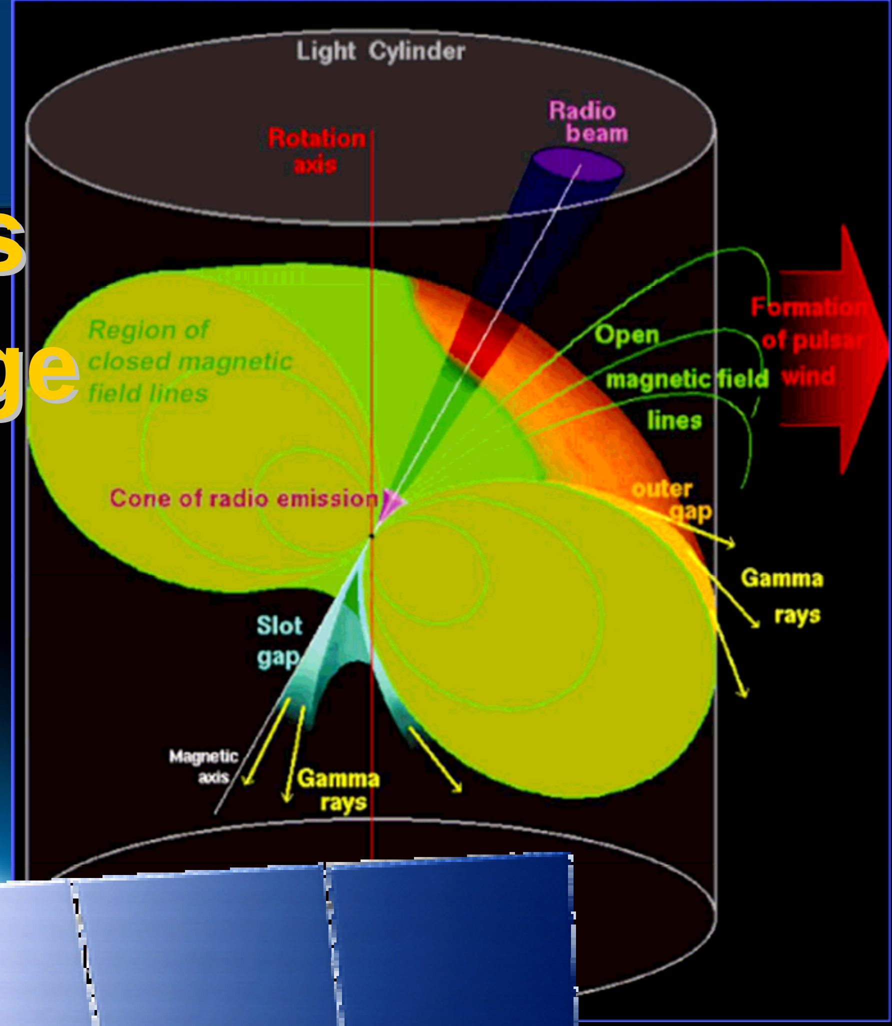
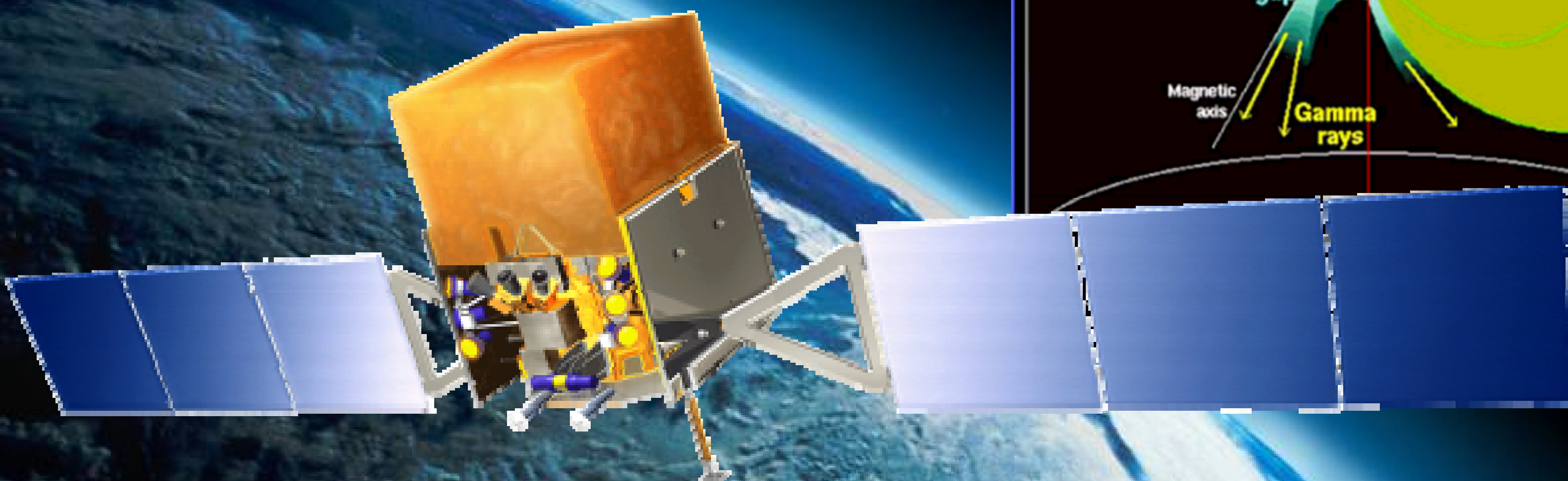
Gamma Ray Pulsars with the GLAST Large Area Telescope





David A. Smith
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(cenbg / in2p3 / cnrs)
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Atelier Pulsars de Nançay
Paris, le 16-17 janvier 2006

GeV gamma ray pulsars

1. Qui et quand pour GLAST?
2. Bref rappel de l’intérêt spécifique des gammas pour l’étude de pulsars
3. What is GLAST?
4. Des candidats…
5. Les besoins en datation.
6. Éphémérides fournies par d’autres radio-observatoires.
7. Une opportunité pour Nançay et les pulsaristes français.

When & who is GLAST?

Lancement prévu pour le 7 septembre 2007.

Mission NASA-DOE pour les 3/4.

Principaux labos USA:

Stanford Linear Accelerator Center = “SLAC” (près de San Francisco)

NASA Goddard Space Flight Center (près de Washington, D.C.)

Naval Research Laboratory (Washington, D.C.)

Réalisation de trajectograph en silicium:

INFN-Pise (avec participation financière de l’ASI)

La Suède a acheté les cristaux CsI ukrainiens. Présence japonaise importante.

En France:

IN2P3/CNRS -- Réalisation de la structure mécanique du calorimètre, caractérisation du calo sous faisceau, reconstruction de gammas.

LLR Ecole Polytechnique ; CEN de Bordeaux ; LPTA Montpellier

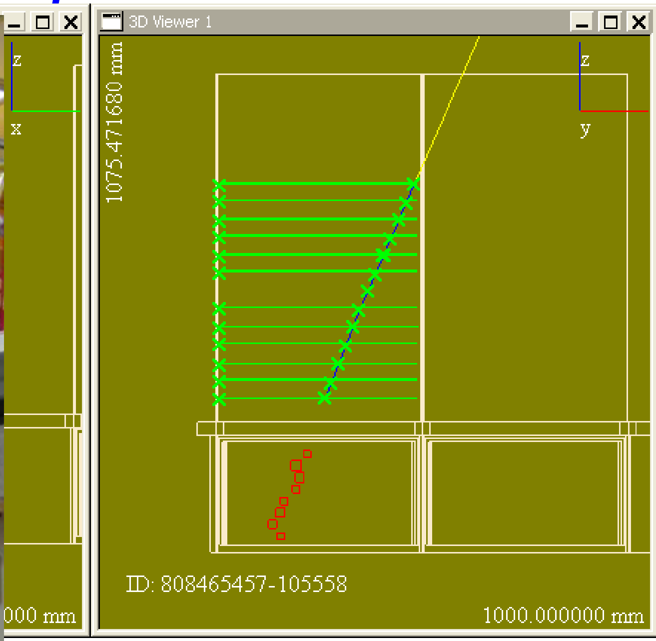
Sap du CEA-Saclay -- Préparation du catalogue, aidé par le CESR-Toulouse.

L’actualité de GLAST

http://www-glast.slac.stanford.edu

- **Le LAT = (Large Area Telescope) terminé depuis décembre (Stanford).**
- **février -- début de 3 mois de “shake n’ bake” au NRL.**
- **Printemps: spacecraft integration at Spectrum Astro in Tuscon, Az.**
- **Lancement depuis la Floride, fusée delta-E, septembre 2007.**

- ***Au bout d’un an, toutes données deviendront publique sous 48 heures.***



Un vrai muon atmosphérique

Achèvement du LAT, 23/11/05.

Some GLAST pulsar people

Au sein de GLAST, le "Pulsars, SNRs, and Plerions Working Group" est organisé par Dave Thompson & Roger Romani (qui, avec Isabelle Grenier du SAp m'ont gentiment aidé à la préparation de cette présentation). Le groupe "Sources non-identifiées, populations, et autres galaxies" est organisé par Patrizia Caraveo et Olaf Reimer. ("coordination of deep multi-wavelength searches").

Je "pomperai" de la présentation suivante, ainsi que de d'autres du même gars:
(les transparents en anglais viennent de lui)

GLAST Pulsar Overview
7 June 2005 GUC meeting

Steve Thorsett
UCSC

GUC = GLAST Users Committee
S. Thorsett est un des 4 "IDS" (=Interdisciplinary scientist) engagés par la collaboration GLAST.

L’intérêt des pulsars gamma

Very brief science goals

- Gamma-ray pulsar population
  - Radio beam comparisons
  - luminosities
  - number, fraction radio quiet

Gemingas bis!

- Emission studies
  - beam geometry
  - phase resolved spectra
  - relation of efficiency to period, e-dot, age, ...

Radio is a convenient observing band, and the observed phenomenology is rich, but connection to emission physics has been elusive:

- Radio is a tiny fraction of energy budget
- Radio emission is coherent (i.e., non-linear) process

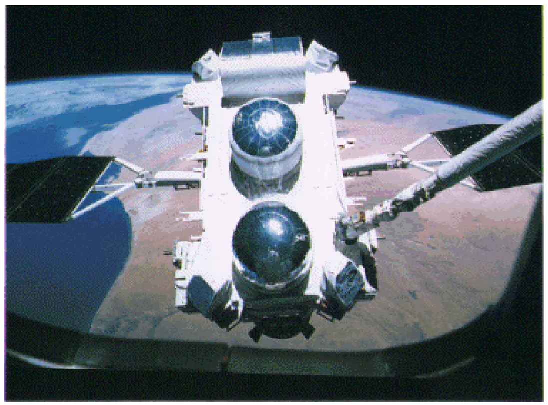
Gamma-ray band is at or near peak in pulsar spectrum, and gamma-ray emission physics is relatively straightforward (at least, it is incoherent!).

