Extended Gamma Analysis of SNR G330.2+1.0

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Fermi Gamma-ray Space Telescope

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Abstract

Analyzing gamma rays is an important aspect of modern astronomy and astrophysics, for they are the most powerful bands of energy on the electromagnetic spectrum. Comprehending gamma rays allows for deeper understanding of countless phenomena within our universe, such as cosmic rays. Cosmic rays are high energy particles thought to be formed via extremely violent explosions within our universe. These accelerated particles mirror conditions present in a supernova. A supernova is what occurs when a star at least 8 times as massive as our sun reaches the end of its lifespan and bursts. These explosions are the most powerful events ever to be recorded by astronomers and can be used to assist our understanding of cosmic rays in many ways. Using the Fermi Large Area Telescope (LAT), we observed the supernova remnant (SNR) G330.2+1.0. Previous X-ray observations could only characterize the spectra of a few regions within the SNR. In this project we compared previous X-ray data with the most current gamma-ray data from Fermi at GeV energy levels. While the SNR itself is not detected by Fermi, we placed the upper limits on the maximum GeV emission coming from this SNR. Our results help to discriminate between previously published models of the particle acceleration that has occurred in this SNR.

What's a Supernova Remnant (SNR)?

- A supernova occurs when a star at least 8 times as massive as our sun reaches the end of its life and explodes, causing extremely powerful shockwaves.
- When these shockwaves occur, particles are scattered back and forth across the shock by magnetic waves, causing them to gain energy and emit light at x- and gamma-ray energies, via Inverse Compton Scattering, depicted in Figure 3.
- A supernova remnant (SNR) is the outer blast wave left behind after the initial event. These shells can persist for tens of thousands of years after the supernova. It is plausible to have a residual neutron star form from the matter of the explosion. This occurs when the protons and electrons merge together to form neutrons. Neutron stars can spin at incredible speeds, sometimes hundreds of revolutions per second, creating their own shockwaves from the winds from their magnetic fields.
- SNR G330.2+1.0 is a young, but relatively unstudied SNR. It was the focus of this work to see if it may be accelerating cosmic rays.

NASA's Fermi Large Area Telescope (LAT)

- *Fermi* LAT was launched in 2008 and is still in operation.
- LAT detects gamma-ray light at MeV to TeV energies.
- Fermi was initially launched to find the sources of cosmic rays.
- *Fermi* then began to detect large amounts of gamma-rays from "small" pinpoints that they then determined to be SNRs.
- SNRs are a promising source for cosmic rays, as there are only a handful of events powerful enough to accelerate particles to these enormous energies.
- Fermi has seen many other cosmic ray sources, including black holes, pulsars and star clusters.

