SLAC/INFN Summer Exchange Program 2016

ANNUAL SOURCE VARIABILTY

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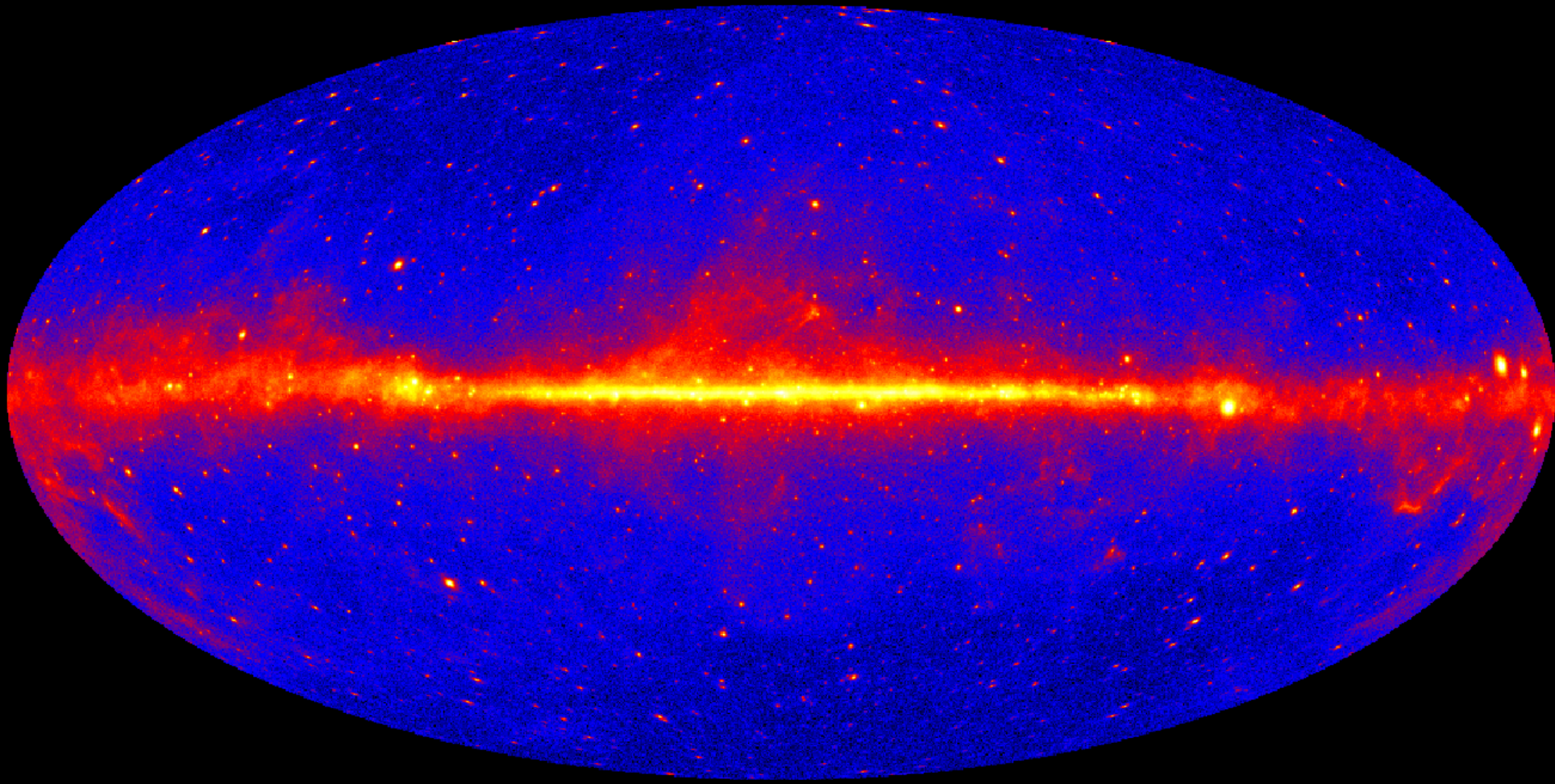
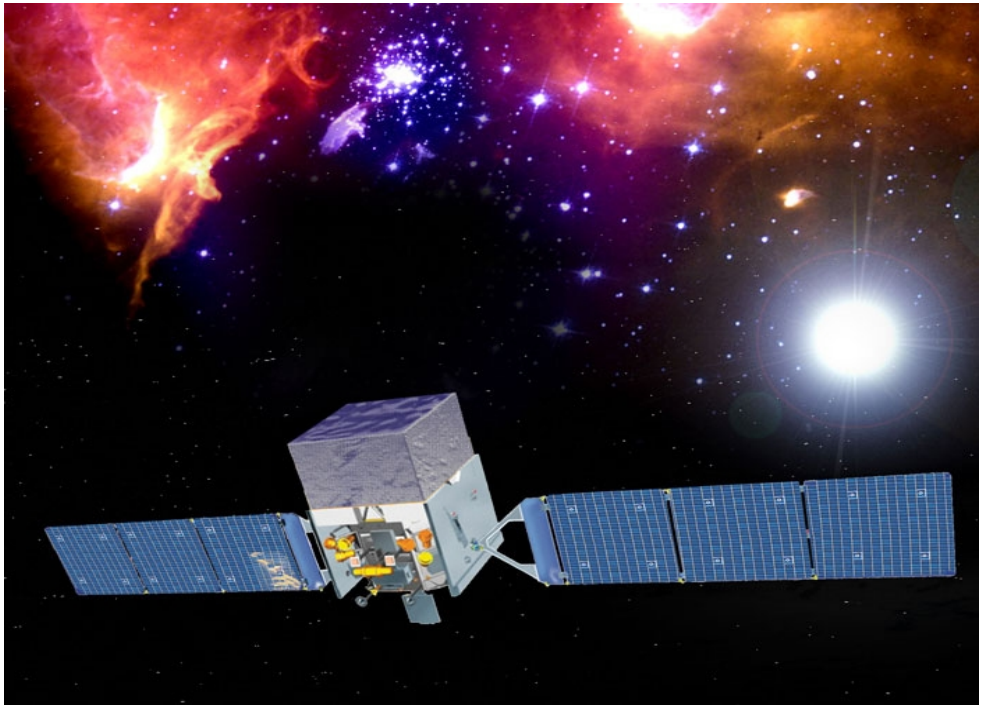
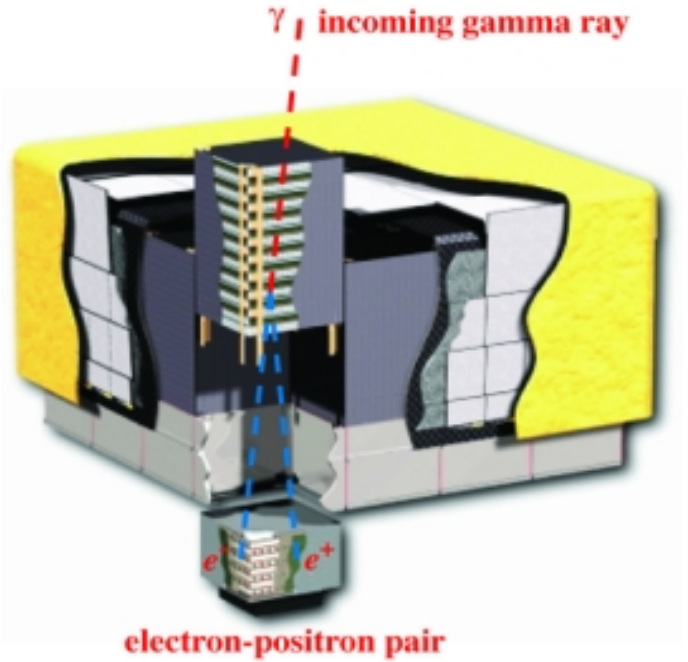


Introduction: Fermi-LAT





Fermi is a Gamma Ray Space Telescope spacecraft.

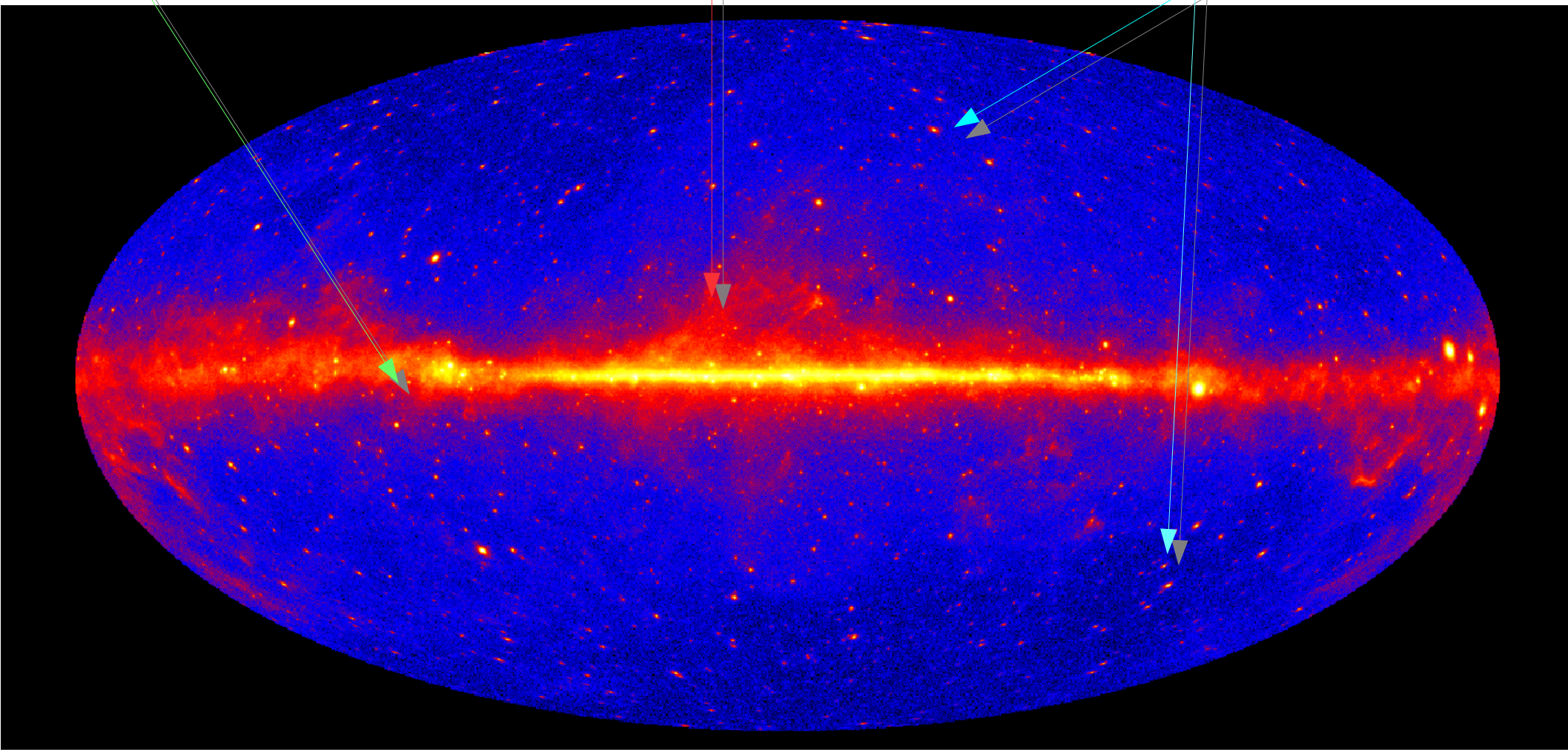
LAT is Fermi's principal scientific instrument, it is an imaging high-energy gamma-ray telescope covering the energy range from about 20 MeV to more than 300 GeV.
The LAT field of view covers about 20% of the sky at any time, and it scans continuously, covering the whole sky every three hours.

Introduction: gamma maps of the sky

Galactic plane

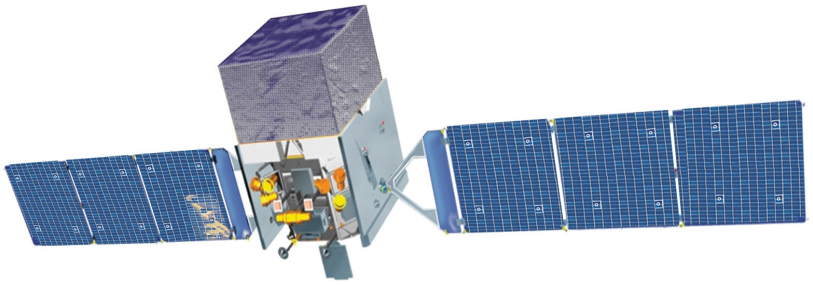
Galactic center

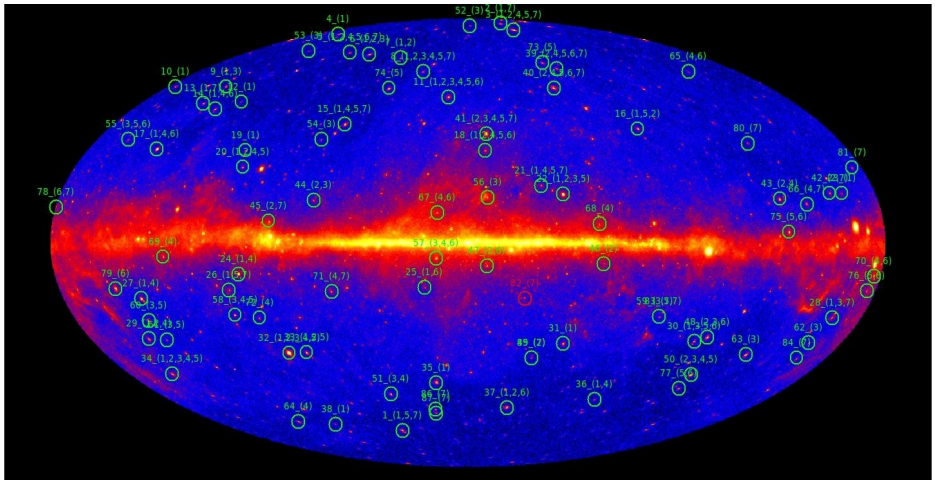
Extragalactic sources



Summary: Analysis

- Fermi-LAT data of seven years (08/2008 – 08/2015)
- Counts normalized with exposure maps of seven year
- Fermi-LAT PSF
- Counts difference and significant variation
- Extraction of the variable sources
- Characteristics of variable sources



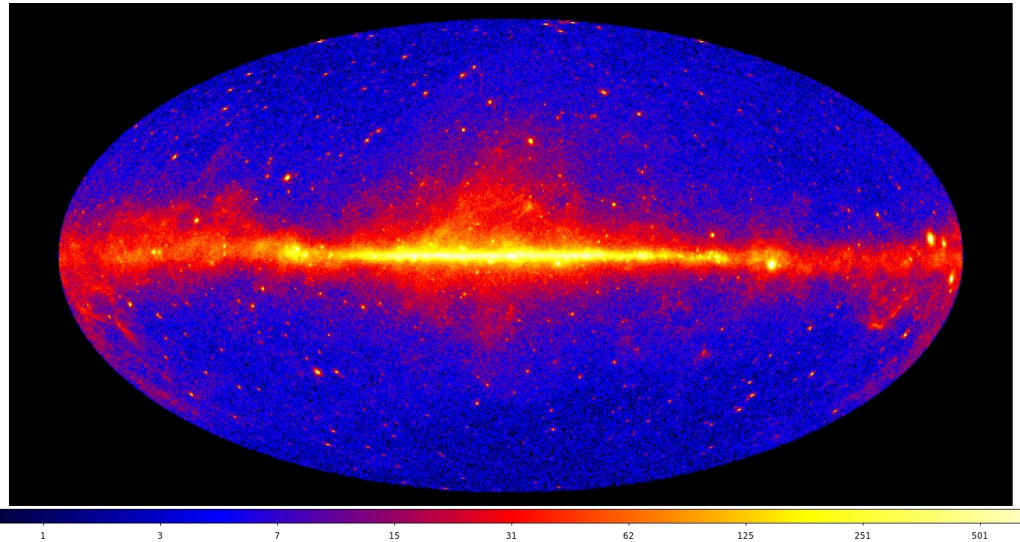


Motivation for this analysis

- Study of long term variability, never investigated by Stanford researchers
- Model independent analysis
- Identification of sources in the galactic center to try to have a better knowledge of the background

