Pulsars and Plerions from a Multiwavelength Perspective.

O.C. de Jager,
Unit for Space Physics, PU vir CHO, Pothcefstroom, South Africa

The Main Issues:

•Did ground-based Gamma-Ray Astronomy come to age with respect to the detection of pulsed γ-rays?

•The parameters determining the γ-ray detectability of plerions.

Pulsed γ-Ray Emission from Ground-Based Experiments

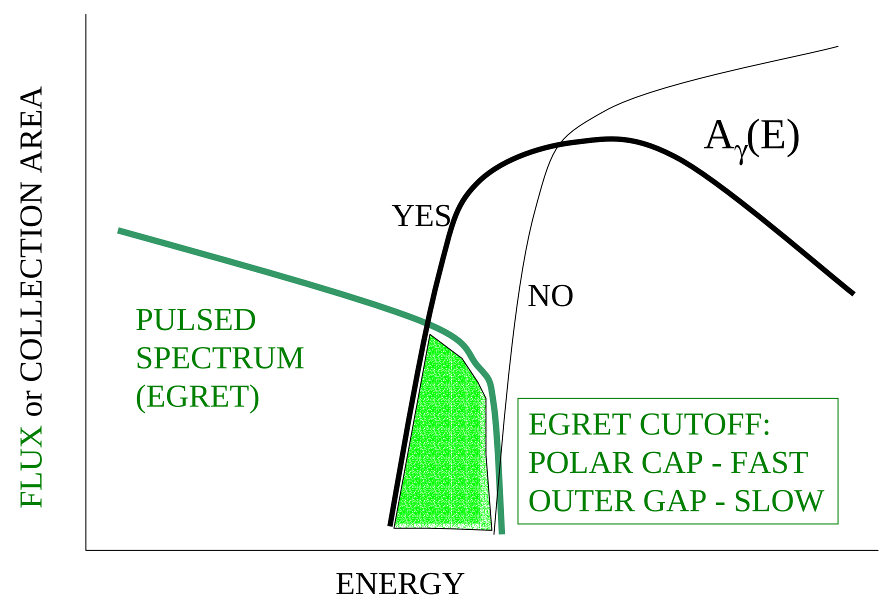
- We have been humbled by past experience. Lots of false detections due to our inability in understanding statistics and our drive to arrive at positive detections - “Ph.D pressure”.
- TeV upper limits from the Crab main pulse - at a level of a mCrab or less - outergap models (e.g. Hirotani) predict pulsed TeV emission at even lower levels - sensitivity problem - large stereo arrays important for background rejection.
- Safer venue - catch EGRET tails of pulsed emission extending to ≈30 GeV with a large mirror area telescopes (mono mode) with pixelized imaging cameras, high QE, and ≈3 ns gate time on trigger. Employ a special “pulsar trigger” in hardware/software - even at the expense of sacrificing collection area above 50 GeV.

See J. Dyks (G09): Polar Cap cutoff signatures

vs

J. Takata (G18): Outergap Emission

CONCEPT OF THE "CONSERVATIVE PULSAR TRIGGER"



Why pulsed γ-rays above 10 GeV?

- Pulsar polar cap potential drop $>10^{12}$ volt ⇒ electrons are accelerated to energies $E > 10^{12}$ eV.
- Curvature/synchrotron radiation & inverse Compton scattering above polar cap ⇒ gamma-ray emission of similar energies.
- Magnetic pair production ⇒ electron photon cascade ⇒ high multiplicity M (≈100 to 10^4) of $e^{\pm}$ pairs.
- ⇒ Maximum gamma-ray energies 5 to 50 GeV, depending on field strength and geometry.
- Outergap emission imply pulsed TeV γ-ray emission.
- EGRET (CGRO) had a poor sensitivity above 10 GeV.

S. Osone (T21)

CheSS: 10 - 100 GeV on SUBARU optical/IR telescope

A.K. Harding (2002), astro-ph/0208421

PSR	P (ms)	$\dot{P}$ (10^{-15} ss^{-1})	Gamma-ray	X-Ray	Radio	SNR/Name
B0531+21	33.0	422.0	X	X	X	Crab
B1509-58	150.0	1540.0	X	X	X	MSH15-52
B0833-45	89.0	124.0	X	X	X	Vela
B1706-44	102.0	92.2	X	X	X	
B1951+32	39.5	5.9	X	X	X	CTB 80
J0633+1746	237.0	11.4	X	X	(X)	Geminga
B1055-52	197.0	5.8	X	X	X	
B0656+ 14	384.0	55.0	(X)	X	X	
J0218+4232	2.3	8.3E-05	(X)	X	X	
B1046-58	124.0	103.6	(X)	X	X	
J2229+6114	51.6	78.3	(X)	X	X	
B1957+21	1.60	1.1E-04		X	X	
J0437+4715	5.70	5.7E-05		X	X	
JO030+0451	4.86	1.0E-05		X	X	
J2124-3358	4.93	2.1E-05		X	X	
B1821-24	3.05	1.6E-03		X	X	
B1929+10	226.0	1.2		X	X	
B0540-69	50.0	479.0		X	X	
J1420-6048	68.0	83.0		X	X	Kookaburra
Jl124-5916	136.0	740.0		X	X	G292.0+1.8
J0205+6449	65.7	193.0		X	X	3C 58
J0537-6910	16.1	51.2		X		N147B
J0635+0533	33.9	*		X		
J1811-1926	64.7	44.0		X		G11.2-0.3
J1846-0258	324.0	7097.1		X		Kes75
J161730-50	69.0	140.0		X		RCW 103
J0822-43	75.3	149.0		X		Puppis A
1E1207.4-52	424.0	*		X		PKS1209-52

EGRET γ-ray pulsars (pulsed)

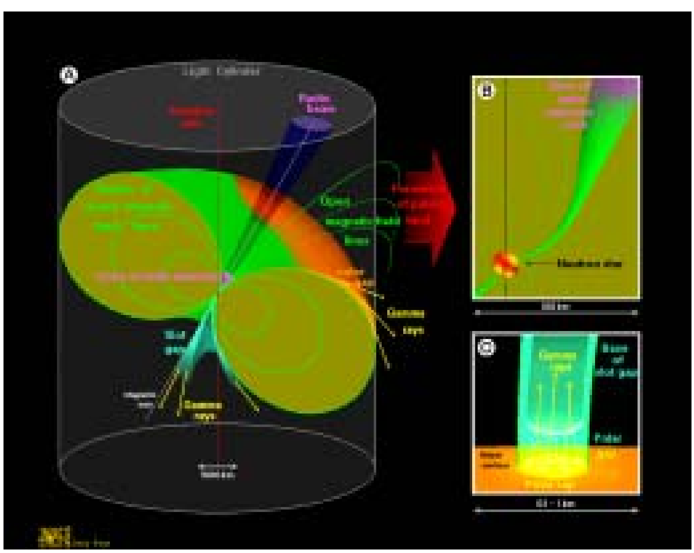
Possibly pulsed γ-ray emission

Pulsed X-ray and radio emission detected

Radio quiet; Pulsed X-ray emission

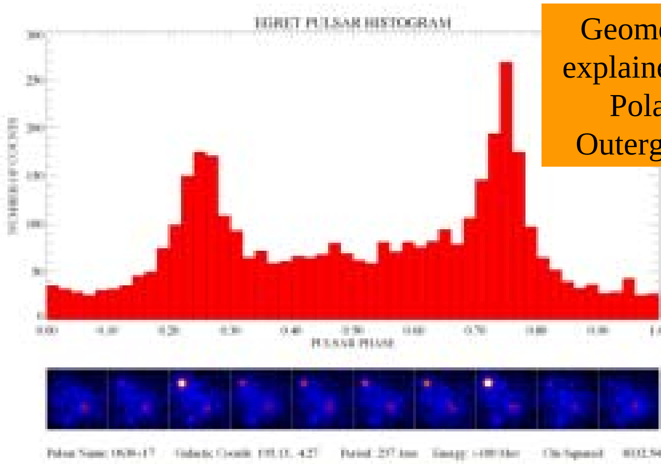
Kaspi & Helfand (2002), ASP

Pulsar Magnetosphere



GEMINGA (P=237 ms)

Gamma-ray Energies (0.1 GeV - 10 GeV)



Geometry can be explained with both Polar Cap & Outergap models.

$m_v=26$

Spectral Tails of γ-Ray Pulsars

No evidence of cutoff below 30 GeV for 1706 & 1951

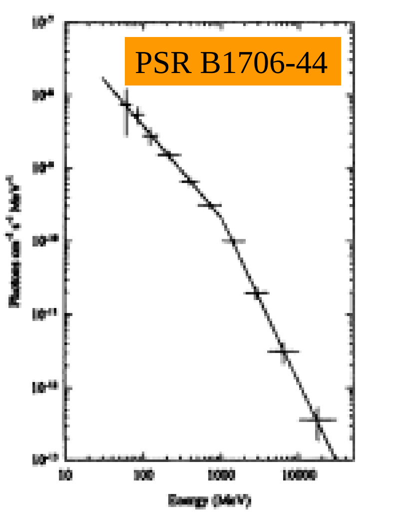


FIG. 7.—Phase-averaged energy spectrum of PSR B1706−44. The fit to a broken power law is described in the text. The uncertainties shown are statistical only.

