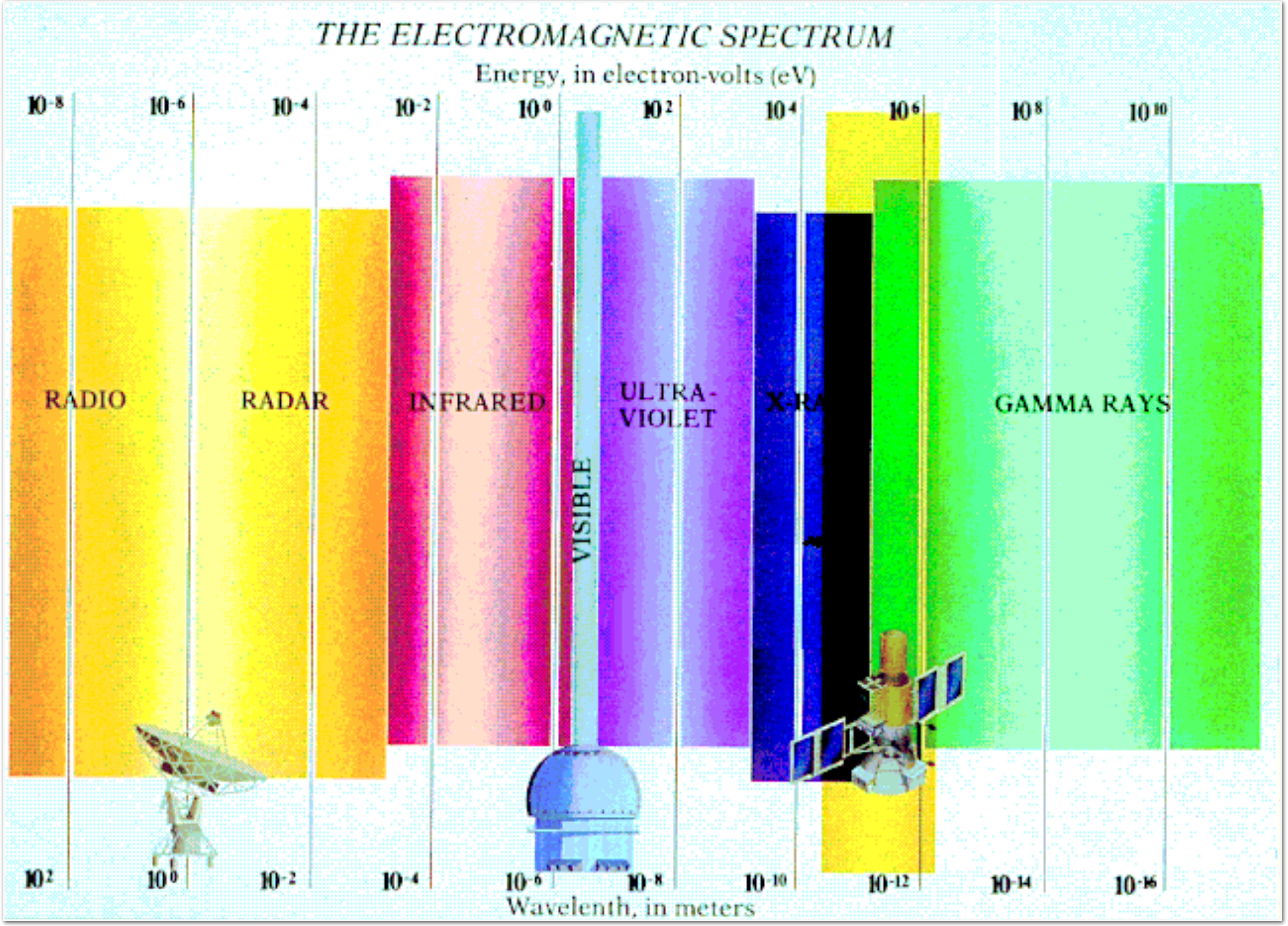
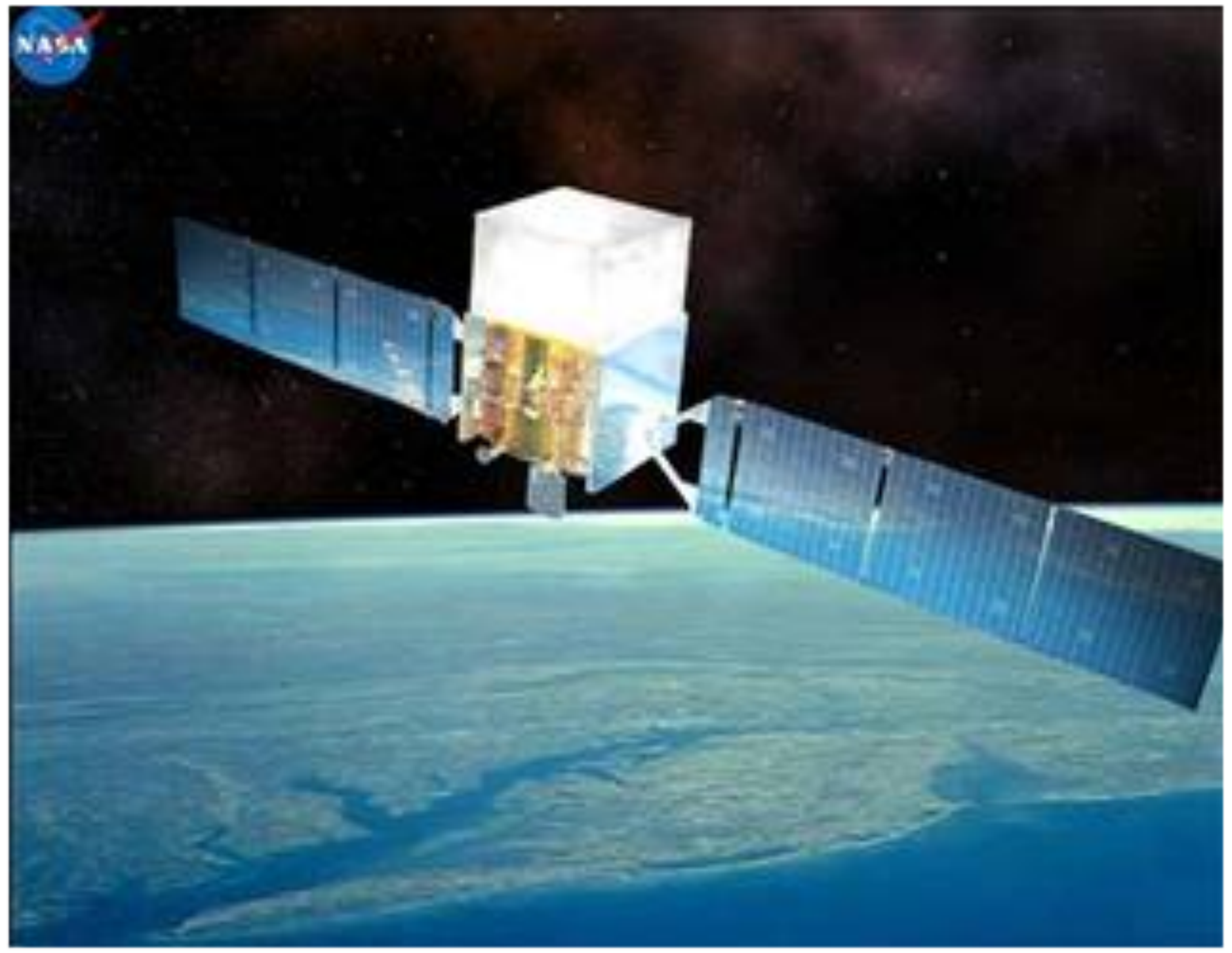
THE GAMMA-RAY SKY



