

Gamma ray emissions from galaxy clusters

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Department

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

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

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

$$M \propto r$$

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

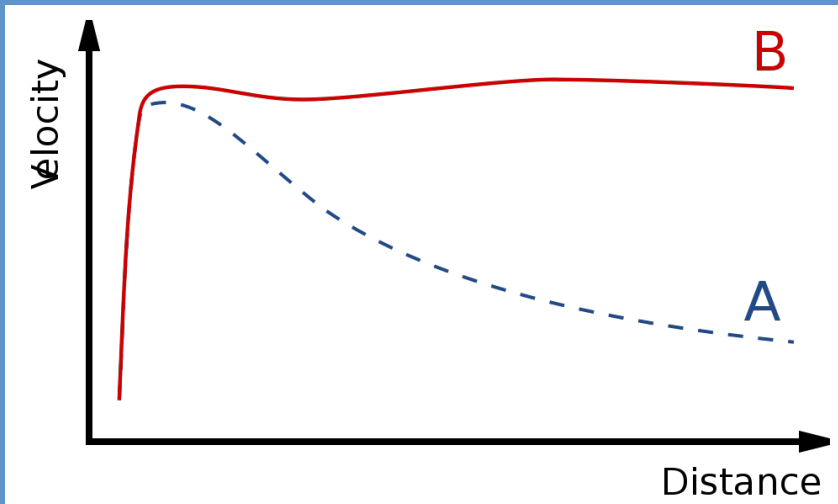
$$dM = \rho(r) 2\pi r dr$$

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

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

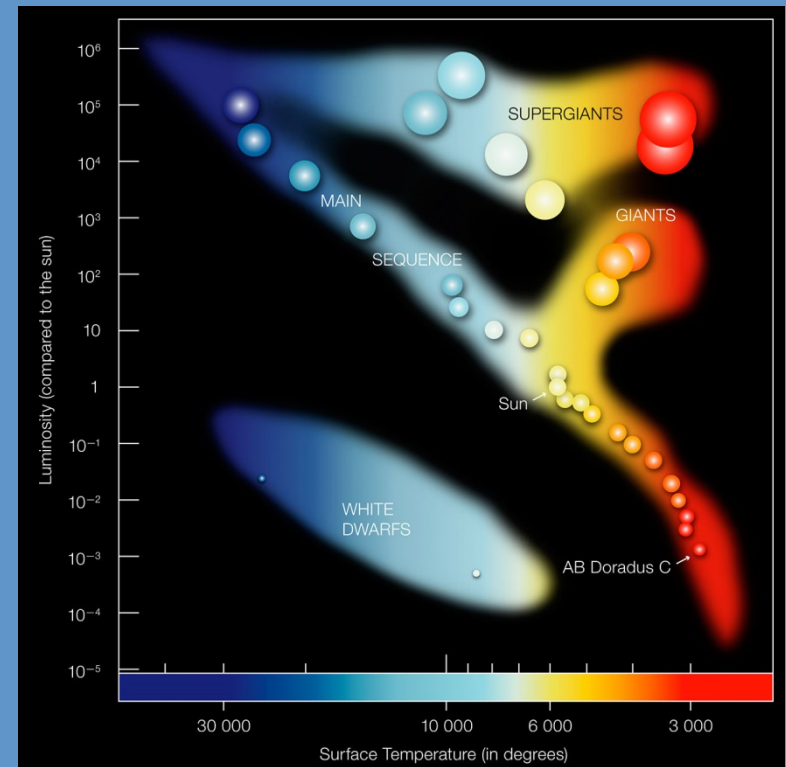
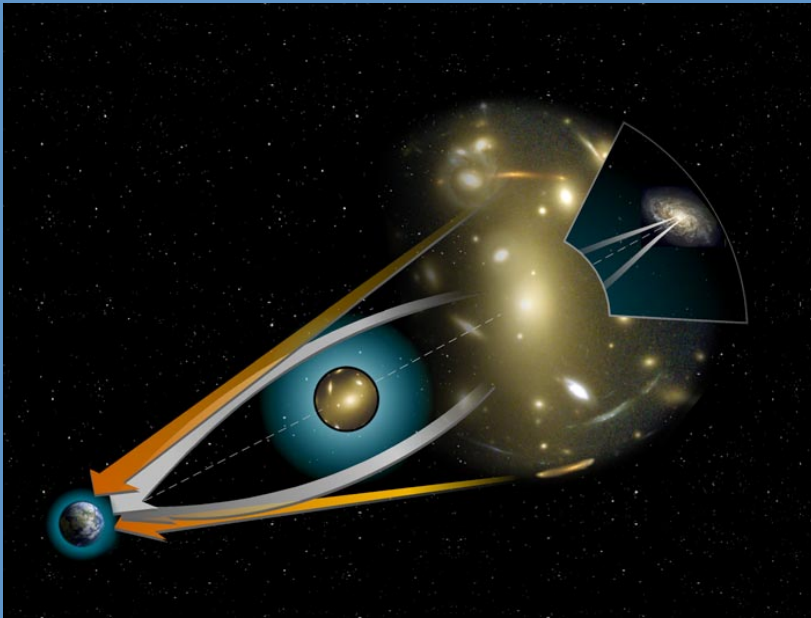
$$\rho(r) \propto \exp(-Ar^\alpha).$$

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

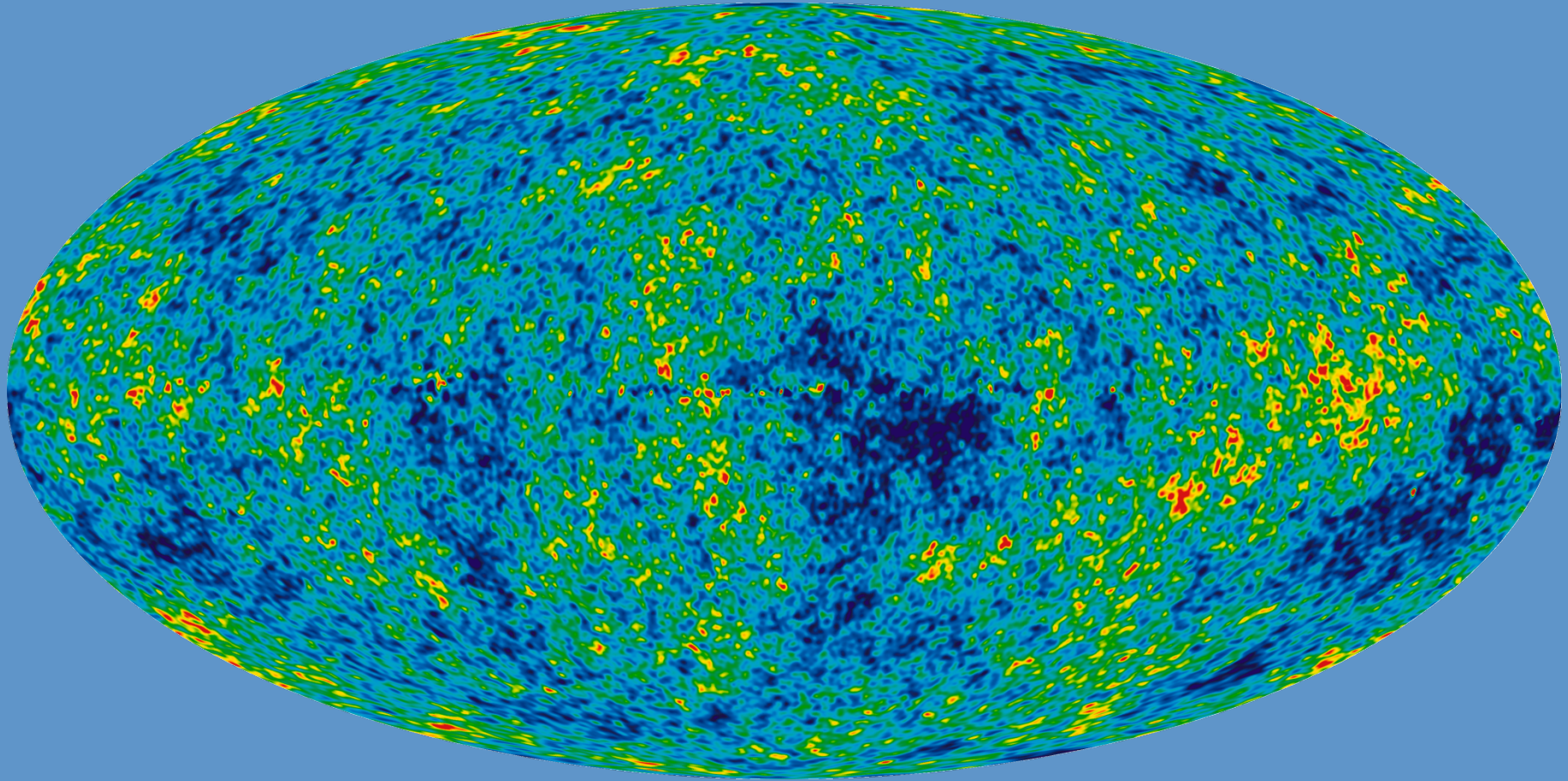


Why does it matter?

- Gravitational lensing measurements
- Mass-to-light ratios (1-30 typical)