Déjà vu: l'héritage d'EGRET

et du CGRO

(Compton Gamma Ray Observatory)

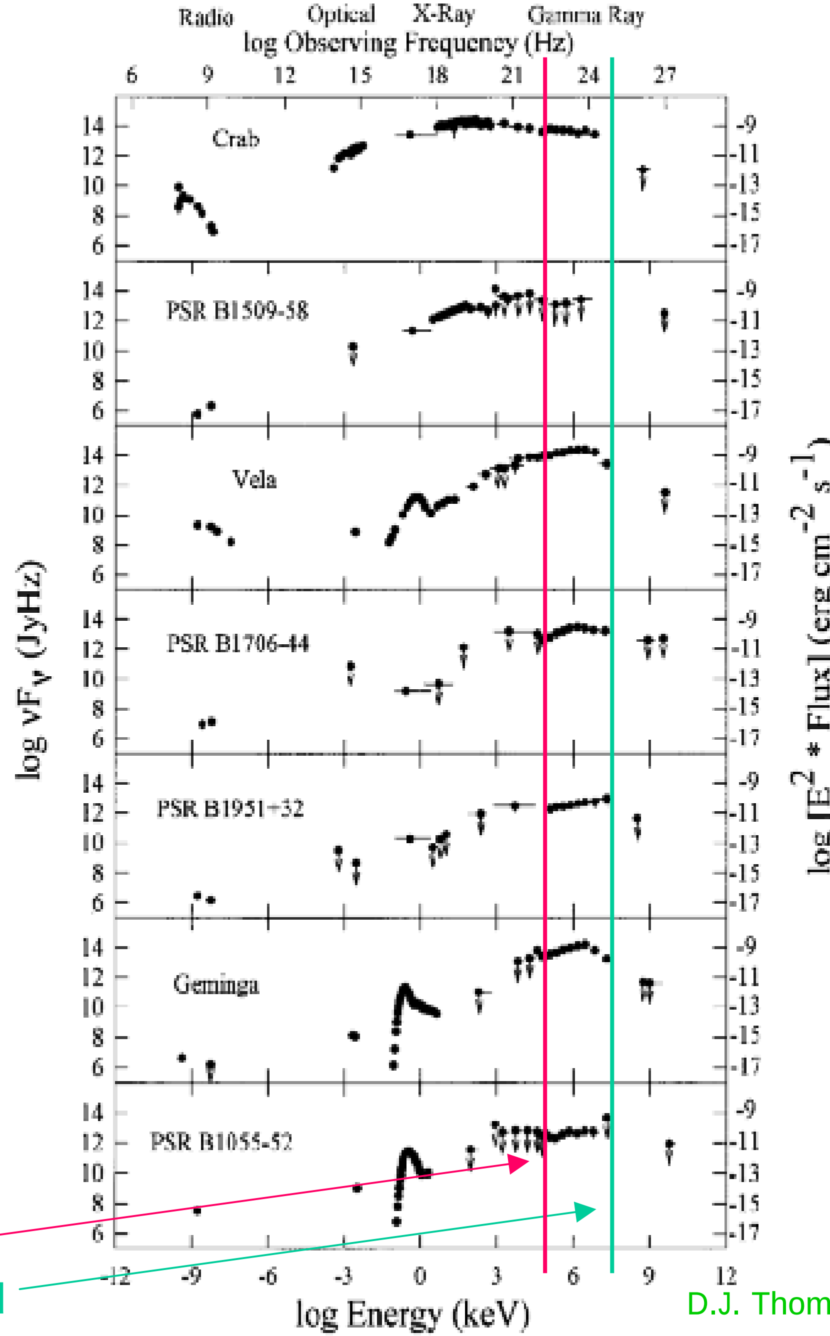
(avril 1991 - juin 2000)



EGRET found 6 of 7 pulsars

(a few more perhaps)

Contribution radio au budget énergétique est négligeable.



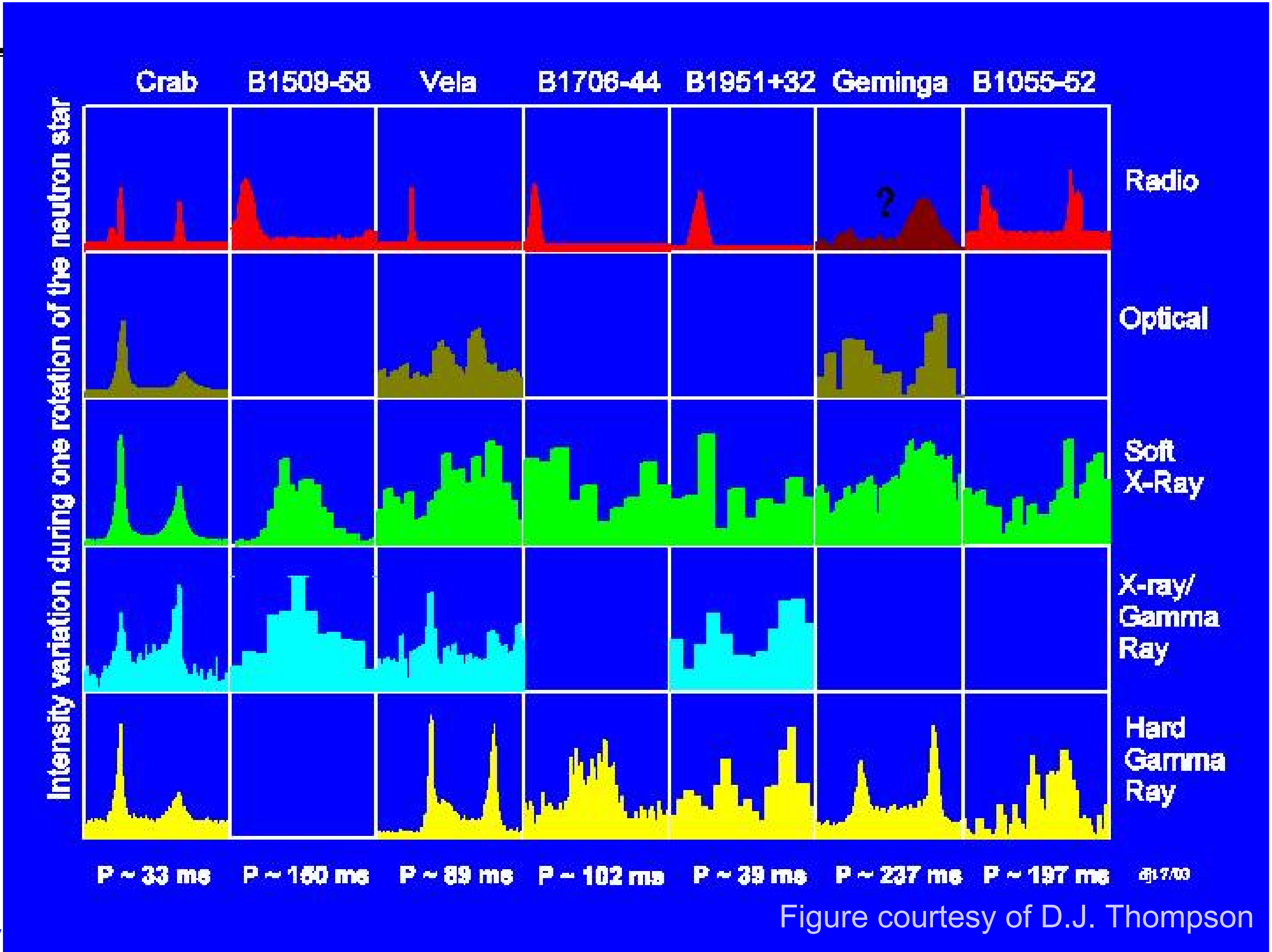
GLAST energy threshold

Celeste energy threshold

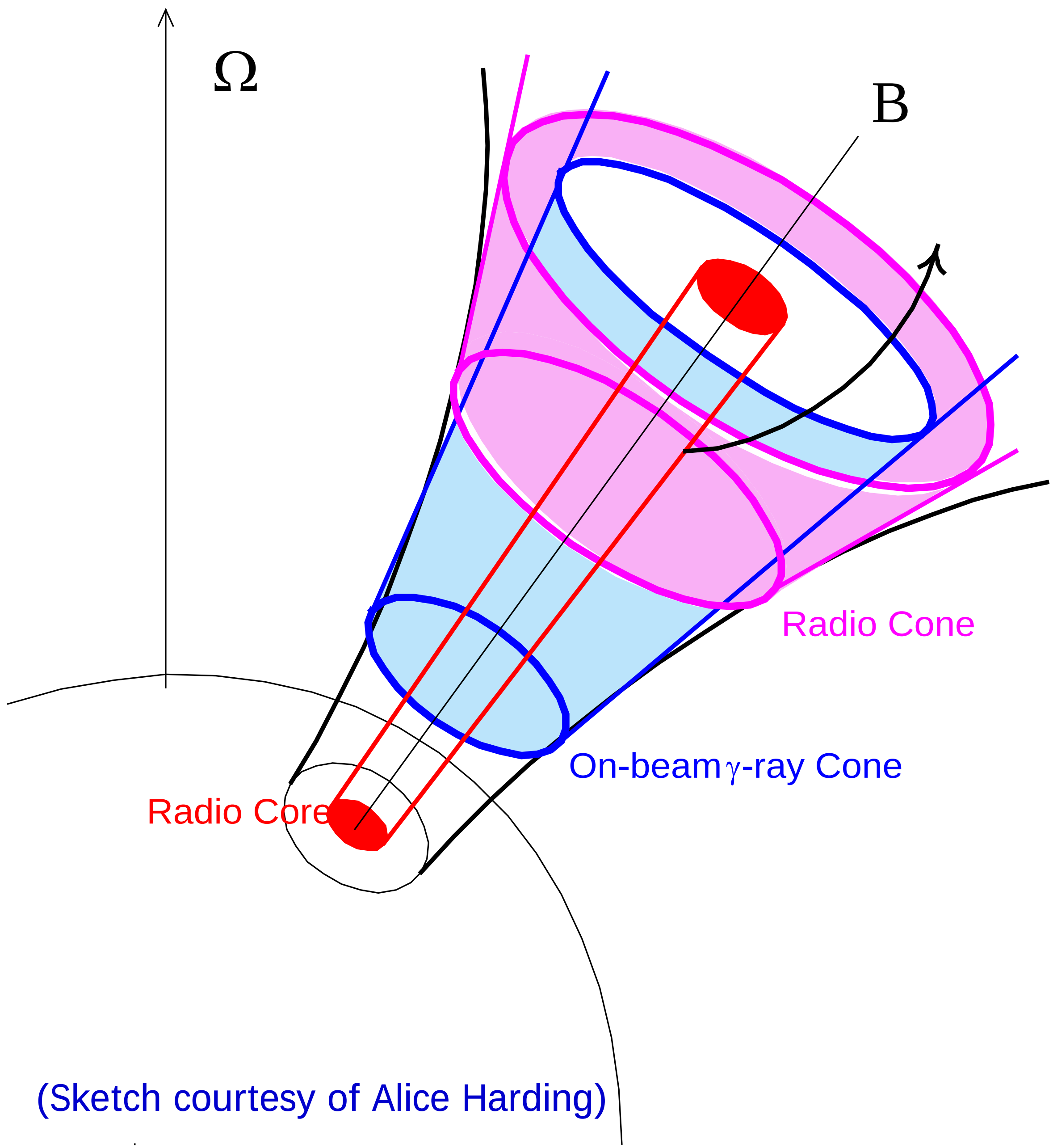
Fig. 4.—Multiwavelength energy spectra for the known gamma-ray pulsars. References for this figure are given in Table 3.

