Neutron Star Physics with GLAST

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GLAST

The **G**amma-Ray **L**arge **A**rea **S**pace **T**elescope is a high energy mission planned for launch in September 2007. GLAST will significantly contribute to our understanding of ***Neutron Star Physics*** in addition to advances in SNRs, γ-ray bursts, AGNs, diffuse emission from galactic/extragalactic sources, dark matter, and unidentified γ-ray sources.

This 300 M $ project is funded under the presidential budget and is expected not to be affected by possible future budget cuts.

GLAST features two instruments:
1) Large Area Telescope-LAT (PI: Peter Michelson, Stanford) operating in the 20 MeV-300 GeV range.
2) Gamma-Ray Burst Monitor-GBM (PI: Charles Meegan, MSFC) operating in the 10 keV-25 MeV range.

LAT: This will be the main instrument to be utilized to study Neutron Stars/Pulsars and related phenomenon. The main component of LAT is the tracker-converter that converts each incoming γ-ray photon into electron-positron pairs ($\gamma \rightarrow e^- + e^+$). The paths of these pairs are subsequently followed by the particle tracking device. Unlike previous telescopes which used spark chamber technology, LAT has no consumables. This design provides excellent efficiency, reliability and resolution. The conversion of particle energies to scintillations in the crystal is done via the CsI (TI) calorimeter directly below the tracker. This is the central process that measures the energy of each incoming γ-ray photon. The distribution and cascade progress of the shower initiated in the tracker is deduced by the segmentation of the calorimeter which provides the necessary information for coherence. The overwhelming charged particle background caused by cosmic rays is blocked by the anticoincidence shield that surrounds each tracker.

GLAST will be flown in low earth orbit at 575 km with a 28.5^0 inclination and is planned to operate both in "zenith pointing" and "stare" mode. In addition to the capability to observe the unexplored energy range above 10 GeV, GLAST/LAT will be able to scan >16% of the sky at a time and ~75% of the sky in zenith pointing mode in every orbit (95 minutes). Combined with a good angular resolution (table) this large effective area gives a photon sensitivity of 4×10^{-9} photons cm^{-2} s^{-1} (>100 MeV) for a one year all sky survey. This is at least a factor of ~25 improvement over EGRET (Fig 1).

GLAST, with its outstanding wide energy range expanding over 4 decades above the unexplored region >10 GeV and the superb angular resolution of γ-rays which is ~3 times better than EGRET, will offer an unprecedented opportunity for pulsar astronomers and neutron star physicists to study some of the very basic but unanswered questions.

Parameter	EGRET	INTEGRAL	AGILE	GLAST
Energy Range	20 MeV-30 GeV	15 keV – 10 MeV	30 MeV – 50 GeV	20 MeV-300 GeV
Energy Resolution	10 %	0.2 % (at 1 MeV)	~ 1 %	10 %
Effective Area	1500 cm^2	2621 cm^2	200 cm^2	10000 cm^2
Field of View	0.5 sr	16^0	2.5 – 3 sr	2.5 sr
Angular resolution (100 MeV)	5.8^0	-	-	~ 3.0^0
Angular Resolution (10 GeV)	0.54^0	2.0^0 (at 1 MeV)	~ 0.27^0	~ 0.15^0
Sensitivity (>100 MeV) cm^{-2} s^{-1}	8×10^{-7}	5×10^{-6}	6×10^{-7}	4×10^{-9}
Source Location Accuracy	5' – 30'	> 1'	5' – 20'	< 1.0'
Event Dead Time	100 ms	114 μs	~ 250 μs	25 μs

