Gamma ray emissions from galaxy clusters

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Introductions

- Rising senior from Adlai E. Stevenson HS in Lincolnshire, IL
- Physics, math
- Never knew programming

- Jargon-free presentation
- Confusion? Let me know.

What is dark matter?

- Wikipedia – "matter hypothesized to account for a large part of the total mass in the universe"
- Difficult to detect: no direct EM emissions
- 23% of entire universe
- Outnumbers regular matter by nearly 5 to 1
- Several theories: WIMPs, MACHOs, etc.
  - WIMPs ~ neutrinos but more massive
  - MACHOs ~ normal matter: planets, black holes
- Distinct from dark energy (another topic wholly)

Why does it matter?

- Discrepancy in *orbital velocities* of stars and entire galaxies

$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$

$$v \propto \sqrt{\frac{M}{r}}$$

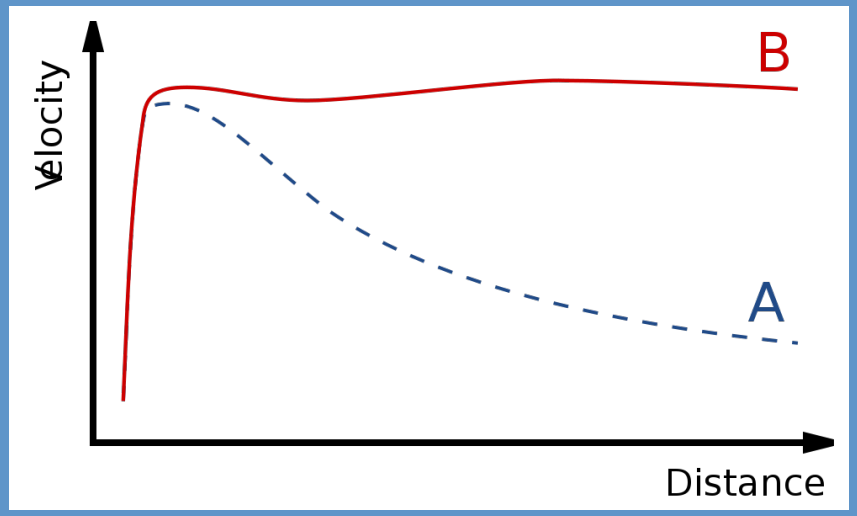
$$M \propto r$$

$$M = \sigma \pi r^2$$

$$dM = \rho(r) 2\pi r dr$$

$$\rho(r) \propto 1$$

$$\rho(r) \propto \frac{1}{r}$$

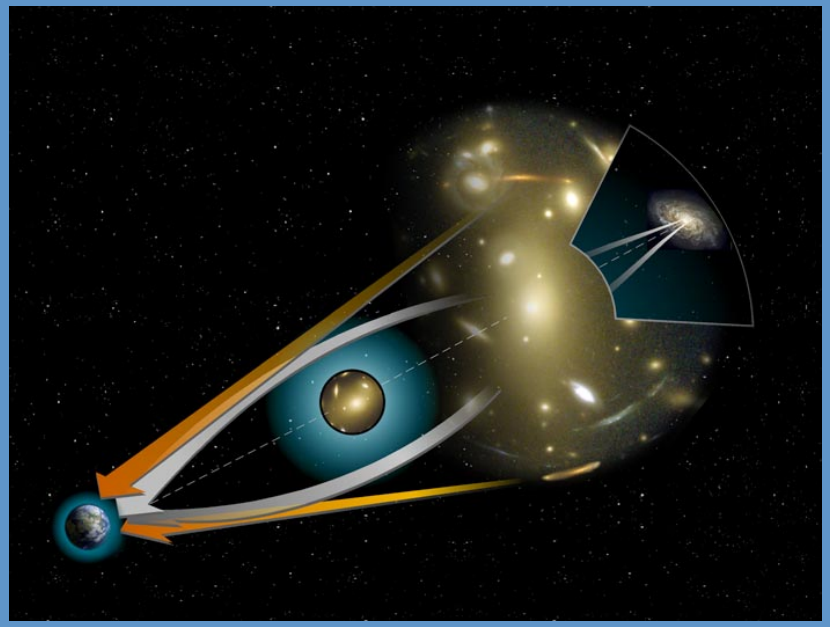


$$\rho(r) \propto \exp\left(-Ar^{\alpha}\right).$$

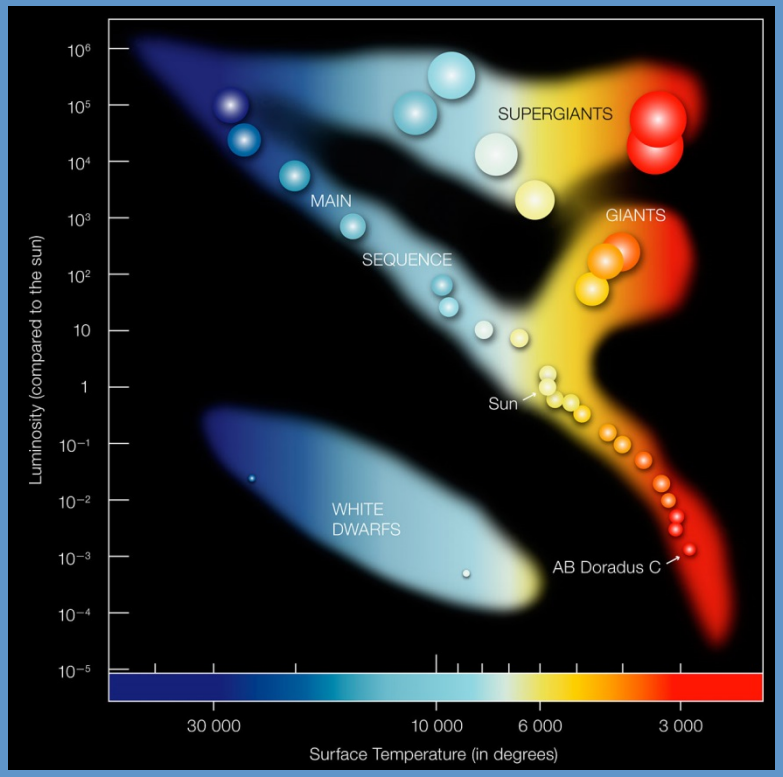
$$\rho(r) = \frac{\rho_0}{\frac{r}{R_s}\left(1+\frac{r}{R_s}\right)^2}$$

Why does it matter?

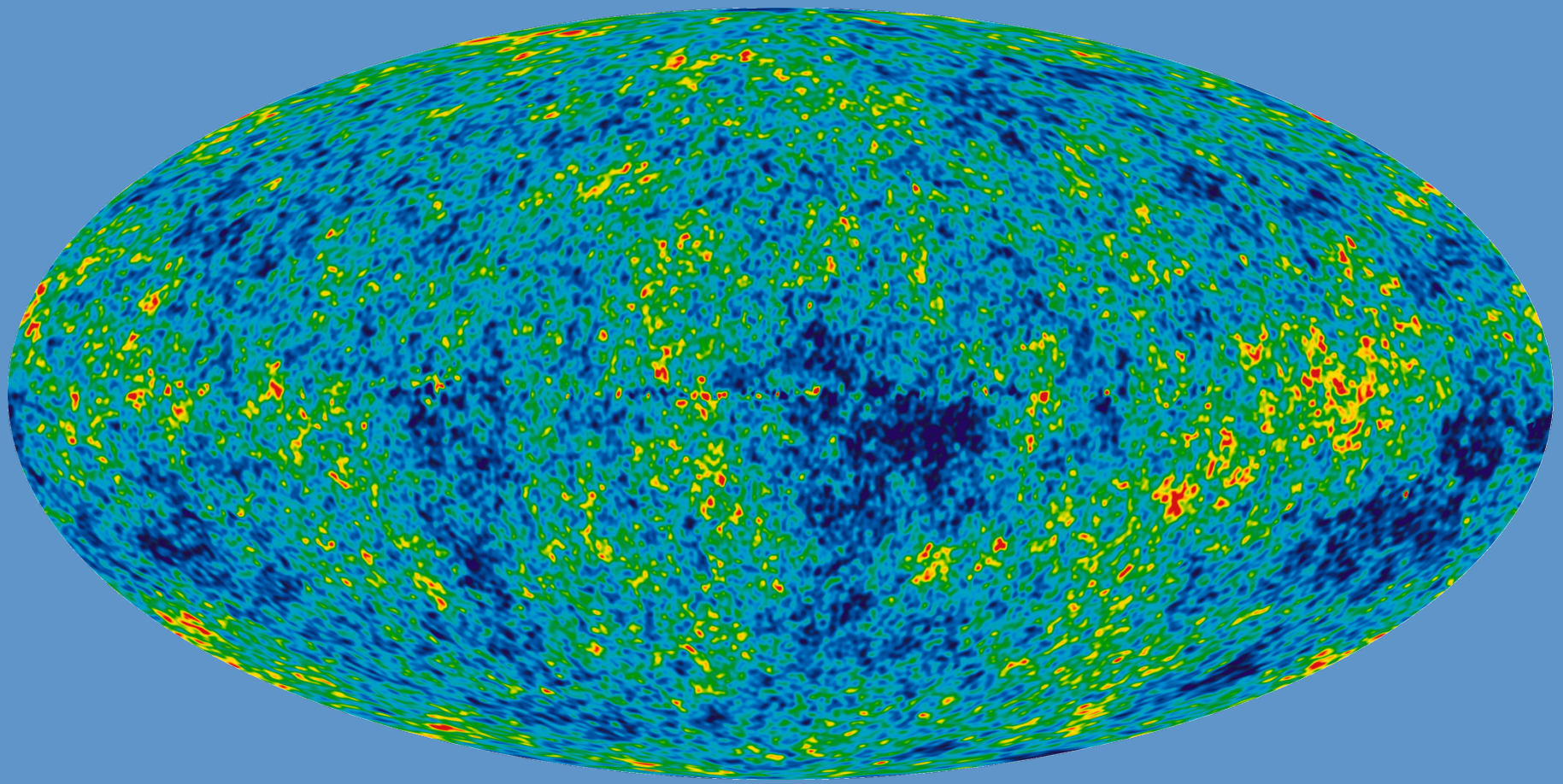
- Gravitational lensing measurements



- Mass-to-light ratios (1-30 typical)



Serendipitous discovery of CMB



Arno Penzias + Robert Wilson - 1964

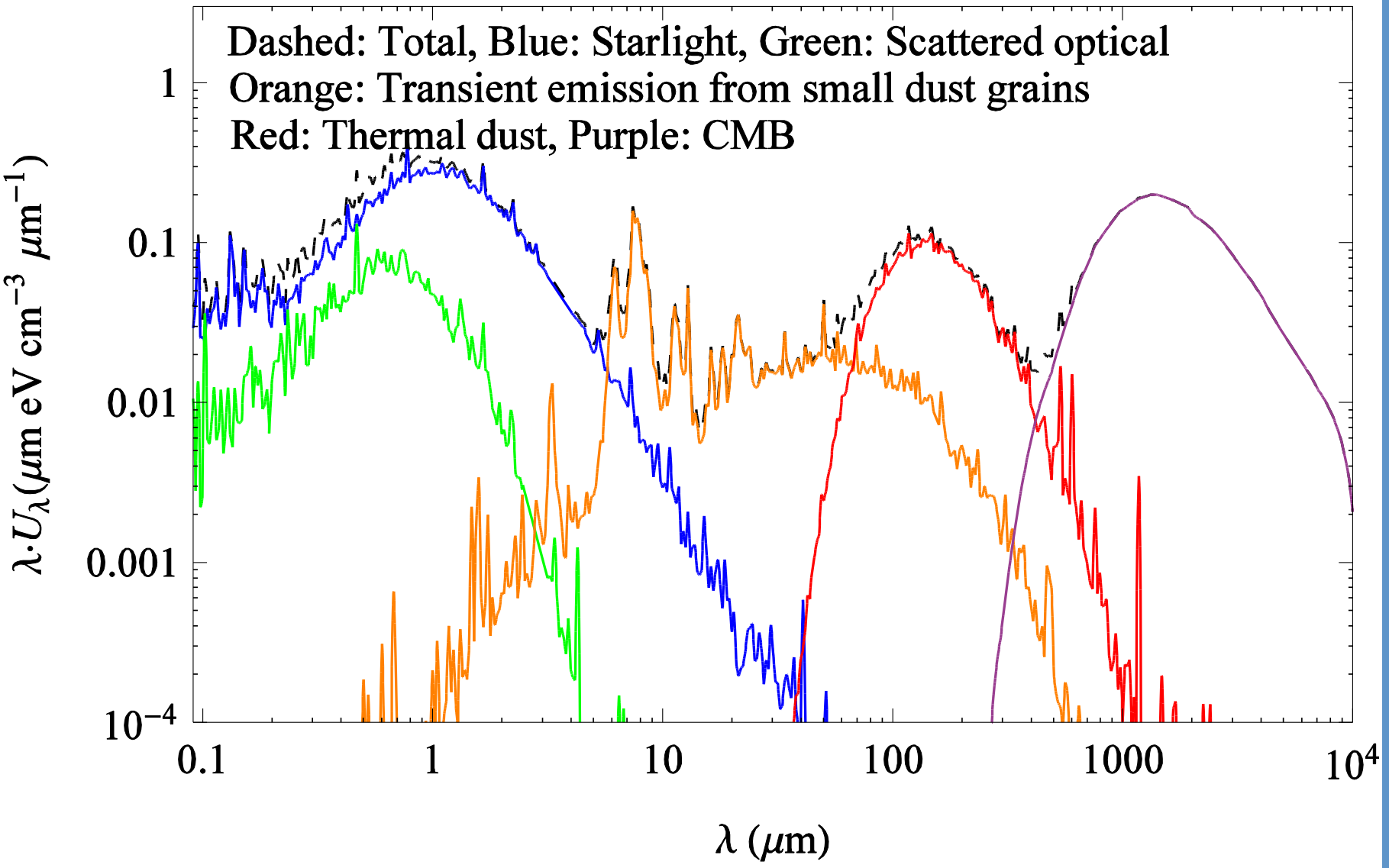
The Goal

- Learn a lot
- Analyze and plot observations of high-energy gamma rays from galaxy clusters
- Possibly compare data to known models for possible dark matter emissions
- Have fun!

