Energetic Particles In Star Forming Galaxies

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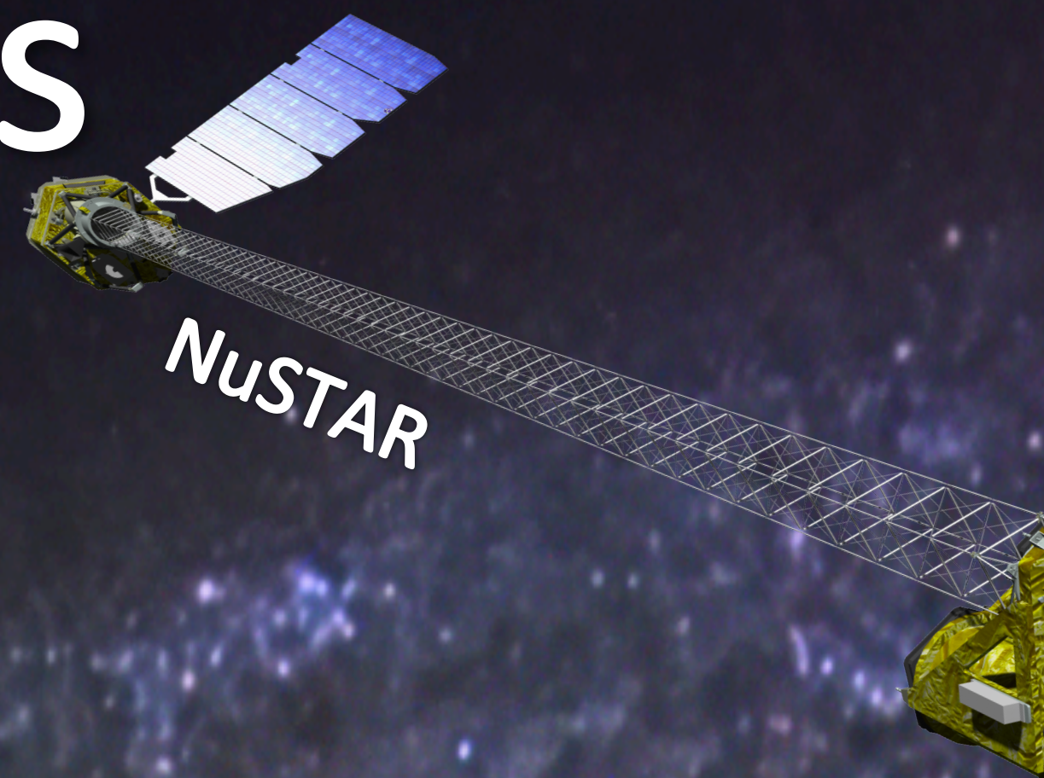
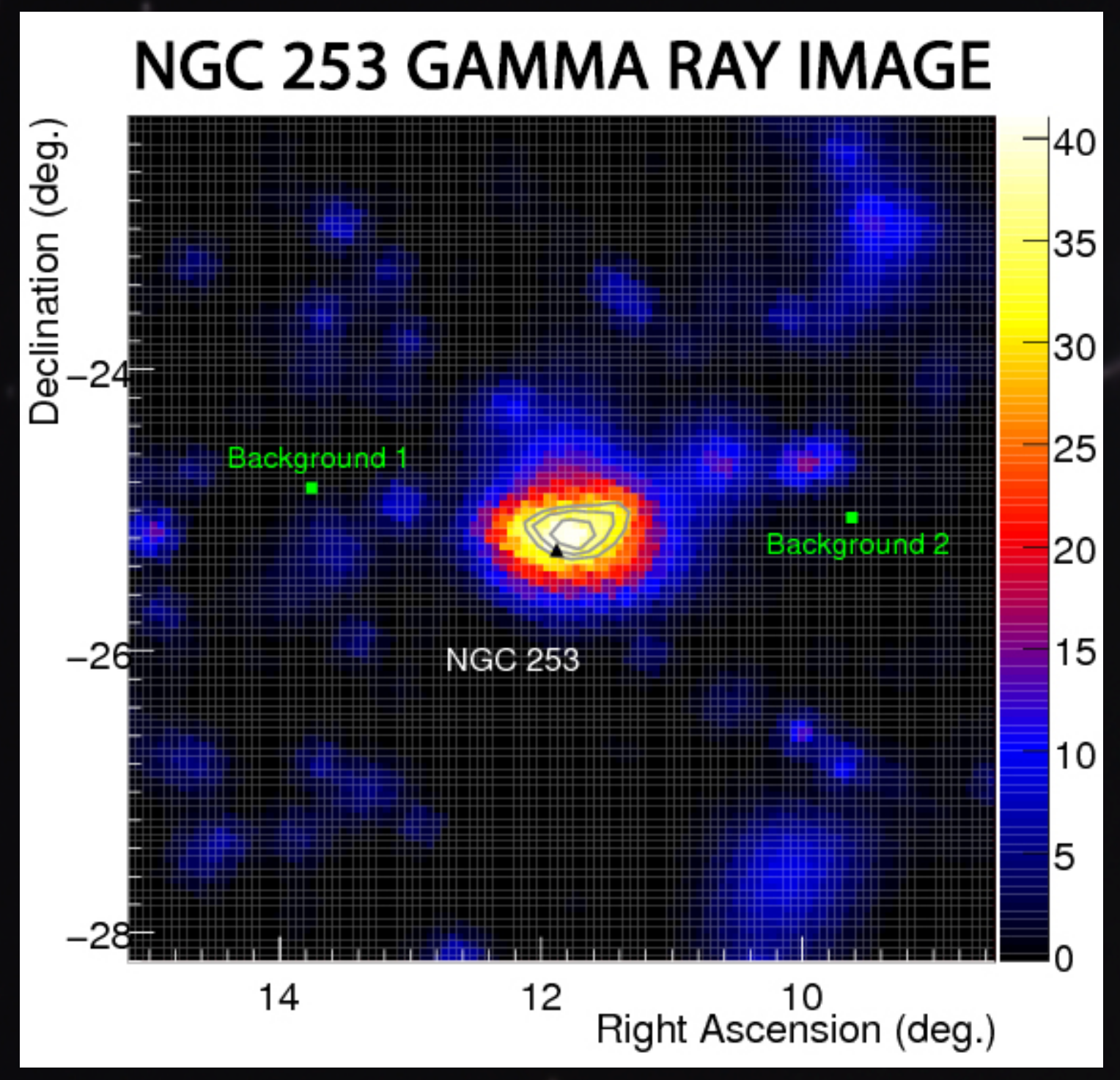
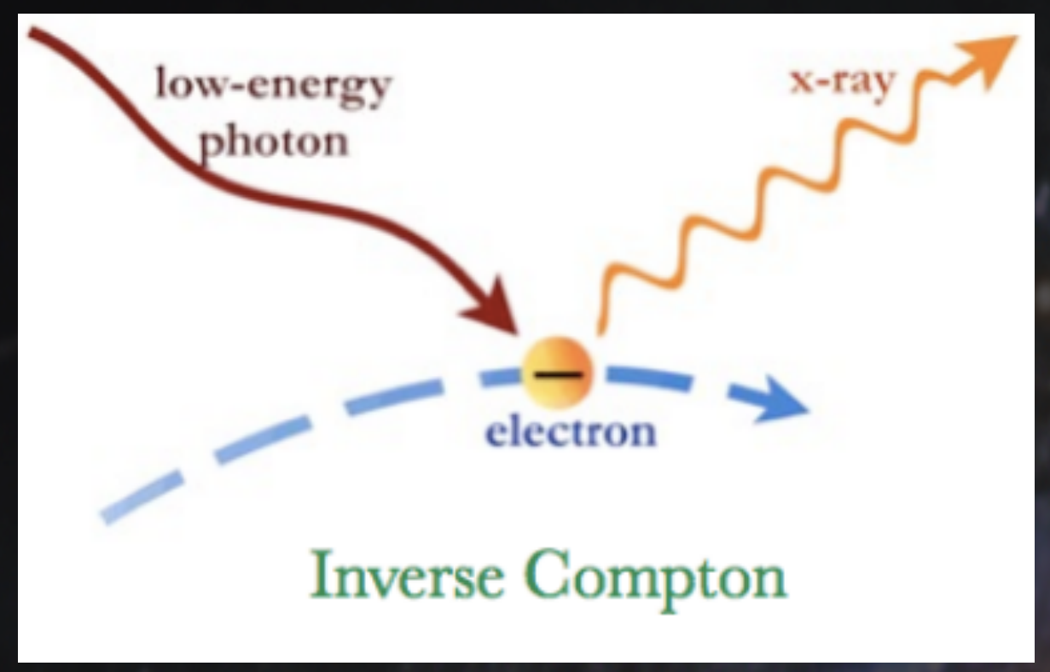


