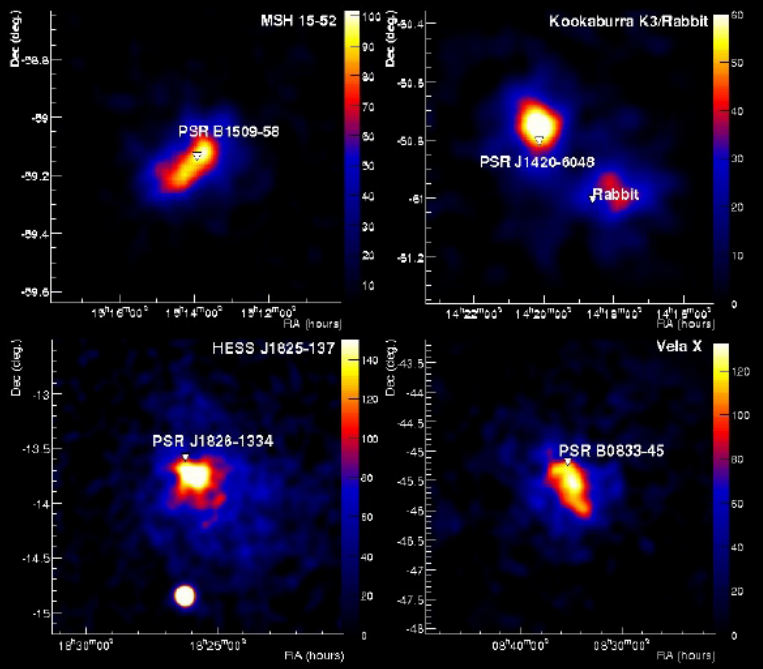
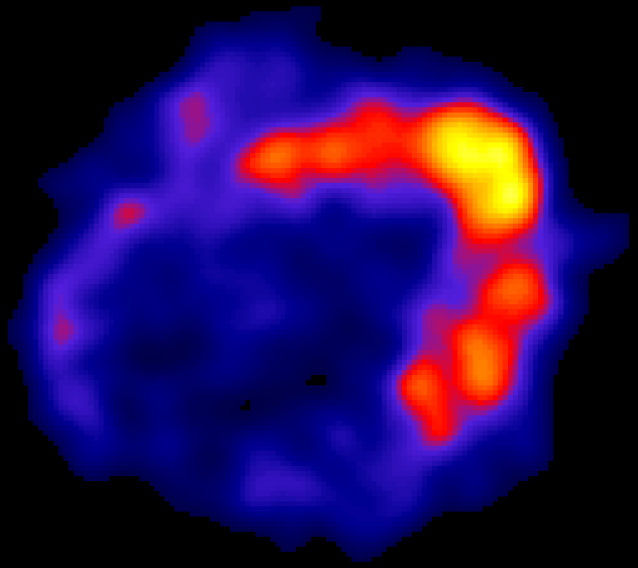
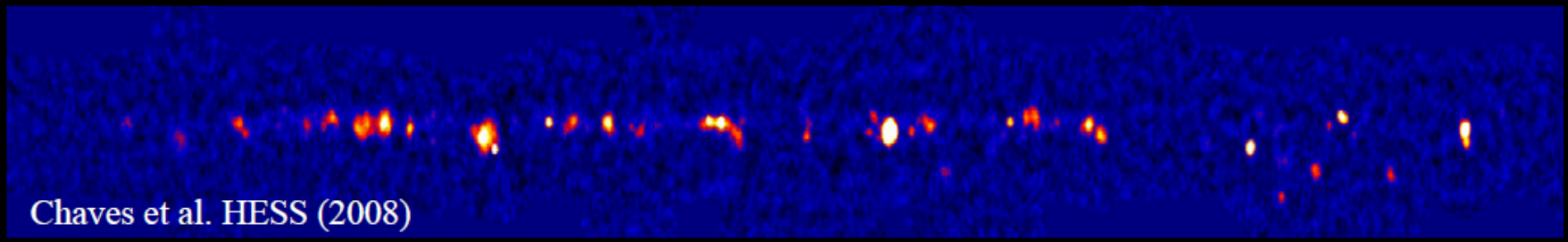
H.E.S.S. Observations of SNRs and PWNe



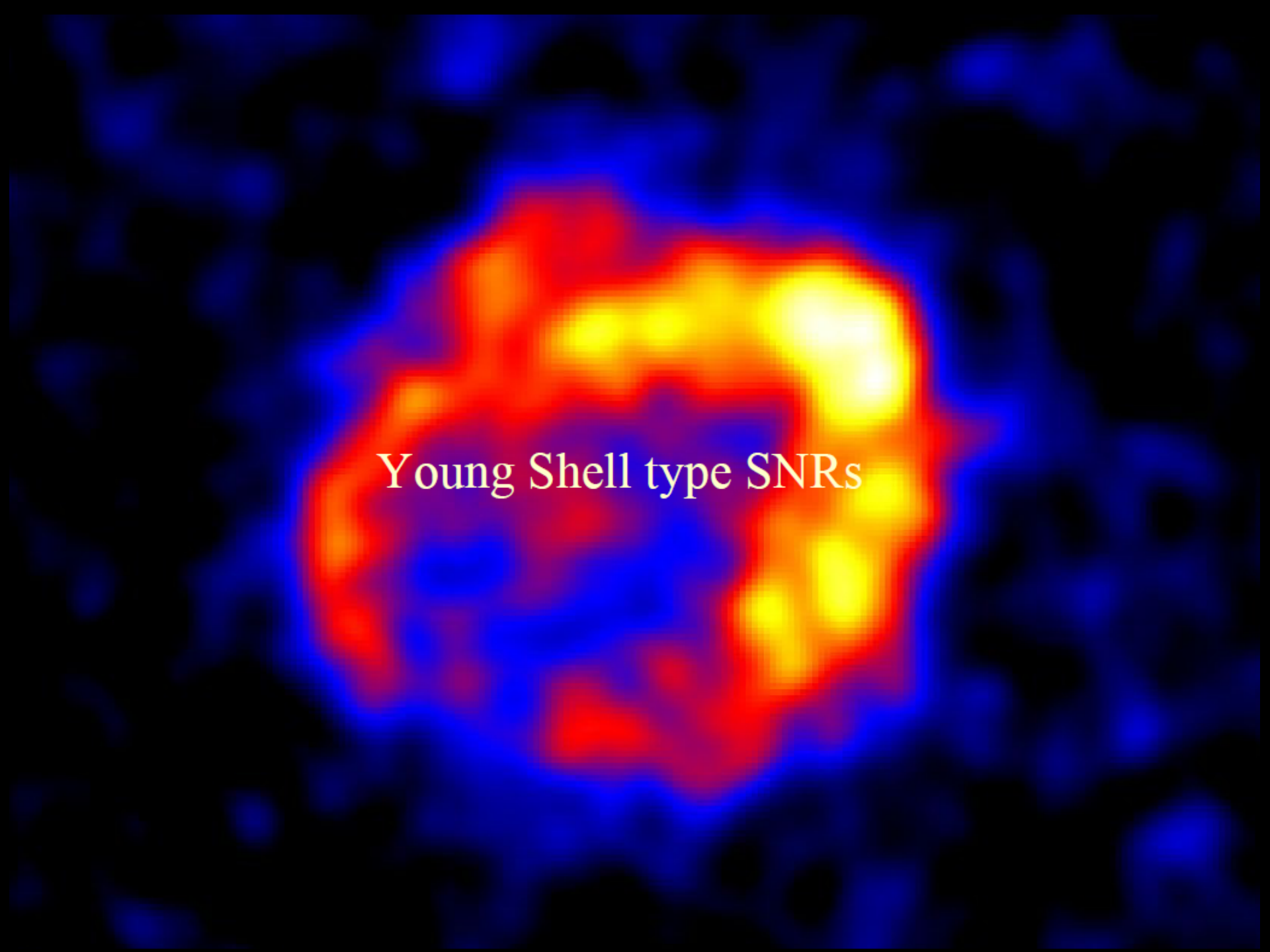




Marianne Lemoine-Goumard
(CENBG, Université Bordeaux I, CNRS-IN2P3, France)

for the H.E.S.S. Collaboration

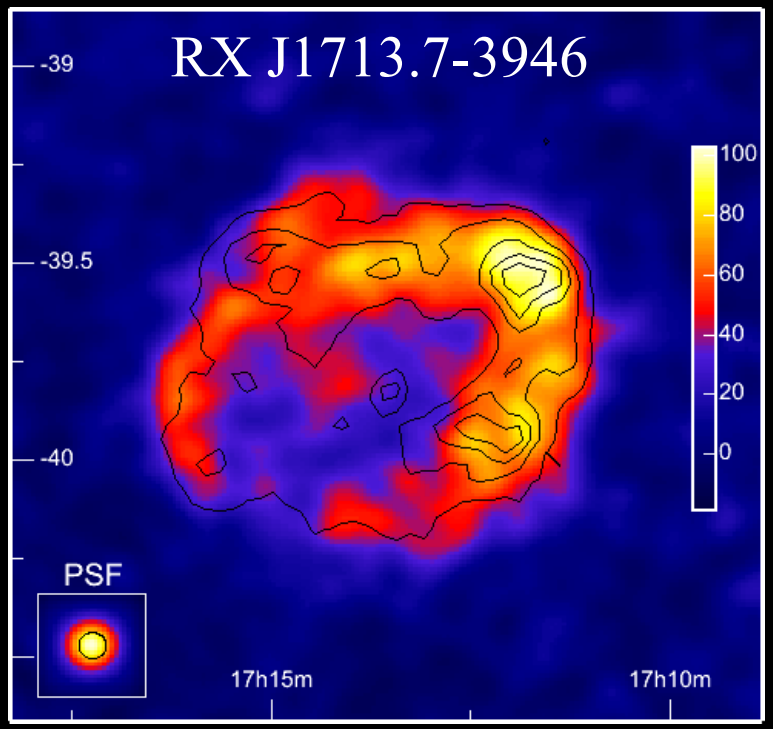
SNR/PWN in the Chandra era, Boston, 8-10 July 2009

