Future GLAST Observations of Supernova Remnants and Pulsar Wind Nebulae

S Funk[1]

(for the GLAST LAT Collaboration Pulsars, Supernova Remnants and Plerions working group)

[1] Kavli Institute for Particle Astrophysics and Cosmology, Stanford, PO-Box 0029, 2575 Sand Hill Road, Menlo Park, CA-94025, USA

Abstract

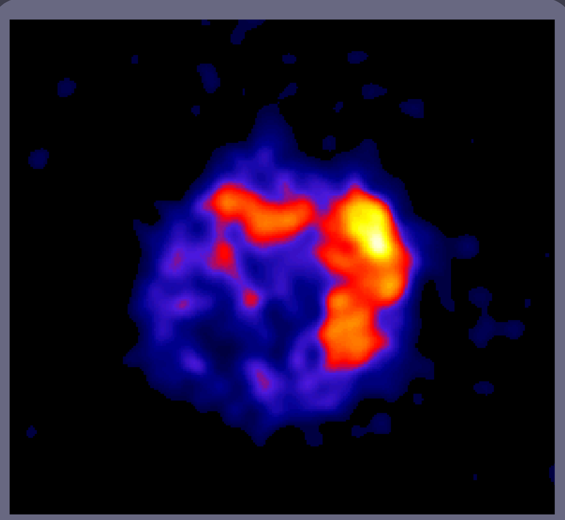
Shell-type Supernova remnants (SNRs) have long been known to harbour a population of ultra-relativistic particles, accelerated in the Supernova shock wave by the mechanism of Diffusive shock acceleration [1]. Experimental evidence for the existence of electrons up to energies of ~100 TeV was first provided by the detection of hard X-ray synchrotron emission as e.g. in the shell of the young SNR SN1006 [2]. Furthermore using theoretical arguments shell-type Supernova remnants have long been considered as the main accelerator of protons – Cosmic rays – in the Galaxy; definite proof of this process is however still missing.

Pulsar Wind Nebulae (PWN) – diffuse structures surrounding young pulsars - are another class of objects known to be a site of particle acceleration in the Galaxy, again through the detection of hard synchrotron X-rays such as in the Crab Nebula [3].

Gamma-rays above 100 MeV provide a direct access to acceleration processes. Ultra-relativistic electrons emit gamma-radiation through Inverse Compton scattering in ubiquitous photon fields (such as CMBR, star light and dust emission or local synchrotron radiation), protons emit gamma-radiation through the decay of π^0s, generated in proton-proton interactions with Interstellar material such as gas clouds. Recent advances in ground-based gamma-ray astronomy e.g. made by Cherenkov Telescopes above an energy threshold of 100 GeV have shown, that both shell-type SNRs and PWN are classes of gamma-ray emitting objects in the Galaxy [4,5].

The upcoming GLAST Large Area Telescope (LAT) will be operating in the energy range between 30 MeV and 300 GeV and will provide excellent sensitivity, angular and energy resolution in a poorly investigated energy band. Shell-type SNRs as well as PWN provide natural targets for GLAST observations and detections and in this poster we will describe prospects for the investigation of these Galactic particle accelerators with GLAST.

Shell-type Supernova remnants



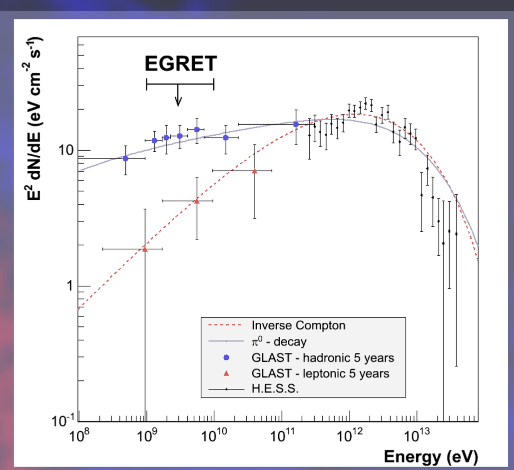
Shell-type SNR RX J1713.7-3946 as seen in gamma-rays above 100 GeV, by the Cherenkov telescope H.E.S.S. [4]. The emission is found to trace very well the non-thermal X-ray emission found in the shell of the SNR. GLAST measuring in the energy band bracketed by existing data will shed new light on acceleration processes in objects of this kind.

Supernova remnants, through shocks in their expanding shells, have long been thought to accelerate charged particles to ultra-relativistic energies. These charged particles can subsequently emit X-ray photons or Gamma-rays through interactions with magnetic fields and surrounding material. In spite of recent detailed studies in these wavebands, the nature of the parent population responsible for the gamma-ray emission remains elusive. However, it is not yet evident, whether the bulk of the gamma-rays are produced by Inverse Compton scattering of electrons (e.g. on the CMBR), or by hadronic interactions and subsequent π^0-decay. If the hadronic origin of the gamma-ray emission can be established, this would be a great step towards the final proof that shell-type SNRs are the long sought source of cosmic rays in the Galaxy.

