Fermipy Documentation

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Contents

CHAPTER 1

Introduction

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

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

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

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

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

1.1 Getting Help

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

1.2 Documentation Contents

1.2.1 Installation

Note: Fermipy is only compatible with Science Tools v10r0p5 or later. If you are using an earlier version, you will need to download and install the latest version from the FSSC. Note that it is recommended to use the *non-ROOT* binary distributions of the Science Tools.

These instructions assume that you already have a local installation of the Fermi Science Tools (STs). For more information about installing and setting up the STs see *Installing the Fermi Science Tools*. 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. The *Installing with Docker* instructions can be used to install the STs on both OSX and Linux machines that are new enough to support Docker.

Installing the Fermi Science Tools

The Fermi STs are a prerequisite for fermipy. To install the STs we recommend using one of the non-ROOT binary distributions available from the FSSC. The following example illustrates how to install the binary distribution on a Linux machine running Ubuntu Trusty:

```
$ curl -OL http://fermi.gsfc.nasa.gov/ssc/data/analysis/software/tar/ScienceTools-v10r0p5-fssc-201505
$ tar xzf ScienceTools-v10r0p5-fssc-20150518-x86_64-unknown-linux-gnu-libc2.19-10-without-rootA.tar.g
$ export FERMI_DIR=ScienceTools-v10r0p5-fssc-20150518-x86_64-unknown-linux-gnu-libc2.19-10-without-ro
$ source $FERMI_DIR/fermi-init.sh
```

More information about installing the STs as well as the complete list of the available binary distributions is available on the FSSC software page.

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 anaconda 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.

If you already have an existing anaconda python installation then fermipy can be installed from the conda-forge channel as follows:

```
$ conda config --append channels conda-forge
$ conda install fermipy
```

If you do not have an anaconda installation, the `condainstall.sh` script can be used to create a minimal anaconda installation from scratch. First download and source the `condainstall.sh` script from the fermipy repository:

```
$ curl -OL https://raw.githubusercontent.com/fermiPy/fermipy/master/condainstall.sh
$ source 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 anaconda installed and the `conda` command is in your path the script will use your existing installation. After running `condainstall.sh` fermipy can be installed with conda:

```
$ conda install fermipy
```

Alternatively fermipy can be installed from source following the instructions in *Building from Source*.

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

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

If you installed fermipy in a specific conda environment you should switch to this environment before running the script:

```
$ source activate fermi-env
$ source condasetup.sh
```

Installing with Docker

Note: This method for installing the STs is currently experimental and has not been fully tested on all operating systems. If you encounter issues please try either the pip- or anaconda-based installation instructions.

Docker is a virtualization tool that can be used to deploy software in portable containers that can be run on any operating system that supports Docker. Before following these instruction you should first install docker on your machine following the installation instructions for your operating system. Docker is currently supported on the following operating systems:

- macOS 10.10.3 Yosemite or later
- Ubuntu Precise 12.04 or later
- Debian 8.0 or later

- RHEL7 or later
- Windows 10 or later

Note that Docker is not supported by RHEL6 or its variants (CentOS6, Scientific Linux 6).

These instructions describe how to create a docker-based ST installation that comes preinstalled with anaconda python and fermipy. The installation is fully contained in a docker image that is roughly 2GB in size. To see a list of the available images go to the fermipy Docker Hub page. Images are tagged with the release version of the STs that was used to build the image (e.g. 11-05-00).

To install an image first download the image file:

```
$ docker pull fermipy/fermist-python:11-05-00
$ docker tag fermipy/fermist-python:11-05-00 fermist
```

This will create an image called *fermist*. Now change to the directory where you plan to do your analysis and run the following command to launch a docker container instance:

```
$ docker run -it --rm -p 8888:8888 -v $PWD:/workdir -w /workdir fermist
```

This will start an ipython notebook server that will be attached to port 8888. Once the server is running you can start a notebook session by navigating to the URL http://localhost:8888/. The `-v $PWD:/workdir` argument mounts the current directory to the working area of the container. Additional directories may be mounted by adding more volume arguments `-v` with host and container paths separated by a colon.

The same docker image may be used to launch python, ipython, or a bash shell by passing the command as an argument to `docker run`:

```
$ docker run -it --rm -v $PWD:/workdir -w /workdir fermist ipython
$ docker run -it --rm -v $PWD:/workdir -w /workdir fermist python
$ docker run -it --rm -v $PWD:/workdir -w /workdir fermist /bin/bash
```

By default interactive graphics will not be enabled. The following code can be inserted at the top of your analysis script to fall-back to a non-interactive backend:

```
from fermipy.utils import init_matplotlib_backend
init_matplotlib_backend()
```

The following commands can be used to enable X11 forwarding for interactive graphics on an OSX machine. This requires you to have installed XQuartz 2.7.10 or later. First enable remote connections by default and start the X server:

```
$ defaults write org.macosforge.xquartz.X11 nolisten_tcp -boolean false
$ open -a XQuartz
```

Now check that the X server is running and listening on port 6000:

```
$ lsof -i :6000
```

If you don't see X11 listening on port 6000 then try restarting XQuartz.

Once you have XQuartz configured you can enable forwarding by setting DISPLAY environment variable to the IP address of the host machine:

```
$ export HOST_IP=`ifconfig en0 | grep "inet " | cut -d " " -f2`
$ xhost +$HOST_IP
$ docker run -it --rm -e DISPLAY=$HOST_IP:0 -v $PWD:/workdir -w /workdir fermist ipython
```

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 11-05-00). To manually override the ST version you can provide the release tag as an argument to `slacsetup`:

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

```
$ pip show fermipy
```

or `conda info`:

```
$ conda info fermipy
```

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

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

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

```
$ conda update fermipy
```

Building from Source

These instructions describe how to install fermipy from its git source code repository using the `setup.py` script. Installing from source can be useful if you want to make your own modifications to the fermipy source code or test features in an untagged commit. Note that non-expert users are recommended to install a tagged release of fermipy following the *Installing with pip* or *Installing with Anaconda Python* instructions above.

First clone the fermipy git repository and cd to the root directory of the repository:

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

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

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

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

```
# Install a link to your source code installation
$ python setup.py develop --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 run `git tag`. 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 switch to the `Agg` backend at runtime before importing fermipy:

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

However note that this backend does not support interactive plotting.

If you are running OSX El Capitan or newer you may see errors like the following:

```
dyld: Library not loaded
```

In this case you will need to disable the System Integrity Protections (SIP). See here for instructions on disabling SIP on your machine.

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
```

1.2.2 Quickstart Guide

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

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

Creating a Configuration File

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

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

binning:
  roiwidth   : 10.0
  binsz      : 0.1
  binsperdec : 8

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

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

model:
  src_roiwidth : 15.0
  galdiff  : '$FERMI_DIFFUSE_DIR/gll_iem_v06.fits'
```

```
  isodiff   : 'iso_P8R2_SOURCE_V6_v06.txt'
  catalogs : ['3FGL']
```

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

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

```
components:
  - { selection : { evtype : 4  } } # PSF0
  - { selection : { evtype : 8  } } # PSF1
  - { selection : { evtype : 16 } } # PSF2
  - { selection : { evtype : 32 } } # PSF3
```

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

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

Creating an Analysis Script

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

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

```
from fermipy.gtanalysis import GTAnalysis

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

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

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

```
gta.optimize()
```

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

```
gta.print_roi()
```

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

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

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

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

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

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

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

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

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

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

```
gta.fit()
```

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

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

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

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

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

```
         'SpectrumType' : 'PowerLaw'}

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

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

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

```
gta.sed('mkn421')
```

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

Extracting Analysis Results

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

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

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

The output dictionary contains the following top-level elements:

Table 1.1: File Dictionary

Key	Description	
`roi`	dict	A dictionary containing information about the ROI as a whole.
`sources`	dict	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.
`config`	dict	The configuration dictionary of the `GTAnalysis` instance.
`version`	str	The version of the fermiPy package that was used to run the analysis. This is automatically generated from the git release tag.

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

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

```
>>> print c['sources']['3FGL J1104.4+3812']['npred']
31583.7166495
```

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

```
>>> # Load the source catalog file
>>> from astropy.table import Table
>>> tab = Table.read('fit_model.fits')
>>> print(tab[['name','class','ts','npred','flux']])
    name       class       ts           npred                    flux [2]
                                                              1 / (cm2 s)
---------------- ----- -------------- ------------- ----------------------------------
3FGL J1104.4+3812   BLL  87455.9709683 31583.7166495 2.20746290445e-07 .. 1.67062058528e-09
3FGL J1109.6+3734   bll    42.34511826 93.7971922425  5.90635786943e-10 .. 3.6620894143e-10
...
3FGL J1136.4+3405  fsrq  4.78089819776 261.427034151 1.86805869704e-08 .. 8.62638727067e-09
3FGL J1145.8+4425  fsrq  3.78006883967 237.525501441 7.25611442299e-08 .. 3.77056557247e-08
```

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

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

Reloading from a Previous State

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

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

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

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

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

```
from fermipy.gtanalysis import GTAnalysis

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

gta.write_roi('prefit_model')
```

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

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

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

IPython Notebook Tutorials

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

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

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

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

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

1.2.3 Configuration

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

Class Configuration

Classes in the Fermipy package follow a common convention for configuring the runtime behavior of a class instance. Internally every class instance has a dictionary that defines its configuration state. Elements of the configuration dictionary can be scalars (str, int, float) or dictionaries defining nested groups of parameters.

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

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

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

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

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

Configuration File

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

Listing 1.1: Sample Configuration

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

binning:
  roiwidth   : 10.0
  binsz      : 0.1
  binsperdec : 8

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

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

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

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

binning

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

Listing 1.2: Sample *binning* Configuration

```
binning:

  # Binning
  roiwidth   : 10.0
```

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

Listing 1.3: *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 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 is defined as a list of dictionaries 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. Files associated to each component will be given a suffix according to their order in the list (e.g. file_00.fits, file_01.fits, etc.).

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

data

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

Listing 1.4: Sample *data* Configuration

```
data :
  evfile : ft1.lst
```

```
  scfile : ft2.fits
  ltcube : null
```

Listing 1.5: *data* Options

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

extension

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

Listing 1.6: *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.
psf_scale_fn	None	Tuple of vectors (logE,f) defining an energy-dependent PSF scaling function that will be applied when building spatial models for the source of interest. The tuple (logE,f) defines the fractional corrections f at the sequence of energies logE = log10(E/MeV) where f=0 means no correction. The correction function f(E) is evaluated by linearly interpolating the fractional correction factors f in log(E). The corrected PSF is given by P'(x;E) = P(x/(1+f(E));E) where x is the angular separation.
save_model_map	False	Save model counts cubes for the best-fit model of extension.
spatial_model	RadialGaussian	Spatial model use for extension test.
sqrt_ts_threshold	None	Threshold on sqrt(TS_ext) that will be applied when update is True. If None then nothreshold is applied.
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 1.7: Sample *fileio* Configuration

```
fileio:
   outdir : null
```

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

Listing 1.8: *fileio* Options

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

gtlike

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

Listing 1.9: *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.
expscale	None	Exposure correction that is applied to all sources in the analysis component. This correction is superseded by src_expscale if it is defined for a source.
irfs	None	Set the IRF string.
llscan_npts	20	Number of evaluation points to use when performing a likelihood scan.
minbinsz	0.05	Set the minimum bin size used for resampling diffuse maps.
resample	True	
rfactor	2	
src_expscale	None	Dictionary of exposure corrections for individual sources keyed to source name. The exposure for a given source will be scaled by this value. A value of 1.0 corresponds to the nominal exposure.
srcmap	None	
wmap	None	Likelihood weights map.

lightcurve

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

Listing 1.10: *lightcurve* Options

Option	Default	Description
`binsz`	86400.0	Set the lightcurve bin size in seconds, default is 1 day.
`free_radius`	3.0	Free normalizations of background sources within this angular distance in degrees from the source of interest.
`free_sources`	None	List of sources to be freed. These sources will be added to the list of sources satisfying the free_radius selection.
`nbins`	None	Set the number of lightcurve bins. The total time range will be evenly split into this number of time bins.
`time_bins`	None	Set the lightcurve bin edge sequence in MET. This option takes precedence over binsz and nbins.

