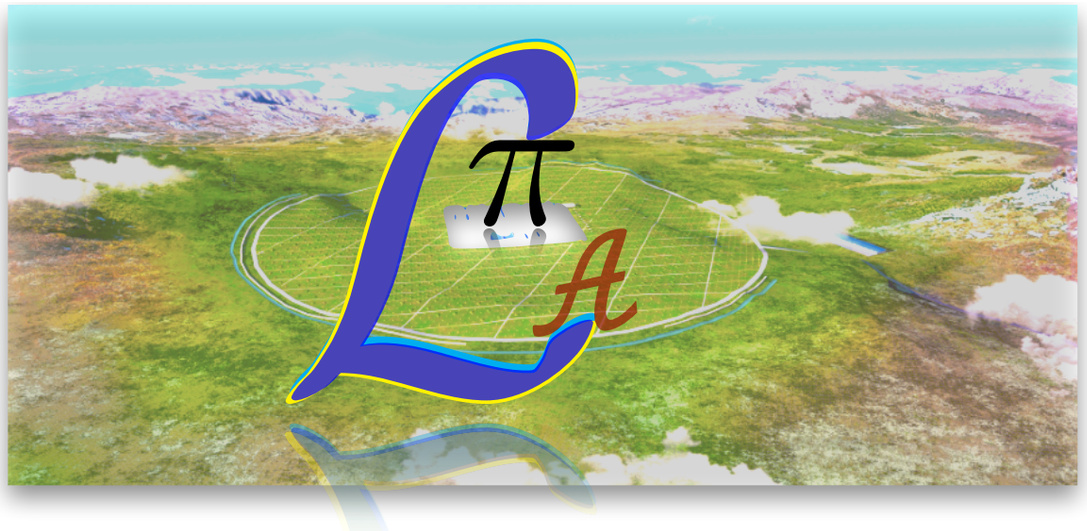

LHAASO Astronomy Python package

杨莉莉

物理与天文学院，中山大学

国家重点研发计划“基于高海拔宇宙线观测站LHAASO 的科学研究”项目2019年度进展会

2019年8月27日

软件组成员

- 高能所：胡红波，张毅，陈松战，郭义庆，林苏杰，常潇川，郭莹莹等
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- 紫金山天文台：袁强，黄晓渊等
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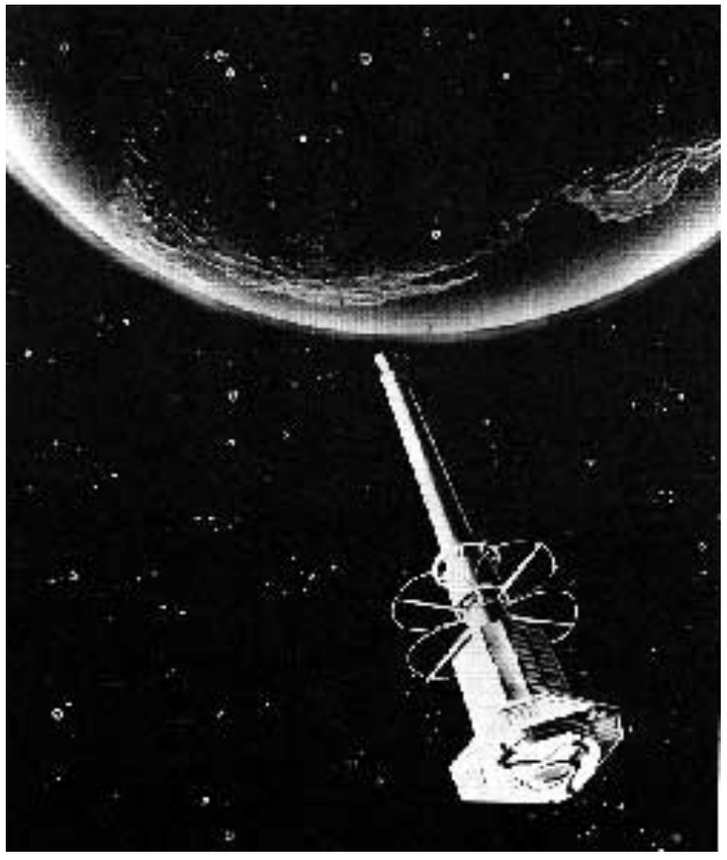
- 中山大学：谭柏轩，崔昱东，何新波，杨莉莉等

伽马天文的过去和现在

1961年发射的探索者11号卫星是第一个伽马射线天文望远镜，第一批的伽马射线源的发现



1961年发射的探索者11号卫星是第一个伽马射线天文望远镜，第一批的伽马射线源的发现

1990s，开始建立一个通用的数据格式

FITS数据格式作为成功的一种通用格式被接受

https://heasarc.gsfc.nasa.gov/

Astronomical Data Analysis Software and Systems IV
ASP Conference Series, Vol. 77, 1995
R. A. Shaw, H. E. Payne, and J. J. E. Hayes, eds.

The OGIP FITS Working Group

M. F. Corcoran, L. Angelini, I. George, T. McGlynn, K. Mukai, W. Pence, A. Rots

Office of Guest Investigator Programs, Goddard Space Flight Center, Greenbelt, MD, 20771

Abstract. We present an overview of the workings of the OGIP FITS Working Group (OFWG).

1. Introduction

Nearly all high-energy astrophysics projects provide data in FITS format (Wells, Greisen, & Harten 1981). However, arbitrary and/or inconsistent use of file formats and header keywords leads to confusion and requires that specialized software be used for correct data interpretation and analysis. The need to support specialized FITS formats and software systems is a significant (sometimes unmanageable) burden for data archives. However, adherence to simple, agreed-upon conventions can alleviate this burden at little cost.

The Office of Guest Investigator Programs (OGIP) at the Goddard Space Flight Center has organized a working group to identify appropriate conventions, and, with community support, to encourage adherence to these conventions.

2. The OFWG

The OFWG was set up to (1) ensure that new FITS definitions used within the OGIP do not violate any established FITS standards/conventions; (2) encourage standardization of keyword usage, data types, and FITS file formats used within the OGIP (i.e., the so-called Rationalized Data File or RDF format); and (3) disseminate OFWG recommendations to the broader High Energy Astrophysics and FITS communities to promote community-wide standardization.

