append to the name of the output file.
- **name** (*str*) – Name of the component.

**get_free_params** ()

**get_free_source_params** (*name*)

**get_model_map** (*name=None*)

**get_source_name** (*name*)
Return the name of a source as it is defined in the pyLikelihood model object.

**get_sources** (*cuts=None*, *distance=None*, *minmax_ts=None*, *minmax_npred=None*, *square=False*)
Retrieve list of sources in the ROI model satisfying the given selections.

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

**Return type** list

**get_src_model** (*name*, *paramsonly=False*, *reoptimize=False*, *npts=20*)
Compose a dictionary for the given source with the current best-fit parameters.

**Parameters**

- **name** (*str*) –
- **paramsonly** (*bool*) –
- **reoptimize** (*bool*) – Re-fit background parameters in likelihood scan.
- **npts** (*int*) – Number of points for likelihood scan.

**like**
Return the global likelihood object.

**load_roi**(*infile*)
This function reloads the analysis state from a previously saved instance generated with *write_roi*.

**load_xml**(*xmlfile*)
Load model definition from XML.

**localize**(*name*, ***kwargs*)
Find the best-fit position of a source. Localization is performed in two steps. First a TS map is computed centered on the source with half-width set by `dtheta_max`. A fit is then performed to the maximum TS peak in this map. The source position is then further refined by scanning the likelihood in the vicinity of the peak found in the first step. The size of the scan region is set to encompass the 99% positional uncertainty contour as determined from the peak fit.

**Parameters**

- **name** (*str*) – Source name.
- **dtheta_max** (*float*) – Maximum offset in RA/DEC in deg from the nominal source position that will be used to define the boundaries of the TS map search region.
- **nstep** (*int*) – 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.
- **fix_background** (*bool*) – Fix background parameters when fitting the source position.
- **update** (*bool*) – Update the model for this source with the best-fit position. If newname=None this will overwrite the existing source map of this source with one corresponding to its new location.
- **newname** (*str*) – Name that will be assigned to the relocalized source when update=True. If newname is None then the existing source name will be used.

**Returns** **localize** – Dictionary containing results of the localization analysis. This dictionary is also saved to the dictionary of this source in 'localize'.

**Return type** dict

**make_plots**(*prefix*, *mcube_maps*, ***kwargs*)

**model_counts_map**(*name=None*, *exclude=None*)
Return the model counts map for a single source, a list of sources, or for the sum of all sources in the ROI. The exclude parameter can be used to exclude one or more components when generating the model map.

**Parameters**

- **name** (*str or list of str*) – Parameter controlling the set of sources for which the model counts map will be calculated. If name=None the model map will be generated for all sources in the ROI.

- **exclude** (*str or list of str*) – List of sources that will be excluded when calculating the model map.

**Returns** **maps** – A list of *Map* objects.

**Return type** list

**model_counts_spectrum**(*name*, *emin=None*, *emax=None*, *summed=False*)
Return the predicted number of model counts versus energy for a given source and energy range. If summed=True return the counts spectrum summed over all components otherwise return a list of model spectra.

**npix**
Return the number of energy bins.

**optimize**(***kwargs*)
Iteratively optimize the ROI model. The optimization is performed in three sequential steps:

•Free the normalization of the N largest components (as determined from NPred) that contain a fraction `npred_frac` of the total predicted counts in the model and perform a simultaneous fit of the normalization parameters of these components.

•Individually fit the normalizations of all sources that were not included in the first step in order of their Npred values. Skip any sources that have NPred < `npred_threshold`.

•Individually fit the shape and normalization parameters of all sources with TS > `shape_ts_threshold` where TS is determined from the first two steps of the ROI optimization.

To ensure that the model is fully optimized this method can be run multiple times.

**Parameters**

- **npred_frac** (*float*) – Threshold on the fractional number of counts in the N largest components in the ROI. This parameter determines the set of sources that are fit in the first optimization step.
- **npred_threshold** (*float*) – Threshold on the minimum number of counts of individual sources. This parameter determines the sources that are fit in the second optimization step.
- **shape_ts_threshold** (*float*) – Threshold on source TS used for determining the sources that will be fit in the third optimization step.