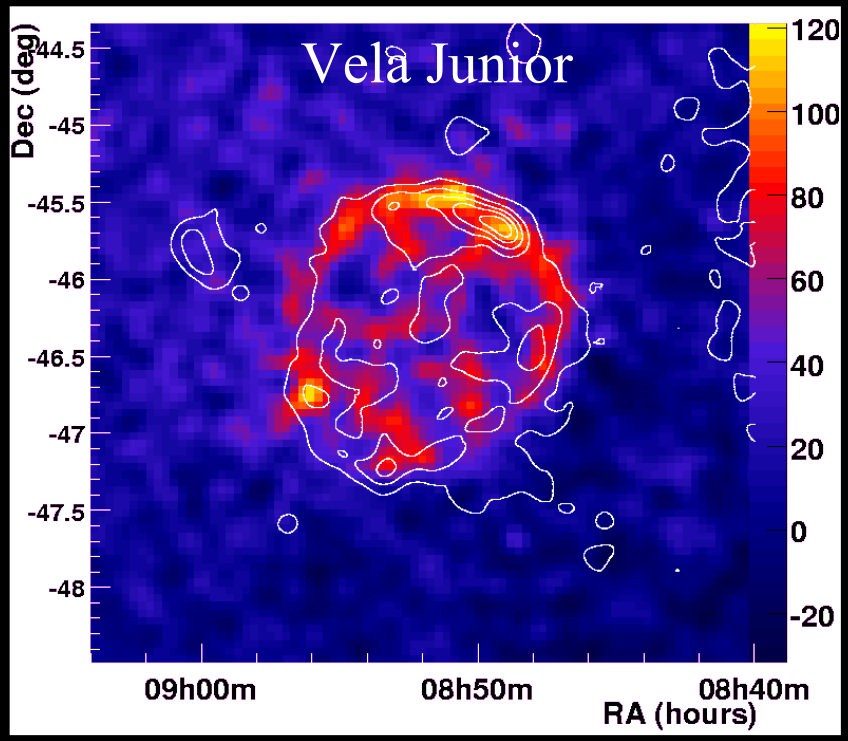

Young Shell type SNRs

RX J1713.7-3946 & Vela Junior

Angular resolution < 0.1° ➔ morphology resolved

- Discovery by ROSAT All-Sky Survey
- X-ray emission mostly non-thermal
- Detection by H.E.S.S.



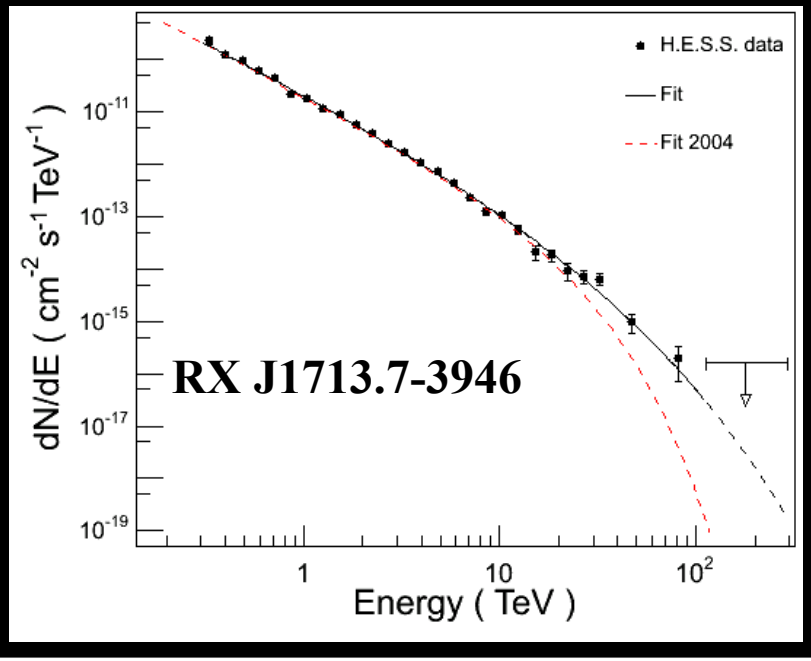


Gamma-ray Spectra of the 2 SNRs

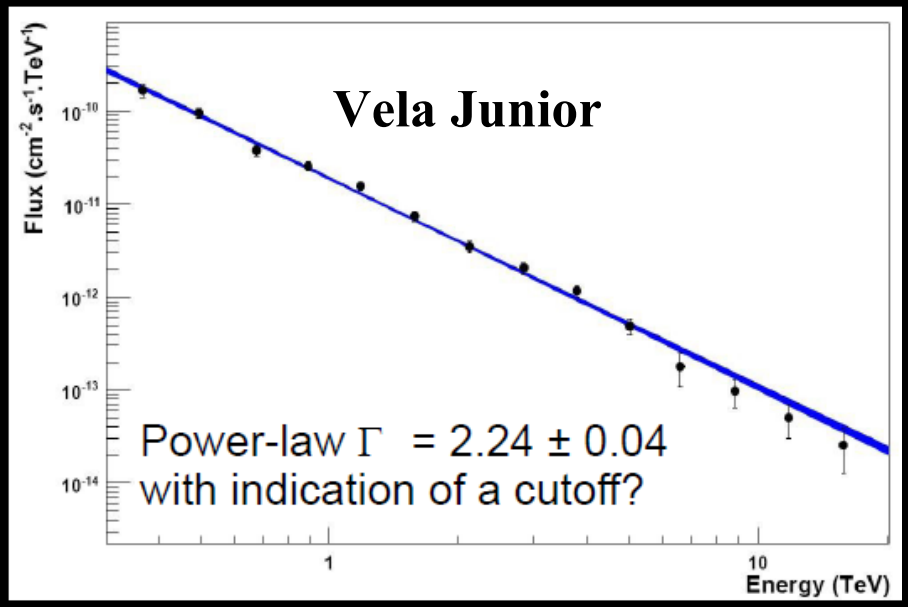
- Pure power-law ruled out
- Significant gamma-ray emission approaches 100 TeV
  - 4.8σ beyond 30 TeV!
- Primary particle energies:
  - Hadronic scenario:

    E_{proton} ~ 200 TeV
  - Leptonic scenario:

    E_e ~ 100 TeV



- Lower statistics: $E_{max,\gamma}$~20 TeV
- Index ~2.24
- Indication of cut-off