1st week – practice

- Learned Python, matplotlib
- Analyzed energy densities of emissions in galactic neighborhood

1st week – practice



2nd week – more practice

- Moved on to Ursa Minor – a "dSph"
- Dwarf spheroidals = very dim satellite galaxies
- Less cluttered, great dark matter candidates
- Formulating process for Virgo Cluster analysis

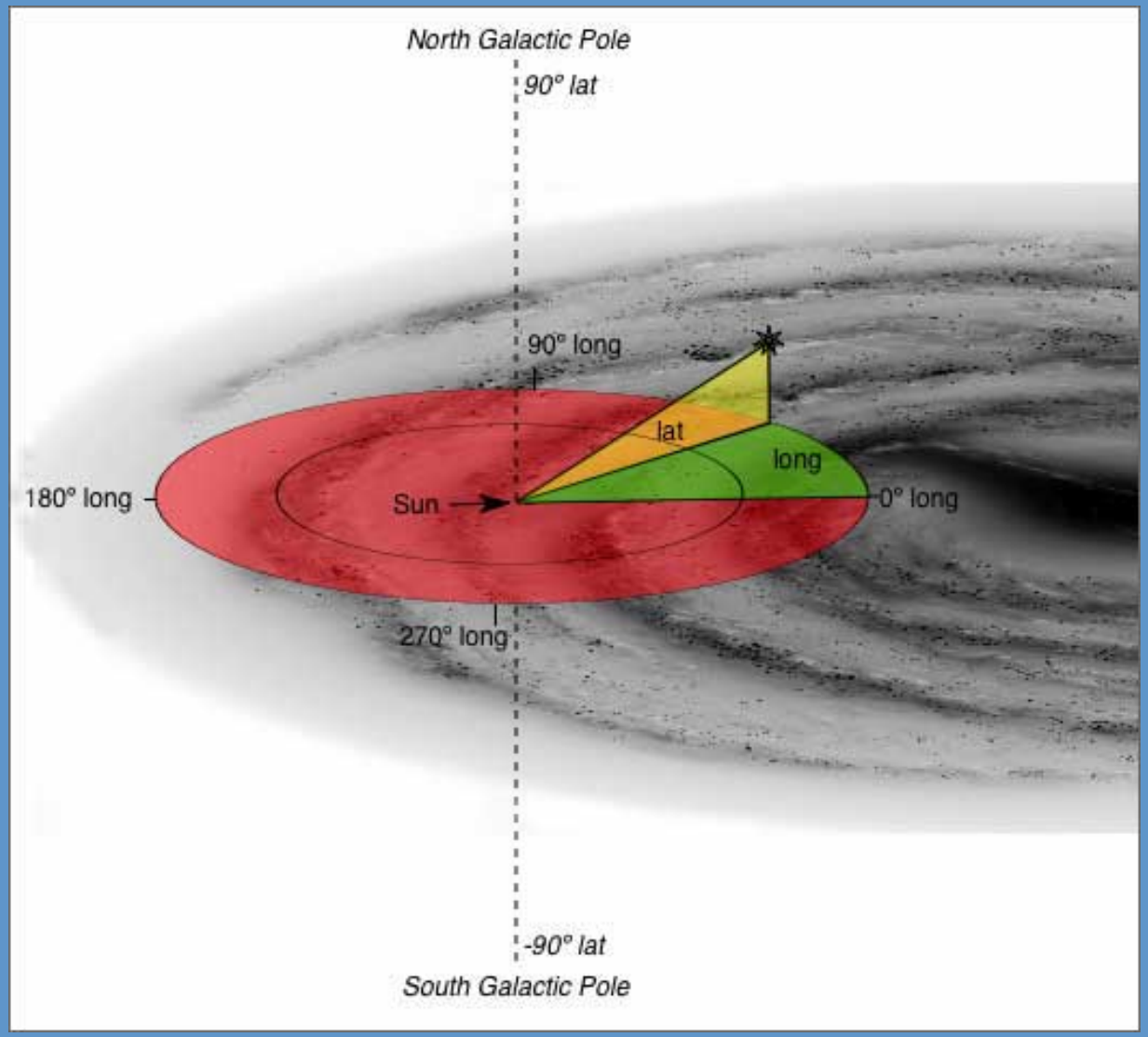
3rd – 4th week – Virgo Cluster

- Galaxy cluster, ~ long = 280, lat = 75
- 2000 galaxies, 54 Mly (still nearest)
- Spans 8 degrees arc
- Large mass indicated by high velocities
- M2L ratio > 450
- Milky Way M2L ratio = 63.8
- Sun's M2L ratio = 1.0

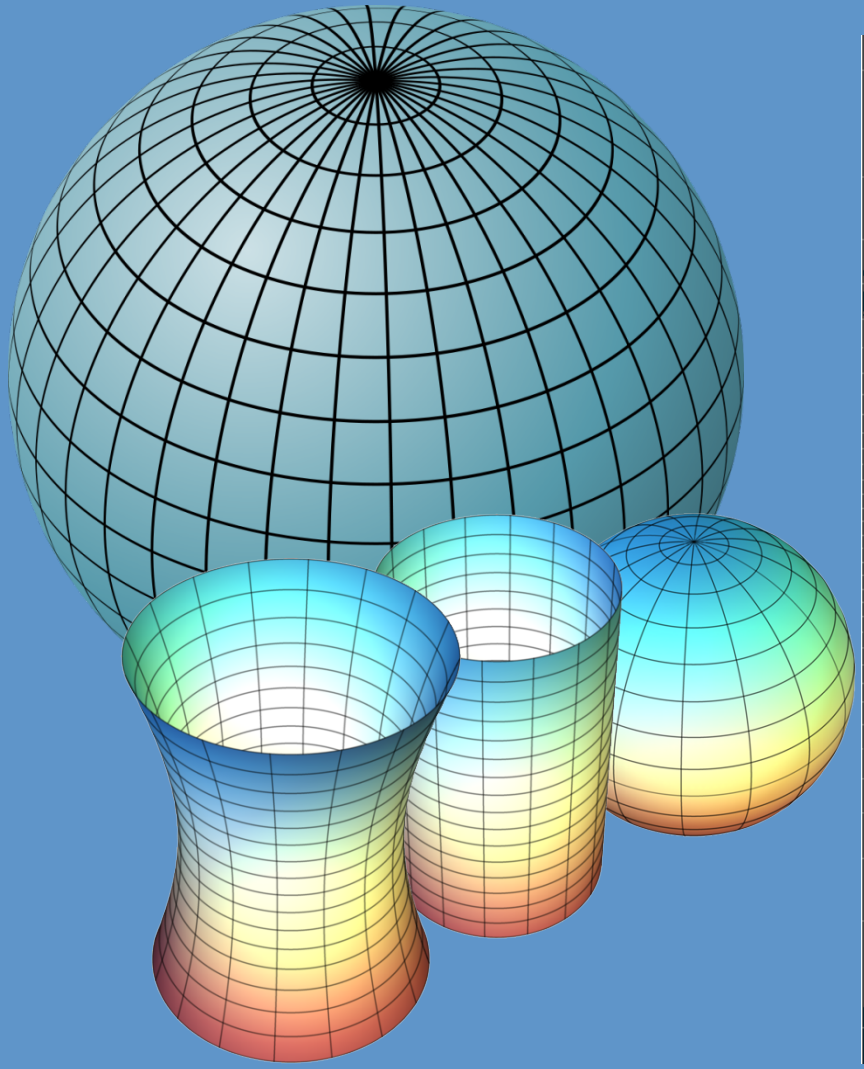
Virgo Cluster analysis

- Visualizing photons: infinitesimal cross-section problem
- Probability density functions – 2D Gaussian function
- Different images at different energies
- Eventually compare to theoretical models for possible dark matter