BACKGROUND

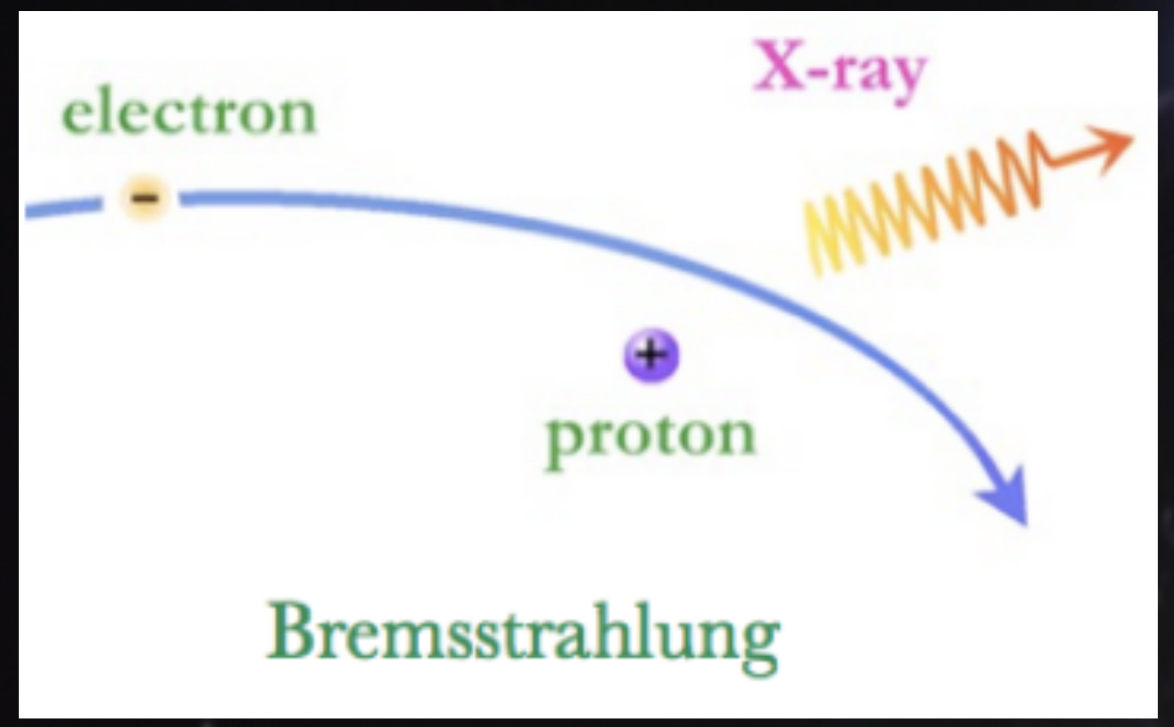


Starburst galaxies are galaxies with high rates of star formation, usually near the core of the galaxy. Because high star density leads to a higher rate of supernovae, the cosmic ray density is also higher, making starburst galaxies a prime source of gamma-ray emission as a result. The nearest starburst galaxies are M82 and NGC 253.