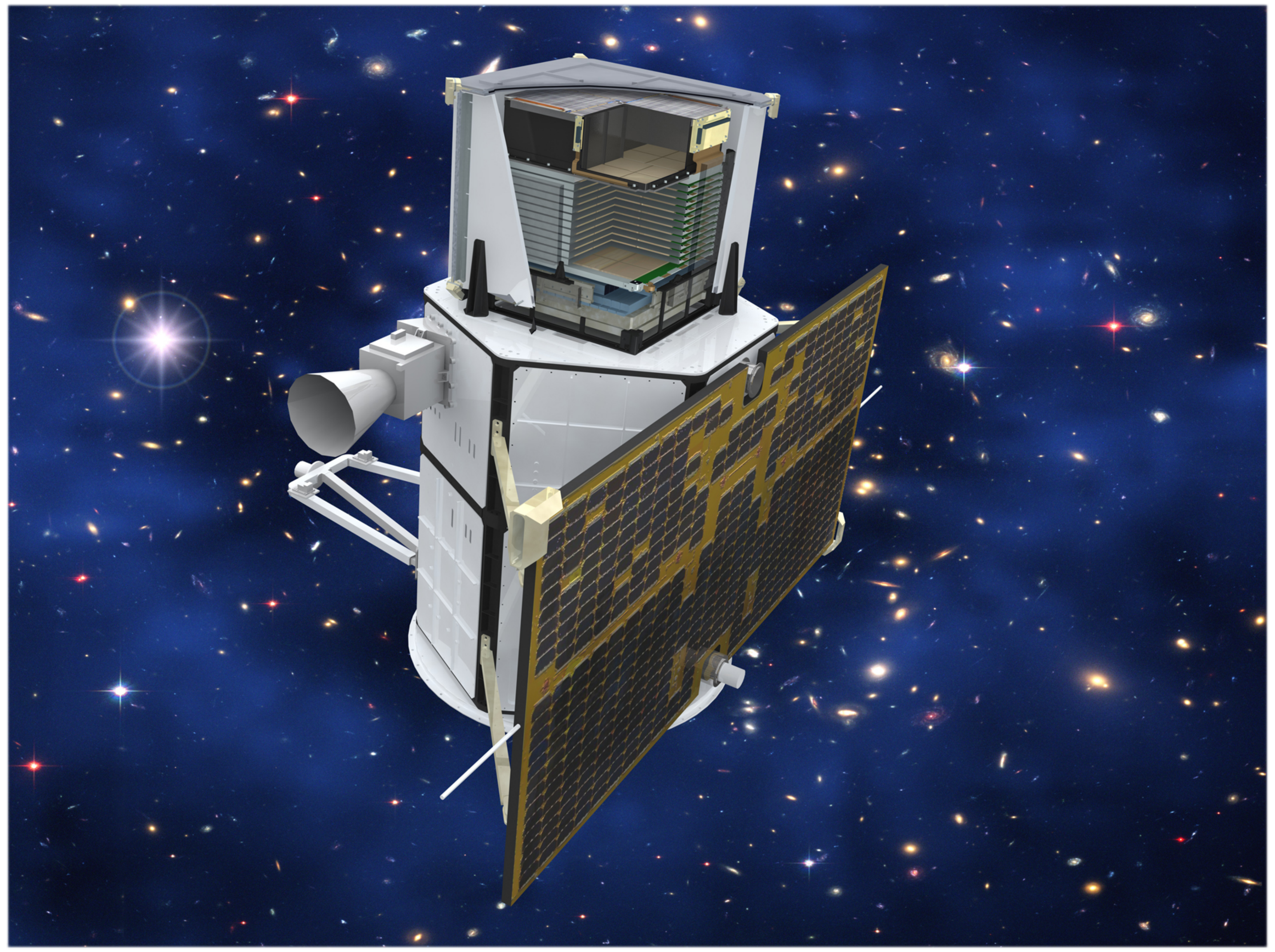
HE OR GEV ASTRONOMY ~30 MEV - 100 GEV — SPACE SATELLITE
VHE OR TEV ASTRONOMY ~100 GEV -100 TEV — GROUND-BASED EXPERIMENT