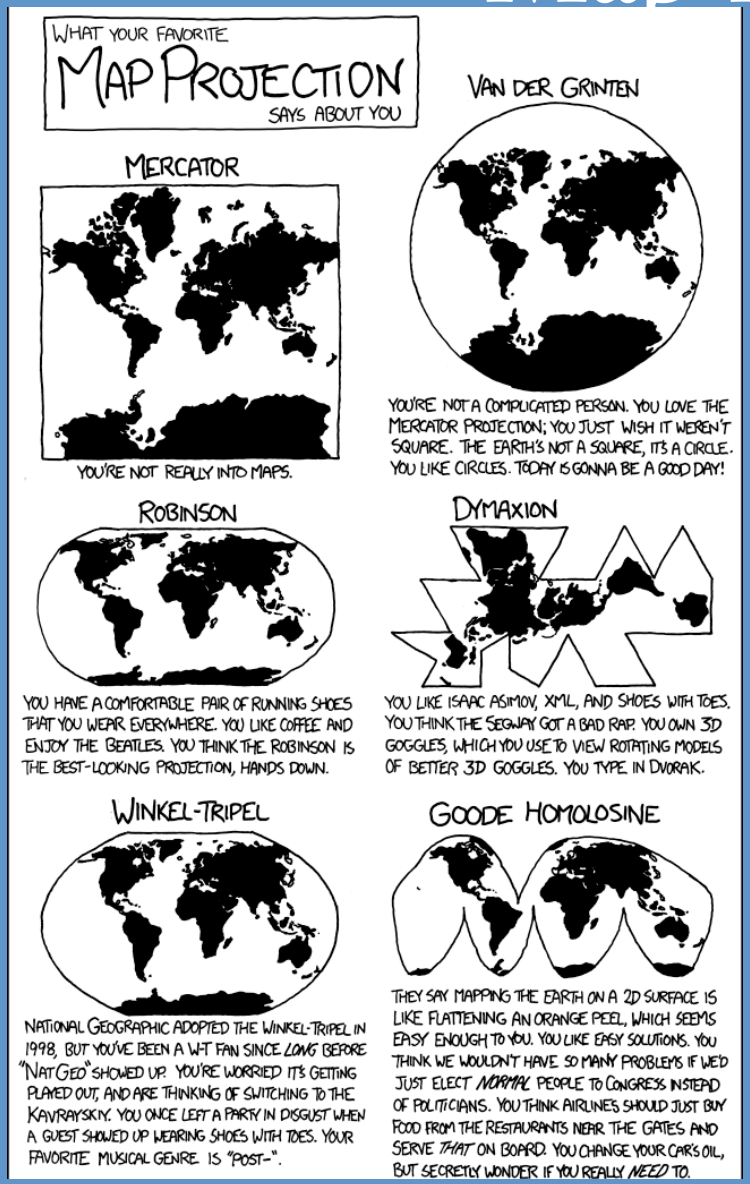
Galactic coordinates

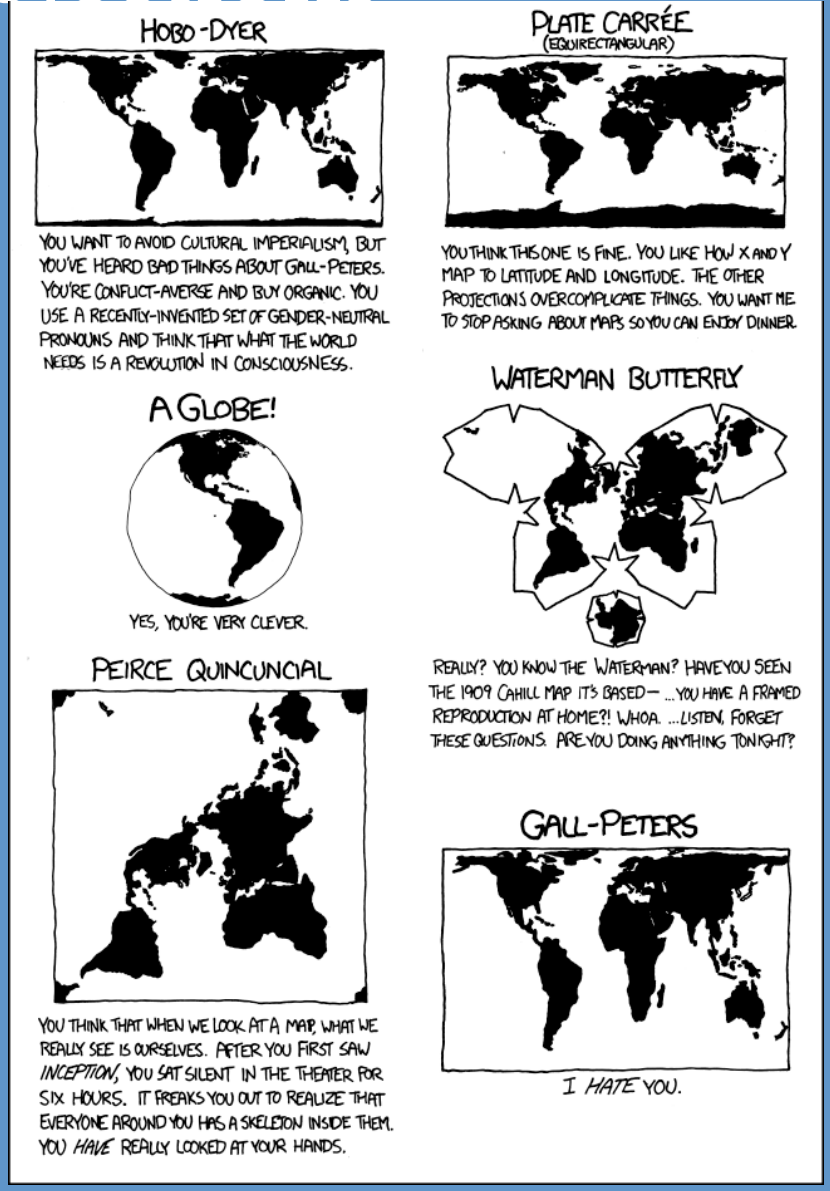


Gauss's Theorema Egregium



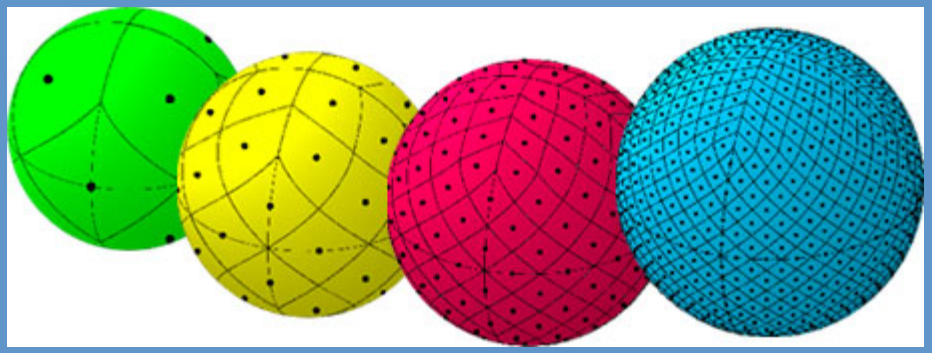
Map Projections

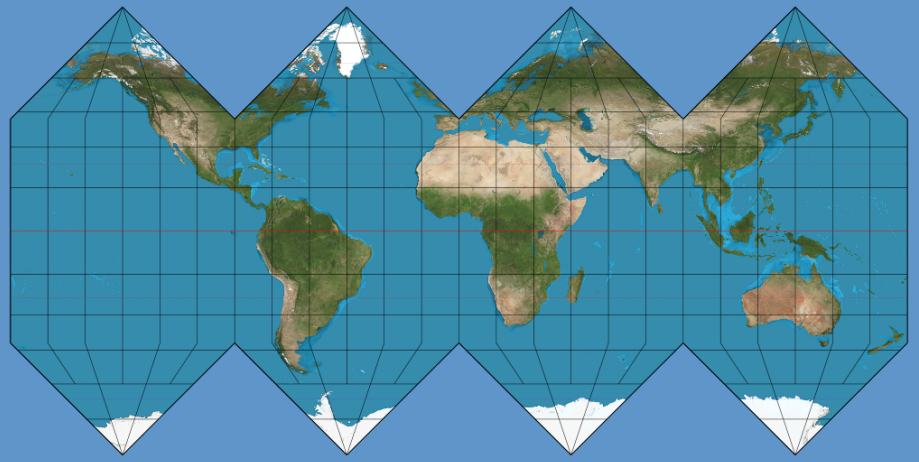


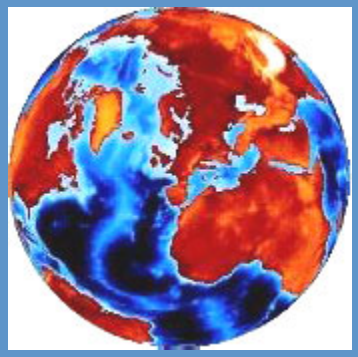


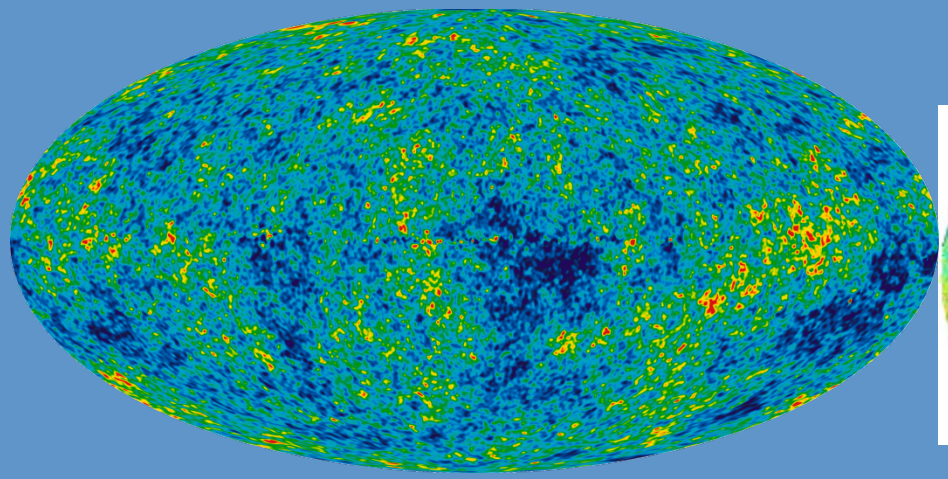
HEALpix

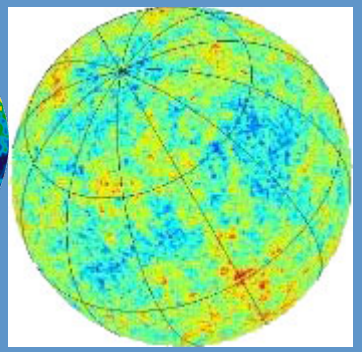
Hierarchical Equal Area isoLatitude
Pixelisation of a 2-sphere