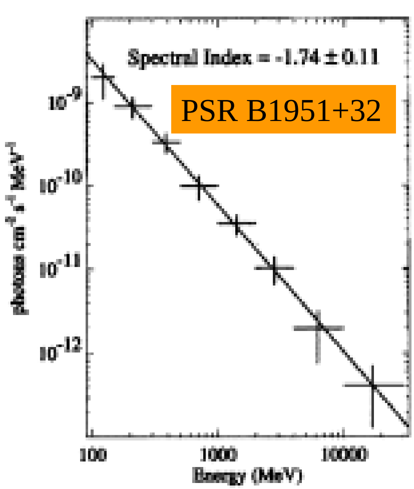
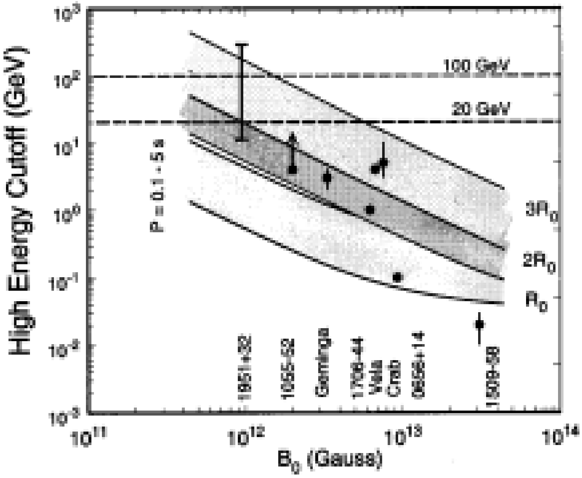


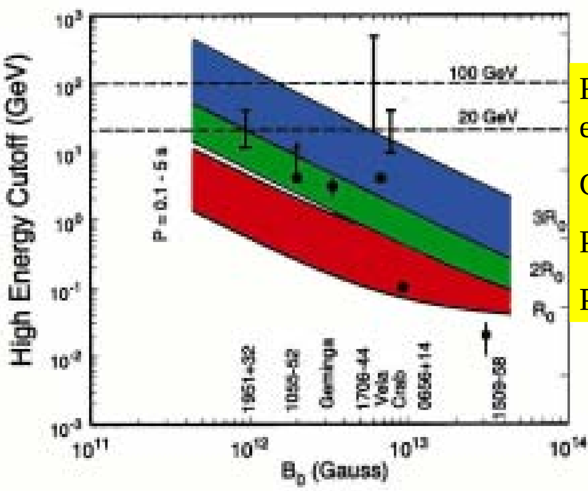
FIG. 2.—Phase-averaged differential energy spectrum of pulsed gamma rays at $E > 100$ MeV in the two peaks (see Fig. 1) after subtracting the background. The points are the data, and the straight line is the power-law fit given by eq. (2) with an exponent of −1.74.



Polar cap cutoffs as a function of surface field strength and altitude above surface.

M.G. Baring (2001) astro-ph/0106161

Figure 1 Maximum pulsar emission energies (from Baring & Harding 2000) imposed by pair creation attenuation at different altitudes, described empirically via Equation (1.3). For each altitude, a range of pulse periods (polar cap sizes) is represented by a shaded band. These energies are determined by the more involved photon propagation/attenuation code described in Baring & Harding (2001). Inferred cutoff energies (or ranges) for 8 gamma-ray pulsars of different B_0 are indicated, from which a trend of declining altitude of emission with increasing B_0 is suggested.



Revised cutoff energies for:

Crab,

PSR B1706-44

PSR B1951+32

Figure 1 Maximum pulsar emission energies (from Baring & Harding 2000) imposed by pair creation attenuation at different altitudes, described empirically via Equation (1.3). For each altitude, a range of pulse periods (polar cap sizes) is represented by a shaded band. These energies are determined by the more involved photon propagation/attenuation code described in Baring & Harding (2001). Inferred cutoff energies (or ranges) for 8 gamma-ray pulsars of different B_0 are indicated, from which a trend of declining altitude of emission with increasing B_0 is suggested.

Harding (2002)
astro-ph/0208421

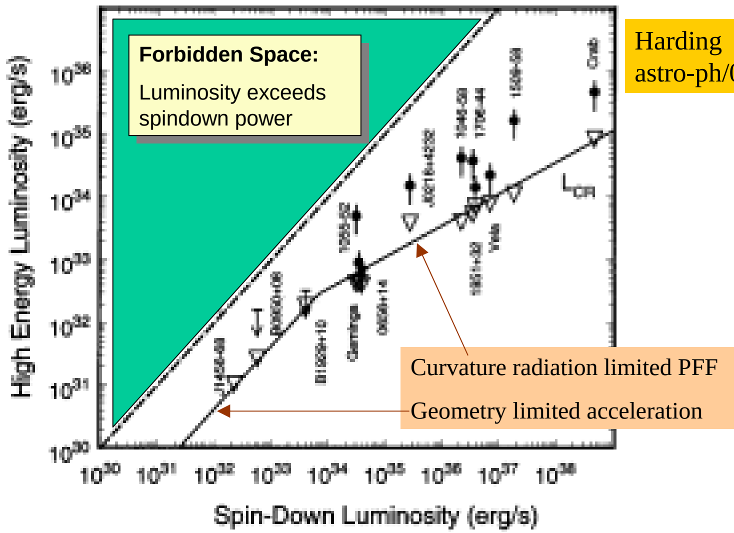
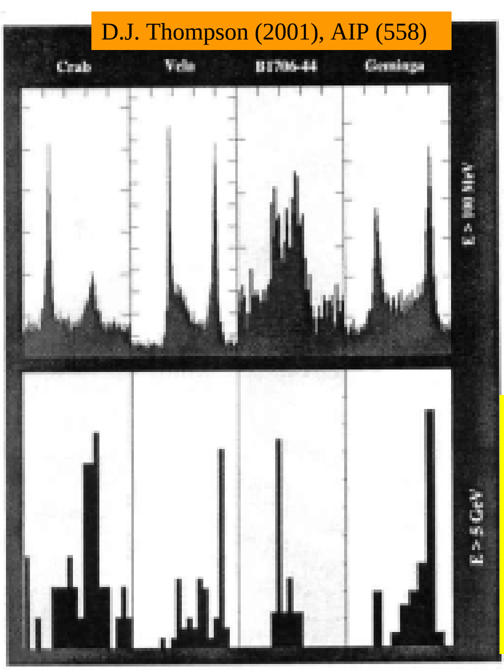


Figure 2: Predicted and observed high energy luminosity vs. spin-down luminosity. The solid curve is the theoretical prediction from eq. (2). The solid circles are the luminosities of the detected γ-ray pulsars[17], derived from detected fluxes above 1 eV assuming a 1 sr. solid angle. The upper limits are for > 100 MeV from[18]. The open triangles are predicted luminosities for the detected pulsars.



Gamma-Ray Pulse Profiles

above 100 MeV

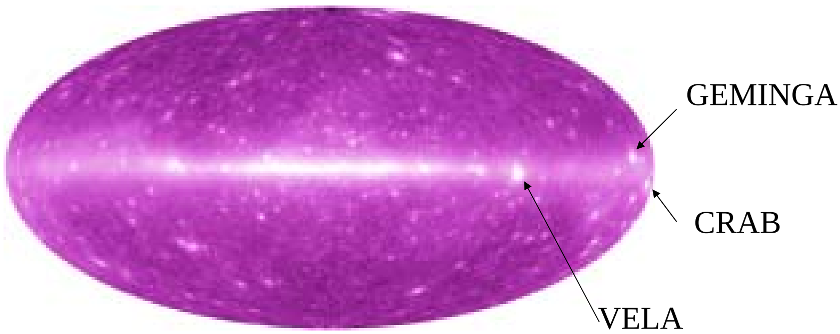
Broad structures

Gamma-ray Pulse Profiles above 5 GeV: single pulses with duty cycle ≈5% or less.

Improved detectability with tests for uniformity ⇒ Power of test increases for same flux.

The Gamma-Ray Sky (>0.1 GeV)

GLAST - 2005



Sensitivity Studies for Ground-Based γ-Ray Astronomy

- Pulsar spectra are typically hard - resemble power laws with very sharp cutoffs between 5 GeV and 40 GeV. Model:
- $dN/dE=KE^{-\Gamma}\exp(-(E/E_0)^b)$ with $b\approx2$
- Maximize the collection area A(E) below 50 GeV - even at the cost of decreasing A(E) above 50 GeV to ≈0, using “pulsar cuts”!!!

Ground Based γ-Observations

- Detection within a few hours important so that independent period search can be performed (restricting trials/aliasing).
- GLAST (0.8 m^2) will capture about 1 photon above 10 GeV in 3 hours from PSR B1706-44 or PSR B1951+32.
- What can new ground-based γ-ray telescopes do in 3 hours?
- Mirror area, timing resolution, camera, trigger condition and background rejection determine sensitivity.
- CELESTE, H.E.S.S. and MAGIC for case studies.

Search for 30 GeV Pulsar emission with the CELESTE "Solar Array" Cherenkov telescope

Stanford Linear Accelerator Center
14 June 2002

David A. Smith
Centre d'Études Nucléaires de Bordeaux-Gradignan, In2p3/CNRS

See F. Piron (S02) on Crab Nebula (pulsar?) observations >50 GeV

CELESTE COLLECTION AREA: A(E)

- Gamma-ray response calculated using Monte Carlo simulations.
- Uncertainties bigger at low energies: detector details, atmosphere model, but also large number of generated gammas for small number of triggers.
- For nebula , can afford to decrease uncertainties by cutting low energy, but the pulsar is another story (*more later*).