Serendipitous discovery of CMB



Arno Penzias + Robert Wilson - 1964

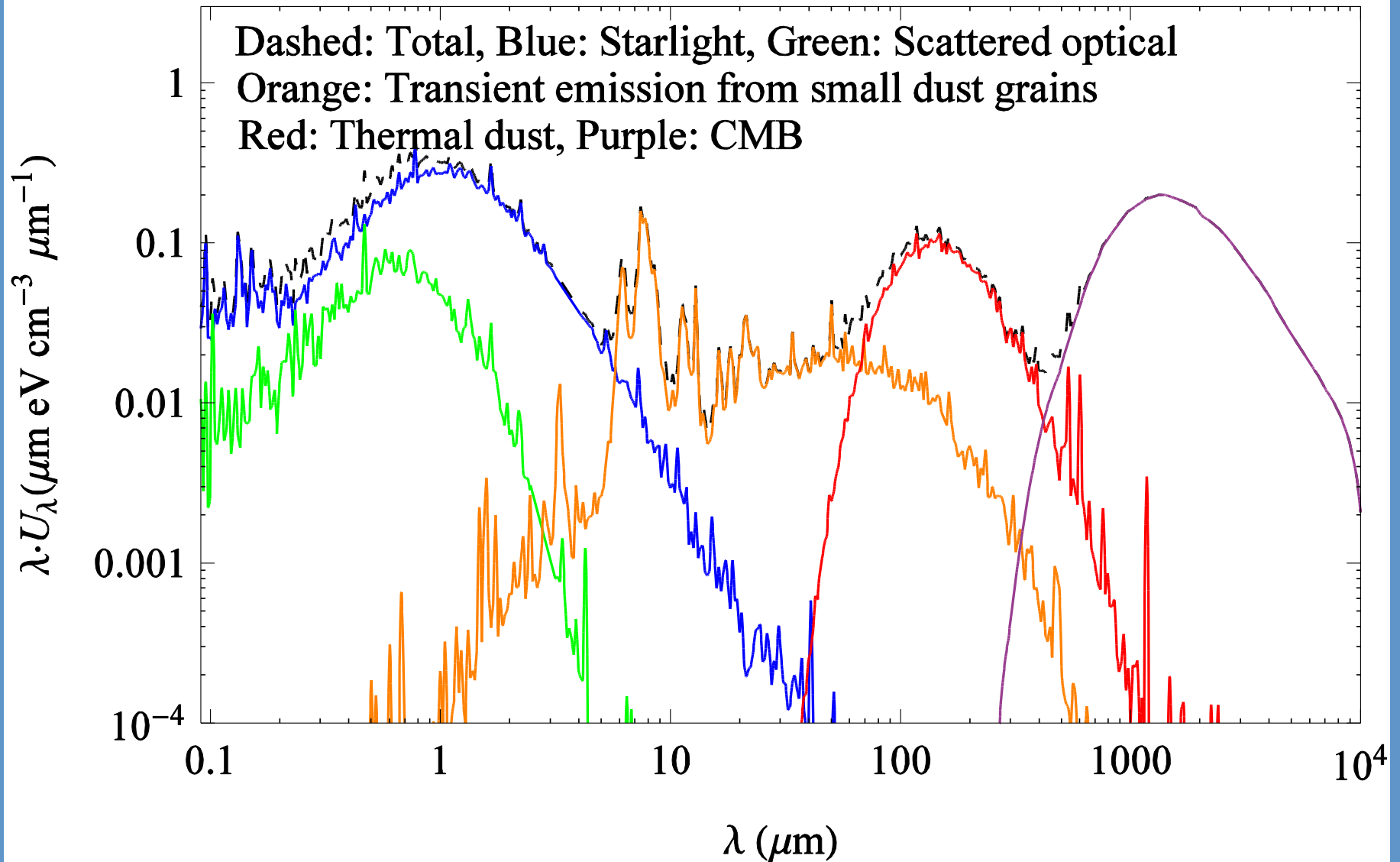
The Goal

- 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

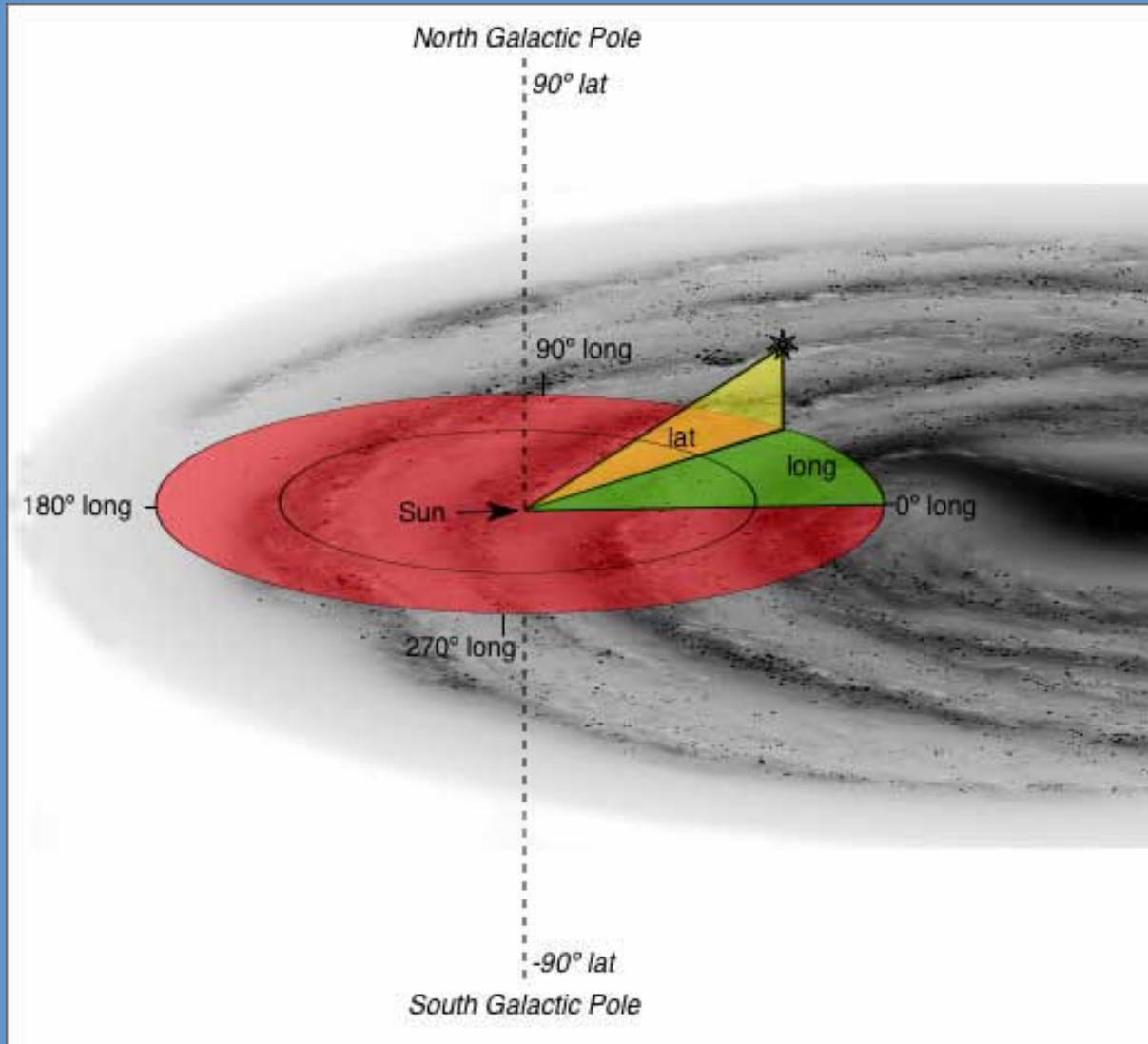
3rd – 4th week – Virgo Cluster

- Galaxy cluster, \sim 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

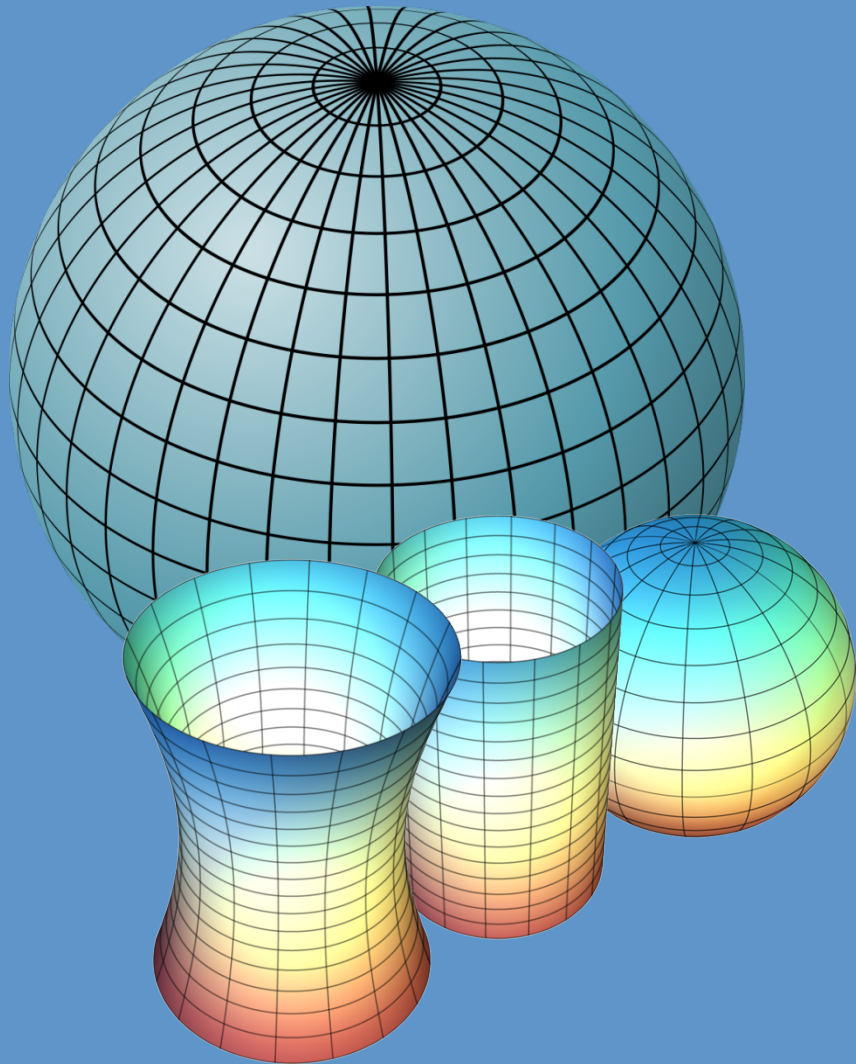
Virgo Cluster analysis

- 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

WHAT YOUR FAVORITE
MAP PROJECTION
SAYS ABOUT YOU

MERCATOR



YOU'RE NOT REALLY INTO MAPS.

ROBINSON



YOU HAVE A COMFORTABLE PAIR OF RUNNING SHOES THAT YOU WEAR EVERYWHERE. YOU LIKE COFFEE AND ENJOY THE BEATLES. YOU THINK THE ROBINSON IS THE BEST-LOOKING PROJECTION, HANDS DOWN.

WINKEL-TRIPLE



NATIONAL GEOGRAPHIC ADOPTED THE WINKEL-TRIPLE IN 1998, BUT YOU'VE BEEN A WFT FAN SINCE LONG BEFORE "NAT GEO" SHOWED UP. YOU'RE WORRIED IT'S GETTING PLAYED OUT, AND ARE THINKING OF SWITCHING TO THE KAVRAYSKY. YOU ONCE LEFT A PARTY IN DISGUST WHEN A GUEST SHOWED UP WEARING SHOES WITH TOES. YOUR FAVORITE MUSICAL GENRE IS "POST-".

VAN DER GRINTEN



YOU'RE NOT A COMPLICATED PERSON. YOU LOVE THE MERCATOR PROJECTION; YOU JUST WISH IT WEREN'T SQUARE. THE EARTH'S NOT A SQUARE, IT'S A CIRCLE. YOU LIKE CIRCLES. TODAY IS GONNA BE A GOOD DAY!

DYMAXION



YOU LIKE ISAAC ASIMOV, XML, AND SHOES WITH TOES. YOU THINK THE SEGWAY GOT A BAD RAP. YOU OWN 3D GOGGLES, WHICH YOU USE TO VIEW ROTATING MODELS OF BETTER 3D GOGGLES. YOU TYPE IN DVORAK.

GOODE HOMOLOSINE



THEY SAY MAPPING THE EARTH ON A 2D SURFACE IS LIKE FLATTENING AN ORANGE PEEL, WHICH SEEMS EASY ENOUGH TO YOU. YOU LIKE EASY SOLUTIONS. YOU THINK WE WOULDN'T HAVE SO MANY PROBLEMS IF WE'D JUST ELECT *NORMAL* PEOPLE TO CONGRESS INSTEAD OF POLITICIANS. YOU THINK AIRLINES SHOULD JUST BUY FOOD FROM THE RESTAURANTS NEAR THE GATES AND SERVE *THAT* ON BOARD. YOU CHANGE YOUR CAR'S OIL, BUT SECRETLY WONDER IF YOU REALLY *NEED* TO.

HOBBO-DYER



YOU WANT TO AVOID CULTURAL IMPERIALISM, BUT YOU'VE HEARD BAD THINGS ABOUT GAIL-PETERS. YOU'RE CONFLICT-AVERSE AND BUY ORGANIC. YOU USE A RECENTLY-INVENTED SET OF GENDER-NEUTRAL PRONOUNS AND THINK THAT WHAT THE WORLD NEEDS IS A REVOLUTION IN CONSCIOUSNESS.

A GLOBE!



YES, YOU'RE VERY CLEVER.

PEIRCE QUINCUNCIAL



YOU THINK THAT WHEN WE LOOK AT A MAP, REALLY WHAT WE REALLY SEE IS OURSELVES. AFTER YOU FIRST SAW *INCEPTION*, YOU SAT SILENT IN THE THEATER FOR SIX HOURS. IT BREAKS YOU OUT TO REALIZE THAT EVERYONE AROUND YOU HAS A SKELETON INSIDE THEM. YOU *HAVE* REALLY LOOKED AT YOUR HANDS.