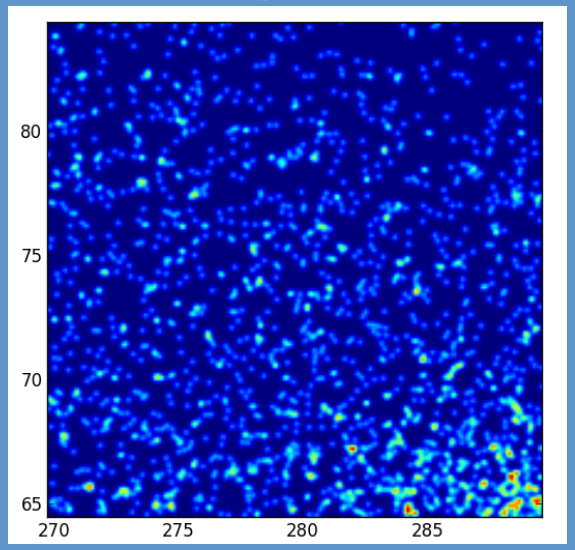




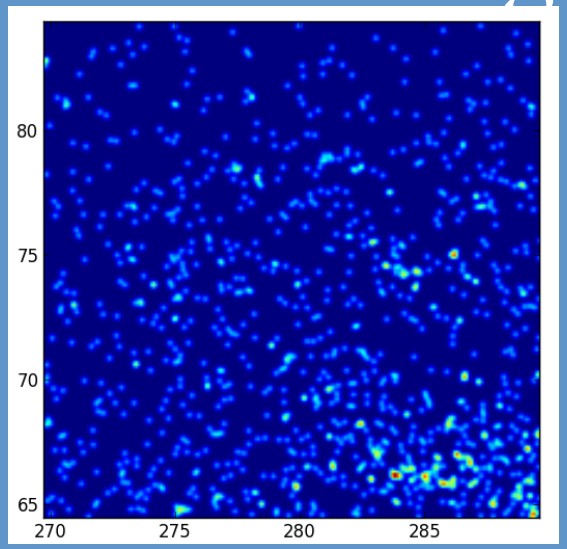




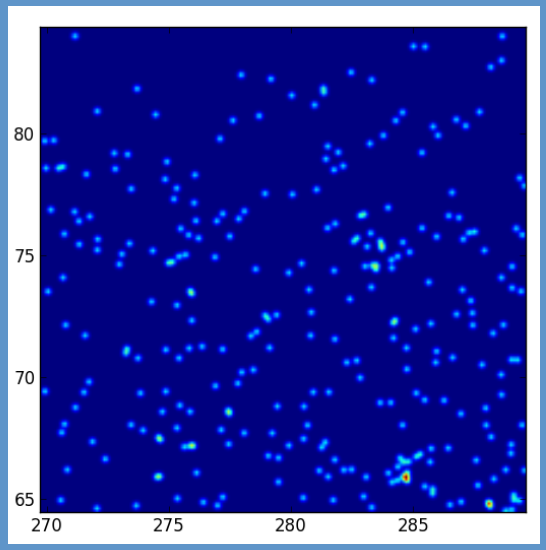
3rd – 4th week – Virgo Cluster



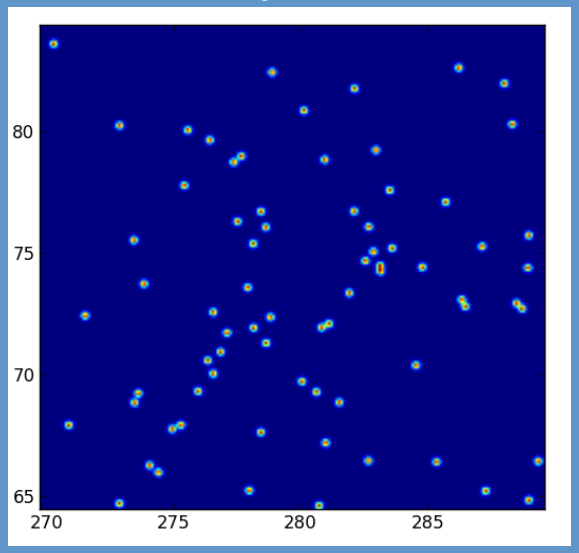
100 – 316 MeV



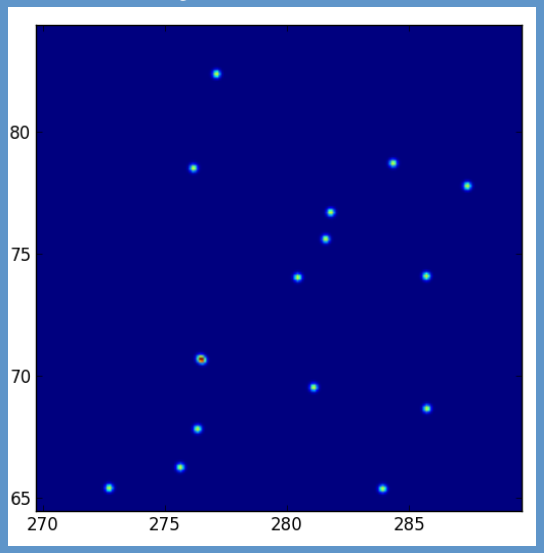
316 – 1000 MeV



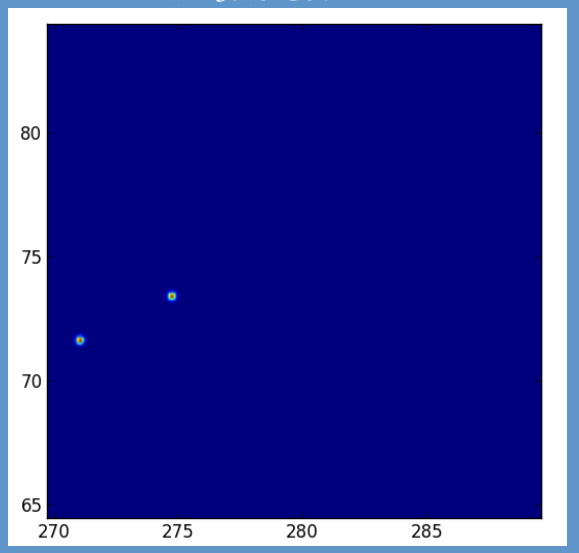
1 – 3.16 GeV



3.16 – 10 GeV



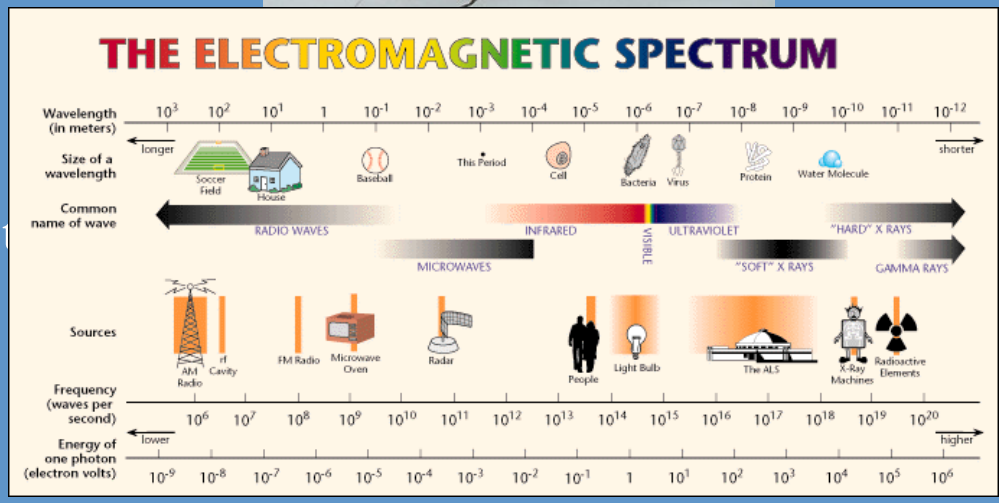
10 – 31.6 GeV



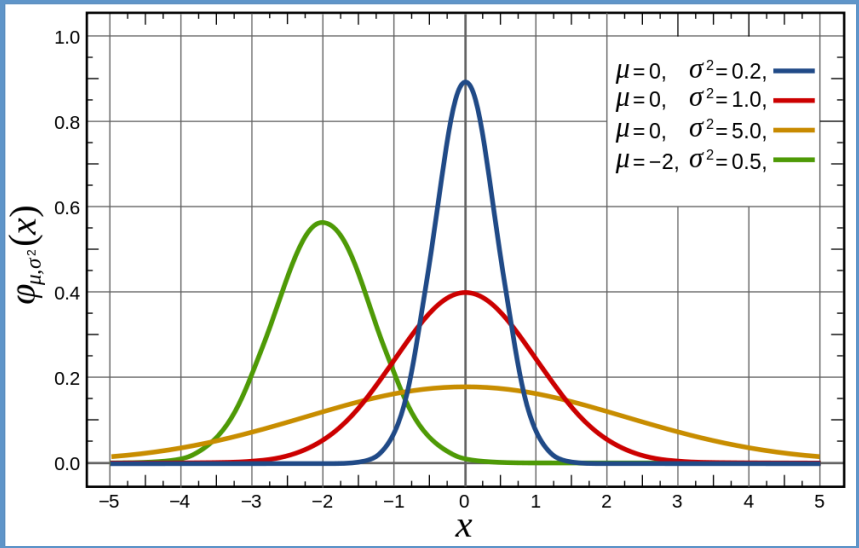
31.6 – 100 GeV

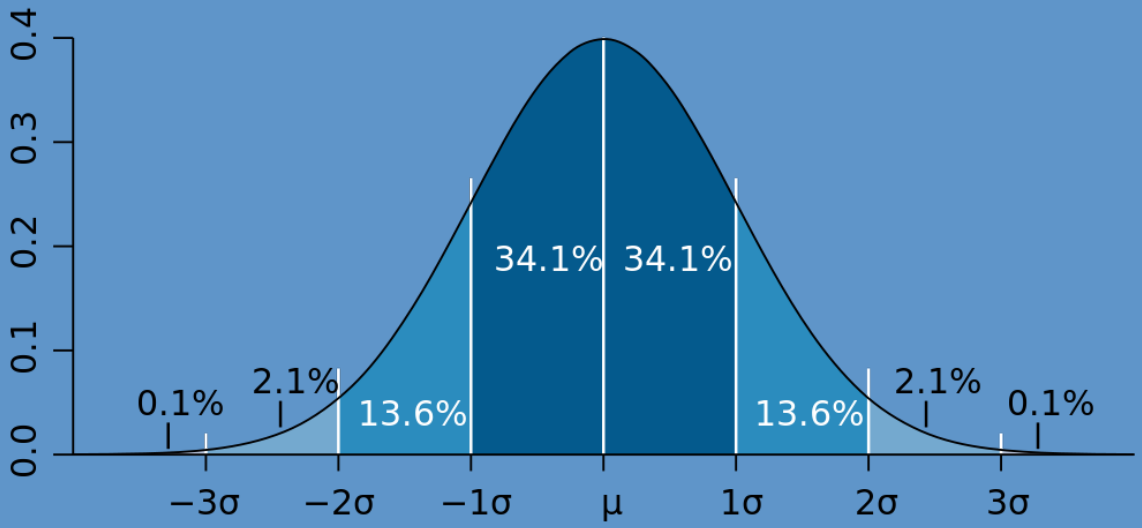
Fermi-LAT detector

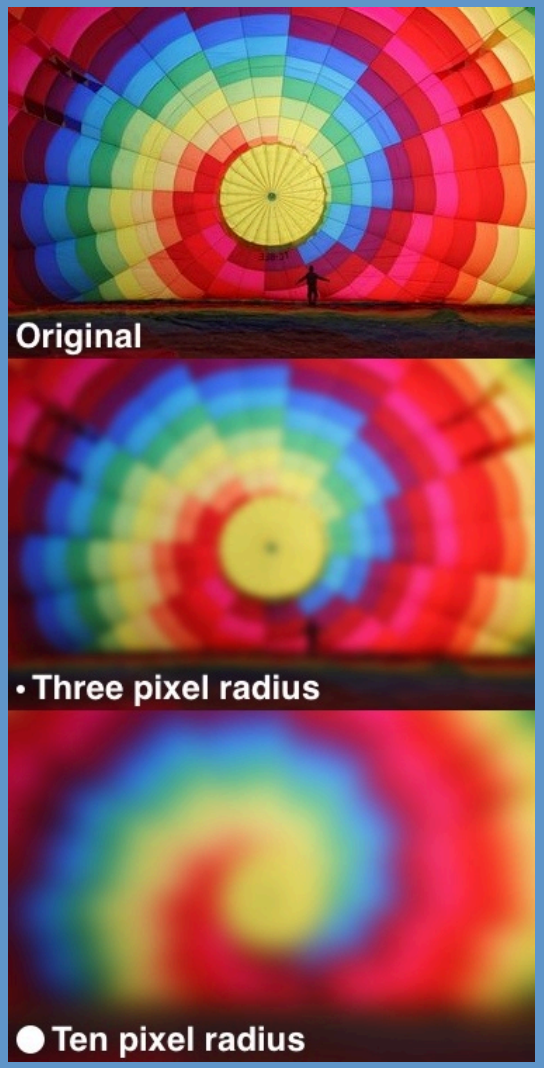
- != Fermilab
- Gamma-ray detector
- Photons range from 30 MeV – 300 GeV
- 10,000 – 100 million times more energetic than visible light
- ~10^20 – 10^26 Hz
- Pair production: $\gamma + \gamma = e^+ + e^-$
- Many layers of metal (tungsten) + calorimeter
- Exposure time of months, almost years