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 1.11: 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 1.12: *model* Options

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

optimizer

Listing 1.13: *optimizer* Options

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

plotting

Listing 1.14: *plotting* Options

Option	Default	Description
`catalogs`	None	
`cmap`	magma	Set the colormap for 2D plots.
`cmap_resid`	RdBu_r	Set the colormap for 2D residual plots.
`format`	png	
`graticule_radii`	None	Define a list of radii at which circular graticules will be drawn.
`label_ts_threshold`	0.0	TS threshold for labeling sources in sky maps. If None then no sources will be labeled.
`loge_bounds`	None	

residmap

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

Listing 1.15: *residmap* Options

Option	Default	Description
`loge_bounds`	None	Lower and upper energy bounds in log10(E/MeV). By default the calculation will be performed over the full analysis energy range.
`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.

roiopt

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

Listing 1.16: *roiopt* Options

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

sed

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

Listing 1.17: *sed* Options

Option	Default	Description
bin_index	2.0	Spectral index that will be use when fitting the energy distribution within an energy bin.
cov_scale	3.0	Scale factor that sets the strength of the prior on nuisance parameters when fix_background is True. Setting this to None disables the prior.
fix_background	True	Fix background normalization parameters when fitting the source flux in each energy bin. If True background normalizations will be profiled with a prior on their value with strength set by cov_scale.
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 1.18: *selection* Options

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

sourcefind

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

Listing 1.19: *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

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

Listing 1.20: *tsmap* Options

Option	Default	Description
loge_bounds	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	Split the TS map calculation across multiple cores.

tscube

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

Listing 1.21: *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
init_lambda	0	Initial value of damping parameter for newton step size calculation. A value of zero disables damping.
max_iter	30	Maximum number of iterations for the Newtons method fitter.
model	None	Dictionary defining the 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.

1.2.4 Output File

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

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

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

The output file can be read with `load`:

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

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

Listing 1.22: File Dictionary

Key	Type	Description
roi	dict	A dictionary containing information about the ROI as a whole.
sources	dict	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.
config	dict	The configuration dictionary of the *GTAnalysis* instance.
version	str	The version of the fermiPy package that was used to run the analysis. This is automatically generated from the git release tag.

ROI Dictionary

Source Dictionary

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

Table 1.2: Source Dictionary

Key	Type	Description
name	str	Name of the source.
Source_Name	str	Name of the source.
SpatialModel	str	Spatial model.
SpatialWidth	float	Spatial size parameter.
SpatialType	str	Spatial type string. This corresponds to the type attribute of the spatialModel component
SourceType	str	Source type string (PointSource or DiffuseSource).
SpectrumType	str	Spectrum type string. This corresponds to the type attribute of the spectrum component i
Spatial_Filename	str	Path to spatial template associated to this source.
Spectrum_Filename	str	Path to file associated to the spectral model of this source.
params	dict	Dictionary of spectral parameters.
correlation	dict	Dictionary of correlation coefficients.
model_counts	ndarray	Vector of predicted counts for this source in each analysis energy bin.
sed	dict	Output of SED analysis. See *SED Analysis* for more information.
extension	dict	Output of extension analysis. See *Extension Fitting* for more information.
localize	dict	Output of localization analysis. See *Source Localization* for more information.
lightcurve	dict	Output of lightcurve analysis. See *Light Curves* for more information.
ra	float	Right ascension of the source in deg.
dec	float	Declination of the source in deg.
glon	float	Galactic Longitude of the source in deg.
glat	float	Galactic Latitude of the source in deg.
offset_ra	float	Angular offset from ROI center along RA.
offset_dec	float	Angular offset from ROI center along DEC
offset_glon	float	Angular offset from ROI center along GLON.
offset_glat	float	Angular offset from ROI center along GLAT.
offset_roi_edge	float	Distance from the edge of the ROI in deg. Negative (positive) values indicate locations ir
offset	float	Angular offset from ROI center.
pos_sigma	float	1-sigma uncertainty (deg) on the source position.
pos_sigma_semimajor	float	1-sigma uncertainty (deg) on the source position along major axis.
pos_sigma_semiminor	float	1-sigma uncertainty (deg) on the source position along minor axis.
pos_angle	float	Position angle (deg) of the positional uncertainty ellipse.
pos_r68	float	68% uncertainty (deg) on the source position.

Table 1.2 – continued from previous page

Key	Type	Description
pos_r95	float	95% uncertainty (deg) on the source position.
pos_r99	float	99% uncertainty (deg) on the source position.
ts	float	Source test statistic.
loglike	float	Log-likelihood of the model evaluated at the best-fit normalization of the source.
dloglike_scan	ndarray	Delta Log-likelihood values for likelihood scan of source normalization.
eflux_scan	ndarray	Energy flux values for likelihood scan of source normalization.
flux_scan	ndarray	Flux values for likelihood scan of source normalization.
npred	float	Number of predicted counts from this source integrated over the analysis energy range.
pivot_energy	float	Decorrelation energy in MeV.
flux	float	Photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range
flux100	float	Photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV.
flux1000	float	Photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV.
flux10000	float	Photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV.
flux_err	float	Photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range
flux100_err	float	Photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV.
flux1000_err	float	Photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV.
flux10000_err	float	Photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV.
flux_ul95	float	95% CL upper limit on the photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range
flux100_ul95	float	95% CL upper limit on the photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 Ge
flux1000_ul95	float	95% CL upper limit on the photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV.
flux10000_ul95	float	95% CL upper limit on the photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV.
eflux	float	Energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range
eflux100	float	Energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV.
eflux1000	float	Energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV.
eflux10000	float	Energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV.
eflux_err	float	Energy flux uncertainty ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy range
eflux100_err	float	Energy flux uncertainty ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 316 GeV.
eflux1000_err	float	Energy flux uncertainty ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 GeV.
eflux10000_err	float	Energy flux uncertainty ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316 GeV.
eflux_ul95	float	95% CL upper limit on the energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated over analysis energy
eflux100_ul95	float	95% CL upper limit on the energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 100 MeV to 31
eflux1000_ul95	float	95% CL upper limit on the energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 1 GeV to 316 G
eflux10000_ul95	float	95% CL upper limit on the energy flux ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) integrated from 10 GeV to 316
dnde	float	Differential photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at the pivot energy.
dnde100	float	Differential photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 100 MeV.
dnde1000	float	Differential photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 1 GeV.
dnde10000	float	Differential photon flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 10 GeV.
dnde_err	float	Differential photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at the pivot energy.
dnde100_err	float	Differential photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 100 MeV.
dnde1000_err	float	Differential photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 1 GeV.
dnde10000_err	float	Differential photon flux uncertainty ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$) evaluated at 10 GeV.
dnde_index	float	Logarithmic slope of the differential photon spectrum evaluated at the pivot energy.
dnde100_index	float	Logarithmic slope of the differential photon spectrum evaluated at 100 MeV.
dnde1000_index	float	Logarithmic slope of the differential photon spectrum evaluated evaluated at 1 GeV.
dnde10000_index	float	Logarithmic slope of the differential photon spectrum evaluated at 10 GeV.

1.2.5 ROI Optimization and Fitting

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

Fitting

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

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

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

Listing 1.23: *fit* Output Dictionary

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

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

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

Reference/API

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

Run the likelihood optimization. This will execute a fit of all parameters that are currently free in the model and update the charateristics of the corresponding model components (TS, npred, etc.). The fit will be repeated N times (set with the `retries` parameter) until a fit quality greater than or equal to `min_fit_quality` and a fit status code of 0 is obtained. If the fit does not succeed after N retries then all parameter values will be reverted to their state prior to the execution of the fit.

Parameters

- **update** (*bool*) – Update the model dictionary for all sources with free parameters.
- **tol** (*float*) – Set the optimizer tolerance.
- **verbosity** (*int*) – Set the optimizer output level.
- **optimizer** (*str*) – Set the likelihood optimizer (e.g. MINUIT or NEWMINUIT).
- **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 from the fit (fit quality, parameter covariances, etc.).

Return type dict

ROI Optimization

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

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

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

Listing 1.24: *optimization* Output Dictionary

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

Reference/API

GTAnalysis.**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.
- **max_free_sources** (*int*) – Maximum number of sources that will be fit simultaneously in the first optimization step.
- **skip** (*list*) – List of str source names to skip while optimizing.
- **optimizer** (*dict*) – Dictionary that overrides the default optimizer settings.

1.2.6 Customizing the Model

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

Configuring Diffuse Components

The simplest configuration uses a single file for the galactic and isotropic diffuse components. By default the galactic diffuse and isotropic components will be named *galdiff* and *isodiff* respectively. An alias for each component will also be created with the name of the mapcube or file spectrum. For instance the galactic diffuse can be referred to as *galdiff* or *gll_iem_v06* in the following example.

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

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

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

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

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

Configuring Source Components

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

```
model:

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

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

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

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

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

Spatial Models

Fermipy supports three types of pre-defined spatial models which can be defined by setting the `SpatialModel` property: PointSource (the default), RadialDisk, and RadialGaussian. The spatial extension of RadialDisk and RadialGaussian can be controlled with the `SpatialWidth` parameter which sets the 68% containment radius in degrees. Note for ST releases prior to 11-01-01, RadialDisk and RadialGaussian sources will be represented with the `SpatialMap` type.