Although EGRET did find a statistical associations of gamma-ray emission with shell-type SNRs (and related sources) [6], no individual shell-type SNR was unambiguously identified. GLAST, however, has the spectral and angular resolution to make the first detailed study of these object in the 30 MeV to 300 GeV band.

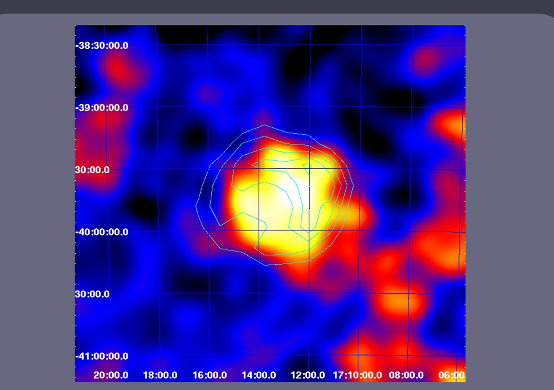
Spectral Studies of shell-type Supernova remnants

The GLAST-LAT will provide measurements of gamma-ray spectra between 30 MeV and 300 GeV, a previously poorly-explored energy regime. Using LAT data will allow us to distinguish between different models for the gamma-ray emission. Gamma-rays of leptonic origin (produced by IC) can be distinguished from those of hadronic origin (produced by π0-decay) through their characteristic spectral shape. Previous measurements in higher energy gamma-rays above 100 GeV provide strong constraints on the emission level for these different models. The right hand figure shows prediction for energy spectra for a hadronic and a leptonic model illustrating that the LAT energy range is particularly well suited to distinguish these models and finally possibly provide the first direct evidence of hadronic acceleration in the shells of SNRs.



Spectral energy distribution of the shell-type SNR RX J1713.7-3946 above 100 MeV. The black data points denote measurements with H.E.S.S., the blue and red data points correspond to simulated GLAST data assuming different mechanisms for the gamma-ray emission as described in the text. Please note that this simulation uses the current best estimate of the LAT performance.

Morphology of shell-type Supernova remnants

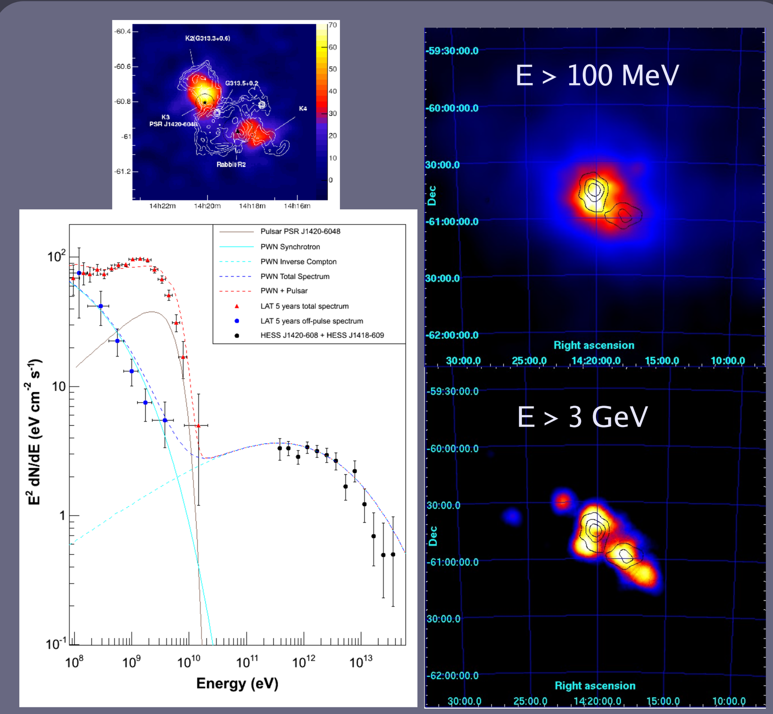


Simulated gamma-rays for RX J1713.7-3946 in a hadronic model above 3 GeV as seen by GLAST in 5 years of observation. A very simple smoothing algorithm has been applied and a more detailed analysis can presumably resolve the shell-like emission in this object.

The unprecedented GLAST-LAT angular resolution will alleviate the problem of source confusion in the Galactic plane and will allow for studies of the gamma-ray emission regions in the larger of the known gamma-ray emitting SNRs, such as RX J0852.0-4622 (Vela Jr.). The angular resolution of the instruments follows $\Delta\Theta = 0.2 (E/GeV)^{-0.8}$, thus young nearby SNRs with angular size $> 1^\circ$ can be significantly resolved above ~10 GeV. Correlation studies with hard X-rays, as well as with VHE gamma-rays will give detailed views into the acceleration sites, providing and energetic coverage of many orders of magnitude. The excellent angular resolution will isolate the shell-emission from the core PWN emission in composite SNRs and allow for population studies of shell-type SNRs in the gamma-ray regime.