Even with data from Fermi (GeV) and NuSTAR (4-30 KeV), the origins of gamma rays within starburst galaxies remains elusive, since there are many particle processes that take place in starburst galaxies that can produce gamma rays:

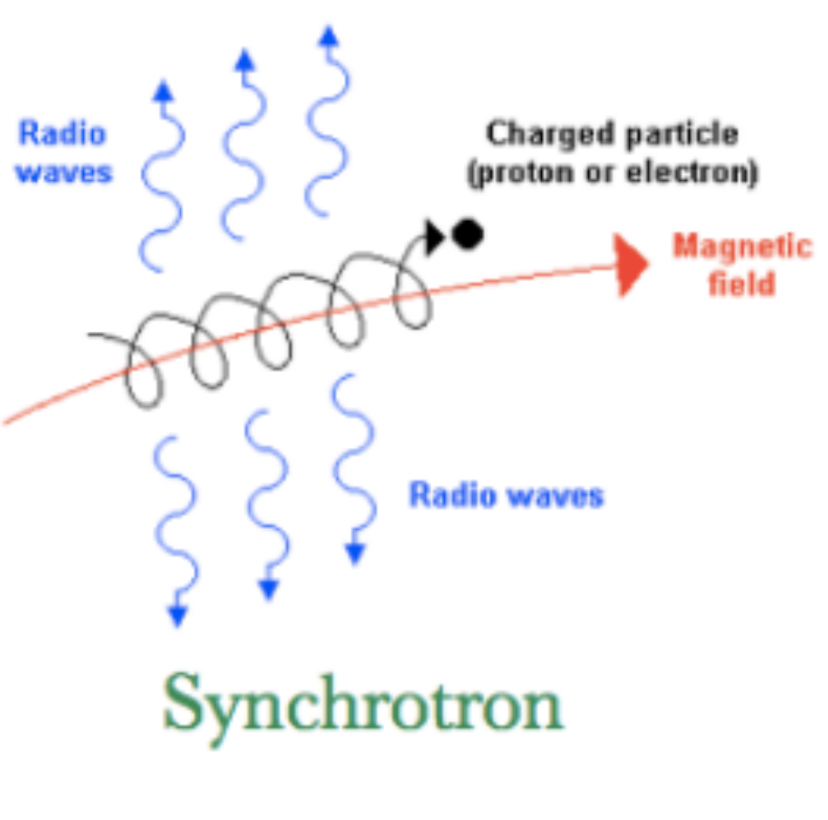


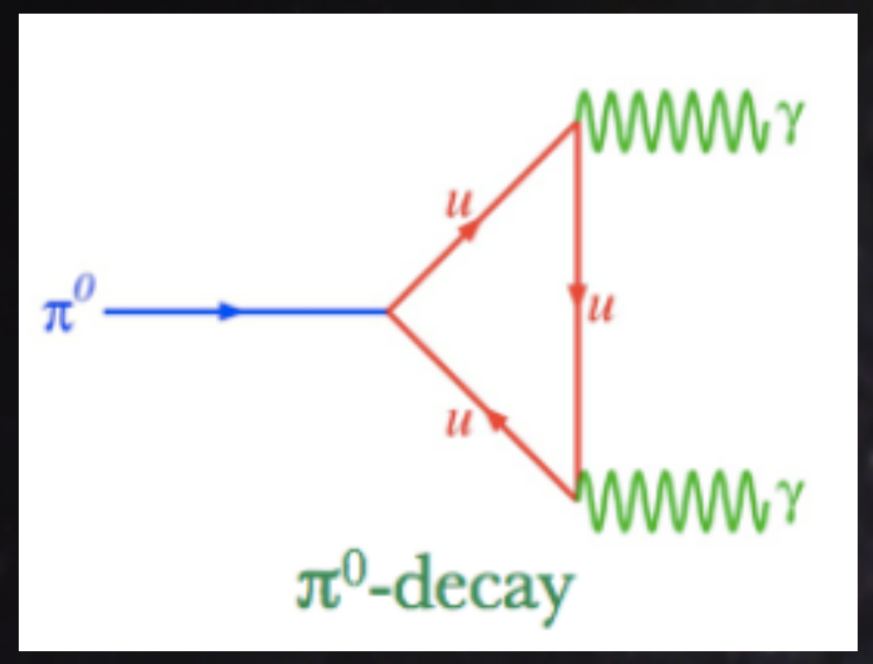
Inverse Compton Scattering: A charged particle transfers part of its energy to a photon, and the photon gains energy.