After cuts, deadtime corrections:

6.1 ± 0.8 gammas/minute

12.1 'ON' hours

(Crab nebula)

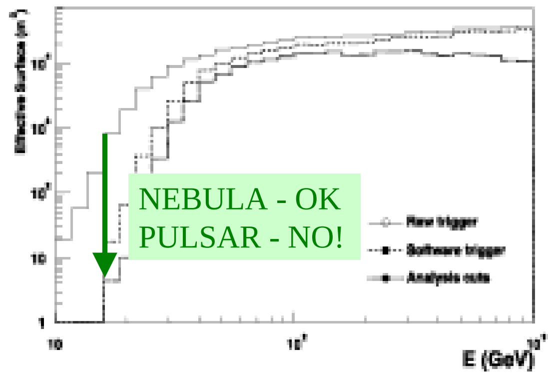
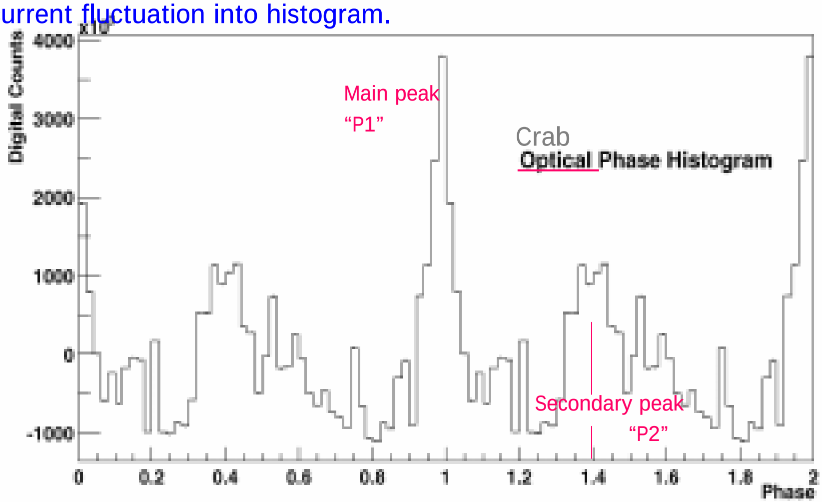


FIG. 10.—Effective surface area for gamma rays of CELESTE for a trigger threshold of 4.5 PEs heliostat^{-1}, in the direction of the Crab at transit. The analysis cuts are $N_{peaks} \geq 10$ and $\sigma_{grp} < 0.25$.

Testing Celeste pulsar search hardware & software.

Sum of AC-coupled PMT anode currents for three heliostats, tracking the Crab.

Sample at 2 kHz for 20 minutes. For each sample, calculate phase and enter current fluctuation into histogram.



1 period = 33 milliseconds. *Nota bene*, **TWO** rotations shown.

(By D. Dumora)

CELESTE: CRAB pulsar seach

The publication concentrated on ON-OFF analysis, not pulsar study.

No huge pulsed signal stood out.

We made a conservative upper limit:

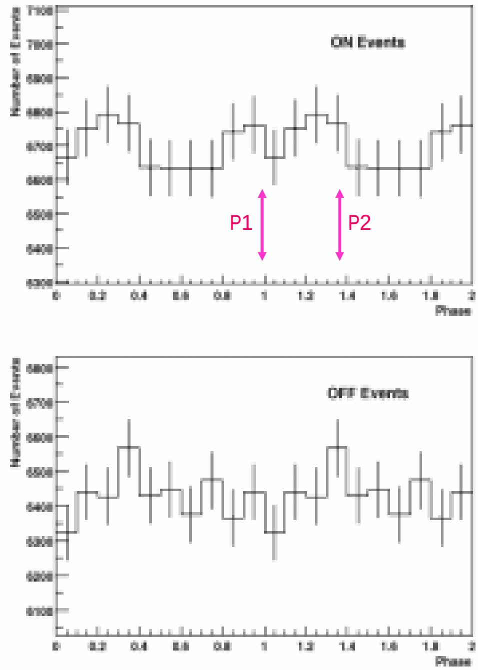
a) same cuts as for nebula

(best understood acceptance, but raises energy)

b) include 30% energy scale uncertainty

Our limit is for P1+P2, as compared to everything else.

(" aye, there's the rub..."   -Hamlet)



CELESTE: CRAB – SIGNAL SHOULD BE MAXIMUM ON DRY NIGHTS

• Step 4 - Exploring cuts for the '1951+32 data gave us the impression that our energy threshold is lower when the air is drier. Try it on the ApJ Crab sample with no cuts:

"H" =

"H-TEST" ANALYSIS NOT RELEVANT IN THIS CASE

Effect at the correct phase!

6 runs, H<34%
driest

10 runs, H<48%
drier

15 runs, H<57%
dry

14 runs, H>57%
wettest

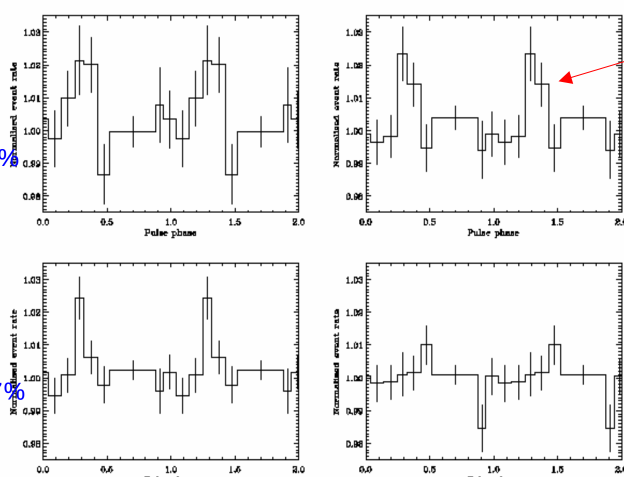
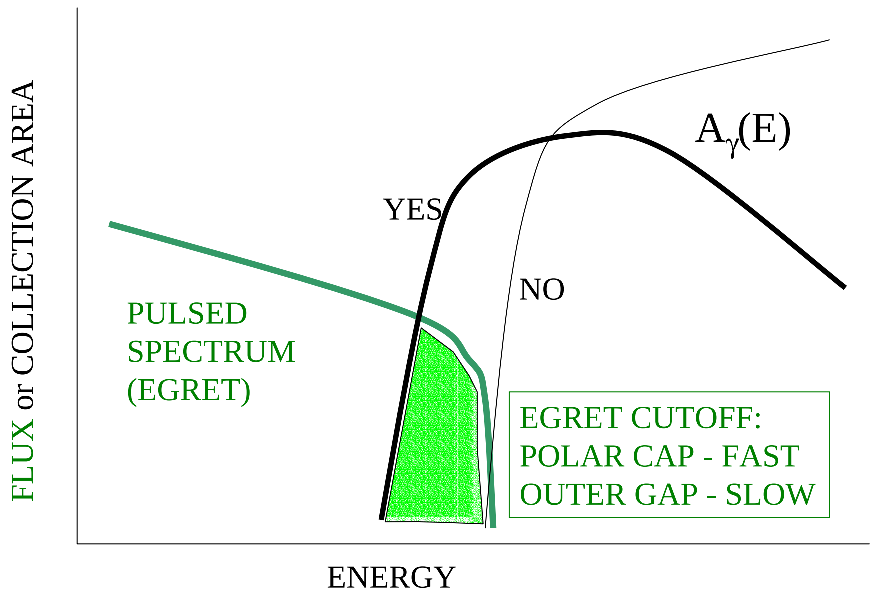
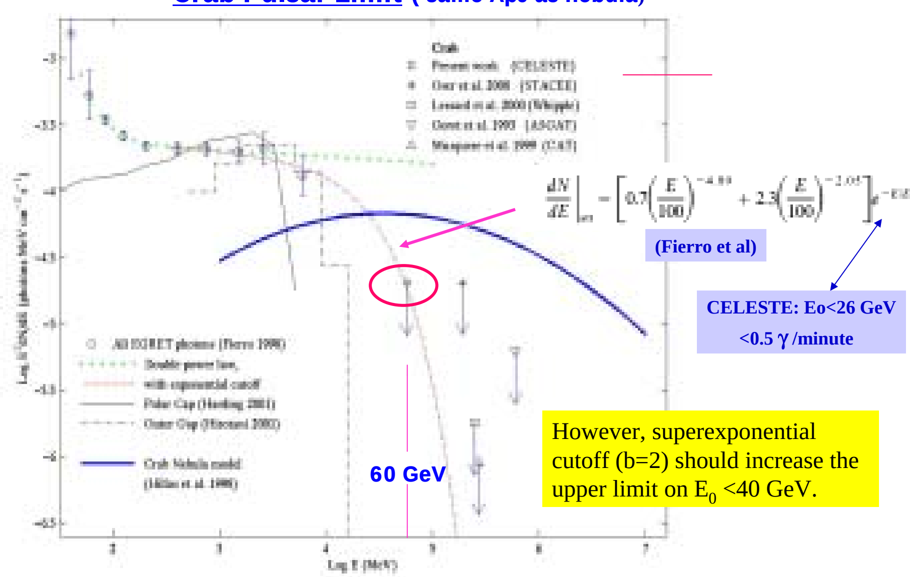


Figure 2: Standard bin phasograms of the raw events in the 6 (top left), 10 (top right) and 15 (bottom left) driest runs, and in the 14 wettest runs (bottom right).