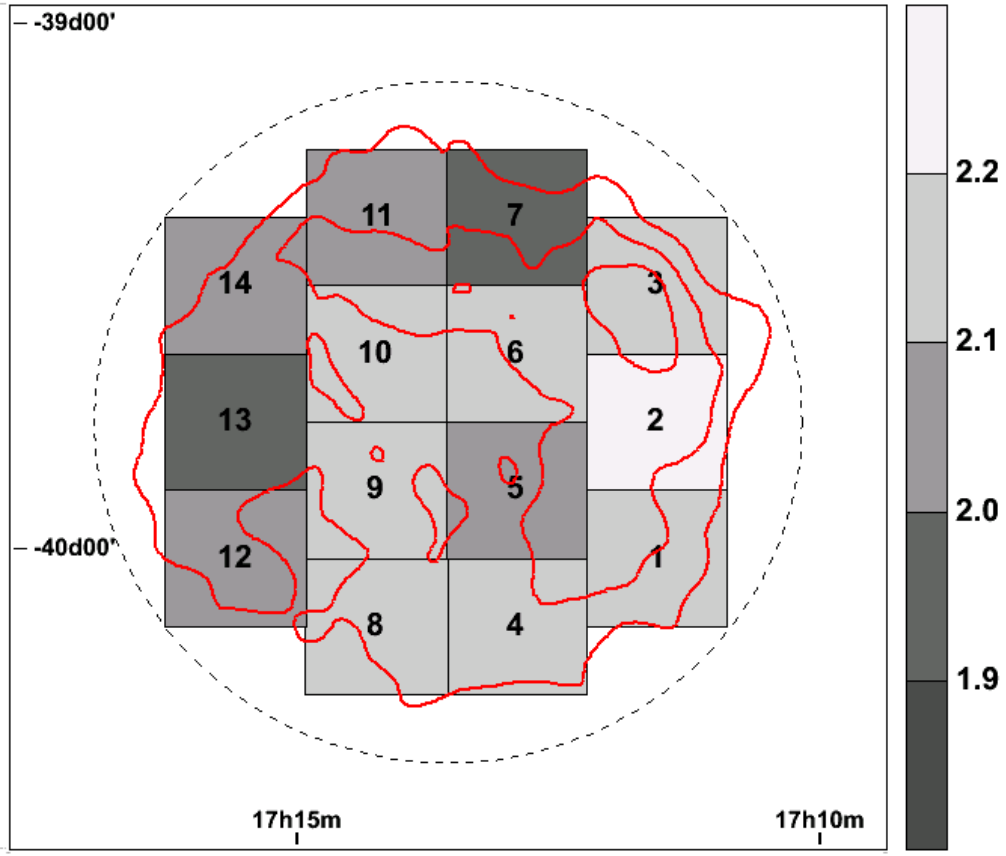


Spatially resolved spectra of RX J1713

No significant change in spectral shape was detected in VHE

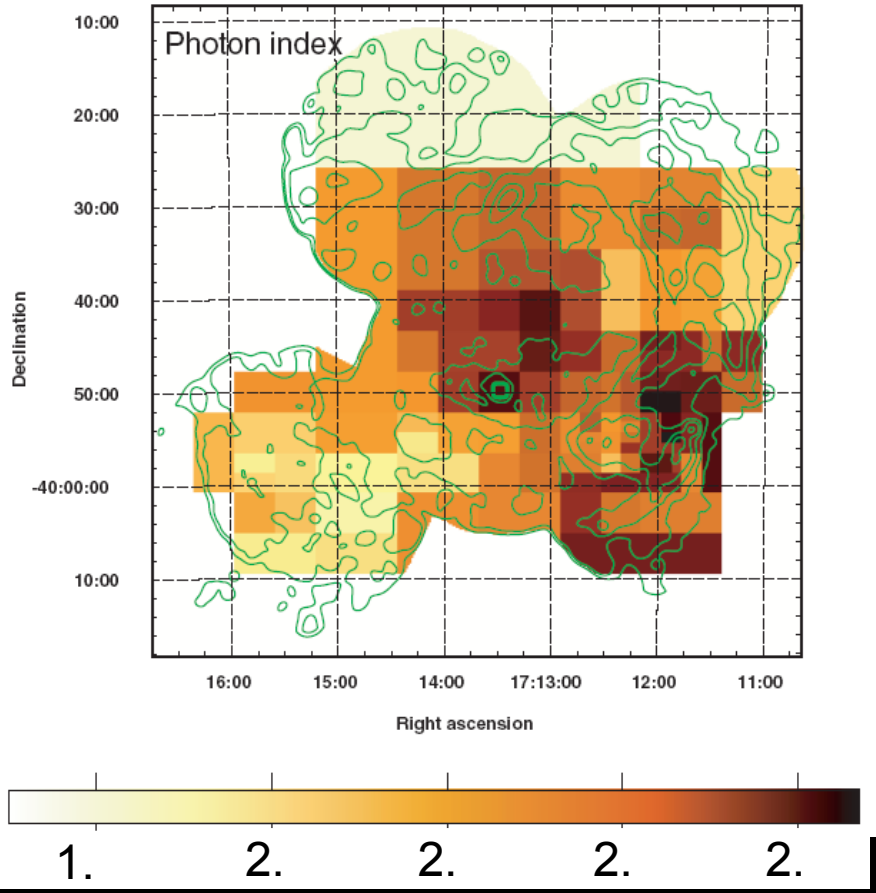
Large variation observed in X-rays...using different regions in size and shape

TeV Photon Index



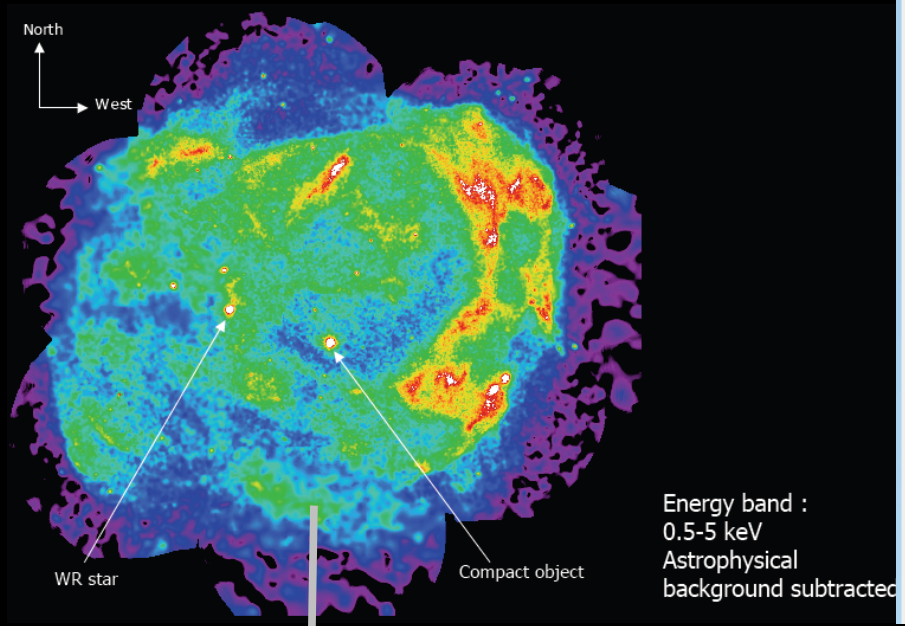
X-ray Photon Index

G. Cassam-Chenaï A&A 427, 199 (2004)

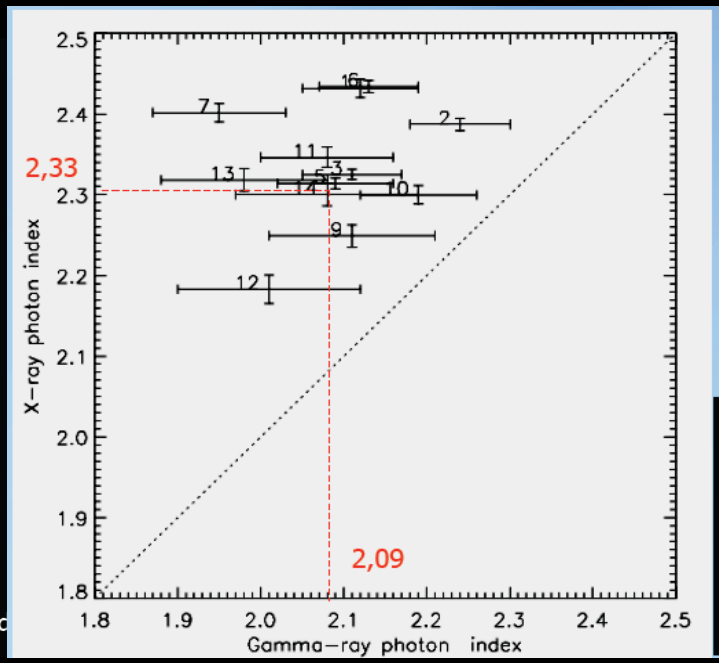


F. Aharonian et al. (H.E.S.S. Collaboration), A&A 449 (2006) 223

X-ray vs gamma-ray correlation on the same scale



Energy band :
0.5-5 keV
Astrophysical
background subtracted

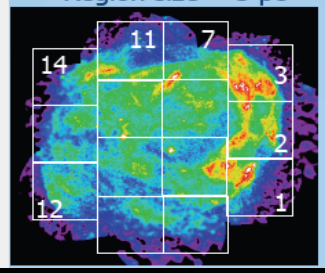


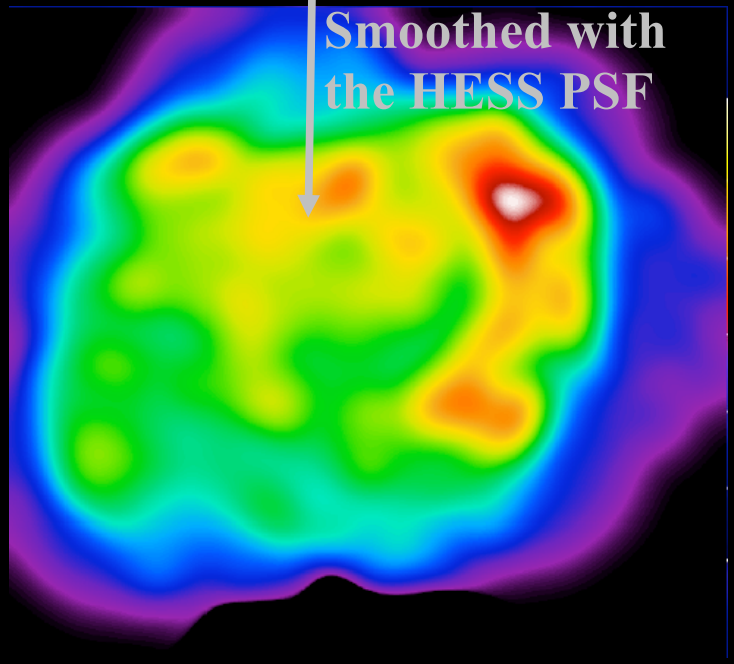
Small scale
$1.9 < \Gamma_x < 2.6$

Large scale + PSF :
$2.2 < \Gamma_x < 2.4$

E_{sync}=23 TeV
(100μG)
E_{ic}=16 TeV

Region size ~ 5 pc





- The spatial variation of the spatial index are smeared out when using larger extraction regions.
- Mean X-ray photon index slightly higher than the gamma-ray index
- Bright regions are brighter in X-rays than in gamma-rays (non linear correlation)

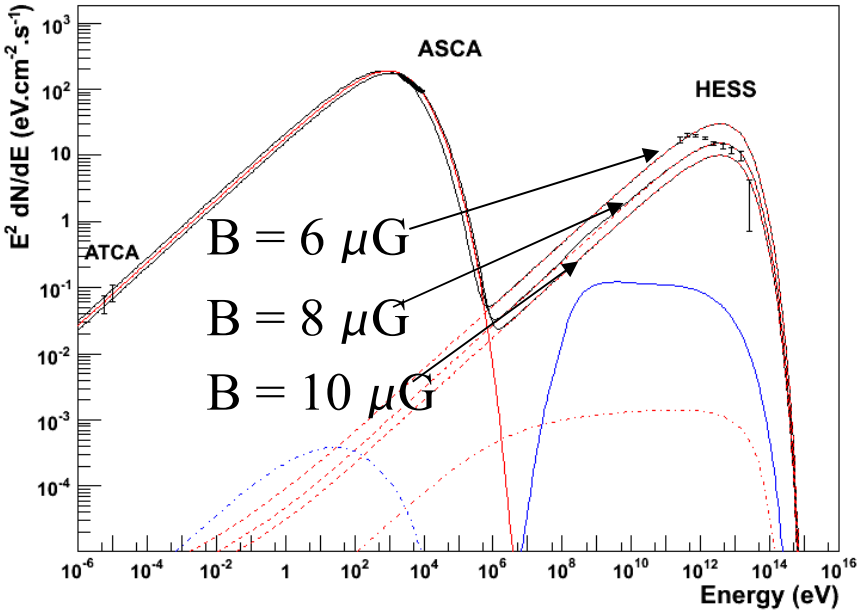
Acero et al., arXiv:0906.1073

Primary population: electrons ?