Bremsstrahlung: Radiation produced from the deceleration of a charged particle, typically an electron. The moving particle loses kinetic energy, which is converted into a photon.

Synchrotron Radiation: Radiation produced when relativistic charged particles spiral through a magnetic field.





Pion Production: The collision of cosmic ray protons and nuclei with interstellar medium particles produces excited states that lead to lead to pion emission.

Data from gamma ray telescopes such as Fermi and Hess cannot distinguish among the many viable models for gamma ray emission in starburst galaxies such as NGC 253. Determining the origins of the gamma ray emission would reveal important properties, specifically, the magnetic field strength, the cosmic ray spectrum, and the density of the interstellar medium and interstellar radiation.

INTRODUCTION

As can be imagined, the proton spectrum established from a cosmic ray detector near Earth will have a different form than at its origin in a supernova remnant shock wave. However, the original proton spectrum can be inferred through the following diffusion loss equation:

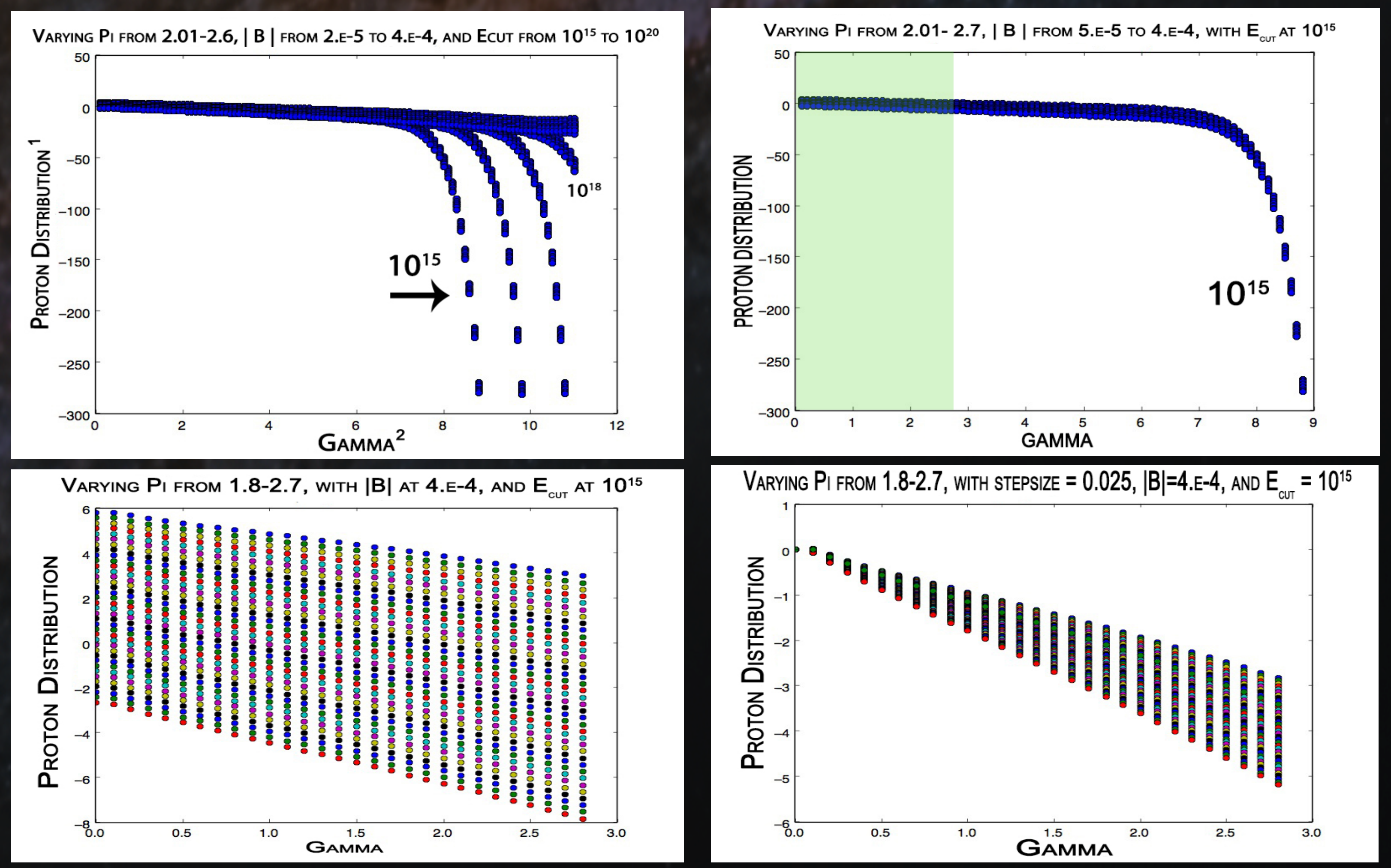
$$\frac{\partial}{\partial E}[b(E)N(E)] = \frac{N(E)}{\tau(E)} - Q(E)$$