CONCEPT OF THE "CONSERVATIVE PULSAR TRIGGER"



Crab Pulsar Limit (same ApJ as nebula)

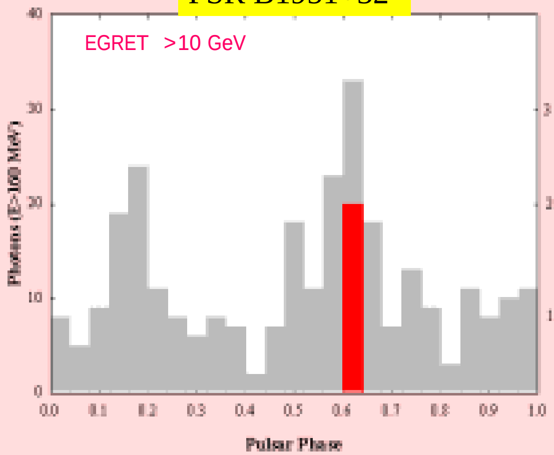


(Celeste limit calculated differently than Whipple & Stacee -- vary Eo to match rate limit)

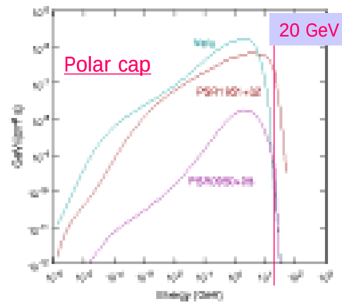
(Bertsch et al Baltimore symposium poster)

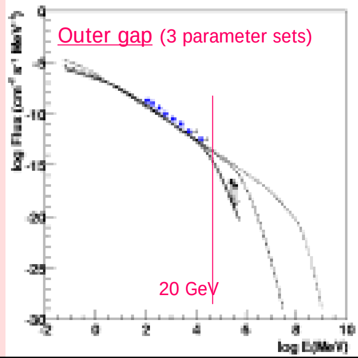
(don't recall where I stole this - glast maybe?)

PSR B1951+32



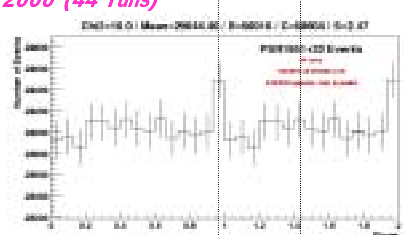
Arrival Time (Julian Days)	Date	Pulsed (P)	Enrgy (GeV)	to Psr (deg.)	Pulsar Phase
2449068.29424792	03/21/93	p	17.6	0.245	0.6127
2449543.43345538	07/09/94	p	13.8	0.674	0.6220



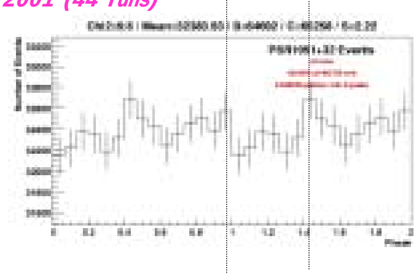


CELESTE - PSR B1951+32: Raw data

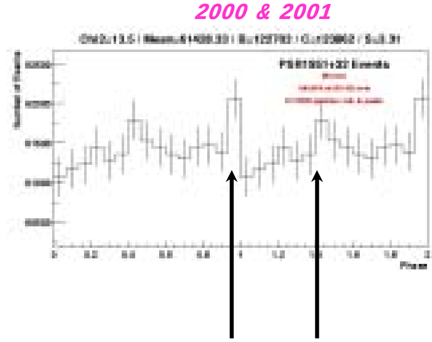
2000 (44 runs)



2001 (44 runs)



2000 & 2001



Our basic problem: these two bins very close to EGRET phase separation, BUT wrong absolute phase. Too small to claim detection, big enough to confuse upper limit.
We've "surfed" cuts & data selection so much that *N_trials* is muddled.

CELESTE upper limit for PSR B1951+32

assume spectral shape:

$$k(E/E_1)^{-\gamma}\, e^{-(E/E_o)^{a}}$$

with k= (1.1 ± 0.12)x10 $^{-7}$ /cm^2/s/GeV, E_1 = 0.42 GeV, γ = 1.89 ± 0.07 from Kuiper *et al* 1998,

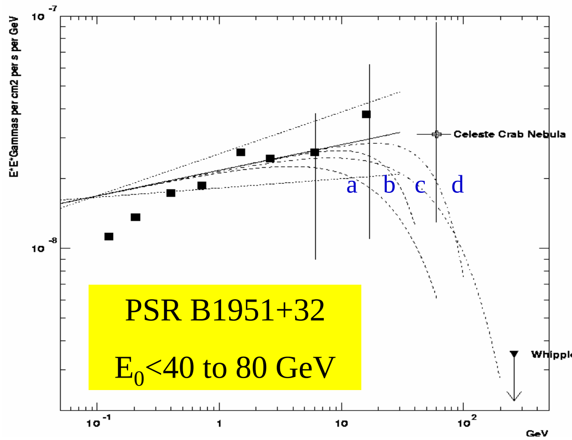
a = 1 or 2 (simple exponential versus hard cutoff). Here, raw acceptance.

'1951 is 10º farther north than Crab, increases energy threshold from 30 to 40 GeV.

exponential: Eo = 35 (75) GeV

super exp : Eo = 41 (80) GeV

nominal (30 % degraded) raw acceptance

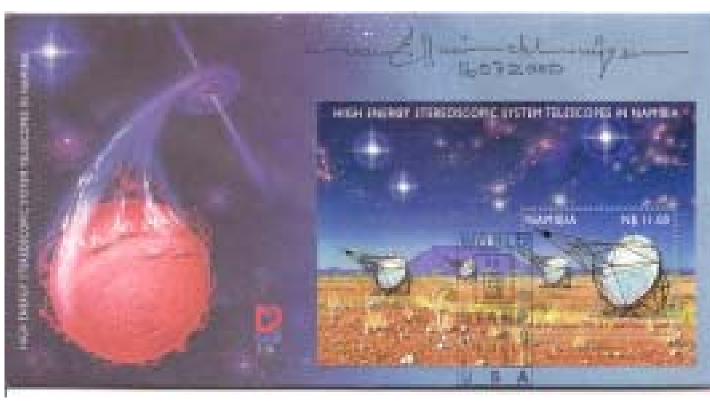


Preliminary upper limit curves for PSR B1951+32: The solid straight line is the EGRET power law, the dotted lines are ±1σ, and the black squares are the data, all taken from (Kuiper *et al* 1998). The curves, when convoluted with the CELESTE energy dependent acceptance A(E), give the CELESTE 99% confidence level upper limit of <1.8 gammas/minute, assuming a) simple exponential, nominal acceptance, b) super exponential, nominal acceptance, c) simple exponential, energy scale degraded by 30%, d) super exponential, energy scale degraded by 30%. The Whipple upper limit is taken from (Srinivasan *et al*, 1997). The CELESTE Crab nebula flux measurement is shown for comparison.

High Energy Stereoscopic System (H.E.S.S.) - Namibia

•4 Telescopes operating in Stereo mode allow a special topological trigger to select lowest energy showers at the expense of unwanted high energy events.

•Implies a "non-imaging" cut on cosmic ray shower rate: <8 Hz.



Signed on First Day of Issue by the artist himself!

Catalog (SACC) Value of Unsigned FDC:

•2000: US\$2-

•2002: US\$4-

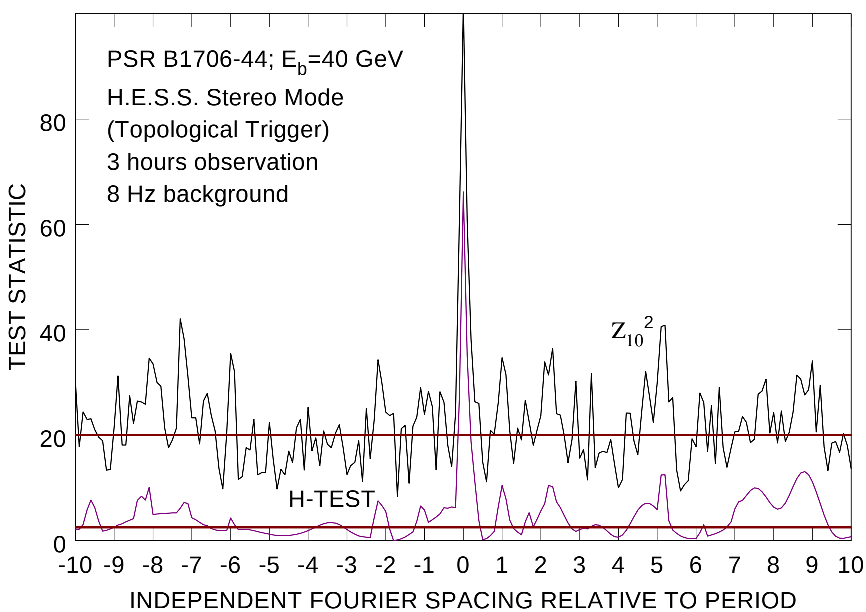
•2004: ??

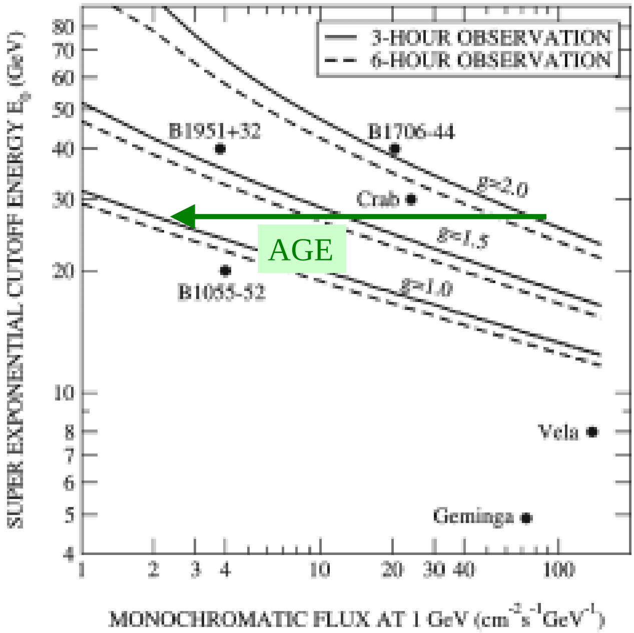
H.E.S.S. Sensitivity- Stereo Mode: 4 CT
See talk by W. Hofmann (T03)

- Source spectrum: hard power law + superexponential cutoff
- Shower simulations: background rate (8 Hz) and source rate
- Collection area increases rapid with increasing energy.