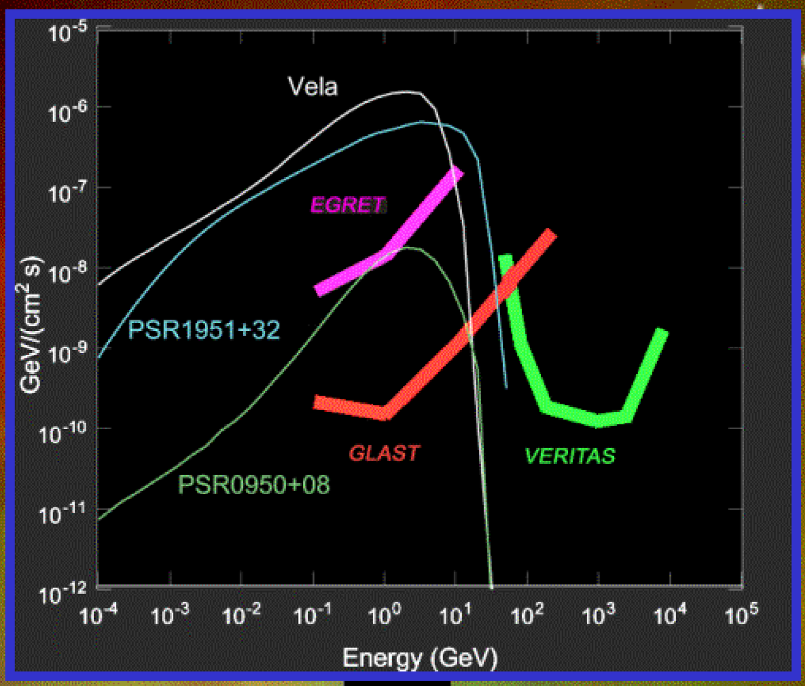

Fig 1.

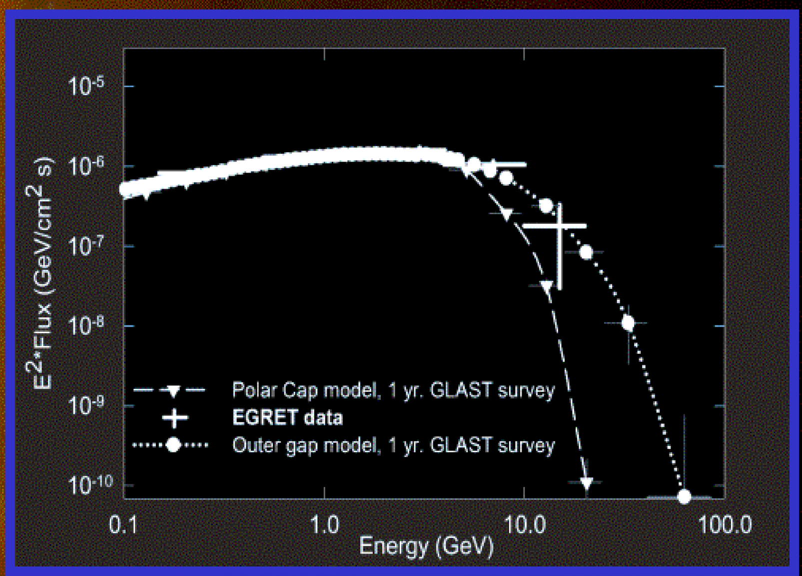

Fig 2.

Polar Cap Model

- High energy particles accelerated above neutron star surface resulting in γ-rays from curvature radiation OR inverse Compton induced pair cascade in strong **B**
- High energy spectral attenuation by magnetic pair production at energies are dependent on **B**
- Subclasses depend on whether or not free emission exists at the surface
- Sharp spectral cut-off at several GeV due to photon pair production attenuation (Fig 2)
- Emergent cascade spectrum is dominated by synchrotron radiation from the pairs.

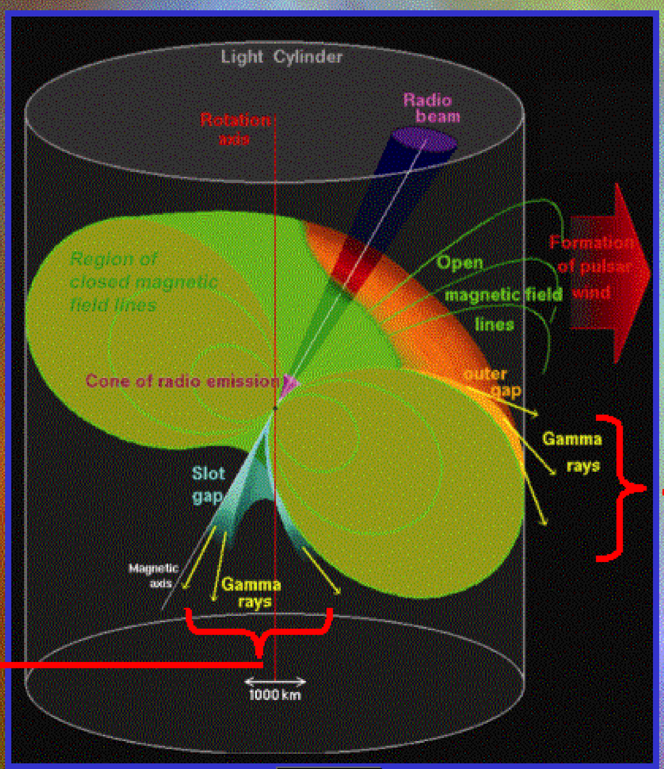

Fig 3.