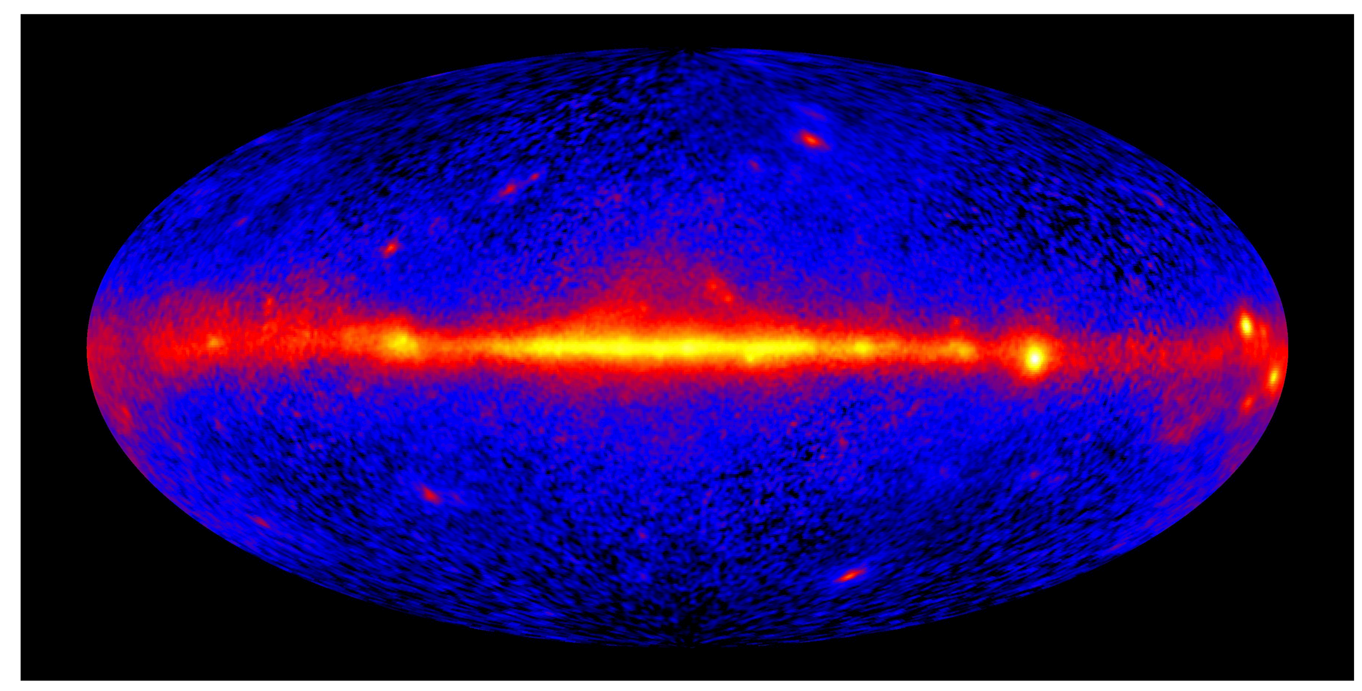

Figure 1: This shows all the gamma ray emission from the Milky Way Galaxy in a 360° view. The center "line" is the galactic plane, where most of the gamma emission is shown to come from. [2]

Searching for high-energy gamma-rays from SNR G330.2+1.0

- The SNR G330.2+1.0 is known to be relatively young, ~1,000 years old. Since this SNR is at least 15,000 light years away, it has not been previously detected in gamma rays by *Fermi*. It has also been concluded to have mostly nonthermal emission, which is interesting because it is one of the very few to fall into this category. We can use the analysis done on this SNR to help determine possible sources for cosmic rays. These rays are thought to be created via Inverse Compton Scattering, or the excitement of lower energy particles.
- We obtained 11.5 years of data from Fermi-LAT. To complete the analysis, we used the Python-based analysis tool "*Fermipy*". It is a very usable online program with "preset" guides and notebooks allowing the public to run various analyses with the LAT Data. Our analysis included a simple point Source upper limit analysis using pylikelihood.
- In our analysis, we used the standard analysis settings for a point source using the fermi science tools v1.2.23, as well as the standard isotropic and galactic diffuse emission models.
- The 4th Fermi LAT catalog of sources (4FGL) was used as a model for gamma rays, that allowed us to search for a new source at the location of the SNR.

We found a 95% confidence level upper limits for two energy ranges:

- We did not find any significant gamma rays to attribute to the SNR, but were able to place an upper limit on the flux that Fermi LAT would have been able to see.