Fermi-LAT data (08/2014 – 08/2015)

Counts Map year 7

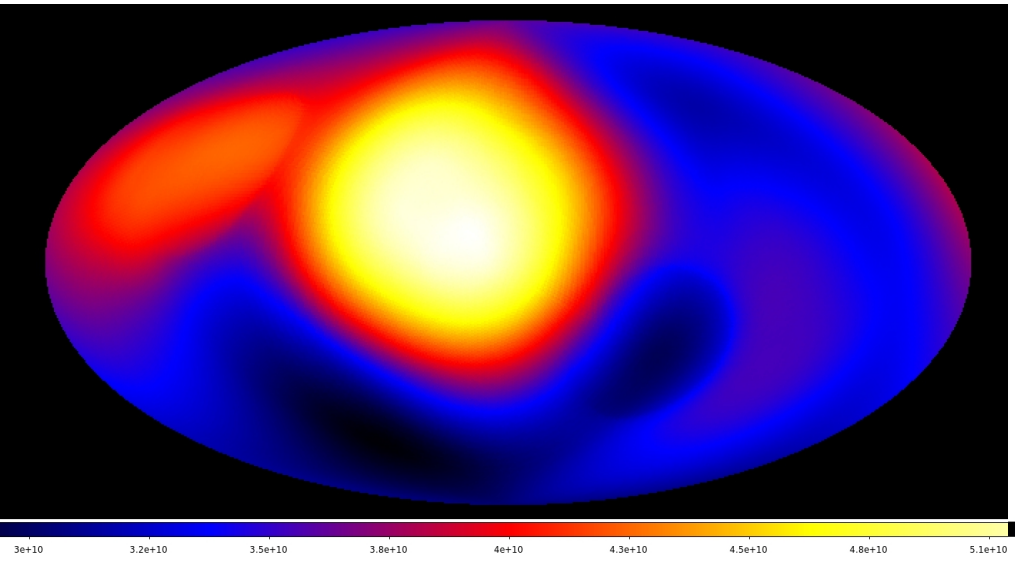


Pass 8 Events file

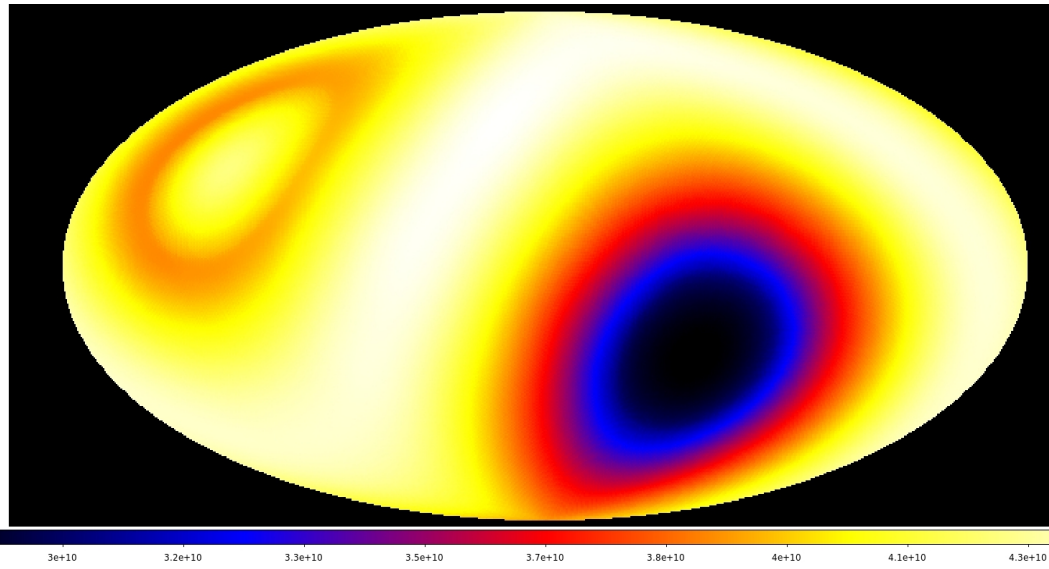
- Energy range [1-500]GeV
- zmax=90deg
- event class=128 (source)
- event type=FRONT +BACK
- bin size of 0.5 deg.

Counts map

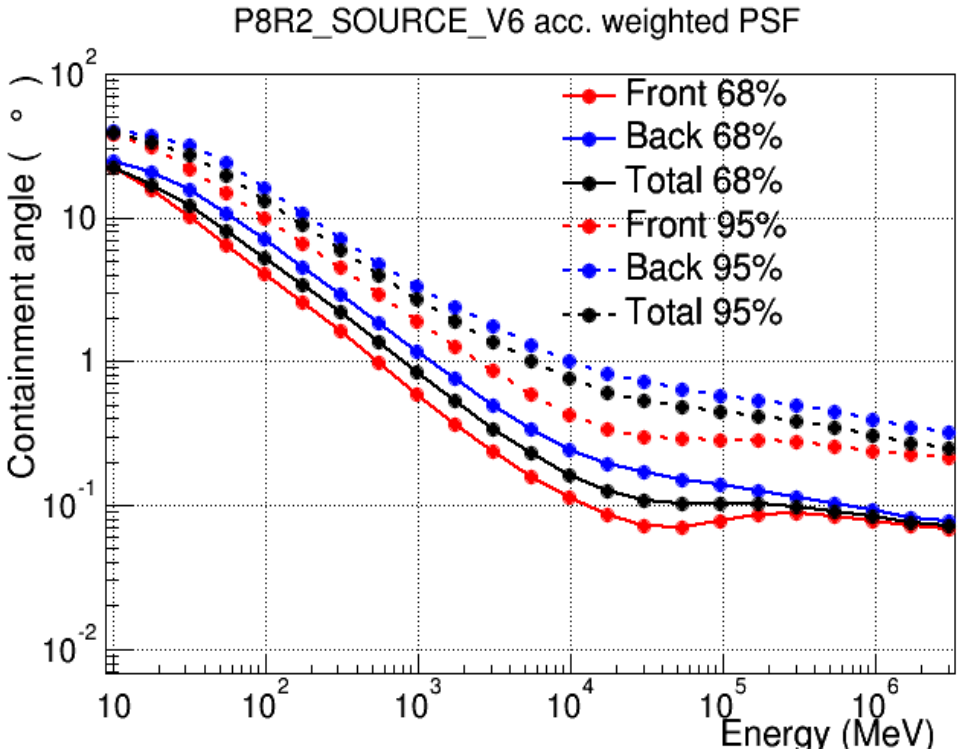
Exposure map year 7



Exposure map year 1



Fermi-LAT PSF smoothing



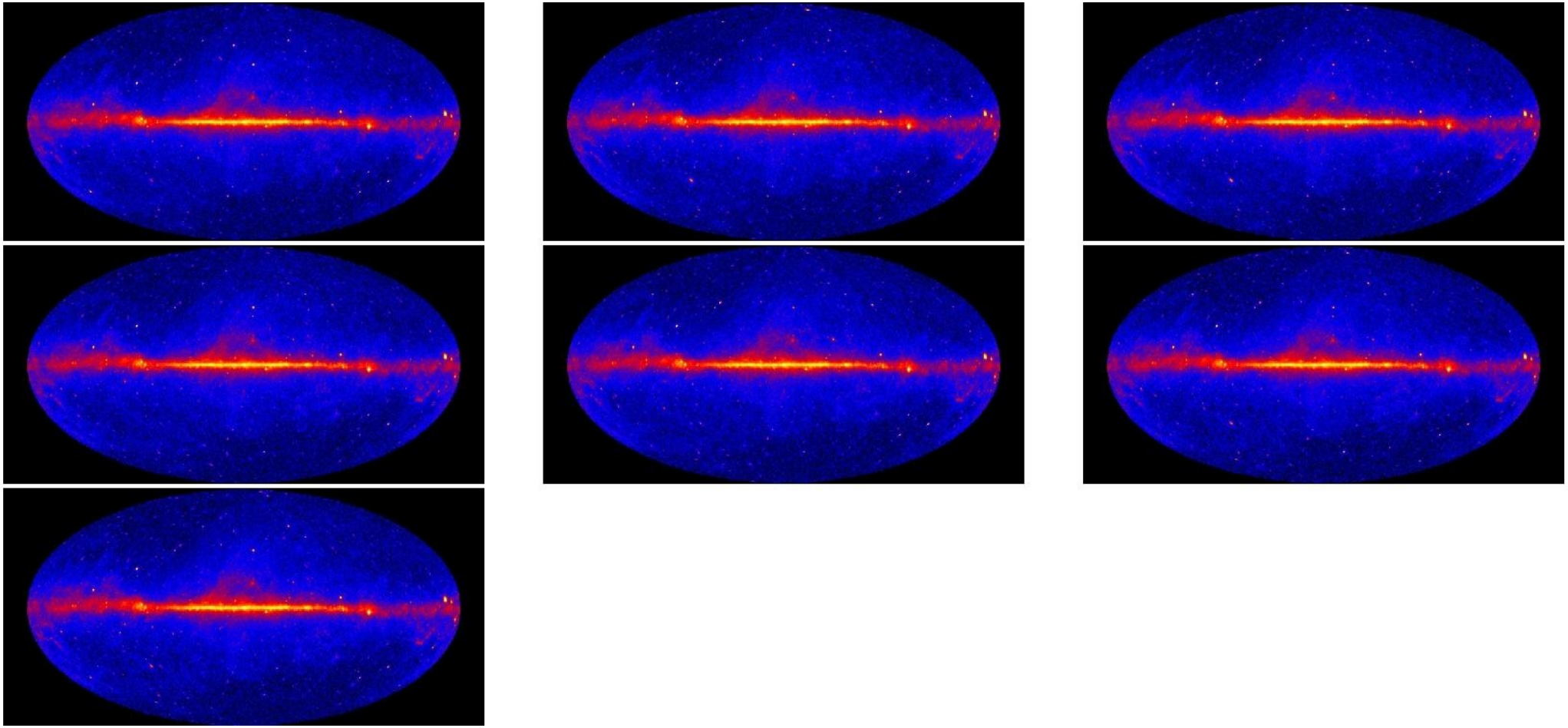
Width PSF (1GeV, 68%) ~0.8 deg

Pixel size 0.5 deg

Convolve the counts map with a normalized filter mask of FermiLAT PSF(1GeV)

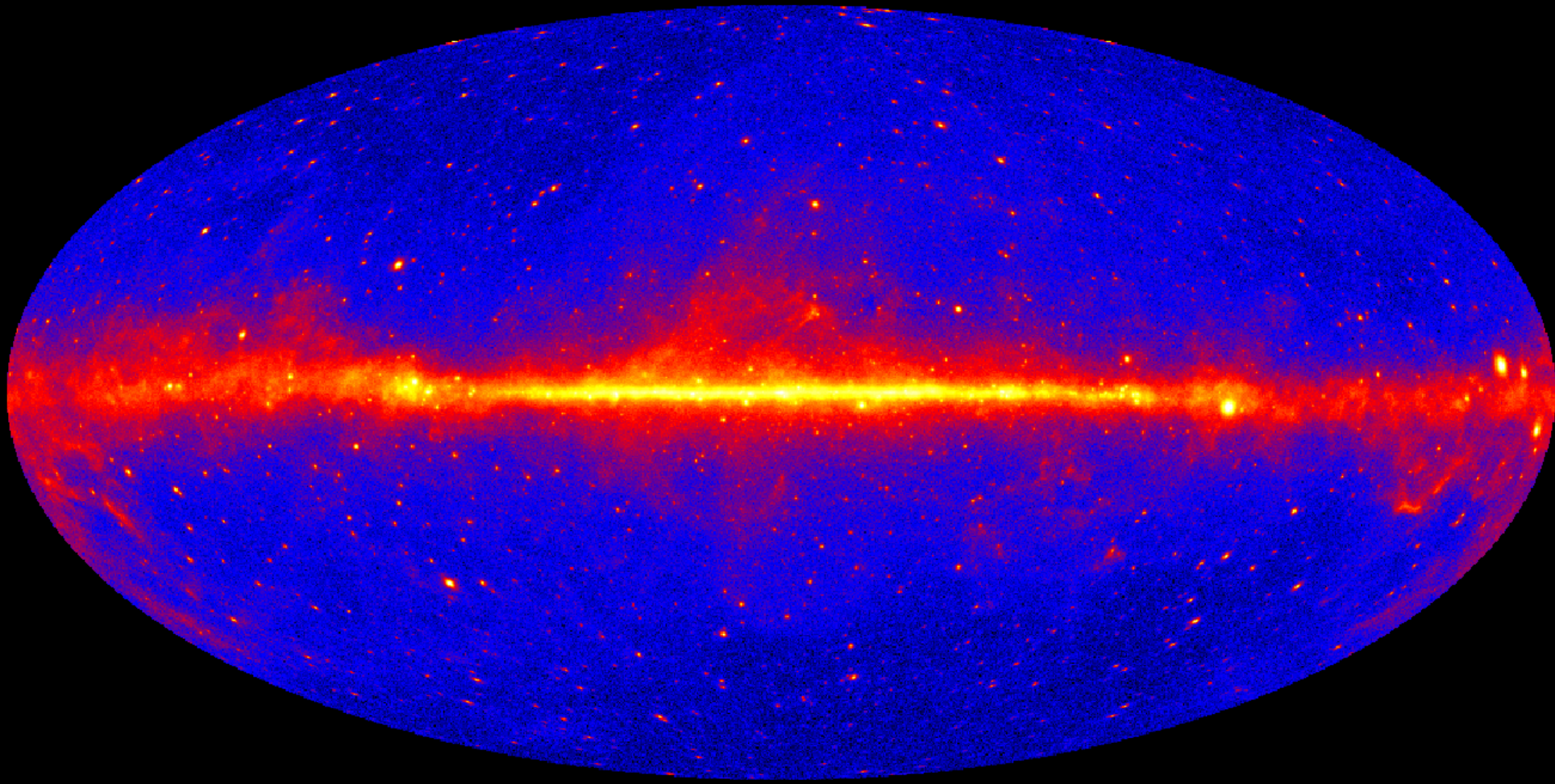
Tools: FermiScienceTools, python

Counts normalized with exposure map (08/2008 – 08/2015)