D.J. Thompson et al. ApJ **516** p.297 (1999

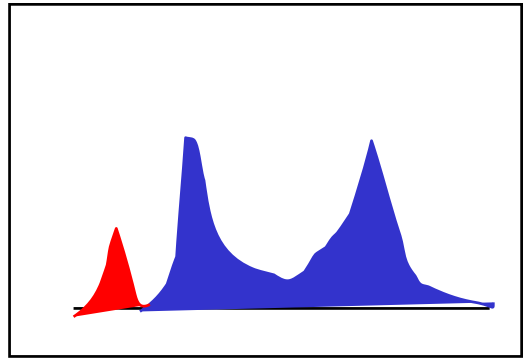
Profiles EGRET versus radio



Geometry of Polar Cap radio and γ-ray beams



(Sketch courtesy of Alice Harding)



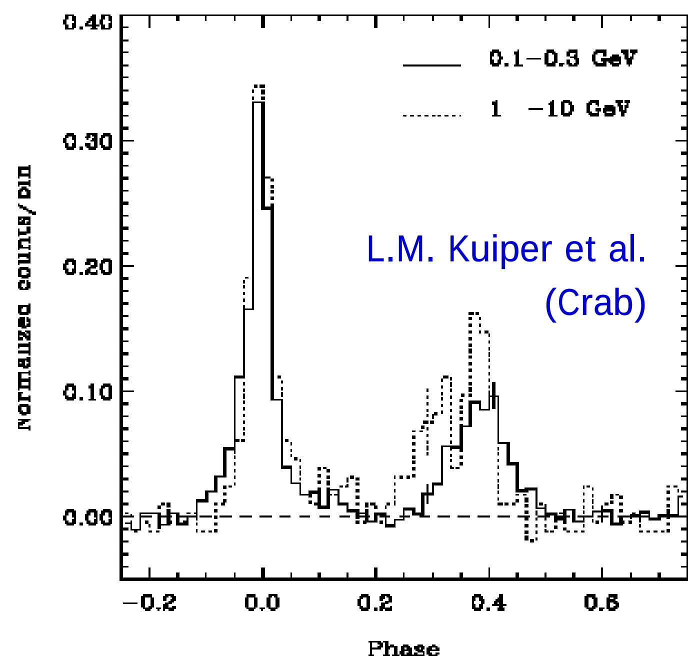
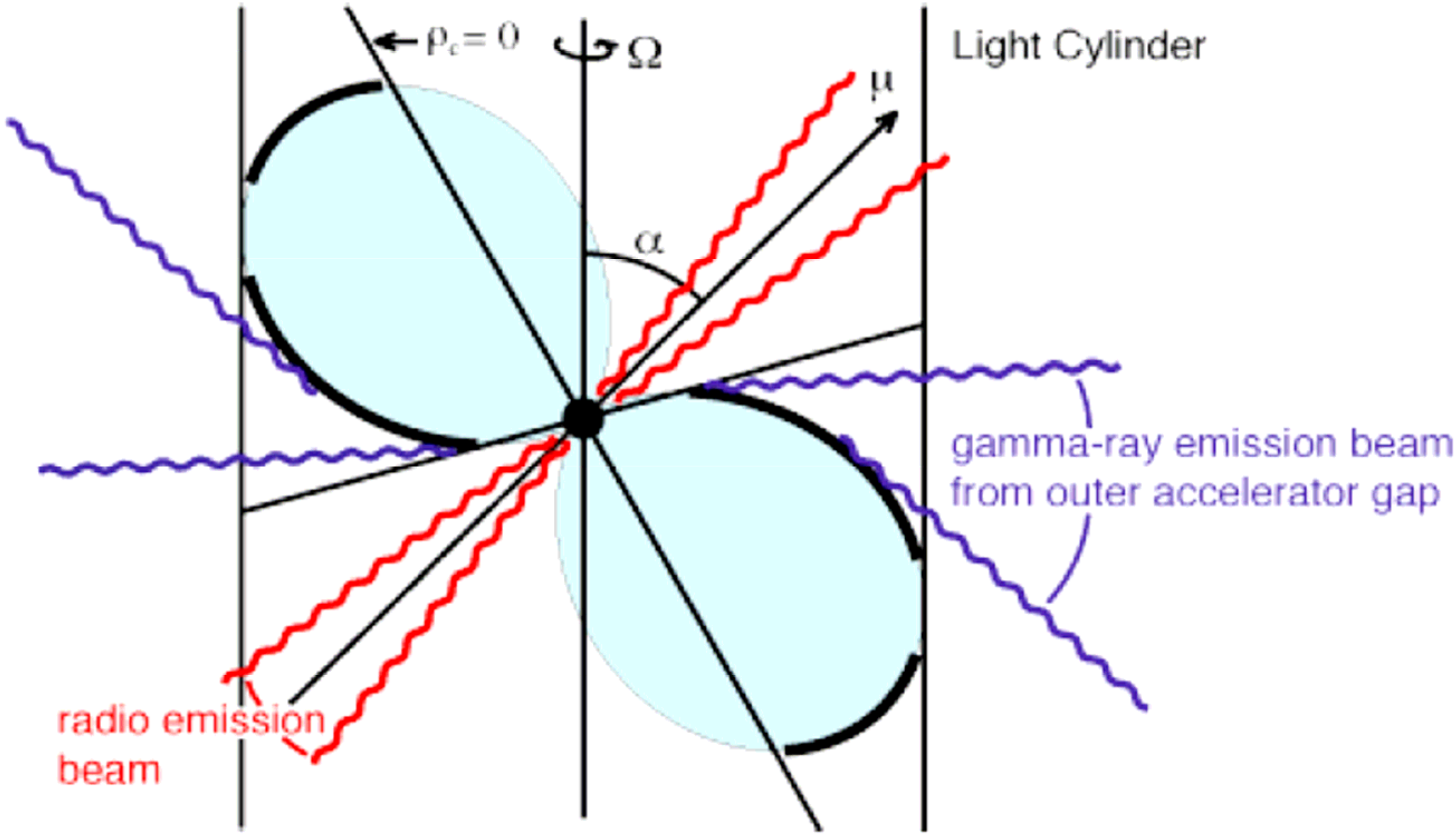


Fig. 12. EGRET pulse profiles (60 bins) using CGRO EGRET Cycle 0–VI data: 1–10 GeV, dotted line; 100–300 MeV, solid line. The profiles are normalized on their emission in P1. Typical error bars are indicated for both profiles. A clear increase is visible in the LW2 phase interval (0.25–0.32) for the 1–10 GeV energy interval with respect to the 100–300 MeV interval.

Two generic models for high-energy emission:

- Polar cap models: emission occurs in open field line region above magnetic pole (where radio emission occurs)
- Outer gap models: emission occurs in outer magnetosphere, through particle acceleration in charge-separated regions



Why study pulsars at high energy? (1 of 2)

- Pulsars are prodigious high energy particle accelerators
- Gamma-rays are the "natural" energy band for so-called radio pulsars, around the spectral peak
- Gamma-ray emission is "simple" in a way radio emission isn't:
  - radio emission is a coherent process, not dependent in a simple way on primary particle energies and densities
  - gamma-ray models make relatively straightforward predictions about spectral properties
  - those of us who fear we are studying "weather" in the radio might hope to be studying "climate" at high energy

Why study pulsars at high energy? (2 of 2)

- Beaming properties are different
  - we believe gamma-ray beams are larger
  - in any case, comparisons of radio and gamma-ray beaming fractions will give us a better estimate of the fraction of pulsars that is observed
- Gamma-rays are penetrating
  - radio telescopes are “more sensitive” in the sense that they detect (and will continue to detect) far more pulsars
  - however, radio observations near the Galactic center are difficult because of dispersion and scattering
- May get a better estimate of the pulsar birth rate/core collapse supernova rate/massive star birth rate/nucleosynthesis rate both locally and near the Galactic center

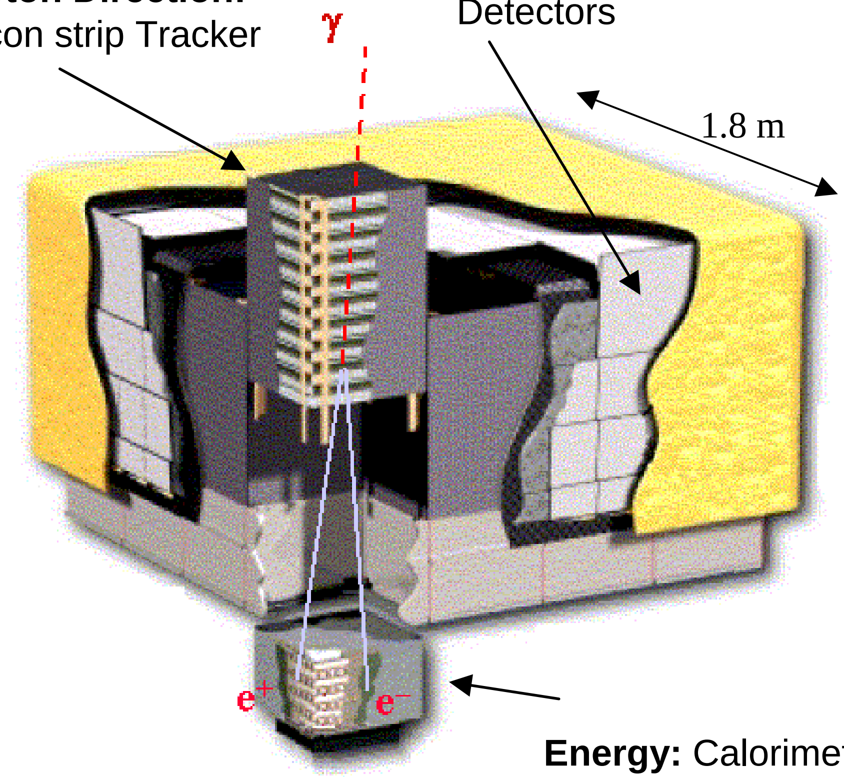
Deux instruments sur GLAST

Large Area Telescope (LAT)
20 MeV-300 GeV
PI: Peter Michelson
Stanford University