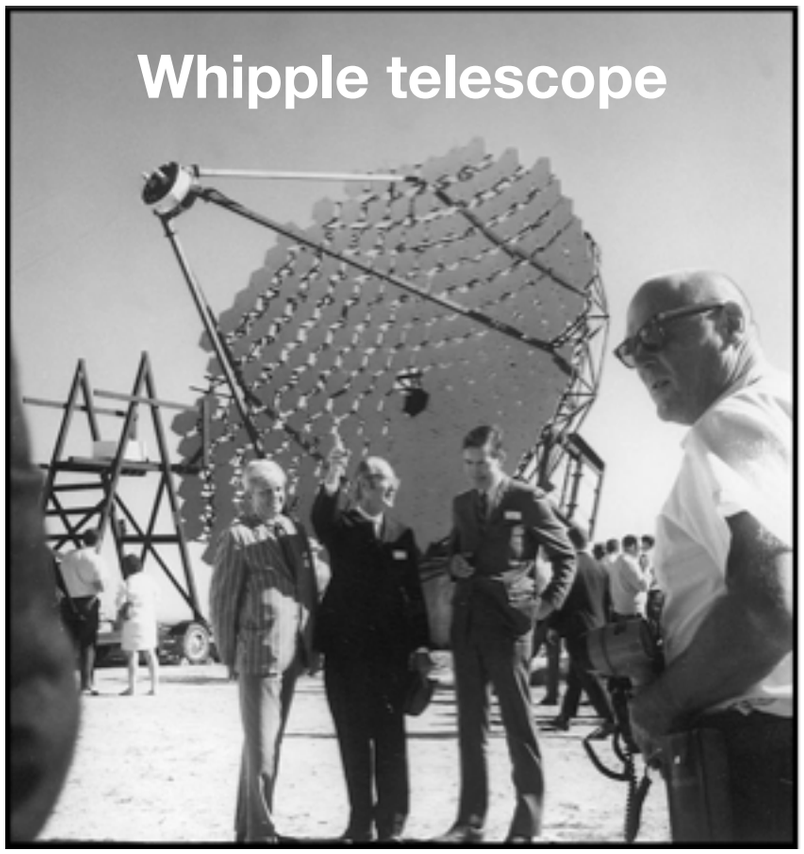
3. Community Involvement

地面望远镜

1960s到1980s，开始进行地面望远镜的建造与探索

1989年，Whipple望远镜探测到了第一个TeV源

每一个合作组有各自的内部软件，大多数基于C++和ROOT

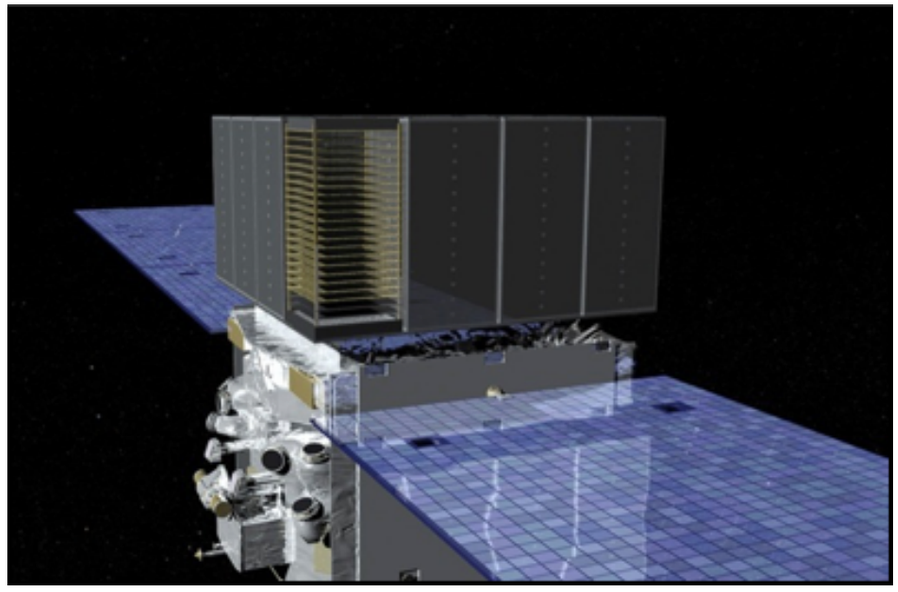


目前的发展

2008年，NASA发射费米-LAT望远镜，大概3000个GeV源

数据以FITS格式完全开放

科学工具：C++&Python



从2000以来，几个IACTs和HAWC，大概200个TeV源

合作组成员逐渐增多

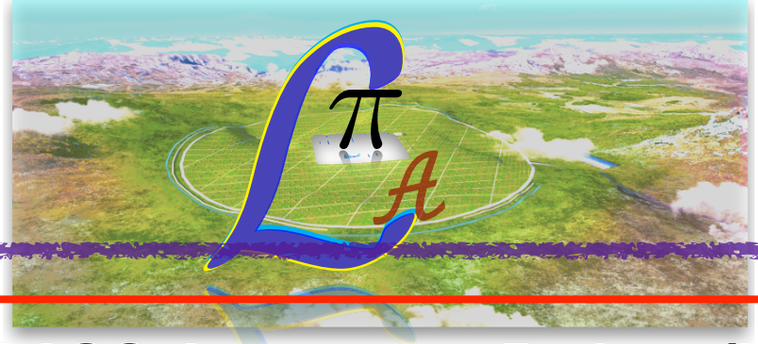
伽马数据的特点

高级伽马射线数据的共同点（标定、重建、p/γ分辨）：

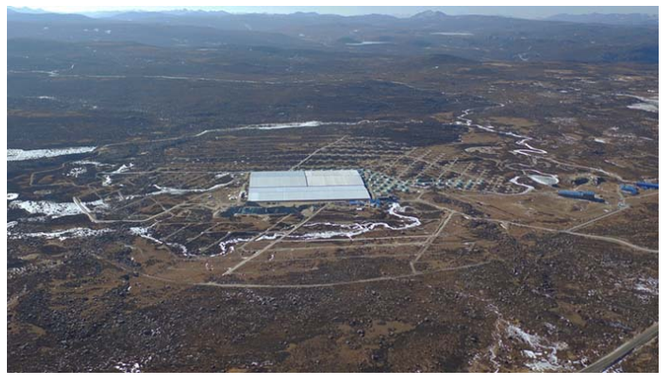
- 事例（时间，方位，能量）
- 仪器响应（有效面积、角度分辨、能量分辨、背景事件）

高级伽马射线数据的差别：

- 指向性（IACT）
- 转向性（Fermi-LAT，HAWC，LHAASO）



LHAASO Astronomy Python (LA-py)



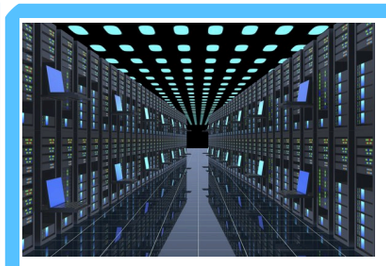
Gamma-ray data (Level 1&2)

标定
重建
选择

Data (Level 3)

事件
本底
曝光
响应
….