**print_model**()

**print_roi**()

**profile**(*name*, *parName*, *emin=None*, *emax=None*, *reoptimize=False*, *xvals=None*, *npts=None*, *savestate=True*)
Profile the likelihood for the given source and parameter.

**profile_norm**(*name*, *emin=None*, *emax=None*, *reoptimize=False*, *xvals=None*, *npts=20*, *savestate=True*)
Profile the normalization of a source.

**Parameters**

- **name** (*str*) – Source name.
- **reoptimize** (*bool*) – Re-optimize all free parameters in the model at each point in the profile likelihood scan.

**projtype**
Return the type of projection to use

**reload_source**(*name*)
Delete and reload a source in the model. This will refresh the spatial model of this source to the one defined in the XML model.

**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.
- **model** (*dict*) – Dictionary defining the properties of the convolution kernel.
- **exclude** (*str or list of str*) – Source or sources that will be removed from the model when computing the residual map.
- **erange** (*list*) – 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** (*bool*) – Write image files.
- **make_fits** (*bool*) – Write FITS files.

**Returns** **maps** – A dictionary containing the *Map* objects for the residual significance and amplitude.

**Return type** dict

**restore_counts_maps**()
Revert counts maps to their state prior to injecting any simulated components.

**roi**
Return the ROI object.

**scale_parameter**(*name*, *par*, *scale*)

**sed**(*name*, *profile=True*, *energies=None*, ***kwargs*)
Generate an SED for a source. This function will fit the normalization of a given source in each energy bin.

**Parameters**

- **name** (*str*) – Source name.
- **profile** (*bool*) – Profile the likelihood in each energy bin.
- **energies** (ndarray) – Sequence of energies in log10(E/MeV) defining the edges of the energy bins. If this argument is None then the analysis energy bins will be used. The energies in this sequence must align with the bin edges of the underyling analysis instance.
- **bin_index** (*float*) – Spectral index that will be use when fitting the energy distribution within an energy bin.
- **use_local_index** (*bool*) – 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.
- **fix_background** (*bool*) – Fix background components when fitting the flux normalization in each energy bin. If fix_background=False then all background parameters that are currently free in the fit will be profiled. By default fix_background=True.
- **ul_confidence** (*float*) – Set the confidence level that will be used for the calculation of flux upper limits in each energy bin.

**Returns** **sed** – This dictionary is also saved to the 'sed' dictionary of the *Source* instance.

**Return type** dict Dictionary containing output of the SED analysis.

**setEnergyRange**(*emin*, *emax*)
Set the energy range of the analysis.

**set_edisp_flag**(*name*, *flag=True*)
Enable or disable the energy dispersion correction for the given source.

**set_free_params**(*free*)

**set_log_level**(*level*)

**set_norm**(*name*, *value*)

**set_norm_scale**(*name*, *value*)

**set_parameter**(*name*, *par*, *value*, *true_value=True*, *scale=None*, *bounds=None*, *update_source=True*)

**set_parameter_bounds**(*name*, *par*, *bounds*)
Set the bounds of a parameter.

**Parameters**

- **name** (*str*) – Source name.
- **par** (*str*) – Parameter name.
- **bounds** (*list*) – Upper and lower bound.

**setup**(*init_sources=True*, *overwrite=False*)
Run pre-processing for each analysis component and construct a joint likelihood object. This function performs the following tasks: data selection (gtselect, gtmktime), data binning (gtbin), and model generation (gtexpcube2,gtsrcmaps).

**Parameters**

- **init_sources** (*bool*) – Choose whether to compute properties (flux, TS, etc.) for individual sources.
- **overwrite** (*bool*) – Run all pre-processing steps even if the output file of that step is present in the working directory. By default this function will skip any steps for which the output file already exists.

**simulate_roi**()
Perform a simulation of the whole ROI. This will replace the current counts cube with a simulated realization of the current model. The counts cube can be restored to its original state by calling `restore_counts_maps`.