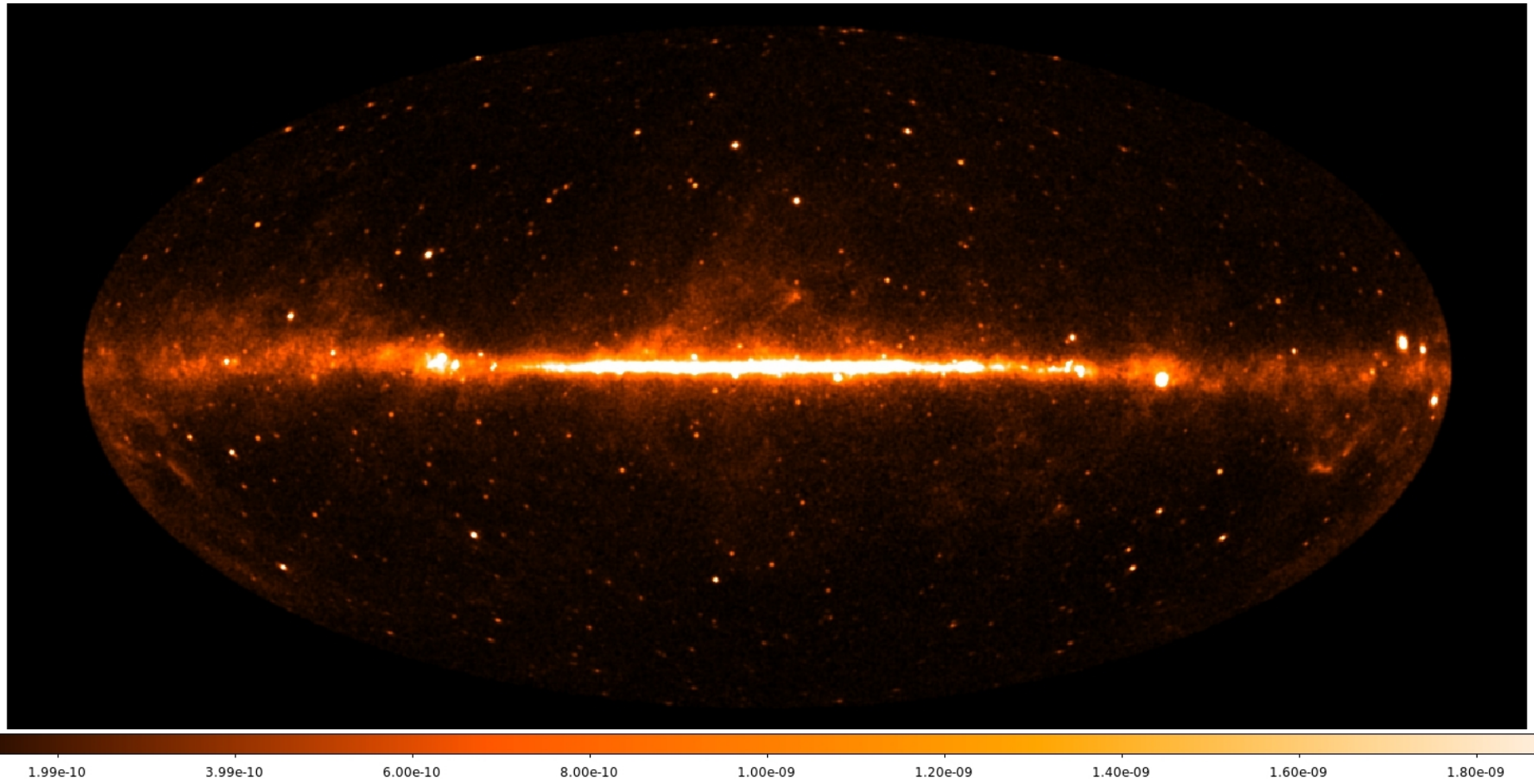


Tools used: Fermi Science Tools, FTOOLS, ds9, fv.

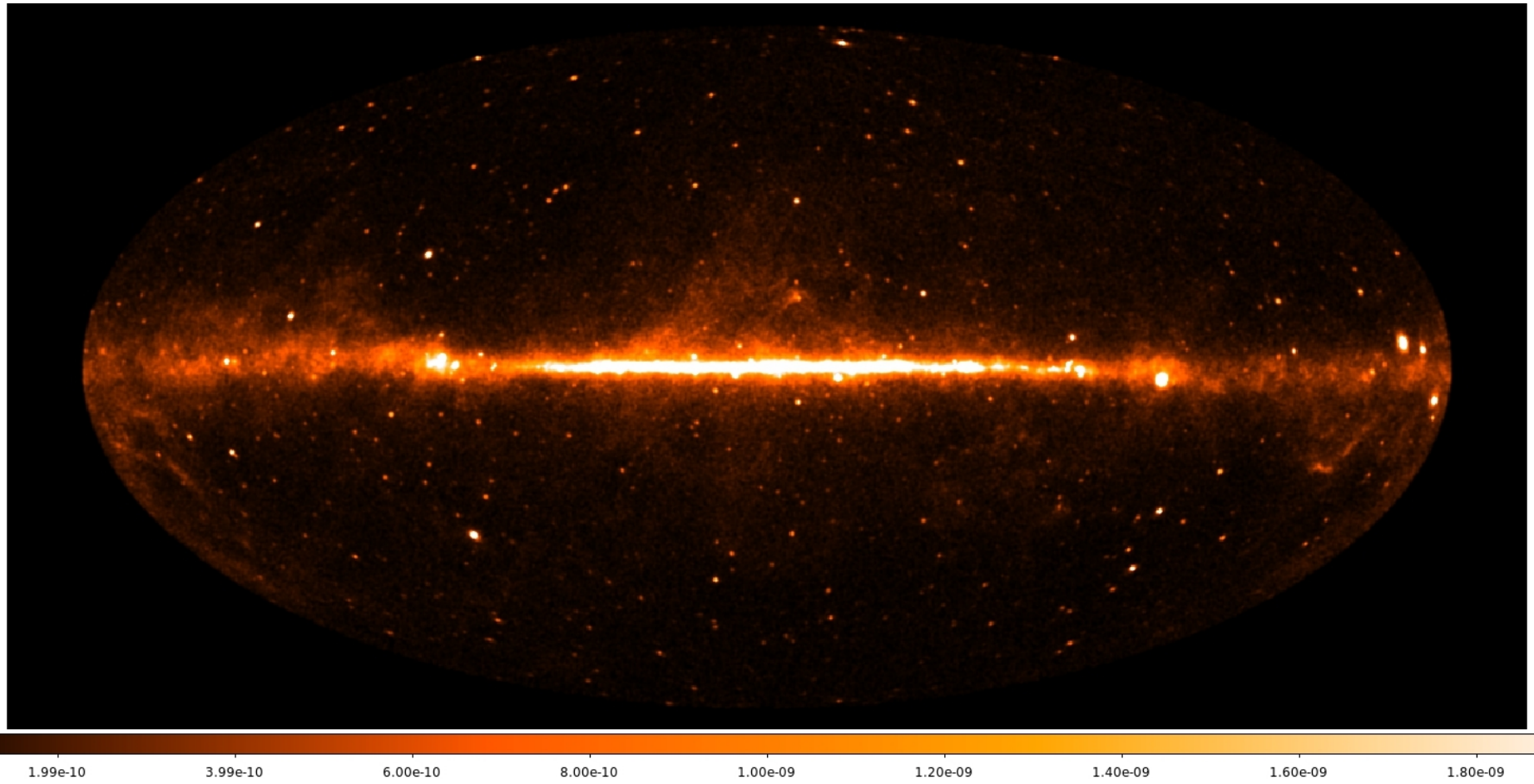
Counts normalized with the exposure 2008-2015



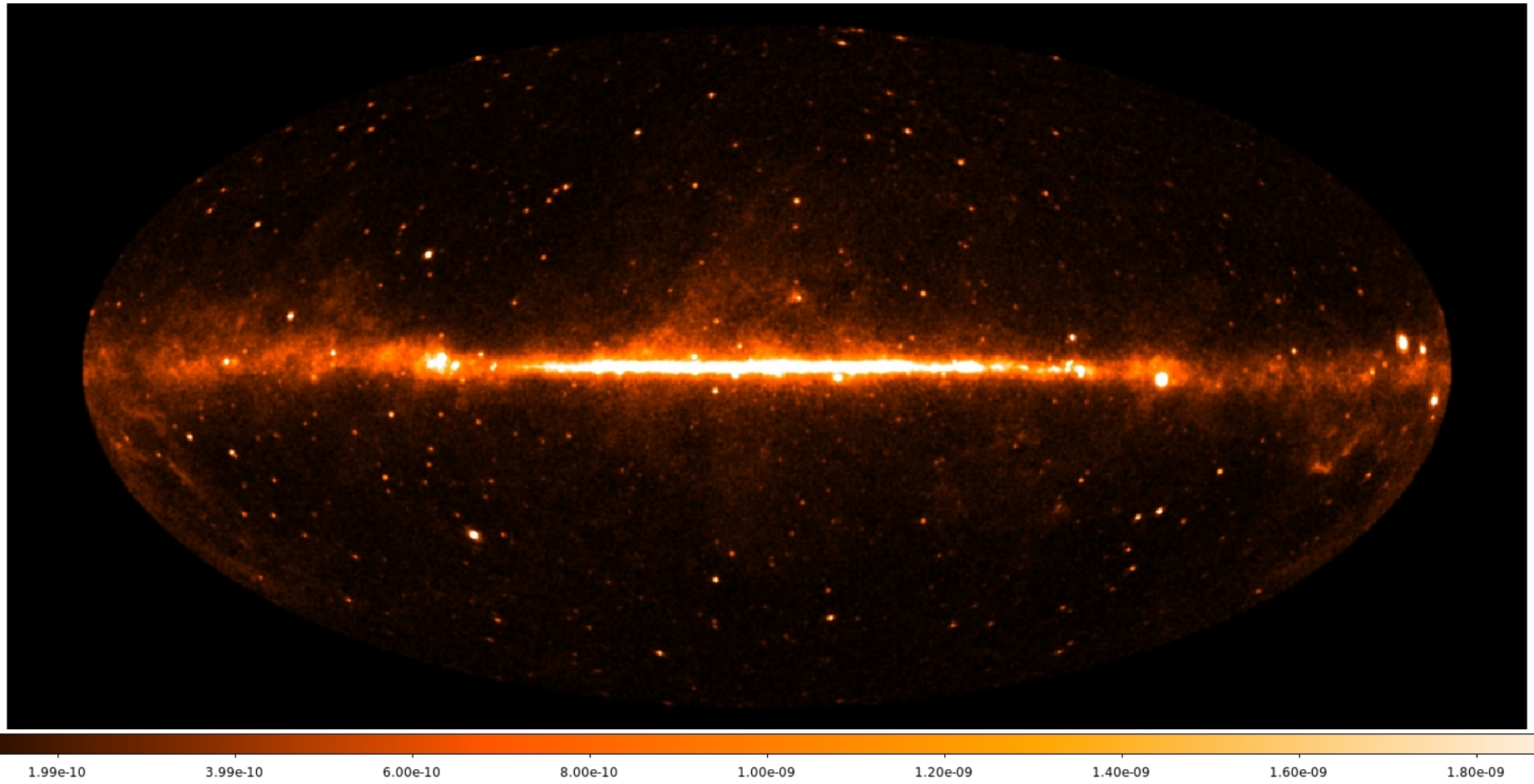
Counts normalized with the exposure 2008-2009



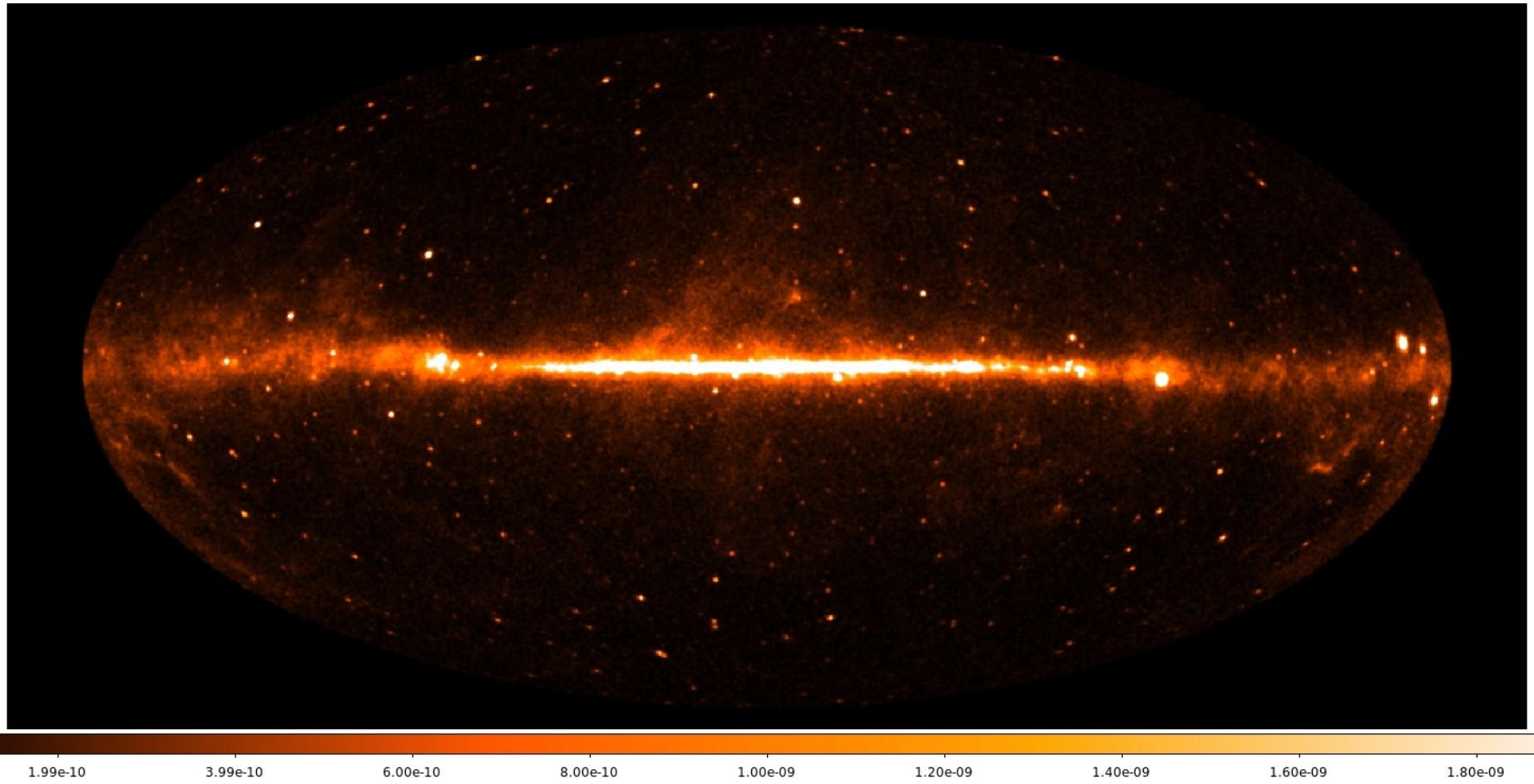
Counts normalized with the exposure 2009-2010