天图



科学工具

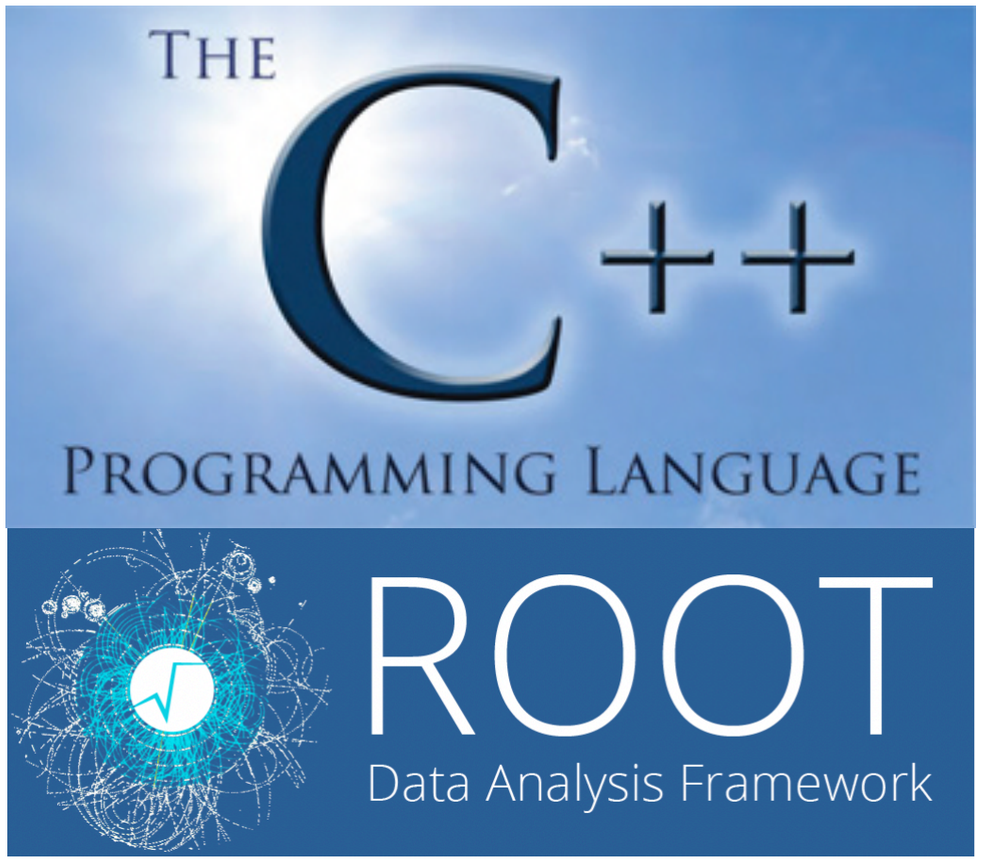
LA-Py

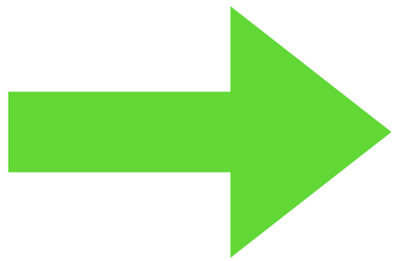
输出

结果 (Level 4&5)

图像
能谱
光谱
拟合结果
星表
…

编码程序


THE
C++
PROGRAMMING LANGUAGE
ROOT
Data Analysis Framework




python™


The
Astropy
Project

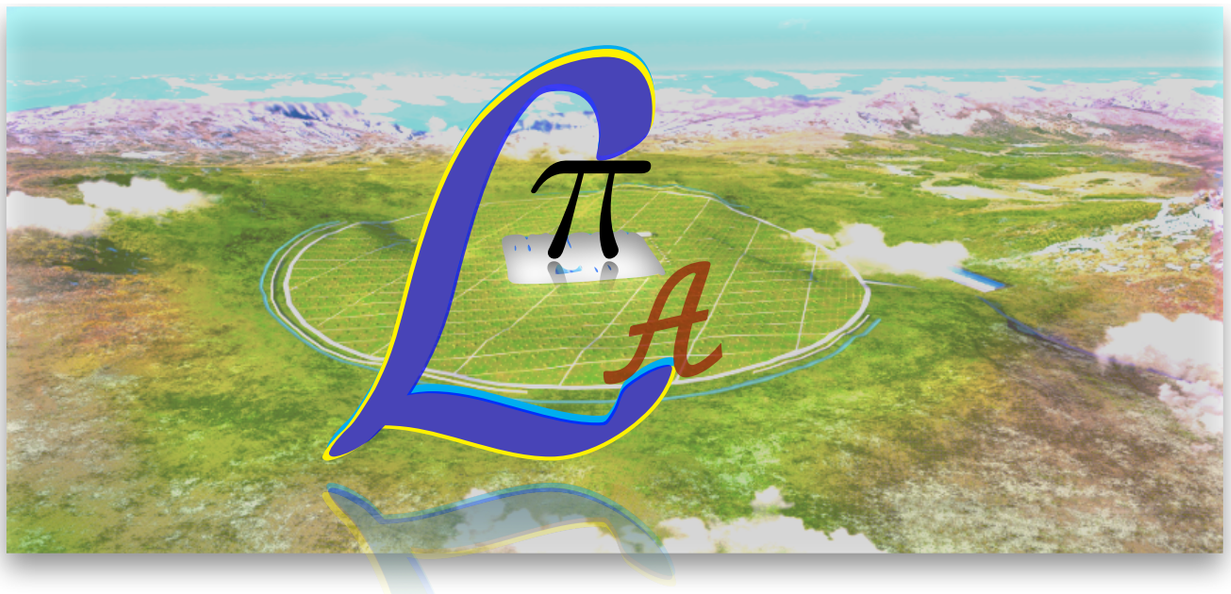

SciPy

LA-Py-0.1

```
Processing /Users/liliyang/Downloads/LA-Py
Requirement already satisfied: numpy>=1.10 in /Users/liliyang/anaconda3/lib/python3.7/site-packages (from LA-Py==0.1) (1.16.4)
Requirement already satisfied: astropy>=2.0 in /Users/liliyang/anaconda3/lib/python3.7/site-packages (from LA-Py==0.1) (3.2.1)
Requirement already satisfied: scipy>=0.15 in /Users/liliyang/anaconda3/lib/python3.7/site-packages (from LA-Py==0.1) (1.3.0)
Requirement already satisfied: regions>=0.4 in /Users/liliyang/anaconda3/lib/python3.7/site-packages (from LA-Py==0.1) (0.4)
Requirement already satisfied: pyyaml in /Users/liliyang/anaconda3/lib/python3.7/site-packages (from LA-Py==0.1) (5.1.1)
Requirement already satisfied: click in /Users/liliyang/anaconda3/lib/python3.7/site-packages (from LA-Py==0.1) (7.0)
Requirement already satisfied: pathlib in /Users/liliyang/anaconda3/lib/python3.7/site-packages (from LA-Py==0.1) (1.0.1)
Requirement already satisfied: six in /Users/liliyang/anaconda3/lib/python3.7/site-packages (from regions>=0.4->LA-Py==0.1) (1.12.0
)
Building wheels for collected packages: LA-Py
  Building wheel for LA-Py (setup.py) ... done
  Stored in directory: /Users/liliyang/Library/Caches/pip/wheels/da/3a/a4/3105215cadf60c4f8ac01e8f0b20f1de6e0164c5a5fd9536d9
Successfully built LA-Py
Installing collected packages: LA-Py
  Found existing installation: LA-Py 0.1
    Uninstalling LA-Py-0.1:
      Successfully uninstalled LA-Py-0.1
Successfully installed LA-Py-0.1
```

- Code: https://github.com/lyang54/lapy

- License: BSD-3 (same as Numpy, Scipy, Astropy, ...)



A Python package for LHAASO Astronomy

Edit

Manage topics

6 commits | 2 branches | 0 releases | BSD-3-Clause

Branch: master | New pull request | Create new file | Upload files | Find File | Clone or download

lyang54 correct a few features — Latest commit 24ae4a1 1 minute ago

doc	correct a few features	1 minute ago
lapy	correct a few features	1 minute ago
.DS_Store	add more features	2 days ago
LICENSE.rst	add more features	2 days ago
README.md	add more features	2 days ago
logo.pdf	Logo	16 days ago
setup.py	add more features	2 days ago

README.md

LA-Py

It's a python package for LHAASO Astronomy analysis.

