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Future GLAST observations of Supernova remnants and Pulsar Wind Nebulae

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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. 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. 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. Gamma-rays above 100 MeV provide a direct access to acceleration processes. The 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 previously rather poorly explored energy band. We will describe prospects for the investigation of these Galactic particle accelerators with GLAST.

Shell-type Supernova remnants

Supernova remnants, through shocks in their expanding shells, have long been thought to accelerate charged particles to ultra-relativistic energies [1, 2]. These charged particles can subsequently emit radio, X-rays or gamma-rays through interactions with magnetic fields and surrounding material. In spite of recent detailed studies of Supernova remnants in particular with VHE gamma-rays [3, 4], the nature of the parent population responsible for the gamma-ray emission remains elusive. It is not yet evident, whether the bulk of the gamma-rays are produced by Bremsstrahlung or Inverse Compton (IC) scattering of electrons, or by hadronic interactions and subsequent π^0-decay. If in the future a hadronic origin of the gamma-ray emission can be established, this would represent a great step towards the final proof that shell-type SNRs are the long sought source of cosmic rays in the Galaxy. In the GeV band EGRET data showed a statistical associations of gamma-ray emission with radio SNRs (and related sources) [5], however, no individual shell-type SNR could unambiguously be identified. The upcoming GLAST-LAT instrument, however, has the spectral and angular resolution to perform first detailed study of these object between 30 MeV and 300 GeV.

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 rather poorly-explored energy regime. LAT data will allow us to distinguish between different models for the gamma-ray emission. Gamma-rays of leptonic origin (produced by IC) can in principle be distinguished from those of hadronic origin (produced by π^0-decay) through their characteristic spectral shape, although recent claims have been made that under certain conditions the leptonic gamma-ray spectra might resemble those of pionic decays [6]. Previous measurements in higher energy gamma-rays above 100 GeV provide rather stringent constraints on the absolute emission level for the different models. Figure 1 (bottom) shows predictions for GLAST-LAT

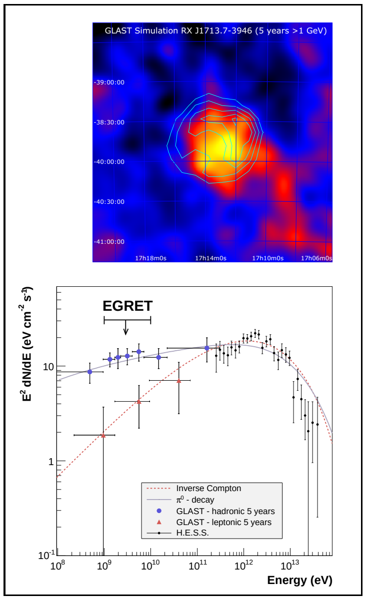

Figure 1: **Top:** Simulated map (smoothed counts) for RX J1713.7–3946 in a hadronic model above 1 GeV as seen by the LAT in 5 yrs of observation (H.E.S.S. contours in blue). **Bottom:** SED for the same SNR. H.E.S.S. data are shown in black, simulated GLAST-LAT spectra are shown for different emission mechanisms of the gamma-rays (blue: hadronic, red: leptonic).

measured energy spectra (in 5 years of scanning observations) for a hadronic and a leptonic emission scenario illustrating that the LAT energy range is particularly well suited to distinguish these models and potentially provide the first direct evidence of hadronic acceleration in the shells of SNRs.