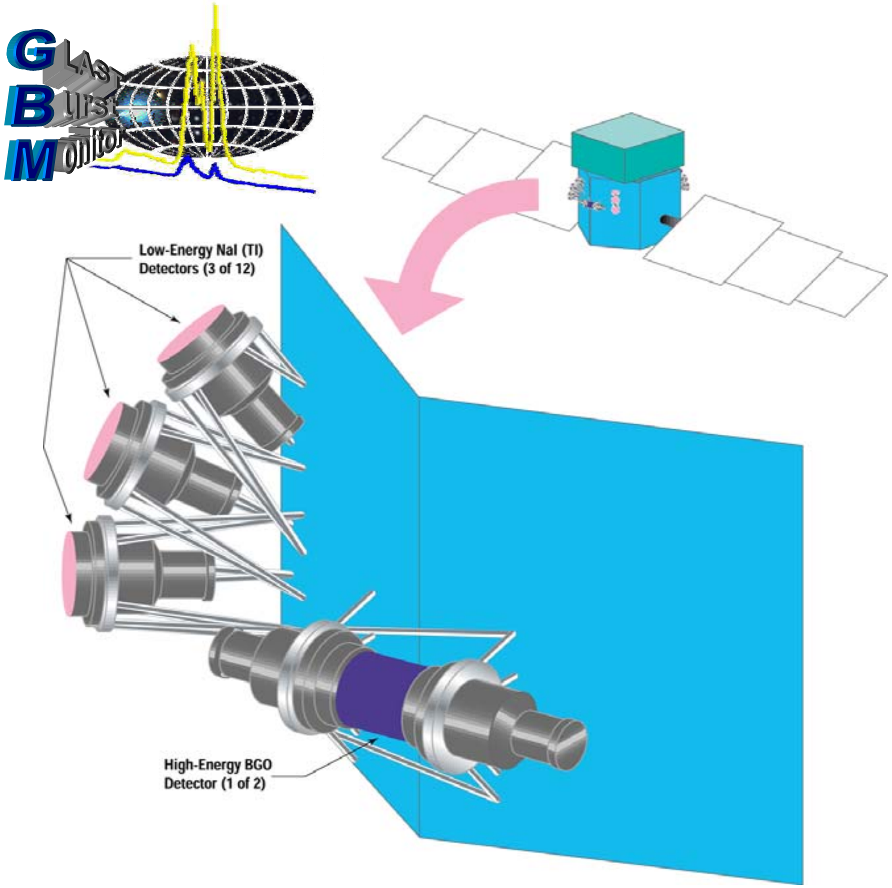
GLAST Burst Monitor (GBM)
10 keV-25 MeV
PI: Charles Meegan
Marshall Space Flight Center

Background rejection: Anti-coincidence Detectors

Photon Direction: Silicon strip Tracker



Energy: Calorimeter



LAT (Large Area Telescope)
20 MeV-300 GeV

Budget: $ 160 M

Si W Tracker

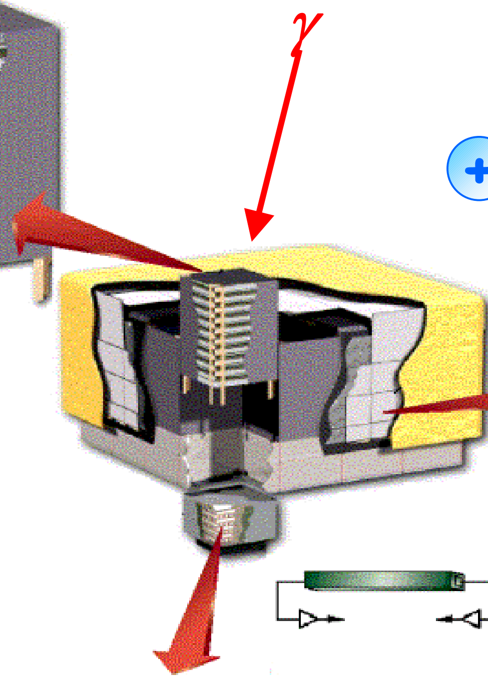
fine pitch: 228 µm

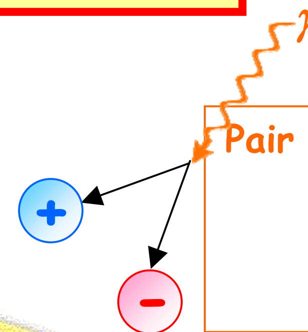
12 x 0.03 X_0 front-end

4 x 0.18 X_0 back-end

2 blank planes

884736 ch. of electronics



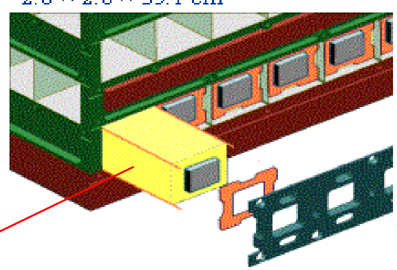


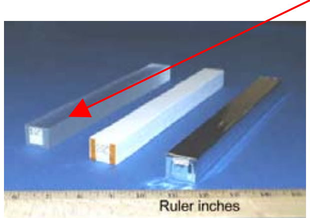
Pair conversion telescope
16 towers
- Veto
- Tracker
- Calorimeter

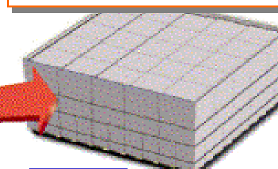
CsI Calorimeter

8.6 X_0 8 × 12 bars

2.0 × 2.8 × 35.1 cm





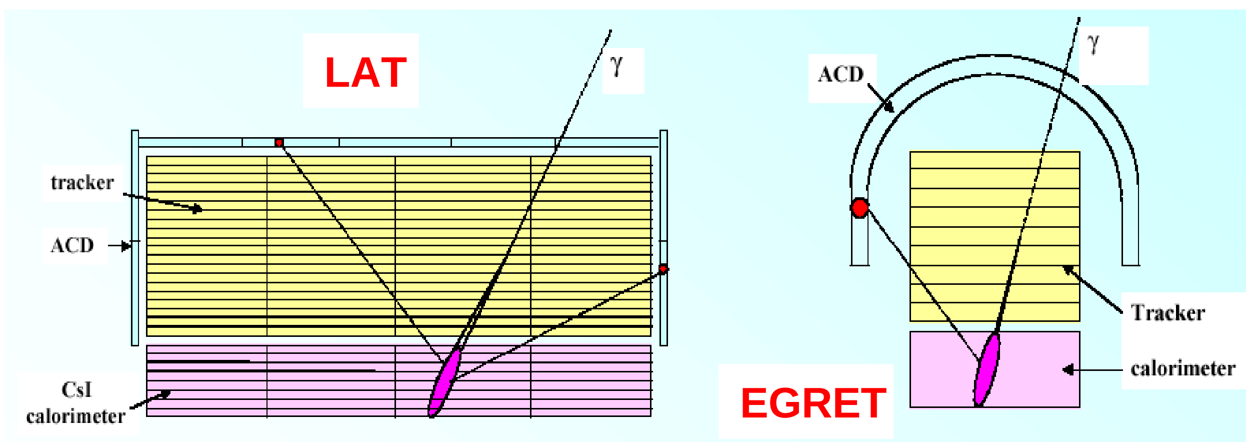


ACD

89 scintillator tiles

0.9997 efficiency

Plastic scintillator to reject charged cosmic rays



Plus compact
==> champ de vue
4.8 fois plus grand

Résumé: GLAST 25 fois plus sensible qu'EGRET, avec une meilleure localisation.

	EGRET	GLAST	
Detector technology	Spark chambers+ NaI calorimeter	Si-strips+ CsI calorimeter	
Energy range	20 MeV-30 GeV	20 MeV-300 GeV	
Energy resolution	10%	10%	
Effective area	1500 cm^2	10000 cm^2	x 6.7
Deadtime per photon	100 ms	20μs	
Field of view	0.5 sr	2.4 sr	x 4.8
Angular resolution (PSF)	5.8° at 100 MeV	3° at 100 MeV 0.2° > 10 GeV	$(5.8/3)^2 = 3.7$
Source localisation	5'-30'	30''-5'	(PSF/√N)
Sensitivity (>100 MeV)	10^{-7} $cm^{-2}s^{-1}$	4 10^{-9} $cm^{-2}s^{-1}$	x 25
Power	160 W	650W	
Orbit	350 km/ 28.5°	550 km/ 28.5°	
Mass	1810 kg	3000 kg	
Lifetime	1991-2000	2007-2012(17)	

Fond 6.7/3.7 = 1.8 plus grand, donc sensibilité 6.7x4.8/ √ 1.8 = 24

(pour valeurs plus précises voir http://www-glast.stanford.edu/software/IS/glast_lat_performance.htm)

Candidats pour une émission pulsée au GeV

Pulsar	P s	τ yr	$\dot{E}$ erg s^{-1}	F_E erg cm^{-2}s^{-1}	d kpc	L_{HE} erg s^{-1}	η
Crab	0.033	1300	4.5×10^{38}	1.3×10^{-8}	2.0	5.0×10^{35}	0.001
B1509−58	0.150	1500	1.8×10^{37}	8.8×10^{-10}	4.4	1.6×10^{35}	0.009
Vela	0.089	11,000	7.0×10^{36}	9.9×10^{-9}	0.5	2.4×10^{34}	0.003
B1706−44	0.102	17,000	3.4×10^{36}	1.3×10^{-9}	2.4	6.9×10^{34}	0.020
B1046−58	0.124	20,000	2.0×10^{36}	2.5×10^{-10}	3.0	2.1×10^{34}	0.011
B1951+32	0.040	110,000	3.7×10^{36}	4.3×10^{-10}	2.5	2.5×10^{34}	0.007
Geminga	0.237	340,000	3.3×10^{34}	3.9×10^{-9}	0.16	9.6×10^{32}	0.029
B1055−52	0.197	530,000	3.0×10^{34}	2.9×10^{-10}	1.5	6.2×10^{33}	0.20

EGRET pulsars

If ranked by $\dot{E} / d^2$ (spin-down flux at Earth), these pulsars are numbers 1, 2, 3, 4, 5, 6, 9, and 24. (Number 7 is a nearby millisecond pulsar, and 8 is a recently discovered pulsar.)