**simulate_source**(*src_dict=None*)
Inject a simulated source into the ROI.

**Parameters** **src_dict** (*dict*) –

**stage_input**()
Copy data products to intermediate working directory.

**stage_output**()
Copy data products to final output directory.

**tscube**(*prefix=''*, ***kwargs*)
Generate a spatial TS map for a source component with properties defined by the `model` argument. This method uses the `gttscube` ST application for source fitting and will simultaneously fit the test source normalization as well as the normalizations of any background components that are currently free. The

output of this method is a dictionary containing *Map* objects with the TS and amplitude of the best-fit test source. By default this method will also save maps to FITS files and render them as image files.

**Parameters**

- **prefix** (*str*) – Optional string that will be prepended to all output files (FITS and rendered images).
- **model** (*dict*) – Dictionary defining the properties of the test source.
- **do_sed** (*bool*) – Compute the energy bin-by-bin fits.
- **nnorm** (*int*) – Number of points in the likelihood v. normalization scan.
- **norm_sigma** (*float*) – Number of sigma to use for the scan range.
- **tol** (*float*) – Critetia for fit convergence (estimated vertical distance to min < tol ).
- **tol_type** (*int*) – Absoulte (0) or relative (1) criteria for convergence.
- **max_iter** (*int*) – Maximum number of iterations for the Newton's method fitter
- **remake_test_source** (*bool*) – If true, recomputes the test source image (otherwise just shifts it)
- **st_scan_level** (*int*) –
- **make_plots** (*bool*) – Write image files.
- **make_fits** (*bool*) – Write FITS files.

**Returns** **maps** – A dictionary containing the *Map* objects for TS and source amplitude.

**Return type** dict

**tsmap** (*prefix=''*, ***kwargs*)

Generate a spatial TS map for a source component with properties defined by the `model` argument. The TS map will have the same geometry as the ROI. The output of this method is a dictionary containing *Map* objects with the TS and amplitude of the best-fit test source. By default this method will also save maps to FITS files and render them as image files.

This method uses a simplified likelihood fitting implementation that only fits for the normalization of the test source. Before running this method it is recommended to first optimize the ROI model (e.g. by running *optimize()*).

**Parameters**

- **prefix** (*str*) – Optional string that will be prepended to all output files (FITS and rendered images).
- **model** (*dict*) – Dictionary defining the properties of the test source.
- **exclude** (*str or list of str*) – Source or sources that will be removed from the model when computing the TS map.
- **erange** (*list*) – 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.
- **max_kernel_radius** (*float*) – Set the maximum radius of the test source kernel. Using a smaller value will speed up the TS calculation at the loss of accuracy. The default value is 3 degrees.
- **make_plots** (*bool*) – Write image files.

- **make_fits** (*bool*) – Write FITS files.

**Returns** **maps** – A dictionary containing the *Map* objects for TS and source amplitude.

**Return type** dict

**unzero_source**(*name*)

**update_source**(*name*, *paramsonly=False*, *reoptimize=False*, *npts=20*)
Update the dictionary for this source.

**Parameters**

- **name** (*str*) –
- **paramsonly** (*bool*) –
- **reoptimize** (*bool*) – Re-fit background parameters in likelihood scan.
- **npts** (*int*) – Number of points for likelihood scan.

**workdir**
Return the analysis working directory.

**write_roi**(*outfile=None*, *make_residuals=False*, *make_tsmap=False*, *save_model_map=True*, *format=None*, ***kwargs*)
Write current model to a file. This function will write an XML model file and an ROI dictionary in both YAML and npy formats.

**Parameters**

- **outfile** (*str*) – Name of the output file. The extension of this string will be stripped when generating the XML, YAML and Numpy filenames.
- **make_residuals** (*bool*) – Run residual analysis.
- **save_model_map** (*bool*) – Save the current counts model as a FITS file.
- **format** (*str*) – Set the output file format (yaml or npy).