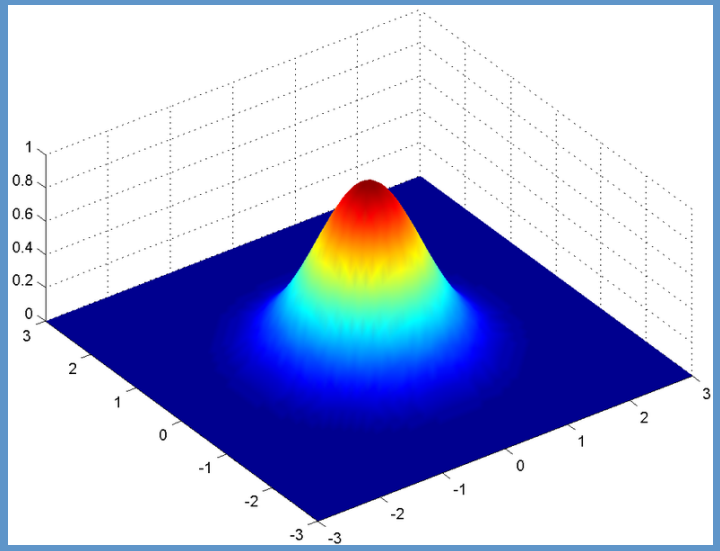
Gaussian functions

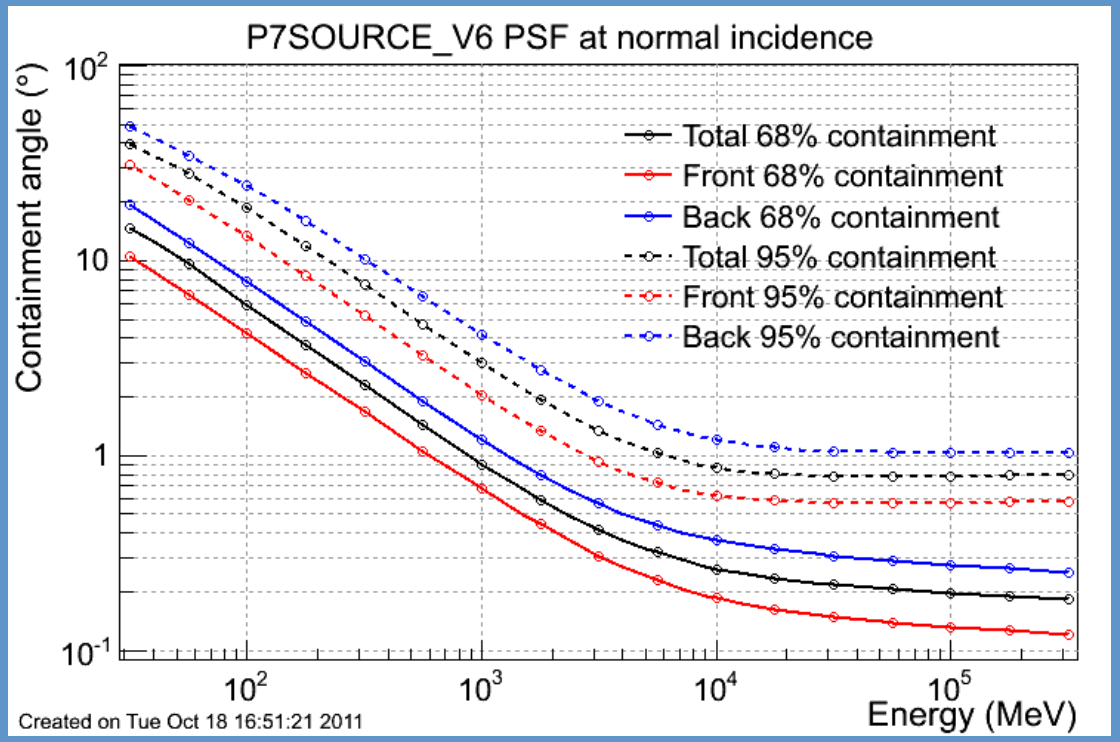






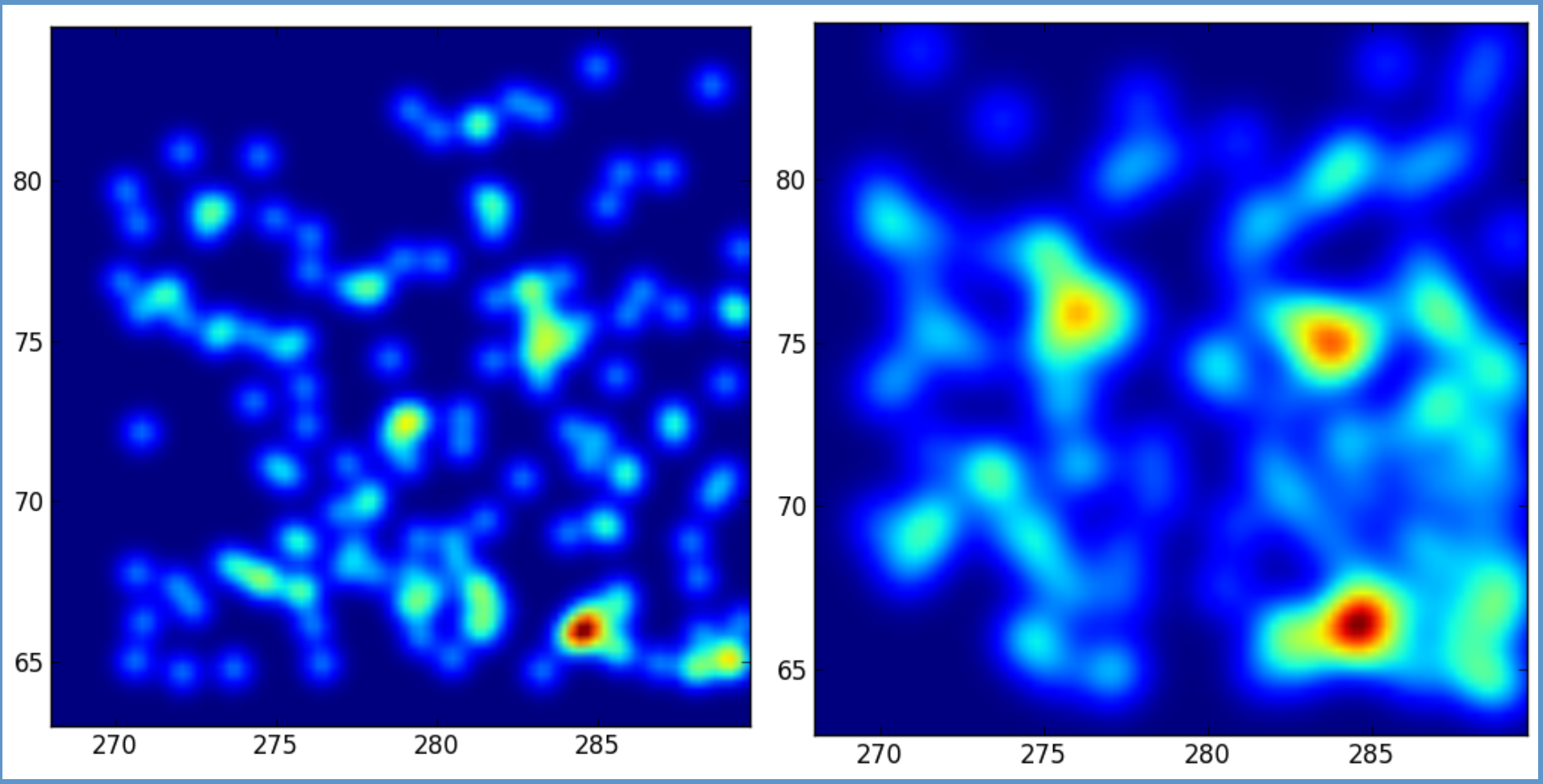
Gaussian functions



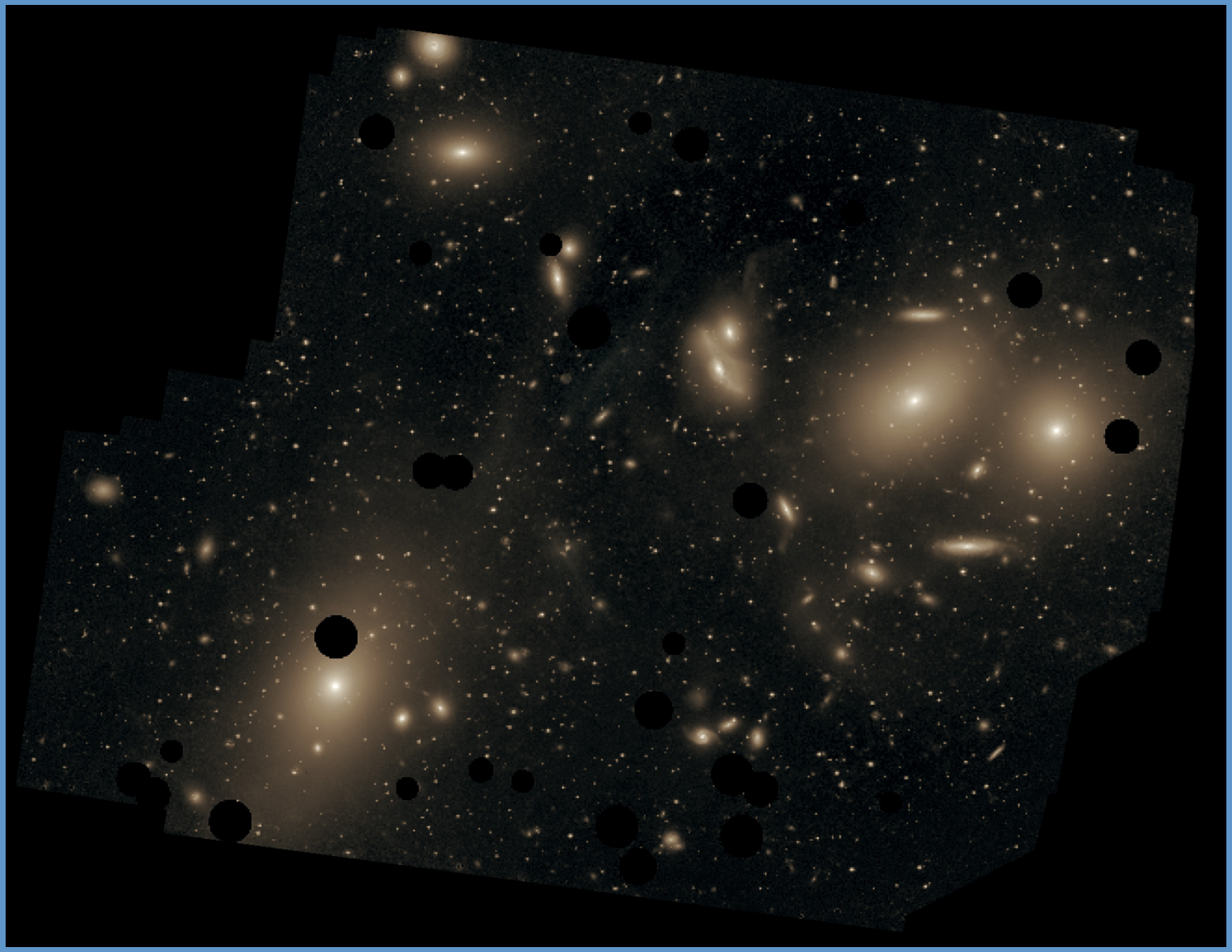


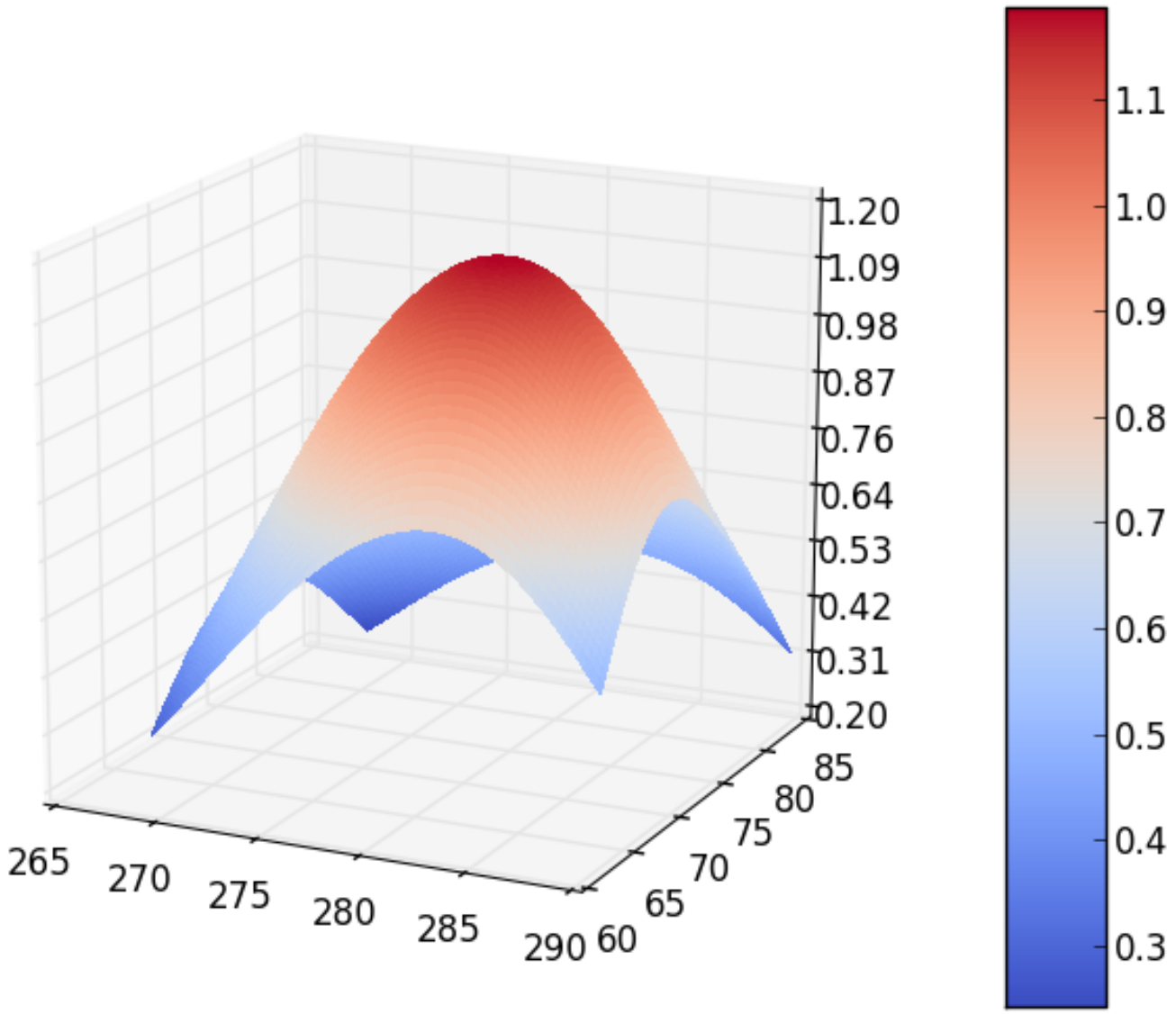
$$f(x,y) = A exp\left(-\left(\frac{(x-x_0)^2}{2\sigma_x^2} + \frac{(y-y_0)^2}{2\sigma_y^2} \right) \right)$$