PLATE CARRÉE
(EQUIRECTANGULAR)



YOU THINK THIS ONE IS FINE. YOU LIKE HOW X AND Y MAP TO LATITUDE AND LONGITUDE. THE OTHER PROJECTIONS OVERCOMPLICATE THINGS. YOU WANT ME TO STOP ASKING ABOUT MAPS SO YOU CAN ENJOY DINNER.

WATERMAN BUTTERFLY



REALLY? YOU KNOW THE WATER-MAN? HAVE YOU SEEN THE 1909 CAHILL MAP IT'S BASED— ... YOU HAVE A FRAMED REPRODUCTION AT HOME?! WHOA. ...LISTEN. FORGET THESE QUESTIONS. ARE YOU DOING ANYTHING TONIGHT?

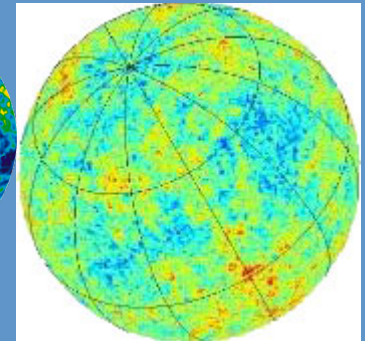
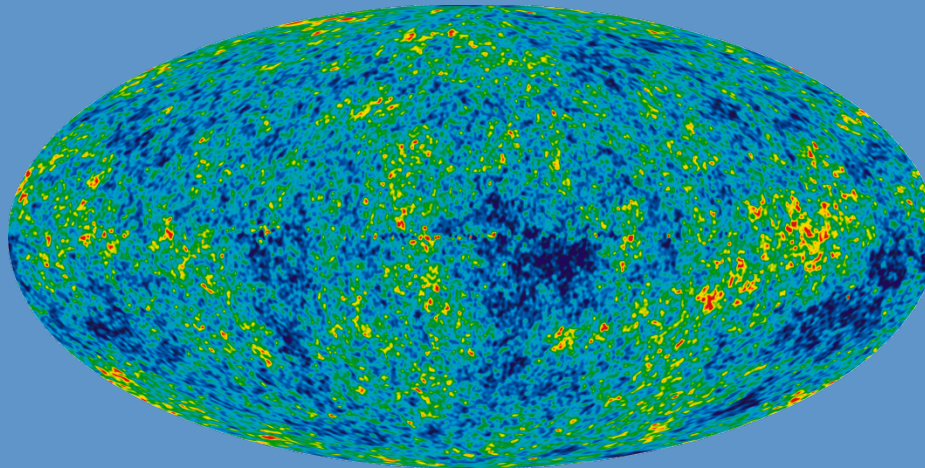
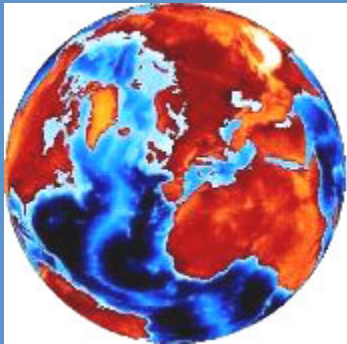
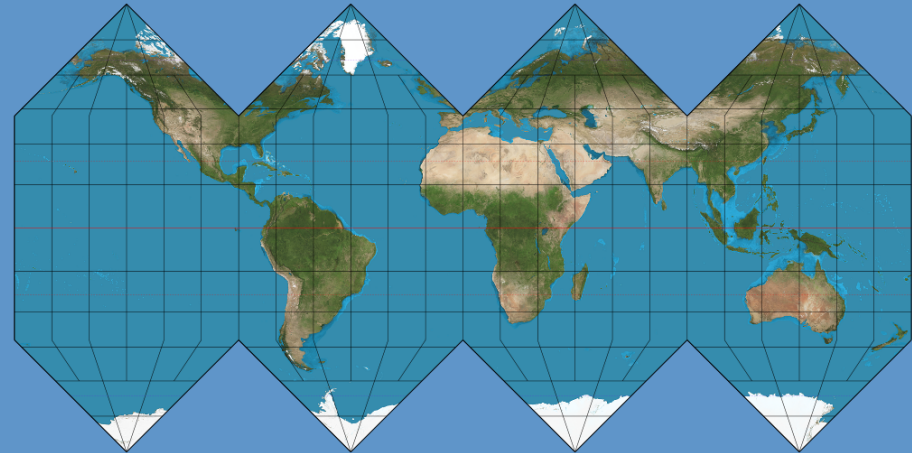
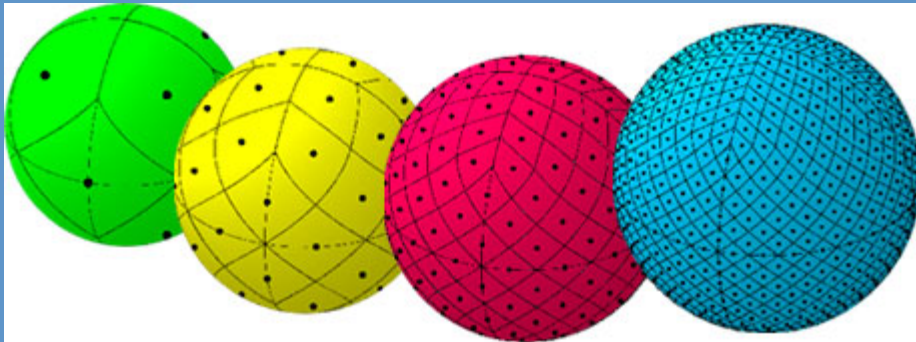
GAIL-PETERS



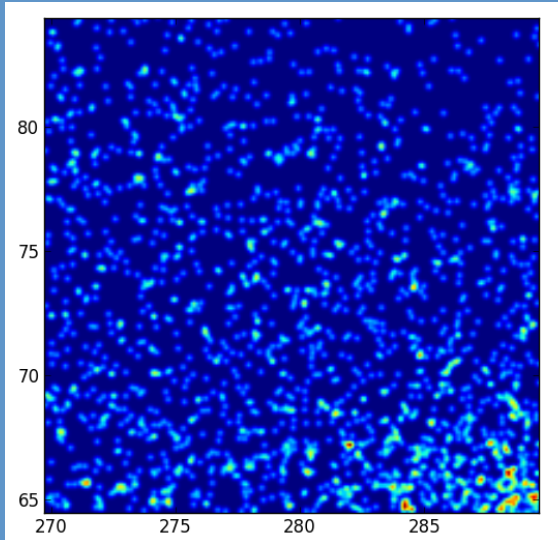
I HATE YOU.

HEALpix

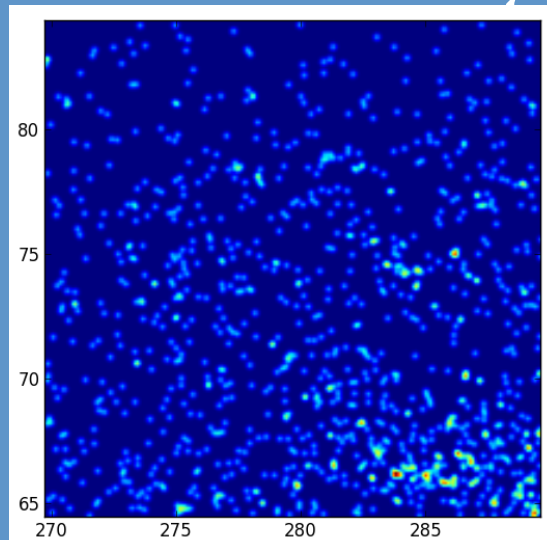
Hierarchical Equal Area isoLatitude
Pixelisation of a 2-sphere