Object	K ($\times10^{-8}$ $cm^{-2}s^{-1}Gev^{-1}$)	Γ	E_0 (GeV)	b	F(>1 GeV) ($cm^{-2}s^{-1}$)	R_p (hr^{-1})	T (10-hour days)
Crab	24.0	2.08	30	2	22	100	3
Vela	138	1.62	8.0	1.7	148	8	400
Geminga	73.0	1.42	5.0	2.2	76	<<1	-
PSR B1951+32	3.80	1.74	40	2	4.9	180	1
PSR B1055-52	4.00	1.80	20	2	4.5	8	420
PSR B1706-44	20.5	2.10	40	2	20	240	1
PSR J2229+61	4.8	2.24	40	2	3.9	32	25
PSR J1420-60	6.9	2.02	40	2	6.9	110	2
PSR J1837-06	5.5	1.82	40	2	6.7	190	1

De Jager et al. (2001), ICRC





H.E.S.S. Sensitivity

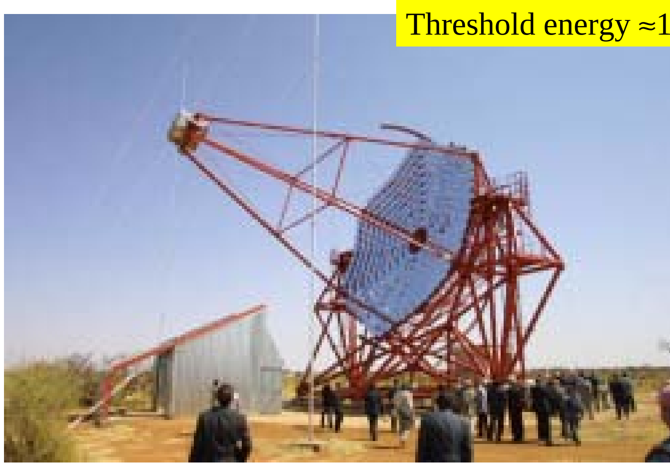
High cutoff energy requires low normalising flux at 1 GeV - faint EGRET/GLAST source can be seen..

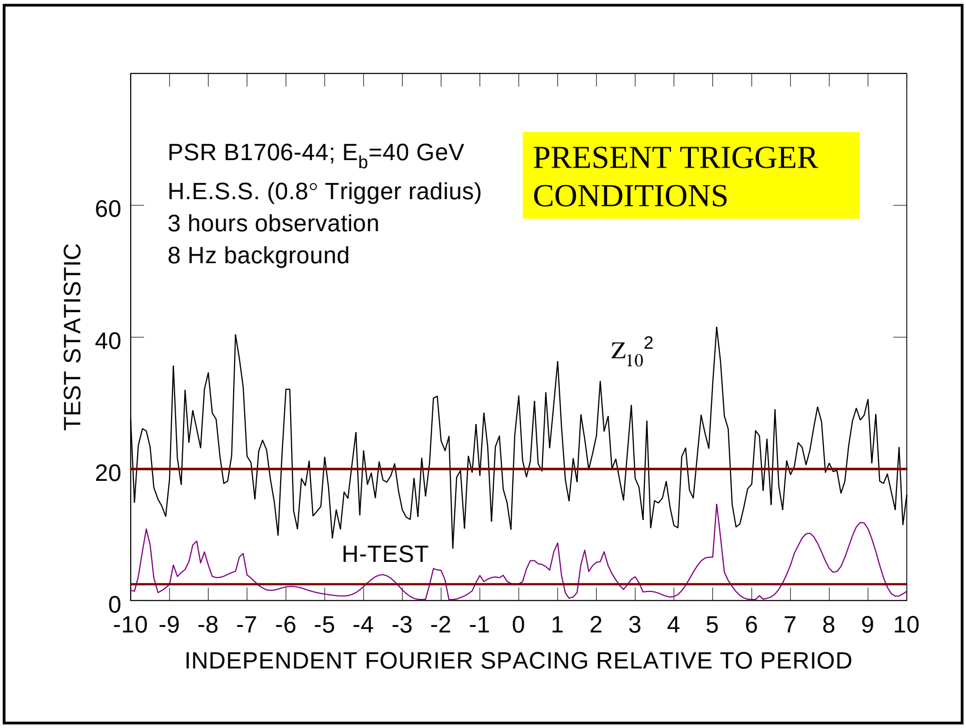
Low cutoff energy requires very large GeV flux - bright EGRET/GLAST source.

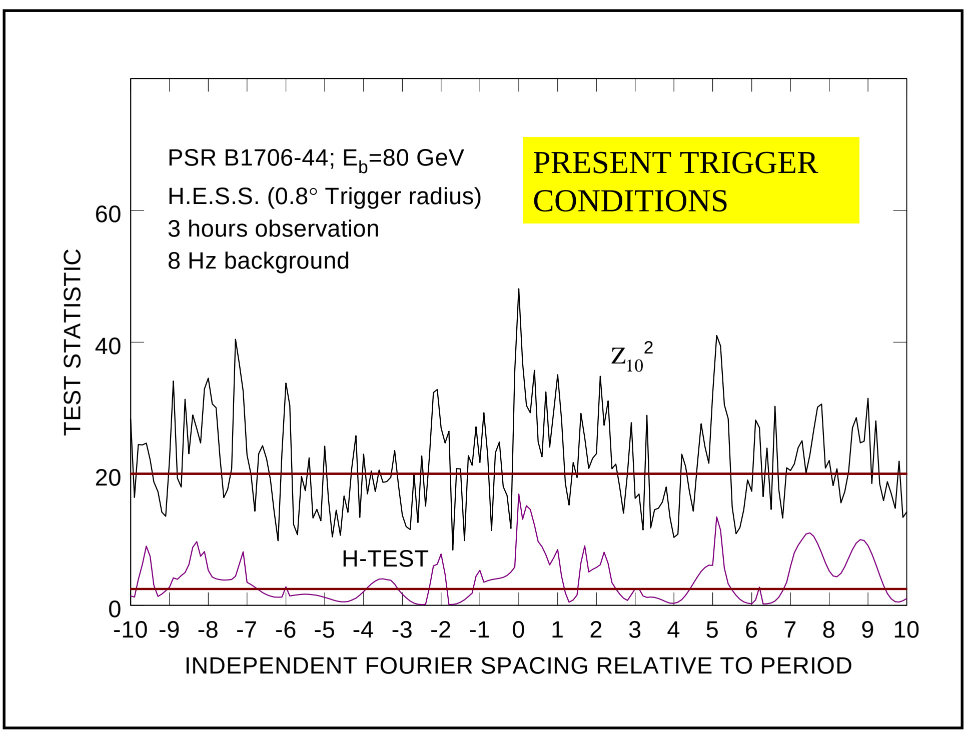
H.E.S.S. - First Telescope (see talk by W. Hoffman: T03)

http://www.mpi-hd.mpg.de/hfm/HESS/HESS.html

Threshold energy ≈150 GeV




PSR B1706-44; E$_b$=40 GeV
H.E.S.S. (0.8° Trigger radius)
3 hours observation
8 Hz background
PRESENT TRIGGER CONDITIONS
Z_{10}^2
H-TEST
TEST STATISTIC
0
20
40
60
-10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
INDEPENDENT FOURIER SPACING RELATIVE TO PERIOD

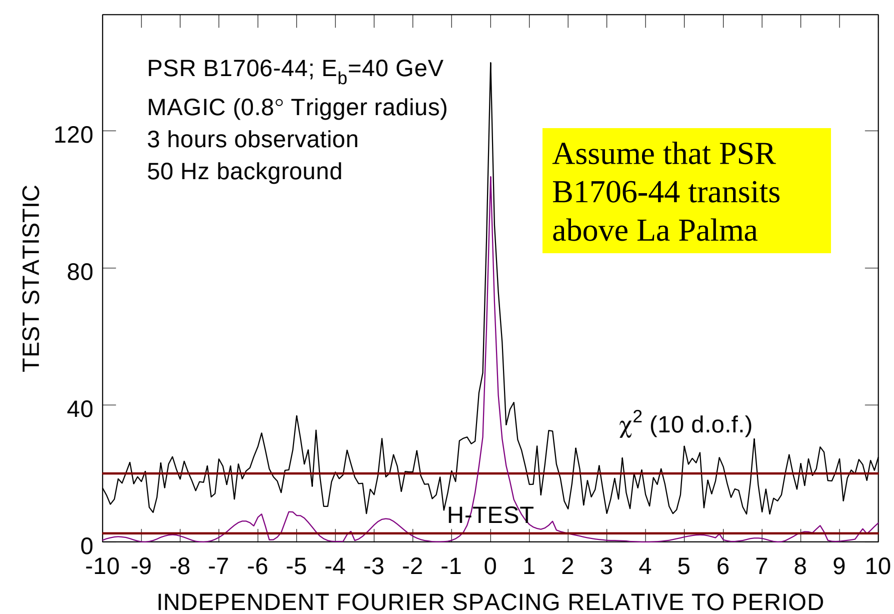

PSR B1706-44; E$_b$=80 GeV
H.E.S.S. (0.8° Trigger radius)
3 hours observation
8 Hz background
PRESENT TRIGGER CONDITIONS
Z_{10}^2
H-TEST
TEST STATISTIC
0
20
40
60
-10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
INDEPENDENT FOURIER SPACING RELATIVE TO PERIOD