LA-Py is a tentative and young project and there are many areas where the features, implementation and documentation is work in progress. So please have some patience and let us know where we should put our priorities. We can also discuss possible contributions if you want to become a co-developer.

https://github.com/lyang54/LA-Py

Branch: master ▾ LA-Py / lapy / Create new file | Upload files | Find file | History

lyang54 correct a few features — Latest commit 24ae4a1 15 hours ago

接收GCN以及AMON的信号报告

..		
__pycache__	res	3 days ago
alert	add more features	3 days ago
catalog	correct a few features	15 hours ago
cube	add more features	3 days ago
data	correct a few features	15 hours ago
image	correct a few features	15 hours ago
irf	correct a few features	15 hours ago
skymaps	correct a few features	15 hours ago
spectrum	correct a few features	15 hours ago
stats	correct a few features	15 hours ago
time	add more features	3 days ago
utils	add more features	3 days ago
.DS_Store	add more features	3 days ago
__init__.py	add more features	3 days ago

lapy.catalog

```
>>> from lapy.catalog import source_catalogs
>>> source_catalogs.info()
Source catalog registry:
 catalog                      description                        no of sources
--------- --------------------------------------------------- -------------
     HGPS H.E.S.S. Galactic plane survey (HGPS) source catalog            78
gamma-cat                  An open catalog of gamma-ray sources           162
     3FGL                       LAT 4-year point source catalog          3034
     1FHL     First Fermi-LAT Catalog of Sources above 10 GeV           514
     2FHL              LAT second high-energy source catalog            360
     3FHL               LAT third high-energy source catalog           1556
     2HWC              2HWC catalog from the HAWC observatory             40
  IceCube          HESE event list from the IceCube observatory           78
```

```
>>> source_catalogs['2HWC'].table
<Table length=40>
  source_name      ra     dec     glon    glat   ... spec1_dnde_err spec1_index spec1_index_err spec1_radius
                  deg     deg     deg     deg    ... 1 / (cm2 s TeV)                                 deg
     str15      float64 float64 float64 float64 ...     float64       float64       float64        float64
-------------- ------- ------- ------- ------- ... -------------- ----------- --------------- ------------
 2HWC J0534+220  83.628  22.024 184.547  -5.783 ...            nan         nan             nan          nan
 2HWC J0631+169  97.998  16.997 195.614   3.507 ...       6.85e-15       -2.23            0.08        2.000
 2HWC J0635+180  98.833  18.053 195.037   4.697 ...            nan         nan             nan          nan
 2HWC J0700+143 105.117  14.323 201.103   8.440 ...       7.26e-15       -2.03            0.14        2.000
 2HWC J0819+157 124.980  15.791 207.997  26.524 ...            nan         nan             nan          nan
            ...     ...     ...     ...     ... ...            ...         ...             ...          ...
 2HWC J2006+341 301.553  34.184  71.326   1.159 ...       4.21e-15       -2.40            0.11        0.900
 2HWC J2019+367 304.937  36.795  75.024   0.301 ...       4.55e-15       -2.24            0.04        0.700
 2HWC J2020+403 305.156  40.375  78.072   2.186 ...            nan         nan             nan          nan
2HWC J2024+417* 306.035  41.760  79.589   2.431 ...            nan         nan             nan          nan
 2HWC J2031+415 307.925  41.511  80.210   1.138 ...       4.41e-15       -2.52            0.05        0.700
```

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data	correct a few features	15 hours ago
image	correct a few features	15 hours ago
irf	correct a few features	15 hours ago
skymaps	correct a few features	15 hours ago
spectrum	correct a few features	15 hours ago
stats	correct a few features	15 hours ago
time	add more features	3 days ago
utils	add more features	3 days ago
.DS_Store	add more features	3 days ago
__init__.py	add more features	3 days ago

数据的读写与处理

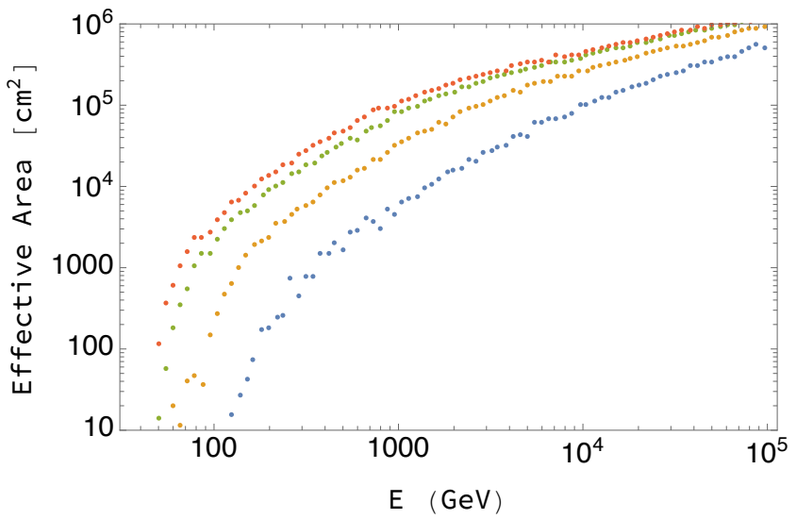
LHAASO实验响应

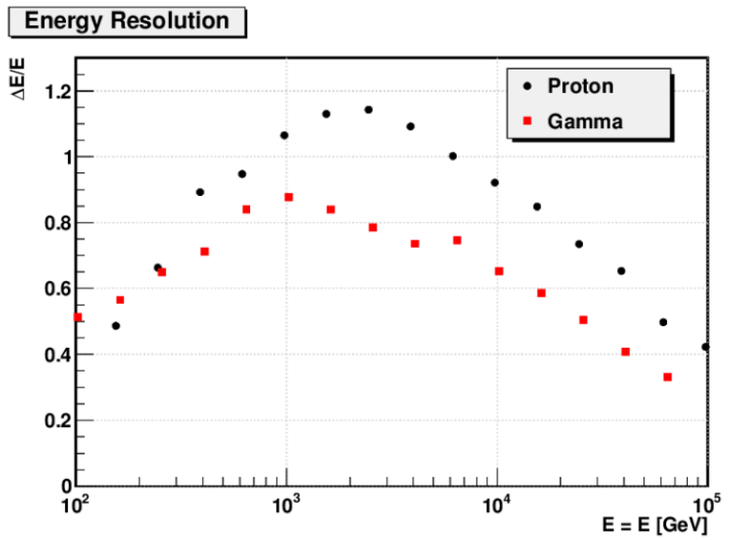
LHAASO

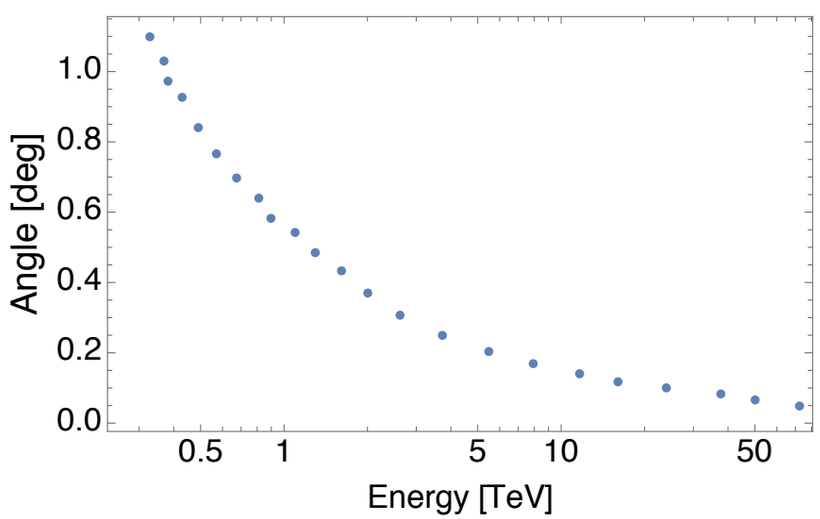
fv: Summary of lhaaso_v4.fits in /Users/liliyang/Downloads/LA-Py_local/