Outer Gap Model

- γ-rays produced along the null charge surfaces in outer magnetosphere by proton-proton pair production induced cascade
- Gradual high energy turnover at ~ 10 GeV (Fig 2)
- Inverse Compton component extending to TeV
- Spectral cut-off more gradual than polar cap models
- In young (Crab-like) pulsars pairs are produced by curvature radiation from the primary particles interacting with non-thermal synchrotron X-rays from the same pair
- In old (Vela-like) pulsars the pairs are produced by the interaction of the primary particles inverse Compton and IR photons OR thermal X-ray photons interact with primary radiation to produce pairs replacing IR
- Old pulsars have thicker gaps than young pulsars

Observations

Compton GRO identified a number of γ-rays pulsars with different levels of significance (Fig 4). There are at least 7 confirmed γ-ray pulsars with different pulse profiles in different wavelengths (Fig 5). 3 additional γ-ray pulsar candidates have been detected by EGRET with less statistical significance (B1046-58, B0656+14, J0218+4232). The light curves are a manifestation of a combination of pulsars emission mechanism and geometry both of which are energy dependent (Fig 3). Six of the seven confirmed γ-ray pulsars show a double peak feature in their light curves. In all γ-ray pulsars, except B1706-44, the trailing pulse dominates the profile above 5 GeV. This suggests that the energy range plays a significant role in the γ-ray production.

In all γ-ray pulsars, the dominant power is detected above the hard X-ray band (>100 keV for Crab). Fig 2 shows the spectrum of Vela with the polar cap and outer gap model calculations superimposed. The large error bars of EGRET data makes the observations consistent with both models, whereas GLAST will easily distinguish the model that is more favorable by measuring the high energy cutoff with much smaller error bars associated with the observation. GLAST will also elucidate whether there is a second inverse Compton component of the pulsed radiation at higher energies expected in some outer gap models.

The multi-wavelength fluxes of known γ-rays pulsars

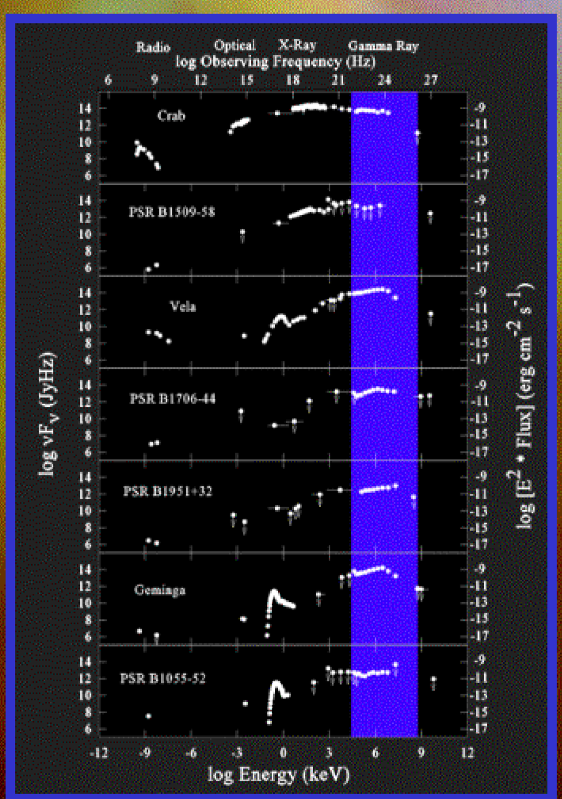

Fig 4.