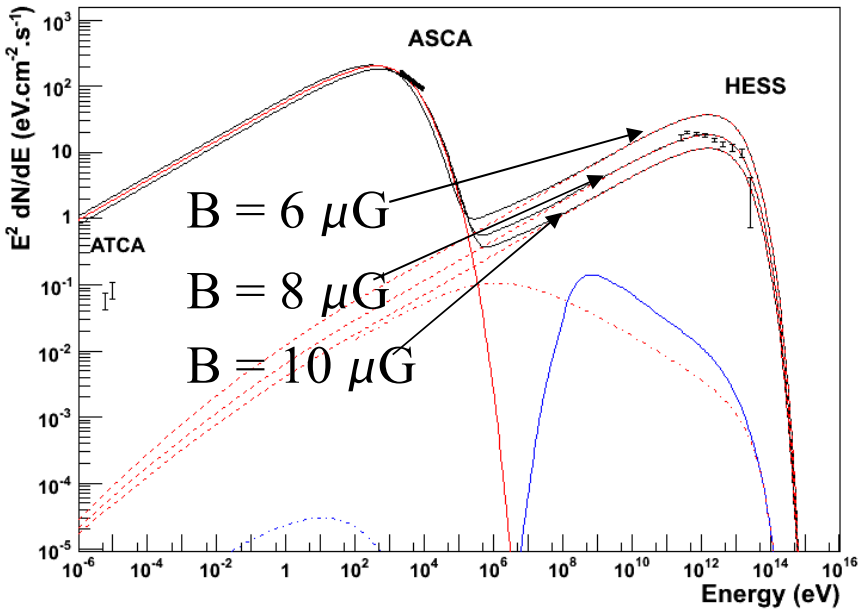
- **Need about 8 μG B field to match flux ratios**
- **Simplest electronic models don't work well:**
  - **steep spectrum in conflict with radio flux**
  - **Very large E_{max} and low B can hardly co-exist in standard models**

- Simple one-zone model
- Electrons & protons injected with the same spectral shape
- Energy losses + escape of particles out of the shell taken into account

Power-law index = 2.2 at injection level



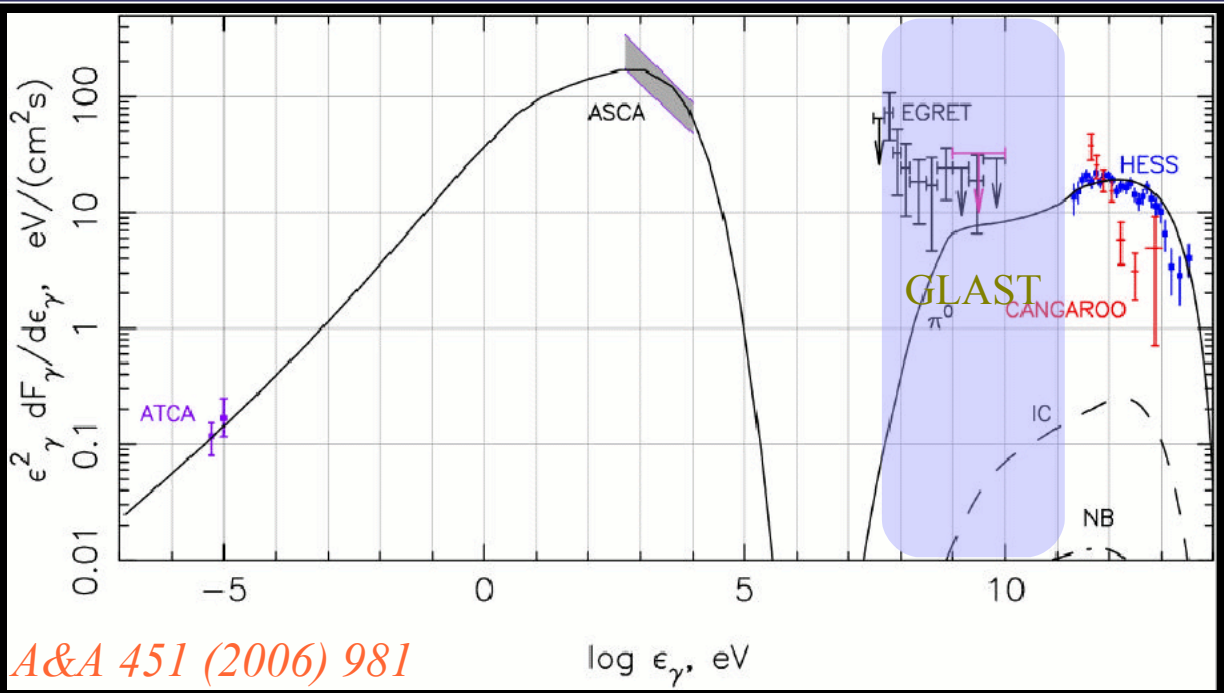
Power-law index = 2.4 at injection level



Primary population: protons ?

- Assuming that RX J1713 was a core collapse SN which exploded into a very diluted bubble created by the wind of a massive progenitor star
- Explosion energy = 1.8×10^{51} erg
- Proton injection rate = 3×10^{-4}
- Bubble density = 10^{-2} cm^{-3} & ISM density= 300 cm^{-3}

- Magnetic field = 126 μG in agreement with the lower limit derived from the narrow filament resolved by XMM (65 μG)
- But XMM-Newton limit on thermal X-rays implies a very low density in the remnant (0.02 cm^{-3}) => needs a bubble to make such hadronic model works in terms of energetics



Berezhko & Völk, A&A 451 (2006) 981

Supernova 1006

First non-thermal hard X-ray SNR (1995)

Shell-type supernova

distance = 2.2 ± 0.08 kpc

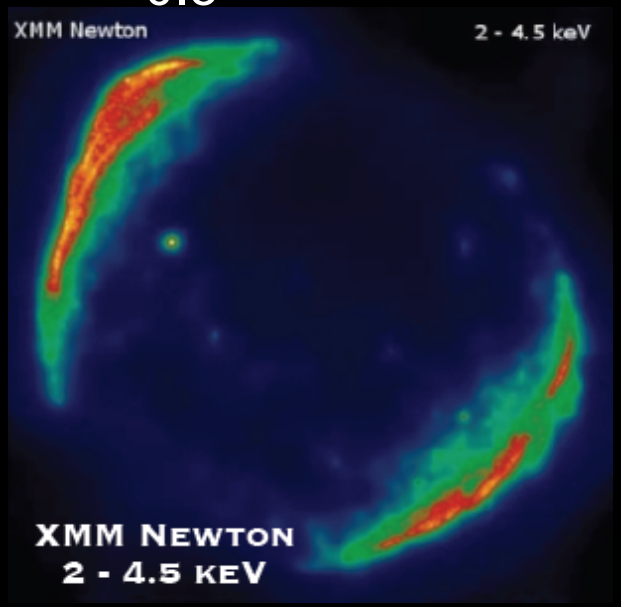
$N_H \approx 0.05\ cm^{-3}$

XMM-Newton (Acero et al. 2007)

HESS 18hrs (2tels) + 6hrs (4tels):
=> Upper Limit

Chandra (X-rays)