Morphological Studies of shell-type Supernova remnants

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 (also known as Vela Junior). The angular resolution of the instruments follows the relation $\delta\Theta = 0.6(\mathrm{E/GeV})^{-0.8}$, resulting in an angular resolution of $\sim 0.6^\circ$ at 1 GeV. Young nearby SNRs with angular size in excess of $\sim 1^\circ$ can thus be significantly resolved above $\sim 3-10$ GeV provided sufficient photon flux at these high energies. The brightest VHE gamma-ray SNR RX J1713.7–3946 is shown in Figure 1 (top) above an energy of 1 GeV for 5 years of simulated data in scanning mode. This object will be barely resolvable unless deconvolution methods are applied. Correlation studies of GeV SNR candidates with hard X-rays, as well as with VHE gamma-rays will give detailed views into the acceleration sites, providing an energetic coverage of many orders of magnitude. The excellent angular resolution will isolate the shell-emission from the core PWN emission in nearby 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 are potentially associated with Pulsar Wind Nebulae (PWN). Recent advances 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 [7]. Depending on the position of the peak of the IC emission, several of these are expected to be visible in the GLAST band, in particular because GLAST can probe large angular scales, generally not easily accessible in lower energy bands like radio or X-rays (as shown by H.E.S.S. in cases such as HESS J1825–137 and HESS J1640–465 the high-energy IC gamma-ray PWN can show a larger extent than the X-ray PWN, a property that makes gamma-ray instruments with their wide fields of view ideal instruments to detect these). Figure 2 shows a simulation of GLAST data for the Kookaburra region. The spectral energy distribution shown in the top panel demonstrates that the GeV emission should be dominated by the central pulsar in this region. However, phase analysis can cut out the pulsed emission, revealing the > 100 MeV PWN spectrum. This is also illustrated in the lower figures, showing 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 number of PWN and allow for population studies. Because of the near continuous coverage and stable high sensitivity of GLAST, it is expected 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. Recently Reimer&Funk have shown that by using the high angular resolution gamma-ray detection as provided by H.E.S.S. the EGRET data on the Kookaburra region can be disentangled into two distinct sources [9]. This might be a template case for future studies of such systems in crowded regions in the Galactic plane where GLAST will have to fight with source confusion.

Best candidates for GLAST detections

Shell-type SNRs : The best candidates for detecting gamma-ray emission in the GLAST-LAT energy range are a) SNRs that have been detected in VHE gamma-rays such as RX J1713.7–3946 or b) other young SNRs that emit hard x-ray (synchrotron emission) in their shells or c) older SNRs like e.g. W28 which had sufficient time to accumulate a large amount of cosmic rays in their shells and which potentially have dense molecular clouds in their vincinities that could act as target material for hadronic interactions with subsequent pionic decays into gamma-rays. The best candidates are summarised in table 3.

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 mostly around young energetic pulsars as shown in Figure 3. A significant correlation has now been established between VHE gamma-ray sources above 100 GeV and energetic pulsars (in terms of $\dot{E}/d^2$) from the ATNF catalogue (see Carrigan, these proceedings). Even though the GLAST gamma-ray fluxes might be contaminated by photons from the pulsar, the most energetic pulsars are a promising target for