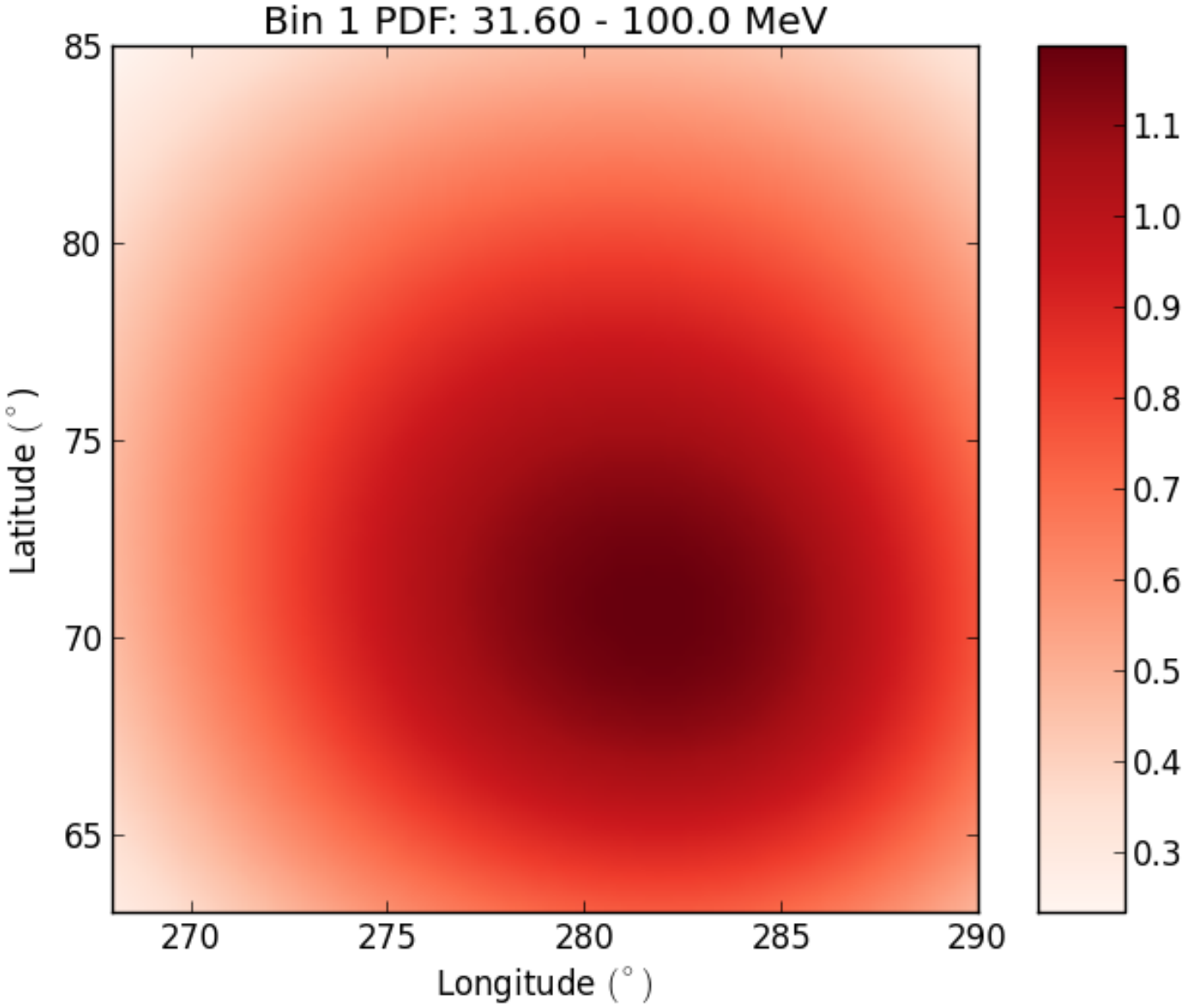
Front – back smearing

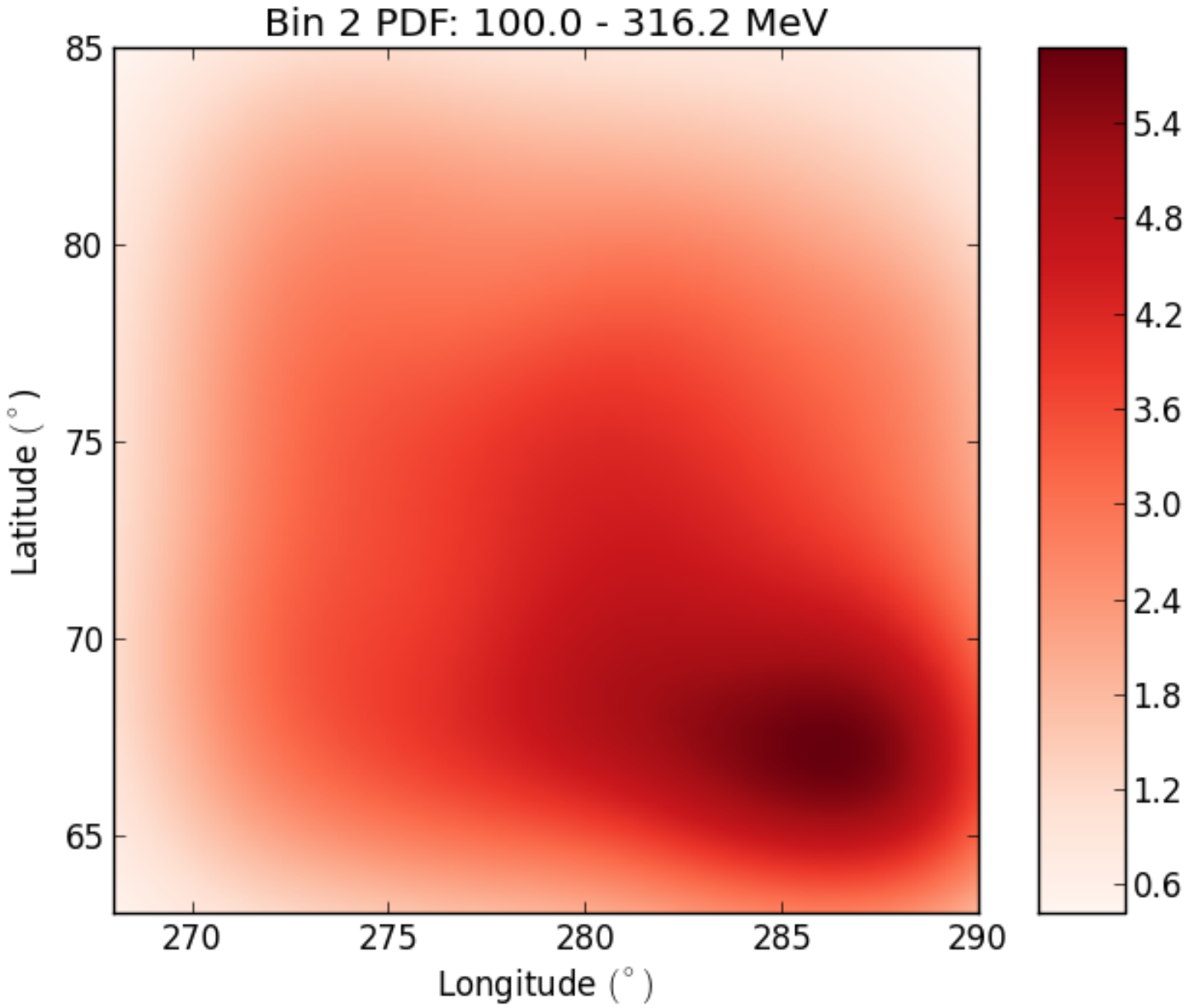


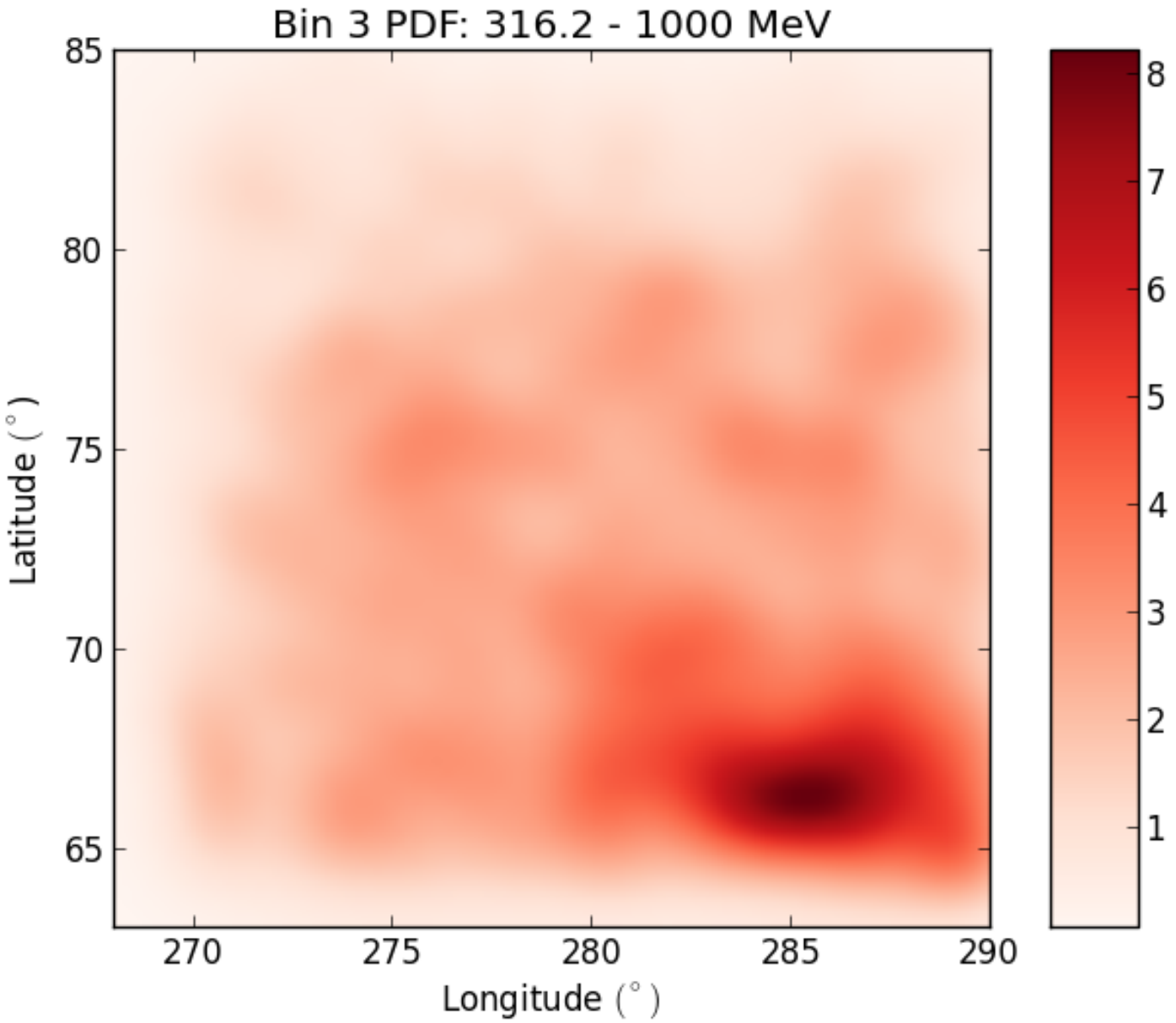
1 – 3.16 GeV




1.20
1.09
0.98
0.87
0.76
0.64
0.53
0.42
0.31
0.20
265
270
275
280
285
290
60
65
70
75
80
85
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3


Bin 1 PDF: 31.60 - 100.0 MeV
85
80
75
70
65
Latitude (°)
270
275
280
285
290
Longitude (°)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3


Bin 2 PDF: 100.0 - 316.2 MeV
85
80
75
70
65
Latitude (°)
270
275
280
285
290
Longitude (°)
5.4
4.8
4.2
3.6
3.0
2.4
1.8
1.2
0.6