```
model:
  sources  :
```

```
    - { name: 'DiskSource', glon : 120.0, glat : 0.0,
     SpectrumType : 'PowerLaw', Index : 2.0, Scale : 1000, Prefactor : !!float 1e-11,
     SpatialModel: 'RadialDisk', SpatialWidth: 1.0 }
    - { name: 'GaussSource', glon : 120.0, glat : 0.0,
     SpectrumType : 'PowerLaw', Index : 2.0, Scale : 1000, Prefactor : !!float 1e-11,
     SpatialModel: 'RadialGaussian', SpatialWidth: 1.0 }
```

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.

1.2.7 Advanced Analysis Methods

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

- *TS Map*: Generate a test statistic (TS) map for a new source centered at each spatial bin in the ROI.
- *TS Cube*: Generate a TS map using the `gttscube` ST application. In addition to generating a TS map this method can also extract a test source likelihood profile as a function of energy and position over the whole ROI.
- *Residual Map*: Generate a residual map by evaluating the difference between smoothed data and model maps (residual) at each spatial bin in the ROI.
- *Source Finding*: Find new sources using an iterative source-finding algorithim. Adds new sources to the ROI by looking for peaks in the TS map.
- *SED Analysis*: Compute the spectral energy distribution of a source by fitting its amplitude in a sequence of energy bins.
- *SED Analysis*: Compute the lightcurve of a source by fitting its amplitude in a sequence of time bins.
- *Extension Fitting*: Fit the angular extension of a source.

- *Source Localization*: Find the best-fit position of a source.
- *Phased Analysis*: Instructions for performing a phased-selected analysis.
- *Sensitivity Tools*: Scripts and classes for estimating sensitivity.

SED Analysis

The *sed()* method computes a spectral energy distribution (SED) by fitting for the flux normalization of a source 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).

The `fix_background` and `cov_scale` parameters can be used to control how nuisance parameters are dealt with in the fit. By default this method will fix the parameters of background components ROI when fitting the source normalization in each energy bin (`fix_background` = True). Setting `fix_background` to False will profile the normalizations of all background components that were free when the method was executed. In order to minimize overfitting, background normalization parameters are constrained with priors taken from the global fit. The strength of the priors is controlled with the `cov_scale` parameter. A larger (smaller) value of `cov_scale` applies a weaker (stronger) constraint on the background amplitude. Setting `cov_scale` to None can be used to perform the fit without priors.

Examples

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

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

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

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

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

The return value of *sed()* is a dictionary with the results of the analysis. 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']

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

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

SED FITS File

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

Listing 1.25: *sed* Output Dictionary

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

SED Dictionary

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

Table

Key	Type	Description
`loge_min`	`ndarray`	Lower edges of SED energy bins (log10(E/MeV)).

Table 1.3 -

Key	Type	Description
loge_max	ndarray	Upper edges of SED energy bins (log10(E/MeV)).
loge_ctr	ndarray	Centers of SED energy bins (log10(E/MeV)).
loge_ref	ndarray	Reference energies of SED energy bins (log10(E/MeV)).
e_min	ndarray	Lower edges of SED energy bins (MeV).
e_max	ndarray	Upper edges of SED energy bins (MeV).
e_ctr	ndarray	Centers of SED energy bins (MeV).
e_ref	ndarray	Reference energies of SED energy bins (MeV).
ref_flux	ndarray	Flux of the reference model in each bin ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$).
ref_eflux	ndarray	Energy flux of the reference model in each bin ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$).
ref_dnde	ndarray	Differential flux of the reference model evaluated at the bin center ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$)
ref_dnde_e_min	ndarray	Differential flux of the reference model evaluated at the lower bin edge ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$)
ref_dnde_e_max	ndarray	Differential flux of the reference model evaluated at the upper bin edge ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$)
ref_e2dnde	ndarray	E^2 x the differential flux of the reference model evaluated at the bin center ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
ref_npred	ndarray	Number of predicted counts in the reference model in each bin.
norm	ndarray	Normalization in each bin in units of the reference model.
flux	ndarray	Flux in each bin ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$).
eflux	ndarray	Energy flux in each bin ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$).
dnde	ndarray	Differential flux in each bin ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$).
e2dnde	ndarray	E^2 x the differential flux in each bin ($\mathrm{MeV}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$).
dnde_err	ndarray	1-sigma error on dnde evaluated from likelihood curvature.
dnde_err_lo	ndarray	Lower 1-sigma error on dnde evaluated from the profile likelihood (MINOS errors).
dnde_err_hi	ndarray	Upper 1-sigma error on dnde evaluated from the profile likelihood (MINOS errors).
dnde_ul95	ndarray	95% CL upper limit on dnde evaluated from the profile likelihood (MINOS errors).
dnde_ul	ndarray	Upper limit on dnde evaluated from the profile likelihood using a CL = ul_confidence.
e2dnde_err	ndarray	1-sigma error on e2dnde evaluated from likelihood curvature.
e2dnde_err_lo	ndarray	Lower 1-sigma error on e2dnde evaluated from the profile likelihood (MINOS errors).
e2dnde_err_hi	ndarray	Upper 1-sigma error on e2dnde evaluated from the profile likelihood (MINOS errors).
e2dnde_ul95	ndarray	95% CL upper limit on e2dnde evaluated from the profile likelihood (MINOS errors).
e2dnde_ul	ndarray	Upper limit on e2dnde evaluated from the profile likelihood using a CL = ul_confidence
ts	ndarray	Test statistic.
loglike	ndarray	Log-likelihood of model for the best-fit amplitude.
npred	ndarray	Number of model counts.
fit_quality	ndarray	Fit quality parameter for MINUIT and NEWMINUIT optimizers (3 - Full accurate covarianc
fit_status	ndarray	Fit status parameter (0=ok).
index	ndarray	Spectral index of the power-law model used to fit this bin.
lnlprofile	dict	Likelihood scan for each energy bin.
norm_scan	ndarray	Array of NxM normalization values for the profile likelihood scan in N energy bins and M sc
dloglike_scan	ndarray	Array of NxM delta-loglikelihood values for the profile likelihood scan in N energy bins and
loglike_scan	ndarray	Array of NxM loglikelihood values for the profile likelihood scan in N energy bins and M sca
params	dict	Dictionary of best-fit spectral parameters with 1-sigma uncertainties.
param_covariance	ndarray	Covariance matrix for the best-fit spectral parameters of the source.
param_names	ndarray	Array of names for the parameters in the global spectral parameterization of this source.
param_values	ndarray	Array of parameter values.
param_errors	ndarray	Array of parameter errors.
model_flux	dict	Dictionary containing the differential flux uncertainty band of the best-fit global spectral para
config	dict	Copy of input configuration to this method.

Configuration

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

Listing 1.26: *sed* Options

Option	Default	Description
bin_index	2.0	Spectral index that will be use when fitting the energy distribution within an energy bin.
cov_scale	3.0	Scale factor that sets the strength of the prior on nuisance parameters when fix_background is True. Setting this to None disables the prior.
fix_background	True	Fix background normalization parameters when fitting the source flux in each energy bin. If True background normalizations will be profiled with a prior on their value with strength set by cov_scale.
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.

Reference/API

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

Generate a spectral energy distribution (SED) for a source. This function will fit the normalization of the source in each energy bin. By default the SED will be generated with the analysis energy bins but a custom binning can be defined with the loge_bins parameter.

Parameters

- **name** (*str*) – Source name.
- **prefix** (*str*) – Optional string that will be prepended to all output files (FITS and rendered images).
- **loge_bins** (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.
- **cov_scale** (*float*) – Scaling factor that will be applied when setting the gaussian prior on the normalization of free background sources. If this parameter is None then no gaussian prior will be applied.
- **make_plots** (*bool*) – Generate plots.
- **write_fits** (*bool*) – Write the output to a FITS file.
- **write_npy** (*bool*) – Write the output dictionary to a numpy file.

- **optimizer** (*dict*) – Dictionary that overrides the default optimizer settings.

Returns **sed** – Dictionary containing output of the SED analysis.

Return type dict

Light Curves

lightcurve() can be used to fit a source in a sequence of time bins.

Examples

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

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

Reference/API

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

Generate a lightcurve for the named source. The function will complete the basic analysis steps for each bin and perform a likelihood fit for each bin. Extracted values (along with errors) are Integral Flux, spectral model, Spectral index, TS value, pred. # of photons.

Parameters

- **name** (*str*) – source name
- **binsz** (*float*) – Set the lightcurve bin size in seconds, default is 1 day.
- **nbins** (*int*) – Set the number of lightcurve bins. The total time range will be evenly split into this number of time bins.
- **time_bins** (*list*) – Set the lightcurve bin edge sequence in MET. When defined this option takes precedence over binsz and nbins.
- **free_radius** (*float*) – Free normalizations of background sources within this angular distance in degrees from the source of interest.
- **free_sources** (*list*) – List of sources to be freed. These sources will be added to the list of sources satisfying the free_radius selection

Returns **LightCurve** – Dictionary containing output of the LC analysis

Return type dict

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 (*RadialGaussian*) or a 2D disk (*RadialDisk*).

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

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

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

By default the extension method will profile over any background parameters that were free when the method was executed. One can fix all background parameters by setting `fix_background=True`:

```
# 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:

Listing 1.27: *extension* Output Dictionary

Key	Type	Description
width	ndarray	Vector of width values.
dloglike	ndarray	Sequence of delta-log-likelihood values for each point in the profile likelihood scan.
loglike	ndarray	Sequence of likelihood values for each point in the scan over the spatial extension.
loglike_ptsrc	float	Model log-Likelihood value of the best-fit point-source model.
loglike_ext	float	Model log-Likelihood value of the best-fit extended source model.
loglike_base	float	Model log-Likelihood value of the baseline model.
ext	float	Best-fit extension in degrees.
ext_err_hi	float	Upper (1 sigma) error on the best-fit extension in degrees.
ext_err_lo	float	Lower (1 sigma) error on the best-fit extension in degrees.
ext_err	float	Symmetric (1 sigma) error on the best-fit extension in degrees.
ext_ul95	float	95% CL upper limit on the spatial extension in degrees.
ts_ext	float	Test statistic for the extension hypothesis.
source_fit	dict	Dictionary with parameters of the best-fit extended source model.
config	dict	Copy of the input configuration to this method.

Configuration

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

Listing 1.28: *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.
psf_scale_fn	None	Tuple of vectors (logE,f) defining an energy-dependent PSF scaling function that will be applied when building spatial models for the source of interest. The tuple (logE,f) defines the fractional corrections f at the sequence of energies logE = log10(E/MeV) where f=0 means no correction. The correction function f(E) is evaluated by linearly interpolating the fractional correction factors f in log(E). The corrected PSF is given by P'(x;E) = P(x/(1+f(E));E) where x is the angular separation.
save_model_map	False	Save model counts cubes for the best-fit model of extension.
spatial_model	Radial-Gaus-sian	Spatial model use for extension test.
sqrt_ts_threshold	None	Threshold on sqrt(TS_ext) that will be applied when update is True. If None then nothreshold is applied.
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.

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 to test the source extension. The spatial scale parameter of the respective model will be set such that the 68% containment radius of the model is equal to the width parameter. The following spatial models are supported:
  - RadialDisk : Azimuthally symmetric 2D disk.
  - RadialGaussian : Azimuthally symmetric 2D gaussian.
- **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 if TS_ext > `tsext_threshold`.
- **sqrt_ts_threshold** (*float*) – Threshold on sqrt(TS_ext) that will be applied when `update` is true. If None then no threshold will be applied.
- **psf_scale_fn** (*tuple*) – Tuple of vectors (logE,f) defining an energy-dependent PSF scaling function that will be applied when building spatial models for the source of interest. The tuple (logE,f) defines the fractional corrections f at the sequence of energies logE = log10(E/MeV) where f=0 means no correction. The correction function f(E) is evaluated by linearly interpolating the fractional correction factors f in log(E). The corrected PSF is given by P'(x;E) = P(x/(1+f(E));E) where x is the angular separation.
- **optimizer** (*dict*) – Dictionary that overrides the default optimizer settings.

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

TS Map

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

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

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

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

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

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

Examples

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

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

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

# Generate TS maps for a power-law point source with Index=1.5, 2.0, and 2.5
```

```
model={'SpatialModel' : 'PointSource'}
maps = []
for index in [1.5,2.0,2.5]:
    model['Index'] = index
    maps += [gta.tsmap('fit1',model=model)]
```

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

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

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

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

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

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

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

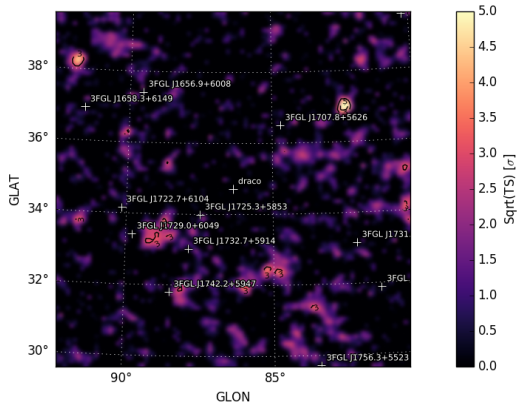
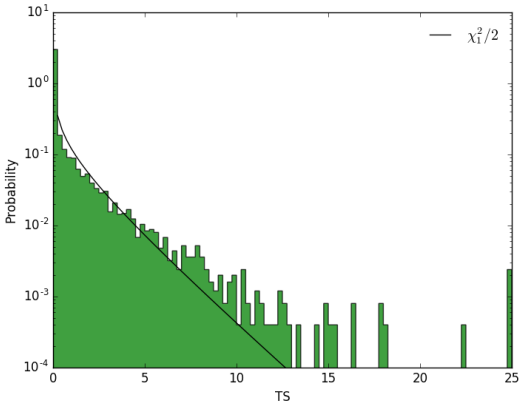
The `write_fits` and `write_npy` options can used to write the output to a FITS or numpy file. All output files are prepended with the `prefix` argument.

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

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

This will generate the following plots:

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

Sqrt(TS) Map	TS Histogram
	

Configuration

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

Listing 1.29: *tsmap* Options

Option	Default	Description
`loge_bounds`	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	Split the TS map calculation across multiple cores.

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`** (*list*) – Source or sources that will be removed from the model when computing the TS map.
- **`loge_bounds`** (*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*) – Generate plots.
- **write_fits** (*bool*) – Write the output to a FITS file.
- **write_npy** (*bool*) – Write the output dictionary to a numpy file.

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

Return type dict

TS Cube

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

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

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

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

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

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

Examples

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

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

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

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