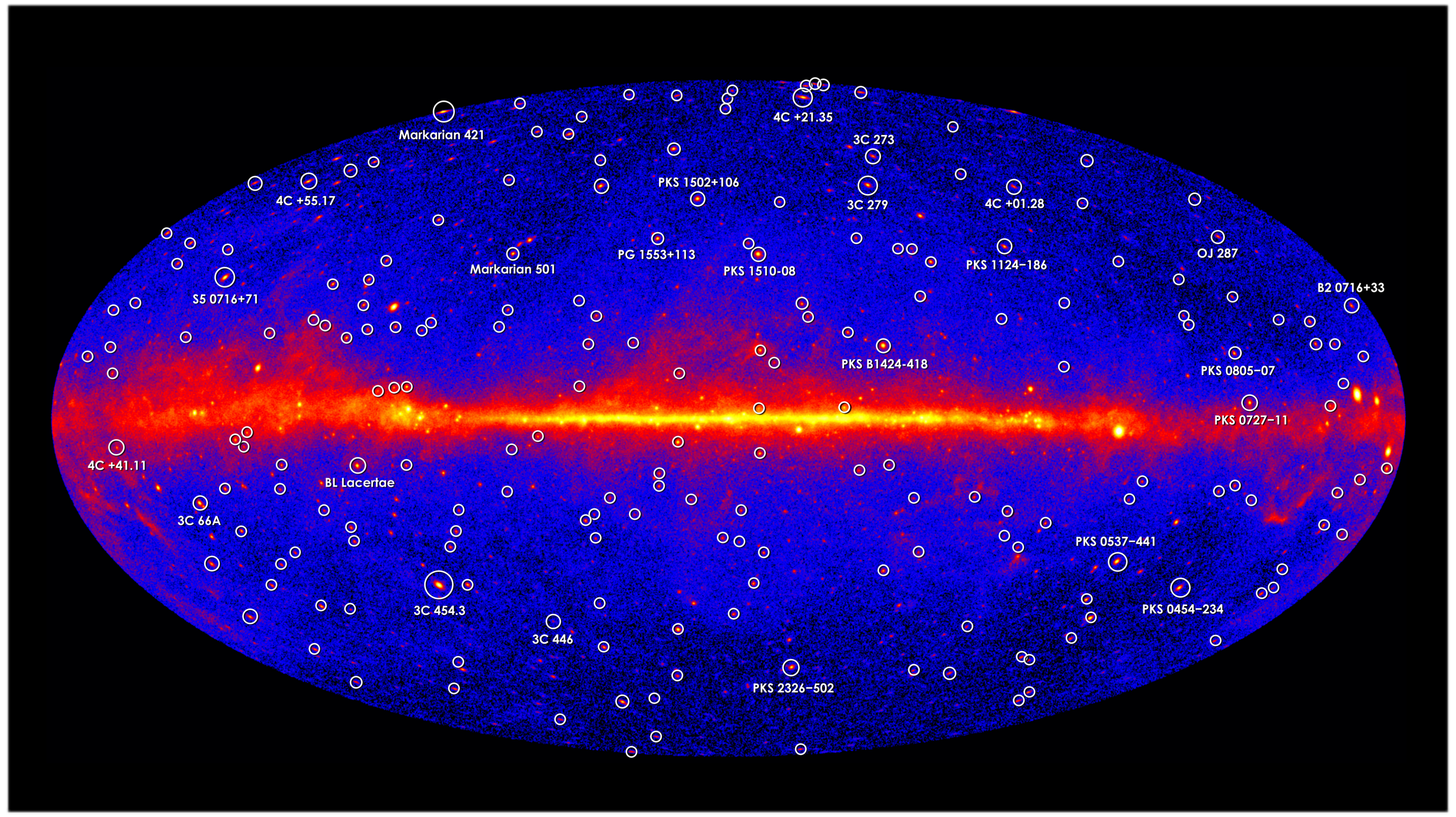
GAMMA-RAY SATELLITES

FERMI



AGILE





X-RAY AND GAMMA-RAY DATA REDUCTIONS SHOW SIMILARITY BUT ALSO SEVERAL DIFFERENCES

SIMILARITY:

INPUT FILES: EVENT FILE AND HOUSKEEPING FILE.

EVENT FILE PROVIDES THE ARRIVAL TIME, THE ENERGY AND THE POSITION IN THE SKY OF THE DETECTED EVENT

HOUSEKKEPING FILE DESCRIBES THE STATE AND THE CONFIGURATION OF THE SATELLITE

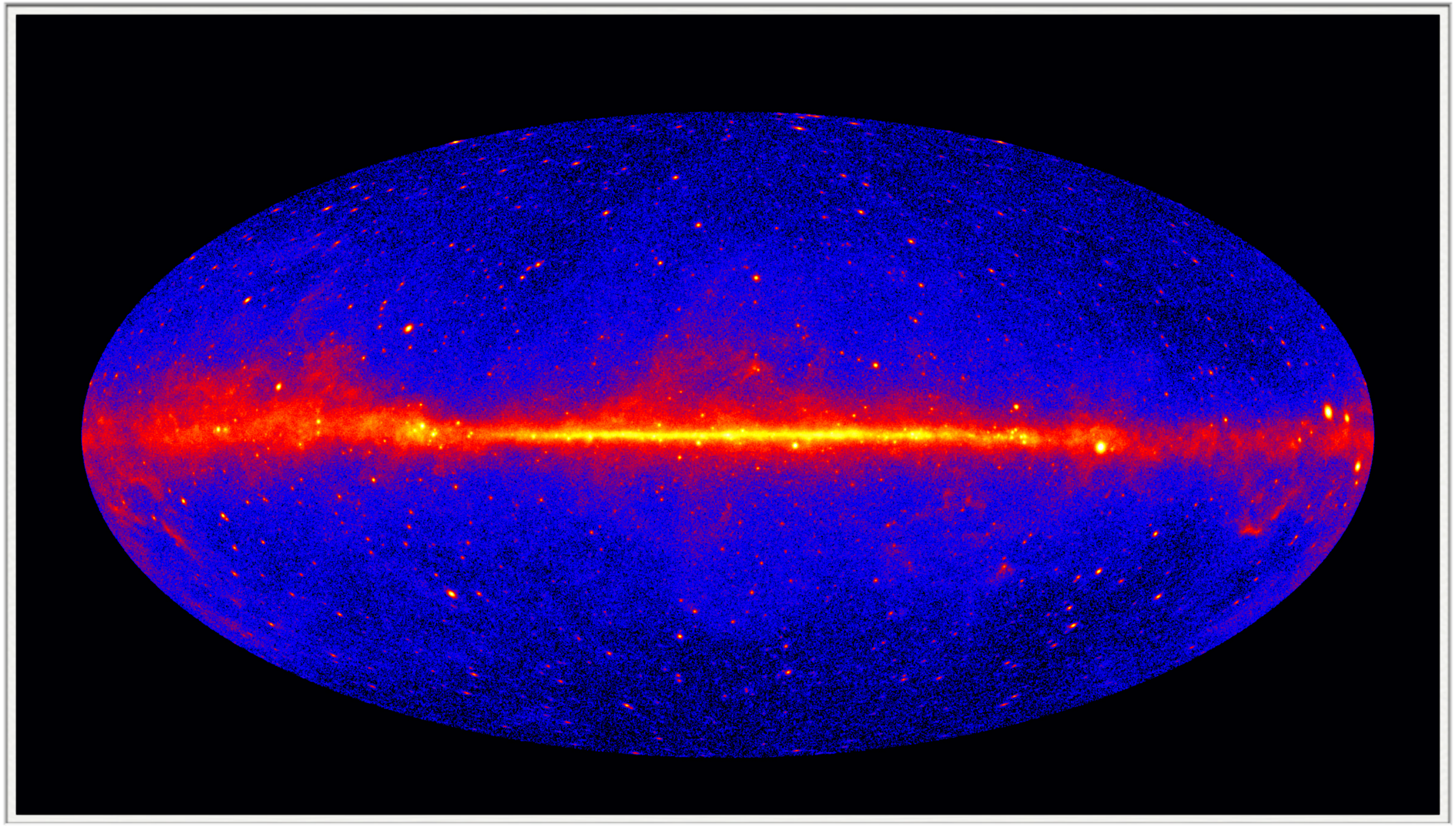
CLEANING OF THE DATA

BACKGROUND CHARACTERISATION AND DEFINITION OF THE INSTRUMENTAL RESPONSE

Gamma-ray Background

Gamma-ray background consists of two components:

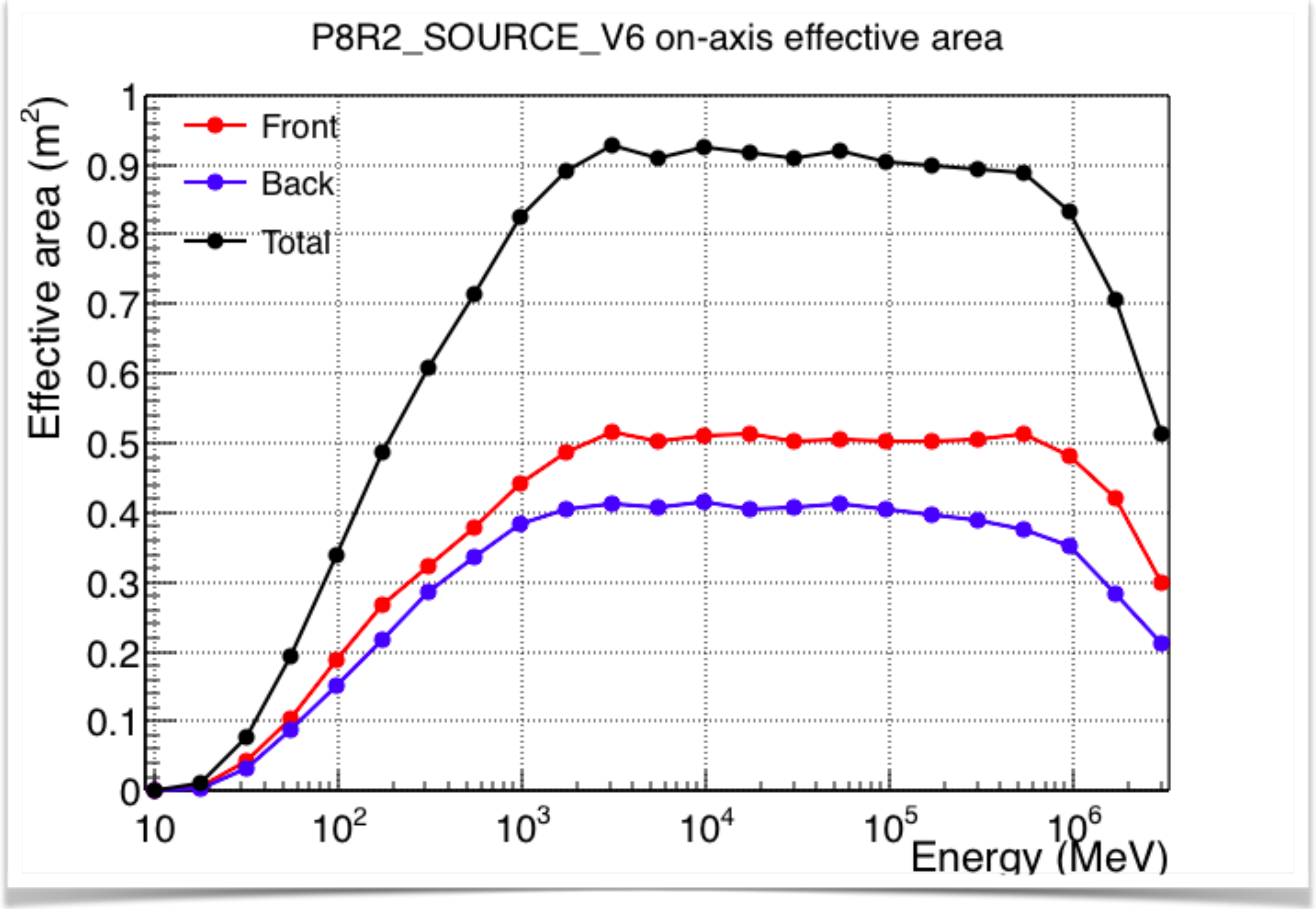
- Galactic background due to Cosmic Ray, hadrons and electrons interactions with the interstellar gas and photon field
- Isotropic Diffusion Emission (extragalactic background)

