Cosmic Ray Electron Science with GLAST

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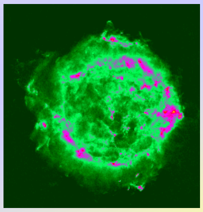
Abstract: Cosmic ray electrons at high energy carry information about their sources, their diffusion in local magnetic fields and their interactions with the photon fields through which they travel. The spectrum of the particles is affected by inverse Compton losses and synchrotron losses, the rates of which are proportional to the square of the particle's energy making the spectra very steep. However, GLAST will be able to make unique and very high statistics measurements of electrons from ~20 to ~700 GeV (see accompanying poster by Moiseev et al.) that will allow us to search for anisotropies in arrival direction and spectral features associated with some dark matter candidates. Complementary information on electrons of still higher energy will be required to see effects of possible individual cosmic ray sources.

Origin of Cosmic Rays up to 1 TeV: Outstanding Questions

- Supernova shock acceleration
  - Localized supernova
  - Superbubble clustered supernova
- Cosmic ray propagation
  - Diffusion coefficient ✓
  - Uniformity across galaxy ✓
  - Arm, inter-arm intensity contract
  - Penetration into clouds
- Spectrum and intensity of cosmic-rays
  - Local interstellar spectrum ✓

Cas A radio



✓ Accurate measurements of cosmic ray electrons up to 1TeV are important for this science

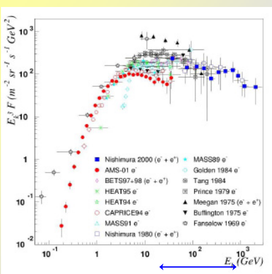
Overview

In an accompanying poster we demonstrate that the LAT will be capable of high precision measurements of cosmic ray electrons over the energy range ~20 to ~700 GeV. These measurements will be unique and contribute to the understanding of cosmic ray electrons and their production of photons by inverse Compton and synchrotron processes in the local environment. It is in this energy band that the spectral steepening is expected from these processes.

With its large field of view and collecting power LAT will be able to measure the dipole anisotropy in electron arrival directions, to study their diffusion and to search for effects of electron streaming in the local galactic magnetic fields (1).

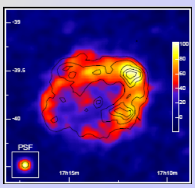
Finally, we will be able to search for the spectral feature (a sharp upper edge) that might be produced by the decay of dark matter candidates such as Kaluza Klein dark matter particles (2).

Cosmic Ray electron spectrum

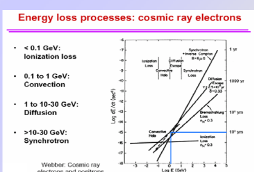


LAT range

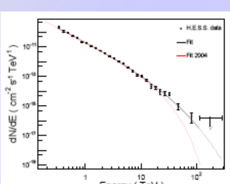
Compendium[9] of electron measurements shows our poor understanding of the very steep electron spectrum in the range from a few GeV to 100 GeV and the paucity of measurements up to 1 TeV.



TeV photon image (ref 11) of RX J1713.7-3946. The 1-3 keV ASCA contours drawn as black lines (Uchiyama et al. 2002) for comparison, combined with the emission of 1-100 TeV photons demonstrates the presence of high energy electrons with very short lifetimes. This combination suggests the conclusion that high energy particle acceleration is taking place in the remnant.



Spectral shape over the LAT band is determined by losses of particles on a galactic scale by diffusion and convection from the galaxy (see ref. 5).

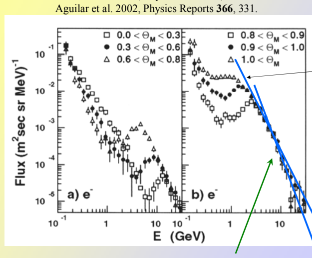


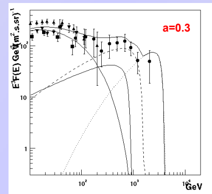
HESS spectrum of RX J1713.7-3946 shows slope with power law index 1.8, implying an index for the electron spectrum of 2.6. This is somewhat steeper than would be expected at the source of galactic cosmic rays. Diffusion models, in which the rigidity dependence of the diffusion coefficient varies as $E^{-0.33}$, should lead to an electron spectrum with a slope $E^{-(2.6+0.33)} = E^{-2.93}$ in the range between 1 and 7 GeV. Then, due to synchrotron and Compton losses it should steepen to $E^{-3.6}$ in the range 10-100 GeV. On the other hand, the x-ray data (synchrotron) is consistent with a much harder source spectrum. Accurate measurements of the electron spectrum at Earth are essential to resolving these discrepant models for the source spectrum of cosmic rays.