Pourquoi 24? "d" pas toujours fiable… ('1055)

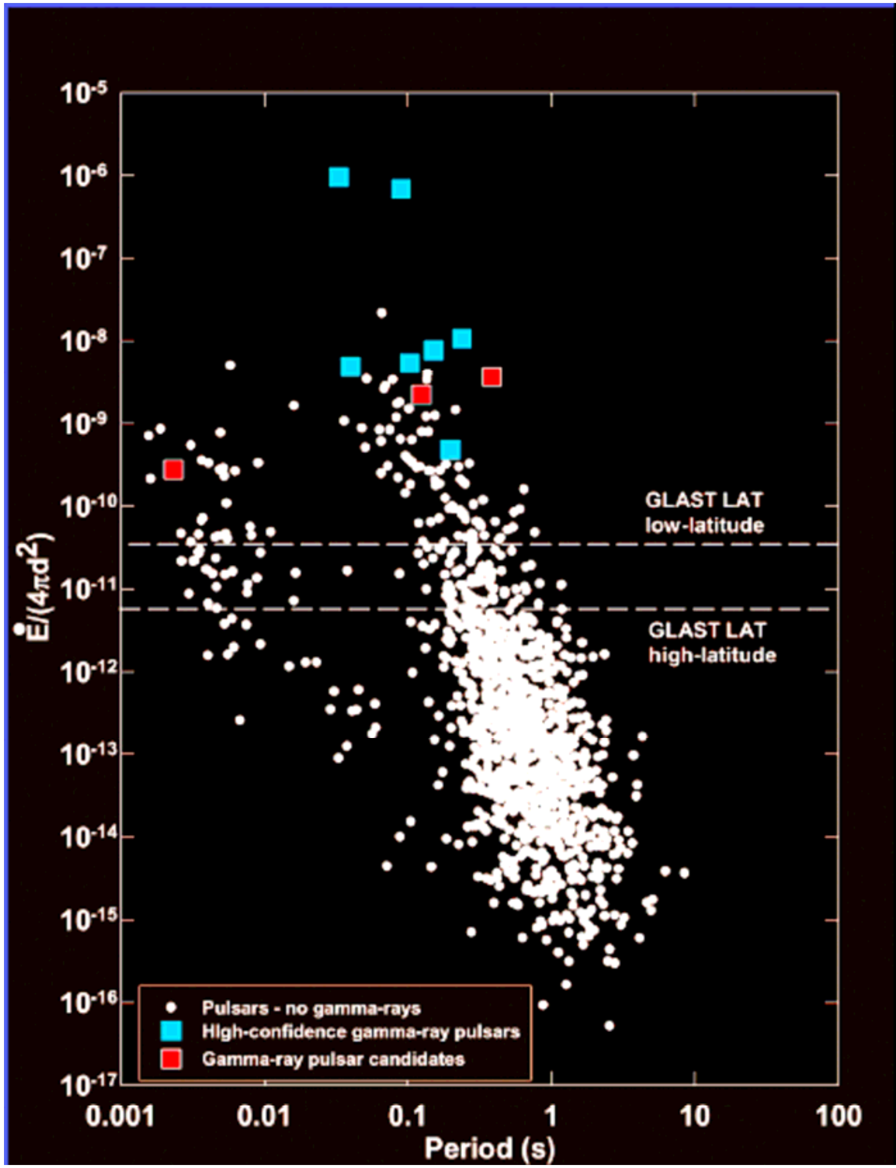
Clearly, **spin-down flux at Earth is an excellent proxy for gamma-ray luminosity**.

Pulsars proches, jeunes, sujets à glitches

- 600 pulsars radios connus à l'époque d'EGRET, ~1600 attendus d'ici le lancement de GLAST.
- La découverte après EGRET de J2229+6114 a déclenché une recherche tardive. Peu de photons, ephémérides tardives => *échec*.

astro-ph/0112518

- POINT CLEF: Il faudra bien les 10 ans de données pour les plus faibles, donc un suivi soutenu de datation.



Prédictions polar cap à 50 GeV

Date: Wed, 22 May 2002 13:47:02 -0400 (EDT)
From: Alice Harding <harding@twinkie.gsfc.nasa.gov>
To: D.A. Smith <smith@cenbg.in2p3.fr>
Subject: MS pulsars
Hi David,
I know it has been a long time since I promised to get you a list of pulsars to observe with Celeste, but other things just seemed to get in the way ... Anyway, I did a crude estimate of expected flux at 50 GeV for the ms pulsars in the ATNF catalog. In the polar cap model, ms pulsars are the only sources which are expected to have detectable emission above 30 GeV. More of the details are in my paper that was just accepted and is on astro-ph/0205077. In ms pulsars, the electric field is unscreened by pairs, so the particles accelerate to the curvature radiation reaction limit and radiate a very hard spectrum (photon index -2/3) out to energies of 20-100 GeV, depending on pulsar parameters. IF the flux is high enough, you might see it. So my list of the top candidates based on a rank ordering in flux*E^2 at 50 GeV is

J0437-4715 J1744-1134 J2124-3358 J0030+0451 J1959+2048
J1300+1240 J1024-0719 J0034-0534 J1012+5307

Several of these, J0437-4715, J2124-3358 and J0030+0451 are X-ray pulsars. Just about all of these are nearby sources, less than a kpc.
I hope you will be able to hunt for a few of these and let me know if you need any more info.
Best Regards, Alice

Les pulsars optiques

THE ASTROPHYSICAL JOURNAL, 547:967–972, 2001 February 1

(Cette article est une excellente introduction au sujet.)

IMPLICATIONS OF THE OPTICAL OBSERVATIONS OF ISOLATED NEUTRON STARS

ANDY SHEARER AND AARON GOLDEN
The National University of Ireland, Galway, Newcastle Road, Galway, Ireland

Seulement 5 connus…

TABLE 1

MAIN CHARACTERISTICS OF OPTICAL PULSARS

	Name	D (kpc)	P (ms)	$\dot{P}$ (10^{-14} s s^{-1})	log Age (yr)	B_S (log G)	B_{LC} (log G)	Optical Luminosity (μcrab) Integrated	Optical Luminosity (μcrab) Peak	Spectral Index at 4500 Å	Cutoff (Å)
γ	Crab	2	33	42	3.09	12.6	6.1	10^6	10^6	−0.11	15000(?)
γ	Vela	0.5	89	11	4.11	12.5	4.8	27	21	0.2	6500(?)
	PSR 0545−69	49	50	40	3.20	12.7	5.7	1.1×10^6	1.4×10^5	0.2	>7000
	PSR 0656+14	0.25(?)	385	1.2	5.50	12.7	3.0	1.8	0.3	1.3	>8000
γ	PSR 0633+17 (geminga)	0.16	237	1.2	4.99	12.2	3.2	0.3	0.1	1.9	>8000

Des candidats:

TABLE 3

PREDICTED LUMINOSITY OF X- AND γ-RAY–EMITTING PULSARS

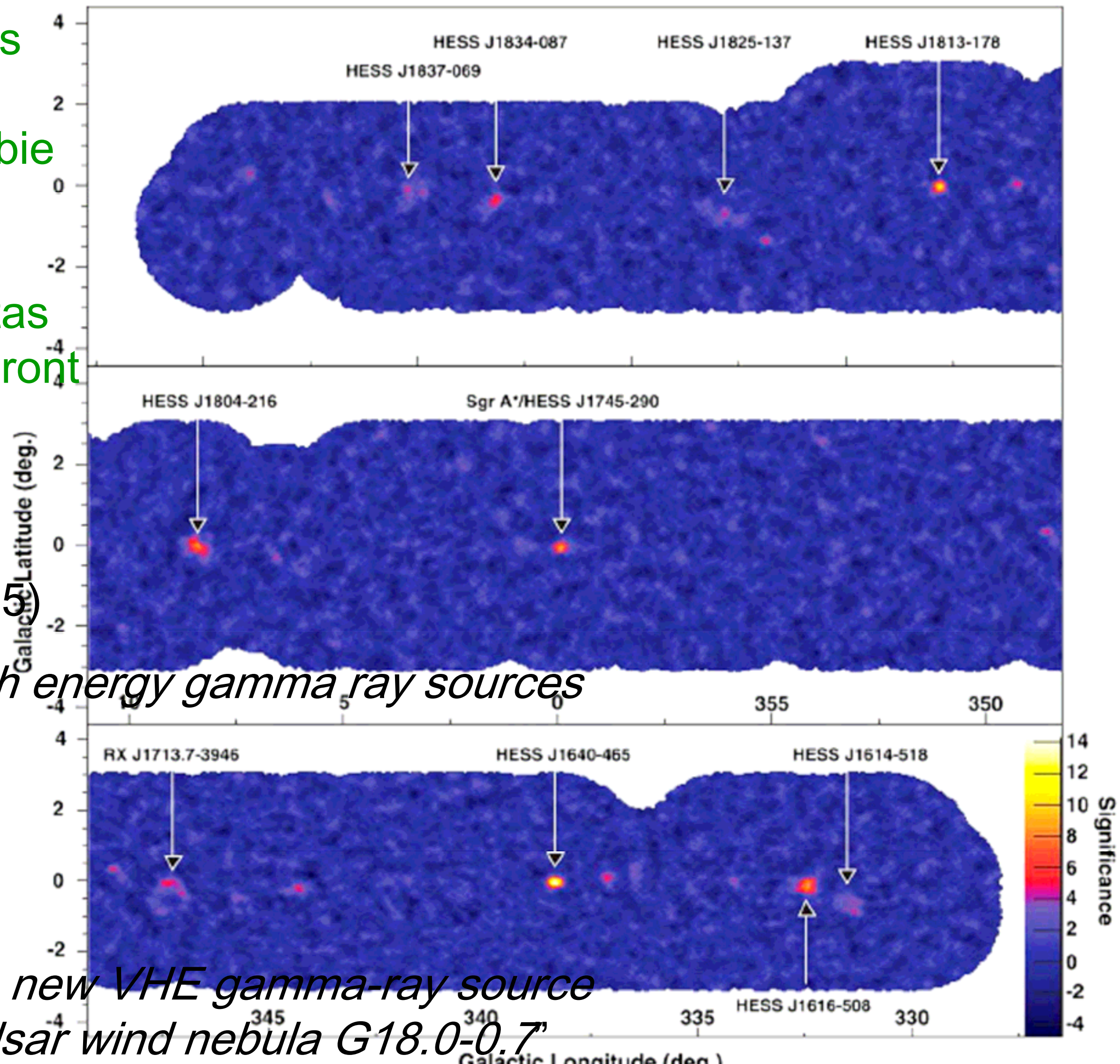
	Name	D (kpc)	P (ms)	$\dot{P}$ (10^{-14} s s^{-1})	B_S (log G)	B_{LC} (log G)	Duty Cycle	Predicted Luminosity (μcrab)
γ	PSR 1055−52	1.5	197	0.6	12.03	3.11	0.2	0.01
γ	PSR 1706−44	1.8	102	9.3	12.49	4.42	0.14	35
γ	PSR 1951+32	2.5	40	0.6	11.69	4.86	0.08	670
	PSR 1821−24(M28)	5.1	3	1.1^{-4}	9.3	5.8	0.1	0.3–1 × 10^6
	PSR J2322+2057	0.78	4.8	7.0^{-7}	8.3	4.2	0.3(?)	8
	1E 1841−045	7	11770	4700	≈15	−2	0.5?	≤ 10^{-10}

NOTE.—The duty cycle has been estimated from γ-ray observations. Also included are the nearby millisecond pulsar PSR J2322+2057 (Nice et al. 1993) and the anomalous X-ray pulsar 1E 1841−045 (Vasisht & Gotthelf 1997).