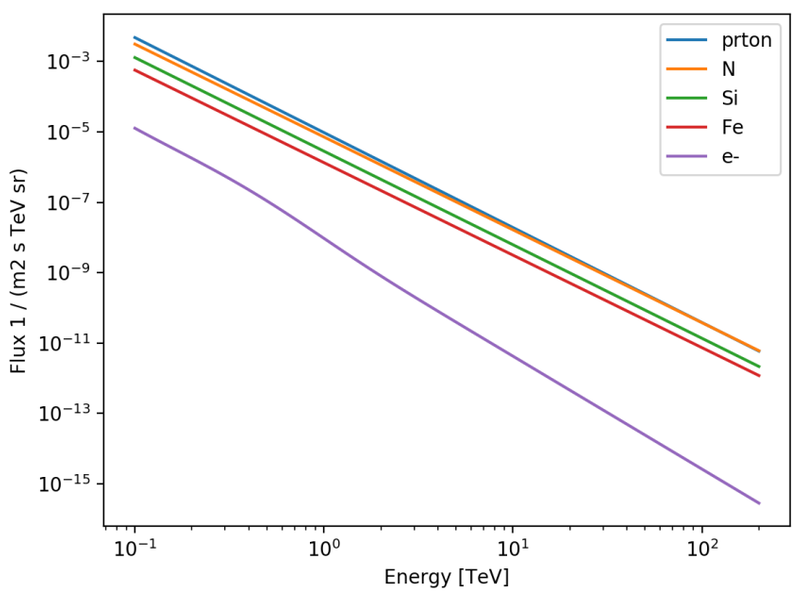
File Edit Tools Help

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header Image Table
1	EFFECTIVE AREA	Binary	5 cols X 1 rows	Header Hist Plot All Select
2	POINT SPREAD FUNCTION	Binary	10 cols X 1 rows	Header Hist Plot All Select
3	BACKGROUND	Binary	7 cols X 1 rows	Header Hist Plot All Select
4	ENERGY DISPERSION	Binary	7 cols X 1 rows	Header Hist Plot All Select







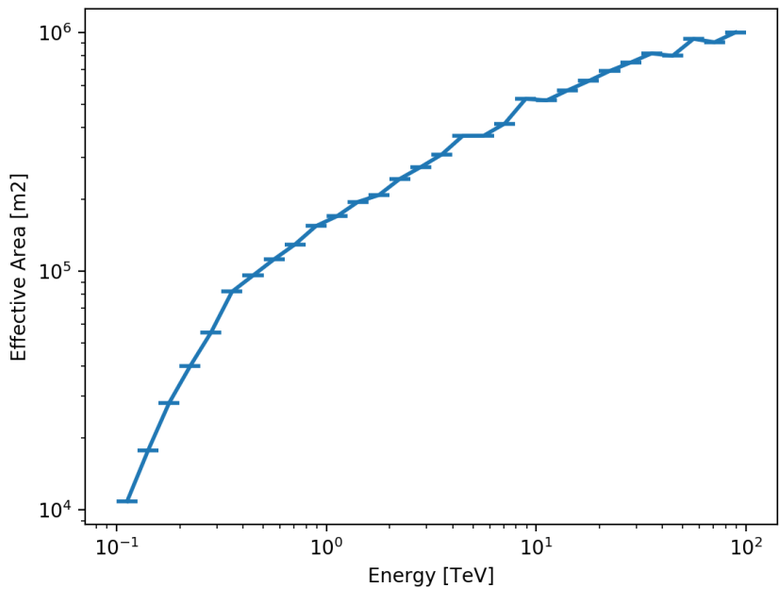


fv: Summary of lhaaso_v4.fits in /Users/liliyang/Downloads/LA-Py_local/

File Edit Tools Help

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header Image Table
1	EFFECTIVE AREA	Binary	5 cols X 1 rows	Header Hist Plot All Select
2	POINT SPREAD FUNCTION	Binary	10 cols X 1 rows	Header Hist Plot All Select
3	BACKGROUND	Binary	7 cols X 1 rows	Header Hist Plot All Select
4	ENERGY DISPERSION	Binary	7 cols X 1 rows	Header Hist Plot All Select

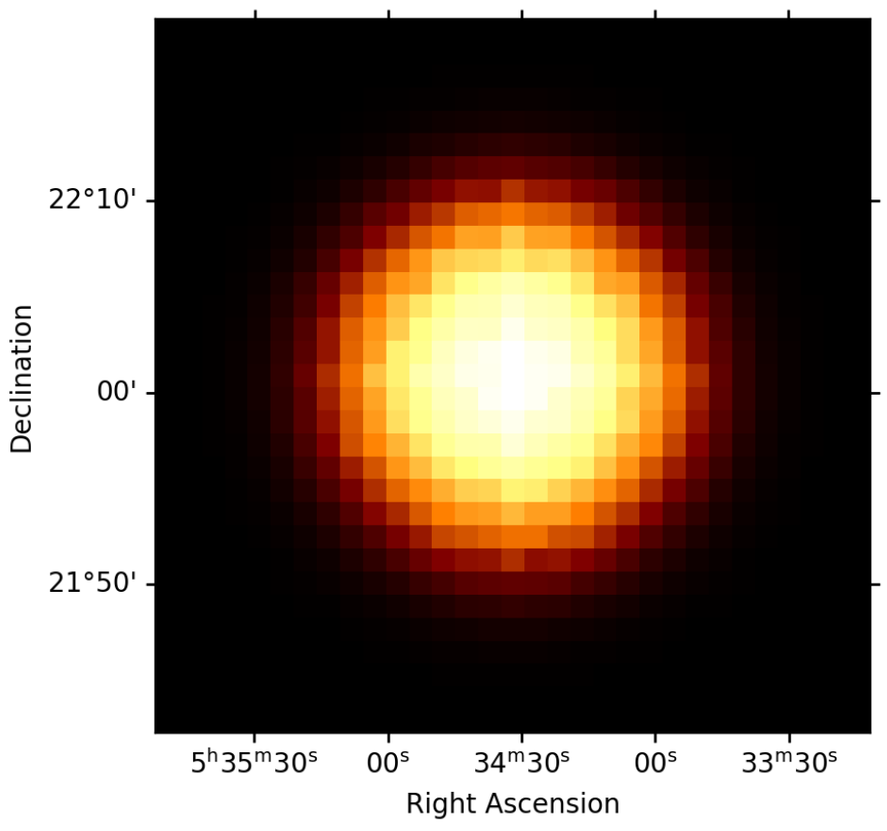
```
>>> filename = ("lhaaso_V4.fits")
>>> lhaaso_irf = load_lhaaso_irfs(filename)
>>> aeff = lhaaso_irf["aeff"].to_effective_area_table(offset=offset, energy=energy)
>>> aeff.plot()
<matplotlib.axes._subplots.AxesSubplot object at 0x1c20b88b70>
>>> plt.loglog()
[]
>>> print(lhaaso_irf["aeff"].data)
NDDataArray summary info
MapAxis

        name       : energy
        unit       : 'TeV'
        nbins      : 80
        node type  : edges
        edges min  : 5.0e-02 TeV
        edges max  : 1.5e+02 TeV
        interp     : log
MapAxis

        name       : offset
        unit       : 'deg'
        nbins      : 4
        node type  : edges
        edges min  : 0.0e+00 deg
        edges max  : 6.0e+01 deg
        interp     : lin
Data           : size =   320, min =  5.751 m2, max = 1496480.000 m2
```