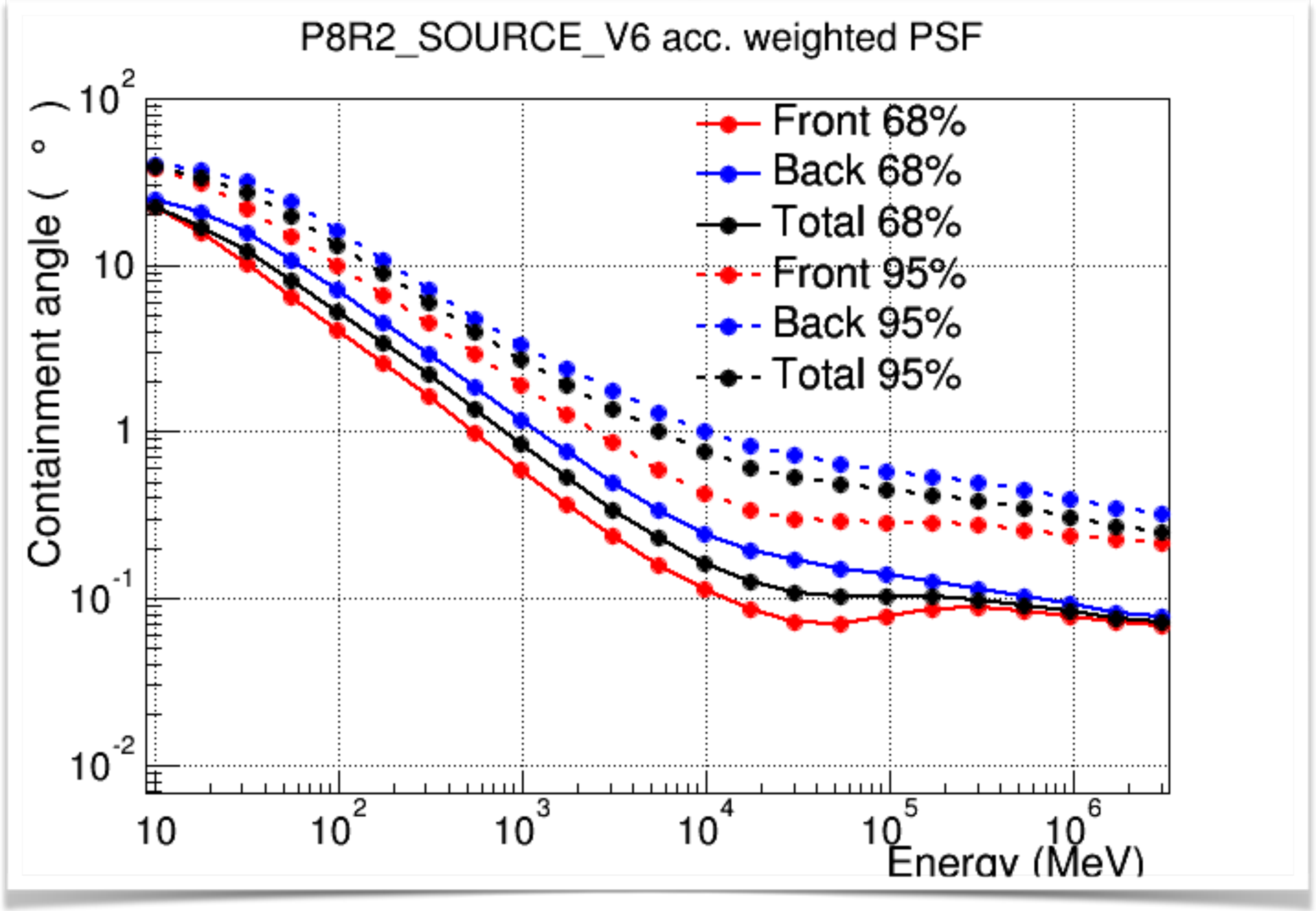


THE LAT RESPONSE FUNCTIONS DEFINE THE RESPONSE OF THE INSTRUMENT TO GAMMA RAYS OF A GIVEN ENERGY AND ARRIVAL DIRECTION IN INSTRUMENT COORDINATES.

$$R(E',\phi' ; E,\phi)=A_{eff}(E,\phi)p_{PSF}(\phi' ;E,\phi)\ p_E(E' ;E)$$

the **photon** parameters are the energy **E** and the inclination angle **φ** (the