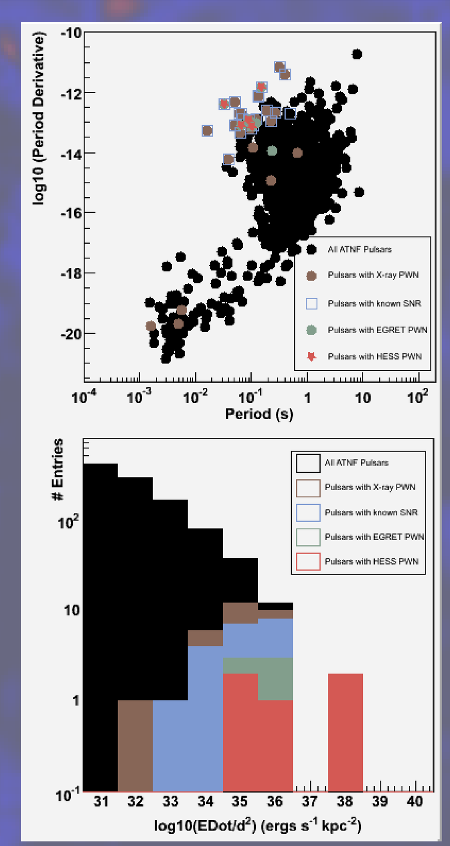
GLAST Studies of Pulsar Wind Nebulae

EGRET found a number of bright variable Galactic objects that could possibly be associated with Pulsar Wind Nebulae (PWN). Recent advantages in VHE gamma-rays above 100 GeV by H.E.S.S. have shown that there are at least 8 PWN emitting at gamma-ray energies detected in a survey of the southern Galactic plane. Many of these are expected to be visible in the GLAST band. For example, the right hand panel shows a simulation of GLAST data for the Kookaburra region. The SED shows that the GeV emission should be dominated by the central pulsar. However, phase analysis can cut out the pulsed emission, revealing the > 100 MeV PWN spectrum. This is also illustrated in the right hand figures, which shows the GLAST simulated 2D-map above 2 different energies. The upper plot above 100 MeV is completely dominated by the pulsed photons, the lower panel above 3 GeV allow morphological studies of the region, due to the strong cutoff in the pulsar spectrum. GLAST will be able to determine morphologies and energy spectra for a large number of PWN and allow for detailed population studies. Because of the near continuous coverage and stable high sensitivity of GLAST, we expect that slow (month-year) variability of the PWN synchrotron component from the wind termination shock should be measurable in some cases providing a new probe of PWN dynamics.



The Kookaburra region, in gamma-rays. **Top left:** VHE gamma-ray image [7]. **Bottom Left:** Spectral Energy distribution, containing a simulated Pulsar and PWN in the GLAST range and the VHE gamma-ray measurements by H.E.S.S. [7]. **Right:** Corresponding GLAST gamma-ray image as (**top:** above 100 MeV, **bottom:** above 3 GeV).

Best Candidates for GLAST detections



Top: P-Pdot diagram of all ATNF pulsars (black), showing the pulsars with detected X-ray PWN (brown), pulsars for which the corresponding SNR is known [9] (blue), those who can be associated to an EGRET PWN (green) and those associated to a H.E.S.S. VHE PWN (red). **Bottom:** Energy output distribution for the selections used in the top panel.

Shell-type SNRs: The best candidates for finding gamma-ray emission are a) SNRs that have been detected in VHE gamma-rays such as RX J1713.7-3946 and RX J0852.0-4622 or b) young SNRs that emit hard x-ray (synchrotron emission) in their shells. The best candidates are summarized in the following table.

Pulsar Wind Nebulae: The best candidates for gamma-ray PWN are a) PWN detected in VHE gamma-rays b) PWN detected in X-rays. About 30 X-ray PWN have been detected [8] mostly around young energetic pulsars as shown in the left-hand Figure. The most energetic ones are summarized in the following table.

Candidate SNRs	Candidate PWN
RX J1713.7-3946	Crab
RX J0852.0-4622	VelaX
Cas A	MSH15-52
SN 1006	Kookaburra
RCW 86	PSR B1706-44
Tycho SNR	PSR B1823-13
Kepler SNR	PSR B1706-44
IC 443	MSH11-54
	3C58
	W44
	CTB 80
	CTA 1

Summary

The prospects for GLAST of detailed investigations of Supernova Remnants and Pulsar Wind Nebulae promise to provide a sensitive new probe of particle acceleration mechanisms in our Galaxy . Measurements in adjacent X-ray and VHE gamma-rays (above 100 GeV) energy bands allow for detailed predictions of possible gamma-ray signatures in the GLAST energy range. The best candidates for a gamma-ray detection with GLAST are thus young supernova remnants which have been detected in VHE gamma-rays or exhibit hard x-ray synchrotron emission in their shells and PWN around energetic pulsars as detected in X-rays and VHE gamma-rays.

References

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