Energy Range	Energy Flux
1-10 GeV	0.771 eV/cm^2/s
10-100 GeV	0.509 eV/cm^2/s

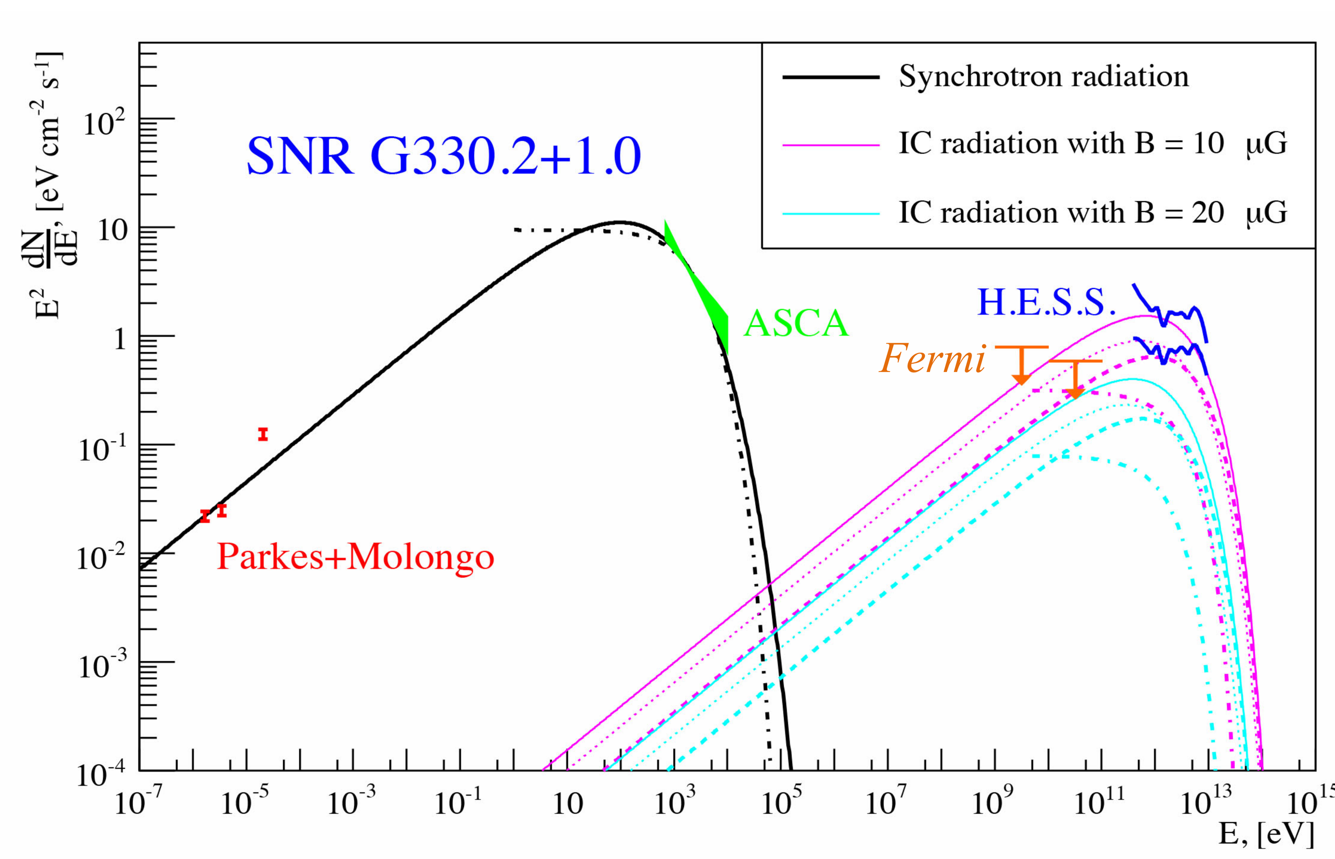

Figure 2: This is a spectral energy distribution of the SNR G330.2+1.0. The orange bars indicate the upper limits in two regions of this spectrum. The original distribution is provided from the HESS analysis done on G330.2+1.0 [3]

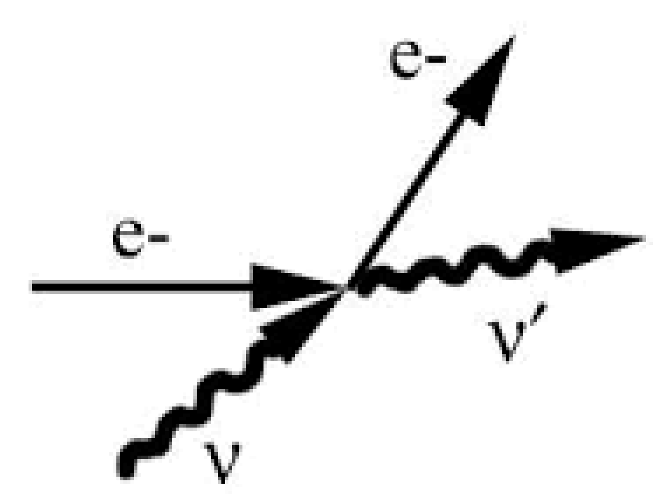

Figure 3: This depicts Inverse Compton Scattering, a process that occurs within supernovae. Inverse Compton Scattering is when an incident particle interacts with an electron and takes some of its energy, exciting the incident particle to a higher state.