**write_xml**(*xmlfile*)
Save current model definition as XML file.

**Parameters** **xmlfile** (*str*) – Name of the output XML file.

**zero_source**(*name*)

### 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 get**(*name*, *logfile*, *loglevel=10*)

**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.**logLevel**(*level*)
This is a function that returns a python like level from a HEASOFT like level.

### fermipy.roi_model module

**class** fermipy.roi_model.**Catalog**(*table*, *extdir=''*)
Bases: object

Source catalog object. This class provides a simple wrapper around FITS catalog tables.

**static create**(*name*)

**glonlat**

**radec**

**skydir**

**table**
Return the Table representation of this catalog.

**class** fermipy.roi_model.**Catalog2FHL**(*fitsfile=None*, *extdir=None*)
Bases: *fermipy.roi_model.Catalog*

**class** fermipy.roi_model.**Catalog3FGL**(*fitsfile=None*, *extdir=None*)
Bases: *fermipy.roi_model.Catalog*

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

**diffuse**

**filefunction**

**write_xml**(*root*)

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

**diffuse**

**mapcube**

**write_xml**(*root*)

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

Base class for source objects. This class is a container for both spectral and spatial parameters as well as other source properties such as TS, Npred, and location within the ROI.

**add_name**(*name*)

**assoc**

**check_cuts**(*cuts*)

**static create_from_dict**(*src_dict*)

**data**

**get_norm**()

**items**()

**name**

**names**

**params**

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

**set_spectral_pars**(*spectral_pars*)

**spatial_pars**

**spectral_pars**

**update_data**(*d*)

**update_from_source**(*src*)

**class** fermipy.roi_model.**PowerLaw**(*phi0*, *x0*, *index*)
Bases: object

**dfde**(*x*)

**static eval_dfde**(*x*, *phi0*, *x0*, *index*)

**static eval_flux**(*phi0*, *x0*, *index*, *xmin*, *xmax*)

**static eval_norm**(*x0*, *index*, *xmin*, *xmax*, *flux*)

**params**

**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 emission 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
-------------------------------------------------------------------------------
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']
```

•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
```

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

**copy_source**(*name*)

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

static **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.

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

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

static **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*)
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*

**defaults = {'logfile': (None, '', <type 'str'>), 'catalogs': (None, '', <type 'list'>), 'src_roiwidth': (None, 'Select sources v**

**delete_sources**(*srcs*)

**diffuse_sources**

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

**get_source_by_name**(*name*, *unique=False*)
Return a source in the ROI by 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*) –
- **unique** (*bool*) – Require a unique match. If more than one source exists with this name an exception is raised.

**get_sources**(*cuts=None*, *distance=None*, *minmax_ts=None*, *minmax_npred=None*, *square=False*, *exclude_diffuse=False*, *coordsys='CEL'*)
Retrieve list of sources satisfying the given selections.

**Returns** **srcs** – List of source 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_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**

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

**sources**

**src_name_cols = ['Source_Name', 'ASSOC', 'ASSOC1', 'ASSOC2', 'ASSOC_GAM', '1FHL_Name', '2FGL_Name',**

**write_xml**(*xmlfile*)
Save this ROI model as an XML file.

**class** fermipy.roi_model.**Source**(*name*, *data=None*, *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 >>> print src['ts']

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

**associations**

**static create_from_dict**(*src_dict*)
Create a source object from a python dictionary.

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

**data**

**diffuse**

**extended**

**load_from_catalog**()
Load spectral parameters from catalog values.

**radec**

**separation**(*src*)

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

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

**set_roi_direction**(*roidir*)

**set_spatial_model**(*spatial_model*, *spatial_width=None*)

**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.**add_columns**(*t0*, *t1*)
Add columns of table t1 to table t0.

fermipy.roi_model.**create_model_name**(*src*)

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.**join_tables**(*t0*, *t1*, *key0*, *key1*)

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

fermipy.roi_model.**make_parameter_dict**(*pdict*, *fixed_par=False*)

fermipy.roi_model.**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.roi_model.**resolve_file_path**(*path*, ***kwargs*)

fermipy.roi_model.**row_to_dict**(*row*)

fermipy.roi_model.**scale_parameter**(*p*)

fermipy.roi_model.**strip_columns**(*t*)

fermipy.roi_model.**xyz_to_lonlat**(**args*)