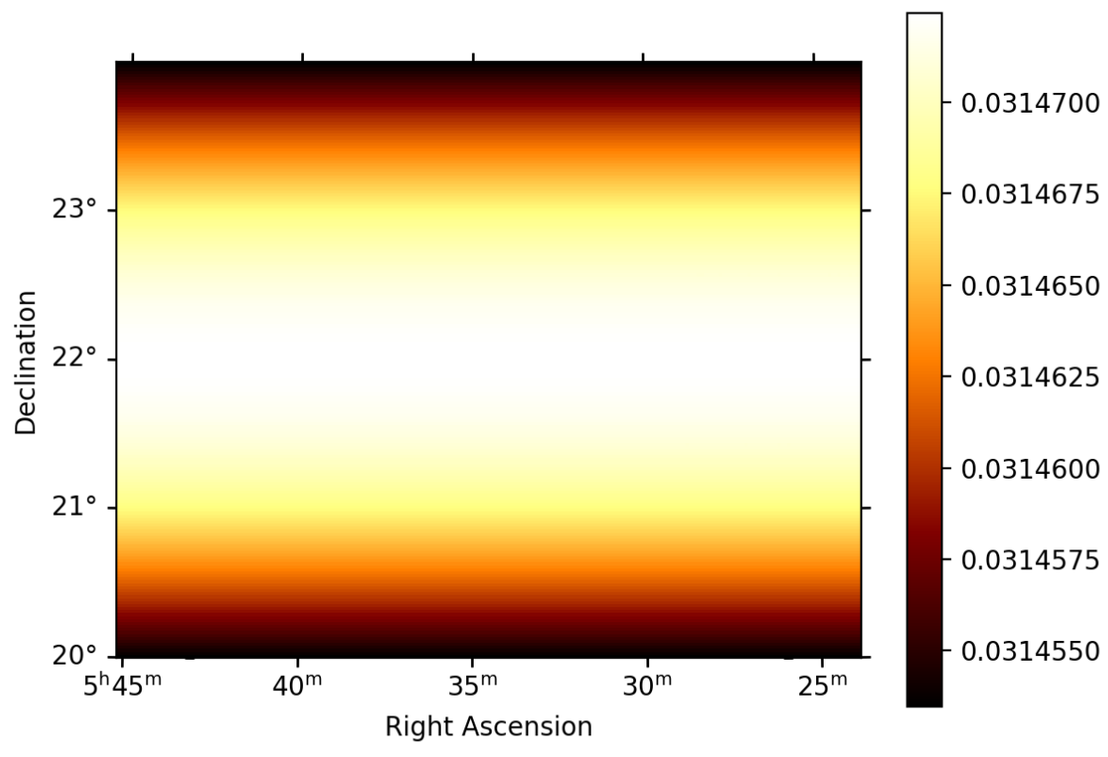


fv: Summary of lhaaso_v4.fits in /Users/liliyang/Downloads/LA-Py_local/

File Edit Tools Help

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header | Image | Table
1	EFFECTIVE AREA	Binary	5 cols X 1 rows	Header | Hist | Plot | All | Select
2	POINT SPREAD FUNCTION	Binary	10 cols X 1 rows	Header | Hist | Plot | All | Select
3	BACKGROUND	Binary	7 cols X 1 rows	Header | Hist | Plot | All | Select
4	ENERGY DISPERSION	Binary	7 cols X 1 rows	Header | Hist | Plot | All | Select