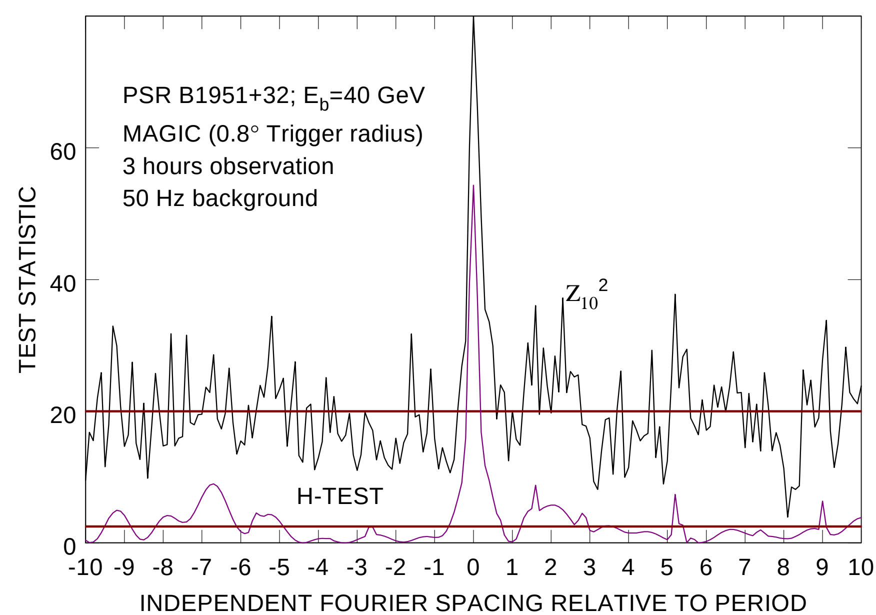
HOWEVER, THE MISSION OF H.E.S.S. IS NOT TO FIND NEW SOURCES OF PULSED GAMMA RAY EMISSION –

PULSARS ARE A SIDE ISSUE!

MAGIC - La Palma - 2200 m asl
See talk by E. Lorenz (T02)

Telescope parameters from Lopez-Moya et al. (2001), ICRC


PSR B1706-44; E_b=40 GeV
MAGIC (0.8° Trigger radius)
3 hours observation
50 Hz background
Assume that PSR B1706-44 transits above La Palma
χ2 (10 d.o.f.)
H-TEST
TEST STATISTIC
INDEPENDENT FOURIER SPACING RELATIVE TO PERIOD


PSR B1951+32; E_b=40 GeV
MAGIC (0.8° Trigger radius)
3 hours observation
50 Hz background
Z10 2
H-TEST
TEST STATISTIC
INDEPENDENT FOURIER SPACING RELATIVE TO PERIOD

Conclusions – Pulsed Emission

- Measurement of cutoff energies are important to distinguish between polar cap & outer gap models.
- CELESTE may have seen the CRAB pulsed emission?
- H.E.S.S. can detect pulsed emission if the cutoff energy is > 30 GeV. Stereo mode required.
- Large mirror area and pixelization of MAGIC makes pulsar searches within a single night possible if the cutoff energy >20 GeV.
- All γ-ray pulsars appear to be X-ray point sources ⇒ point at such positions within unidentified EGRET source boxes.
- Search for a new γ-ray pulsar only possible if the signal can be seen from a single pointing (night) & confirm detection the following night, and the night thereafter ….
- Simultaneous LIDAR/UBV photometry important!!!!

PLERIONS

- Crab: Particle Transport in Kennel& Coroniti (1984) MHD flow. Spectrum: Synchrotron/IC spectral cutoffs & variability.
- VELA: “Lip” problem - Shibata solution, polarization swing, magnetic pair production (M) and magnetization (σ) constraints.
- PSR B1706-44: ROSAT/CHANDRA discre-pancies, M vs σ constraints, “Kolmogorov” refinement of “AAK” entrapment of electrons - effect of correlation length of turbulence.

See F. Pacini (G03)

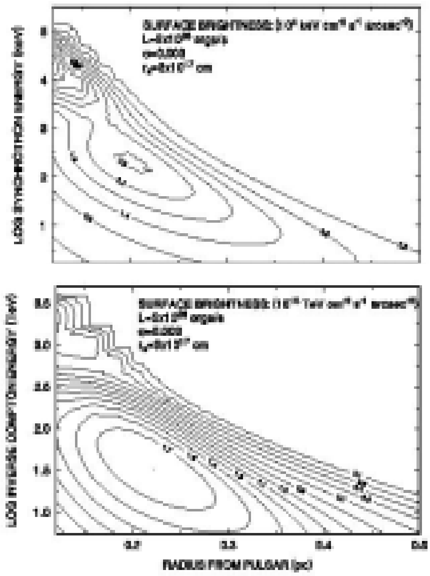
Quenching of the pulsar wind by inverse Compton scattering against thermal radiation from the neutron star.

See A. Kawachi (S27)
&
N. Shibazaki (G21)

CANGAROO II observations &
X-Ray & Gamma-Ray emission from the PSR B1259-63/SS2883 Binary

CRAB NEBULA

BOTTOM: CHANDRA image of pulsar/torus.
RIGHT: Numerical simulations of MHD flow beyond pulsar wind shock: toroidal synchroton & IC - size energy dependant (de Jager 2001, AIP)



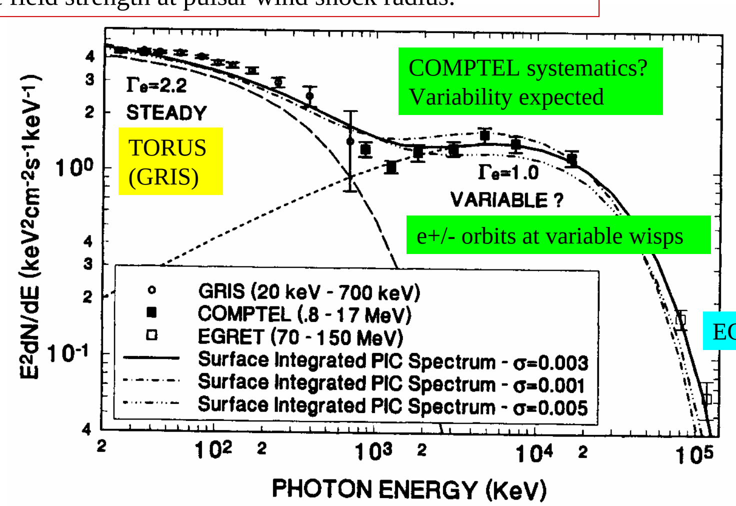
See S. Shibata, G.01 talk:

"The Crab Nebula: 3-D modelling"

CRAB NEBULA

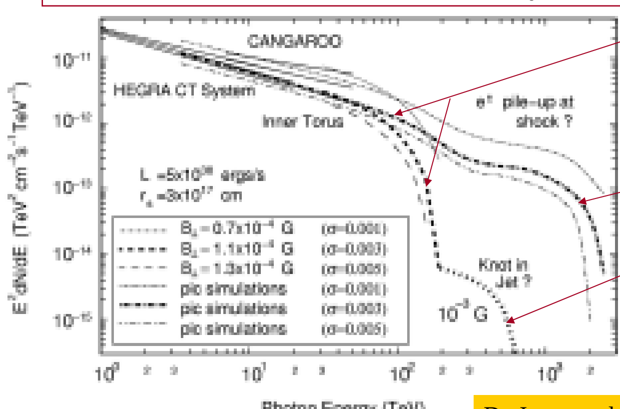
Particle-in-cell simulation of a 2-component injection spectrum, with second component particle acceleration rate equal to electron gyroperiod giving 25 MeV cutoff, independent of magnetic field strength at pulsar wind shock radius.

De Jager (2001), AIP (558)



CRAB VHE/UHE Nebular Spectrum

- GRIS, COMPTEL & EGRET spectrum of Crab Nebular Synchrotron tail constrain inverse Compton spectrum at highest energies.
- H.E.S.S. LZA observations ⇒ detection beyond 50 TeV ?



X-ray spectrum shows a turn-over below 1 MeV, indicating termination of this component.

COMPTEL/EGRET: a hard component extending >1 MeV, cutting off above 25 MeV. Could be due to electron pile-up in pulsar wind shock (as a result of synchrotron losses), or, synchrotron emission in high-B knot in X-ray jet.

Surface integral over IC brightness distribution in torus gives predicted flux consistent with observations up to 50 TeV.

De Jager et al. (2001), AIP (558)

Crab Nebula

Comparison between observed and predicted fluxes of the "inverse Compton" component above the synchrotron cutoff:

- D96 – de Jager et al. (1996), ApJ
- AA96 – Aharonian & Atoyan (1996), MNRAS
- H98, - Hillas et al. (1998), ApJ

de Jager (2001), AIP (558)

TABLE 1. Observed and predicted monochromatic fluxes at 1 GeV, 1 TeV and the ratio thereof. See text for a discussion.