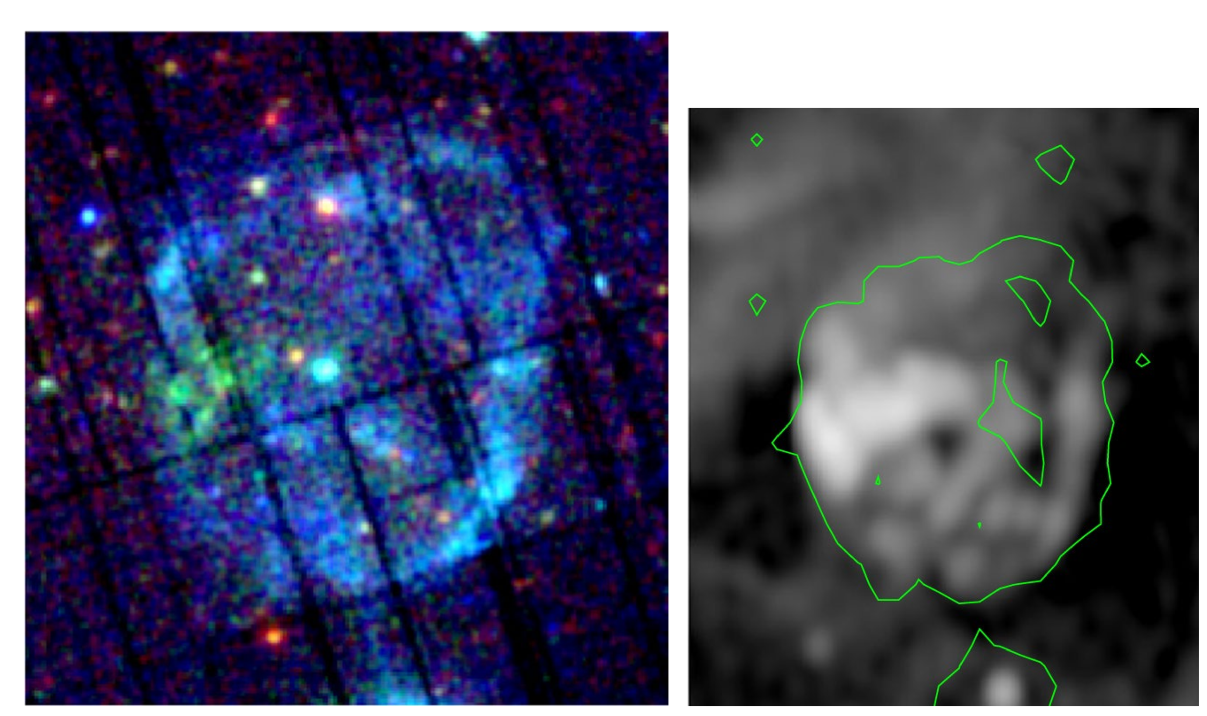

Figure 4: These are side by side images depicting G330.2+1.0 using different wavelengths to gather an image. The left is a multi band image using a range of energies from 0.4-7.0 keV. The right is using only radio waves at 843 MHz to gather information. [4]

Conclusions

From Figure 2, we can conclude that that the magnetic field of this SNR is at least 20µG. This is consistent with the findings of [5] done using the Chandra-X telescope, as fields of about 100µG are expected for particle acceleration to occur. This is a positive comparison for it furthers the conclusion this young SNR may be actively accelerating cosmic rays. However, there is not enough target material for the freshly accelerated cosmic rays to see any gamma-rays due to hadronic pion decay. The electron spectrum is known from radio and x-rays, which is why there are constraints in *Fermi* seeing G330.2+1.0 in gamma rays.

References (as needed)

[1] https://arxiv.org/abs/1404.1613
[2] https://svs.gsfc.nasa.gov/12969
[3] https://ui.adsabs.harvard.edu/abs/2014MNRAS.441..790H/abstract
[4] https://ui.adsabs.harvard.edu/abs/2018ApJ...855..118W/abstract
[5] https://ui.adsabs.harvard.edu/abs/2018ApJ...868L..21B/abstract