Bin 3 PDF: 316.2 - 1000 MeV
85
80
75
70
65
Latitude (°)
270
275
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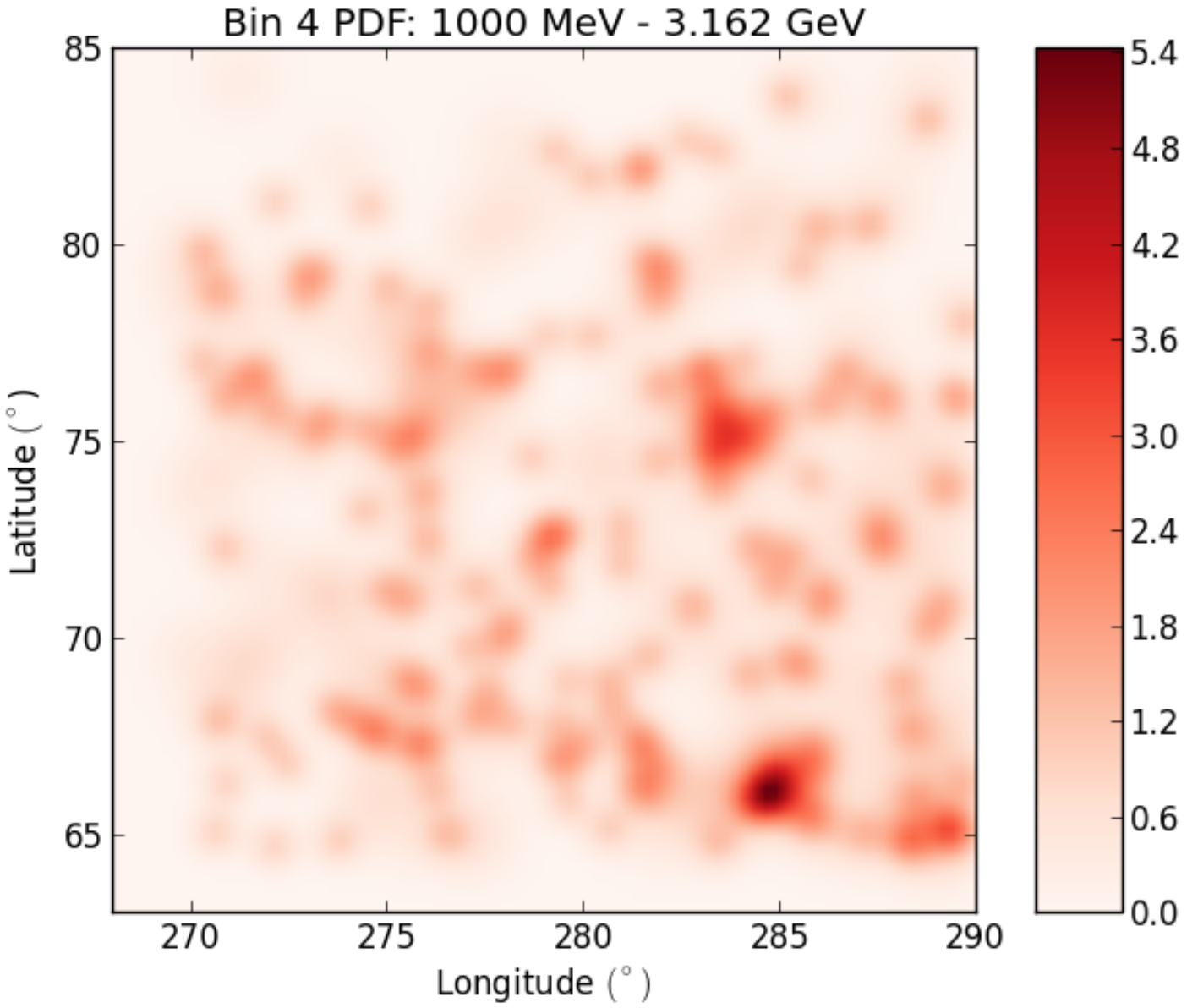
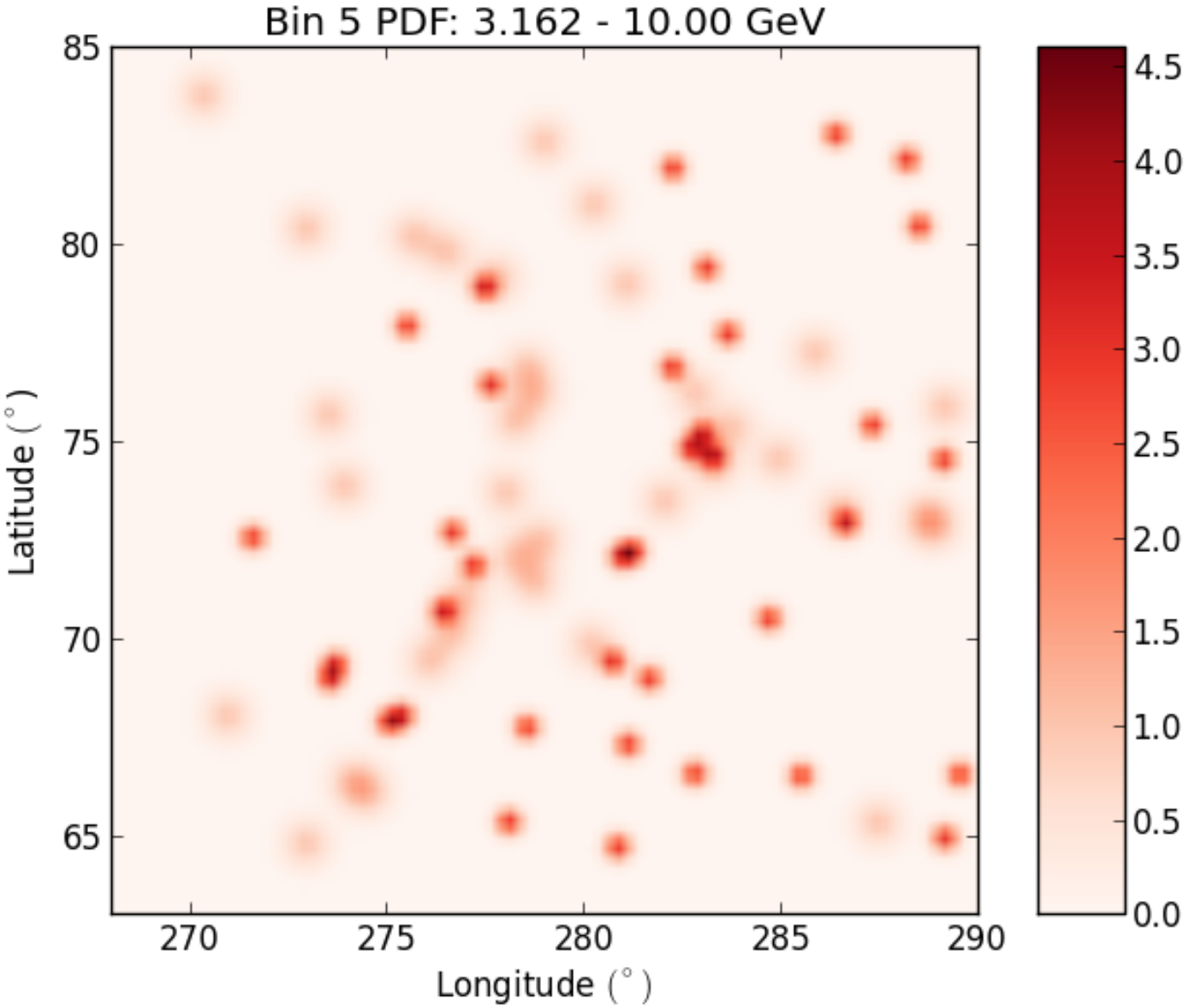
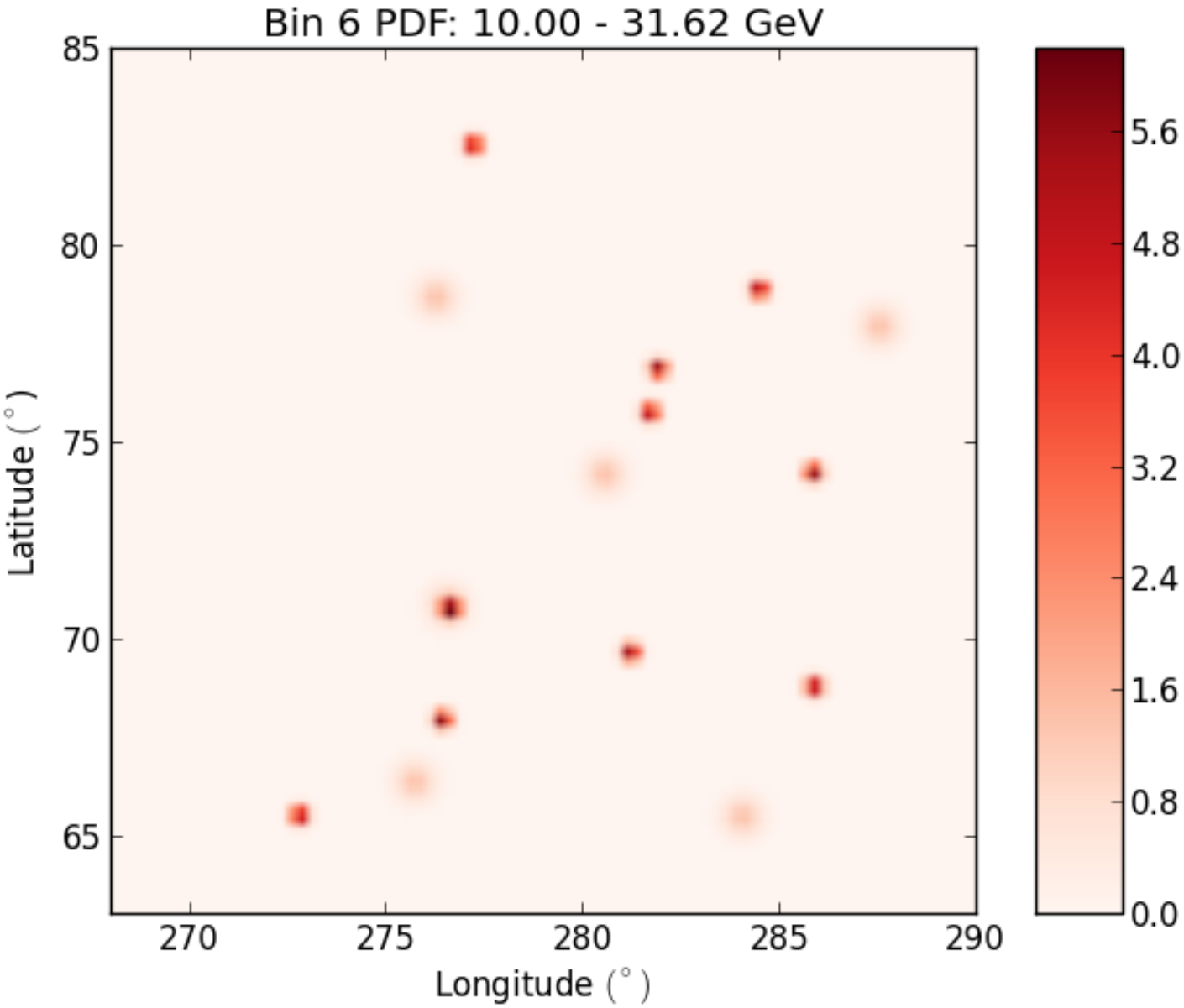
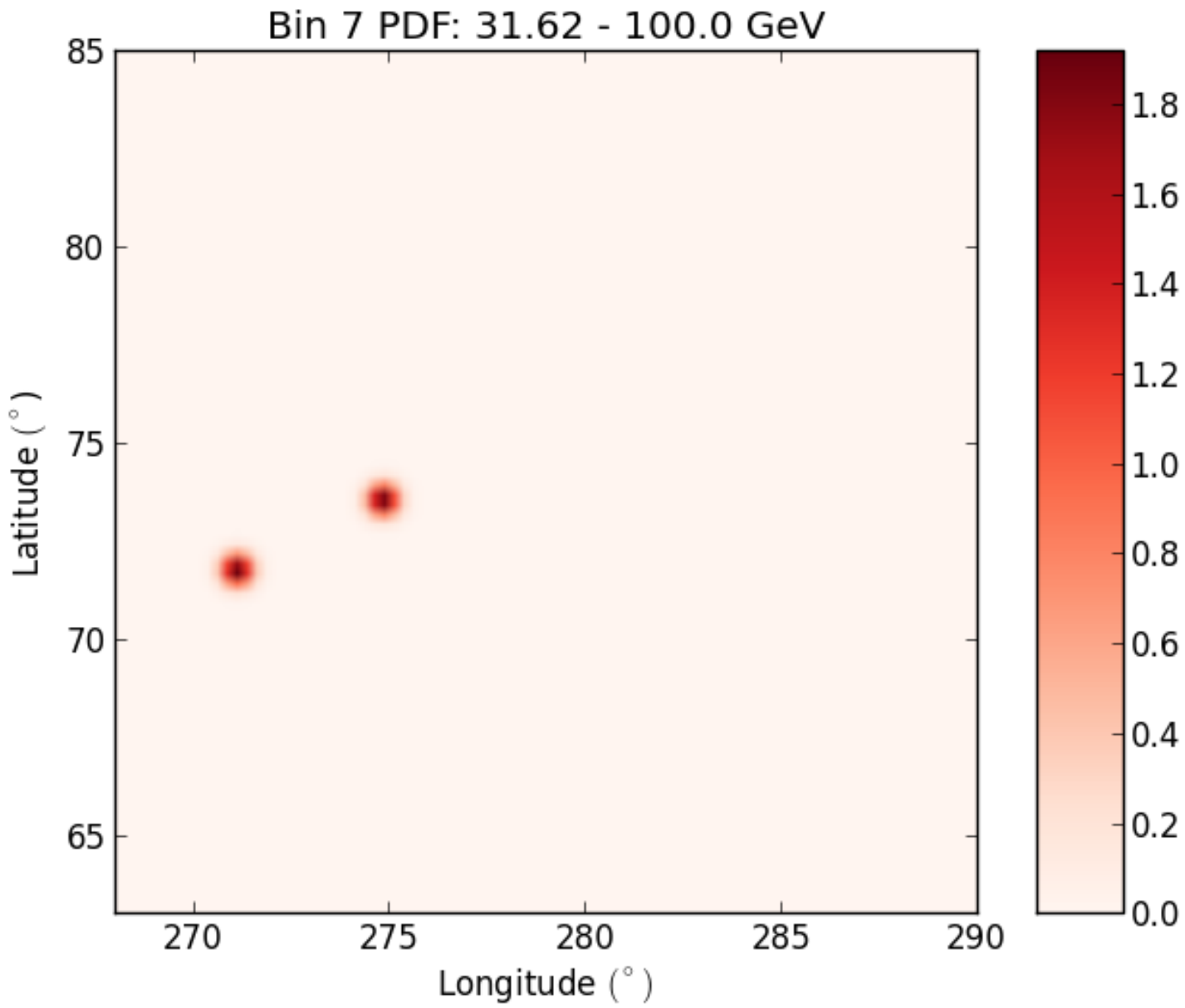
285
290
Longitude (°)
8
7
6
5
4
3
2
1