angle between the LAT normal and the true source position) and t
event is characterized by the apparent energy **E'** and the apparent source position **φ'**.





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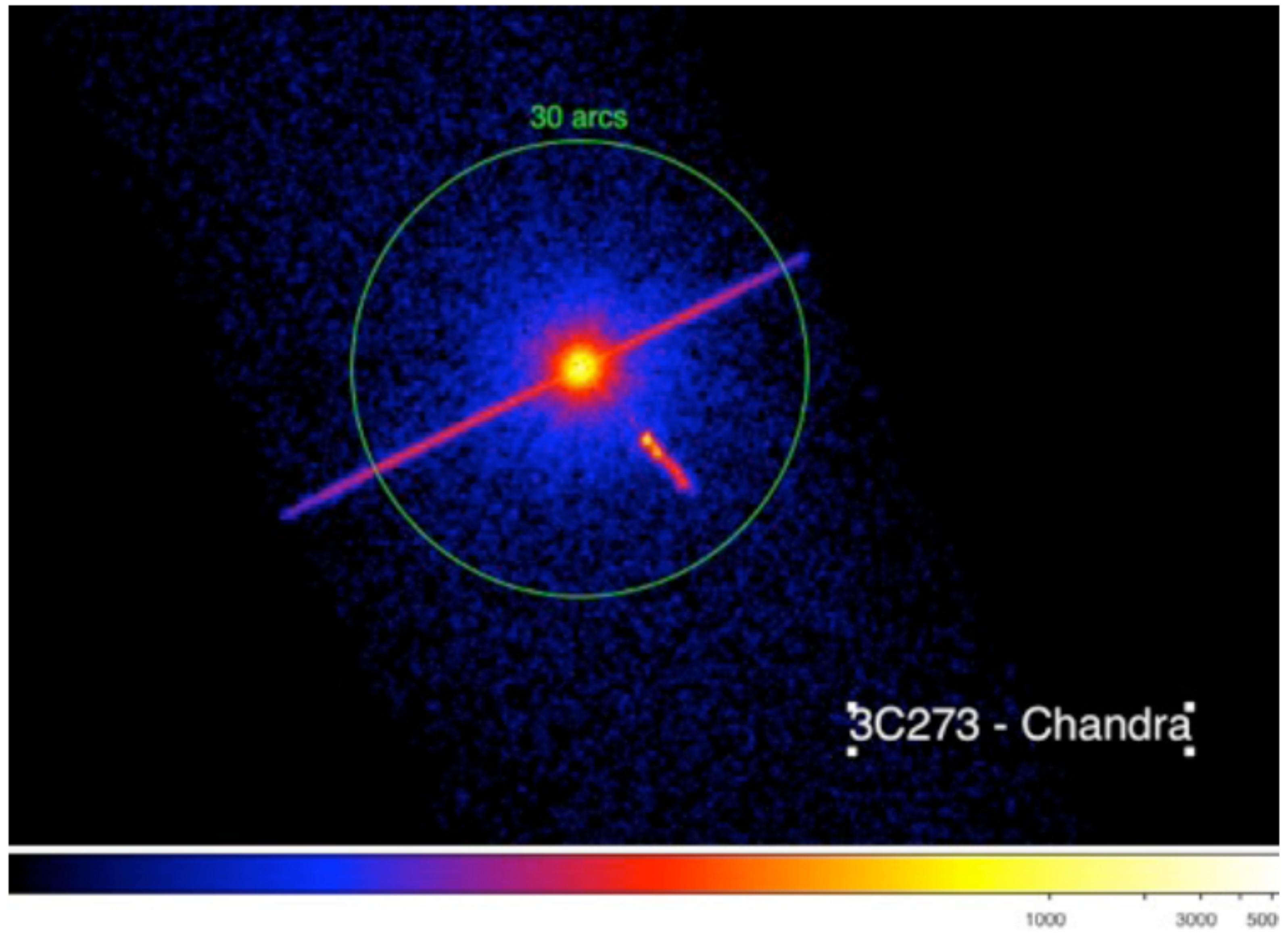
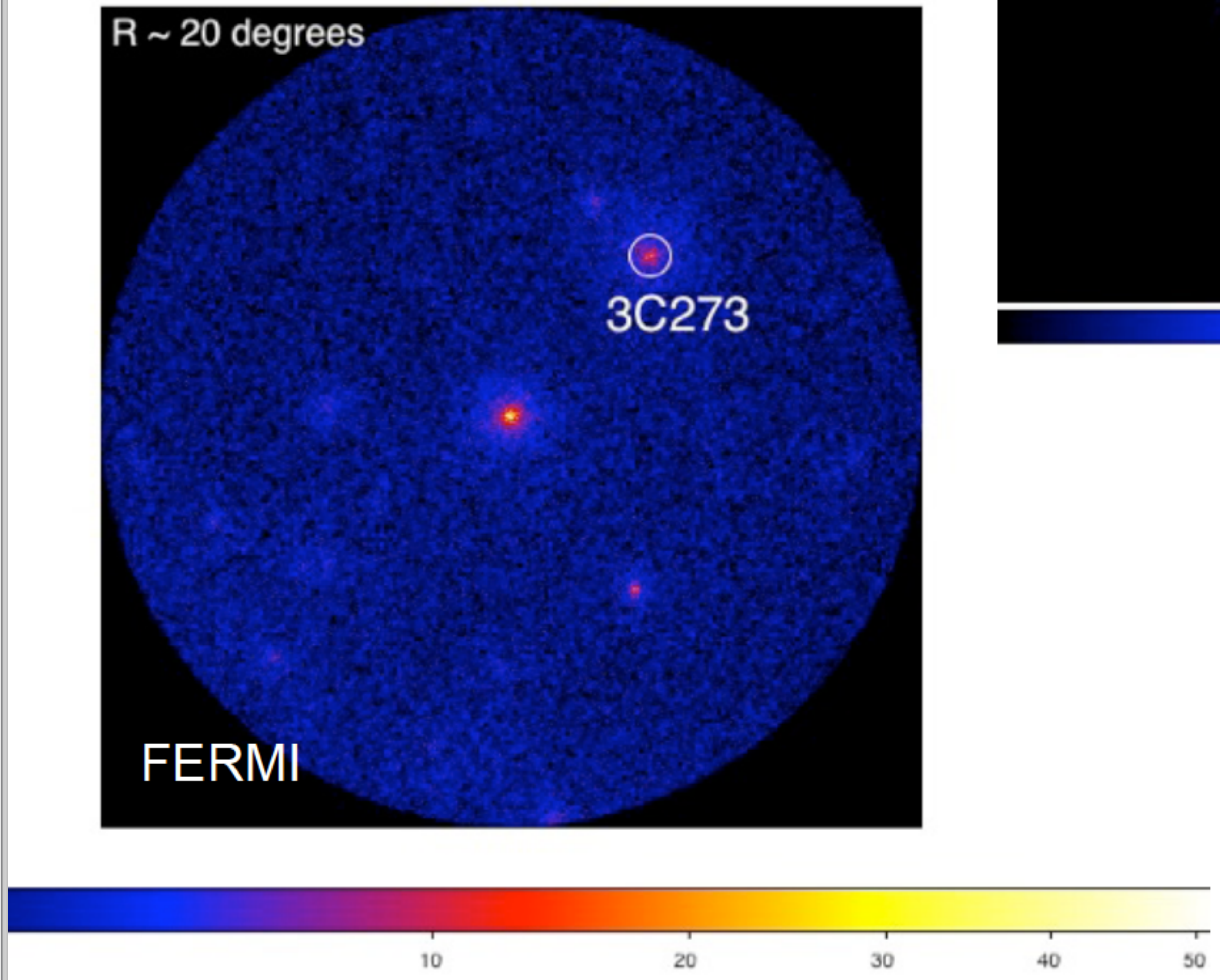
PRODUCTION OF AN IMAGE A LIGHT CURVE AND A SPECTRUM