What can GLAST contribute to electron science?

1) Precise measurement of electron spectrum from 10 to 800 GeV.

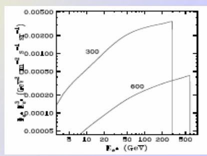
Alcaraz et al. 2000, Phys. Lett. B **484**, 10. See also Aguilar et al. 2002, Physics Reports **366**, 331.





Green arrow indicates break in spectral slope at ~7 GeV corresponds to change between energy regions where diffusion and synchrotron losses dominate. Above this energy, the spectrum will continue with a constant slope until effects of nearby sources and diffusion in local magnetic fields become interesting above 1 TeV.

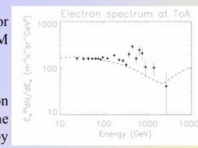
2) Kaluza-Klein dark matter particles (?) for GLAST energy band.



Flux of e+ + e- from KKDM annihilations from Baltz and Hooper (2). Note the sharp spectral upper bound at the particle mass.

Left: The electron signature for 300 and 600 GeV mass KKDM particles (ref 2).

Right: **Preliminary** electron spectrum at the top of the atmosphere as measured by ATIC-2 show a feature that begs further investigation (ref 4).



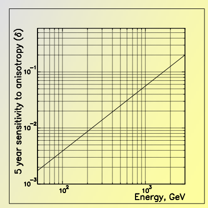
Absolute electron spectrum comparison with calculated model by a diffusion coefficient of $D=2.0\times10^{29}(E/TeV)^{0.3}$ cm^2 s^{-1} and a power index for the injection spectrum of 2.4.

3) Measurement of electron anisotropy

Below 100 GeV, GLAST should observe anisotropies in the arrival direction of electrons due to diurnal variations and due to the motion of the Earth around the sun and be able to see the large scale effects of the solar magnetic field. Above 100 GeV we should become sensitive to the local interstellar magnetic fields. Figure to right courtesy R. Terrier[8].

When located within the diffusing zone of particles coming from a single source[10], the expected anisotropy can be related to the gradient in the particle density as follows:

$$\delta = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$



Current and Planned electron detectors (10-1000 GeV)

Experiment	Energy meas.	Collecting power	Top Energy
BETS balloon payload	calorimeter	1 m^2 sr day	100 GeV
ATIC balloon payload	calorimeter	10 m^2 sr days	1.5 TeV
CREAM balloon payload	calorimeter	30 m^2 sr days	2 TeV
CREST balloon payload	synchrotron	>300 m^2 sr day	3-50 TeV
AMS-1	magnet spect.	0.2 m^2 sr days	30 GeV
PAMELA satellite	magnet spect.	40 m^2 sr days	1-2 TeV
AMS-2	magnet spect.	400 m^2 sr days	2-3 TeV
CALET[7]	calorimeter	700 m^2 sr days	5 TeV
GLAST	calorimeter	>3000 m^2 sr days	0.7 TeV

Conclusions

- GLAST will make important new measurements of the electron spectrum from 20-800 GeV determining the intensity and spectral slope in the range where the shape is determined by synchrotron and Inverse Compton energy losses.
- With high statistics GLAST can look for spectral features on this spectrum that would be produced by various models for the dark matter in the galaxy, complimenting other LAT searches. In particular, we should be sensitive to Kaluza Klein Dark Matter particles with masses up to 800 GeV.
- GLAST can study anisotropies in arrival directions associated with the large scale solar field, including diurnal and sidereal effects. It can also search for anisotropies associated with cosmic rays from nearby supernova remnants and streaming in the local galactic magnetic fields.

References

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