SOURCE	$F(1\ \mathrm{GeV}) \times 10^{-8}$ $(\mathrm{cm}^{-2}\mathrm{s}^{-1})$	$F(1\ \mathrm{TeV}) \times 10^{-11}$ $(\mathrm{cm}^{-2}\mathrm{s}^{-1})$	$F(1\ \mathrm{TeV})/F(1\ \mathrm{GeV}) \times 10^{-4}$
EGRET & HEGRA	(3.5 ± 1.0)	(2.8 ± 0.5)	(8 ± 3)
EGRET & WHIPPLE	(3.5 ± 1.0)	(3.3 ± 0.7)	(9 ± 3)
D96 ($\sigma = 0.003$)	(1.8 ± 0.9)	(3.0 ± 1.5)	(17 ± 10)
AA96 ($\sigma = 0.003$)	2	2.8	14
H98 (16 nT)	2.4	3.7	15
H98 (16 nT)	2.2	2.5	11

1 GeV　　1 TeV　　1 TeV / 1 GeV

X-ray torus of the Crab Nebula

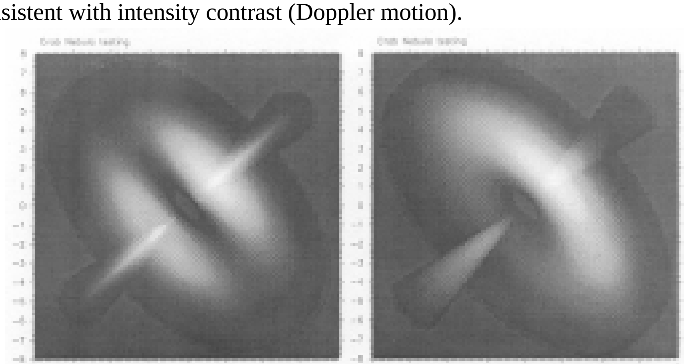
2-Dimensional MHD simulation

S. Shibata et al. (2002)

Astro-ph/0207437

$\gamma(\mathrm{wind}) = 3\mathrm{x}10^6$ & $\sigma = 0.003$

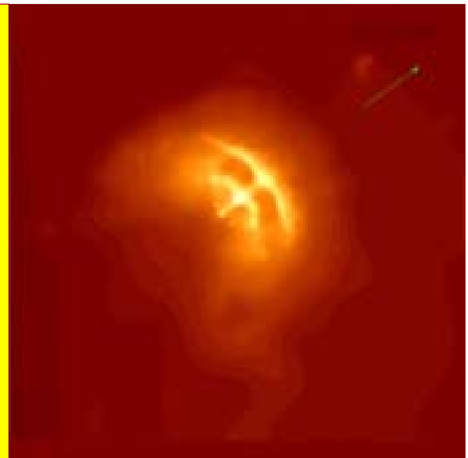
- Pure toroidal field with pitch angle effect predicts a lip-shaped X-ray torus (Vela?)
- Confirms de Jager (2001) spatially resolved X-ray surface brightness with small $\sigma = 0.003$, but inconsistent with intensity contrast (Doppler motion).



Pure toroidal field with pitch angle effect　　Electron pitch angles randomized.

Vela Pulsar: Unpulsed

- HST Parallax distance: d=300±50 pc.
- **<u>Two X-ray arcs:</u>** most likely shocked interaction of pulsar wind electrons on thermal gas of Vela SNR. Origin of electrons either (a) N-S interface between wavy neutral sheet and polar regions, or (b) electrons from N-S magnetic poles sweeping across sky.
- **<u>Proper motion</u>**: V=81 km/s (green arrow) within 1° in same direction as X-ray jet ⇒ spin-aligned natal kick.
- X-ray photons trail towards **<u>birthplace of pulsar</u>** expected at displacement VT~10 arcmin (T = 11,000 years the spindown age). Excess seen in X-rays.



Vela Unpulsed Detections.

- CANGAROO observations detected emission from Vela “birthplace” more than once.
- “Birthplace” position and angular resolution no longer certain (Tanimori, 2001, personal communication) ??
- No detection by Durham group.

<u>INTERPRETATION:</u>

- Small diffusion coefficient for electrons on wrapped (B_ϕ) field around pulsar-wind trail can contain particles ⇒ particle drift towards birthplace. But: Containment problem at birthplace:
- A too small B-field (few microgauss - Harding, de Jager & Gotthelf, 1997) is required to suppress synchrotron emission at birthplace relative to observed TeV intensity.

PSR B1706-44

- Similar period, period derivative, age, magnetic field strength compared to Vela pulsar.
- Distance 2.4 to 3.2 kpc based on HI observations.
- Shows a compact X-ray nebula (plerion) (Gotthelf, Halpern & Dodson, ApJ, 2002) – pulsar wind shock at 1” distance from pulsar. Large ROSAT PSPC discrepancy: SIZE: 30” - 5” & INTENSITY: Factor 5 - 10!
- Plerionic luminosities of Vela (d=260 pc) and 1706 (d=3 kpc) are the same in the CHANDRA band. Similar scaling for PWN shock radius.
- Unpulsed TeV emission detected by both CANGAROO and Durham groups.

See talk by J. Kushida (S28)

Study of the TeV Gamma-Ray emission mechanism of PSR 1706-44 based on multi-wavelength spectrum.

Broken power law injection model for Vela & 1706

Sefako & de Jager (2002), submitted to ApJ

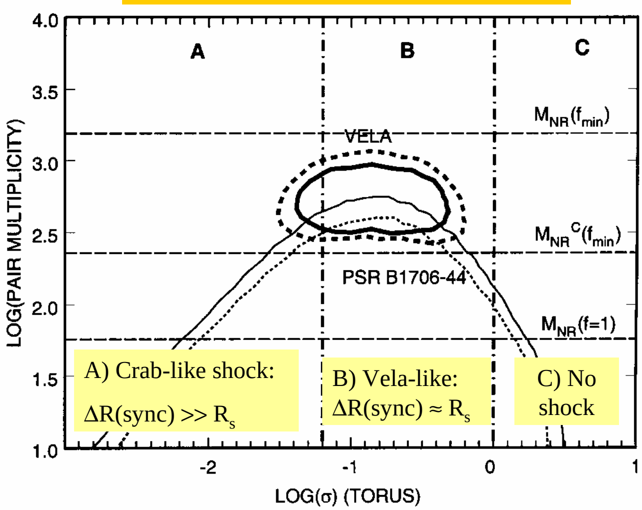
Injection spectrum is constrained by

1. Energy equation (involving spindown power & "sigma" parameter at pulsar wind shock radius).
2. Continuity equation (involving pulsar current and magnetospheric pair production multiplicity).

Calculate the synchrotron emissivity of the pulsar wind nebula at and beyond the shock, assuming that the Kennel & Coroniti (1984) model is correct (σ unknown).

Confidence Contours for Pair production multiplicity M & σ

Sefako & de Jager (2002), submitted to ApJ



Hibschman & Arons (2001):

Non-resonant IC (multipole)

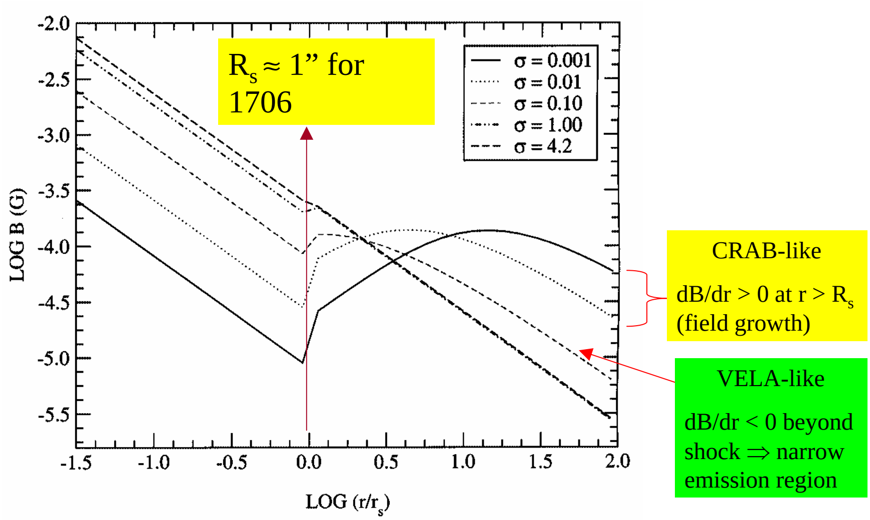
Non-resonant IC (multipole) from polar cap alone

Non-resonant IC (dipole) from entire stellar surface.