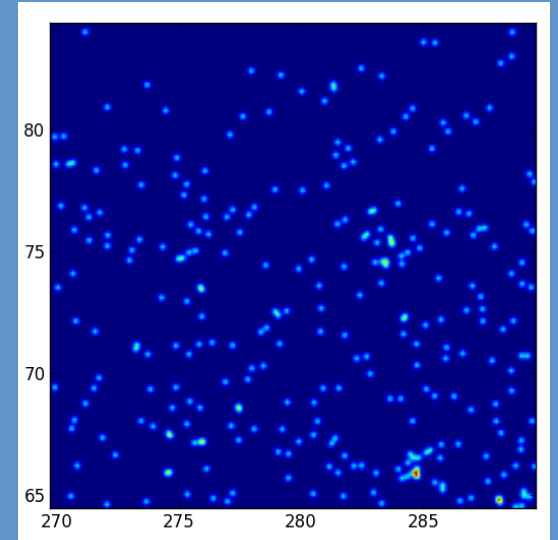
3rd – 4th week – Virgo Cluster



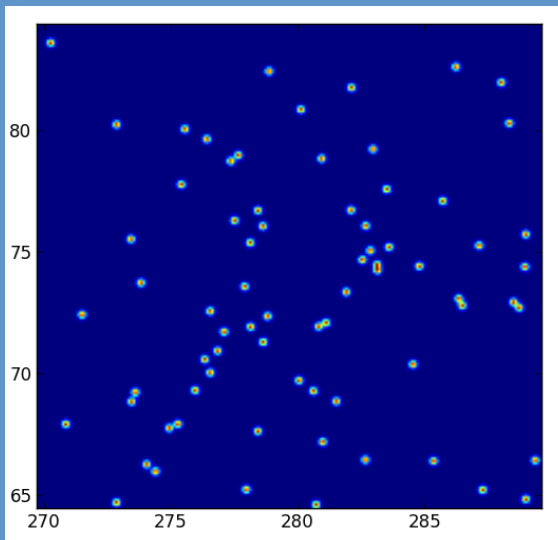
100 – 316 MeV



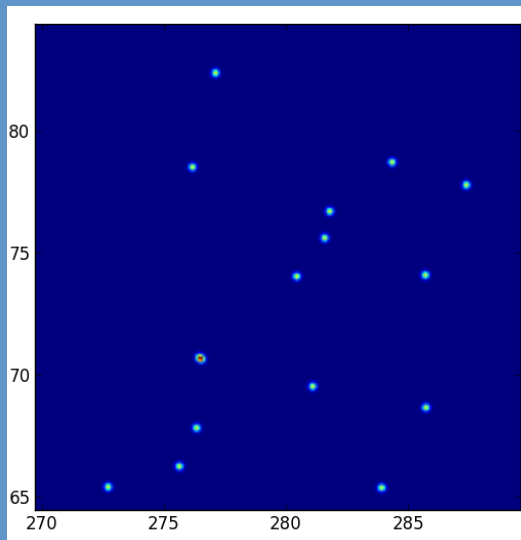
316 – 1000 MeV



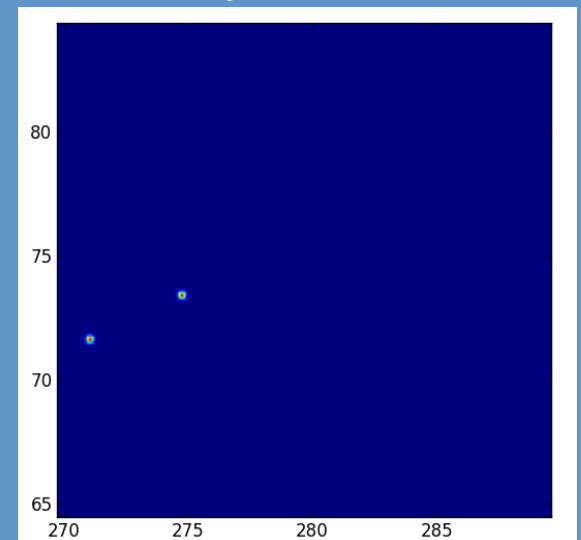
1 – 3.16 GeV



3.16 – 10 GeV



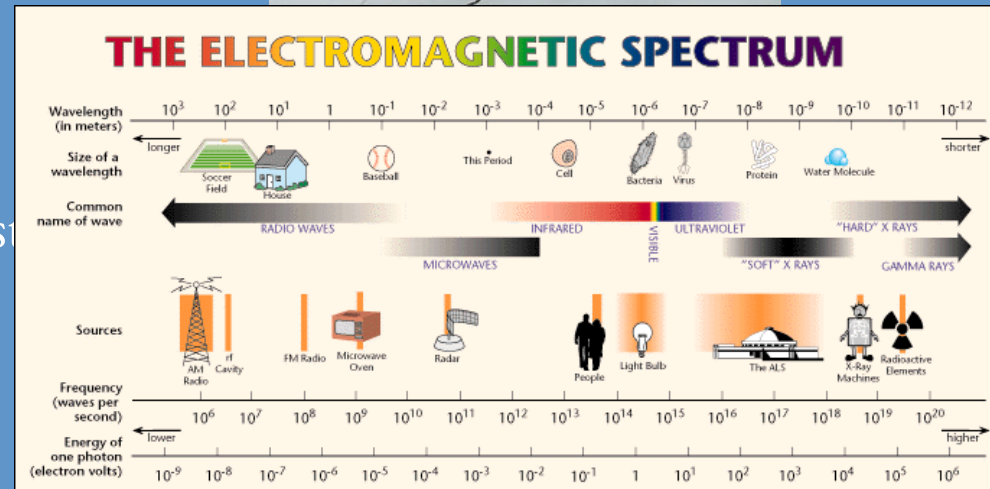
10 – 31.6 GeV



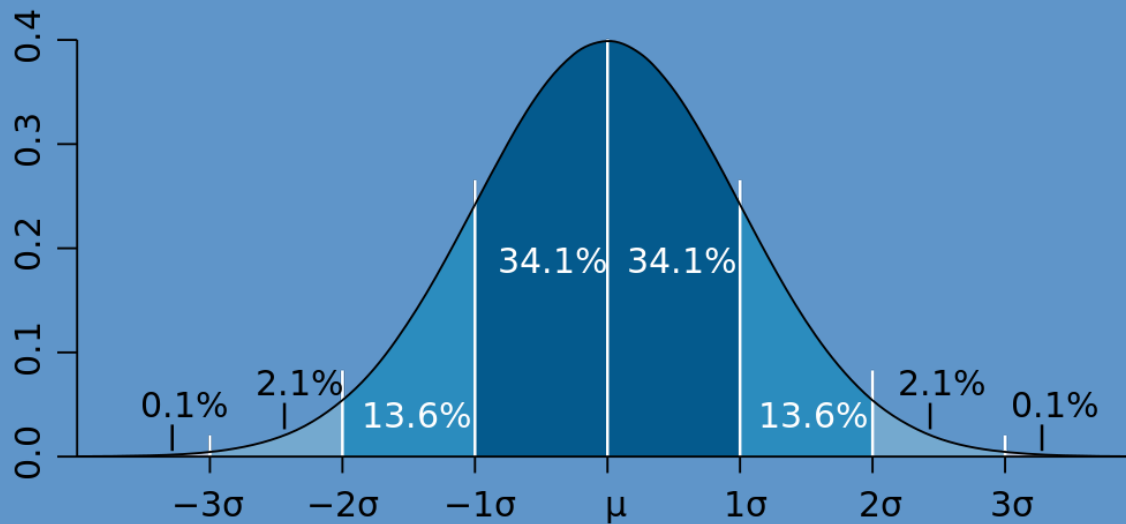
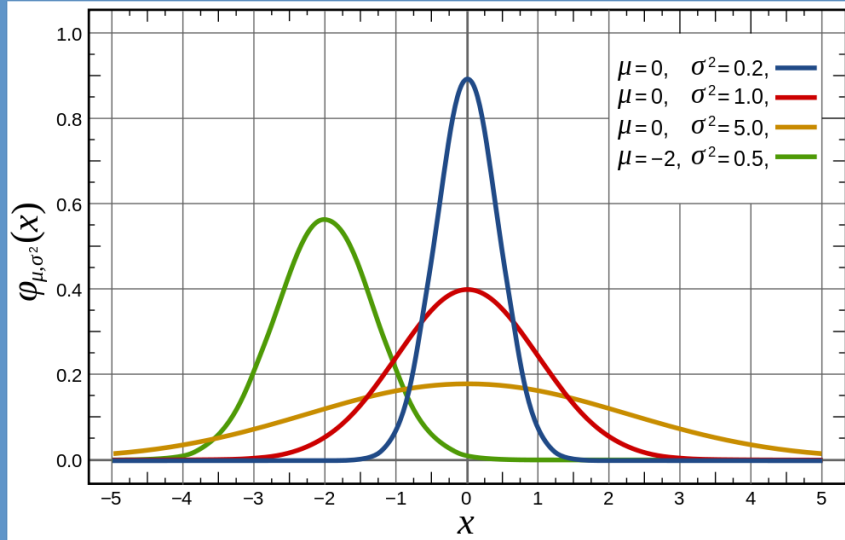
31.6 – 100 GeV

Fermi-LAT detector

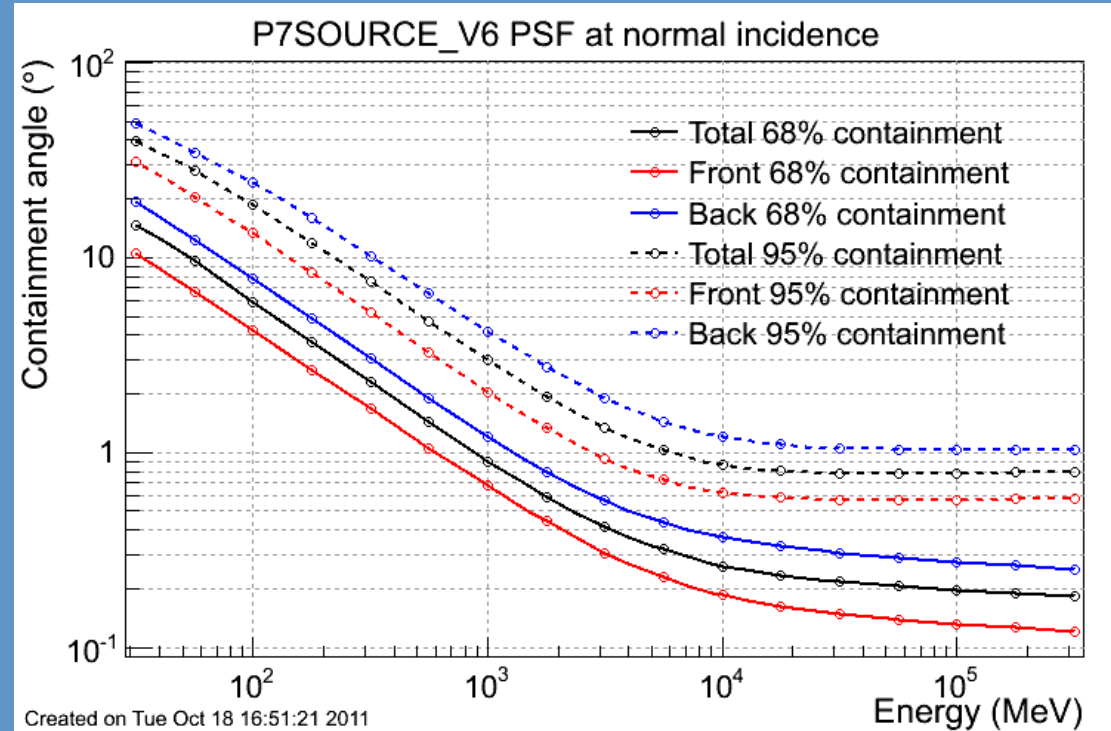
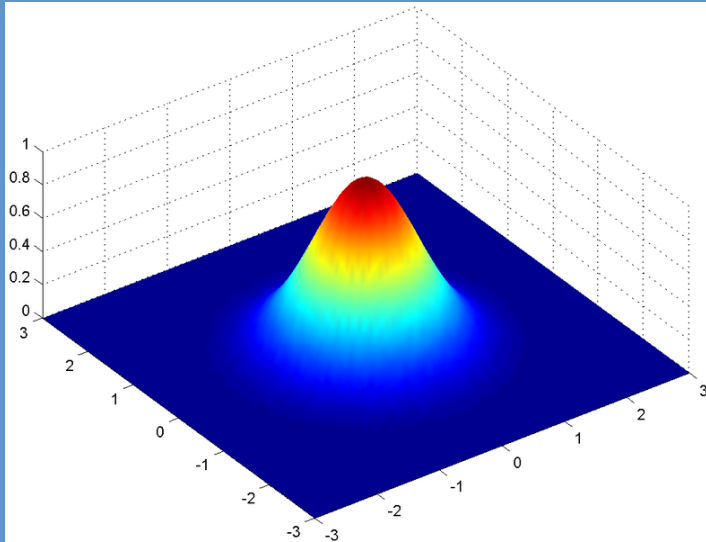
- != Fermilab
- Gamma-ray detector
- Photons range from 30 MeV – 300 GeV
- 10,000 – 100 million times more energetic than visible light
- $\sim 10^{20} - 10^{26}$ Hz
- Pair production: $\gamma + \gamma = e^+ + e^-$
- Many layers of metal (tungsten) + calorimeter
- Exposure time of months, almost years