### fermipy.utils module

**class** fermipy.utils.**Map**(*counts*, *wcs*)
Bases: *fermipy.utils.Map_Base*

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

**static create_from_fits**(*fitsfile*, ***kwargs*)

**static create_from_hdu**(*hdu*, *wcs*)

**create_image_hdu**(*name=None*)

**create_primary_hdu**()

**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 the pixel xy coordinates from the pixel index

if colwise is True (False) this uses columnwise (rowwise) indexing

**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 Map center.

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

**wcs**

**width**
Return the sky coordinate of the Map center.

**xy_pix_to_ipix**(*xypix*, *colwise=False*)
Return the pixel index from the pixel xy coordinates

if colwise is True (False) this uses columnwise (rowwise) indexing

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

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

**counts**

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

fermipy.utils.**cl_to_dlnl**(*cl*)
Compute the delta-log-likehood corresponding to an upper limit of the given confidence level.

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

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_source_name**(*skydir*)

fermipy.utils.**create_wcs**(*skydir*, *coordsys='CEL'*, *projection='AIT'*, *cdelt=1.0*, *crpix=1.0*, *naxis=2*, *energies=None*)

Create a WCS object.

**Parameters** **skydir** (SkyCoord) – Sky coordinate of the WCS reference point.

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

fermipy.utils.**delete_source_map**(*srcmap_file*, *name*, *logger=None*)

Delete a map from a binned analysis source map file if it exists.

**Parameters**

- **srcmap_file** (*str*) – Path to the source map file.
- **name** (*str*) – HDU key of source map.

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

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

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

fermipy.utils.**extract_mapcube_region**(*infile*, *skydir*, *outfile*, *maphdu=0*)

Extract a region out of an all-sky mapcube file.

**Parameters**

- **infile** (*str*) – Path to mapcube file.
- **skydir** (SkyCoord) –

fermipy.utils.**find_function_root**(*fn*, *x0*, *xb*, *delta*)

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.**fit_parabola**(*z*, *ix*, *iy*, *dpix=2*, *zmin=None*)

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_coordsys**(*wcs*)

fermipy.utils.**get_parameter_limits**(*xval*, *logLike*, *ul_confidence=0.95*)

Compute upper/lower limits, peak position, and 1-sigma errors from a 1-D likelihood function.

**Parameters**

- **xval** (ndarray) – Array of parameter values.
- **logLike** (ndarray) – Array of log-likelihood values.

- **ul_confidence** (*float*) – Confidence level to use for limit calculation.

fermipy.utils.**get_target_skydir**(*config*, *default=None*)

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

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

fermipy.utils.**make_cdisk_kernel**(*psf*, *sigma*, *npix*, *cdelt*, *xpix*, *ypix*, *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*, *normalize=False*)
Make a kernel for a PSF-convolved 2D gaussian.

**Parameters**

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

fermipy.utils.**make_cgauss_mapcube**(*skydir*, *psf*, *sigma*, *outfile*, *npix=500*, *cdelt=0.01*, *rebin=1*)

fermipy.utils.**make_disk_kernel**(*sigma*, *npix=501*, *cdelt=0.01*, *xpix=0.0*, *ypix=0.0*)
Make kernel for a 2D disk.

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

fermipy.utils.**make_disk_spatial_map**(*skydir*, *sigma*, *outfile*, *npix=501*, *cdelt=0.01*)

fermipy.utils.**make_gaussian_kernel**(*sigma*, *npix=501*, *cdelt=0.01*, *xpix=0.0*, *ypix=0.0*)
Make kernel for a 2D gaussian.