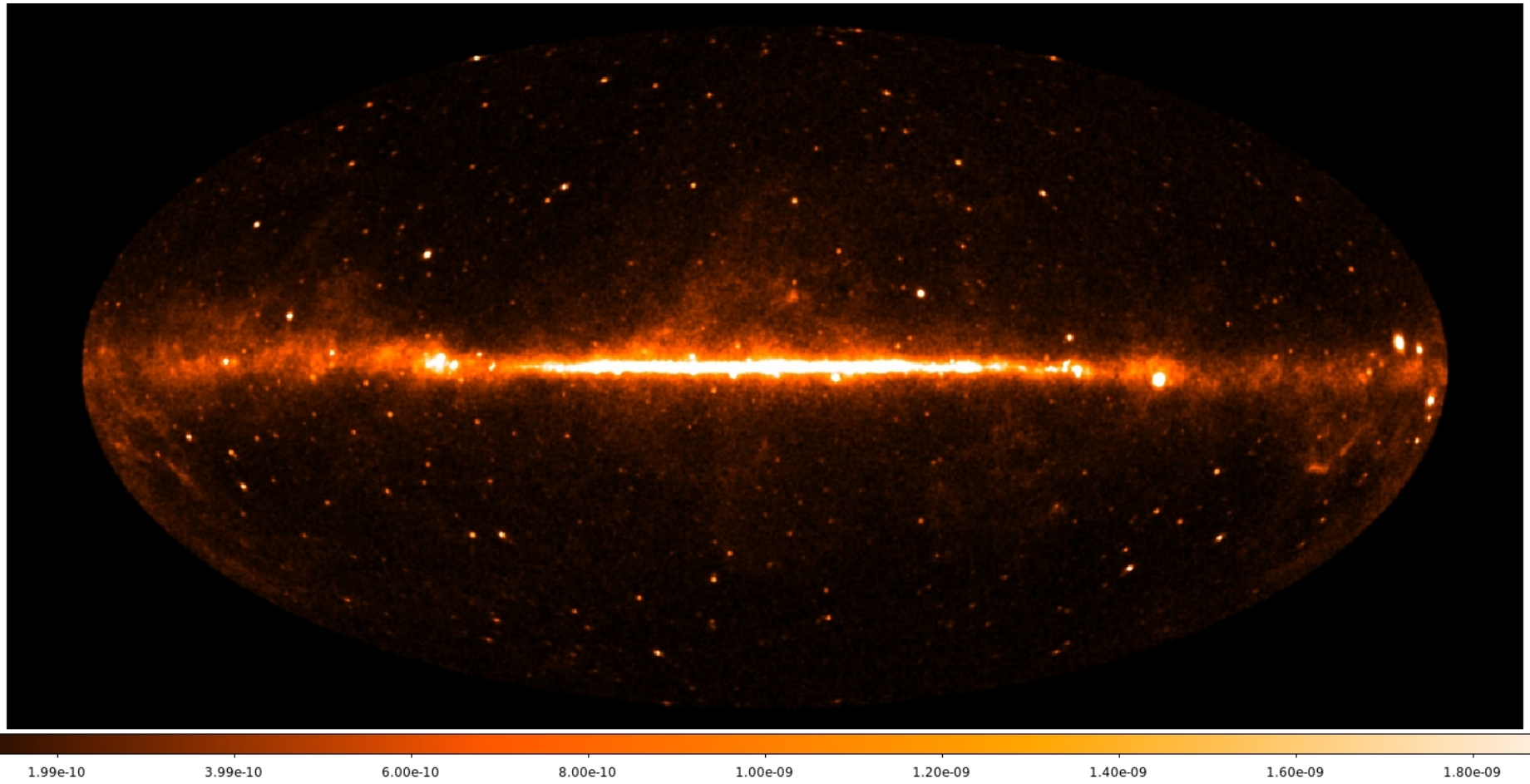
Counts normalized with the exposure 2010-2011



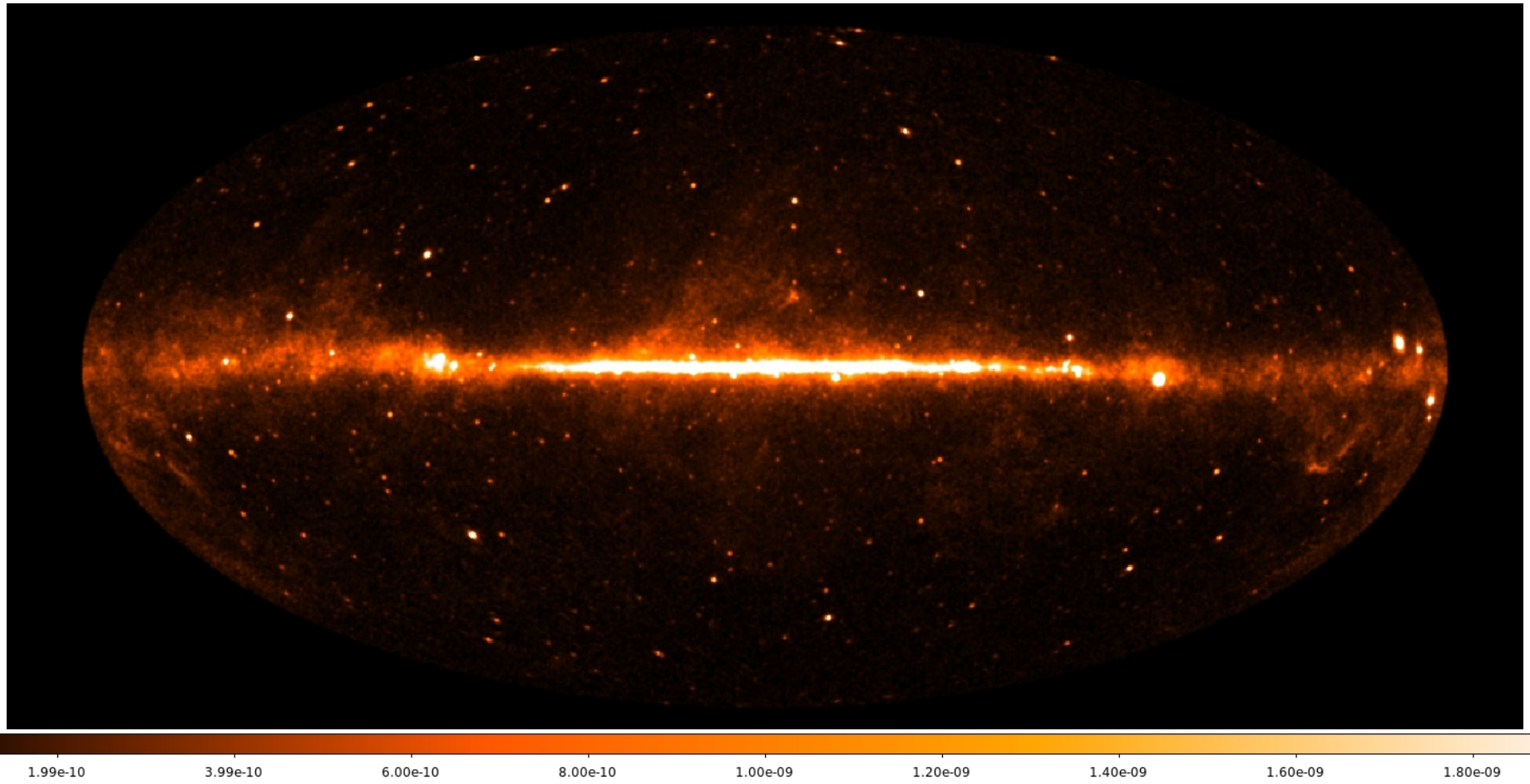
Counts normalized with the exposure 2011-2012



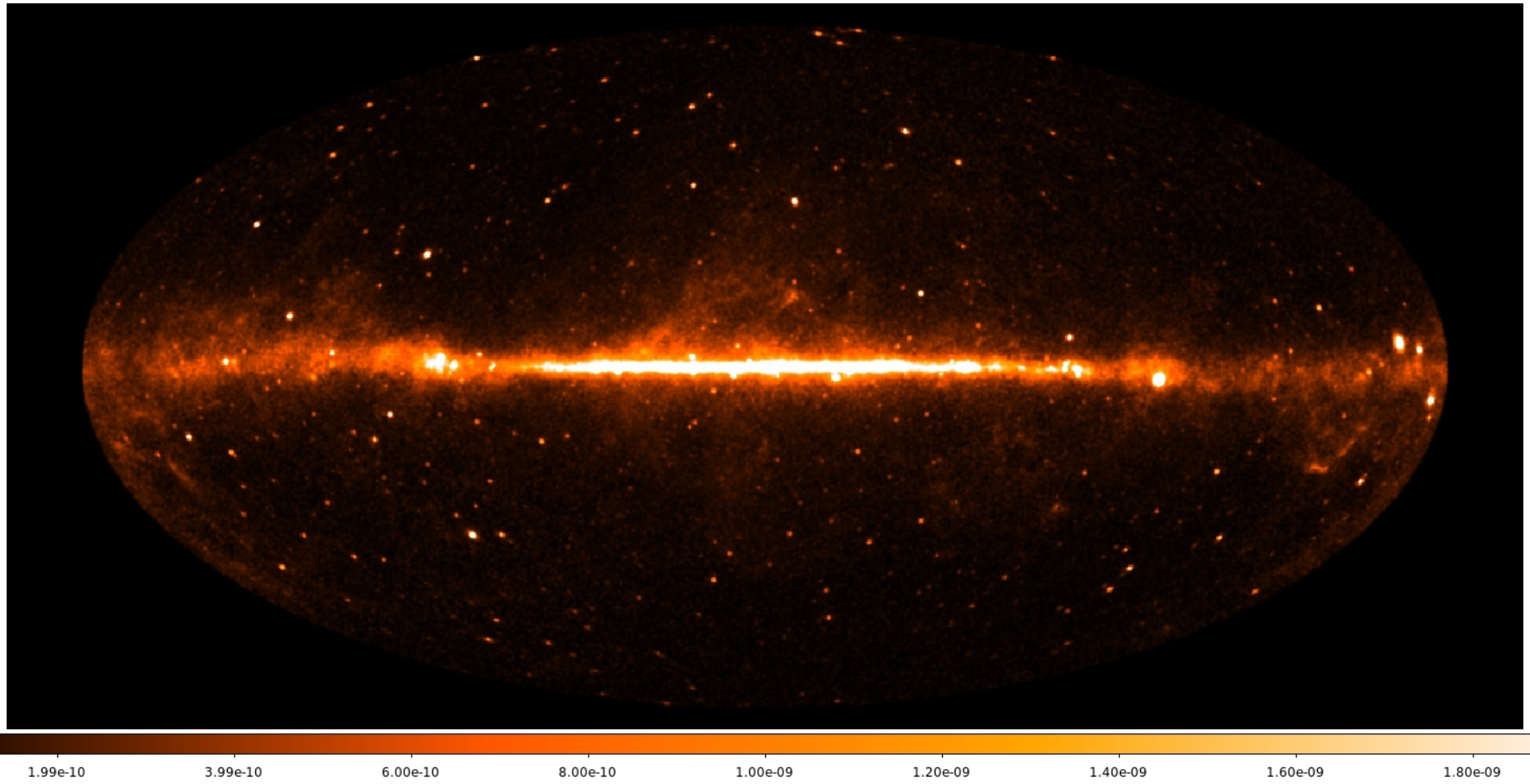
Counts normalized with the exposure 2012-2013



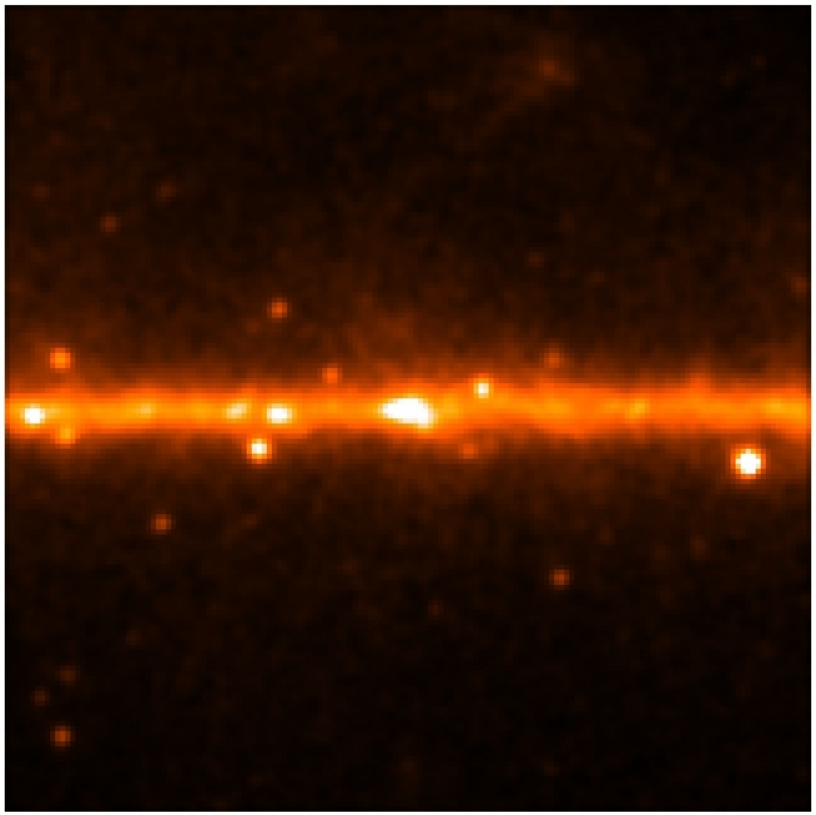
Counts normalized with the exposure 2013-2014

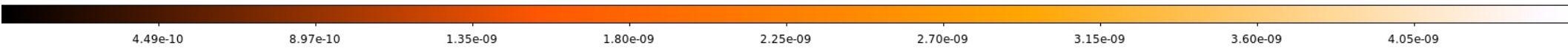


Counts normalized with the exposure 2014-2015

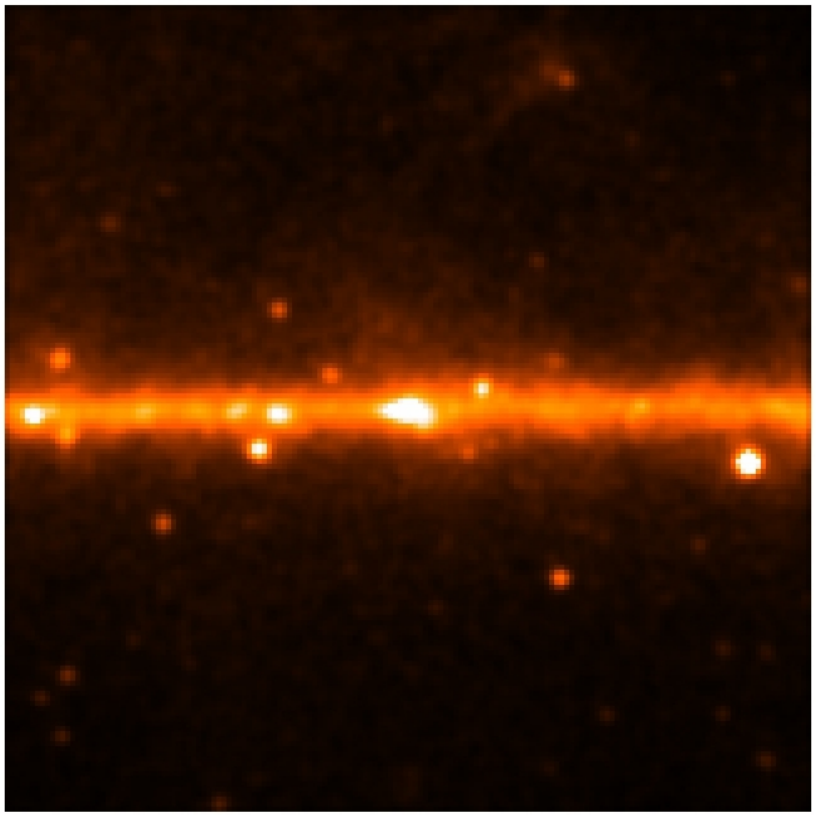


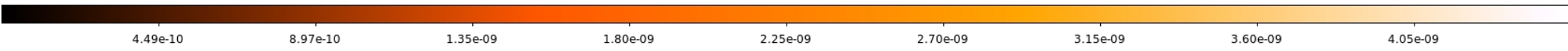
Counts normalized with the exposure
Galactic Center
2008-2009