```
    model['Index'] = index
    cubes += [gta.tsmap('fit1',model=model)]
```

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

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

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

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

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

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

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

Configuration

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

Listing 1.30: *tscube* Options

Option	Default	Description
cov_scale	-1.0	Scale factor to apply to broadband fitting cov. matrix in bin-by-bin fits (< 0 -> fixed)
cov_scale_bb	-1.0	Scale factor to apply to global fitting cov. matrix in broadband fits. (< 0 -> no prior)
do_sed	True	Compute the energy bin-by-bin fits
init_lambda	0	Initial value of damping parameter for newton step size calculation. A value of zero disables damping.
max_iter	30	Maximum number of iterations for the Newtons method fitter.
model	None	Dictionary defining the 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.

Reference/API

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.
- **write_fits** (*bool*) – Write a FITS file with the results of the analysis.

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

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

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

where n_k and m_k are the data and model maps at energy plane k and f_k is the convolution kernel. The convolution kernel is proportional to the counts expectation at a given pixel and normalized such that

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

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

Examples

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

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

# 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.

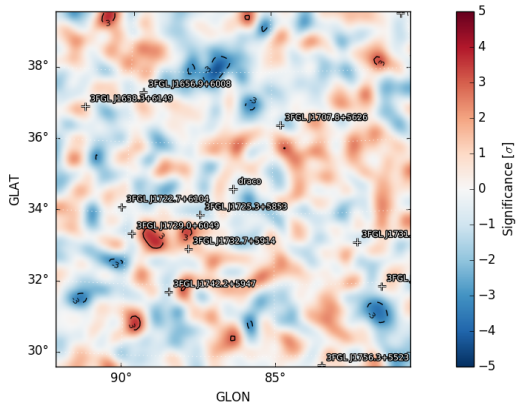
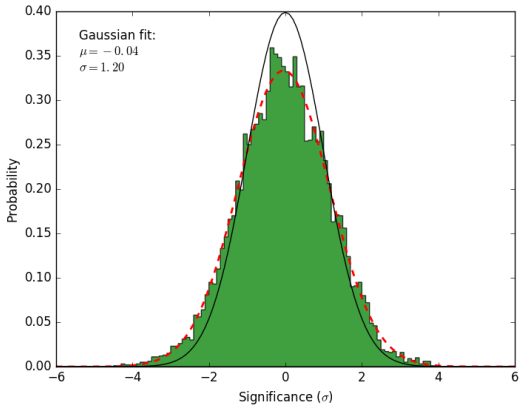
The `write_fits` and `write_npy` options can used to write the output to a FITS or numpy file. All output files are prepended with the `prefix` argument.

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

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

This will generate the following plots:

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

Residual Significance Map	Significance Histogram
	

Configuration

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

Listing 1.31: *residmap* Options

Option	Default	Description
`loge_bounds`	None	Lower and upper energy bounds in log10(E/MeV). By default the calculation will be performed over the full analysis energy range.
`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.

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.
- **`loge_bounds`** (*`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`*) – Generate plots.
- **`write_fits`** (*`bool`*) – Write the output to a FITS file.
- **`write_npy`** (*`bool`*) – Write the output dictionary to a numpy file.

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

Return type dict

Source Finding

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

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

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

Examples

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

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

Reference/API

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.

Returns

- **peaks** (*list*) – List of peak objects.
- **sources** (*list*) – List of source objects.

Source Localization

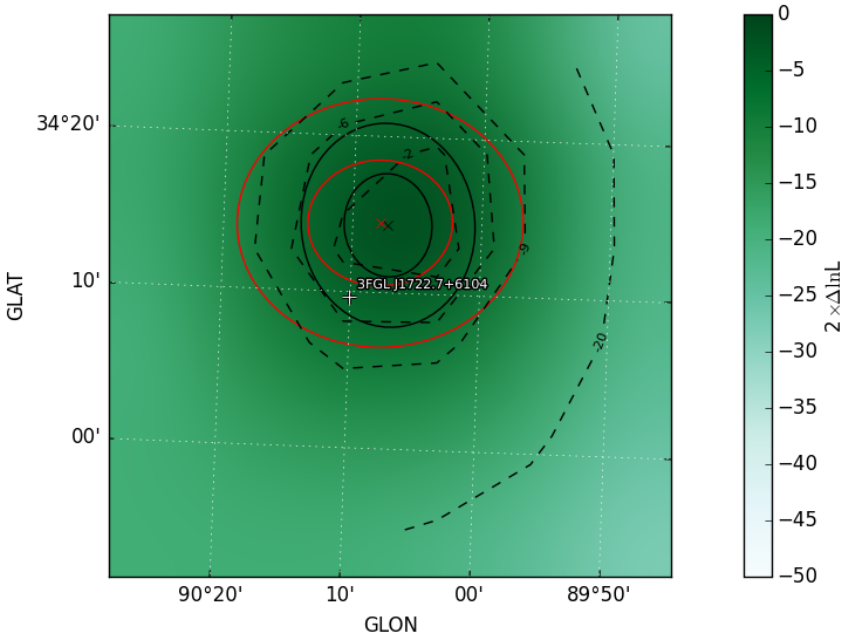
The *localize()* method can be used to spatially localize a source. Localization is performed by scanning the 2D likelihood surface in a local patch around the nominal source position. The current implementation of the localization analysis proceeds in two steps:

- **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 1.32: *localize* Output

Key	Type	Description
ra	float	Right ascension of best-fit position in deg.
dec	float	Declination of best-fit position in deg.
glon	float	Galactic Longitude of best-fit position in deg.
glat	float	Galactic Latitude of best-fit position in deg.
offset	float	Angular offset in deg between the old and new (localized) source positions.
sigma	float	1-sigma positional uncertainty in deg.
r68	float	68% positional uncertainty in deg.
r95	float	95% positional uncertainty in deg.
r99	float	99% positional uncertainty in deg.
sigmax	float	1-sigma uncertainty in deg in longitude.
sigmay	float	1-sigma uncertainty in deg in latitude.
sigma_semimajor	float	1-sigma uncertainty in deg along major axis of uncertainty ellipse.
sigma_semiminor	float	1-sigma uncertainty in deg along minor axis of uncertainty ellipse.
xpix	float	Longitude pixel coordinate of best-fit position.
ypix	float	Latitude pixel coordinate of best-fit position.
theta	float	Position angle of uncertainty ellipse.
eccentricity	float	Eccentricity of uncertainty ellipse defined as sqrt(1-b**2/a**2).
eccentricity2	float	Eccentricity of uncertainty ellipse defined as sqrt(a**2/b**2-1).
config	dict	Copy of the input parameters to this method.

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.
- **make_plots** (*bool*) – Generate plots.
- **write_fits** (*bool*) – Write the output to a FITS file.
- **write_npy** (*bool*) – Write the output dictionary to a numpy file.

- **optimizer** (*dict*) – Dictionary that overrides the default optimizer settings.

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

Phased Analysis

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

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

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

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

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

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

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

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

Sensitivity Tools

The `fermipy-flux-sensitivity` script can be used to calculate the LAT detection threshold versus energy. Inputs are the galactic diffuse model and the livetime cube of the observation epoch. The `obs_time_yr` option can be used to rescale the livetime cube to a shorter or longer observation time.

```
$ fermipy-flux-sensitivity --glon=30 --glat=30 --output=flux.fits \
--ltcube=ltcube.fits --galdiff=gll_iem_v06.fits --event_class=P8R2_SOURCE_V6
```

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

The output FITS file contains a table with the flux threshold in each energy bin.