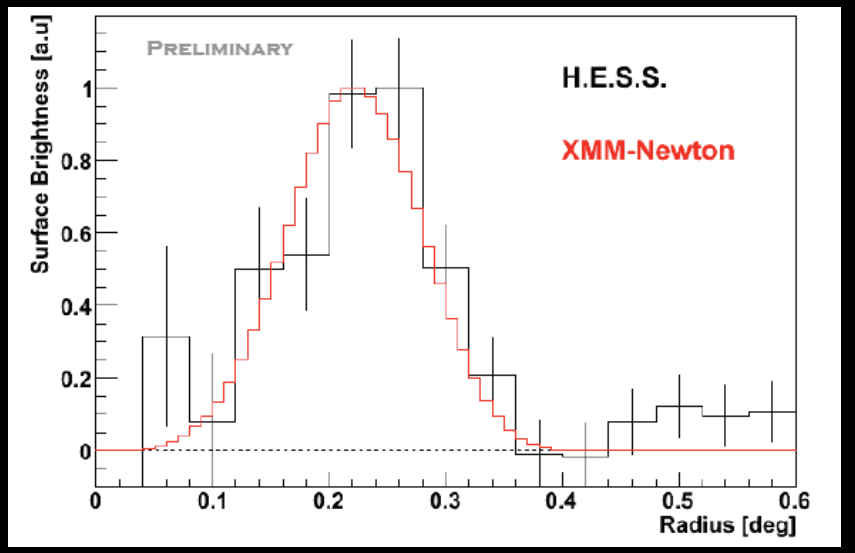
50 light years
0.5°

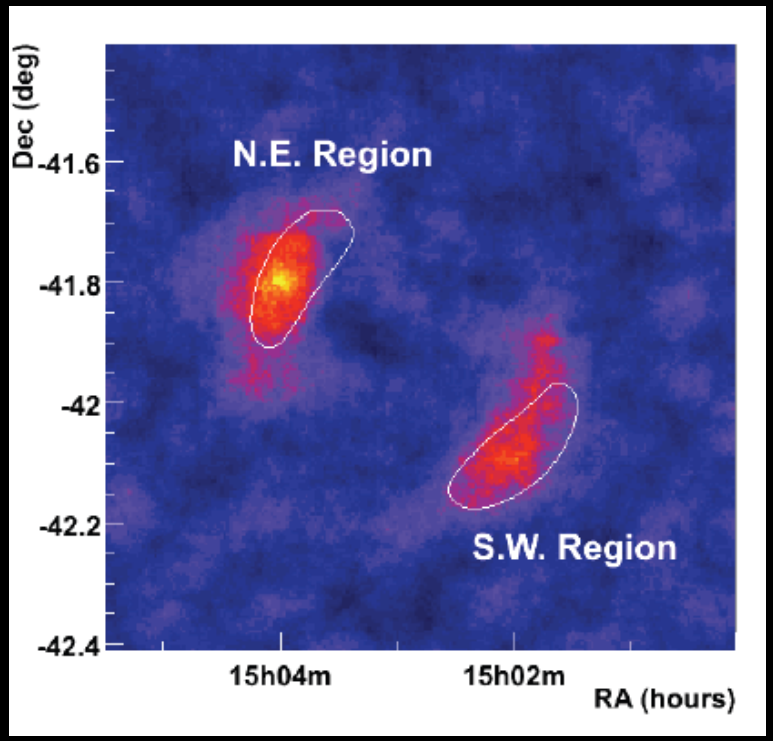


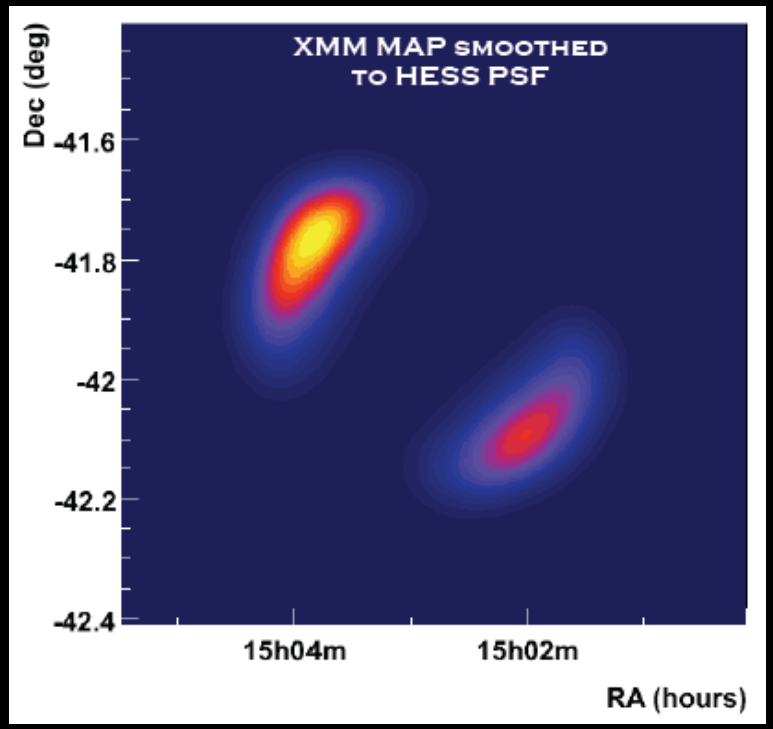
H.E.S.S. detection of SN 1006

Continued obs: 130hrs live time
Detection: 9.3σ in the NE and 8.7σ in SW

- Model combined analysis
- 2 pre-defined regions from XMM-Newton smoothed map: 80% of total emission







H.E.S.S. Spectral analysis of SN 1006

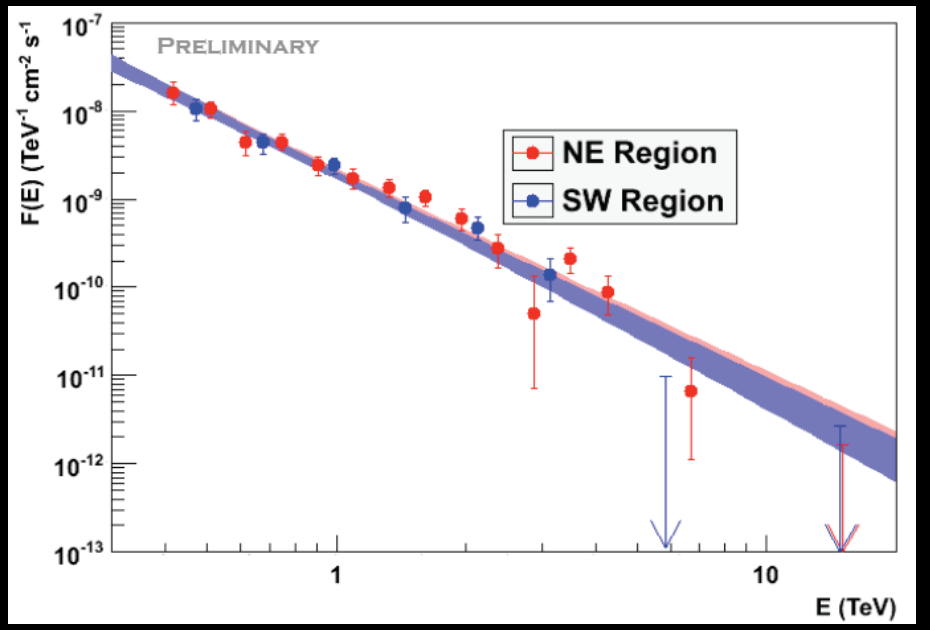
· Spectra compatible with straight power-law for both regions

· $\Gamma \sim 2.4$ and Flux ~1% Crab => SN1006 is one of the faintest VHE source

· Similar excess events and spectra in both regions attesting the bipolar morphology of the remnant in the TeV range => injection most efficient in the polar cap regions

· Leptonic scenario => B ~ 30 μG

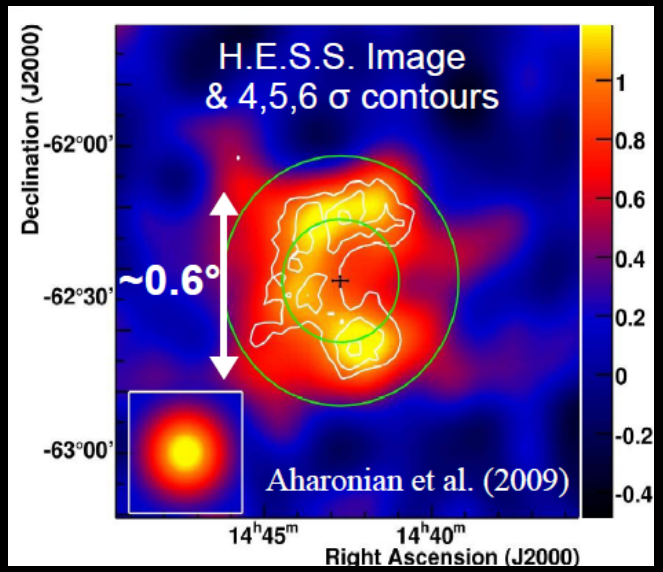
· Hadronic scenario => $W_{CR} \sim 20\% E_{SN}$



	$\Phi(>1\text{TeV})$ x10^{-12}cm^{-2}s^{-1}	Γ
NE	0.186±0.024	2.54±0.15
SW	0.165±0.031	2.34±0.22

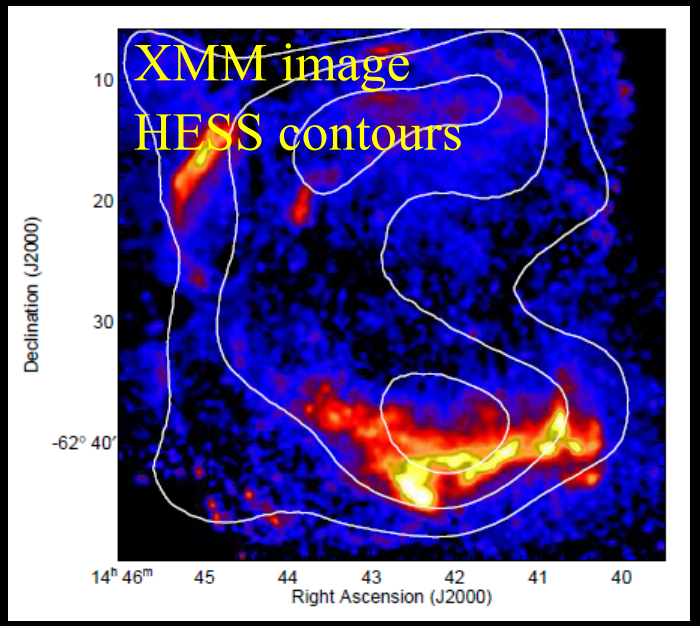
H.E.S.S. Detection of RCW 86

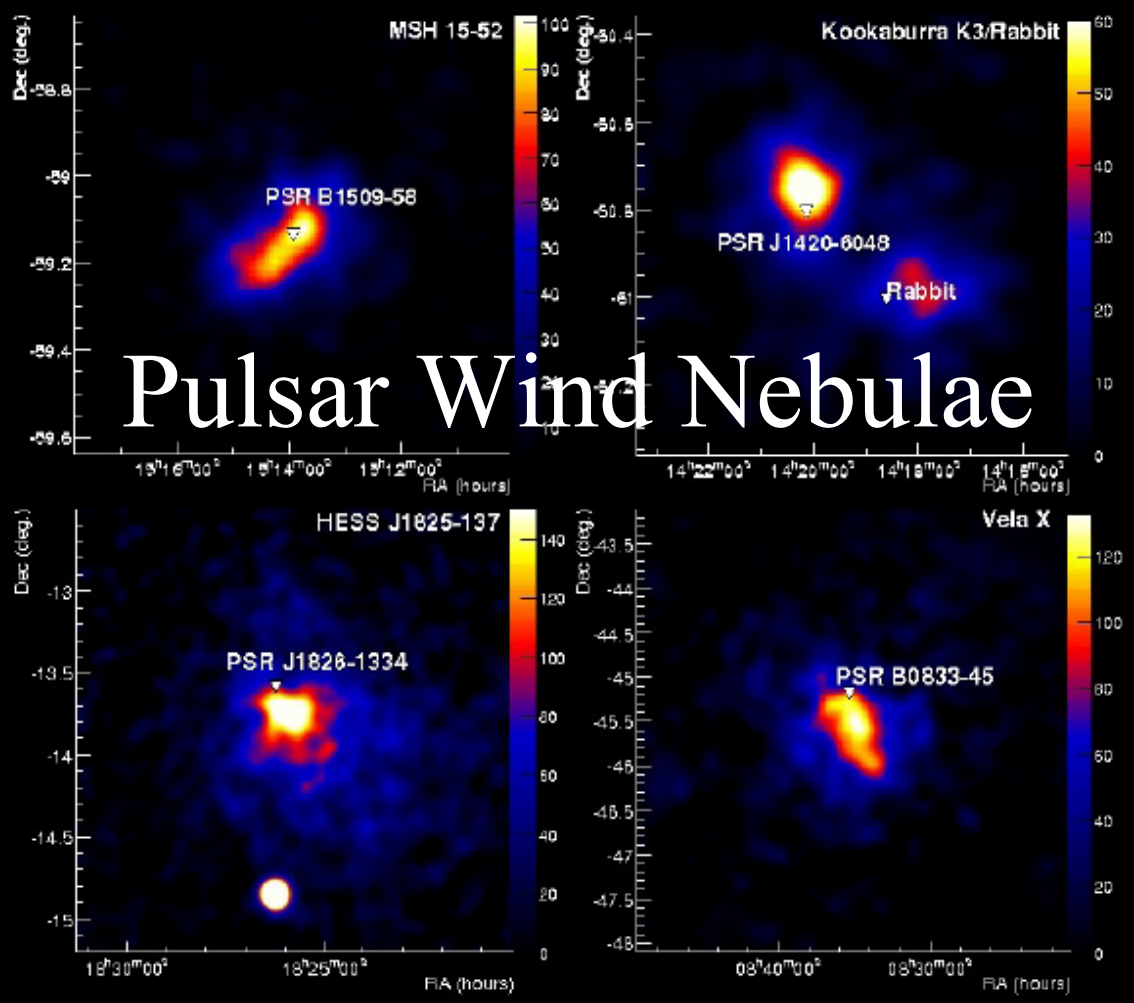
- Complete shell in radio, optical and X-rays
- Possible association with SN185