$T=1.6\times10^6$ K

for Vela and PSR B1706-44

Pre and Post Shock Field Strength for Vela-like pulsars

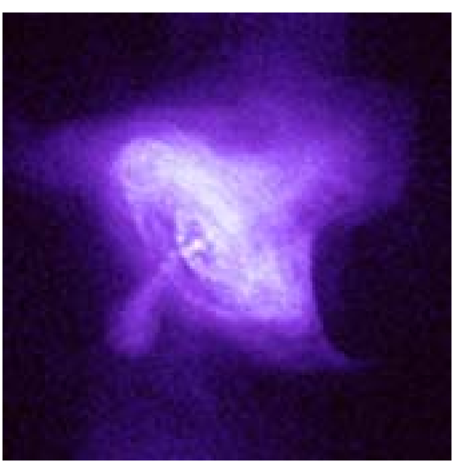


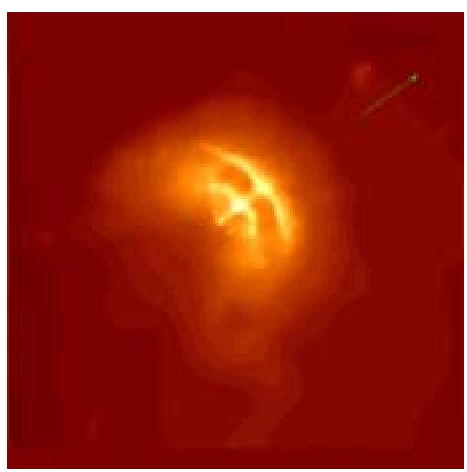
CRAB/LMC PULSAR

Radiation maximum at $r >> R_s$

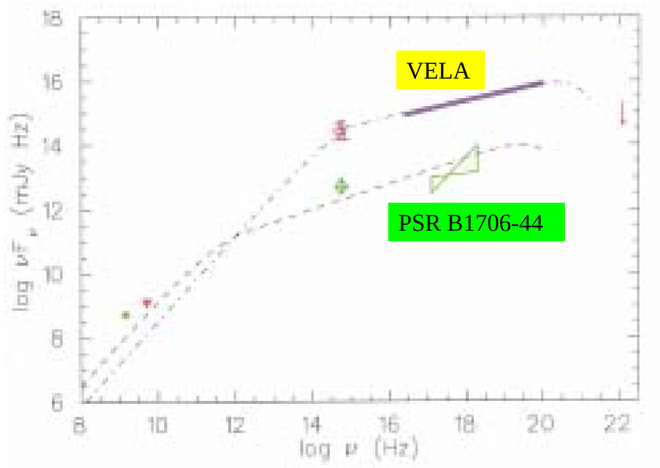
VELA/PSR B1706-44

Radiation maximum at $r \approx R_s$





Predicted & observed multiwavelength synchrotron spectra of Vela & PSR B1706-44

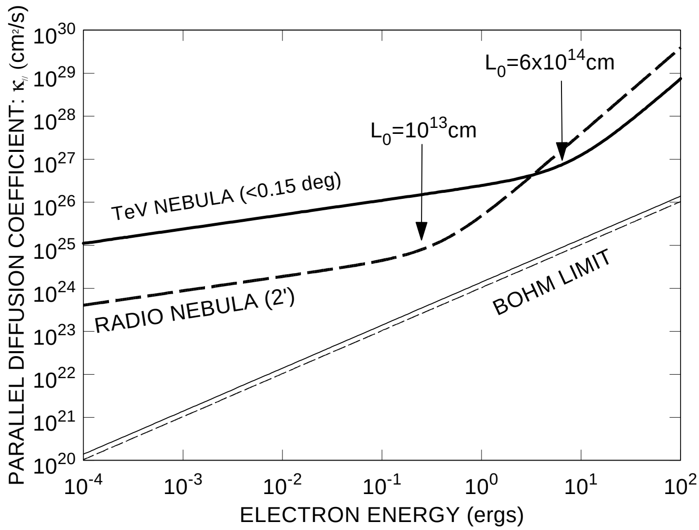


PLERIONIC TeV EMISSION?

- CRAB appears to be well understood – not an efficient TeV emitter because of dominant synchrotron losses in large B-field.
- Lower B-field in middle-aged pulsar/plerion systems do not burn their electrons away due to synchrotron losses.
- Problem with confinement of electrons/positrons.
- Aharonian, Atoyan & Kifune (AAK, 1995) and Harding & de Jager (1995) suggested the detection of IC γ-rays beyond the compact X-ray plerion. AAK explored the trapping problem in more detail.
- Suppose that middle-aged pulsars do have $\sigma \approx 0.1$ near shock. Then it means that a significant fraction of spindown power is converted to TeV electrons and injected into the ISM.
- Diffusion coefficient !!!!?

PSR B1706-44

PARALLEL DIFFUSION COEFFICIENT
for 2’ RADIO- and 0.15 degree TeV NEBULA

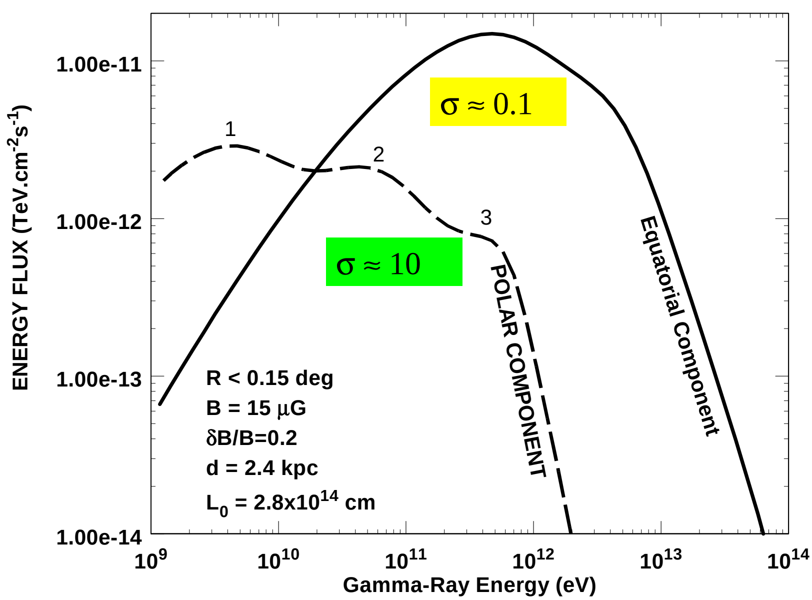


Turbulence theory predicts that scale size L_0 should increase with increasing distance from source.

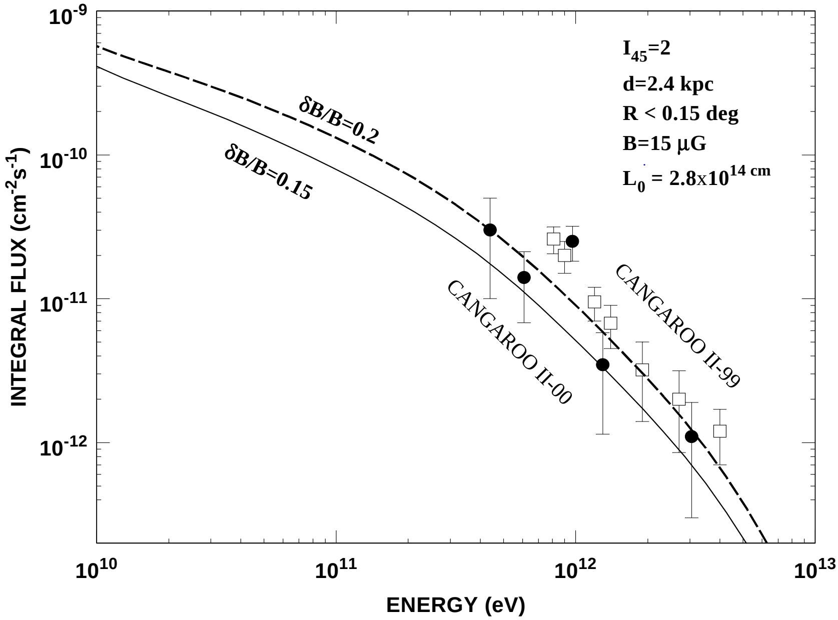
Diffusion coefficient is comfortably larger than minimum “Bohm” limit.

Diffusion coefficient is variable through B, L_0 and relative turbulence δB/B.

Gamma-Ray Spectrum of Extended Nebula (PSR B1706-44): IC + Brems.

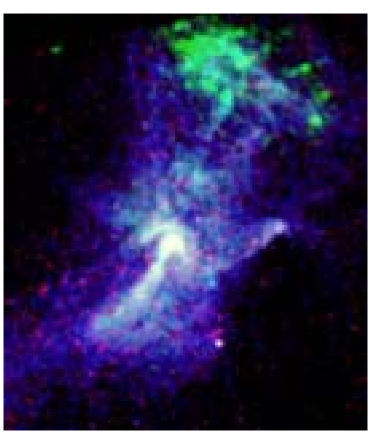


Integral Flux of PSR B1706-44 from 10 GeV to 10 TeV



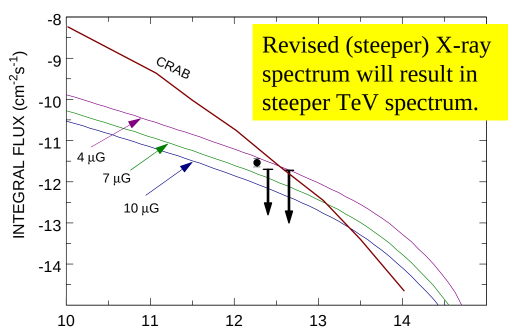
PSR B1509-58 in MSH15-52 - (HESS/CANGAROO Candidate)

- CHANDRA image shows that polar component is dominant relative to equator.
- Model inverse C. spectrum: du Plessis et al. (1995) assuming an X-ray spectrum harder than E^{-2}.
- New theoretical predictions require softer (observed) X-ray spectrum in 15 arcminute source.
- First TeV Detection: Sako et al. (2000) - CANGAROO (1997).
- No pulsed emission at TeV energies; Pulsations terminate near 1 MeV.



Inverse Compton γ-Ray Spectrum

Assuming Magnetic Field Strength as indicated.



CONCLUSIONS:

- Testing pulsar polar cap pulsed emission model from ground requires large mirror area, high quantum efficiency PMTs & small trigger radius in camera. Reject large size events with additional optimized cuts. Pulsar detection in a single night possible if cutoff energy $\geq$ 20 GeV.
- Testing outer gap models for low-level pulsed TeV emission requires optimal background rejection. Stereo telescope configurations best suited for this purpose.

Conclusions (cont.)

- Detections of plerions near/in molecular clouds is expected, since $B \approx 30\ \mu G$ with efficient trapping, with additional IC scattering on 20-25K dust associated with cloud. Search within unidentified EGRET boxes!
- New low-threshold energy telescopes may be able to see spectral features at low energies as a result of transition between high energy equatorial and lower energy polar components.