Branch: master ▾ **LA-Py** / **lapy** /

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..		
__pycache__	add more features	3 days ago
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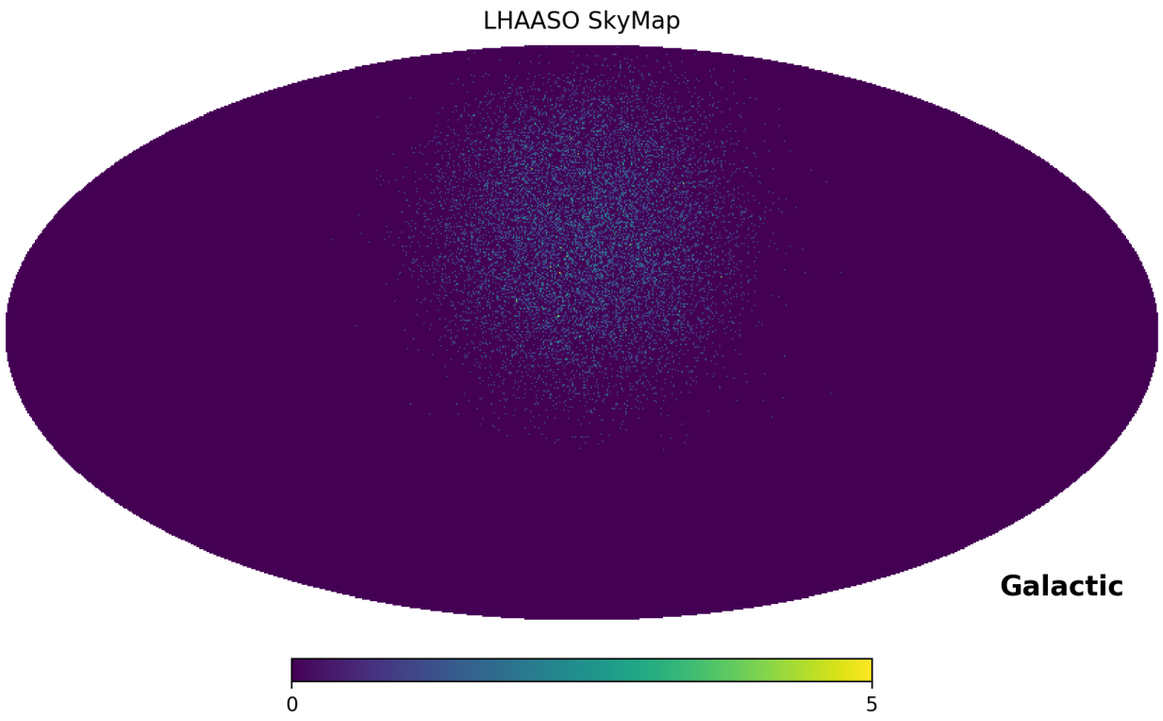
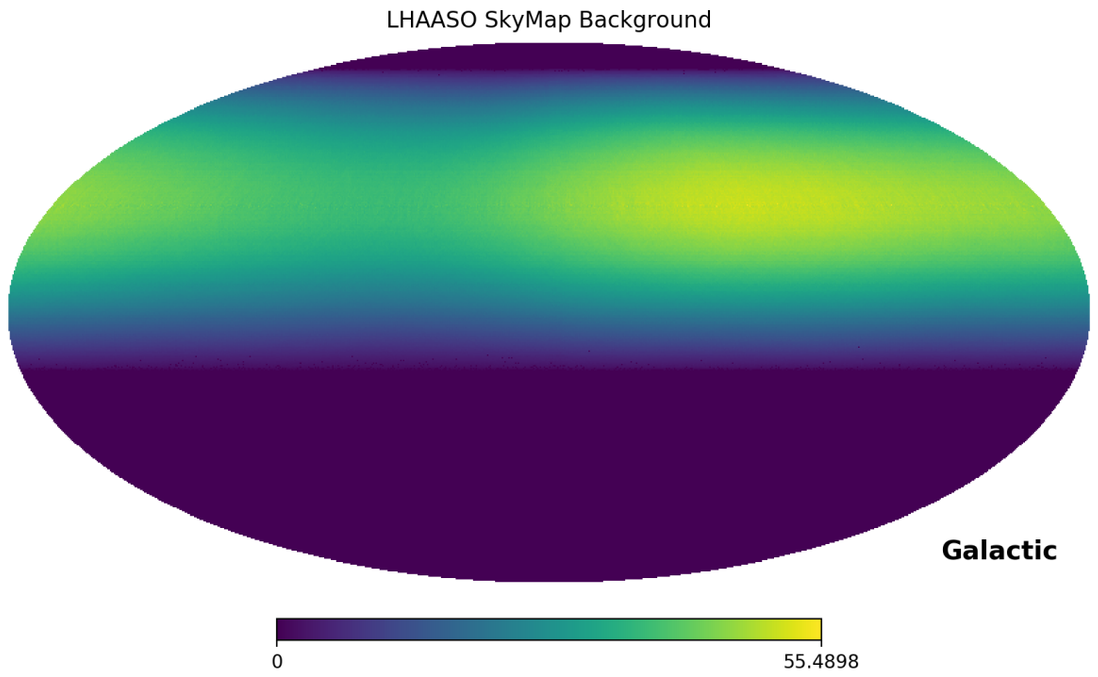
spectrum	correct a few features	15 hours ago
stats	correct a few features	15 hours ago
time	add more features	3 days ago
utils	add more features	3 days ago
.DS_Store	add more features	3 days ago
__init__.py	add more features	3 days ago

天图的读取与处理

统计计算





Made by 林苏杰

```
>>> from lapy.stats import significance
>>> significance(n_on=10, mu_bkg=8, method="lima", n_on_min=1)
array([0.68034625])
```

Branch: master ▾ **LA-Py** / **lapy** /

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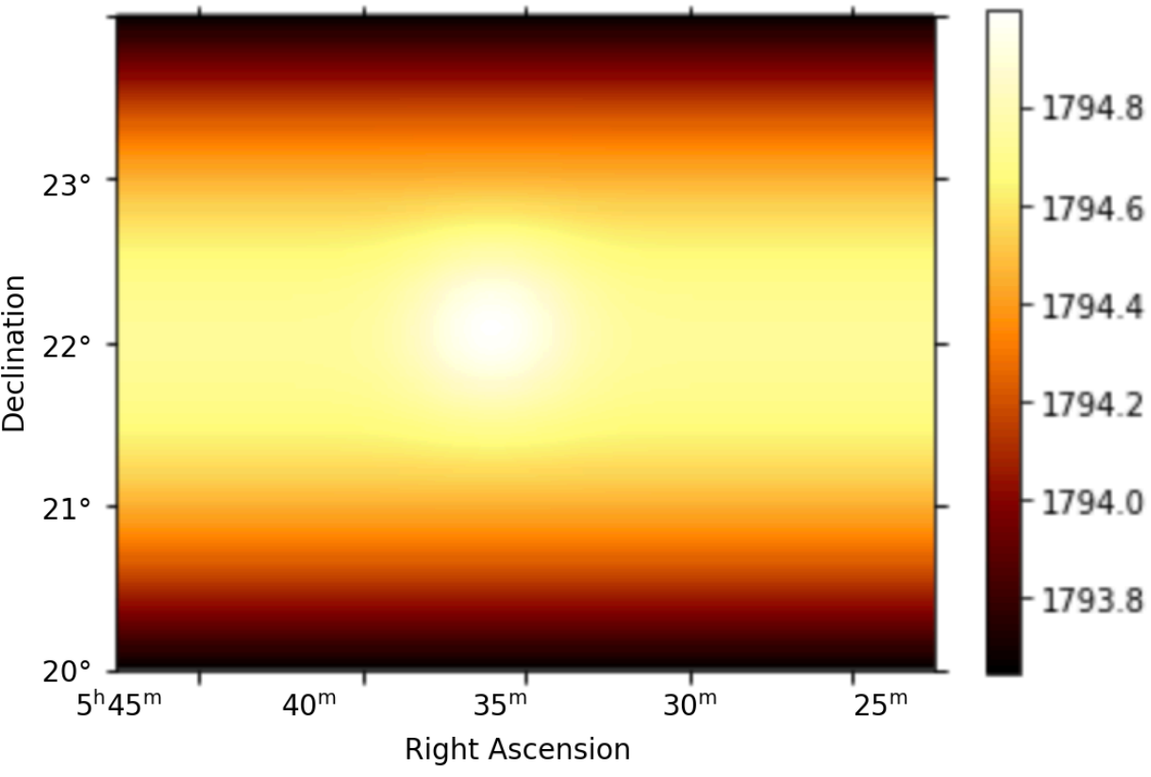
time	add more features	3 days ago
utils	add more features	3 days ago
.DS_Store	add more features	3 days ago
__init__.py	add more features	3 days ago

天图的读取与处理

```
background_model = BackgroundModel(background)
dataset = MapDataset(
    model=sky_model,
    exposure=exposure,
    background_model=background_model,
    psf=psf_kernel,
    edisp=edisp,
)
```

```
npred = dataset.npred()
```