```
from astropy.table import Table
tab = Table.read('flux.fits')
print(tab['e_min'], tab['e_max'], tab['flux'])
```

1.2.8 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.**ConfigSchema**(*options=None*, ***kwargs*)
Bases: object

Class encapsulating a configuration schema.

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

add_section(*name*, *section*)

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

items()

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

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

config
Return the configuration dictionary of this class.

configdir

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

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

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

schema
Return the configuration schema of this class.

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

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

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

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

Parameters

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

Returns **cfgout**

Return type dict

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

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

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

fermipy.defaults module

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

fermipy.gtanalysis module

class fermipy.gtanalysis.**GTAnalysis**(*config*, ***kwargs*)
Bases: *fermipy.config.Configurable*, *fermipy.sed.SEDGenerator*, *fermipy.residmap.ResidMapGenerator*, *fermipy.tsmap.TSMapGenerator*, *fermipy.tsmap.TSCubeGenerator*, *fermipy.sourcefind.SourceFinder*, *fermipy.lightcurve.LightCurve*

High-level analysis interface that 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 to the constructor can be used to override parameters in the configuration dictionary.

__delattr__
x.__delattr__('name') <==> del x.name

__format__()
default object formatter

__getattribute__
x.__getattribute__('name') <==> x.name

__hash__

__reduce__()
helper for pickle

__reduce_ex__()
helper for pickle

__repr__

__setattr__
x.__setattr__('name', value) <==> x.name = value

__sizeof__() → int
size of object in memory, in bytes

__str__

add_gauss_prior(*name*, *parName*, *mean*, *sigma*)

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.

add_sources_from_roi(*names*, *roi*, *free=False*, ***kwargs*)
Add multiple sources to the current ROI model copied from another ROI model.

Parameters

- **names** (*list*) – List of str source names to add.
- **roi** (*ROIModel* object) – The roi model from which to add sources.
- **free** (*bool*) – Initialize the source with a free normalization paramter.

bowtie(*name*, *fd=None*, *loge=None*)
Generate a spectral uncertainty band (bowtie) for the given source. This will create an uncertainty band on the differential flux as a function of energy by propagating the errors on the global fit parameters. Note that this band only reflects the uncertainty for parameters that are currently free in the model.

Parameters

- **name** (*str*) – Source name.
- **fd** (*FluxDensity*) – Flux density object. If this parameter is None then one will be created.
- **loge** (*array-like*) – Sequence of energies in log10(E/MeV) at which the flux band will be evaluated.

cleanup()

components
Return the list of analysis components.

config
Return the configuration dictionary of this class.

configdir

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

constrain_norms(*srcNames*, *cov_scale=1.0*)
Constrain the normalizations of one or more sources by adding gaussian priors with sigma equal to the parameter error times a scaling factor.

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 configuration 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*, *build_fixed_wts=True*, ***kwargs*)
Delete a source from the ROI model.

Parameters

- **name** (*str*) – Source name.
- **save_template** (*bool*) – Delete the SpatialMap FITS template associated with this source.
- **delete_source_map** (*bool*) – Delete the source map associated with this source from the source maps file.

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

Return type *Model*

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

Parameters

- **cuts** (*dict*) – Dictionary of [min,max] selections on source properties.
- **distance** (*float*) – Cut on angular distance from `skydir`. If None then no selection will be applied.
- **skydir** (`SkyCoord`) – Reference sky coordinate for `distance` selection. If None then the distance selection will be applied with respect to the ROI center.
- **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.

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

Return type list

energies
Return the energy bin edges in MeV.

enumbins
Return the number of energy bins.

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 to test the source extension. The spatial scale parameter of the respective model will be set such that the 68% containment radius of the model is equal to the width parameter. The following spatial models are supported:
  - RadialDisk : Azimuthally symmetric 2D disk.
  - RadialGaussian : Azimuthally symmetric 2D gaussian.
- **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 if TS_ext > `tsext_threshold`.
- **sqrt_ts_threshold** (*float*) – Threshold on sqrt(TS_ext) that will be applied when `update` is true. If None then no threshold will be applied.
- **psf_scale_fn** (*tuple*) – Tuple of vectors (logE,f) defining an energy-dependent PSF scaling function that will be applied when building spatial models for the source of interest. The tuple (logE,f) defines the fractional corrections f at the sequence of energies logE = log10(E/MeV) where f=0 means no correction. The correction function f(E) is evaluated by linearly interpolating the fractional correction factors f in log(E). The corrected PSF is given by P'(x;E) = P(x/(1+f(E));E) where x is the angular separation.
- **optimizer** (*dict*) – Dictionary that overrides the default optimizer settings.

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.

Returns

- **peaks** (*list*) – List of peak objects.
- **sources** (*list*) – List of source objects.

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

Run the likelihood optimization. This will execute a fit of all parameters that are currently free in the model and update the charateristics of the corresponding model components (TS, npred, etc.). The fit will be repeated N times (set with the `retries` parameter) until a fit quality greater than or equal to `min_fit_quality` and a fit status code of 0 is obtained. If the fit does not succeed after N retries then all parameter values will be reverted to their state prior to the execution of the fit.

Parameters

- **update** (*bool*) – Update the model dictionary for all sources with free parameters.
- **tol** (*float*) – Set the optimizer tolerance.
- **verbosity** (*int*) – Set the optimizer output level.
- **optimizer** (*str*) – Set the likelihood optimizer (e.g. MINUIT or NEWMINUIT).
- **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 from the fit (fit quality, parameter covariances, etc.).

Return type dict

fit_correlation()

free_index(*name*, *free=True*, ***kwargs*)
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*, ***kwargs*)
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*, ***kwargs*)
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*, ***kwargs*)
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*, *skydir=None*, *minmax_ts=None*, *minmax_npred=None*, *exclude=None*, *square=False*, ***kwargs*)
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 each 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*) – Cut on angular distance from skydir. If None then no selection will be applied.
- **skydir** (SkyCoord) – Reference sky coordinate for distance selection. If None then the distance selection will be applied with respect to the ROI center.
- **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.
- **exclude** (*list*) – Names of sources that will be excluded from the selection.
- **square** (*bool*) – Switch between applying a circular or square (ROI-like) selection on the maximum projected distance from the ROI center.

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

Return type list

free_sources_by_name(*names*, *free=True*, *pars=None*, ***kwargs*)

Free all sources with names matching names.

Parameters

- **names** (*list*) – List of source names.
- **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 each source. If none then all source parameters will be freed/fixed. If pars='norm' then only normalization parameters will be freed.

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

get_config()

Return a default configuration dictionary for this class.

get_free_param_vector()

get_free_source_params(*name*)

get_norm(*name*)

get_params(*freeonly=False*)

get_source_dnde(*name*)

Return differential flux distribution of a source. For sources with FileFunction spectral type this returns the internal differential flux array.

Returns

- **loge** (ndarray) – Array of energies at which the differential flux is evaluated (log10(E/MeV)).
- **dnde** (ndarray) – Array of differential flux values (cm^{-2} s^{-1} MeV^{-1}) evaluated at energies in loge.

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*, *skydir=None*, *minmax_ts=None*, *minmax_npred=None*, *exclude=None*, *square=False*)
Retrieve list of sources in the ROI satisfying the given selections.

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

Return type list

get_src_model(*name*, *paramsonly=False*, *reoptimize=False*, *npts=None*, ***kwargs*)
Compose a dictionary for a source with the current best-fit parameters.

Parameters

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

Returns **src_dict**

Return type dict

lightcurve(*name*, ***kwargs*)
Generate a lightcurve for the named source. The function will complete the basic analysis steps for each bin and perform a likelihood fit for each bin. Extracted values (along with errors) are Integral Flux, spectral model, Spectral index, TS value, pred. # of photons.

Parameters

- **name** (*str*) – source name
- **binsz** (*float*) – Set the lightcurve bin size in seconds, default is 1 day.
- **nbins** (*int*) – Set the number of lightcurve bins. The total time range will be evenly split into this number of time bins.
- **time_bins** (*list*) – Set the lightcurve bin edge sequence in MET. When defined this option takes precedence over binsz and nbins.
- **free_radius** (*float*) – Free normalizations of background sources within this angular distance in degrees from the source of interest.
- **free_sources** (*list*) – List of sources to be freed. These sources will be added to the list of sources satisfying the free_radius selection

Returns **LightCurve** – Dictionary containing output of the LC analysis

Return type dict

like
Return the global likelihood object.

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

Parameters

- **infile** (*str*) –
- **reload_sources** (*bool*) – Regenerate source maps for non-diffuse sources.

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

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

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.
- **make_plots** (*bool*) – Generate plots.
- **write_fits** (*bool*) – Write the output to a FITS file.
- **write_npy** (*bool*) – Write the output dictionary to a numpy file.
- **optimizer** (*dict*) – Dictionary that overrides the default optimizer settings.

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

log_energies
Return the energy bin edges in log10(E/MeV).

loge_bounds
Current analysis energy bounds in log10(E/MeV).

make_plots (*prefix*, *mcube_map=None*, ***kwargs*)
Make diagnostic plots using the current ROI model.

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 map

Return type *Map*

model_counts_spectrum(*name*, *logemin=None*, *logemax=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.
- **max_free_sources** (*int*) – Maximum number of sources that will be fit simultaneously in the first optimization step.
- **skip** (*list*) – List of str source names to skip while optimizing.
- **optimizer** (*dict*) – Dictionary that overrides the default optimizer settings.

outdir
Return the analysis output directory.

plotter
Return the plotter instance.

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

print_model(*loglevel=20*)

print_params(*allpars=False*, *loglevel=20*)
Print information about the model parameters (values, errors, bounds, scale).

print_roi(*loglevel=20*)
Print information about the spectral and spatial properties of the ROI (sources, diffuse components).

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

Parameters

- **name** (*str*) – Source name.
- **parName** (*str*) – Parameter name.
- **reoptimize** (*bool*) – Re-fit nuisance parameters at each step in the scan. Note that enabling this option will only re-fit parameters that were free when the method was executed.

Returns **lnlprofile** – Dictionary containing results of likelihood scan.

Return type dict

profile_norm(*name*, *logemin=None*, *logemax=None*, *reoptimize=False*, *xvals=None*, *npts=None*, *fix_shape=True*, *savestate=True*, ***kwargs*)
Profile the normalization of a source.

Parameters

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

projtype
Return the type of projection to use

reload_source(*name*, *init_source=True*)
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.

reload_sources(*names*, *init_source=True*)

remove_prior(*name*, *parName*)

remove_priors()
Clear all priors.

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.
- **loge_bounds** (*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*) – Generate plots.
- **write_fits** (*bool*) – Write the output to a FITS file.
- **write_npy** (*bool*) – Write the output dictionary to a numpy file.

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

Return type dict

roi
Return the ROI object.

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

schema
Return the configuration schema of this class.

sed(*name*, ***kwargs*)
Generate a spectral energy distribution (SED) for a source. This function will fit the normalization of the source in each energy bin. By default the SED will be generated with the analysis energy bins but a custom binning can be defined with the `loge_bins` parameter.

Parameters

- **name** (*str*) – Source name.
- **prefix** (*str*) – Optional string that will be prepended to all output files (FITS and rendered images).
- **loge_bins** (`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.
- **cov_scale** (*float*) – Scaling factor that will be applied when setting the gaussian prior on the normalization of free background sources. If this parameter is None then no gaussian prior will be applied.
- **make_plots** (*bool*) – Generate plots.
- **write_fits** (*bool*) – Write the output to a FITS file.
- **write_npy** (*bool*) – Write the output dictionary to a numpy file.
- **optimizer** (*dict*) – Dictionary that overrides the default optimizer settings.

Returns **sed** – Dictionary containing output of the SED analysis.

Return type dict

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

set_energy_range(*logemin*, *logemax*)
Set the energy bounds of the analysis. This restricts the evaluation of the likelihood to the data that falls in this range. Input values will be rounded to the closest bin edge value. If either argument is None then the lower or upper bound of the analysis instance will be used.

Parameters

- **logemin** (*float*) – Lower energy bound in log10(E/MeV).
- **logemax** (*float*) – Upper energy bound in log10(E/MeV).

Returns **eminmax** – Minimum and maximum energy in log10(E/MeV).

Return type array

set_free_param_vector(*free*)

set_log_level(*level*)

set_norm(*name*, *value*, *update_source=True*)

set_norm_bounds(*name*, *bounds*)

set_norm_scale(*name*, *value*)

set_parameter(*name*, *par*, *value*, *true_value=True*, *scale=None*, *bounds=None*, *update_source=True*)
Update the value of a parameter. Parameter bounds will automatically be adjusted to encompass the new parameter value.

Parameters

- **name** (*str*) – Source name.
- **par** (*str*) – Parameter name.
- **value** (*float*) – Parameter value. By default this argument should be the unscaled (True) parameter value.
- **scale** (*float*) – Parameter scale (optional). Value argument is interpreted with respect to the scale parameter if it is provided.
- **update_source** (*bool*) – Update the source dictionary for the object.

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.

set_parameter_scale(*name*, *par*, *scale*)
Update the scale of a parameter while keeping its value constant.

set_source_dnde(*name*, *dnde*, *update_source=True*)
Set the differential flux distribution of a source with the FileFunction spectral type.

Parameters

- **name** (*str*) – Source name.
- **dnde** (ndarray) – Array of differential flux values (cm^{-2} s^{-1} MeV^{-1}).

set_source_spectrum(*name*, *spectrum_type='PowerLaw'*, *spectrum_pars=None*, *update_source=True*)

Set the spectral model of a source. This function can be used to change the spectral type of a source or modify its spectral parameters. If called with spectrum_type='FileFunction' and spectrum_pars=None, the source spectrum will be replaced with a FileFunction with the same differential flux distribution as the original spectrum.

Parameters

- **name** (*str*) – Source name.
- **spectrum_type** (*str*) – Spectrum type (PowerLaw, etc.).
- **spectrum_pars** (*dict*) – Dictionary of spectral parameters (optional).
- **update_source** (*bool*) – Recompute all source characteristics (flux, TS, NPred) using the new spectral model of the source.

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(*name=None*, *randomize=True*, *restore=False*)

Generate a simulation of the ROI using the current best-fit model and replace the data counts cube with this simulation. The simulation is created by generating an array of Poisson random numbers with expectation values drawn from the model cube of the binned analysis instance. This function will update the counts cube both in memory and in the source map file. The counts cube can be restored to its original state by calling this method with `restore` = True.

Parameters

- **name** (*str*) – Name of the model component to be simulated. If None then the whole ROI will be simulated.
- **restore** (*bool*) – Restore the data counts cube to its original state.

simulate_source(*src_dict=None*)

Inject simulated source counts into the data.

Parameters **src_dict** (*dict*) – Dictionary defining the spatial and spectral properties of the source that will be injected.

stage_input()

Copy input files to 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.
- **write_fits** (*bool*) – Write a FITS file with the results of the analysis.

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** (*list*) – Source or sources that will be removed from the model when computing the TS map.
- **loge_bounds** (*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*) – Generate plots.

- **write_fits** (*bool*) – Write the output to a FITS file.
- **write_npy** (*bool*) – Write the output dictionary to a numpy file.

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*, ***kwargs*)
Update the dictionary for this source.

Parameters

- **name** (*str*) –
- **paramsonly** (*bool*) –
- **reoptimize** (*bool*) – Re-fit background parameters in likelihood scan.

workdir
Return the analysis working directory.

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

write_model_map(*model_name*, *name=None*)
Save the counts model map to a FITS file.

Parameters

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

write_roi(*outfile=None*, *save_model_map=False*, *fmt='npy'*, ***kwargs*)
Write current state of the analysis to a file. This method writes an XML model definition, a ROI dictionary, and a FITS source catalog file. A previously saved analysis state can be reloaded from the ROI dictionary file with the *load_roi* method.

Parameters

- **outfile** (*str*) – String prefix of the output files. The extension of this string will be stripped when generating the XML, YAML and npy filenames.
- **make_plots** (*bool*) – Generate diagnostic plots.
- **save_model_map** (*bool*) – Save the current counts model to a FITS file.
- **fmt** (*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.**log_level**(*level*)
This is a function that returns a python like level from a HEASOFT like level.

fermipy.roi_model module

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

add_name(*name*)

assoc

check_cuts(*cuts*)

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

data

get_catalog_dict()

get_norm()

items()

name

names

params

psf_scale_fn

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

set_psf_scale_fn (*fn*)

set_spectral_pars (*spectral_pars*)

spatial_pars

spectral_pars

update_data (*d*)

update_from_source (*src*)

update_spectral_pars (*spectral_pars*)

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

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

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