HESS est formidable!!

Sol & Gallant & Pétri vous l'ont dit… le réseau de 4 « imageurs Tcherenkov » de 12 mètres fonctionne *très bien* en Nambibie depuis plus d'un an.

Il est en train de découvrir un tas d'objets galactiques qui mériteront un follow-up Nançay et/ou GLAST.



Science 307, 1938-1942 (2005)

"*A new population of very high energy gamma ray sources in the Milky Way*"

A&A 442, L25-L29 (2005)

"*A possible association of the new VHE gamma-ray source HESS J1825-137 with the pulsar wind nebula G18.0-0.7*"

Autres éléments pour bâtir une liste

- AGILE (un mini-GLAST italien) sera lancé prochainement, avec une performance EGRET-like.

PROSPECTS FOR HIGH ENERGY STUDIES OF PULSARS WITH THE AGILE GAMMA-RAY TELESCOPE

A. Pellizzoni[1], A. Chen[1,2], M. Conti[1], A. Giuliani[1,2], S. Mereghetti[1], M. Tavani[1], S. Vercellone[1]

dixit Cognard : 31 des candidats dans cet article détectables à Nançay
(dec>-40° et >0.2 mJy @ 1400 MHz)
(la liste étant le classement par ordre de Edot/d²)

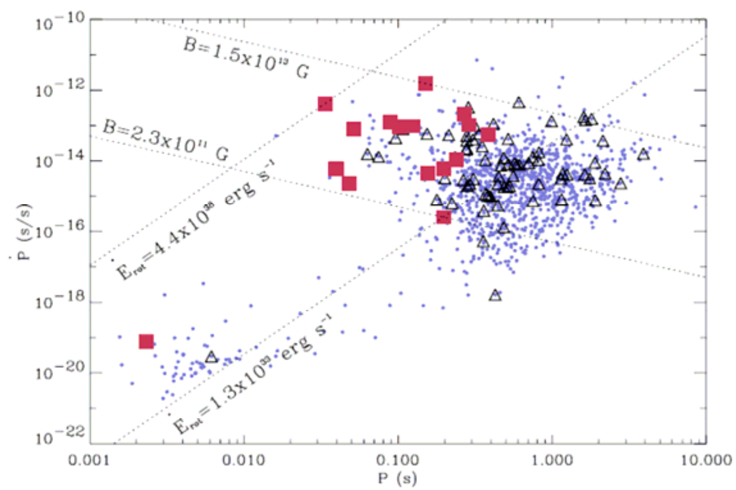


Fig. 2. $P - \dot{P}$ diagram of a set of ~1300 radio pulsars (dots) whose parameters are obtained from public archives. Dotted lines correspond to the extreme values of B and $\dot{E}_{rot}$ (excluding ms pulsars) of the ~15 known and candidate gamma-ray pulsars (filled squares). The "gamma-ray pulsars region" (upper rhomboidal region) includes ~400 radio pulsars likely to be efficient high-energy photons emitters. In this region there are ~20 non-variable EGRET unidentified sources (triangles) coincident with one or more radio pulsars (the total number of radio/gamma coincidences being ~40).

- Le leçon de la prédiction de B1951+32 dans CTB80 mérite attention…

Les besoins de datation de GLAST, et qui prévoit déjà d'en fournir

Radio contributions

- Where should we look? (radio surveys)
- "When" should we look? (radio timing)
- What is that unidentified gamma-ray source? (directed radio searches)
- How far away is that pulsar? How luminous is it? (radio dispersion studies, radio parallax)

The "easy" parts

- Judging from EGRET, we expect radio groups will compete for directed searches of candidate pulsars from *GLAST:* most important telescopes will be Arecibo, GBT, Parkes and perhaps Jodrell
- Distance scale is a challenging problem, but
  - Cordes and group have been working on new dispersion model (NE2001)
  - Our group has been doing very large scale VLBA parallax survey (better than 0.1 mas means better than 10% at 1 kpc)
  - Both will be done before *GLAST* flies

The hard parts

- Two key pulsar advances in *GLAST* era:
  - Improved sensitivity of *GLAST* itself
    - EGRET saw primarily the youngest, relatively nearby pulsars
    - *GLAST* will see an older, more distant population
    - Existing surveys are less complete, and possible targets are much larger in number
  - Substantial increase in known pulsar population
    - Parkes Multibeam Survey
      - ~700 new pulsars, many young
    - Arecibo drift surveys
      - Scores of pulsars, biased towards older population & millisecond pulsars
    - Factor of ~3 more pulsars known than when EGRET flew

Arecibo ALFA system

(Voir la présentation de S. Torchinsky)

- 7 beams at 1400 MHz
- 10 times raw sensitivity of Parkes beams
- New, very broadband (300 MHz) spectrometer (soon)
- 268s dwell times
- 1.8 times as deep (4 times for msec psrs)
- 6 times the volume (50 times for msec psrs)

• Thorsett *et al* ont fait un test de 19 heures sur le centre galactique, ont trouvé les 19 pulsars connus et 12 neufs (!).
• Ils auront 140 heures/trimestre pendant 5 ans, ils prévoient 1000 pulsars neufs.

Follow-up

- All new pulsars must be timed to determine p-dot, E-dot, and detect binary motion
- It takes about a year of observations to separate position from p-dot
- It is roughly 2.6 hours/pulsar, or ~2600 hours!
- This doesn't include longer term monitoring
- So far, time allocation committee has not been very generous with follow-up time

GLAST verra 1 gamma du Crabe par 500 rotations = 16 secondes

GLAST

Contemporaneous radio timing...

- ...is needed to allow gamma-ray photons to be folded synchronously
- ...was relatively easy when targeting only the brightest pulsars for EGRET
- ...is very hard when the number of potentially interesting sources is much higher
- Must be carried out on the very biggest radio telescopes (Arecibo, GBT, Parkes, Jodrell) in the vast majority of cases

Thorsett n'exclu pas Nançay de cette liste…

Lessons from EGRET

- Major timing programs were set up for CGRO:
  - We studied about 100 pulsars at Green Bank (140ft and a small dedicated telescope, neither available any longer)
  - About 280 were studied at Jodrell
  - Parkes also did regular timing (unknown number)
  - Several special cases observed daily (Crab, Vela, ...)
- Very hard work:
  - Most pulsar observers were involved in the early 1990s
  - All major telescopes were involved
  - Lots of observing time was required

Status for *GLAST*

- Good news is Jodrell: currently timing about 500 pulsars regularly
- Parkes has been doing follow-up on PMB-discovered pulsars and others
- US facilities (GBT, Arecibo) heavily oversubscribed
- Other options still uncertain (e.g., Allen Telescope Array)
- Bottom lines:
  - It will be relatively straightforward to time a comparable set as was done for EGRET
  - This is a much smaller fraction of "interesting" sources

Une occasion pour Nançay

1. Nançay n'a pas forcement vocation de faire concurrence aux usines à éphémérides. En revanche GLAST saura avaler tout ce qui nous voudrions lui proposer.
2. Le gros besoin d'un suivi soutenu me semble être une belle opportunité pour Nançay: on pourra étudier en profondeur un petit nombre d'objets qui nous intéressent particulièrement.
3. (personnellement j'ai un faible pour la région du Cygne, mais soyons mieux distribués en A.D.)
4. Je serais heureux de travailler avec des pulsaristes sur un assortissement délectable de pulsars gamma, et de candidats, dont d'éventuels « gemingas ».

Question: supposons qu'on trouvait un pulsar gamma et qu'on voulait faire une recherche approfondie de contrepartie radio -- Nançay est-il un appareil bien adapté?

Question: quels pulsars sont déjà suivis par Nançay?

sadgage

Extra slides….

The remaining challenge: timing

- Goal: fold time-tagged *GLAST* photons at pulsar period
- Obstacle: pulsar period varies
  - deterministically because of spin-down, binary motion, and observatory motion
  - unpredictably because of "timing noise" and discrete "glitches"
- Plan:
  - monitor radio pulsars over *GLAST* life
  - provide mean parameters and piecewise polynomial fit to pulsar phase (collectively, an "ephemeris")

The advantage of 21-cm

- Most surveys at 430 MHz
  - Pulsars are strong/beams are big
  - But sky is bright and dispersion limits distance
- Parkes survey was at 1400 MHz
  - 13 beams simultaneously/long dwell (2100s per pointing)
  - BIG advantages in Galactic plane (where the youngest pulsars are)
  - discovered ~700 new pulsars
- Arecibo ALFA system:
  - 7 beams at 1400 MHz
  - 10 times raw sensitivity of Parkes beams
  - New, very broadband (300 MHz) spectrometer (soon)
  - 1.8 times as deep/6 times the volume (50 times for fast pulsars)

The Astrophysical Journal Supplement Series, 157:324–334, 2005 April

THE HIGHEST-ENERGY PHOTONS SEEN BY THE ENERGETIC GAMMA RAY EXPERIMENT TELESCOPE (EGRET) ON THE *COMPTON GAMMA RAY OBSERVATORY*

D. J. Thompson,[1] D. L. Bertsch,[1,2] and R. H. O'Neal, Jr.[1,3]

ABSTRACT

EGRET is limited at high energies by the photon flux. Typically, spectra of sources have at most a few counts in a 2-week exposure in the interval from 4 to 10 GeV. Nevertheless, the EGRET Total Absorption Shower Counter (TASC) is capable of measuring energies much beyond this region, and for long exposures such as were used for diffuse analysis, spectra beyond 50 GeV have been reported (S. Hunter et al. 1997, ApJ, 481,205 and P. Sreekumar et al. 1998, ApJ, 494, 523). For the entire mission, 1484 events were found above 10 GeV with the highest being over 100 GeV. Despite the small numbers, these events are interesting because the point-spread function is less than 0.5° so that even a small number that are spatially consistent with a known or suspected source is significant.

This paper compares the spatial distribution of these events with the observed diffuse emission above 100 MeV to see if there are differences that might suggest significant sources contributions or give insight into the source mechanism. In addition, a comparison of the positions of high energy events with several classes of potential sources shows that several are compatible with pulsars near the Galactic plane and with blazars at higher latitudes. The pulsar associations are reported here, and a companion paper (B. Dingus et al.) examines the correlation with AGN, especially the blazars detected by EGRET

Motivation for Examining the Very High Energy Events

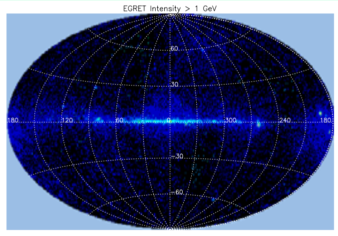


Figure 1. Allsky photon map for energies above 1 GeV for the entire mission

The EGRET point-spread function for very high energy gamma rays (above 10 GeV for this discussion) is 0.45° for 67% containment at 10 GeV and less at higher energies. This is smaller than the contours of many of the EGRET sources. At this level, searches of source classes outside the Galactic plane are feasible. Any correlation would prove interesting, especially if the lower energy emission was not detected, or had spectra that appeared to be breaking.