Counts normalized with the exposure
Galactic Center
2009-2010





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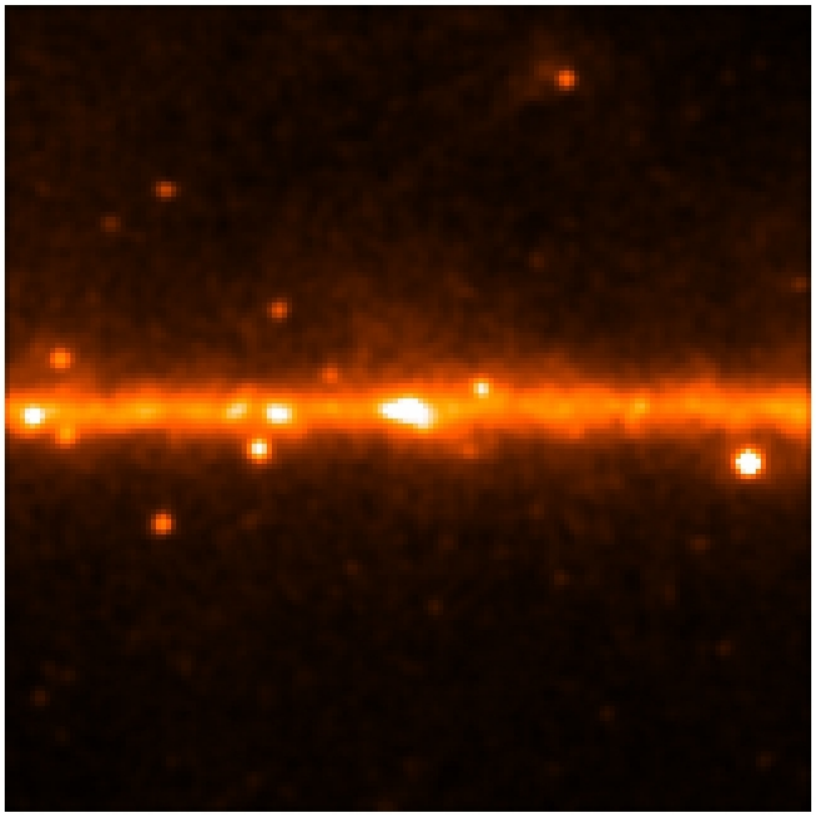
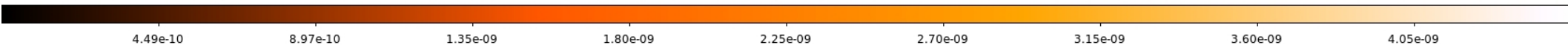
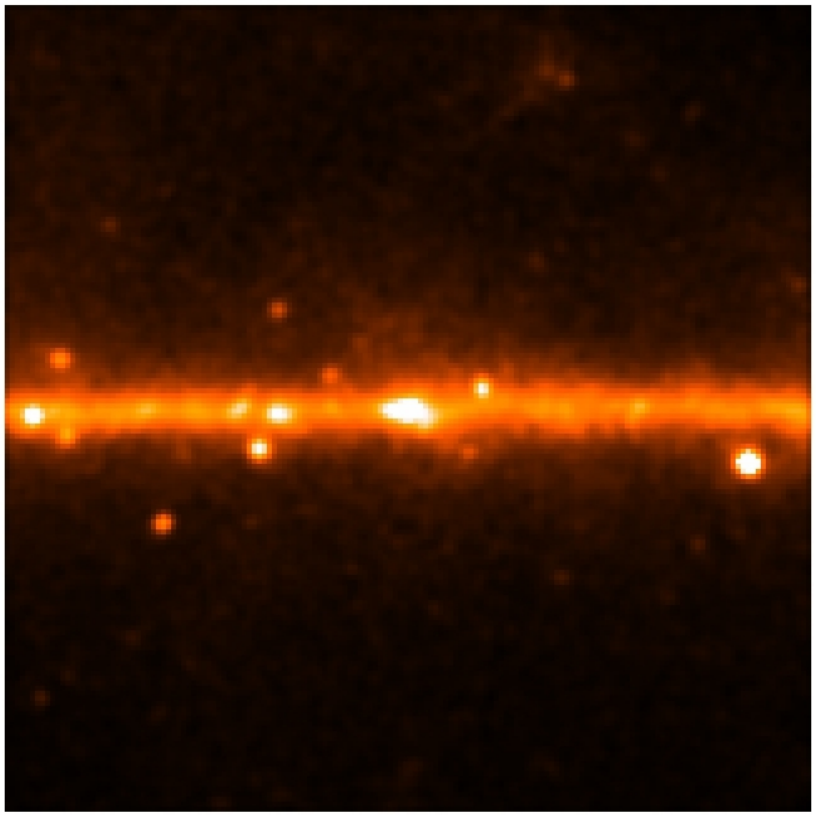
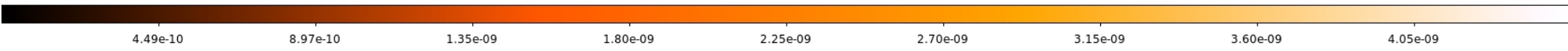


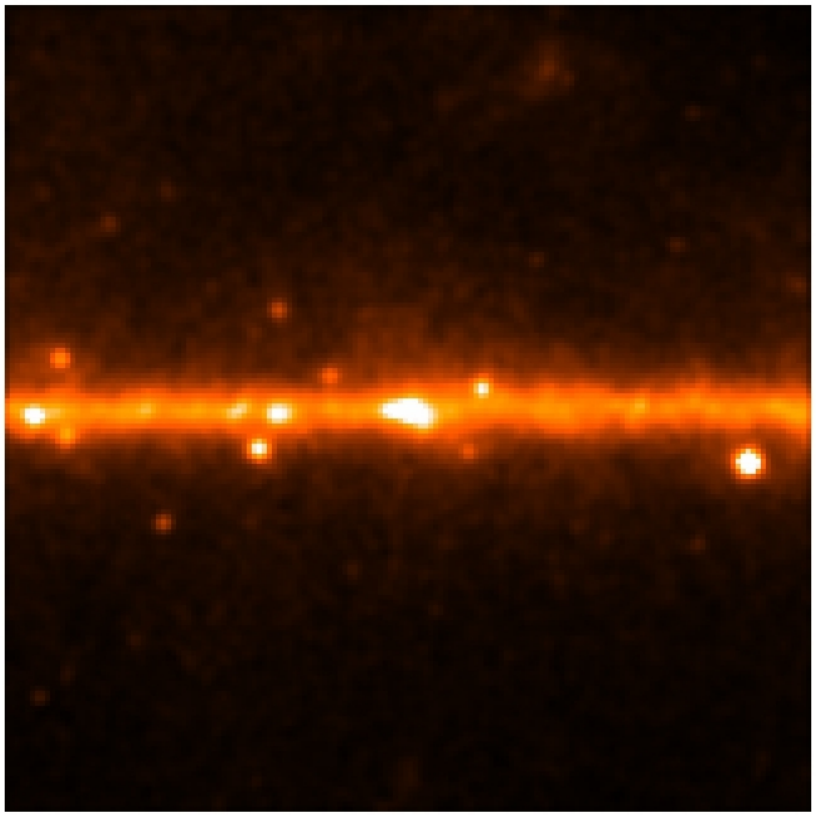


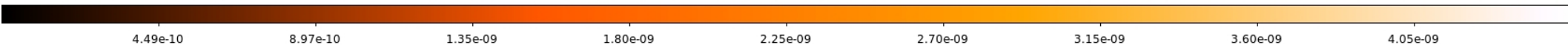
Counts normalized with the exposure
Galactic Center
2011-2012



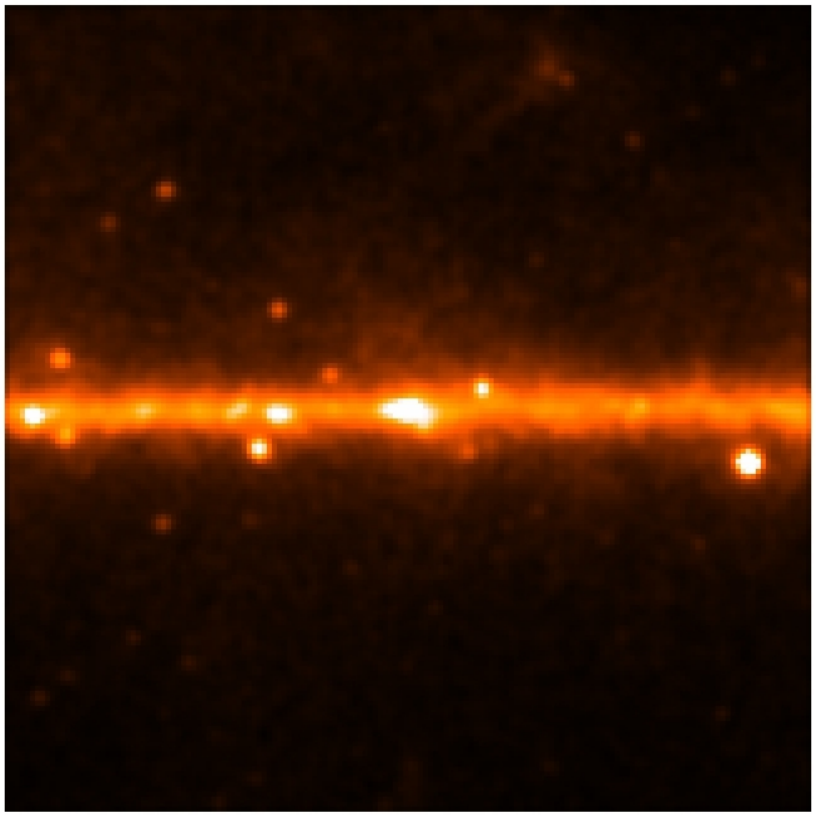


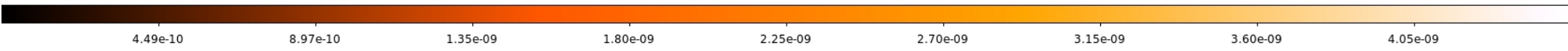
Counts normalized with the exposure
Galactic Center
2012-2013



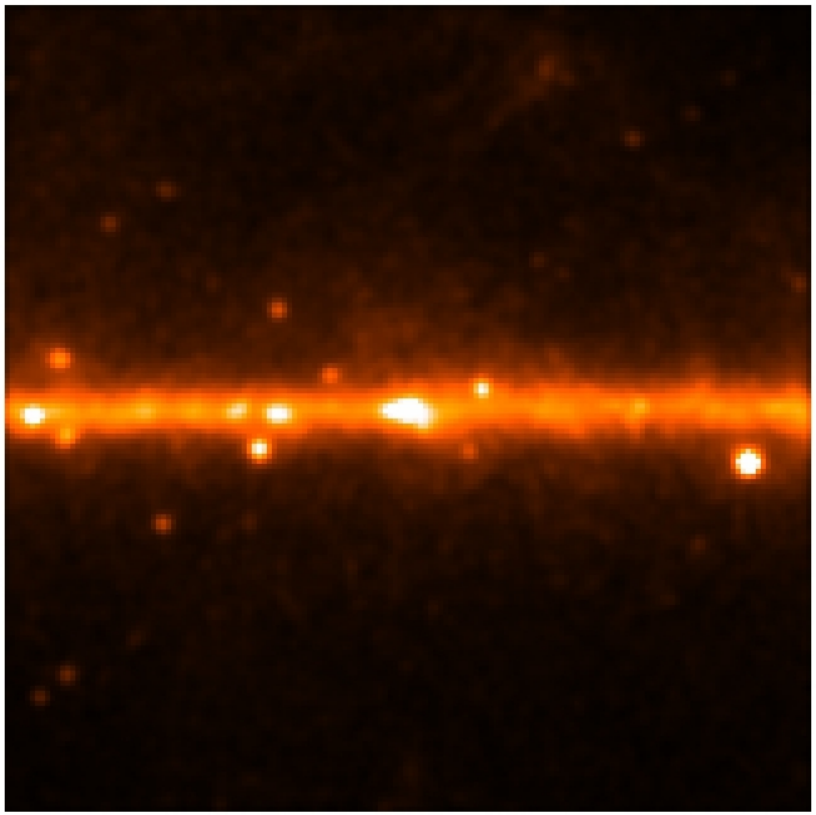


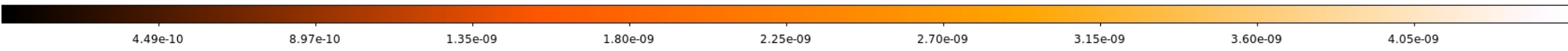
Counts normalized with the exposure
Galactic Center
2013-2014



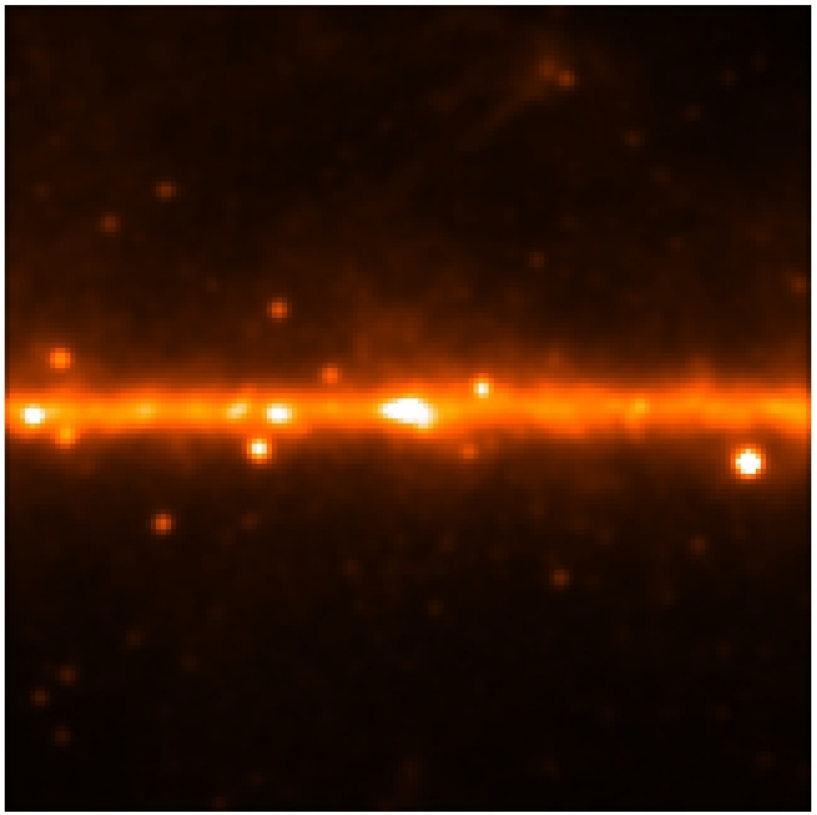


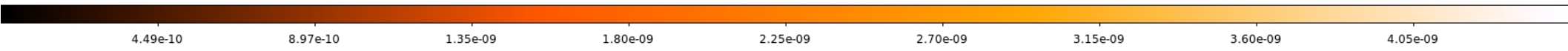
Counts normalized with the exposure
Galactic Center
2014-2015