**Parameters** **sigma** (*float*) – 68% containment radius in degrees.

fermipy.utils.**make_gaussian_spatial_map**(*skydir*, *sigma*, *outfile*, *npix=501*, *cdelt=0.01*)

fermipy.utils.**make_pixel_offset**(*npix*, *xpix=0.0*, *ypix=0.0*)
Make a 2D array with the distance of each pixel from a reference direction in pixel coordinates. Pixel coordinates are defined such that (0,0) is located at the center of the coordinate grid.

fermipy.utils.**make_psf_kernel**(*psf*, *npix*, *cdelt*, *xpix*, *ypix*, *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_psf_mapcube**(*skydir*, *psf*, *outfile*, *npix=500*, *cdelt=0.01*, *rebin=1*)

fermipy.utils.**make_srcmap**(*skydir*, *psf*, *spatial_model*, *sigma*, *npix=500*, *xpix=0.0*, *ypix=0.0*, *cdelt=0.01*, *rebin=1*)
Compute the source map for a given spatial model.

**Parameters**

- **xpix** (*float*) –
- **ypix** (*float*) –

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.

add_new_keys : Do not skip keys that only exist in d1.

append_arrays : If an element is a numpy array set the value of that element by concatenating the two arrays.

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

fermipy.utils.**offset_to_sky**(*skydir*, *offset_lon*, *offset_lat*, *coordsys='CEL'*, *projection='AIT'*)
Convert a cartesian offset (X,Y) in the given projection into a spherical coordinate.

fermipy.utils.**offset_to_skydir**(*skydir*, *offset_lon*, *offset_lat*, *coordsys='CEL'*, *projection='AIT'*)
Convert a cartesian offset (X,Y) in the given projection into a spherical coordinate.

fermipy.utils.**parabola**((*x*, *y*), *amplitude*, *x0*, *y0*, *sx*, *sy*, *theta*)

fermipy.utils.**pix_to_skydir**(*xpix*, *ypix*, *wcs*)
Convert pixel coordinates to a skydir object.

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

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

fermipy.utils.**read_energy_bounds**(*hdu*)
Reads and returns the energy bin edges from a FITs HDU

fermipy.utils.**read_spectral_data**(*hdu*)
Reads and returns the energy bin edges, fluxes and npreds from a FITs HDU

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

fermipy.utils.**sky_to_offset**(*skydir*, *lon*, *lat*, *coordsys='CEL'*, *projection='AIT'*)
Convert sky coordinates to a projected offset. This function is the inverse of offset_to_sky.

fermipy.utils.**skydir_to_pix**(*skydir*, *wcs*)
Convert skydir object to pixel coordinates.

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.

1.numpy arrays into python lists

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

2.numpy strings into python strings.

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

3.an ordered dict to a dict

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

4.converts unicode to regular strings

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

5.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.**update_source_maps**(*srcmap_file*, *srcmaps*, *logger=None*)

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.**write_fits_image**(*data*, *wcs*, *outfile*)

fermipy.utils.**write_hpx_image**(*data*, *hpx*, *outfile*, *extname='SKYMAP'*)

fermipy.utils.**write_maps**(*primary_map*, *maps*, *outfile*)

### fermipy.tsmap module

**class** fermipy.tsmap.**TSCubeGenerator**(*config=None*, ***kwargs*)
Bases: *fermipy.config.Configurable*

**defaults = {'do_sed': (True, 'Compute the energy bin-by-bin fits', <type 'bool'>), 'norm_sigma': (5.0, 'Number of sign**

**make_ts_cube**(*gta*, *prefix*, *src_dict=None*, ***kwargs*)

**class** fermipy.tsmap.**TSMapGenerator**(*config=None*, ***kwargs*)
Bases: *fermipy.config.Configurable*

**defaults = {'multithread': (False, '', <type 'bool'>), 'fileio': {'workdir': (None, 'Override the working directory.', <typ**

**make_ts_map**(*gta*, *prefix*, *src_dict=None*, ***kwargs*)
Make a TS map from a GTAnalysis instance. The spectral/spatial characteristics of the test source can be defined with the src_dict argument. By default this method will generate a TS map for a point source with an index=2.0 power-law spectrum.