- Livetime 31 hours, 1546 gamma-ray excess events (8.5σ)
- Questions of the morphology cannot be settled with the statistics available at the moment
- Photon index: 2.54 $\pm$ 0.12 $\pm$ 0.20
- Integral flux(1-10 TeV) ~ 10% Crab
- No significant cut-off
- Leptonic scenario:

  IC on CMB photons => B ~ 30 μG

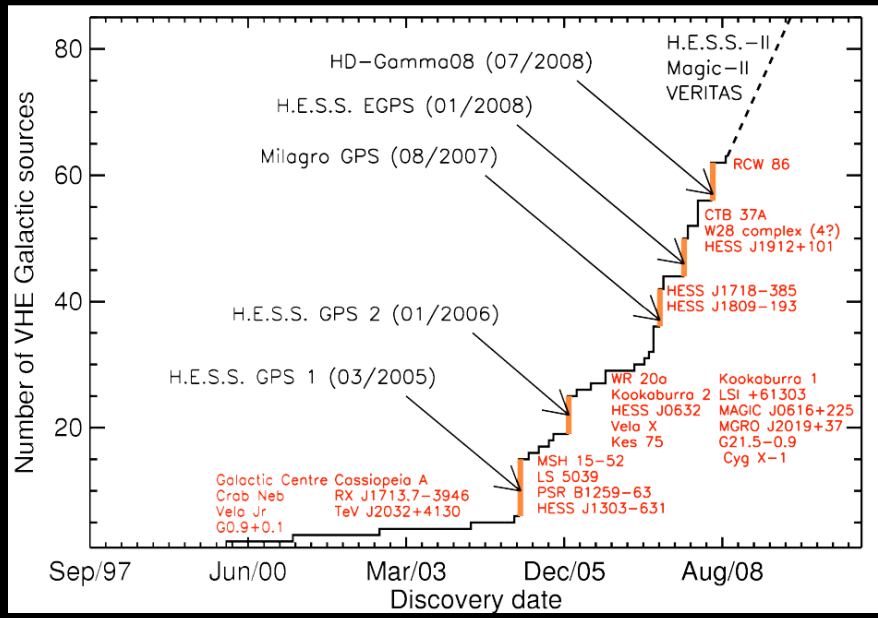


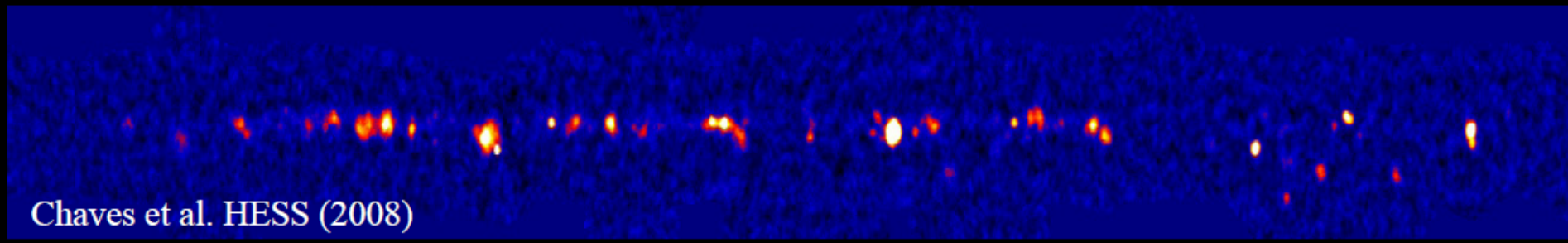


Pulsar Wind Nebulae

Galactic gamma-ray sources and PWNe

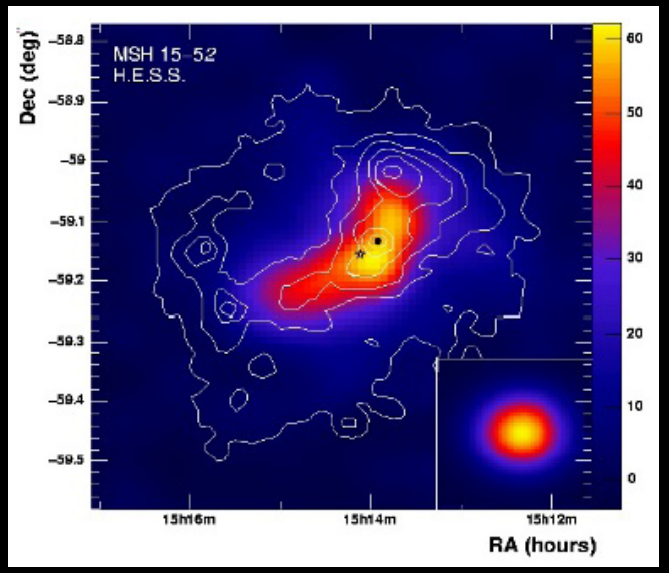
- Much improved sensitivity of current Imaging Atmospheric Cherenkov Telescopes
- Galactic Plane Survey now extended to the region covering longitudes -80° to 60°
- More than ~60 VHE sources: about half of them are PWNe:
  - Established PWNe
  - Coincident with known energetic pulsar
  - Coincident with known X-ray nebula

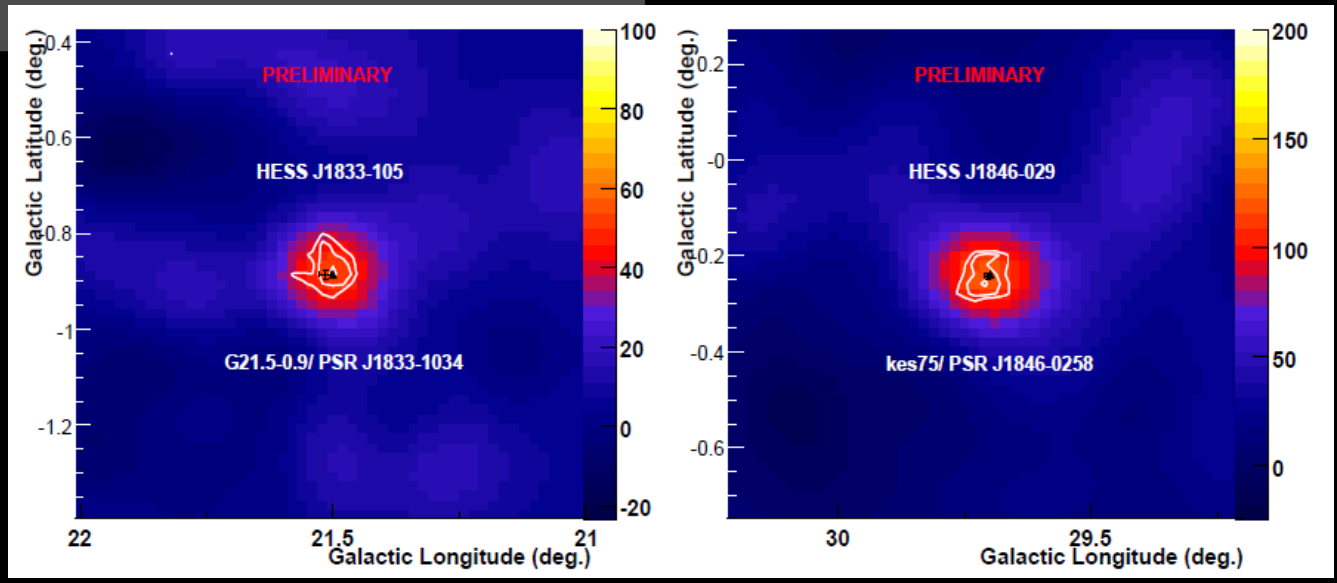




Established PWNe
Young PWNe

- Crab, G0.9+0.1, MSH 15-52, G21.5-0.9, Kes 75...
- MSH 15-52: first PWN morphologically resolved in TeV gamma-rays
- G21.5-0.9 / PSR J1833-1034: P=61.8ms; τ=4.8kyr; but Age < 1000 yrs; Edot=3.3×10^{37} erg/s => 2nd strongest !
- Kes 75 / PSR J1846-0258: P=324 ms;τ=723 yrs; $B_{surf}=4.8\times10^{13}$ G => magnetar limit !
- Both G21.5-0.9 and Kes 75 are particle dominated: B ~15 μG