Gaussian functions

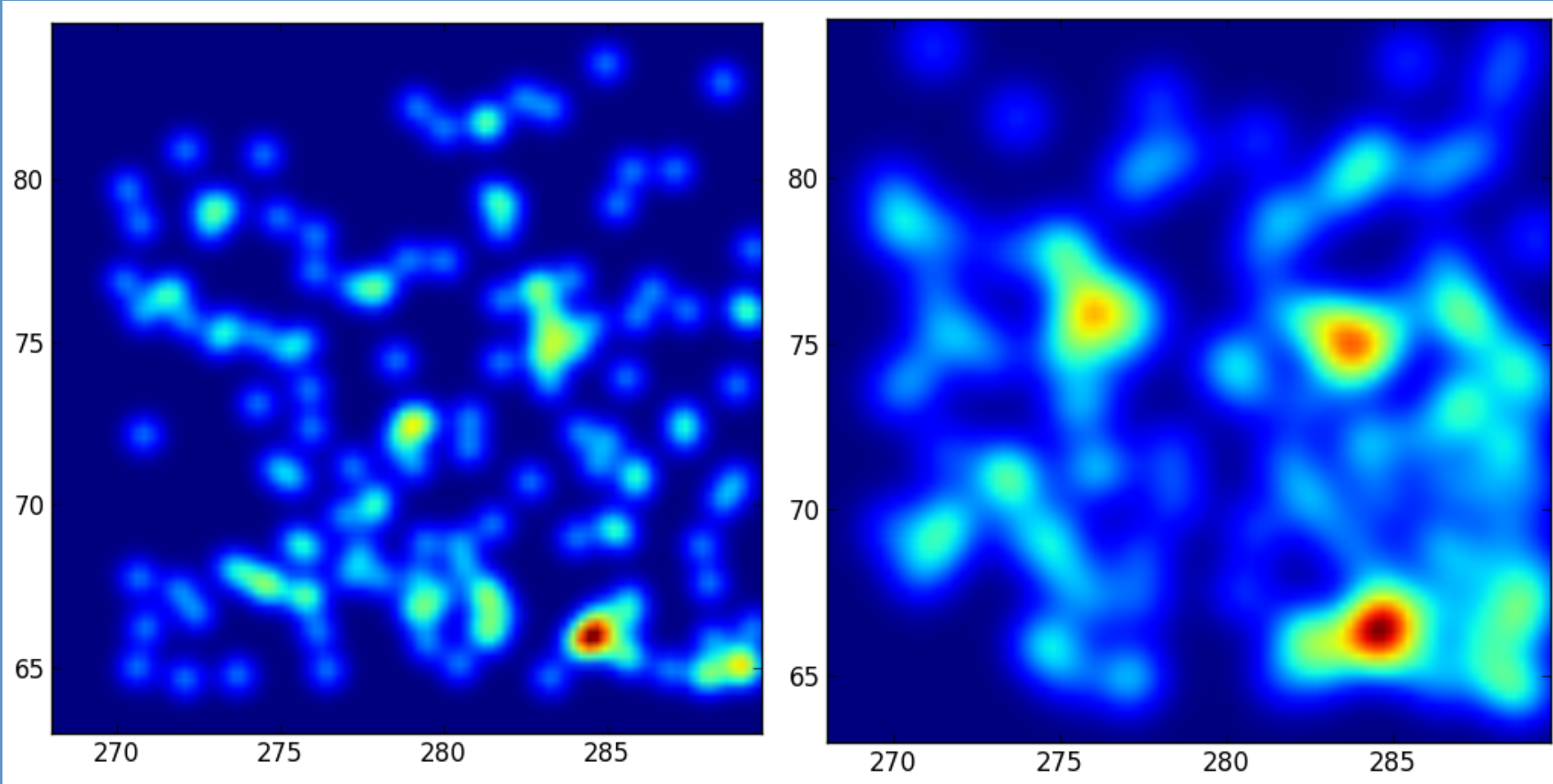


Gaussian functions

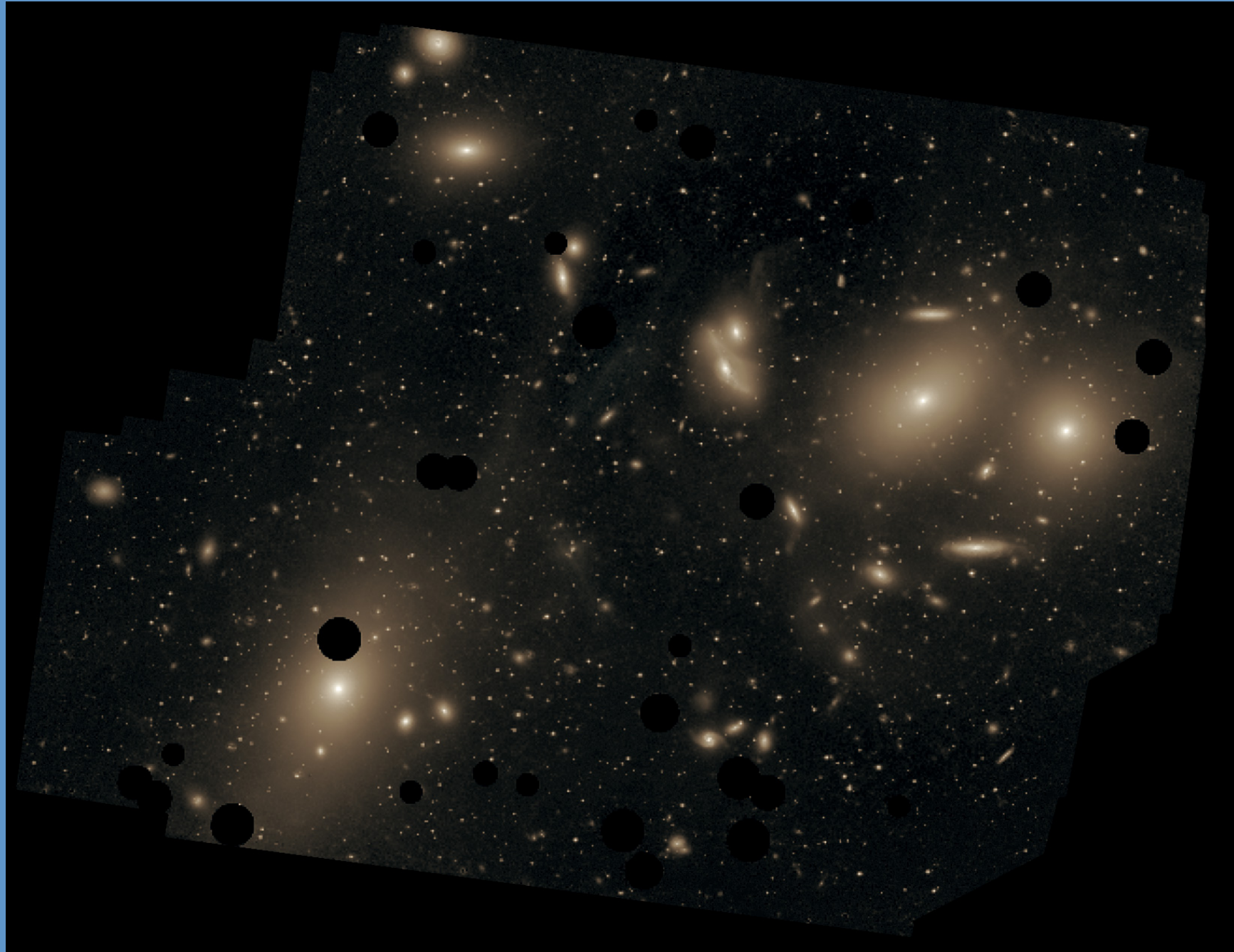


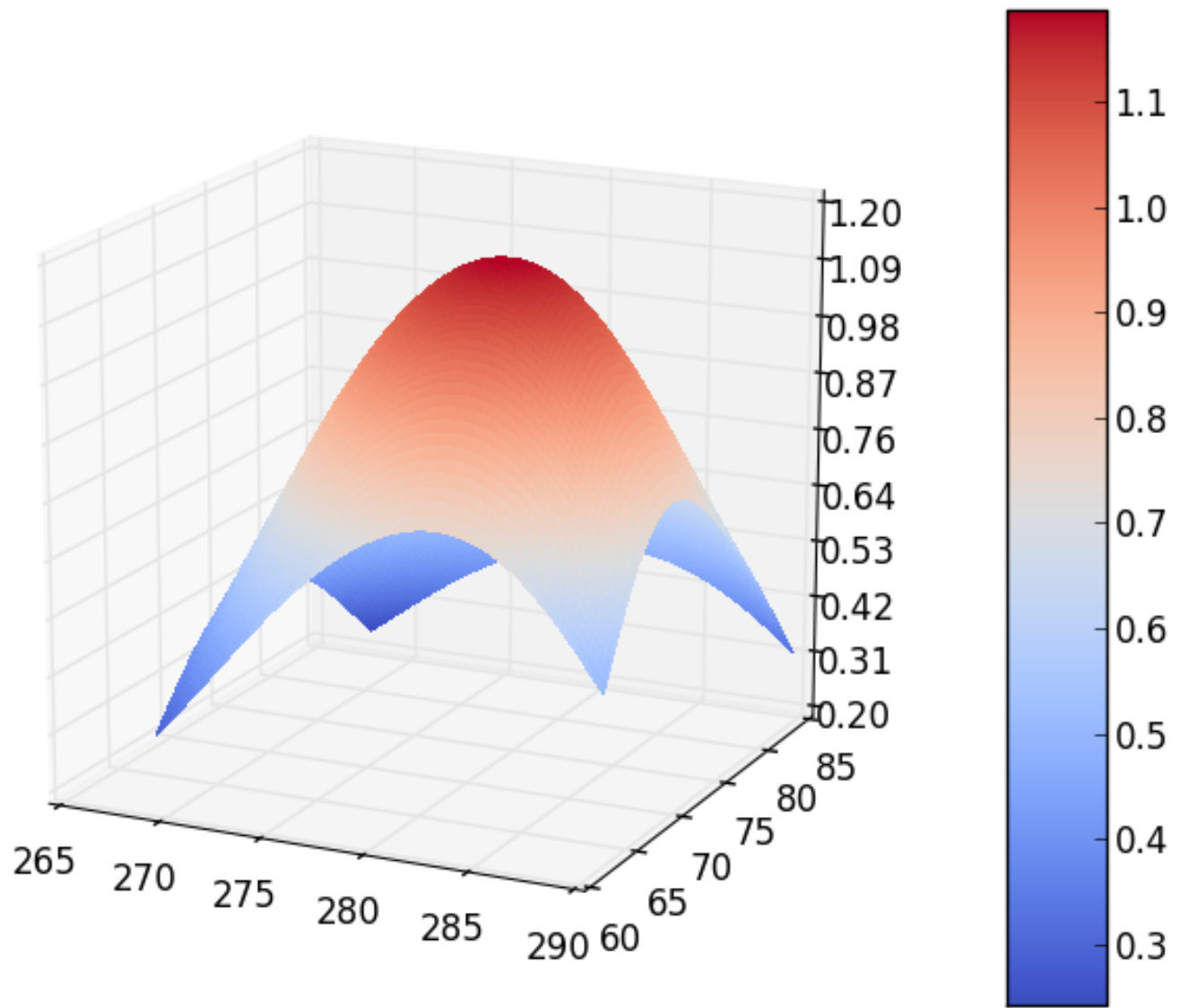
$$f(x,y) = A \exp\left(-\left(\frac{(x-x_0)^2}{2\sigma_x^2} + \frac{(y-y_0)^2}{2\sigma_y^2}\right)\right)$$