**Parameters**

- **gta** (*GTAnalysis*) – Analysis instance.
- **src_dict** (dict or *Source* object) – Dictionary or Source object defining the properties of the test source that will be used in the scan.

fermipy.tsmap.**cash**(*counts*, *model*)
Compute the Poisson log-likelihood function.

fermipy.tsmap.**extract_array**(*array_large*, *array_small*, *position*)

fermipy.tsmap.**extract_large_array**(*array_large*, *array_small*, *position*)

fermipy.tsmap.**extract_small_array**(*array_small*, *array_large*, *position*)

fermipy.tsmap.**f_cash**(*x*, *counts*, *background*, *model*)
Wrapper for cash statistics, that defines the model function.

**Parameters**

- **x** (*float*) – Model amplitude.
- **counts** (ndarray) – Count map slice, where model is defined.
- **background** (ndarray) – Background map slice, where model is defined.
- **model** (ndarray) – Source template (multiplied with exposure).

fermipy.tsmap.**f_cash_sum**(*x*, *counts*, *background*, *model*)

fermipy.tsmap.**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.tsmap.**poisson_log_like**(*counts*, *model*)
Compute the Poisson log-likelihood function for the given counts and model arrays.

fermipy.tsmap.**sum_arrays**(*x*)

fermipy.tsmap.**truncate_array**(*array1*, *array2*, *position*)
Truncate array1 by finding the overlap with array2 when the array1 center is located at the given position in array2.

### fermipy.residmap module

**class** fermipy.residmap.**ResidMapGenerator**(*config=None*, ***kwargs*)
Bases: *fermipy.config.Configurable*

This class generates spatial residual maps from the difference of data and model maps smoothed with a user-defined spatial/spectral template. The resulting map of source significance can be interpreted in the same way as the TS map (the likelihood of a source at the given location). The algorithm approximates the best-fit source amplitude that would be derived from a least-squares fit to the data.

**defaults = {'logging': {'verbosity': (3, '', <type 'int'>), 'chatter': (3, 'Set the chatter parameter of the STs.', <type 'int'**

**make_residual_map**(*gta*, *prefix*, *src_dict=None*, ***kwargs*)

**run**(*gta*, *prefix*, ***kwargs*)

fermipy.residmap.**convolve_map**(*m*, *k*, *cpix*, *threshold=0.001*, *imin=0*, *imax=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.

fermipy.residmap.**get_source_kernel**(*gta*, *name*, *kernel=None*)
Get the PDF for the given source.

fermipy.residmap.**poisson_lnl**(*nc*, *mu*)

### fermipy.sed module

Utilities for dealing with SEDs

**Many parts of this code are taken from dsphs/like/lnlfn.py by** Matthew Wood <mdwood@slac.stanford.edu> Alex Drlica-Wagner <kadrlica@slac.stanford.edu>

**class** fermipy.sed.**CastroData**(*norm_vals*, *nll_vals*, *specData*, *fluxType*)
Bases: object

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

**TS_spectrum**(*spec_vals*)
Calculate and the TS for a given set of spectral values

**__call__**(*x*)
return the log-like for an array of values, summed over the energy bins

x : Array of nEbins x M values

returns an array of M values

**__getitem__**(*i*)
return the LnLFn object for the ith energy bin

**buildTestSpectrumFunction**(*specType*)

**derivative**(*x*, *der=1*)
return the derivate of the log-like summed over the energy bins

x : Array of nEbins x M values der : Order of the derivate

returns an array of M values

**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 the best-fit normalization value

**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

returns the best-fit normalization value

**fit_spectrum**(*specFunc*, *initPars*)
Fit for the free parameters of a spectral function

Parameters

specFunc : The Spectral Function initPars : The initial values of the parameters

Returns (result,spec_out,TS_spec)

result : The output of scipy.optimize.fmin spec_out : The best-fit spectral values TS_spec : The TS of the best-fit spectrum

**fluxType**
Return the Flux type flag

**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

**getLimits**(*alpha*, *upper=True*)
Evaluate the limits corresponding to a C.L. of (1-alpha)%.

**Parameters**

- **alpha**(*limit confidence level.*) –
- **upper**(*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

**specData**
Return the Spectral Data object

**test_spectra**(*spec_types=['PowerLaw', 'LogParabola', 'PLExpCutoff']*)

**ts_vals**()
returns test statistic values for each energy bin

**class** fermipy.sed.**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

**__call__**(*x*)
Return the interpolated values for an array of inputs

x : the inputs

Note that if any x value is outside the interpolation ranges this will return a linear extrapolation based on the slope at the endpoint

**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.sed.**LnLFn**(*x*, *y*, *fluxType=0*)
Bases: object

Helper class for interpolating a 1-D log-likelihood function from a set of tabulated values.