$$N \propto E^{-P_f}$$

Where b(E) is a continuous loss term for protons as a result of ionization losses and pion production, tau(E) is an escape term for particles that leave the system, and Q(E) is a source term which describes the rate of injection of protons and their injection spectra into the source region.

METHODS

There were three variables, magnetic field, energy of the exponential cutoff, and power law index, that had a range of acceptable values which have been observed in other galaxies. Looping over all variables, we produced a variety of potential models that were then refined.

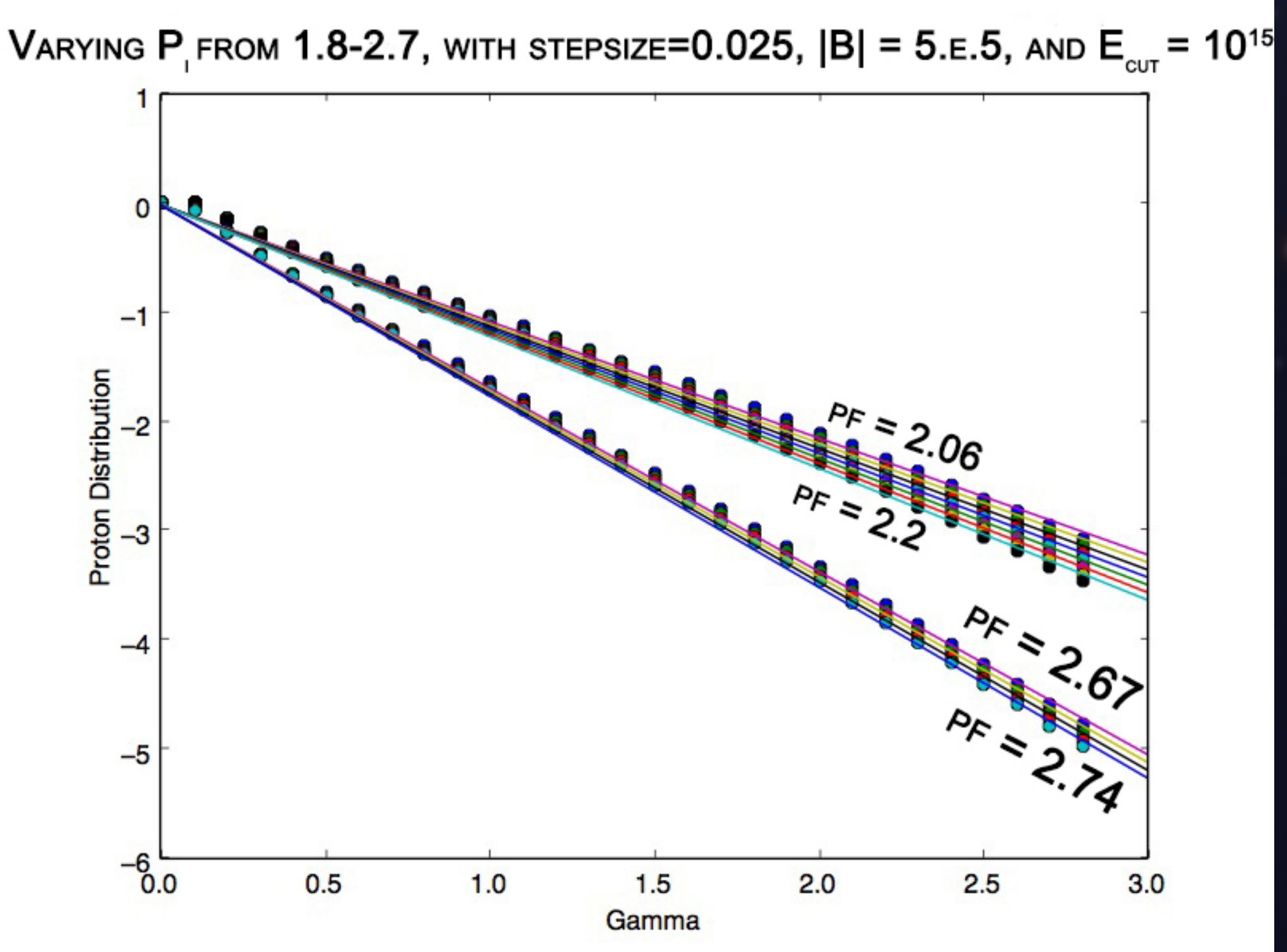


Graph 1: The initial plots of all potential models. Graph2: A conservative value for the magnetic field is chosen, and its discovered that varying the energy of the exponential cutoff is negligible, narrowing the number of models. Graph 3: Focus is narrowed to eliminate the exponential cutoff from calculations. Graph 4: All models are shifted to be plotted through the origin

[1] Proton Distribution is the number of protons per unit volume per logarithmic bin of energy (arbitrary units)

[2] (Gamma)mc^2 = Energy where (Gamma) is the Lorentz factor of the proton.

RESULTS



pi	pf
1.9	2.068887918
1.925	2.09172791
1.95	2.114626031
1.975	2.137587525
2	2.160601338
2.025	2.183675319
2.05	2.206803994
2.55	2.678075674
2.575	2.701978365
2.6	2.725905212
2.625	2.749857725

The best fit line for each model is overlaid onto their model points. The slope of the best fit line corresponds to the value of p_f for the fitted model. By comparing the output p_f values to theoretical expectations (2.1 for M82 and 2.7 for the Milky Way), we were able to remove models that were not around these values. We can now restrict our models to p_i values between 1.9-2.05, and 2.55-2.625.

FUTURE

With further work, future steps would include calculating the secondary particles created from pion production and the resulting gamma ray emission, allowing comparison between the models and data from Fermi, NuSTAR, and HESS. Comparing the models to the data would give us a broader understanding of the processes occurring within NGC 253.

With models alone, we can never definitively understand the conditions within NGC 253 without incorporating actual datasets, thus future steps would use data from Fermi and NuSTAR. There are many parameters in this problem, and we have many classes of models, so we would like to constrain on as many data points as possible.

As a final note, I would like to take this opportunity to thank my mentor, Toni Venters, for the support and guidance of this project.

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