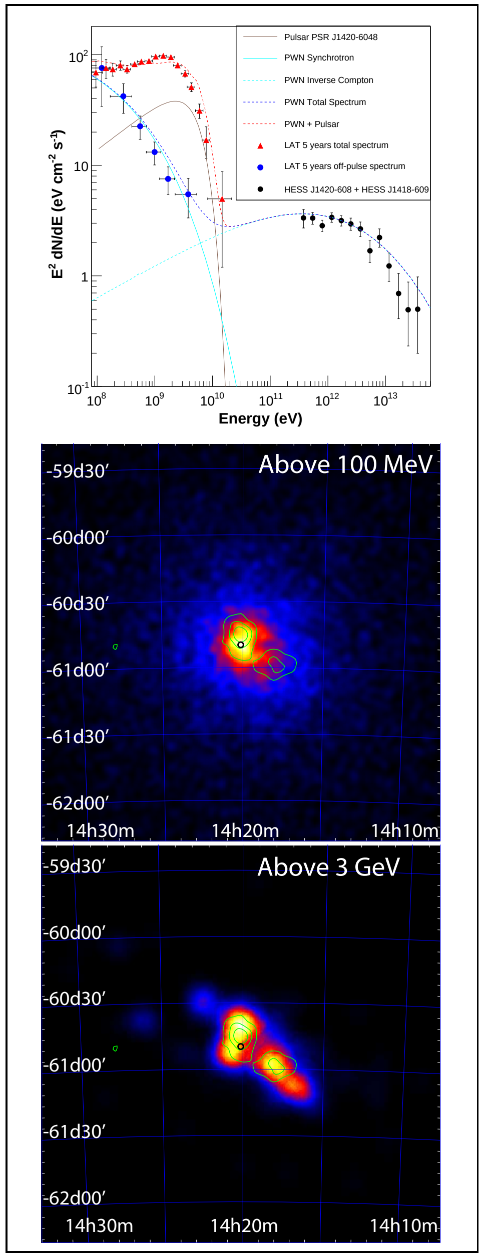

Figure 2: **Top:** Spectral Energy distribution for the Kookaburra region, containing a simulated Pulsar and PWN in the GLAST range and the VHE gamma-ray measurements by H.E.S.S. [8]. **Center:** Corresponding GLAST gamma-ray image simulated as above for energies > 100 MeV, and **Bottom:** > 3 GeV).

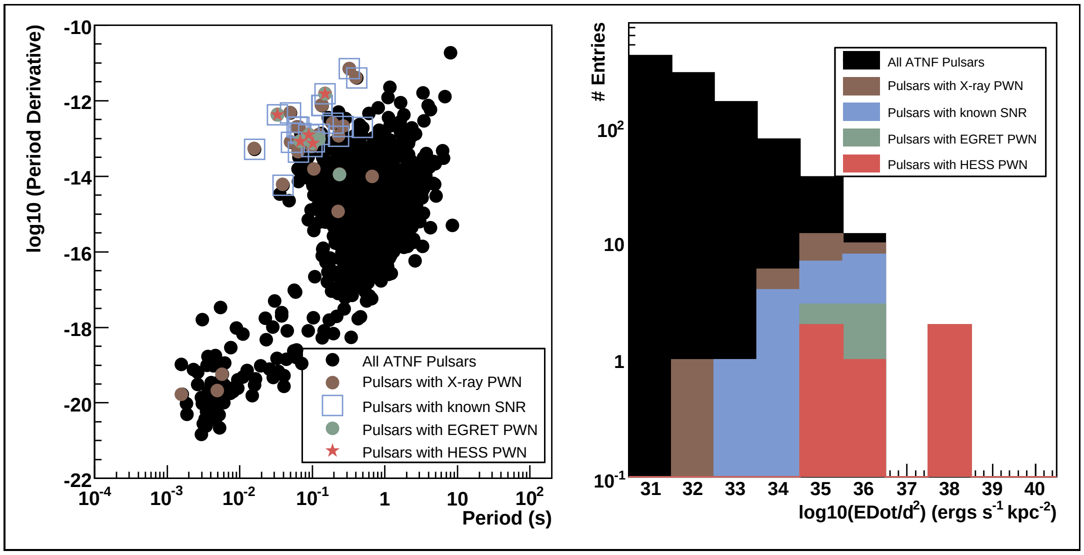

Figure 3: **Top:** $\mathrm{P} - \dot{\mathrm{P}}$ diagram for pulsars: all ATNF pulsars (black), with detected X-ray PWN (brown), with a known corresponding SNR (blue), potentially associated to an EGRET source (green), associated to a H.E.S.S. VHE PWN (red). **Bottom:** Energy output for the selections used at the top.

Candidate SNR	Candidate PWN
RX J1713.7–3946	Crab Nebula
RX J0852.0–4622	Vela X
Cas A	Kookaburra
SN 1006	MSH 15-52
RCW 86	PSR B1706–44
W 28	PSR B1823–13
Tycho SNR	3C58
Kepler SNR	MSH 11-54
IC 443	CTB 80

Table 1: Candidate SNRs and PWNe that might be detectable with the GLAST-LAT.

the detection of a PWNe surrounding the central pulsar (see Table 3).

Summary

The prospects for GLAST of detailed investigations of SNRs and PWNe promise to provide a sensitive new probe of particle acceleration mechanisms in our Galaxy . Measurements in adjacent X-ray and VHE γ-ray energy bands allow for detailed predictions of possible γ-ray signatures in the GLAST energy range.

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