Front – back smearing

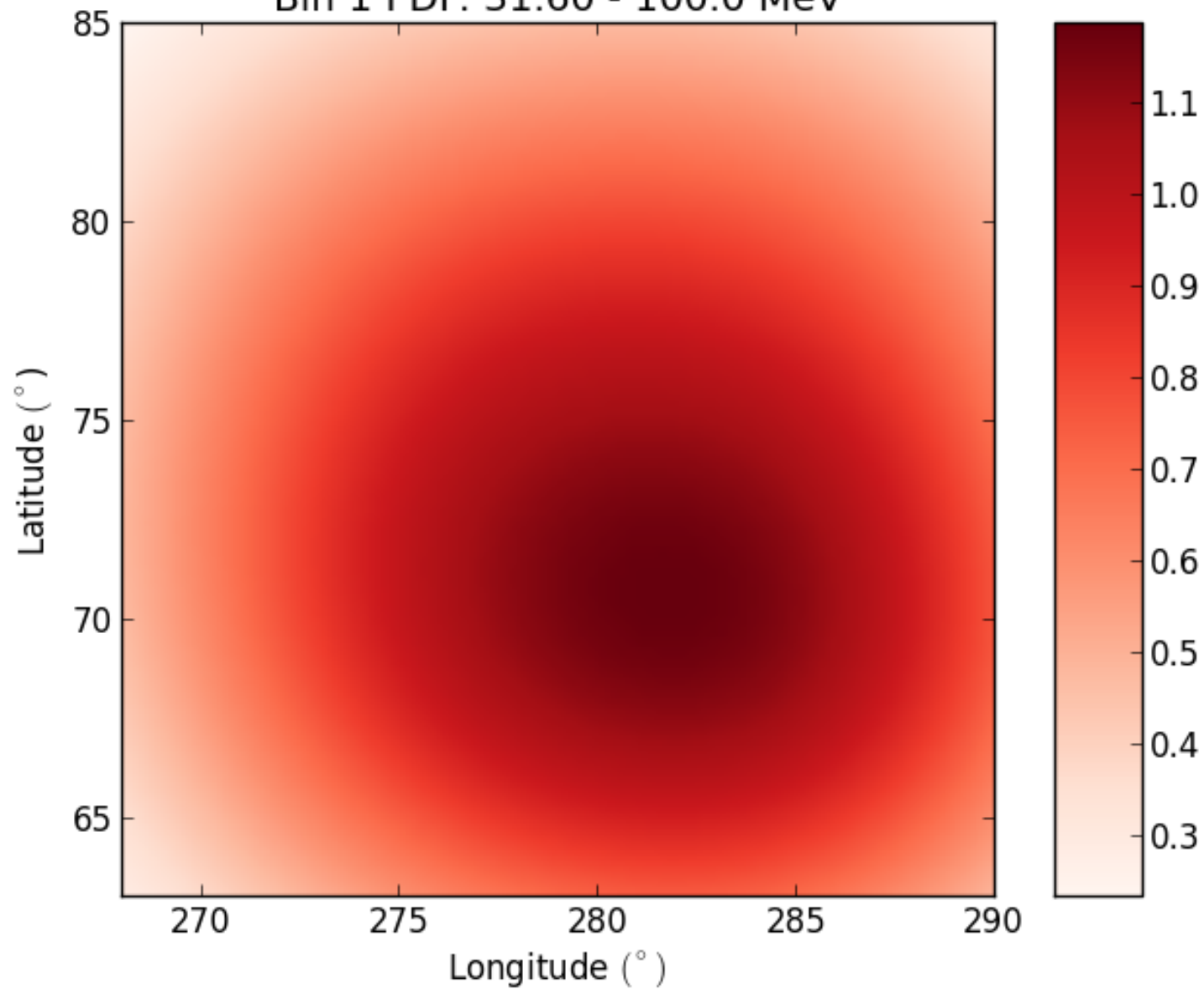


1 – 3.16 GeV

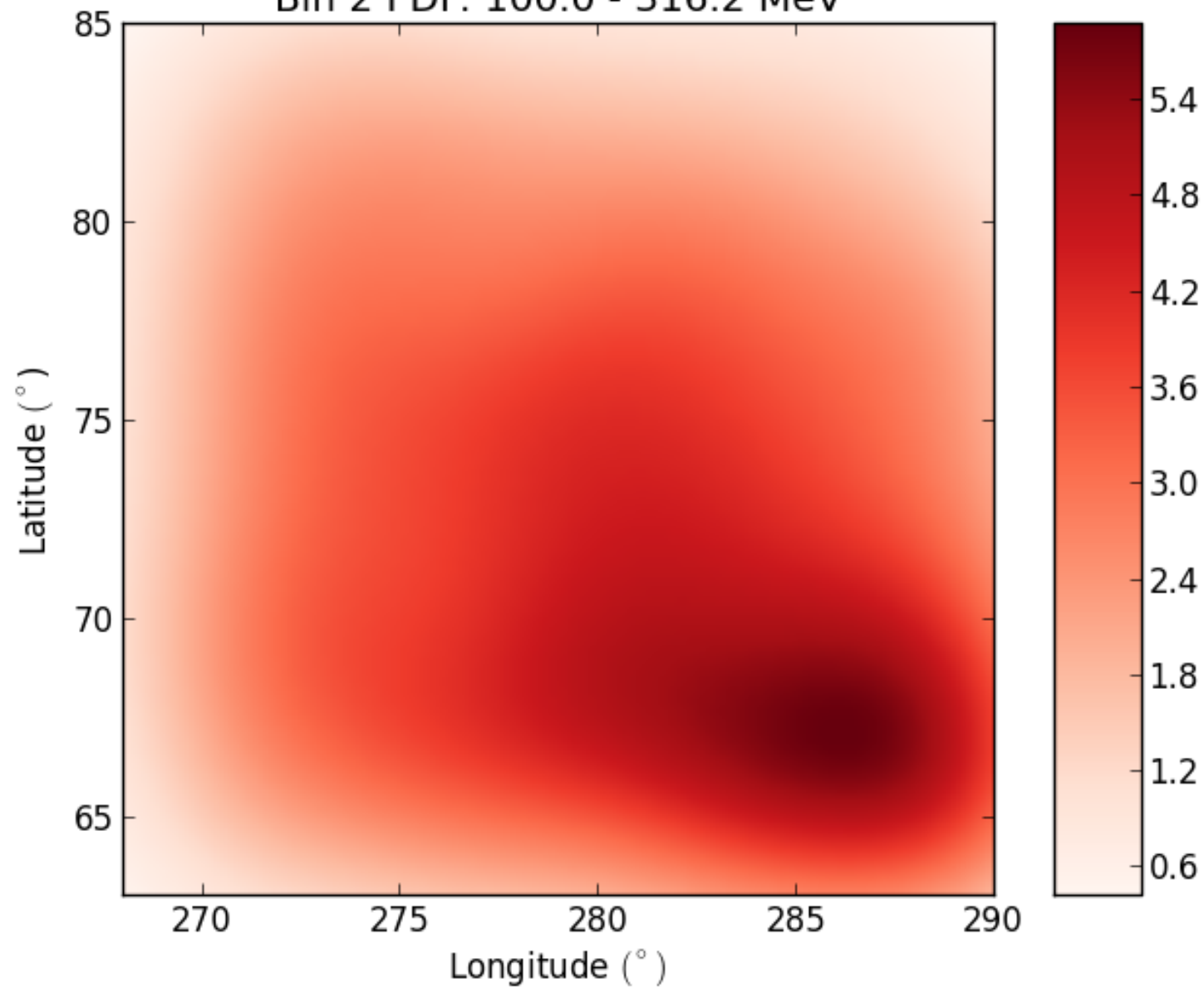




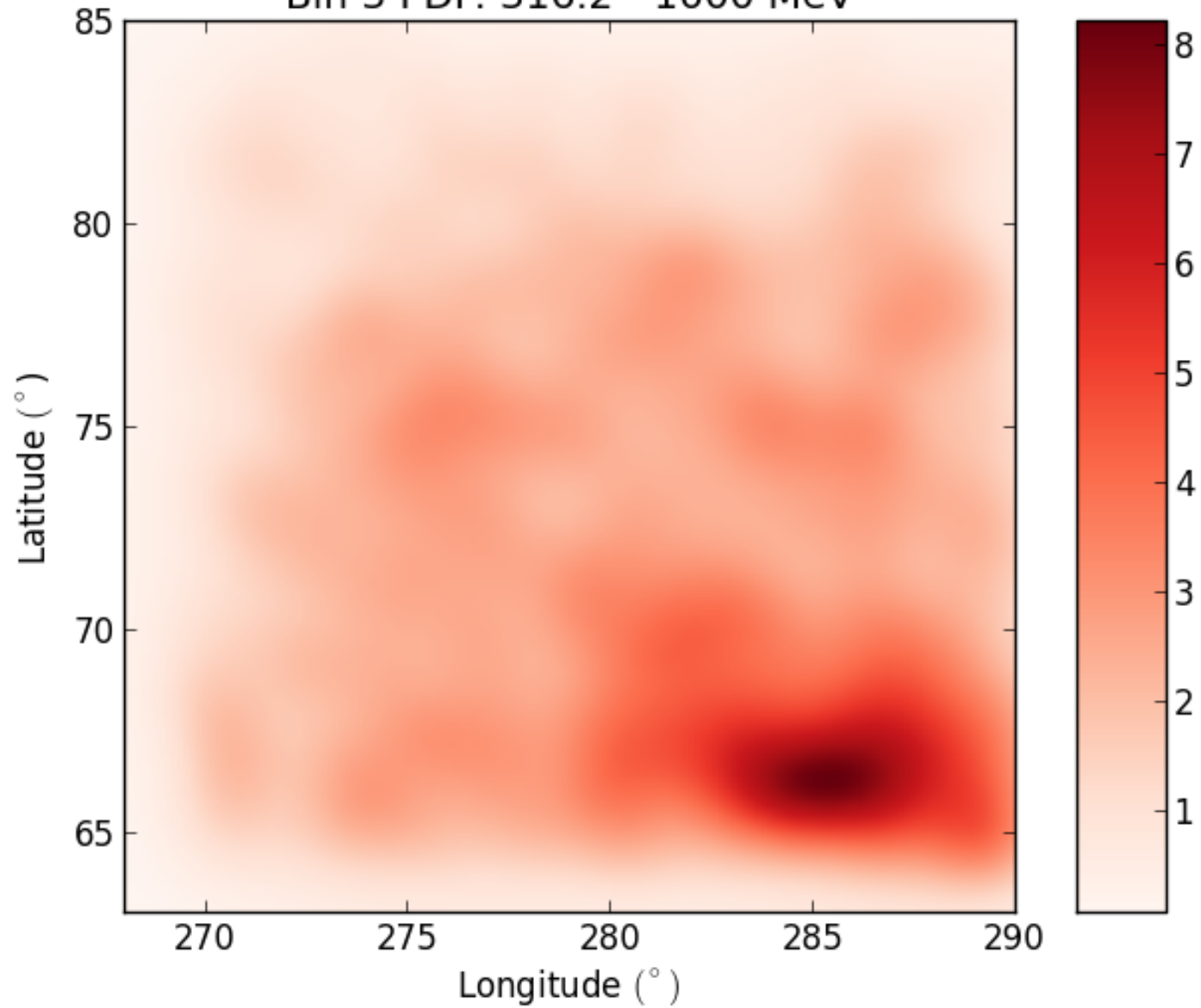
Bin 1 PDF: 31.60 - 100.0 MeV



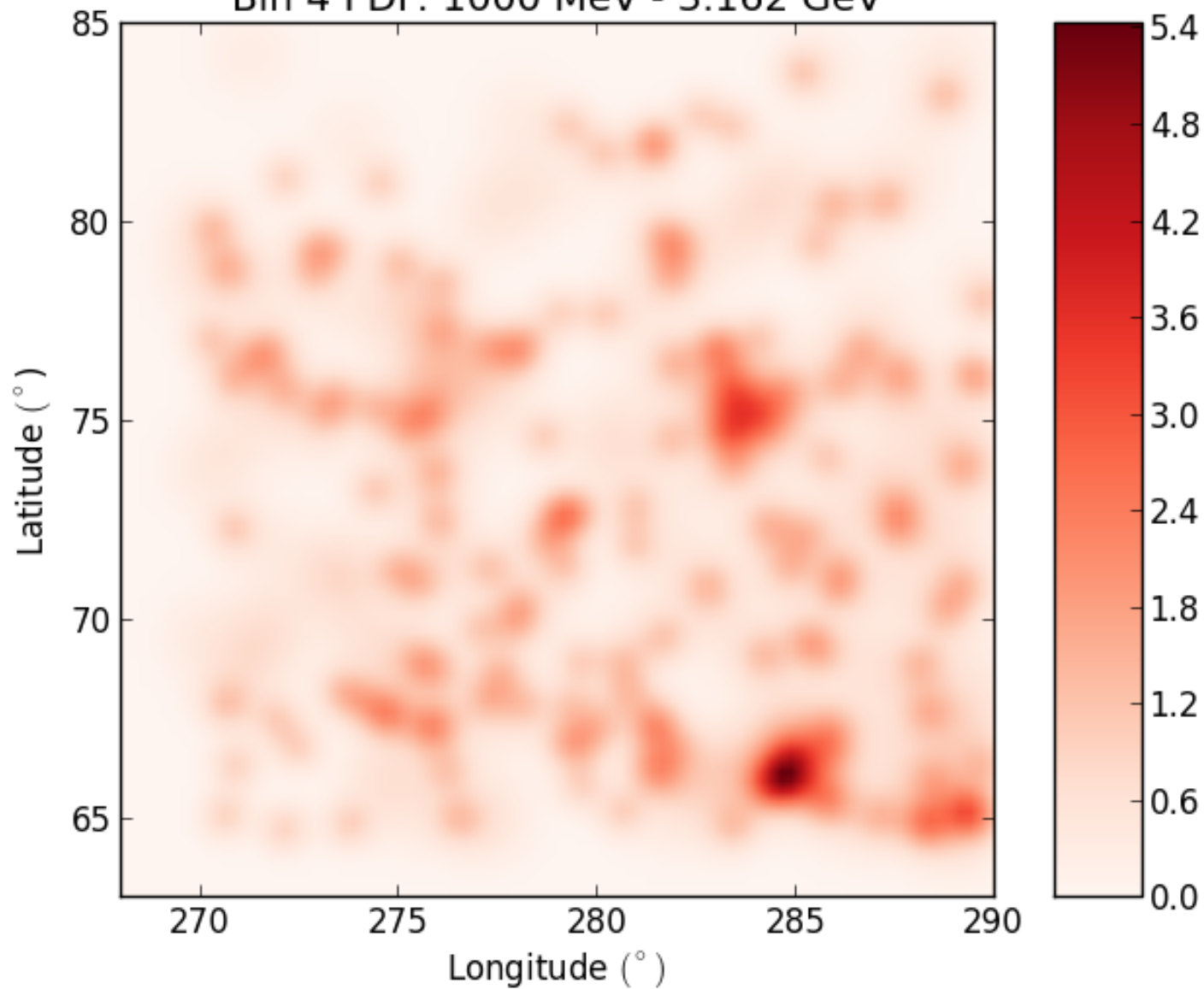
Bin 2 PDF: 100.0 - 316.2 MeV