```
>>> skydir = astropy.coordinates.SkyCoord(0.0,0.0,unit='deg')
>>> roi = ROIModel({'catalogs' : ['3FGL'],'src_roiwidth' : 10.0},skydir=skydir)
>>> print(roi)
name                SpatialModel   SpectrumType     offset         ts       npred
-------------------------------------------------------------------------------
3FGL J2357.3-0150   PointSource    PowerLaw          1.956       nan          0.0
3FGL J0006.2+0135   PointSource    PowerLaw          2.232       nan          0.0
3FGL J0016.3-0013   PointSource    PowerLaw          4.084       nan          0.0
3FGL J0014.3-0455   PointSource    PowerLaw          6.085       nan          0.0
```

•Print a summary of an individual source

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

•Get the SkyCoord for a source

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

•Loop over all sources and print their names

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

clear()
Clear the contents of the ROI.

copy_source(*name*)

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*

create_table()
Create an astropy Table object with the contents of the ROI model.

defaults = {'logfile': (None, '', <type 'str'>), 'catalogs': (None, '', <type 'list'>), 'src_roiwidth': (None, 'Width of squar

delete_sources(*srcs*)

diffuse_sources

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

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

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

Returns **srcs** – A source object.

Return type *Model*

get_sources(*skydir=None*, *distance=None*, *cuts=None*, *minmax_ts=None*, *minmax_npred=None*, *exclude=None*, *square=False*, *coordsys='CEL'*)

Retrieve list of source objects satisfying the following selections:

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

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

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

Return type list

get_sources_by_name(*name*)

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

Parameters **name** (*str*) –

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

Return type list

get_sources_by_position(*skydir*, *dist*, *min_dist=None*, *square=False*, *coordsys='CEL'*)

Retrieve sources within a certain angular distance of a sky coordinate. This function supports two types of geometric selections: circular (square=False) and square (square=True). The circular selection finds all sources with a given angular distance of the target position. The square selection finds sources within an ROI-like region of size R x R where R = 2 x dist.

Parameters

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

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

has_source(*name*)

load(***kwargs*)

Load both point source and diffuse components.

load_diffuse_srcs()

load_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

projection

set_projection(*proj*)

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

sources

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

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

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

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

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

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

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

associations

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

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

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

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_roi_projection(*proj*)

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

Returns **tab**

Return type Table

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

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

fermipy.roi_model.**get_params_dict**(*pars_dict*)

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.utils module

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

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

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

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

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

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

Parameters

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

fermipy.utils.**convolve2d_gauss**(*fn*, *r*, *sig*, *nstep=200*)
Evaluate the convolution f'(r) = f(r) * g(r) where f(r) is azimuthally symmetric function in two dimensions and g is a 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.**cov_to_correlation**(*cov*)

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

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_xml_element**(*root*, *name*, *attrib*)

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

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

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

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

fermipy.utils.**find_function_root**(*fn*, *x0*, *xb*, *delta=0.0*)
Find the root of a function: f(x)+delta in the interval encompassed by x0 and xb.

Parameters

- **fn** (*function*) – Python function.
- **x0** (*float*) – Fixed bound for the root search. This will either be used as the lower or upper bound depending on the relative value of xb.

- **xb** (*float*) – Upper or lower bound for the root search. If a root is not found in the interval [x0,xb]/[xb,x0] this value will be increased/decreased until a change in sign is found.

fermipy.utils.**find_rows_by_string**(*tab, names, colnames=['assoc']*)

Find the rows in a table `tab` that match at least one of the strings in `names`. This method ignores whitespace and case when matching strings.

Parameters

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

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

Return type ndarray

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

Fit a parabola to a 2D numpy array. This function will fit a parabola with the functional form described in *parabola* to a 2D slice of the input array `z`. The boundaries of the fit region within z are set with the pixel centroid (`ix` and `iy`) and region size (`dpix`).

Parameters

- **z** (ndarray) –
- **ix** (*int*) – X index of center pixel of fit region in array `z`.
- **iy** (*int*) – Y index of center pixel of fit region in array `z`.
- **dpix** (*int*) – Size of fit region expressed as a pixel offset with respect the centroid. The size of the sub-array will be (dpix*2 + 1) x (dpix*2 + 1).

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_parameter_limits**(*xval*, *loglike*, *ul_confidence=0.95*, *tol=0.001*)

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

Parameters

- **xval** (ndarray) – Array of parameter values.
- **loglike** (ndarray) – Array of log-likelihood values.
- **ul_confidence** (*float*) – Confidence level to use for limit calculation.
- **tol** (*float*) – Tolerance parameter for spline.

fermipy.utils.**init_matplotlib_backend**(*backend=None*)

This function initializes the matplotlib backend. When no DISPLAY is available the backend is automatically set to 'Agg'.

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

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

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

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

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

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

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

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

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

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

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

Parameters

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

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

Parameters

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

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

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

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

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

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*, *psf_scale_fn=None*, *normalize=False*)
Generate a kernel for a point-source.

Parameters

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

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

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

Parameters

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

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

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

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

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

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

Return type float

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

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

Returns **cl** – Confidence level.

Return type float

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

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

where

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

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

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

Parameters

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

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

Return type ndarray

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

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

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

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

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

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

fermipy.utils.**resolve_file_path_list**(*pathlist*, *workdir=None*, *prefix=''*)

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

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

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

Parameters

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

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

Return type ndarray

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

fermipy.utils.**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.**twosided_cl_to_dlnl**(*cl*)
Compute the delta-loglikehood value that corresponds to a two-sided interval of the given confidence level.

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

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

Return type float

fermipy.utils.**twosided_dlnl_to_cl**(*dlnl*)
Compute the confidence level that corresponds to a two-sided interval with a given change in the loglikelihood value.

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

Returns **cl** – Confidence level.

Return type float

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

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

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

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

fermipy.utils.**val_to_bin**(*edges*, *x*)
Convert axis coordinate to bin index.

fermipy.utils.**val_to_bin_bounded**(*edges*, *x*)
Convert axis coordinate to bin index.

fermipy.utils.**val_to_edge**(*edges*, *x*)
Convert axis coordinate to bin index.

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

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

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

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

fermipy.plotting module

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

defaults = {'catalogs': (None, '', <type 'list'>), 'format': ('png', '', <type 'str'>), 'loge_bounds': (None, '', <type 'list'>

make_components_plots(*gta*, *mcube_maps*, *prefix*, *loge_bounds=None*, ***kwargs*)

make_extension_plots(*prefix*, *loge_bounds=None*, ***kwargs*)

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

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

Parameters

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

make_roi_plots(*gta*, *mcube_map*, *prefix*, *loge_bounds=None*, ***kwargs*)
Make various diagnostic plots for the 1D and 2D counts/model distributions.

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

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

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

Parameters

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

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

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

plot(*iaxis*)

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

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

projtype

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

cmap

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

data

defaults = {'graticule_radii': (None, '', <type 'list'>), 'label_ts_threshold': (0.0, '', <type 'float'>), 'catalogs': (None, '',

draw_circle(*skydir*, *radius*)

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

plot(***kwargs*)

plot_catalog(*catalog*)

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

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

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

proj

projtype

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

zoom(*zoom*)

class fermipy.plotting.**SEDPlotter**(*sed*)
Bases: object

static annotate(*sed*, *xy=(0.05*, *0.93)*, ***kwargs*)

static get_ylims(*sed*)

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

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

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

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

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

static plot_sed(*sed*, *showlnl=False*, ***kwargs*)
Render a plot of a spectral energy distribution.

Parameters

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

sed

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

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

fermipy.plotting.**load_bluered_cmap**()

fermipy.plotting.**load_ds9_cmap**()

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

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

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.**SEDGenerator**
Bases: object

Mixin class that provides SED functionality to *GTAnalysis*.

sed(*name*, ***kwargs*)
Generate a spectral energy distribution (SED) for a source. This function will fit the normalization of the source in each energy bin. By default the SED will be generated with the analysis energy bins but a custom binning can be defined with the loge_bins parameter.

Parameters

- **name** (*str*) – Source name.
- **prefix** (*str*) – Optional string that will be prepended to all output files (FITS and rendered images).
- **loge_bins** (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.
- **cov_scale** (*float*) – Scaling factor that will be applied when setting the gaussian prior on the normalization of free background sources. If this parameter is None then no gaussian prior will be applied.
- **make_plots** (*bool*) – Generate plots.
- **write_fits** (*bool*) – Write the output to a FITS file.
- **write_npy** (*bool*) – Write the output dictionary to a numpy file.
- **optimizer** (*dict*) – Dictionary that overrides the default optimizer settings.

Returns **sed** – Dictionary containing output of the SED analysis.

Return type dict

fermipy.sourcefind module

class fermipy.sourcefind.**SourceFinder**
Bases: object

Mixin class which provides source-finding functionality to *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.

Returns

- **peaks** (*list*) – List of peak objects.
- **sources** (*list*) – List of source objects.

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.
- **make_plots** (*bool*) – Generate plots.
- **write_fits** (*bool*) – Write the output to a FITS file.

- **write_npy** (*bool*) – Write the output dictionary to a numpy file.
- **optimizer** (*dict*) – Dictionary that overrides the default optimizer settings.

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

fermipy.spectrum module

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

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

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

where the params array should be defined with:

•params[0] : sigmav

•params[1] : mass

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

chan
Return the channel string.

chan_code
Return the channel code.

channel_index_mapping = {1: 8, 2: 6, 3: 3, 4: 1, 5: 2, 6: 7, 7: 4, 8: 5, 9: 0, 10: 10, 11: 11, 12: 9}

channel_name_mapping = {1: ['e+e-', 'ee'], 2: ['mu+mu-', 'mumu', 'musrc'], 3: ['tau+tau-', 'tautau', 'tausrc'], 4: ['bl