**TS**()
return the Test Statistic

**fluxType**
return a code specifying the quantity used for the flux

0: Normalization w.r.t. to test source 1: Flux of the test source ( ph cm^-2 s^-1 ) 2: Energy Flux of the test source ( MeV cm^-2 s^-1 ) 3: Number of predicted photons 4: Differential flux of the test source ( ph cm^-2 s^-1 MeV^-1 ) 5: Differential energy flux of the test source ( MeV cm^-2 s^-1 MeV^-1 )

**fn_mle**()
return the function value at the maximum likelihood estimate

**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

fermipy.sed.**LogParabola**(*evals*, *scale*)

fermipy.sed.**PLExpCutoff**(*evals*, *scale*)

fermipy.sed.**PowerLaw**(*evals*, *scale*)

**class** fermipy.sed.**SEDGenerator**(*config=None*, ***kwargs*)
Bases: *fermipy.config.Configurable*

**defaults = {'bin_index': (2.0, 'Spectral index that will be use when fitting the energy distribution within an energy bin.'**

**make_sed**(*gta*, *name*, *profile=True*, *energies=None*, ***kwargs*)
Generate an SED for a source. This function will fit the normalization of a given source in each energy bin.

**Parameters**

- **name** (*str*) – Source name.
- **profile** (*bool*) – Profile the likelihood in each energy bin.
- **energies** (ndarray) – Sequence of energies in log10(E/MeV) defining the edges of the energy bins. If this argument is None then the analysis energy bins will be used. The energies in this sequence must align with the bin edges of the underyling analysis instance.
- **bin_index** (*float*) – Spectral index that will be use when fitting the energy distribution within an energy bin.
- **use_local_index** (*bool*) – 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.
- **fix_background** (*bool*) – Fix background components when fitting the flux normalization in each energy bin. If fix_background=False then all background parameters that are currently free in the fit will be profiled. By default fix_background=True.

**Returns** **sed** – Dictionary containing results of the SED analysis. The same dictionary is also saved to the source dictionary under 'sed'.

**Return type** dict

**class** fermipy.sed.**SpecData**(*ebins*, *fluxes*, *npreds*)
Bases: object

This class wraps spectral data, e.g., energy bin definitions, flux values and number of predicted photons

**bin_widths**
return the energy bin widths

**ebins**
return the energy bin edges

**efluxes**
return the energy flux values

**evals**
return the energy centers

**fluxes**
return the flux values

**log_ebins**
return the log10 of the energy bin edges

**nE**
return the number of energy bins

**npreds**
return the number of predicted events

**class** fermipy.sed.**TSCube**(*tsmap*, *normmap*, *tscube*, *norm_vals*, *nll_vals*, *specData*, *fluxType*)
Bases: object

**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

**static create_from_fits**(*fitsfile*, *fluxType*)
Build a TSCube object from a fits file created by gttscube

**find_and_refine_peaks**(*threshold*, *min_separation=1.0*, *use_cumul=False*)

**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

**normmap**
return the Map of the Best-fit normalization value

**specData**
Return the Spectral Data object

**test_spectra_of_peak**(*peak, spec_types=['PowerLaw', 'LogParabola', 'PLExpCutoff']*)

**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.sed.**alphaToDeltaLogLike_1DOF**(*alpha*)
return the delta log-likelihood corresponding to a particular C.L. of (1-alpha)%

fermipy.sed.**build_source_dict**(*src_name*, *peak_dict*, *spec_dict*, *spec_type*)

### Module contents

CHAPTER 2

# Indices and tables

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