Counts normalized with the exposure
Galactic Center
2008-2015





Difference and Significant maps

$$Diff\ map = Count_{yi} - Count_{7y}$$ Difference

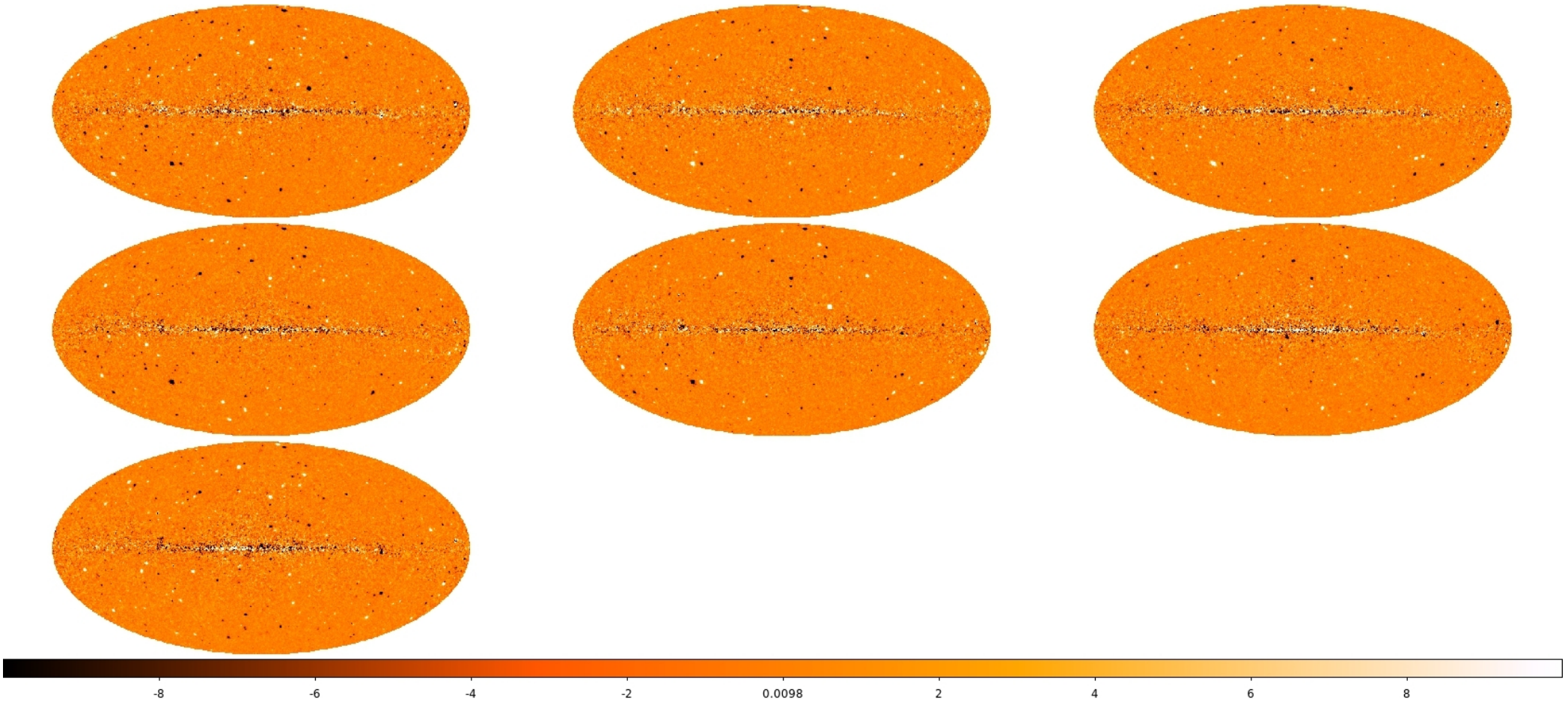
$$Count_{7y} = TotCounts_{7y} \frac{exposure_{yi}}{exposure_{7y}}$$ Expectation

$$\Delta\left(Counts_{yi} - Counts_{7y}\right) = \sqrt{Counts_{yi} + Counts_{7y}\left(\frac{exposure_{yi}}{exposure_{7y}}\right)^2}$$ Difference uncertainty

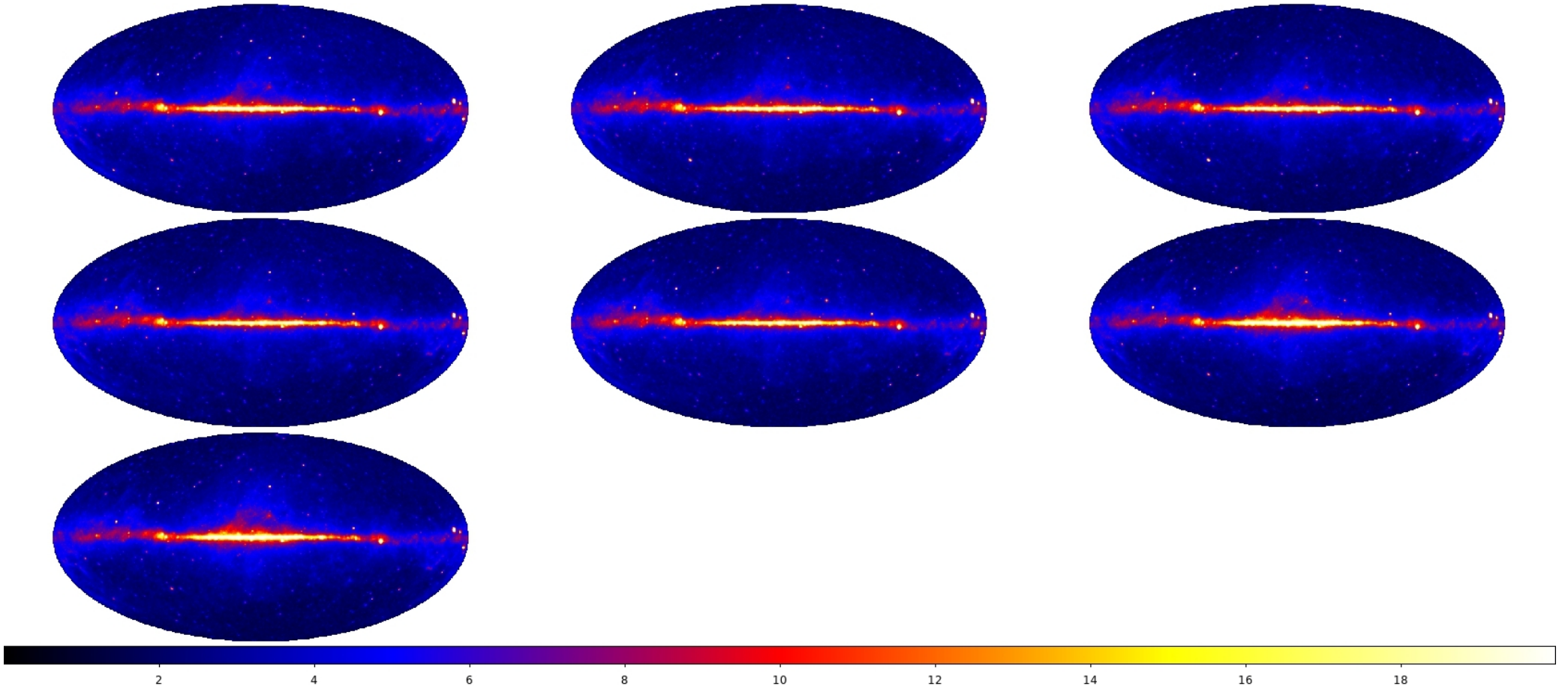
$$S = \sqrt{2}\left[Counts_{yi} \ln\left[\frac{1+a_i}{a_i}\frac{Counts_{yi}}{Counts_{yi}+Counts_{7y}}\right] + Counts_{7y} \ln\left[\left(1+a_i\right)\frac{Counts_{7y}}{Counts_{yi}+Counts_{7y}}\right]\right]$$ Significance Li & Ma

$$a_i = \frac{exposure_{yi}}{exposure_{y7}}$$

Difference maps

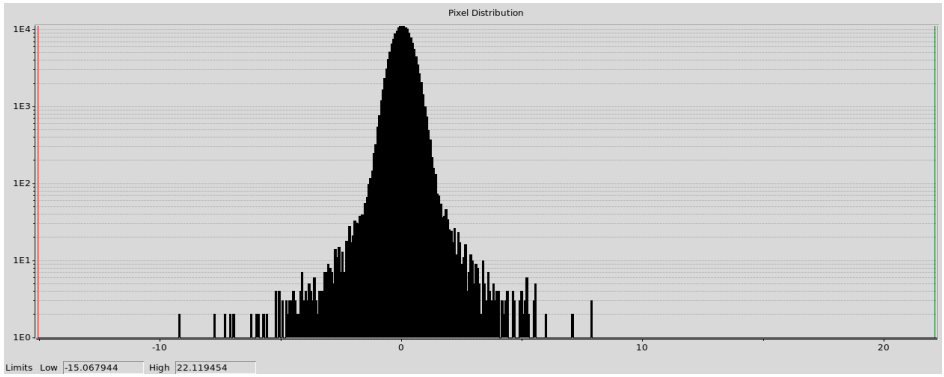


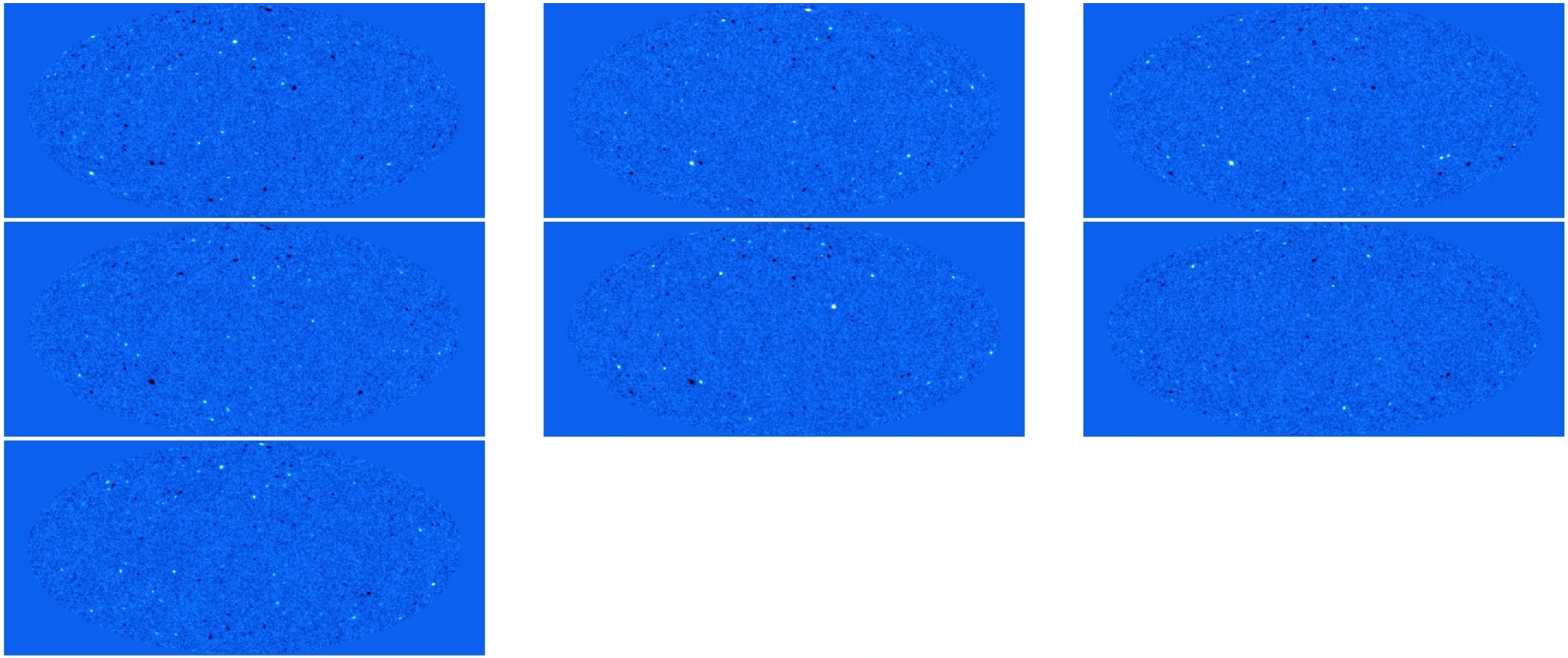
Uncertainty maps



Significance map of Li & Ma

Pixel distribution of the first significance map, picked around zero





Extraction of the variable sources

SExtractor

- Input:

  - Difference map

  - Uncertainty map

- Output:

  - Catalogs of variable sources over 5 sigma from a null background weighted with the uncertainty