The phase aligned multi-wavelength pulse profiles of known γ-ray pulsars

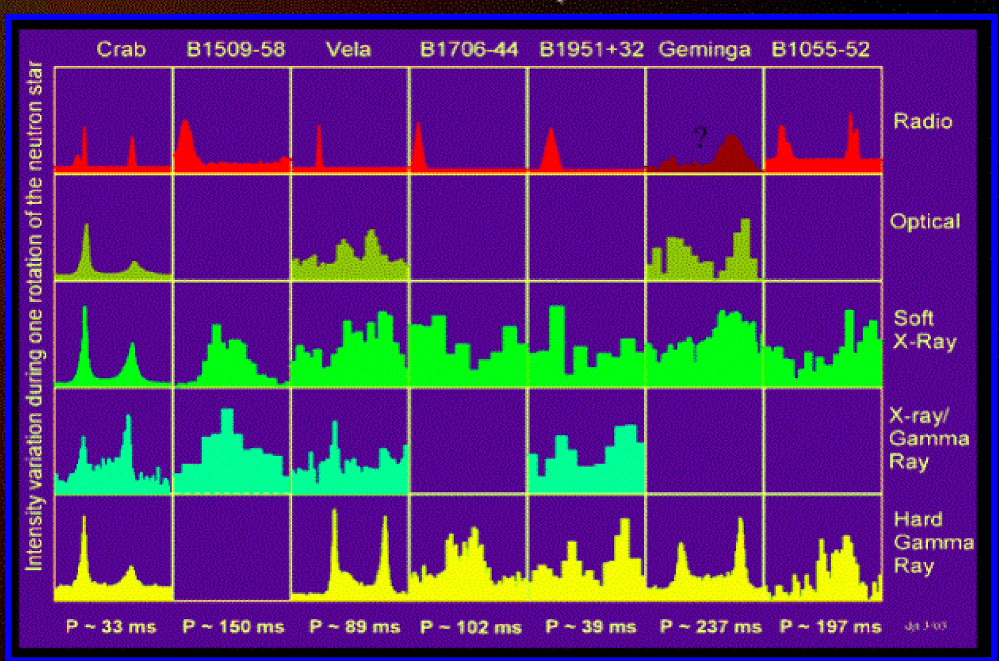

Fig 5.

GLAST's Potential

No pulse has been detected at TeV energies despite the high sensitivity Cherenkov detectors. EGRET data implies that there is pulsed emission above 5 GeV. The relative high luminosity and the drop off at GeV energies suggest that GLAST will be the *next big leap in neutron star physics* and related high energy observations.

GLAST will explore the regions that has not been possible with previous missions Fig 6 shows the phase space for pulsar observability in which GLAST is expected to make unprecedented discoveries by pushing down the observable flux limit.

The number of γ-ray pulsars expected to be discovered depends on the emission mechanism and geometry. A conservative estimate for the increase in the number of ***radio loud γ-ray pulsars*** is 5 → 50 and ***radio quite γ-ray pulsars*** is 1 → 750. The photons are too far apart in time to derive an unambiguous pulse period with EGRET. GLAST will be able to detect previously unknown pulse periods in Geminga-type γ-ray pulsars with its high timing resolution potentially finding a whole new population of rotation powered γ-ray pulsars.

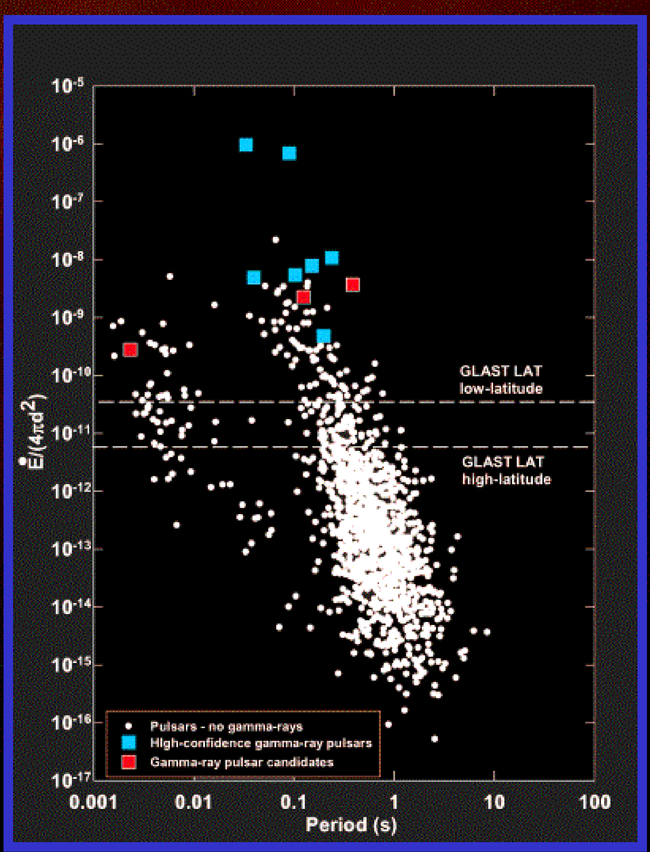

Fig 6.

GLAST will address:

- The physical process that produces the non-thermal high energy emission in pulsars
- The emission model for γ-pulsars : outer gap, polar cap or ???
- The relationship of high energy radiation to the radio emission mechanism
- The ratio of radio loud to radio quite pulsars
- The neutron star surface composition and geometry of **E** & **B**
- The possible existence of a death line for γ-rays at P=0.3 s for B = 10^{12} G for pulsars