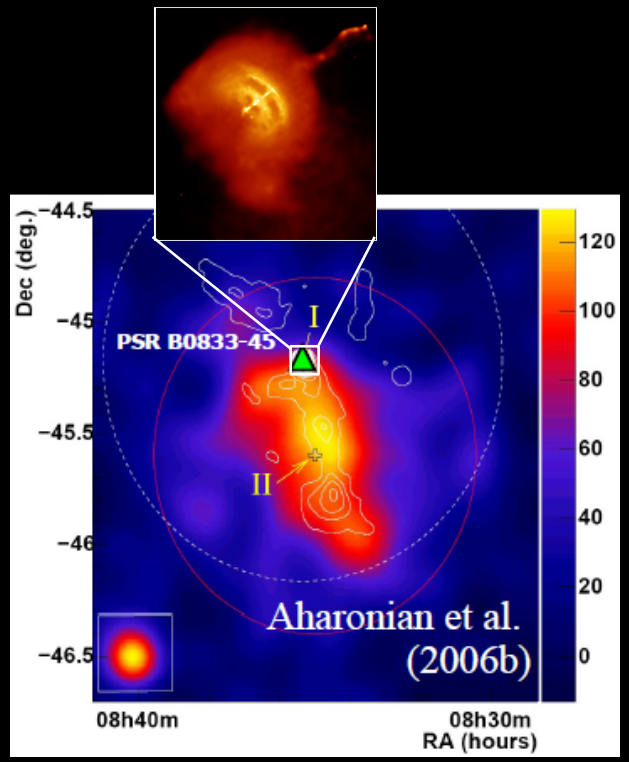




See presentation by A. Djannati-Ataï

Established PWNe
Older and offset PWNe

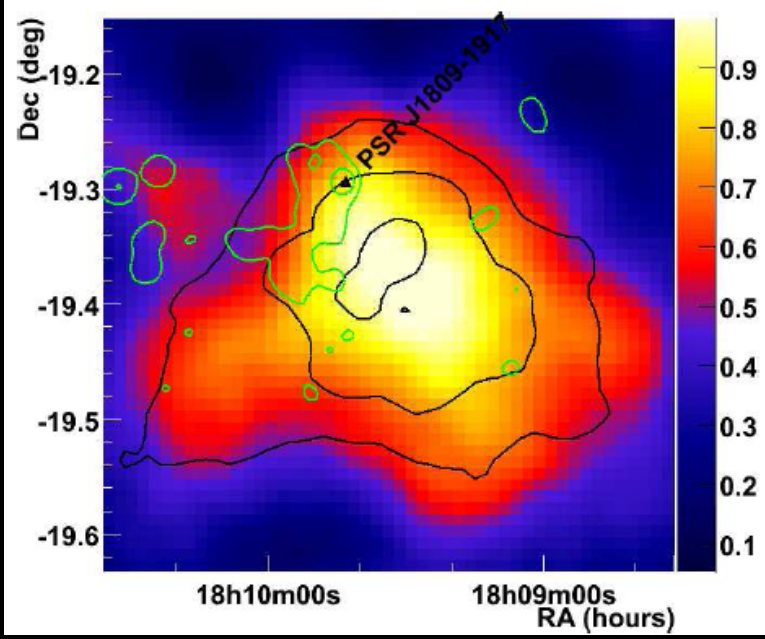
- **Vela X**, nebula of PSR B0833-45
  - Located primarily south of the pulsar
  - Apparently the result of relic PWN being disturbed by asymmetric passage of the SNR reverse shock (e.g Blondin et al. 2001)
- Detected by HESS as an extended VHE emission (A&A, 448, L43, 2006)
  - Coincident with one sided “jet” (Markwardt & Ogelman, 1995)

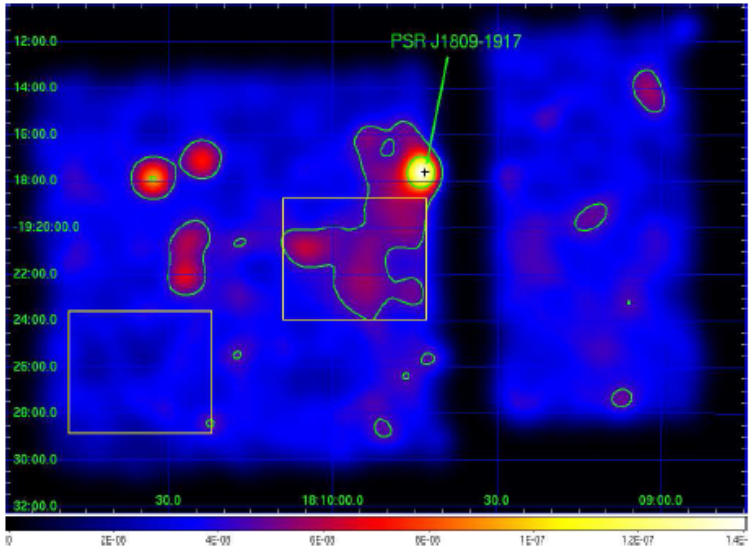


See presentation by B. Glück

PWNe with known pulsars &/or X-ray nebula: e.g. HESS J1809-193

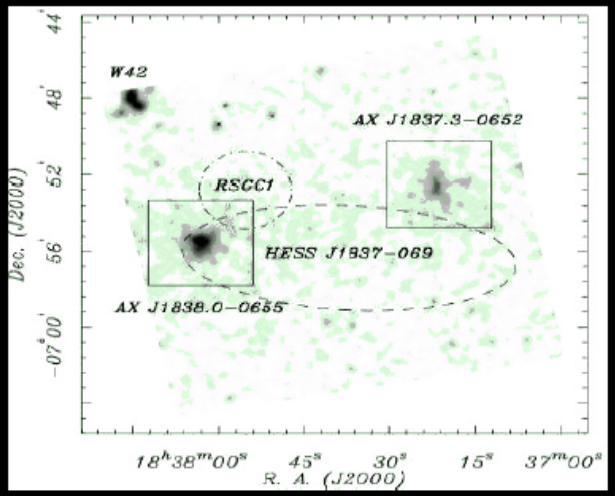
- 3600 events detected, 19σ:
  - Significantly extended, south of the Pulsar PSR J1809-1917
  - Power-law with an index of $2.2 \pm 0.1_{stat} \pm 0.2_{syst}$
  - Flux of $\sim 1.3 \times 10^{-11}$ erg/cm^2/s
- HESS J1809-193, nebula of PSR J1809-1917 ?
  - Required efficency Edot/$L_\gamma \approx 2\%$
  - Strong X-ray nebula detected with Chandra, but extension much smaller

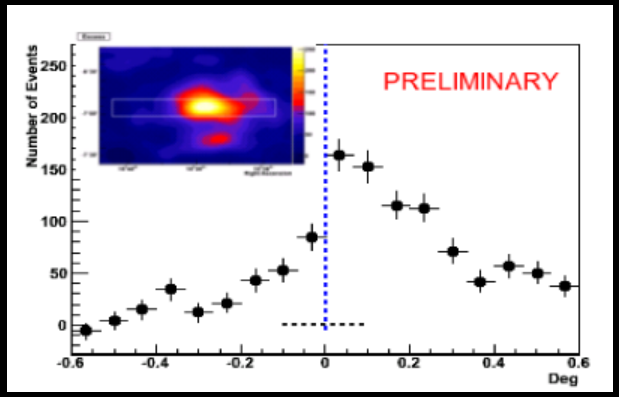




New pulsars coincident with HESS sources

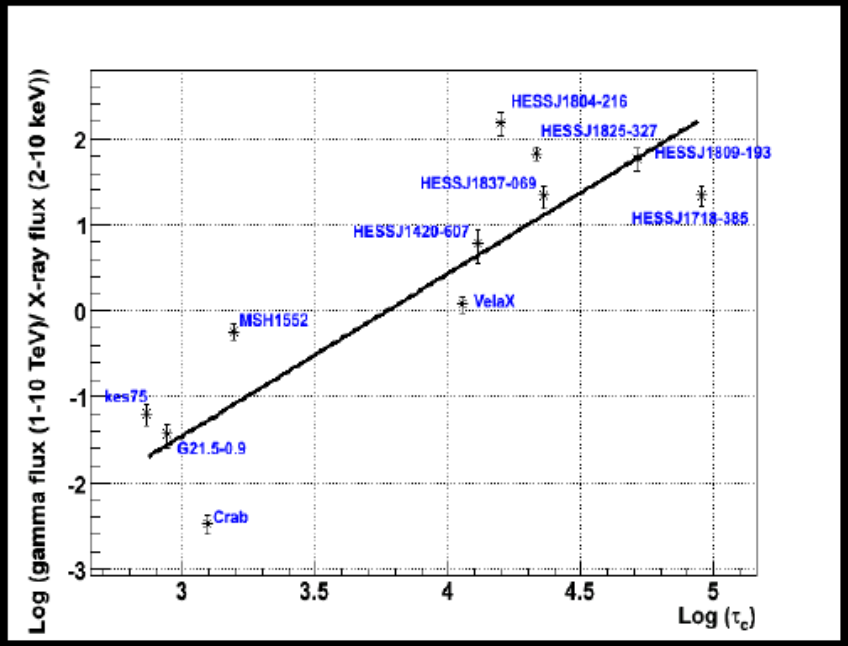
- HESS J1837-069:
  - HESS source detected during the First Galactic Survey; Source extended: $\sigma = 0.22°$
  - Discovery with RXTE of PSR J1838-0655 (P=70.5 ms) with efficiency to power the HESS source of Edot/$L_\gamma \approx 3\%$ (Gotthelf and Halpern, 2008)
  - HESS emission profile assymetric relative to pulsar position => support the association (Marandon et al., HDGS, 2008)