Figure 1 shows an all-sky map of photons above 1 GeV for the entire CGRO mission. While this is an order of magnitude lower in energy, several features can be seen. The Galactic plane emission is very narrow in latitude and concentrated in a longitude zone 30° around the center. The Crab, Geminga, and Vela stand out as do the sources in Cygnus. At high latitudes, the emission appears to be randomly distributed. The analysis by Hunter et al., 1997 showed that near the plane, the distribution at high energy is similar to that at low energies and that there appears to be an excess over the model values. Some discrete, unresolved sources may be responsible for part of this excess.

A paper (5.04) by B. Dingus in this meeting discusses the very high energy event correlation with EGRET blazars and other radio sources. This poster concentrates on the comparing the distribution of very high energy distribution with the presumably largely diffuse emission and examines the class of radio pulsars for high energy emission since in the region near the Galactic plane, they are the only sources that EGRET has clearly identified. If the emission is pulsed, the phase is an important tool in identifying the origin of the event.

Comparison with Diffuse Emission

Results

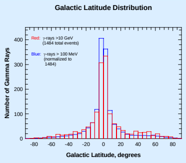


Figure 2.

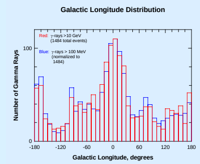


Figure 3.

The latitude and longitude distributions in Figures 3 and 4 of the set of 1484 gamma ray events above 10 GeV are compared with the distribution of > 100 MeV events, normalized to the same total. Both set have the same exposure variations. Both sets appear to have similar distributions, although those at very high energies are somewhat deficient in the two latitude bins about the plane, due in part to the observation that the extragalactic diffuse has a harder spectrum than the galactic diffuse emission. The reduced χ^2 here is 2.88. The difference may also point to more discrete source contributions at high latitudes. The longitude distributions agree very well. It's reduced χ^2 is 1.36. Note that sources have been subtracted from the >100 MeV data, but not from the >10 GeV events.

CONCLUSIONS

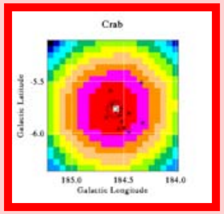
The sample of 1484 gamma rays > 10 GeV observed during the entire CGRO mission by EGRET have a distribution in Galactic latitude and longitude that is similar to that at low energies (>100 MeV). However, in latitude, the high energy events are not quite as peaked in the plane. In part, this reflects the fact that the extragalactic diffuse has a harder spectrum than the Galactic diffuse emission. Some of the high energy events are due to sources, and their number could be significant at high latitudes and cause the same effect.

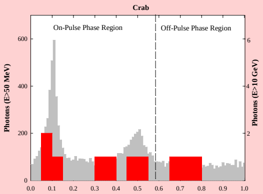
All of the gamma ray pulsars detected by EGRET have associated events that exceed 10 GeV. Most of these events were observed to occur in the pulsed phases of the pulsars even up to the highest energies of over 100 GeV in the case of the Crab. For both Vela and P1706-44, the very high energy events show a remarkable clustering within two week intervals. The spectrum of the pulsars observed by EGRET in general show breaking features at the upper end of the EGRET sensitivity. The results of the present analysis indicate that the breaking spectra do not cutoff completely until at least several 10's of GeV. The events above >10 GeV may indicate emission from pulsars that were not seen as sources, or were not identified as such as in the case of 3EG J1823-1314. Seventy-one other events point to pulsar not detected by EGRET. Some of these undoubtedly will ultimately be show to be real associations.

These results shown here, especially in regard to pulsars, suggest that the next generation instrument, GLAST, should be able to use its high energy and greatly increased sensitivity capabilities to locate the sources of >10 GeV emission. Perhaps this energy range may be very important to resolve pulsars in regions where source confusion may be problematic.

Very High Energy Gamma Ray Associations with Pulsars

Crab

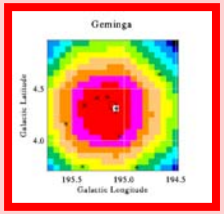


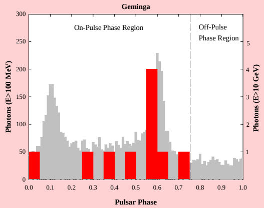


Arrival Time (Julian Days)	Date	Pulsed (P)	Enrgy (GeV)	to Plsr. (deg.)	Pulsar Phase
2448371.41209737	04/24/91		29.2	0.112	0.6972
2448420.22591974	06/12/91	p	22.7	0.253	0.3527
2448847.45561746	08/13/92	p	101.3	0.194	0.1000
2448881.07116046	09/16/92	p	117.4	0.223	0.0700
2449330.28419647	12/08/93	p	21.0	0.245	0.0790
2449334.93486661	12/13/93		10.5	0.271	0.7286
2449395.38567745	02/11/94	p	29.6	0.170	0.5219
2449797.70973554	03/21/95	p	12.8	0.262	0.3446
2450321.04196266	08/26/96		14.4	0.293	0.7539
2451312.53385290	05/14/99	p	26.7	0.122	0.4700

The 10 very high energy events cluster close to the position of the Crab as seen in the skymap image. Eight of the events are found in the pulsed phase of the pulsar. Two events are observed to have energies above 100 GeV, and they are in the main (first) peak.

Geminga

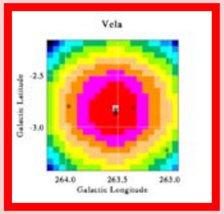


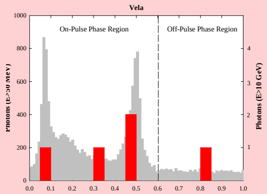


Arrival Time (Julian Days)	Date	Pulsed (P)	Enrgy (GeV)	to Plsr. (deg.)	Pulsar Phase
2448422.08505433	06/14/91	p	11.0	0.230	0.5985
2449333.25443448	12/11/93	p	12.3	0.312	0.5825
2449586.63103641	08/22/94	p	15.0	0.541	0.0028
2449787.85999683	03/11/95	p	23.7	0.265	0.5779
2449815.65828918	04/08/95	p	10.5	0.512	0.4700
2450512.51940695	03/05/97	p	10.6	0.756	0.6200
2451003.04270377	07/08/98	p	24.2	0.867	0.5800
2451006.38230522	07/11/98	p	22.6	0.172	0.7000
2451661.81820632	04/28/00	p	11.5	0.621	0.3700
2451672.74412321	05/09/00	p	11.3	0.459	0.2800

All 20 high energy events that are found near Geminga are within the pulsed phase of the pulsar, although the phase is broad (75%) in this source. Five of the events fall in the main peak. The locations shown in the skymap in the upper panel are more scattered than in the case of the Crab, but are still compatible with the point-spread radius.

Vela

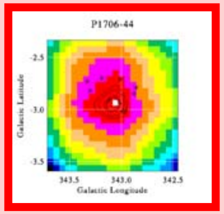


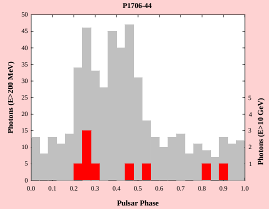


Arrival Time (Julian Days)	Date	Pulsed (P)	Enrgy (GeV)	to Plsr. (deg.)	Pulsar Phase
2448503.58294328	09/04/91	p	16.2	0.698	0.4641
2449603.03832318	09/07/94	p	12.7	0.217	0.3048
2449604.85820373	09/09/94	p	13.6	0.185	0.4649
2449606.02594250	09/10/94	p	11.9	0.482	0.0531
2449615.56235565	09/20/94		20.8	0.918	0.8118

Four out of the 5 events found near this pulsar are in the pulsed phase. The one that is not is 0.9° away. That is twice the value of the point-spread radius of 0.45 ° for 67% containment. This event might be background. However, it is among a collection of 4 events that happened within a two week interval. This clustering in time is most remarkable!

P1706-44

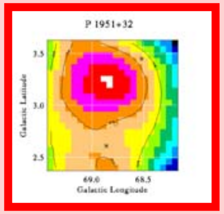


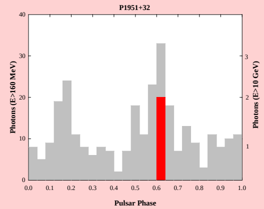


Arrival Time (Julian Days)	Date	Pulsed (P)	Enrgy (GeV)	to Plsr. (deg.)	Pulsar Phase
2448452.29436738	07/14/91	p	15.7	0.133	0.2484
2448455.13701963	07/17/91	p	10.7	0.309	0.2589
2449229.30343782	08/29/93	p	15.2	0.297	0.4795
2449441.34494514	03/29/94	p	10.8	0.412	0.2574
2449888.69506315	06/20/95	p	11.0	0.332	0.2953
2449898.29772262	06/29/95		11.1	0.809	0.8094
2449898.87999492	06/30/95	p	64.3	0.262	0.5246
2449907.94734169	07/09/95		35.9	0.884	0.9022
2450685.07581113	08/24/97	p	13.5	0.148	0.2227

Seven out of 9 events are in the pulsed phase, although that is quite broad for this pulsar. As in the case of Vela, there is a clustering in time for 3 events that occurred within 10 days in mid 1995.

P 1951+32

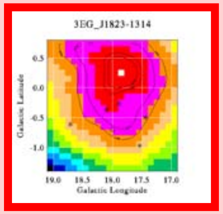




Arrival Time (Julian Days)	Date	Pulsed (P)	Enrgy (GeV)	to Plsr. (deg.)	Pulsar Phase
2449068.29424792	03/21/93	p	17.6	0.245	0.6127
2449543.43345528	07/09/94	p	13.8	0.674	0.6220

Two events are found and they have almost identical phases that fall within the main peak. This source was not included in the 3rd EGRET catalog (Hartman et al., 1999, ApJS, 123, 79) since it fell below the cutoff threshold of significance. However, with added exposure since the end of CGRO cycle 4, it does exceed threshold, and it is clearly pulsed.