channel_rev_map = {'mumu': 2, 'zz': 8, 'gluons': 6, 'ee': 1, 'bbsrc': 4, 'gg': 6, 'wwsrc': 7, 'bb-bar': 4, 'tautau': 3, 'mu

static channels()
Return all available DMFit channel strings

static nparam()

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

Class that evaluates a function with the parameterization:

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

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

•params[0] : Prefactor (p_0)

•params[1] : Index (p_1)

•params[2] : Curvature (p_2)

static nparam()

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

Class that evaluates a function with the parameterization:

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

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

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

static log_to_params(*params*)

static nparam()

static params_to_log(*params*)

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

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

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

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

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

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

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

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

static nparam()

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

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

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

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

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

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

emax

emin

params

scale

spectral_fn

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

params
Return parameter vector of the function.

scale

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

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

fermipy.skymap module

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

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

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

Parameters

- **hpx_in** (*ndarray*) – HEALPix input data
- **sum_ebins** (*bool*) – sum energy bins over energy bins before reprojecting
- **normalize** (*bool*) – True -> perserve integral by splitting HEALPix values between bins
- **(WCS object, np.ndarray() with reprojected data)** (*returns*) –

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

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

static create_from_hdulist(*hdulist*, *extname='SKYMAP'*, *ebounds='EBOUNDS'*)
Creates and returns an HpxMap object from a FITS HDUList

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

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

Parameters

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

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

Return type numpy.ndarray((n))

hpx

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

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

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

Parameters

- **sum_ebins** (*bool*) – sum energy bins over energy bins before reprojecting
- **proj** (*str*) – WCS-projection
- **oversample** (*int*) – Oversampling factor for WCS map

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

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

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

static create(*skydir*, *cdelt*, *npix*, *coordsys='CEL'*, *projection='AIT'*)

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

static create_from_hdu(*hdu*, *wcs*)

create_image_hdu(*name=None*)

create_primary_hdu()

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

Parameters

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

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

Return type numpy.ndarray((n))

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

Parameters

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

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

Return type list

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

interpolate(*lon*, *lat*, *egy=None*)

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

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

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

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

npix

pix_center
Return the ROI center in pixel coordinates.

pix_size
Return the pixel size along the two image dimensions.

skydir
Return the sky coordinate of the image center.

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

wcs

width
Return the dimensions of the image.

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

Parameters

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

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

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

counts

data

get_pixel_indices(*lats*, *lons*)

fermipy.skymap.**make_coadd_hpx**(*maps*, *hpx*, *shape*)

fermipy.skymap.**make_coadd_map**(*maps*, *proj*, *shape*)

fermipy.skymap.**make_coadd_wcs**(*maps*, *wcs*, *shape*)

fermipy.skymap.**read_map_from_fits**(*fitsfile*, *extname=None*)

fermipy.castro module

Utilities for dealing with 'castro data', i.e., 2D table of likelihood values.

Castro data can be tabluated in terms of a variety of variables. The most common example is probably a simple SED, where we have the likelihood as a function of Energy and Energy Flux.

However, we could easily convert to the likelihood as a function of other variables, such as the Flux normalization and the spectral index, or the mass and cross-section of a putative dark matter particle.

class fermipy.castro.**CastroData**(*norm_vals*, *nll_vals*, *refSpec*, *norm_type*)
Bases: *fermipy.castro.CastroData_Base*

This class wraps the data needed to make a "Castro" plot, namely the log-likelihood as a function of normalization for a series of energy bins.

static create_from_fits(*fitsfile*, *norm_type='eflux'*, *hdu_scan='SCANDATA'*, *hdu_energies='EBOUNDS'*, *irow=None*)
Create a CastroData object from a tscube FITS file.

Parameters

- **fitsfile** (*str*) – Name of the fits file
- **norm_type** (*str*) – Type of normalization to use. Valid options are:
  - norm : Normalization w.r.t. to test source
  - flux : Flux of the test source (ph cm^-2 s^-1)
  - eflux: Energy Flux of the test source (MeV cm^-2 s^-1)
  - npred: Number of predicted photons (Not implemented)
  - dnde : Differential flux of the test source (ph cm^-2 s^-1 MeV^-1)
- **hdu_scan** (*str*) – Name of the FITS HDU with the scan data
- **hdu_energies** (*str*) – Name of the FITS HDU with the energy binning and normalization data
- **irow** (*int or None*) – If none, then this assumes that there is a single row in the scan data table Otherwise, this specifies which row of the table to use

Returns castro

Return type *CastroData*

static create_from_flux_points(*txtfile*)
Create a Castro data object from a text file containing a sequence of differential flux points.

static create_from_sedfile(*fitsfile*, *norm_type='eflux'*)
Create a CastroData object from an SED fits file

Parameters

- **fitsfile** (*str*) – Name of the fits file
- **norm_type** (*str*) – Type of normalization to use, options are:
  - norm : Normalization w.r.t. to test source
  - flux : Flux of the test source (ph cm^-2 s^-1)
  - eflux: Energy Flux of the test source (MeV cm^-2 s^-1)
  - npred: Number of predicted photons (Not implemented)
  - dnde : Differential flux of the test source (ph cm^-2 s^-1 MeV^-1)

Returns castro

Return type *CastroData*

static create_from_stack(*shape*, *components*, *ylims*, *weights=None*)
Combine the log-likelihoods from a number of components.

Parameters

- **shape** (*tuple*) – The shape of the return array
- **components** (*[~fermipy.castro.CastroData_Base]*) – The components to be stacked
- **weights** (*array-like*) –

Returns castro

Return type *CastroData*

static create_from_tables(*norm_type='eflux'*, *tab_s='SCANDATA'*, *tab_e='EBOUNDS'*)
Create a CastroData object from two tables

Parameters

- **norm_type** (*str*) – Type of normalization to use. Valid options are:
  - norm : Normalization w.r.t. to test source
  - flux : Flux of the test source (ph cm^-2 s^-1)
  - eflux: Energy Flux of the test source (MeV cm^-2 s^-1)
  - npred: Number of predicted photons (Not implemented)
  - dnde : Differential flux of the test source (ph cm^-2 s^-1 MeV^-1)
- **tab_s** (*str*) – table scan data
- **tab_e** (*str*) – table energy binning and normalization data

Returns **castro**

Return type *CastroData*

create_functor(*specType*, *initPars=None*, *scale=1000.0*)
Create a functor object that computes normalizations in a sequence of energy bins for a given spectral model.

Parameters

- **specType** (*str*) – The type of spectrum to use. This can be a string corresponding to the spectral model class name or a *SpectralFunction* object.
- **initPars** (ndarray) – Arrays of parameter values with which the spectral function will be initialized.
- **scale** (*float*) – The 'pivot energy' or energy scale to use for the spectrum

Returns **fn** – A functor object.

Return type *SEDFunctor*

nE
Return the number of energy bins. This is also the number of x-axis bins.

refSpec
Return a *ReferenceSpec* with the spectral data

spectrum_loglike(*specType*, *params*, *scale=1000.0*)
return the log-likelihood for a particular spectrum

Parameters

- **specTypes** (*str*) – The type of spectrum to try
- **params** (*array-like*) – The spectral parameters
- **scale** (*float*) – The energy scale or 'pivot' energy

test_spectra(*spec_types=None*)
Test different spectral types against the SED represented by this CastroData.

Parameters **spec_types** (*[str, ...]*) – List of spectral types to try

Returns

retDict – A dictionary of dictionaries. The top level dictionary is keyed by spec_type. The sub-dictionaries each contain:

- "Function" : *SpectralFunction*
- "Result" : tuple with the output of scipy.optimize.fmin
- "Spectrum" : ndarray with best-fit spectral values
- "ScaleEnergy" : float, the 'pivot energy' value
- "TS" : float, the TS for the best-fit spectrum

Return type dict

class fermipy.castro.**CastroData_Base**(*norm_vals*, *nll_vals*, *norm_type*)
Bases: object

This class wraps the data needed to make a "Castro" plot, namely the log-likelihood as a function of normalization.

In this case the x-axes and y-axes are generic Sub-classes can implement particul axes choices (e.g., EFlux v. Energy)

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

__call__(*x*)
Return the negative log-likelihood for an array of values, summed over the energy bins

Parameters **x** (ndarray) – Array of N x M values

Returns **nll_val** – Array of negative log-likelihood values.

Return type ndarray

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

build_scandata_table()

chi2_vals(*x*)
Compute the difference in the log-likelihood between the MLE in each energy bin and the normalization predicted by a global best-fit model. This array can be summed to get a goodness-of-fit chi2 for the model.

Parameters **x** (ndarray) – An array of normalizations derived from a global fit to all energy bins.

Returns **chi2_vals** – An array of chi2 values for each energy bin.

Return type ndarray

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

Parameters

- **x** (ndarray) – Array of N x M values
- **der** (*int*) – Order of the derivate

Returns **der_val** – Array of negative log-likelihood values.

Return type ndarray

fitNorm_v2(*specVals*)
Fit the normalization given a set of spectral values that define a spectral shape.

This version uses `scipy.optimize.fmin`.

Parameters

- **specVals** (*an array of (nebin values that define a spectral shape*) –
- **xlims** (*fit limits*) –

Returns **norm** – Best-fit normalization value

Return type float

fitNormalization(*specVals*, *xlims*)
Fit the normalization given a set of spectral values that define a spectral shape

This version is faster, and solves for the root of the derivatvie

Parameters

- **specVals** (*an array of (nebin values that define a spectral shape*) –
- **xlims** (*fit limits*) –
- **the best-fit normalization value** (*returns*) –

fit_spectrum(*specFunc*, *initPars*, *freePars=None*)
Fit for the free parameters of a spectral function

Parameters

- **specFunc** (*SpectralFunction*) – The Spectral Function
- **initPars** (ndarray) – The initial values of the parameters
- **freePars** (ndarray) – Boolean array indicating which parameters should be free in the fit.

Returns

- **params** (ndarray) – Best-fit parameters.
- **spec_vals** (ndarray) – The values of the best-fit spectral model in each energy bin.
- **ts_spec** (*float*) – The TS of the best-fit spectrum
- **chi2_vals** (ndarray) – Array of chi-squared values for each energy bin.
- **chi2_spec** (*float*) – Global chi-squared value for the sum of all energy bins.
- **pval_spec** (*float*) – p-value of chi-squared for the best-fit spectrum.

fn_mles()
returns the summed likelihood at the maximum likelihood estimate

Note that simply sums the maximum likelihood values at each bin, and does not impose any sort of constrain between bins

getIntervals(*alpha*)
Evaluate the two-sided intervals corresponding to a C.L. of (1-alpha)%.

Parameters **alpha** (*float*) – limit confidence level.

Returns

- **limit_vals_hi** (ndarray) – An array of lower limit values.
- **limit_vals_lo** (ndarray) – An array of upper limit values.

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

Parameters

- **alpha** (*float*) – limit confidence level.
- **upper** (*bool*) – upper or lower limits.
- **an array of values, one for each energy bin** (*returns*) –

mles()
return the maximum likelihood estimates for each of the energy bins

nll_null
Return the negative log-likelihood for the null-hypothesis

norm_derivative(*spec*, *norm*)

norm_type
Return the normalization type flag

nx
Return the number of profiles

ny
Return the number of profiles

static stack_nll(*shape*, *components*, *ylims*, *weights=None*)
Combine the log-likelihoods from a number of components.

Parameters

- **shape** (*tuple*) – The shape of the return array
- **components** (*CastroData_Base*) – The components to be stacked
- **weights** (*array-like*) –

Returns

- **norm_vals** (*'numpy.ndarray'*) – N X M array of Normalization values
- **nll_vals** (*'numpy.ndarray'*) – N X M array of log-likelihood values

ts_vals()
returns test statistic values for each energy bin

class fermipy.castro.**Interpolator**(*x*, *y*)
Bases: object

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

Safely deals with overflows and underflows

__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.castro.**LnLFn**(*x*, *y*, *norm_type=0*)
Bases: object

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

TS()
return the Test Statistic

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

getDeltaLogLike(*dlnl*, *upper=True*)
Find the point at which the log-likelihood changes by a given value with respect to its value at the MLE.

getInterval(*alpha*)
Evaluate the interval corresponding to a C.L. of (1-alpha)%.

Parameters **alpha** (*limit confidence level.*) –

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

Parameters

- **alpha** (*limit confidence level.*) –
- **upper** (*upper or lower limits.*) –

interp
return the underlying Interpolator object

mle()
return the maximum likelihood estimate

This will return the cached value, if it exists

norm_type
Return a string specifying the quantity used for the normalization. This isn't actually used in this class, but it is carried so that the class is self-describing. The possible values are open-ended.

class fermipy.castro.**ReferenceSpec**(*emin*, *emax*, *ref_dnde*, *ref_flux*, *ref_eflux*, *ref_npred*, *eref=None*)
Bases: object

This class encapsulates data for a reference spectrum.

Parameters

- **ne** (int) – Number of energy bins

- **ebins** (ndarray) – Array of bin edges.
- **emin** (ndarray) – Array of lower bin edges.
- **emax** (ndarray) – Array of upper bin edges.
- **bin_widths** (ndarray) – Array of energy bin widths.
- **eref** (ndarray) – Array of reference energies. Typically these are the geometric mean of the energy bins
- **ref_dnde** (ndarray) – Array of differential photon flux values.
- **ref_flux** (ndarray) – Array of integral photon flux values.
- **ref_eflux** (ndarray) – Array of integral energy flux values.
- **ref_npred** (ndarray) – Array of predicted number of photons in each energy bin.