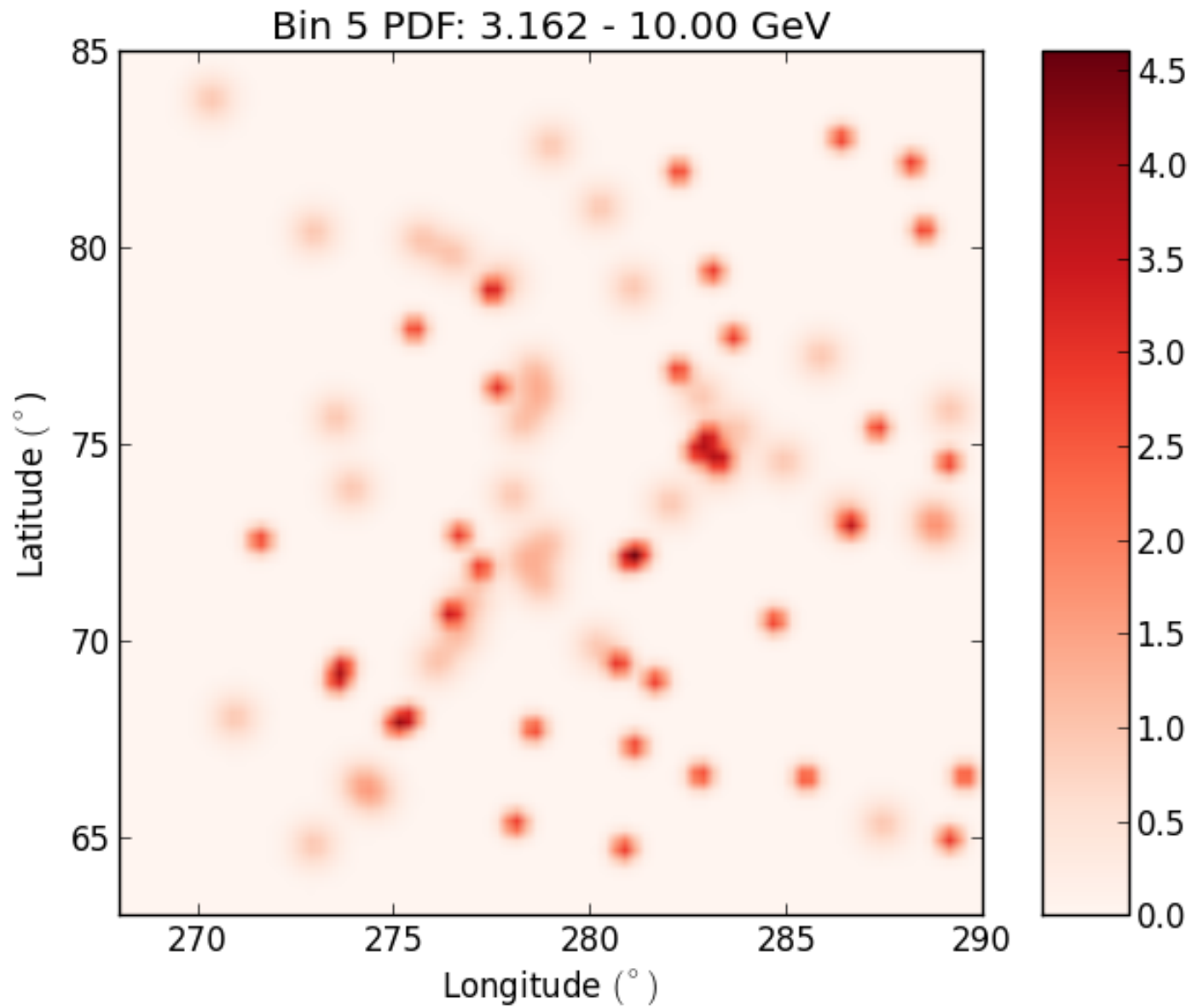


Bin 3 PDF: 316.2 - 1000 MeV

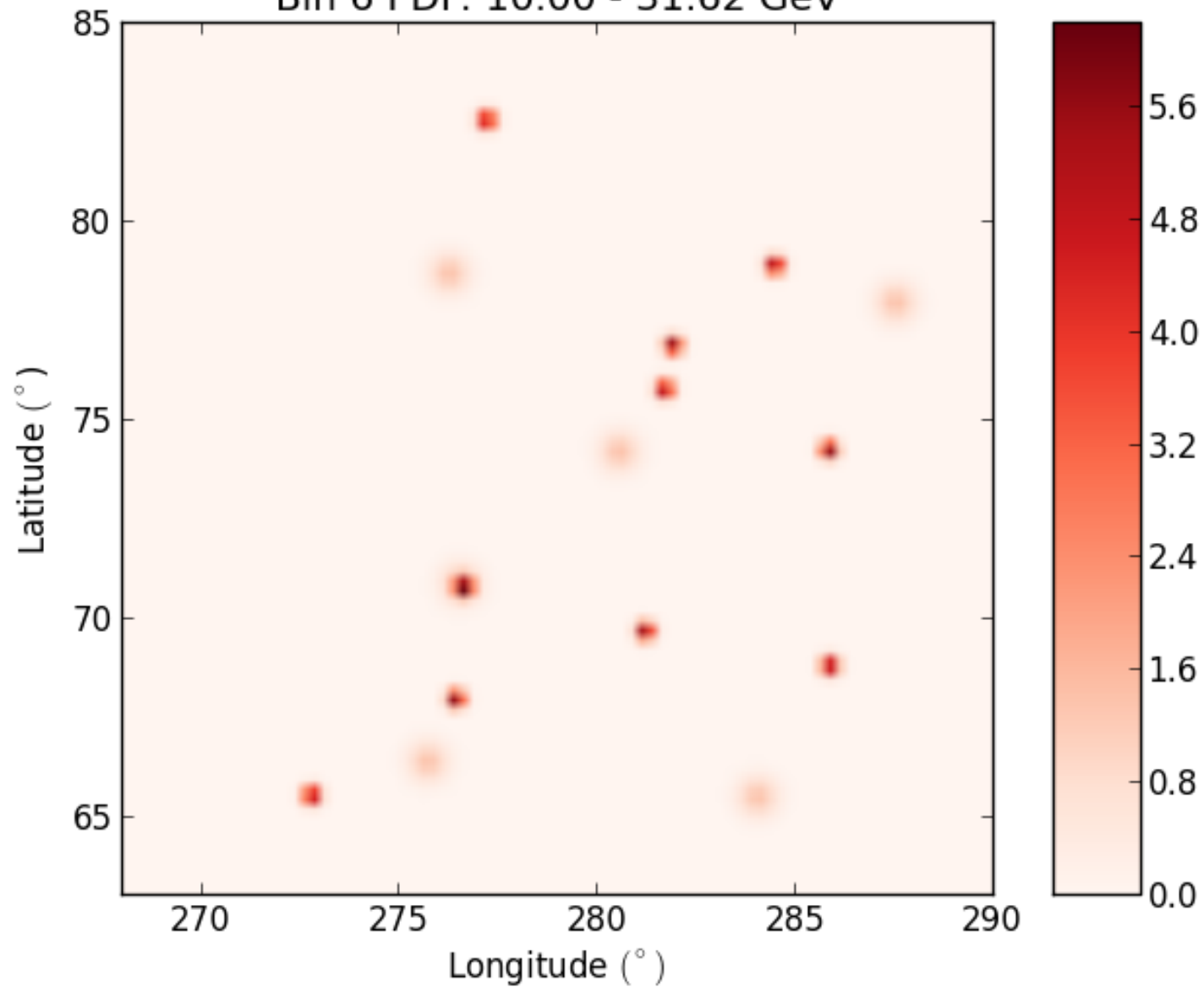


Bin 4 PDF: 1000 MeV - 3.162 GeV

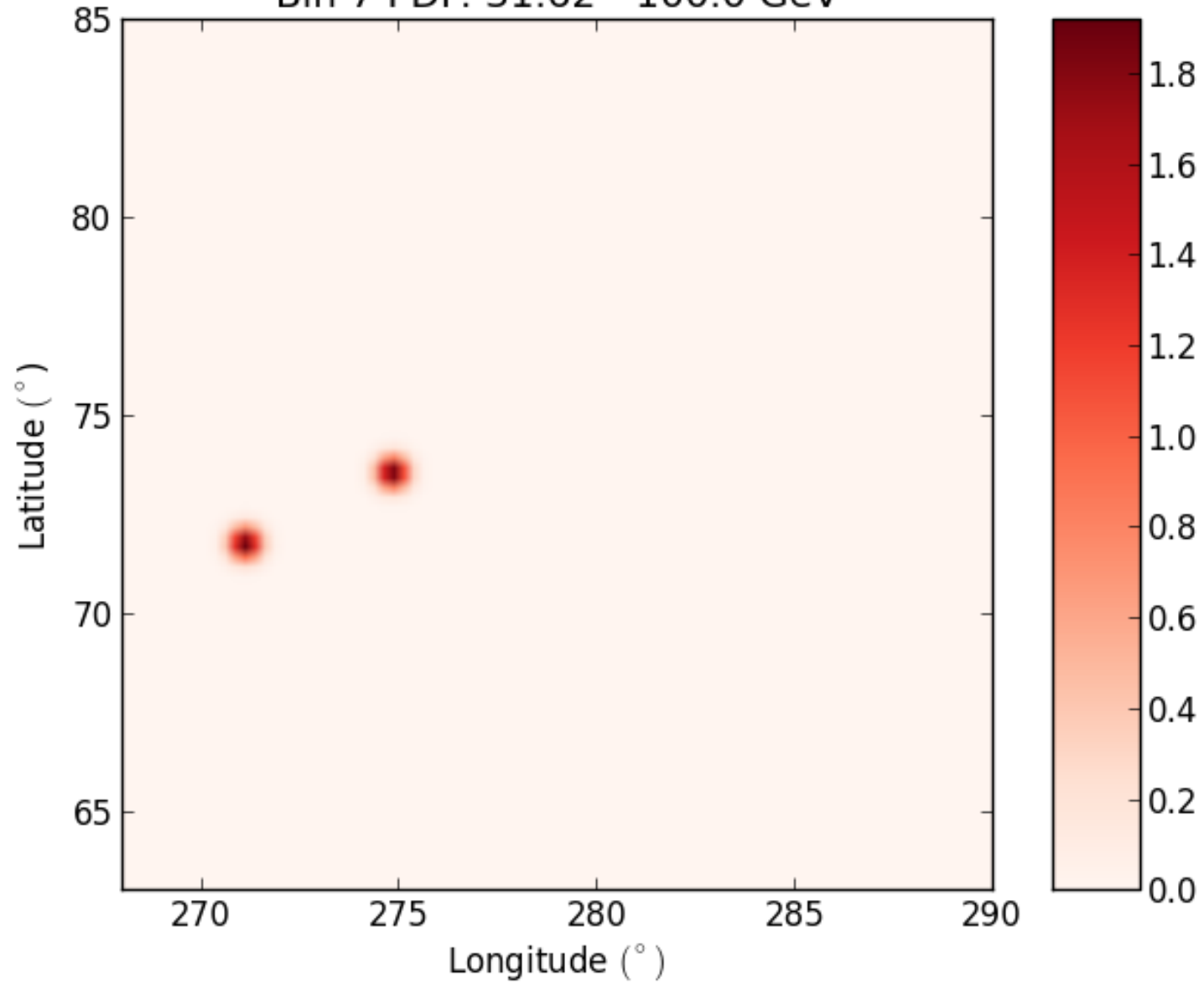




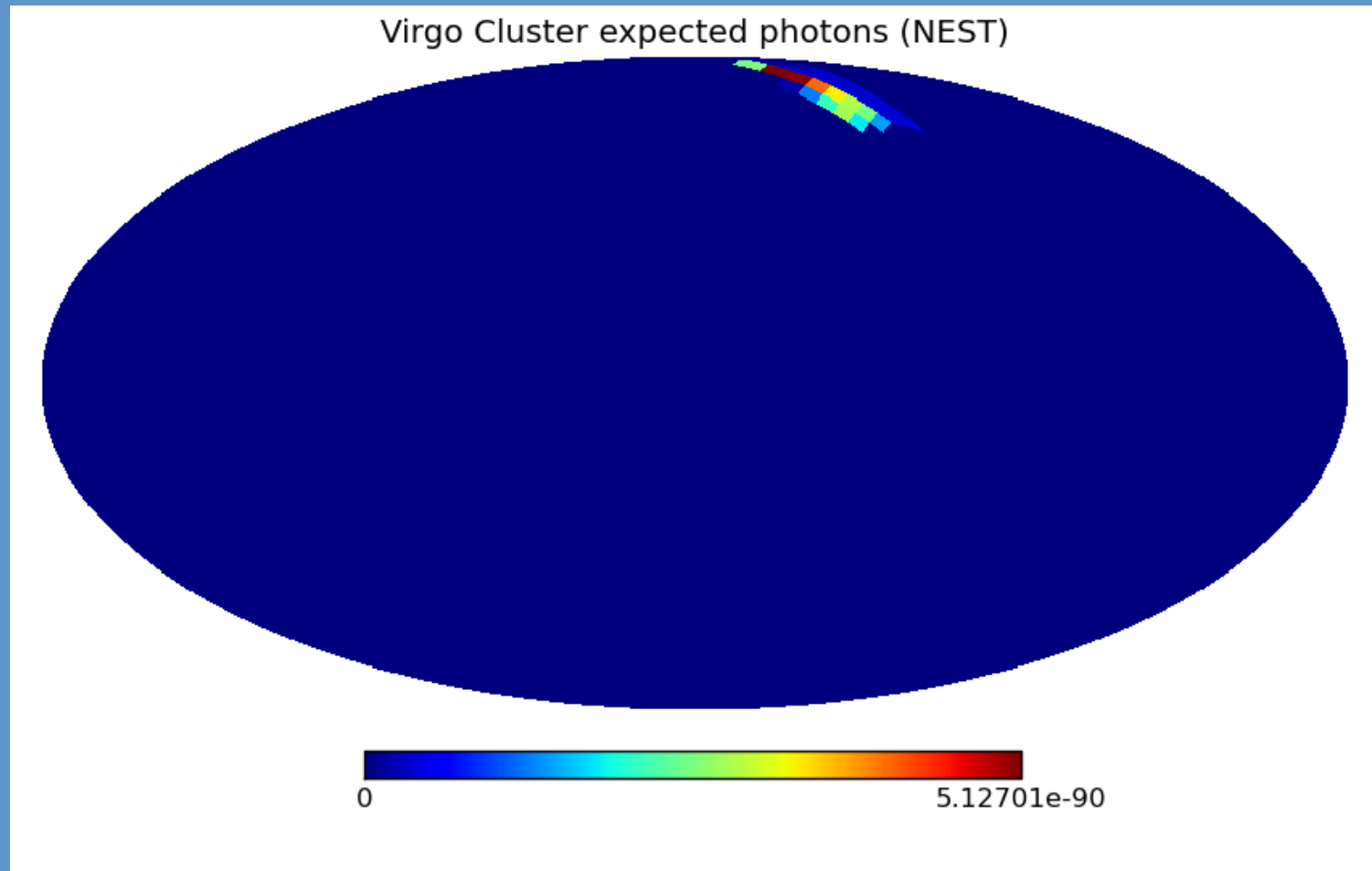
Bin 6 PDF: 10.00 - 31.62 GeV