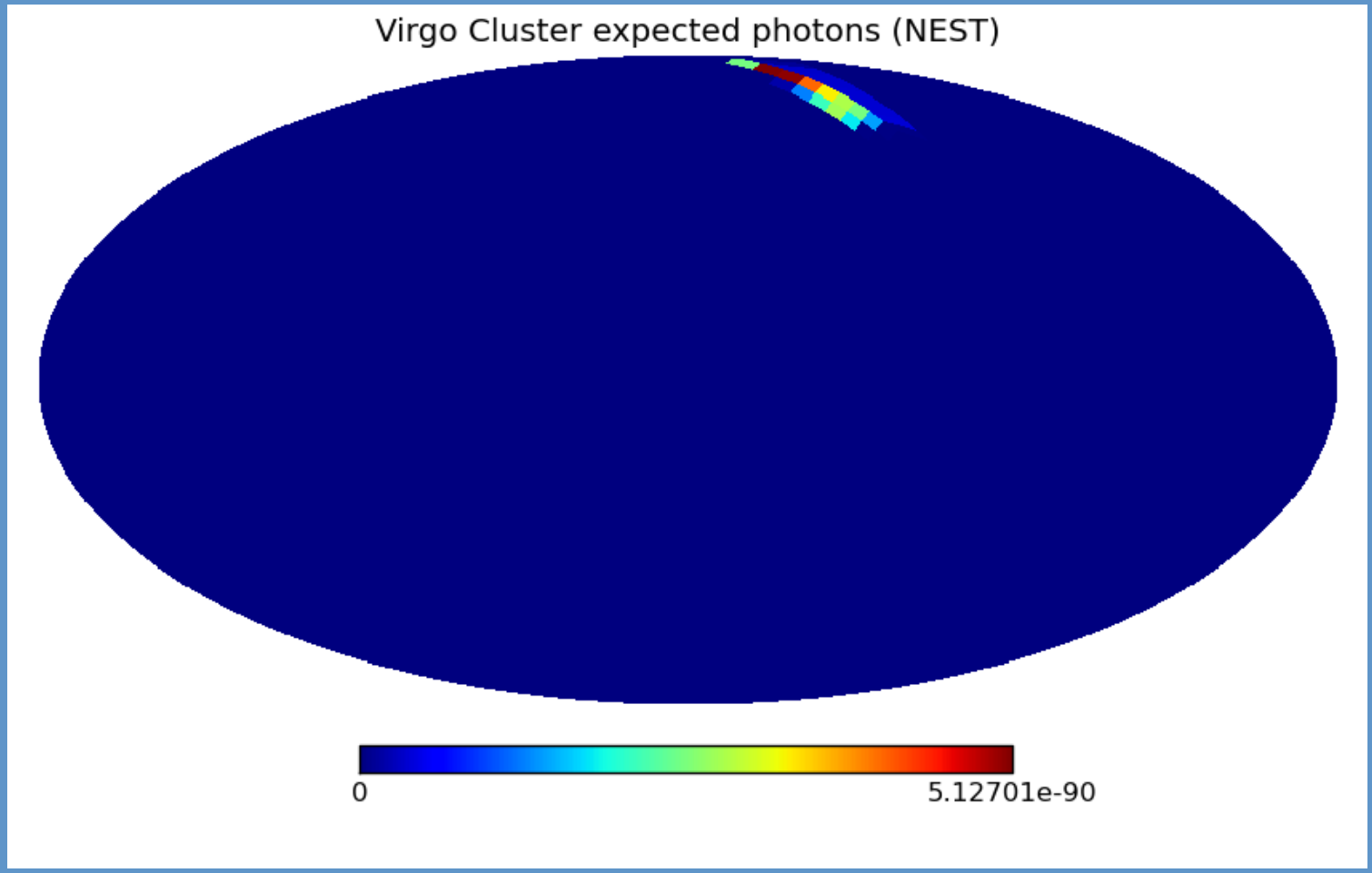

Bin 4 PDF: 1000 MeV - 3.162 GeV
85
80
75
70
65
Latitude (°)
270
275
280
285
290
Longitude (°)
5.4
4.8
4.2
3.6
3.0
2.4
1.8
1.2
0.6
0.0


Bin 5 PDF: 3.162 - 10.00 GeV
85
80
75
70
65
Latitude (°)
270
275
280
285
290
Longitude (°)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0

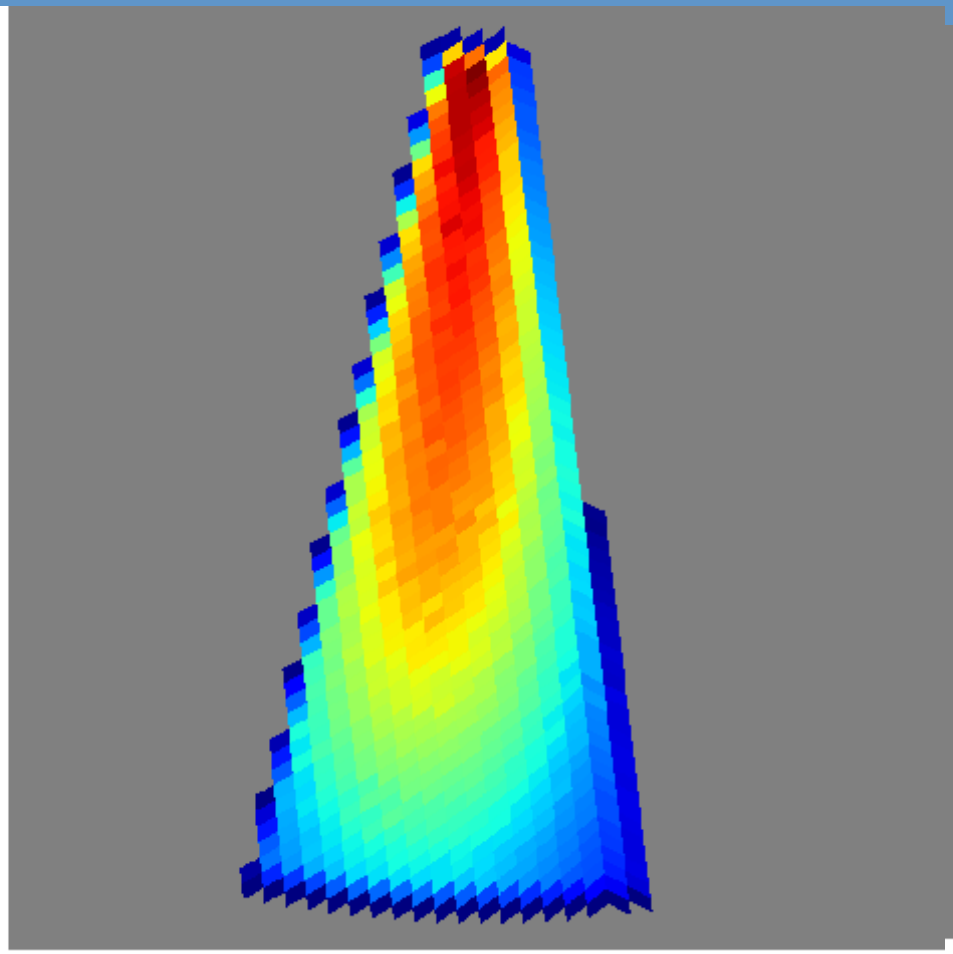

Bin 6 PDF: 10.00 - 31.62 GeV
85
80
75
70
65
Latitude (°)
270
275
280
285
290
Longitude (°)
5.6
4.8
4.0
3.2
2.4
1.6
0.8
0.0

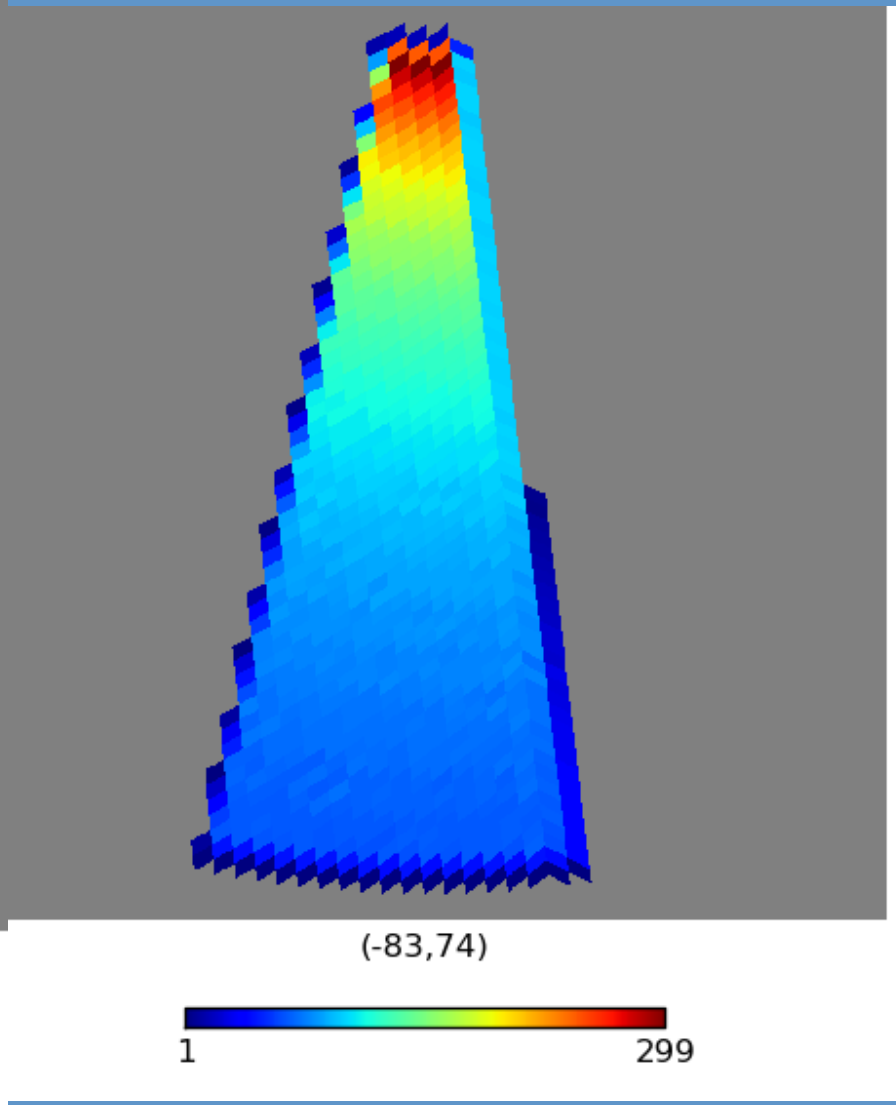

Bin 7 PDF: 31.62 - 100.0 GeV
85
80
75
70
65
Latitude (°)
270
275
280
285
290
Longitude (°)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0

5th Week – First Attempts



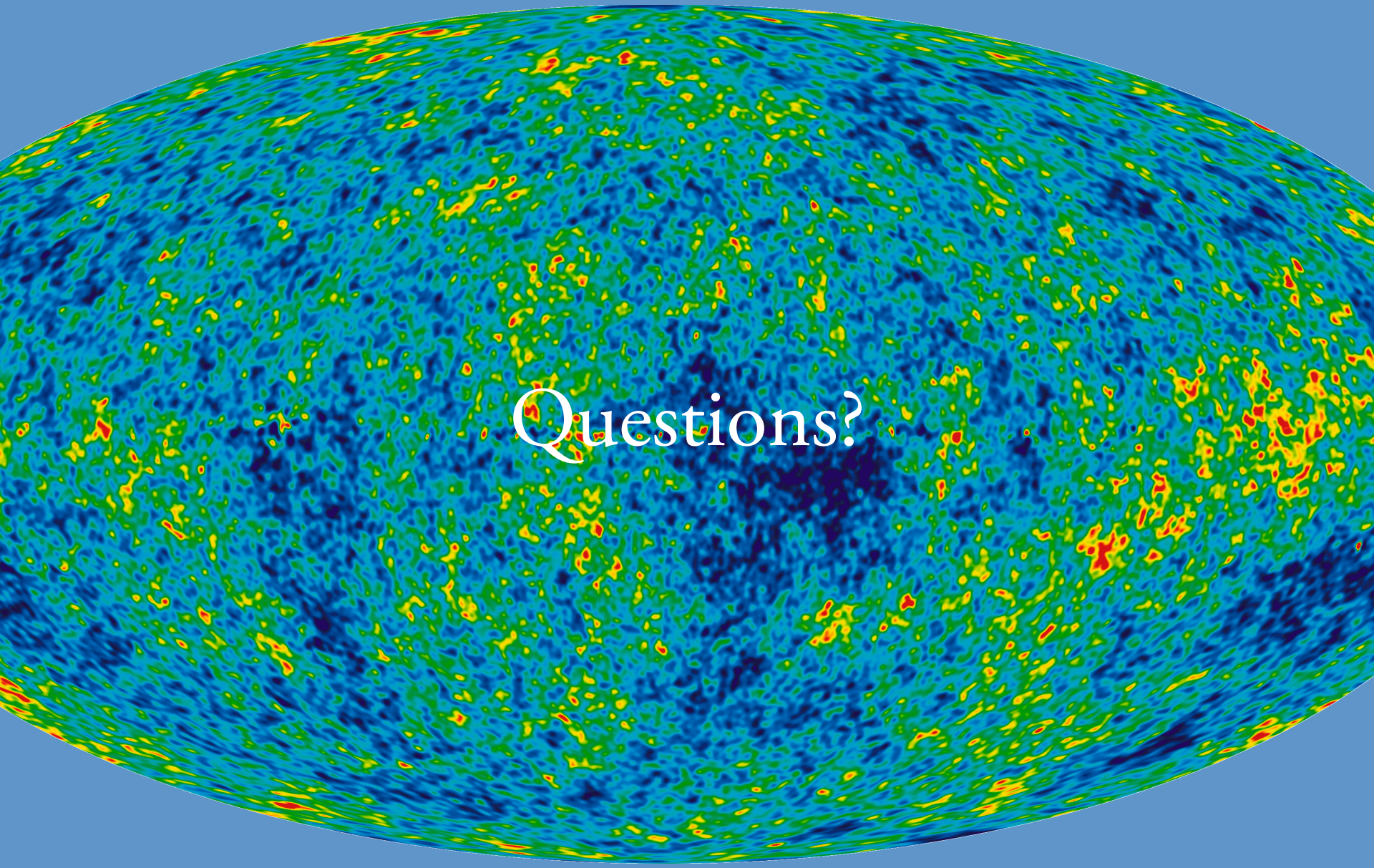
Problem?





The “Future”

- Mentor will continue to analyze data using my methods written in Python
- Return to school: independent study
- Hope to continue similar work


Questions?