Check with the significant

Comparison with the Li & Ma significance map

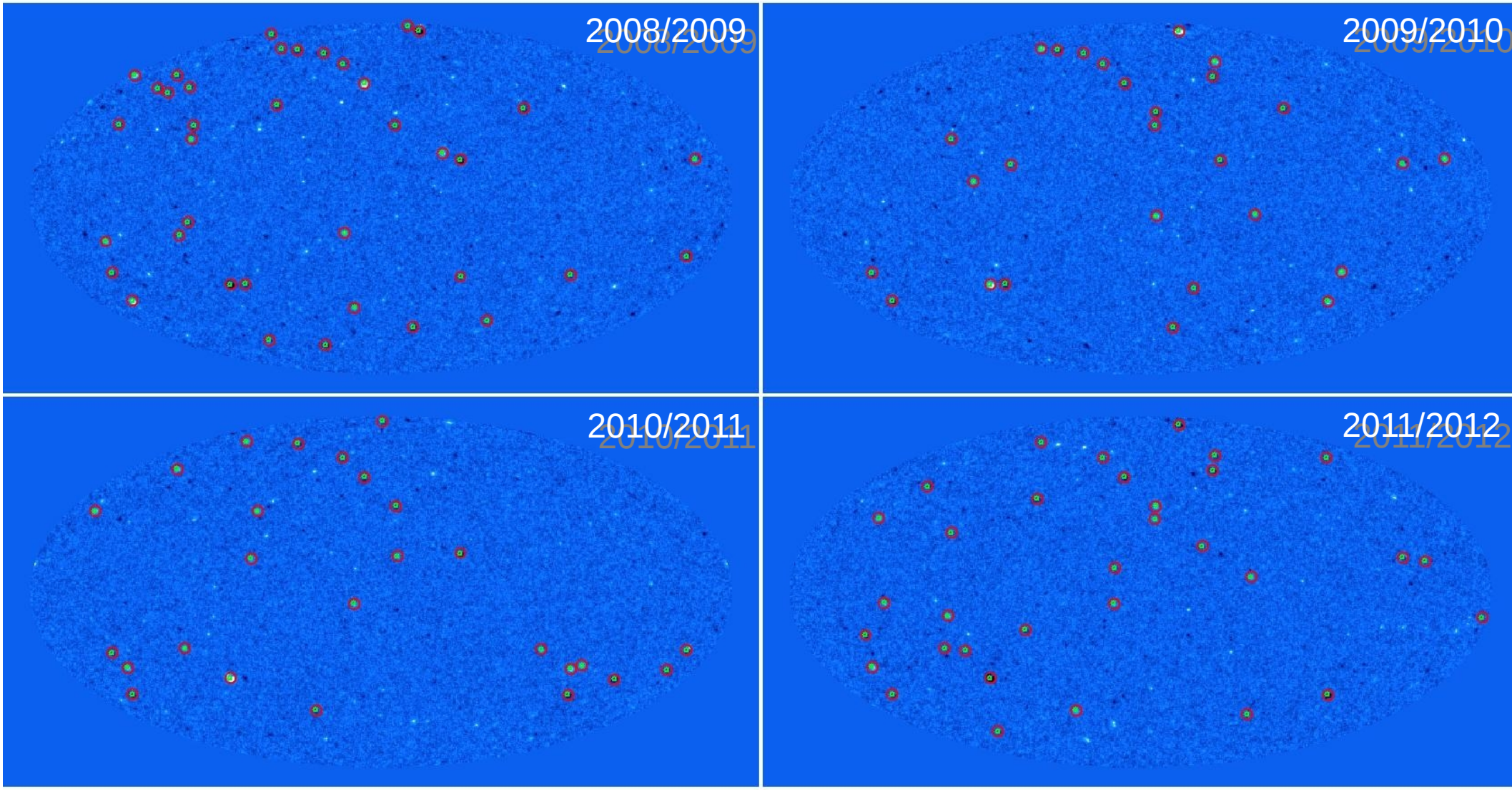
Fermi Science TOOL gtsrcid

Identification of extracted sources with the 3FGL catalog sources

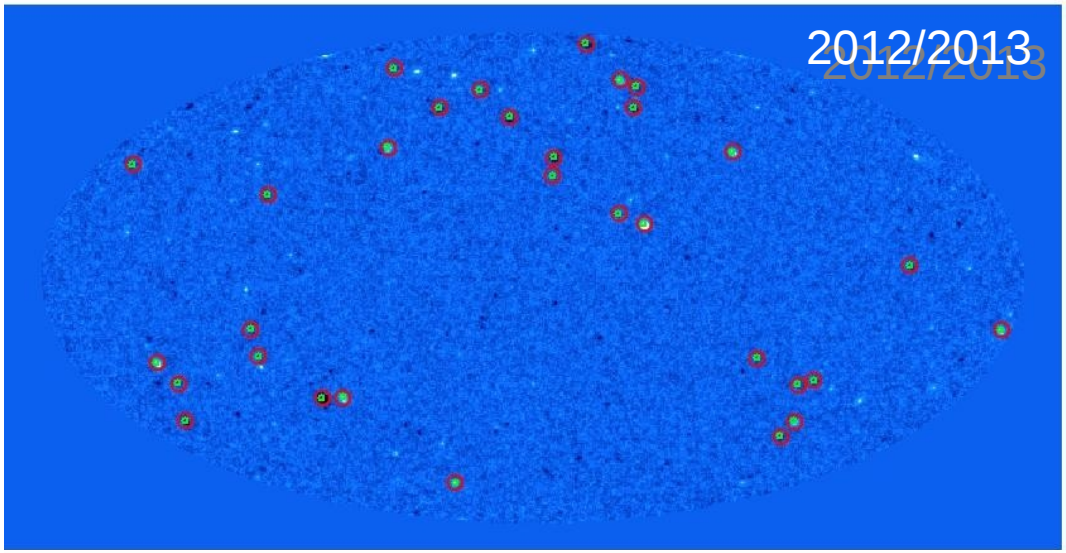
Seven catalogs, one for each year of analysis.

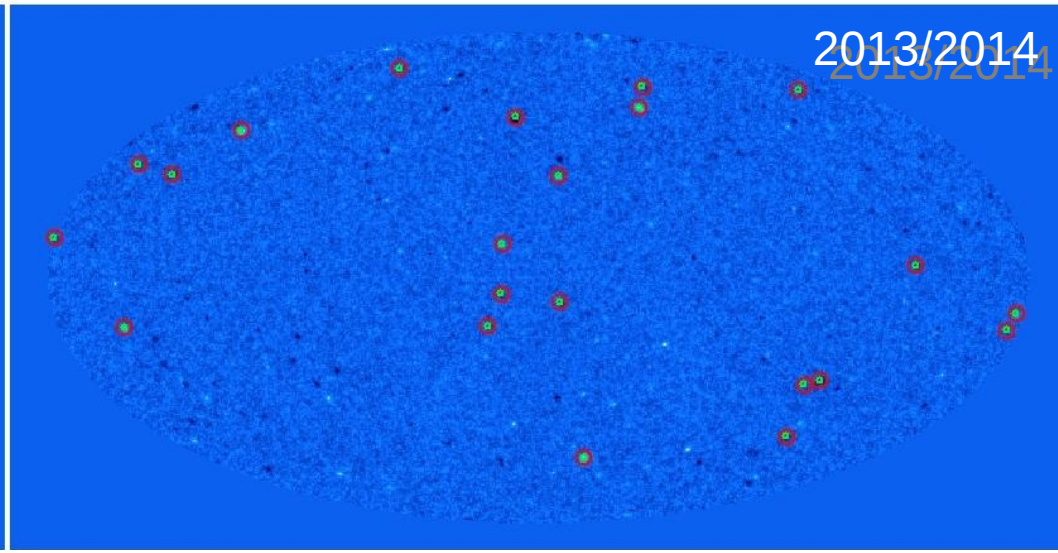
VAR Catalog, comprehensive of all the annual variable sources.

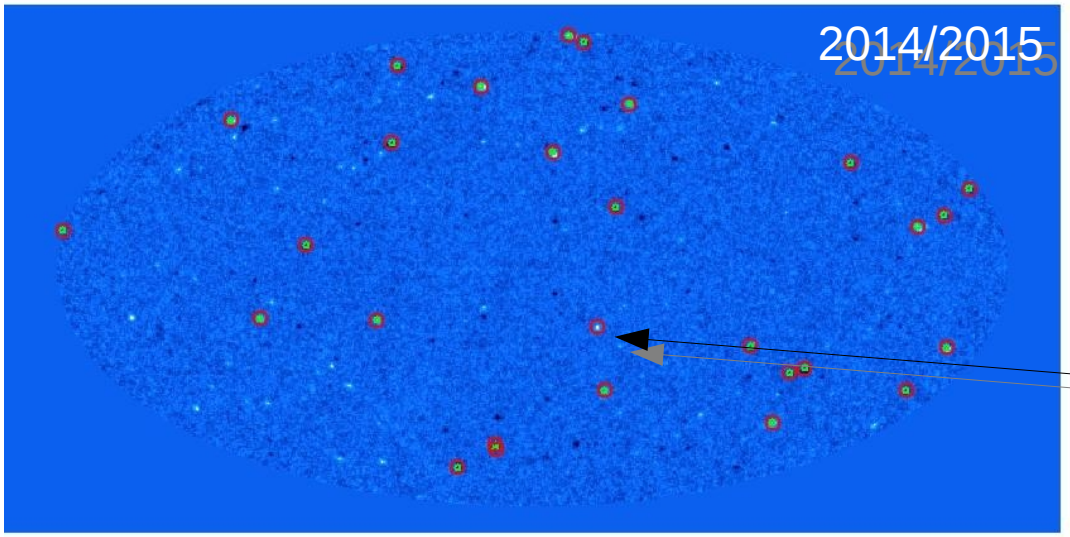
Annual variable sources



Annual variable sources



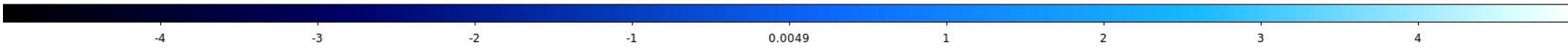




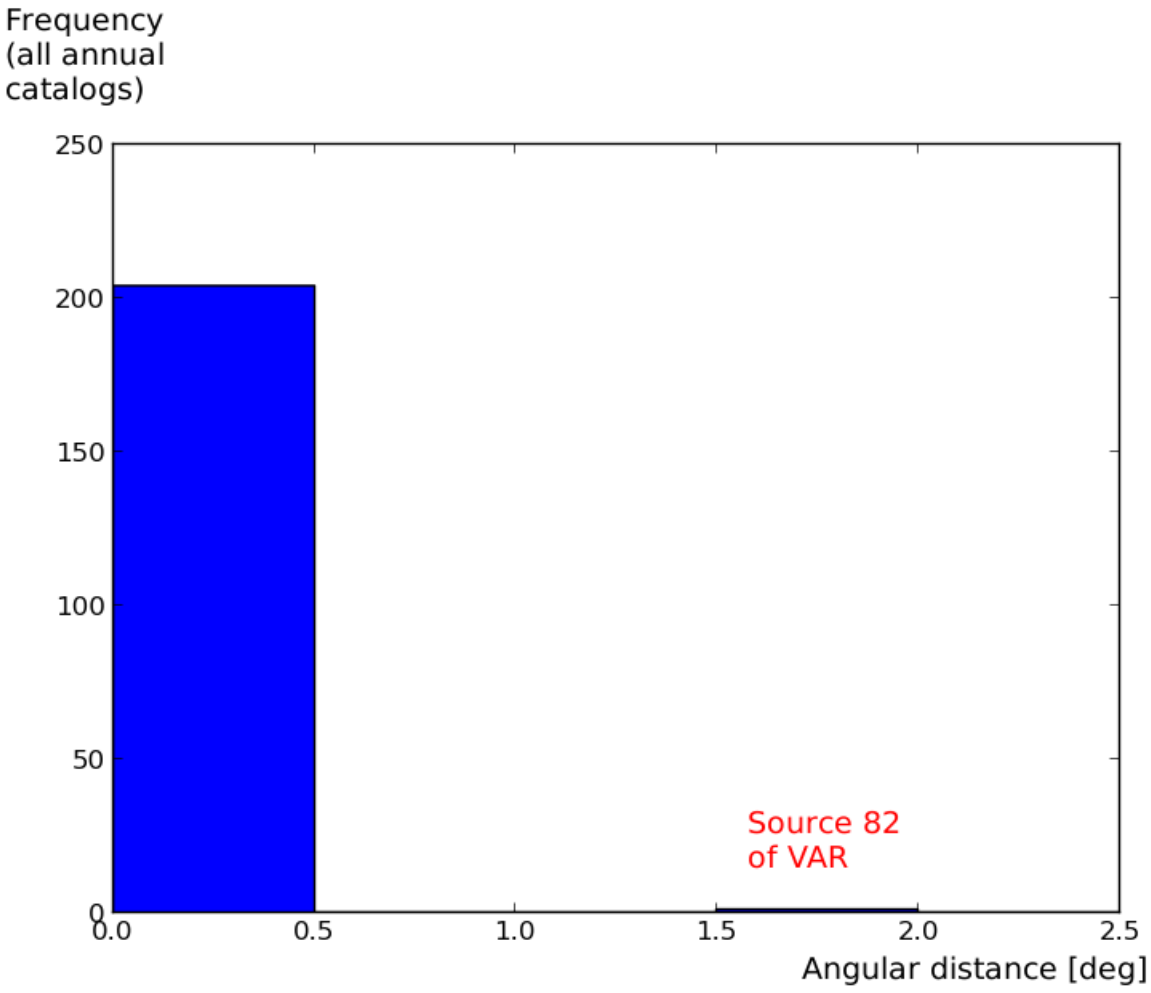
Red circles: variable sources extracted
Green circles: 3FGL association

Only one source is not associated to a 3FGL source

Tools used: FermiScienceTOOLS, sextractor,ds9, python.



Source 82 of VAR



Too far from the nearest 3FGL source.

It appears between 2013 and 2015.

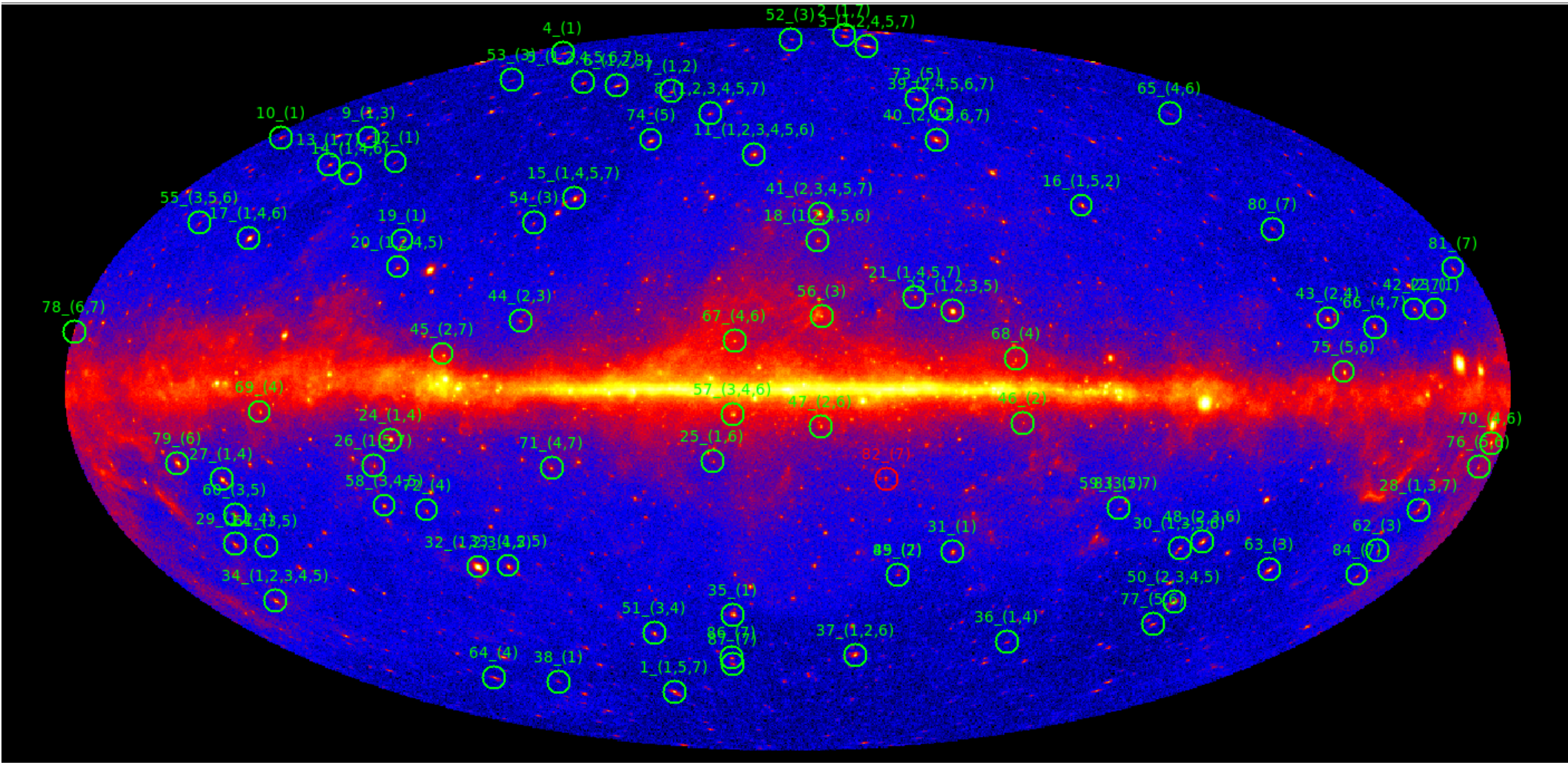
To check the last version of Fermi-LAT catalog.