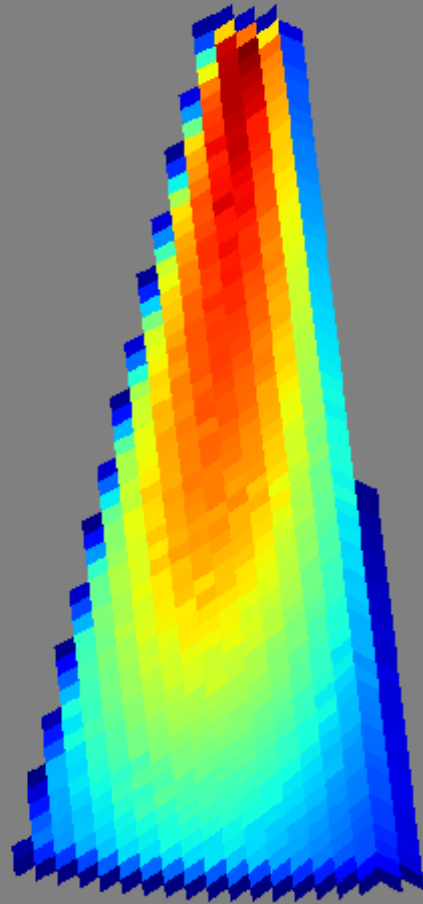
Bin 7 PDF: 31.62 - 100.0 GeV



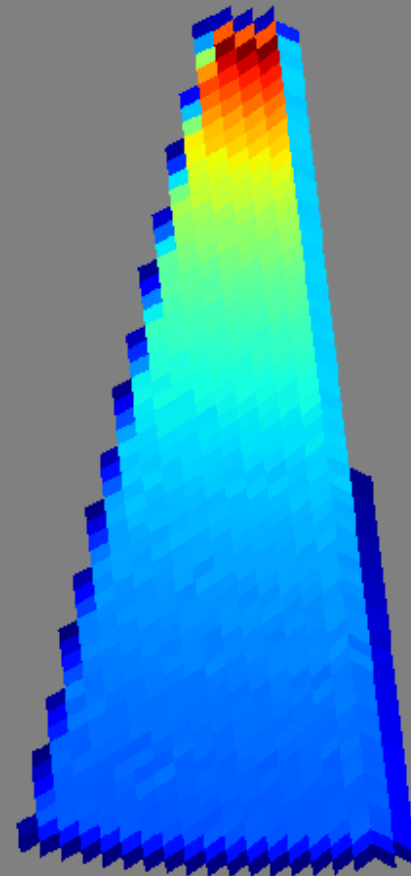
5th Week – First Attempts



Problem?



(-83,74)

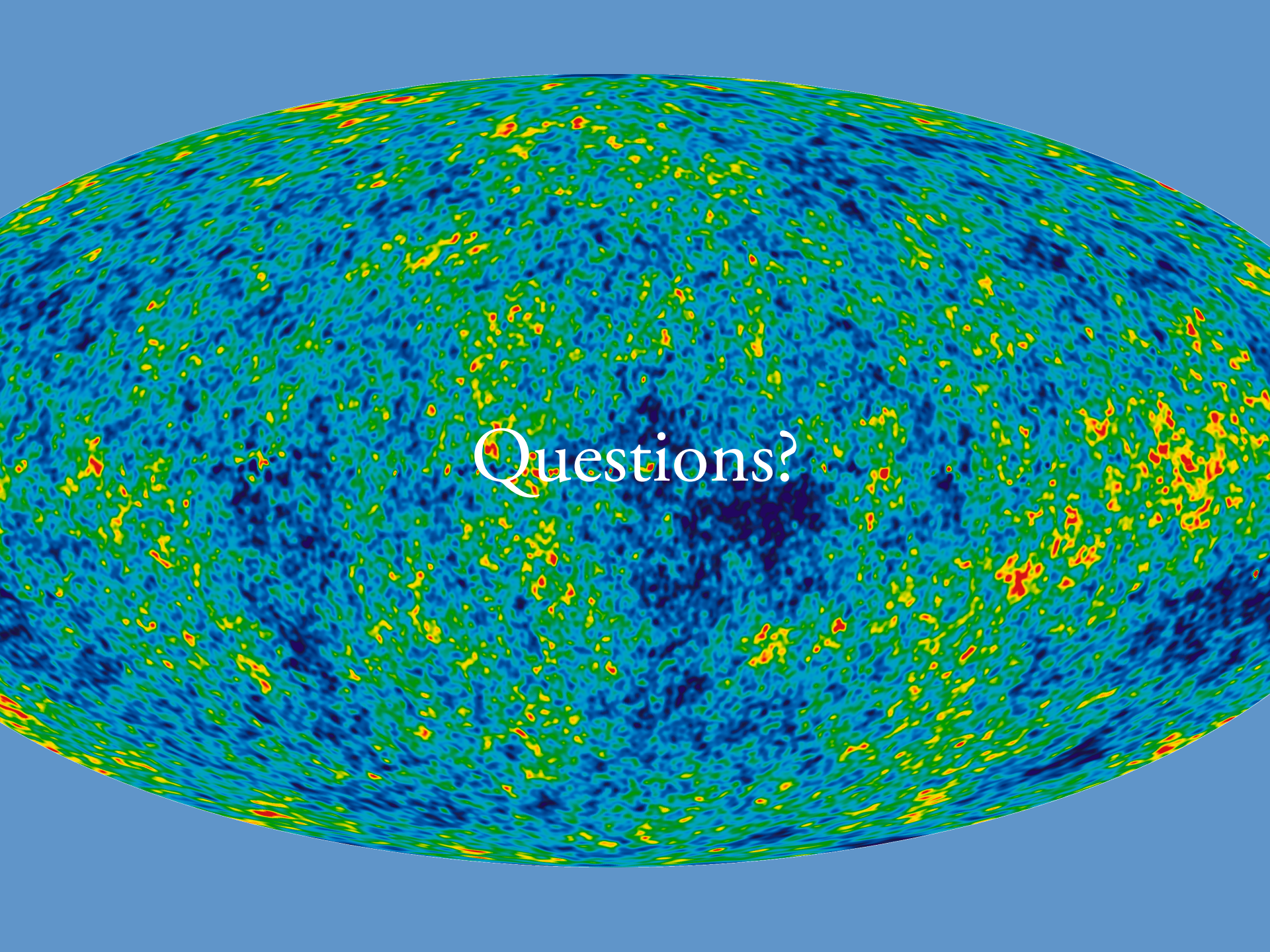


(-83,74)



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?