bin_widths

build_ebound_table()
Build and return an EBOUNDS table with the encapsulated data.

static create_from_table(*tab_e*)

Parameters **tab_e** (Table) – EBOUNDS table.

ebins

emax

emin

eref

log_ebins

nE

ref_dnde

ref_eflux
return the energy flux values

ref_flux
return the flux values

ref_npred
return the number of predicted events

class fermipy.castro.**SpecData**(*ref_spec*, *norm*, *norm_err*)
Bases: *fermipy.castro.ReferenceSpec*

This class encapsulates spectral analysis results (best-fit normalizations, errors, etc.), energy binning, and reference spectrum definition.

Parameters

- **norm** (ndarray) –
- **norm_err** (ndarray) –
- **flux** (ndarray) – Array of integral photon flux values.
- **eflux** (ndarray) – Array of integral energy flux values.
- **dnde** (ndarray) – Differential flux values

- **dnde_err** (ndarray) – Uncertainties on differential flux values
- **e2dnde** (ndarray) – Differential flux values scaled by E^2
- **e2dnde_err** (ndarray) – Uncertainties on differential flux values scaled by E^2

build_spec_table()

static create_from_table(*tab*)

dnde

dnde_err

e2dnde

e2dnde_err

eflux

flux

norm

norm_err

class fermipy.castro.**TSCube**(*tsmap*, *normmap*, *tscube*, *normcube*, *norm_vals*, *nll_vals*, *refSpec*, *norm_type*)

Bases: object

A class wrapping a TSCube, which is a collection of CastroData objects for a set of directions.

This class wraps a combination of:

•Pixel data,

•Pixel x Energy bin data,

•Pixel x Energy Bin x Normalization scan point data

castroData_from_ipix(*ipix*, *colwise=False*)
Build a CastroData object for a particular pixel

castroData_from_pix_xy(*xy*, *colwise=False*)
Build a CastroData object for a particular pixel

static create_from_fits(*fitsfile*, *norm_type='flux'*)
Build a TSCube object from a fits file created by gttscube :param fitsfile: Path to the tscube FITS file.

Parameters **norm_type** (*str*) – String specifying the quantity used for the normalization

find_and_refine_peaks(*threshold*, *min_separation=1.0*, *use_cumul=False*)
Run a simple peak-finding algorithm, and fit the peaks to paraboloids to extract their positions and error ellipses.

Parameters

- **threshold** (*float*) – Peak threshold in TS.
- **min_separation** (*float*) – Radius of region size in degrees. Sets the minimum allowable separation between peaks.
- **use_cumul** (*bool*) – If true, used the cumulative TS map (i.e., the TS summed over the energy bins) instead of the TS Map from the fit to and index=2 powerlaw.

Returns **peaks** – List of dictionaries containing the location and amplitude of each peak. Output of find_peaks

Return type list

find_sources (*threshold*, *min_separation=1.0*, *use_cumul=False*, *output_peaks=False*, *output_castro=False*, *output_specInfo=False*, *output_src_dicts=False*, *output_srcs=False*)

nE
return the number of energy bins

nN
return the number of sample points in each energy bin

normcube
return the Cube of the normalization value per pixel / energy bin

normmap
return the Map of the Best-fit normalization value

nvals
Return the number of values in the tscube

refSpec
Return the Spectral Data object

test_spectra_of_peak (*peak*, *spec_types=None*)
Test different spectral types against the SED represented by the CastroData corresponding to a single pixel in this TSCube

Parameters **spec_types** ([str, ...]) – List of spectral types to try

Returns

- **castro** (CastroData) – The castro data object for the pixel corresponding to the peak
- **test_dict** (*dict*) – The dictionary returned by test_spectra

ts_cumul
return the Map of the cumulative TestStatistic value per pixel (summed over energy bin)

tscube
return the Cube of the TestStatistic value per pixel / energy bin

tsmap
return the Map of the TestStatistic value

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

fermipy.castro.**convert_sed_cols** (*tab*)
Cast SED column names to lowercase.

fermipy.tsmap module

class fermipy.tsmap.**TSCubeGenerator**
Bases: object

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.
- **write_fits** (*bool*) – Write a FITS file with the results of the analysis.

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

Return type dict

class fermipy.tsmap.**TSMapGenerator**

Bases: object

Mixin class for *GTAnalysis* that generates TS maps.

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** (*list*) – Source or sources that will be removed from the model when computing the TS map.
- **loge_bounds** (*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*) – Generate plots.

- **write_fits** (*bool*) – Write the output to a FITS file.
- **write_npy** (*bool*) – Write the output dictionary to a numpy file.

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

Return type dict

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

fermipy.tsmap.**convert_tscube**(*infile*, *outfile*)

fermipy.tsmap.**convert_tscube_old**(*infile*, *outfile*)
Convert between old and new TSCube formats.

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

fermipy.tsmap.**extract_images_from_tscube**(*infile*, *outfile*)
Extract data from table HDUs in TSCube file and convert them to FITS images

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*, *bkg*, *model*)
Wrapper for cash statistics, that defines the model function.

Parameters

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

fermipy.tsmap.**f_cash_sum**(*x*, *counts*, *bkg*, *model*, *bkg_sum=0*, *model_sum=0*)

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.**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**
Bases: object

Mixin class for *GTAnalysis* that generates spatial residual maps from the difference of data and model maps smoothed with a user-defined spatial/spectral template. The map of residual significance can be interpreted in the same way as a TS map (the likelihood of a source at the given location).

residmap(*prefix=''*, ***kwargs*)
Generate 2-D spatial residual maps using the current ROI model and the convolution kernel defined with the model argument.

Parameters

- **prefix** (*str*) – String that will be prefixed to the output residual map files.
- **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.
- **loge_bounds** (*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*) – Generate plots.
- **write_fits** (*bool*) – Write the output to a FITS file.
- **write_npy** (*bool*) – Write the output dictionary to a numpy file.

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

Return type dict

fermipy.residmap.**convolve_map**(*m*, *k*, *cpix*, *threshold=0.001*, *imin=0*, *imax=None*)
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.lightcurve module

class fermipy.lightcurve.**LightCurve**
Bases: object

lightcurve(*name*, ***kwargs*)
Generate a lightcurve for the named source. The function will complete the basic analysis steps for each bin and perform a likelihood fit for each bin. Extracted values (along with errors) are Integral Flux, spectral model, Spectral index, TS value, pred. # of photons.

Parameters

- **name** (*str*) – source name
- **binsz** (*float*) – Set the lightcurve bin size in seconds, default is 1 day.
- **nbins** (*int*) – Set the number of lightcurve bins. The total time range will be evenly split into this number of time bins.
- **time_bins** (*list*) – Set the lightcurve bin edge sequence in MET. When defined this option takes precedence over binsz and nbins.
- **free_radius** (*float*) – Free normalizations of background sources within this angular distance in degrees from the source of interest.
- **free_sources** (*list*) – List of sources to be freed. These sources will be added to the list of sources satisfying the free_radius selection

Returns **LightCurve** – Dictionary containing output of the LC analysis

Return type dict

Module contents

fermipy.**test**(*package=None*, *test_path=None*, *args=None*, *plugins=None*, *verbose=False*, *pastebin=None*, *remote_data=False*, *pep8=False*, *pdb=False*, *coverage=False*, *open_files=False*, ***kwargs*)
Run the tests using py.test. A proper set of arguments is constructed and passed to pytest.main.

Parameters

- **package** (*str, optional*) – The name of a specific package to test, e.g. 'io.fits' or 'utils'. If nothing is specified all default tests are run.
- **test_path** (*str, optional*) – Specify location to test by path. May be a single file or directory. Must be specified absolutely or relative to the calling directory.
- **args** (*str, optional*) – Additional arguments to be passed to pytest.main in the `args` keyword argument.
- **plugins** (*list, optional*) – Plugins to be passed to pytest.main in the `plugins` keyword argument.
- **verbose** (*bool, optional*) – Convenience option to turn on verbose output from py.test. Passing True is the same as specifying `'-v'` in `args`.

- **pastebin** (*{'failed','all',None}, optional*) – Convenience option for turning on py.test pastebin output. Set to `'failed'` to upload info for failed tests, or `'all'` to upload info for all tests.
- **remote_data** (*bool, optional*) – Controls whether to run tests marked with @remote_data. These tests use online data and are not run by default. Set to True to run these tests.
- **pep8** (*bool, optional*) – Turn on PEP8 checking via the pytest-pep8 plugin and disable normal tests. Same as specifying `'--pep8 -k pep8'` in `args`.
- **pdb** (*bool, optional*) – Turn on PDB post-mortem analysis for failing tests. Same as specifying `'--pdb'` in `args`.
- **coverage** (*bool, optional*) – Generate a test coverage report. The result will be placed in the directory htmlcov.
- **open_files** (*bool, optional*) – Fail when any tests leave files open. Off by default, because this adds extra run time to the test suite. Works only on platforms with a working `lsof` command.
- **parallel** (*int, optional*) – When provided, run the tests in parallel on the specified number of CPUs. If parallel is negative, it will use the all the cores on the machine. Requires the pytest-xdist plugin installed. Only available when using Astropy 0.3 or later.
- **kwargs** – Any additional keywords passed into this function will be passed on to the astropy test runner. This allows use of test-related functionality implemented in later versions of astropy without explicitly updating the package template.

1.2.9 Changelog

This page is a changelog for releases of Fermipy.

0.12.0 (11/20/2016)

- Add support for phased analysis (#87). `gtlike.expscale` and `gtlike.src_expscale` can be used to apply a constant exposure correction to a whole component or individual sources within a component. See *Phased Analysis* for examples.
- Add script and tools for calculating flux sensitivity (#88 and #95). The `fermipy-flux-sensitivity` script evaluates both the differential and integral flux sensitivity for a given TS threshold and minimum number of detected counts. See *Sensitivity Tools* for examples.
- Add `fermipy-healview` script for generating images of healpix maps and cubes.
- Improvements to HPX-related classes and utilities.
- Refactoring in `irfs` module to support development of new validation tools.
- Improvements to configuration handling to allow parameter validation when updating configuration at runtime.
- Add lightcurve method (#80). See *Light Curves* for documentation.
- Change convention for flux arrays in source object. Values and uncertainties are now stored in separate arrays (e.g. `flux` and `flux_err`).
- Add *Docker-based installation* instructions. This can be used to run the RHEL6 SLAC ST builds on any machine that supports Docker (e.g. OSX Yosemite or later).
- Adopt changes to column name conventions in SED format. All column names are now lowercase.

0.11.0 (08/24/2016)

- Add support for weighted likelihood fits (supported in ST 11-03-00 or later). Weights maps can be specified with the `wmap` parameter in *gtlike*.
- Implemented performance improvements in *tsmap* including switching to newton's method for step-size calculation and masking of empty pixels (see #79).
- Ongoing development and refactoring of classes for dealing with CastroData (binned likelihood profiles).
- Added *reload_sources* method for faster recomputation of source maps.
- Fixed sign error in localization plotting method that gave wrong orientation for error ellipse..
- Refactored classes in *spectrum* and simplified interface for doing spectral fits (see #69).
- Added DMFitFunction spectral model class in *spectrum* (see #66). This uses the same lookup tables as the ST DMFitFunction class but provides a pure python implementation which can be used independently of the STs.

0.10.0 (07/03/2016)

- Implement support for more spectral models (DMFitFunction, EblAtten, FileFunction, Gaussian).
- New options (`outdir_regex` and `workdir regex`) for fine-grained control over input/output file staging.
- Add `offset_roi_edge` to source dictionary. Defined as the distance from the source position to the edge of the ROI (< 0 = inside the ROI, > 0 = outside the ROI).
- Add new variables in *fit* output (`edm`, `fit_status`).
- Add new package scripts (`fermipy-collect-sources`, `fermipy-cluster-sources`).
- Various refactoring and improvements in code for dealing with castro data.
- Add `MODEL_FLUX` and `PARAMS` HDUs to SED FITS file. Many new elements added SED output dictionary.
- Support NEWTON fitter with the same interface as MINUIT and NEWMINUIT. Running *fit* with `optimizer` = NEWTON will use the NEWTON fitter where applicable (only free norms) and MINUIT otherwise. The `optimizer` argument to *sed*, *extension*, and *localize* can be used to override the default optimizer at runtime. Note that the NEWTON fitter is only supported by ST releases *after* 11-01-01.

0.9.0 (05/25/2016)

- Bug fixes and various refactoring in TSCube and CastroData. Classes for reading and manipulating bin-by-bin likelihoods are now moved to the *castro* module.
- Rationalized naming conventions for energy-related variables. Properties and method arguments with units of the logarithm of the energy now consistently contain `log` in the name.
  - *energies* now returns bin energies in MeV (previously it returned logarithmic energies). *log_energies* can be used to access logarithmic bin energies.
  - Changed `erange` parameter to `loge_bounds` in the methods that accept an energy range.
  - Changed the units of `emin`, `ectr`, and `emax` in the sed output dictionary to MeV.
- Add more columns to the FITS source catalog file generated by *write_roi*. All float and string values in the source dictionary are now automatically included in the FITS file. Parameter values, errors, and names are written to the `param_values`, `param_errors`, and `param_names` vector columns.
- Add package script for dispatching batch jobs to LSF (`fermipy-dispatch`).

- Fixed some bugs related to handling of unicode strings.

0.8.0 (05/18/2016)

- Added new variables to source dictionary:
  - Likelihood scan of source normalization (`dloglike_scan`, `eflux_scan`, `flux_scan`).
  - Source localization errors (`pos_sigma`, `pos_sigma_semimajor`, `pos_sigma_semiminor`, `pos_r68`, `pos_r95`, `pos_r99`, `pos_angle`). These are automatically filled when running *`localize`* or *`find_sources`*.
- Removed camel-case in some source variable names.
- Add `cacheft1` option to *data* disable caching FT1 files. Cacheing is still enabled by default.
- Support FITS file format for preliminary releases of the 4FGL catalog.
- Add `__future__` statements throughout to ensure forward-compatibility with python3.
- Reorganize utility modules including those for manipulation of WCS and healpix images.
- Various improvements and refactoring in *`localize`*. This method now moved to the *`sourcefind`* module.
- Add new global parameter `llscan_pts` in *gtlike* to define the number of likelihood evaluation points.
- Write output of *`sed`* to a FITS file in the Likelihood SED format. More information about the Likelihood SED format is available on this page.
- Write ROI model to a FITS file when calling *`write_roi`*. This file contains a BINTABLE with one row per source and uses the same column names as the 3FGL catalog file to describe spectral parameterizations. Note that this file currently only contains a subset of the information available in the numpy output file.
- Reorganize classes and methods in *`sed`* for manipulating and fitting bin-by-bin likelihoods. Spectral functions moved to a dedicated *`spectrum`* module.
- Write return dictionary to a numpy file in *`residmap`* and *`tsmap`*.

CHAPTER 2

Indices and tables

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