Count map

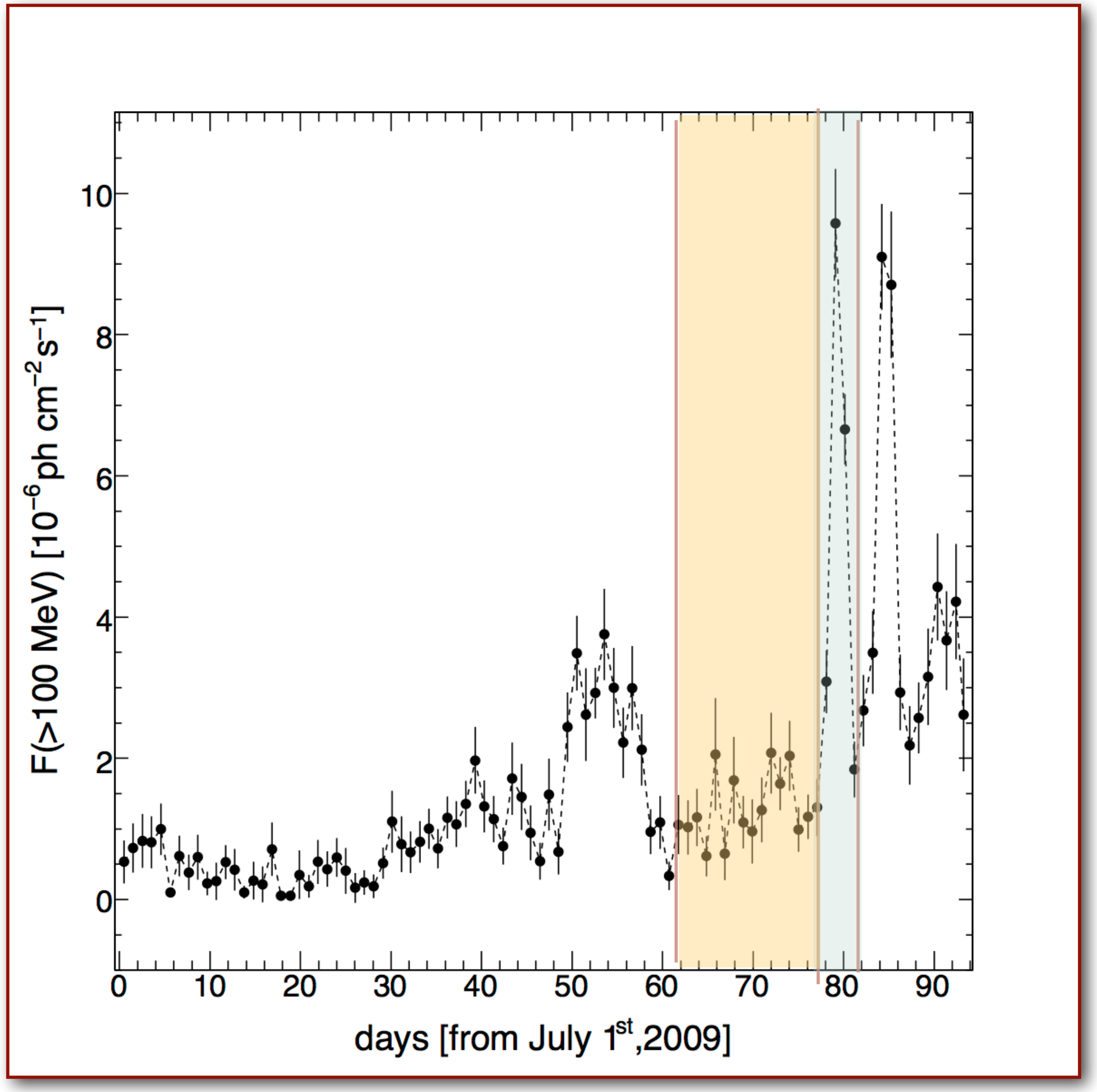


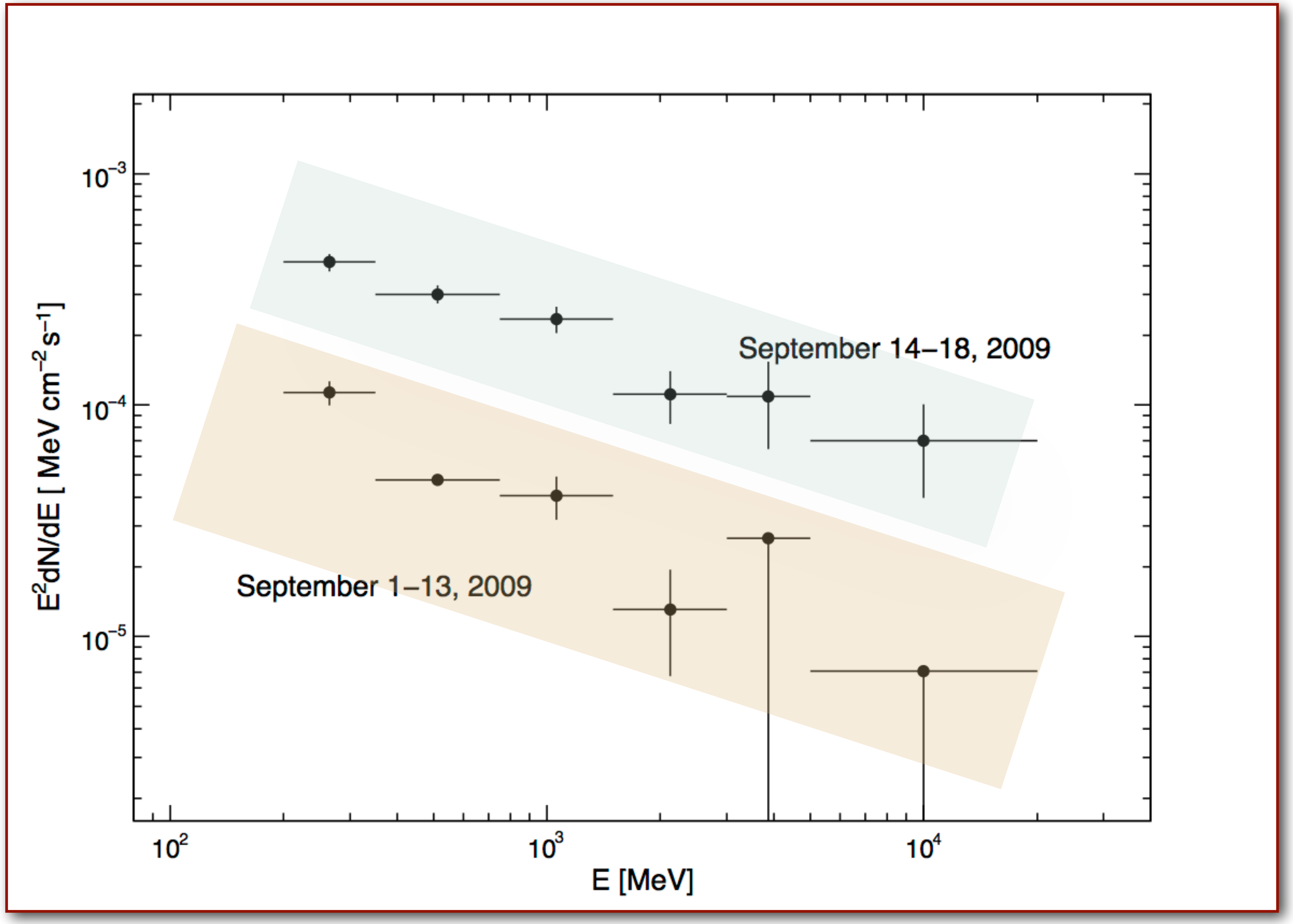


$$F(>100\ \mathrm{MeV}) = \int_{100}^{\infty} \mathrm{k}\ \left(\frac{E}{E_0}\right)^{-\Gamma} dE$$

Light Curve

Spectra





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DEFINITION OF A SOURCE MODEL TO BE FITTED - STATISTIC TEST

MAIN DIFFERENCES:

X-ray	Gamma-ray
Region (") of the source (generally circular) Background region (") near the source	Region of interest (ROI) of several degrees Unique file including all the sources in the ROI, the spectral model for each source and the background
Goodness of the model tested with chi^2 C statistic	Goodness of the source model with Likelihood analysis

BECAUSE OF

THE PAUCITY OF EVENTS,
THE LARGE ERRORS ASSOCIATED WITH DETECTING GAMMA-RAYS
A BRIGHT BACKGROUND

ANALYSIS AND INTERPRETATION OF DATA
REQUIRE COMPLEX
STATISTICAL TECHNIQUES

WE NEED A LIKELIHOOD ANALYSIS

THE LIKELIHOOD L IS THE PROBABILITY OF OBTAINING YOUR DATA GIVEN AN INPUT MODEL

THE INPUT MODEL IS THE DISTRIBUTION OF GAMMA-RAY SOURCES ON THE SKY + BACKGROUND

ONE WILL MAXIMIZE L TO GET THE BEST MATCH OF THE MODEL THE DATA

L IS THE PRODUCT OF THE PROBABILITIES (PK) OF OBSERVING THE DETECTED COUNTS IN EACH BIN (K).

$$\mathrm{L} = \Pi p_k$$

THE NUMBER OF COUNTS IN EACH BIN IS SMALL AND THUS IS CHARACTERIZED BY THE POISSON DISTRIBUTION

$$p_\lambda(n) = \frac{\lambda^n}{n!} e^{-\lambda}$$

λ DOVE È IL NUMERO MEDIO DI EVENTI PER INTERVALLO DI TEMPO, MENTRE N È IL NUMERO DI EVENTI PER INTERVALLO DI TEMPO

L IS THE PRODUCT OF THE PROBABILITIES OF OBSERVING N_K COUNTS IN EACH BIN (K) WHEN THE NUMBER OF COUNTS PREDICTED BY THE MODEL IS M_K

$$\mathrm{L} = \Pi_k \frac{m_k^{n_k} e^{-m_k}}{n_k!} = \Pi_k e^{-m_k} \Pi_k \frac{m_k^{n_k}}{n!} = e^{-N_{pred}} \Pi_k \frac{m_k^{n_k}}{n_k!}$$

natural logarithmic of L

$$\log \mathrm{L} = -N_{Pred} + \sum_K n_k log(m_k) - log(n!)$$

It does not depend on model . It can be neglected

HOW TO BUILD L (BINNED ANALYSIS)