Possible association with the Blasar PKS 1824-582

Distribution of angular distance between VAR sources and the nearest 3FGL sources

VAR catalog

Finally all the variable source in a unique catalog



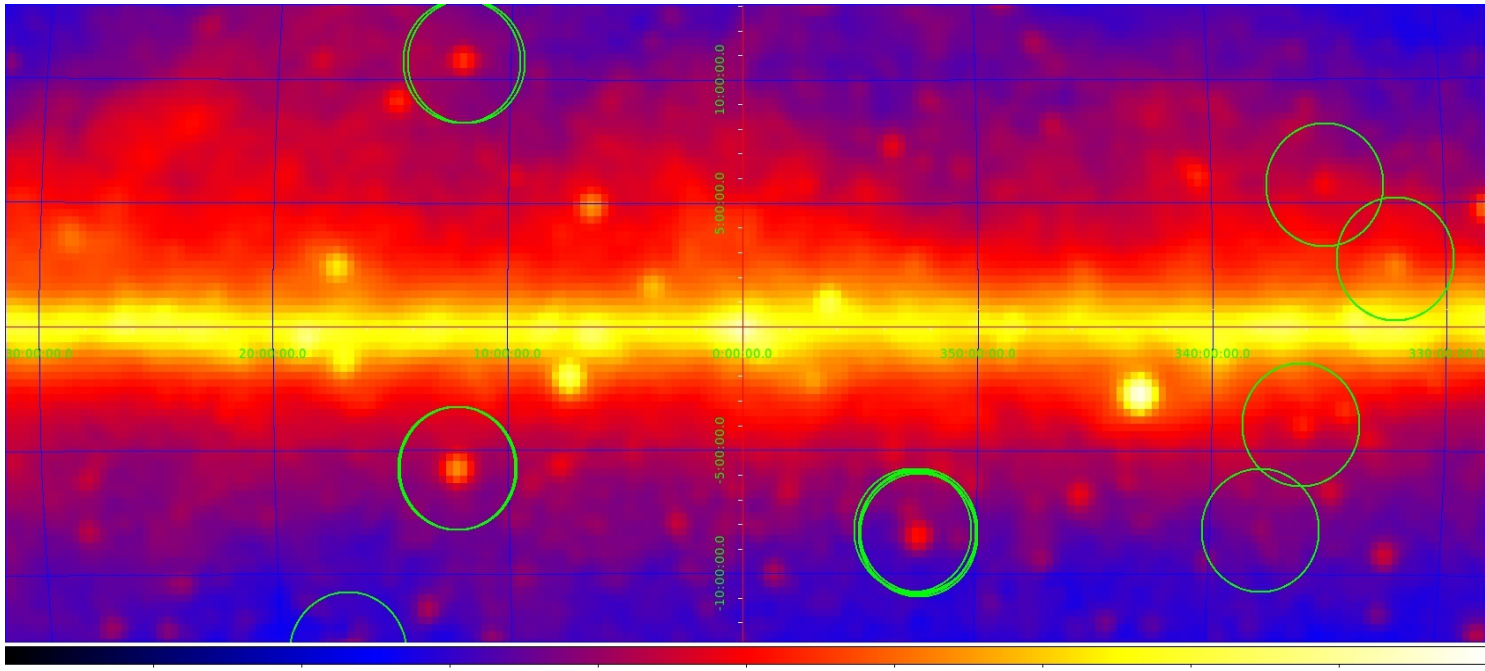
Green circles: VAR sources with a 3FGL association

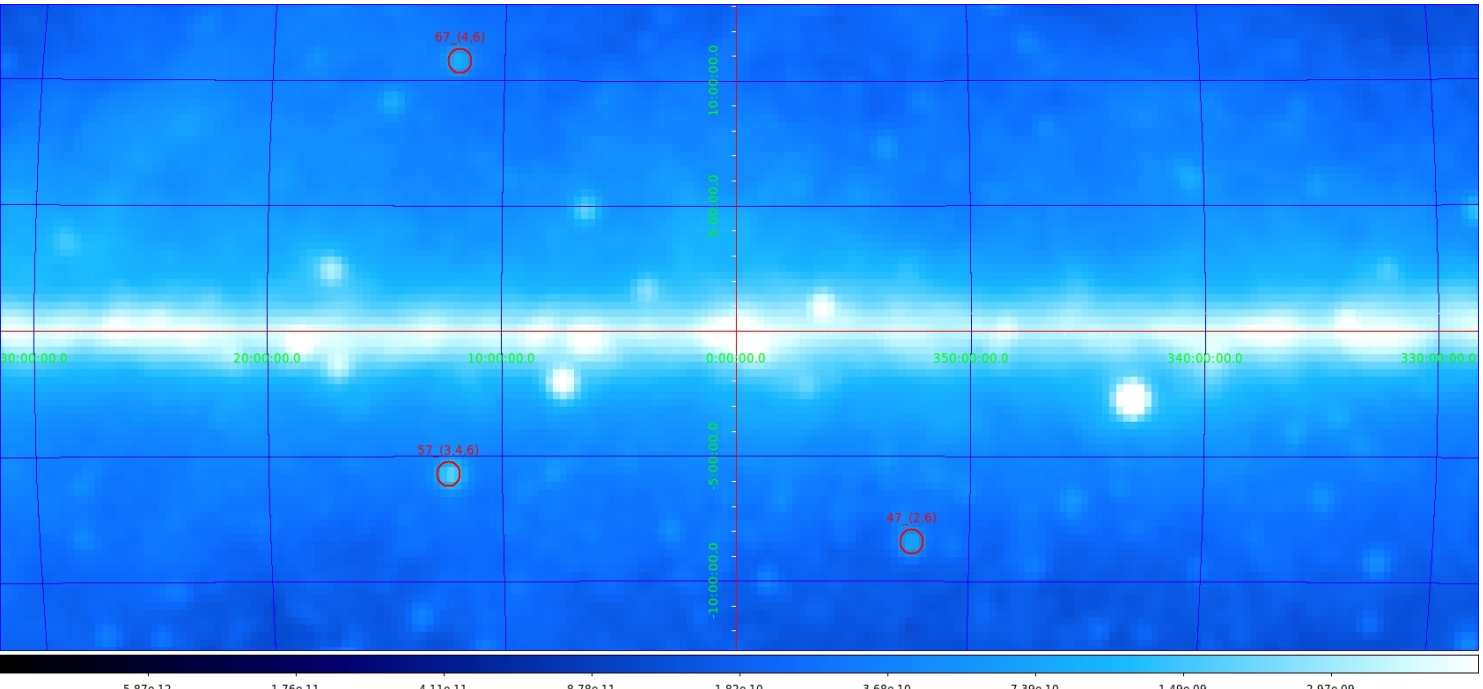
Red circle: VAR source not associated to the 3FGL

In brackets the year of extraction

Variable sources in the center of the Galaxy

3σ →

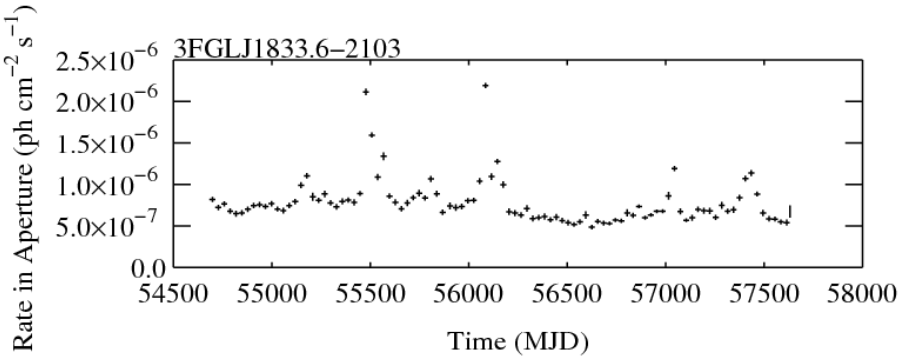




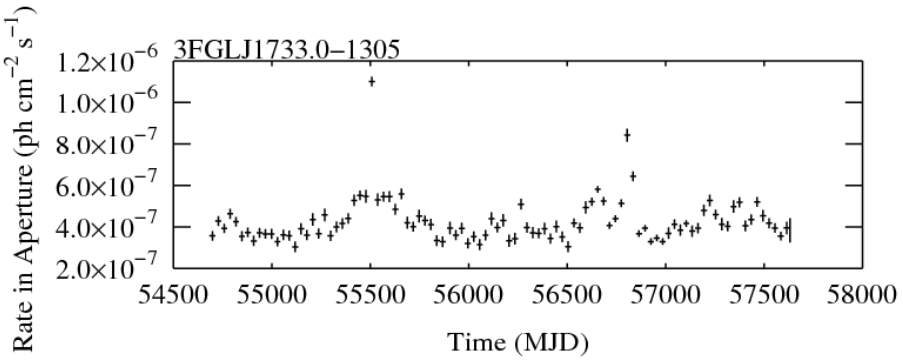
← 5σ

Central sources light curves

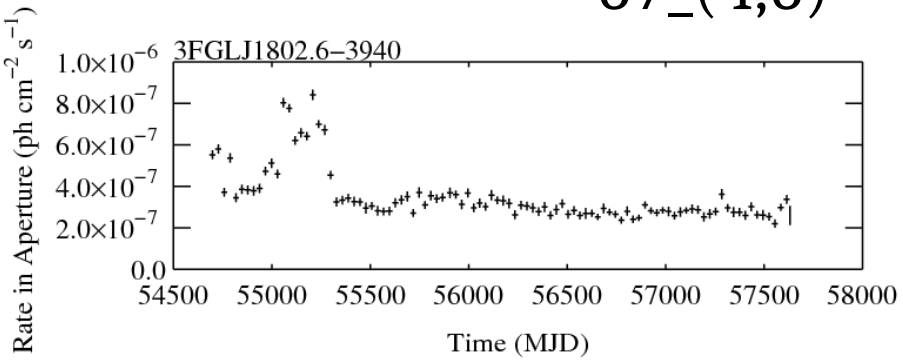
57_(3,4,6)



47_(2,6)



67_(4,6)



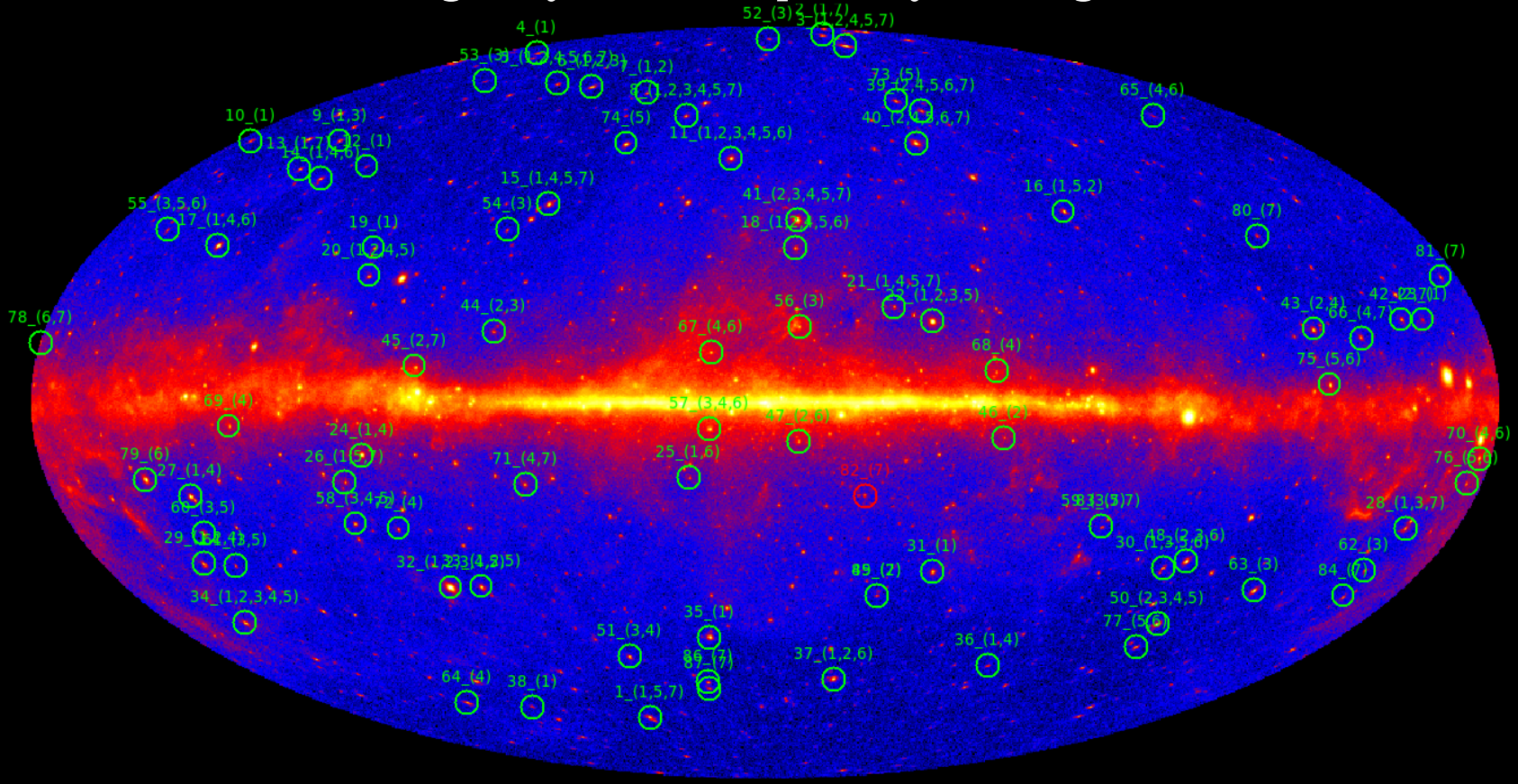
Time in Modified Julian Day

- 1: 2008/08/01 – 2009/08/01 = 54679 – 55044 (MJD)
- 2: 2009/08/01 – 2010/08/01 = 55044 – 55409 (MJD)
- 3: 2010/08/01 – 2011/08/01 = 55409 – 55774 (MJD)
- 4: 2011/08/01 – 2012/08/01 = 55774 – 56140 (MJD)
- 5: 2012/08/01 – 2013/08/01 = 56140 – 56505 (MJD)
- 6: 2013/08/01 – 2014/08/01 = 56505 – 56870 (MJD)
- 7: 2014/08/01 – 2015/08/01 = 56870 – 57235 (MJD)

No particular correlation found.
A more precise study must.

Observations and conclusions

- 87 sources with significant annual variation.
- One source is not associated at the 3FGL catalog.
- All the VAR sources are extragalactic (except source 82 which is not associated to a 3FGL source)
- No new class sources found
- No sources in the galaxy found (expecially in the galactic center)



Future prospects

- Systematic studies of the light curves of VAR source.
- Association of source VAR 82 with the latest version of Fermi-LAT detected sources.
- Association of source VAR 82 with other catalogs.