Unidentified Source with a Pulsar Nearby



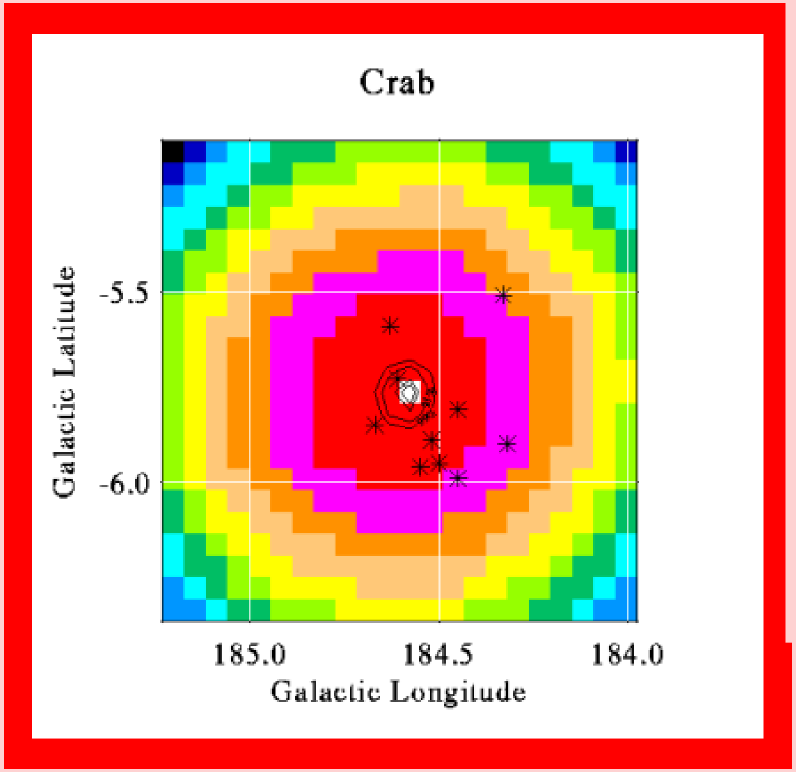
Arrival Time		Galactic		Enrgy
Date	Time	Long.	Lat.	(GeV)
02/15/92	18:43:03	18.71	-0.61	10.3
06/23/93	09:28:28	17.54	-0.97	15.5
06/13/94	15:32:37	18.10	-0.37	14.9
06/14/94	08:53:49	17.89	-0.27	21.2
07/02/94	09:33:12	17.44	-0.50	11.3

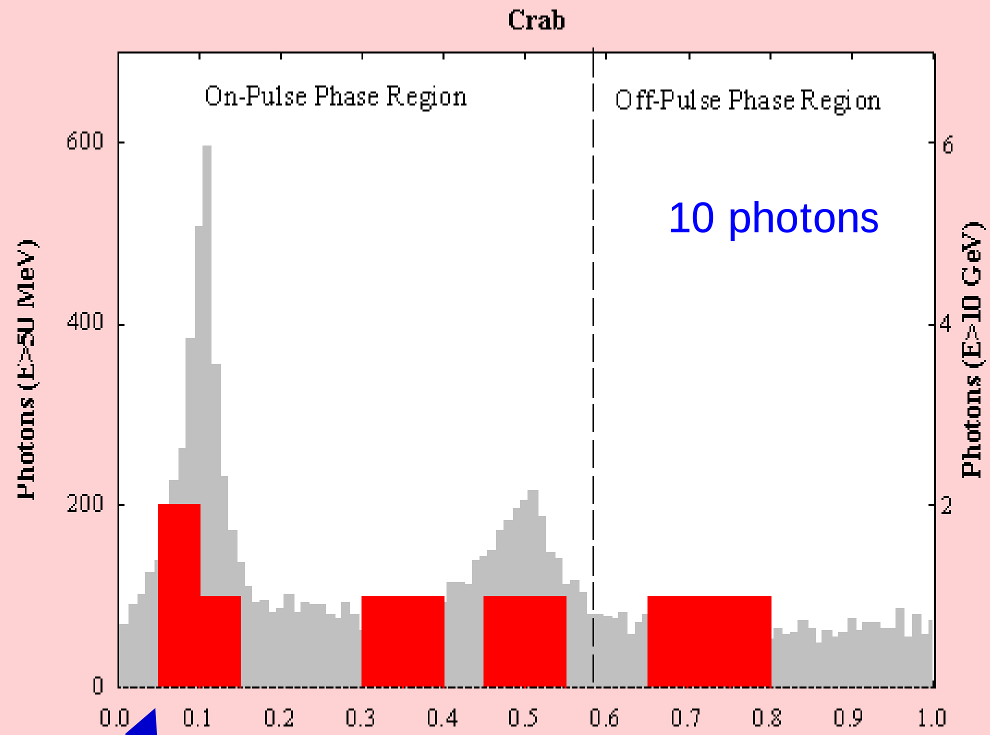
3EG J1823-1314 is listed in the 3rd EGRET catalog as an unidentified source. The radio pulsar, P1823-13, is near the outer contour, and its location is shown in the skymap above as a diamond. Five high energy events cluster around this location. They do not appear to be pulsed in this case.

Seventy-one other very high energy events are in the vicinity of 29 other pulsars in the EGRET potential source list. Of these, 56 are within ±30° longitude of the Galactic center where the intensity is the highest. Consequently, some may be diffuse background events.

EGRET >10 GeV for Crab

EGRET >0.05 GeV





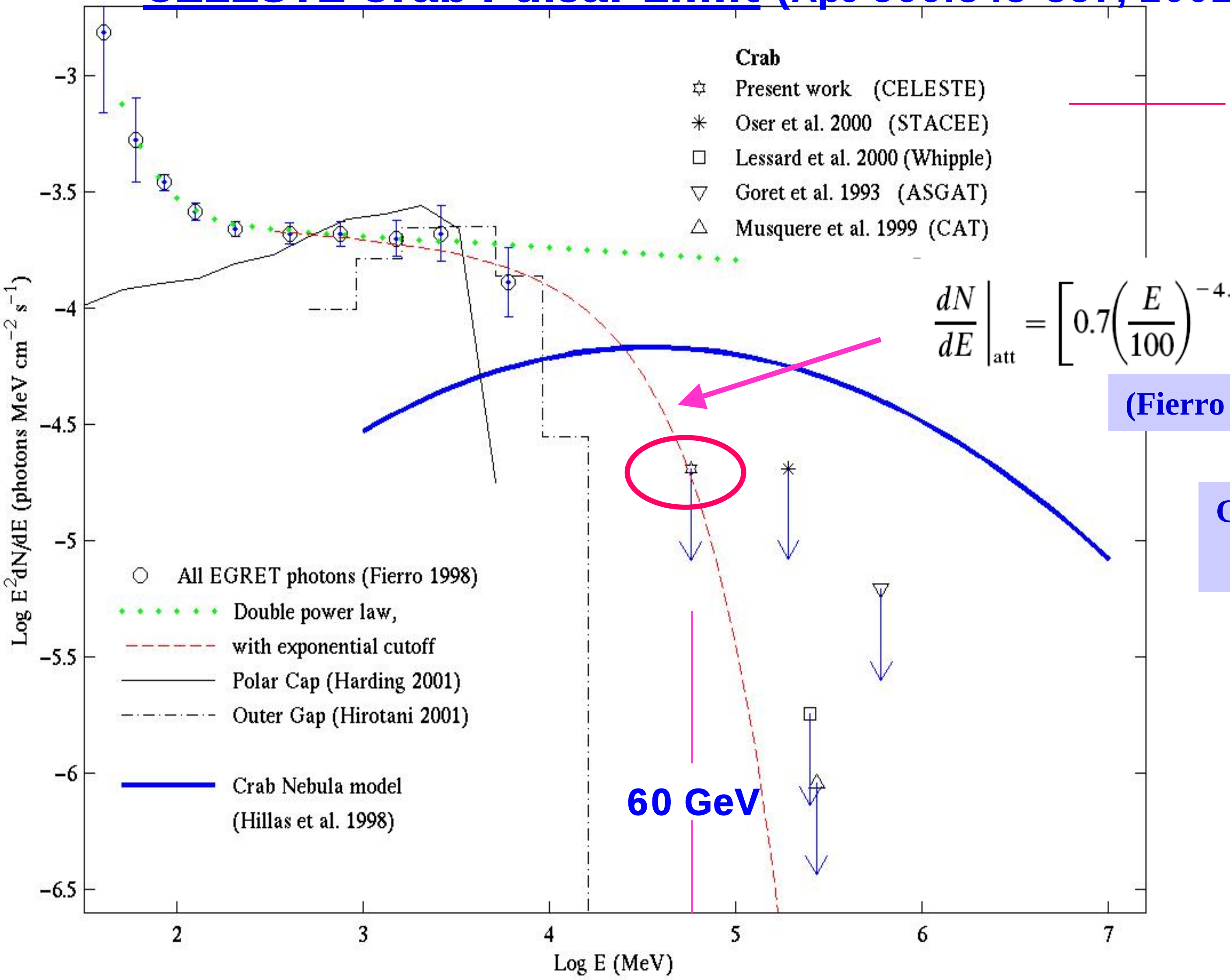
Arrival Time (Julian Days)	Date	Pulsed (P)	Enrgy (GeV)	to Plsr. (deg.)	Pulsar Phase	
2448371.41209737	04/24/91		29.2	0.112	0.6972	
2448420.22591974	06/12/91	p	22.7	0.253	0.3527	P2
2448847.45561746	08/13/92	p	101.3	0.194	0.1000	
2448881.07116046	09/16/92	p	117.4	0.223	0.0700	
2449330.28419647	12/08/93	p	21.0	0.245	0.0790	
2449334.93486661	12/13/93		10.5	0.271	0.7286	
2449395.38567745	02/11/94	p	29.6	0.170	0.5219	
2449797.70973554	03/21/95	p	12.8	0.262	0.3446	P2
2450321.04196266	08/26/96		14.4	0.293	0.7539	
2451312.53385290	05/14/99	p	26.7	0.122	0.4700	TW2

two @ 100 GeV: nebula?

P1 *not* rich...

half 'n half nebula-pulsar 20-ish GeV

CELESTE Crab Pulsar Limit (ApJ 566:343-357, 2002)



$$\left.\frac{dN}{dE}\right|_{att} = \left[0.7\left(\frac{E}{100}\right)^{-4.89} + 2.3\left(\frac{E}{100}\right)^{-2.05}\right] e^{-E/E_0}$$

(Fierro et al)

CELESTE: Eo<26 GeV

<0.5 γ /minute

(Celeste limit calculated differently than Whipple & Stacee -- vary Eo to match rate limit)

“Phase-resolved studies of...Crab, Geminga,Vela Pulsars”,
J.M. Fierro, P.F.Michelson, P.L. Nolan et al. Ap. J. 494, 734-746 (1998)

Showed that Crab P1 spectrum begins cut-off below 6 GeV.
P2 with spectral index -2.16 ± 0.04.
LW2 (= Leading Wing of Peak 2) has spectral index -1.17 ± 0.10.
Naive extrapolation to 50 GeV => brighter than nebula (unless rollover ...)

an excellent update :

A&A 378, 918–935 (2001)
DOI: 10.1051/0004-6361:20011256

Astronomy & Astrophysics

The Crab pulsar in the 0.75–30 MeV range as seen by CGRO COMPTEL

A coherent high-energy picture from soft X-rays up to high-energy γ-rays

L. Kuiper[2], W. Hermsen[2], G. Cusumano[5], R. Diehl[1], V. Schönfelder[1], A. Strong[1],
K. Bennett[3], and M. L. McConnell[4]

Includes EGRET re-analysis with nearly *double* the statistics >1 GeV.
Confirms that LW2 dominates P2