I. SOURCE MODEL S

Power Law model

$$\frac{dN}{dE} = N_0\left(\frac{E}{E_0}\right)^{-\Gamma}$$

N_0 = Prefactor
Gamma = Index
E_0= Scale in MeV

N_0 in unit of
(pho cm^{-2} s^{-1} MeV^{-1})

model.xml

Sources in the ROI

```xml
?xml version="1.0" ?>
source_library title="source library">

!-- Point Sources -->

!-- Sources between [0.0,3.0) degrees of ROI center -->
source name="_2FGLJ1538.1+8159" type="PointSource">
   <spectrum type="PowerLaw">
   <!-- Source is 1.9071384485 degrees away from ROI center -->
      <parameter free="1" max="1e4" min="1e-4" name="Prefactor" scale="1e-14" value="1.3256925363"/>
      <parameter free="0" max="5.0" min="0.0" name="Index" scale="-1.0" value="1.47526"/>
      <parameter free="0" max="5e5" min="30" name="Scale" scale="1.0" value="6677.005859"/>
   </spectrum>
   <spatialModel type="SkyDirFunction">
      <parameter free="0" max="360.0" min="-360.0" name="RA" scale="1.0" value="234.53"/>
      <parameter free="0" max="90" min="-90" name="DEC" scale="1.0" value="81.9877"/>
   </spatialModel>
/source>
source name="_2FGLJ1558.3+8513" type="PointSource">
   <spectrum type="PowerLaw">
   <!-- Source is 2.82555462151 degrees away from ROI center -->
      <parameter free="1" max="1e4" min="1e-4" name="Prefactor" scale="1e-12" value="3.40020329601"/>
      <parameter free="0" max="5.0" min="0.0" name="Index" scale="-1.0" value="2.5236"/>
      <parameter free="0" max="5e5" min="30" name="Scale" scale="1.0" value="609.878479"/>
   </spectrum>
   <spatialModel type="SkyDirFunction">
      <parameter free="0" max="360.0" min="-360.0" name="RA" scale="1.0" value="239.577"/>
      <parameter free="0" max="90" min="-90" name="DEC" scale="1.0" value="85.2198"/>
   </spatialModel>
/source>
source name="_2FGLJ1629.4+8236" type="PointSource">
   <spectrum type="PowerLaw">
   <!-- Source is 0.125980403133 degrees away from ROI center -->
      <parameter free="1" max="1e4" min="1e-4" name="Prefactor" scale="1e-12" value="1.69275260042"/>
      <parameter free="1" max="5.0" min="0.0" name="Index" scale="-1.0" value="2.20077"/>
      <parameter free="0" max="5e5" min="30" name="Scale" scale="1.0" value="911.088135"/>
   </spectrum>
   <spatialModel type="SkyDirFunction">
      <parameter free="0" max="360.0" min="-360.0" name="RA" scale="1.0" value="247.355"/>
      <parameter free="0" max="90" min="-90" name="DEC" scale="1.0" value="82.6137"/>
   </spatialModel>
/source>
```

Background

```xml
<!-- Diffuse Sources -->
<source name="gal_2yearp7v6_v0" type="DiffuseSource">
   <spectrum type="PowerLaw">
      <parameter free="1" max="10" min="0" name="Prefactor" scale="1" value="1"/>
      <parameter free="0" max="1" min="-1" name="Index" scale="1.0" value="0"/>
      <parameter free="0" max="2e2" min="5e1" name="Scale" scale="1.0" value="1e2"/>
   </spectrum>
   <spatialModel file="/RossiFumi/prod/GLAST_EXT/redhat5-x86_64-64bit-gcc41/diffuseModels/v2r0/
ring_2year_P76_v0.fits" type="MapCubeFunction">
      <parameter free="0" max="1e3" min="1e-3" name="Normalization" scale="1.0" value="1.0"/>
   </spatialModel>
</source>
<source name="iso_p7v6source" type="DiffuseSource">
   <spectrum file="/RossiFumi/prod/GLAST_EXT/redhat5-x86_64-64bit-gcc41/diffuseModels/v2r0/
isotrop_2year_P76_source_v0.txt" type="FileFunction">
      <parameter free="1" max="10" min="1e-2" name="Normalization" scale="1" value="1"/>
   </spectrum>
   <spatialModel type="ConstantValue">
      <parameter free="0" max="10.0" min="0.0" name="Value" scale="1.0" value="1.0"/>
   </spatialModel>
</source>
</source_library>
```

II. S IS FOLDED WITH THE INSTRUMENT RESPONSE FUNCTIONS (IRFS) TO OBTAIN THE PREDICTED NUMBER OF COUNTS

$$M(E', \phi') = \int_{SR} dE d\phi R(E, \phi; E', \phi') S(E, \phi)$$

SR source region
R IRF
S source model

III. THE PREDICTED NUMBER OF COUNTS IS ESTIMATED

$$N_{Pred} = \int_{SR} dE' d\phi' M(E', \phi')$$

VI. EXPECTED PHOTONS IN BIN K

$$m_k = \int_{bin_k} M(E'\phi') dE' d\phi'$$

$$\log \mathrm{L} = -N_{Pred} + \sum_K n_k log(m_k)$$

Example (1)

Detector = n_k

2	1	3
1	20	0
2	1	0

Model * IRF = m_k

1	1	1
1	22	1
1	1	1

$\ln(m_k)$

0	0	0
0	~3	0
0	0	0

$\ln\mathcal{L} = \Sigma_k n_k \ln(m_k) - \Sigma_k m_k$

$\Sigma_k m_k = 30$

$\Sigma_k n_k \ln(m_k) \approx 60$

$\ln\mathcal{L} \approx 30.89$ ← Maximize this!

$\mathcal{L}_{max,1} \approx e^{30.89} \approx 2\mathrm{x}10^{13}$

TAKING DECISIONS

THE LIKELIHOOD RATIO ALLOWS TO COMPARE TWO MODELS

WILK'S THEOREM

If the model $M(x_0)$ is correct and the maximum likelihood value obtained by allowing the k parameters of x to vary is $L(x_M)$ then the statistic

$$TS=2[\log L(M(x_M)) - \log L(M(x_0))$$

is asymptotically distributed like χ^2 with k degree of freedoms

$$\sigma \sim \sqrt{TS}$$

TO ATTEST THE SIGNIFICATIVE OF A SOURCE IN A GAMMA-RAY ANALYSIS

LM(X0) LIKELIHOOD CONSIDERING THE ROI WITHOUT THE SOURCE
LM(XM) LIKELIHOOD CONSIDERING THE SOURCE IN THE ROI.

$$TS = -2[\mathrm{LOG}\ L(M(X_O)) - \mathrm{LOG}\ L(M(X_M))$$

IF THE MODEL OF THE TESTED SOURCE IS A POWER LAW

$$F(E) = kE^{-\Gamma}$$

THE ADDITIONAL PARAMETER ARE 2 : $k, E^{-\Gamma}$

THE TS BEHAVIOURS AS A WITH 2 DEGREE OF FREEDOMS

$$\sigma \sim \sqrt{TS}$$

DONEC QUIS NUNC