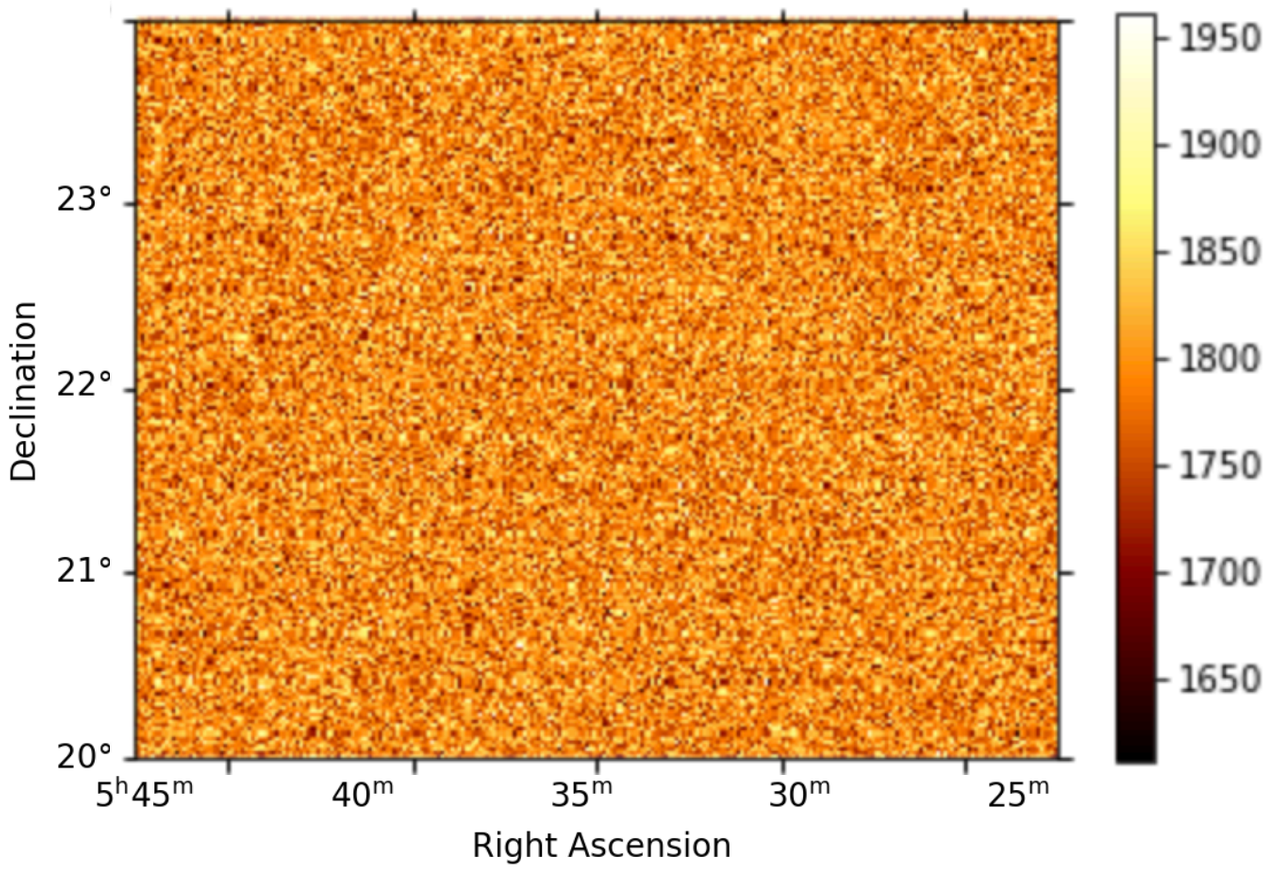
```
npred.sum_over_axes().plot(add_cbar=True);
```



模型数据

```
# This one line is the core of how to simulate data when
# using binned simulation / analysis: you Poisson fluctuate
# npred to obtain simulated observed counts.
# Compute counts as a Poisson fluctuation
rng = np.random.RandomState(seed=42)
counts = rng.poisson(npred.data)
counts_map = WcsNDMap(geom, counts)
```

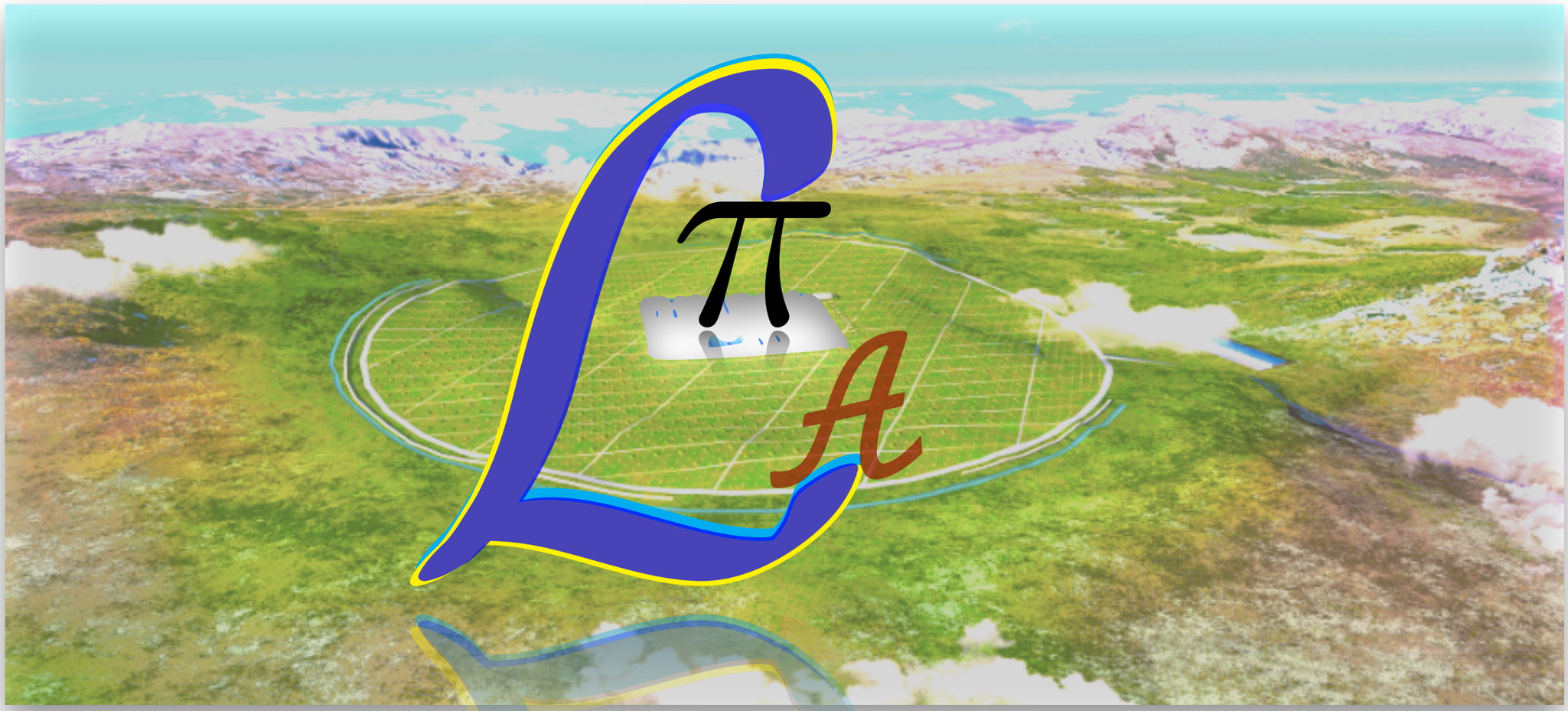
```
counts_map.sum_over_axes().plot(add_cbar=True);
```



模拟数据

计划和展望

- 伽马天文是一个尚处年轻的领域
- 卫星望远镜如Fermi-LAT等，数据公开；地面实验尚未开放公开数据
- 进一步结合LHAASO的模拟，完善响应函数
- 结合各个实验做多波段拟合处理



谢谢！！