Supernova Remnants and Cosmic Ray Acceleration Mechanisms

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Abstract

Supernova remnants (SNRs) are considered to be the primary energy source of galactic-origin cosmic rays. Within this prediction exist two models, leptonic and hadronic, to explain the acceleration of charged particles up to a PeV in energy. Using data from the Fermi Gamma-ray Space Telescope (FGST) each model is expected to produce a distinct spectral energy distribution (SED) over a photon energy range of 100MeV to 100GeV. This analysis is focused on the methods for generating SEDs for the SNR Cassiopeia A and how they can be used to constrain the likelihood of either acceleration model.

1. Fermi Gamma-ray Space Telescope

The FGST was launched in 2008 as a space-based gamma ray observatory. The FGST uses a particle tracking system, the Large Area Telescope (LAT), to reconstruct the incoming energy and angle of gamma ray photons.
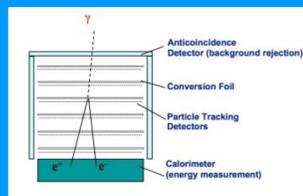

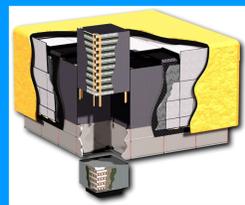Fig 1a – The Fermi LAT (Schematic)

Fig 1b – The Fermi LAT (Cutaway)

The LAT is a 1.8m cube composed of alternating layers of tungsten and silicon strips. A gamma ray photon will tend to convert into an electron-positron pair after interacting within one of the tungsten strips. The incoming photon angle is then reconstructed from the silicon strip track data. The photon energy is reconstructed from the scintillation intensity produced by the electron-positron pairs as they pass into a cesium iodide crystal at the base of the LAT.

2. SNRs

In the aftermath of a supernova a shockwave of gas is produced, expanding at thousands of km/s, and heated through collisionless shock into the interstellar medium (ISM). The magnetic gradient associated with this expanding shell is predicted to be primary driver of cosmic ray acceleration.
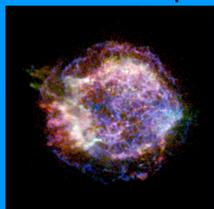

Fig 2 – SNR Cassiopeia A

3. Fermi Acceleration

At the boundary of a SNR there is a probability particles in the ISM will be accelerated by the moving magnetic gradient. There is an additional probability such particles will pass back through the boundary multiple times, picking up an additional acceleration each time. These particles are expected to emit gamma radiation, with emission spectra dependent on the particle population.
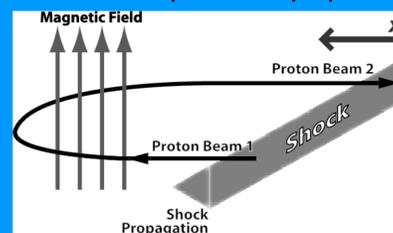

Fig 3 – Fermi Acceleration

Leptonic model - If the accelerated particles are electrons then gamma rays are produced through inverse Compton scattering and Bremsstrahlung radiation.

Hadronic model - If the accelerated particles are protons then gamma rays are the product of neutral pions produced from proton collisions

4. Isolating Sources

To focus on a specific source the background signal, composed of the galatic and intergalactic diffuse emission, is modeled then removed from observational data within a particular region, time window, and energy range.
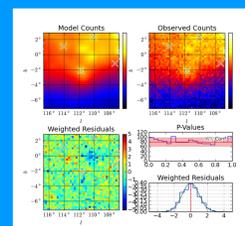

Fig4 – A comparison of observed and modeled data for Cassiopeia A

5. Fitting An SED

With the background data effectively removed a SED, a comparison of the observed photon energy flux versus the photon energy, of a particular source can be be generated. Then, using the *pointlike* analysis package, a spectral function is fit to the SED points.
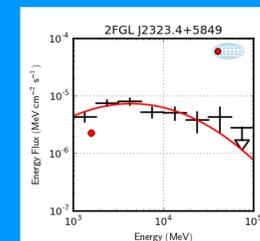

Fig 5 – A SED of Cassiopeia A

6. Conclusions

The photon energy flux, generally falling with photon energy over 1-100GeV, is evidence of a primarily hadronic emission model. However, more reliable results will require longer exposures as this analysis is based on a relatively small number of photons.

7. Acknowledgments