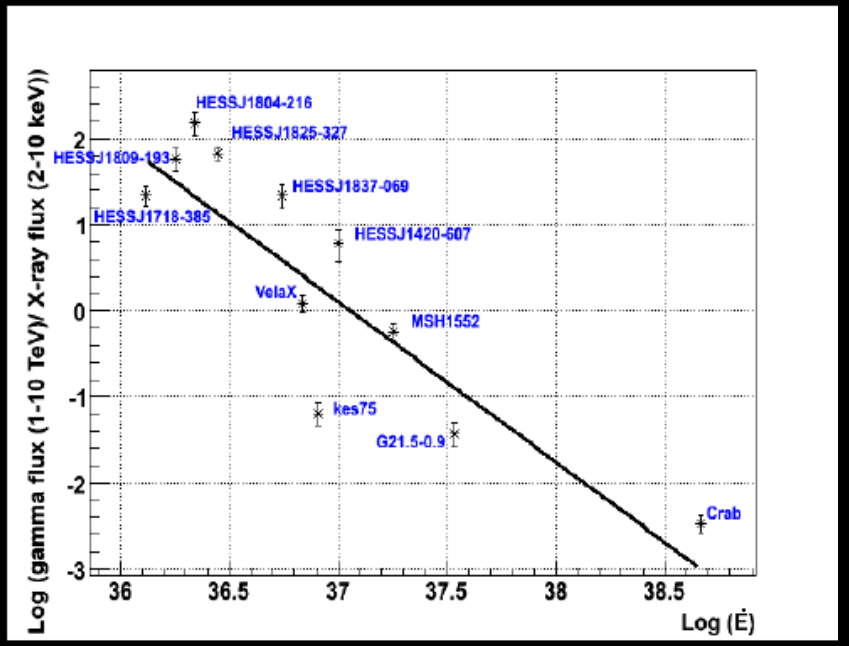




- Discovery of PSR J1856+0245 with Arecibo, possibly powering HESS J1857+026, Edot/$L_\gamma \approx 3\%$ (Hessels et al., 2008)
  - Coincident with unresolved ASCA source AX J185651+0245
- Discovery of Blind search pulsars with Fermi-LAT, for instance the Rabbit in the Kookaburra complex

Time to make population study





See Mattana et al. 2008 & Grenier et al. 2008

$$\frac{L_\gamma}{L_x} \propto t^{2.2}$$

$$\frac{L_\gamma}{L_x} \propto \dot{E}^{-1.9}$$

Conclusions

- HESS has opened a new window for the study of SNRs and PWNe
  - 3 shell-type SNRs (RX J1713, Vela Junior & SN1006) resolved + several detected
  - First time ever spatially resolved spectral study of a gamma-ray source (RX J1713.7-3946)
  - SNR interacting with molecular clouds (eg. W28)
- More than 60 VHE galactic sources, about half of them being PWNe
- Multi-wavelength work, especially in coordination with Fermi and X-ray satellites, can bring new science and help identifying new candidates

Madrid & Macchetto (2009)

HIGH-IMPACT OBSERVATORIES (2006)

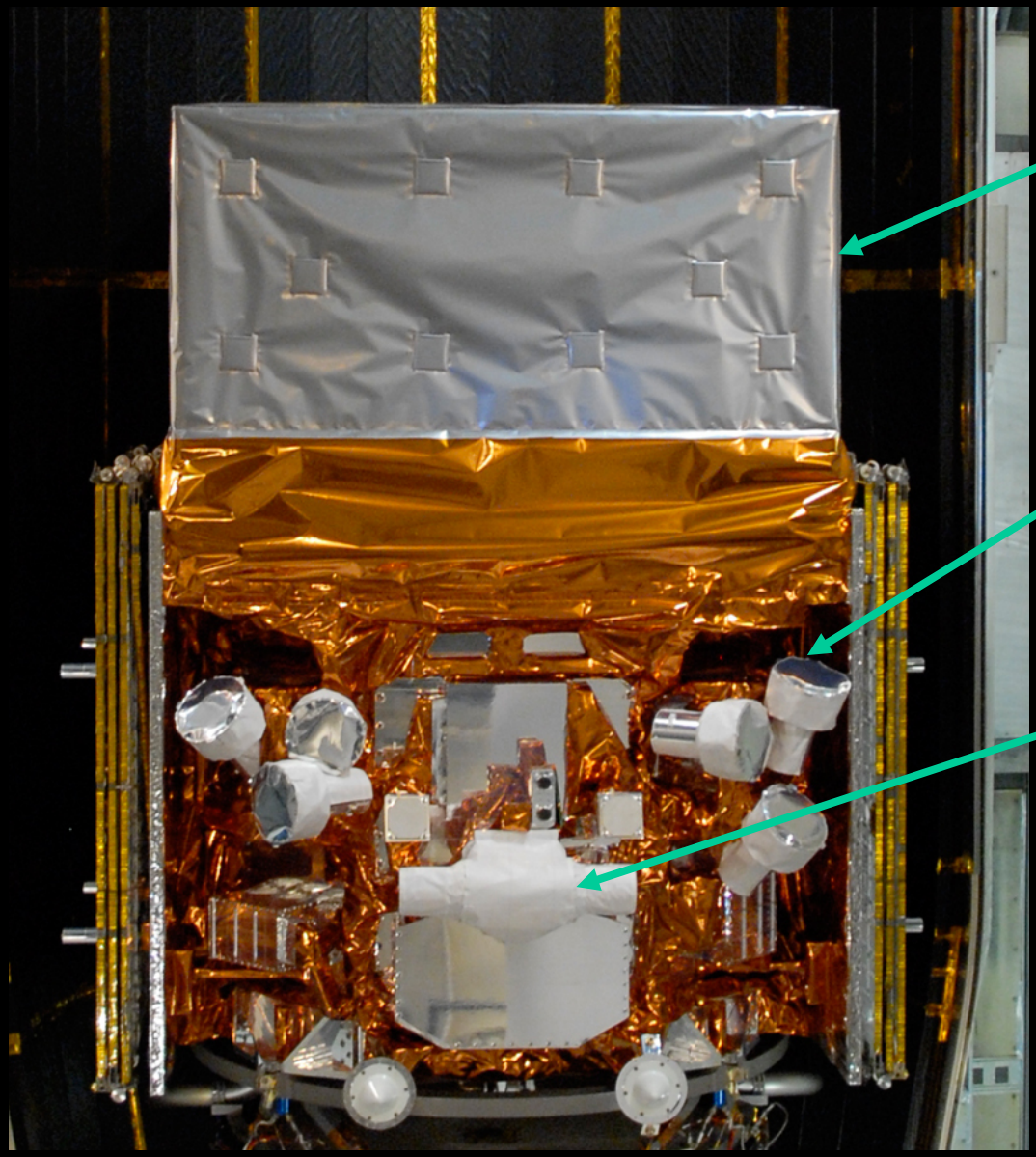
Rank	Facility	Citations	Participation
1	SDSS	1892	14.3%
2	Swift	1523	11.5%
3	HST	1078	8.2%
4	ESO	813	6.1%
5	Keck	572	4.3%
6	CFHT	521	3.9%
7	Spitzer	469	3.5%
8	Chandra	381	2.9%
9	Boomerang	376	2.8%
10	HESS	297	2.2%

The Galaxy in a new light: Observations of the Fermi-LAT

Marianne Lemoine-Goumard
CEN Bordeaux-Gradignan

for the Fermi-LAT Collaboration

The GLAST Observatory



LAT
20 MeV – 300 GeV

GBM
Sodium Iodide
Detector
8 keV – 1 MeV

GBM
Bismuth
Germanate
Detector
150 keV – 30 MeV

Launch

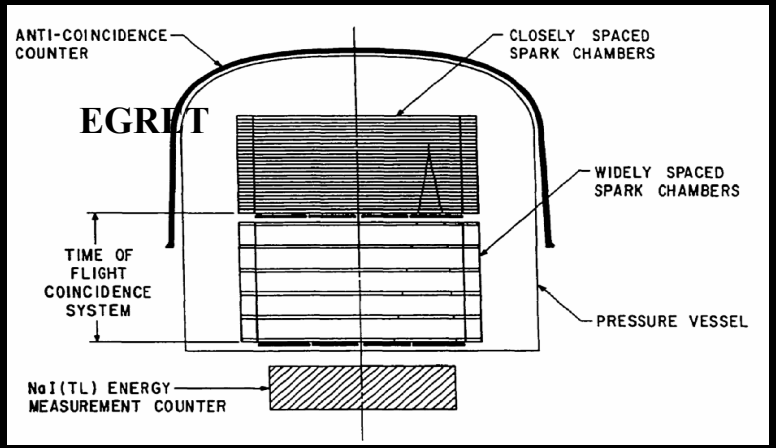
Launched from
Cape Canaveral
on a Delta IIH,
11 June 2008

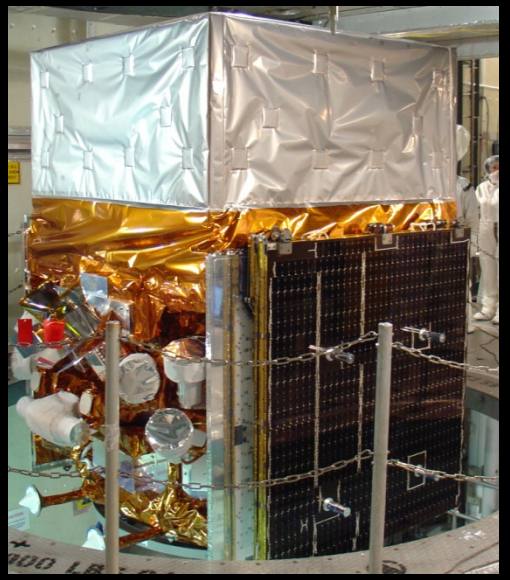
GLAST was renamed the
Fermi Gamma-Ray Space Telescope
on August 26, 2008

Fermi-LAT as a Telescope

	Years	Ang. Res. (100 MeV)	Ang. Res. (10 GeV)	Eng. Rng. (GeV)	$A_{eff}\,\Omega$ (cm^2 sr)	# γ-rays
EGRET	**1991–00**	**5.8°**	**0.5°**	**0.03–10**	**750**	**1.4 × 10^6/yr**
AGILE	**2007–**	**4.7°**	**0.2°**	**0.03–50**	**1,500**	**4 × 10^6/yr**
***Fermi* LAT**	**2008–**	**3.5°**	**0.1°**	**0.02–300**	**25,000**	**1 × 10^8/yr**

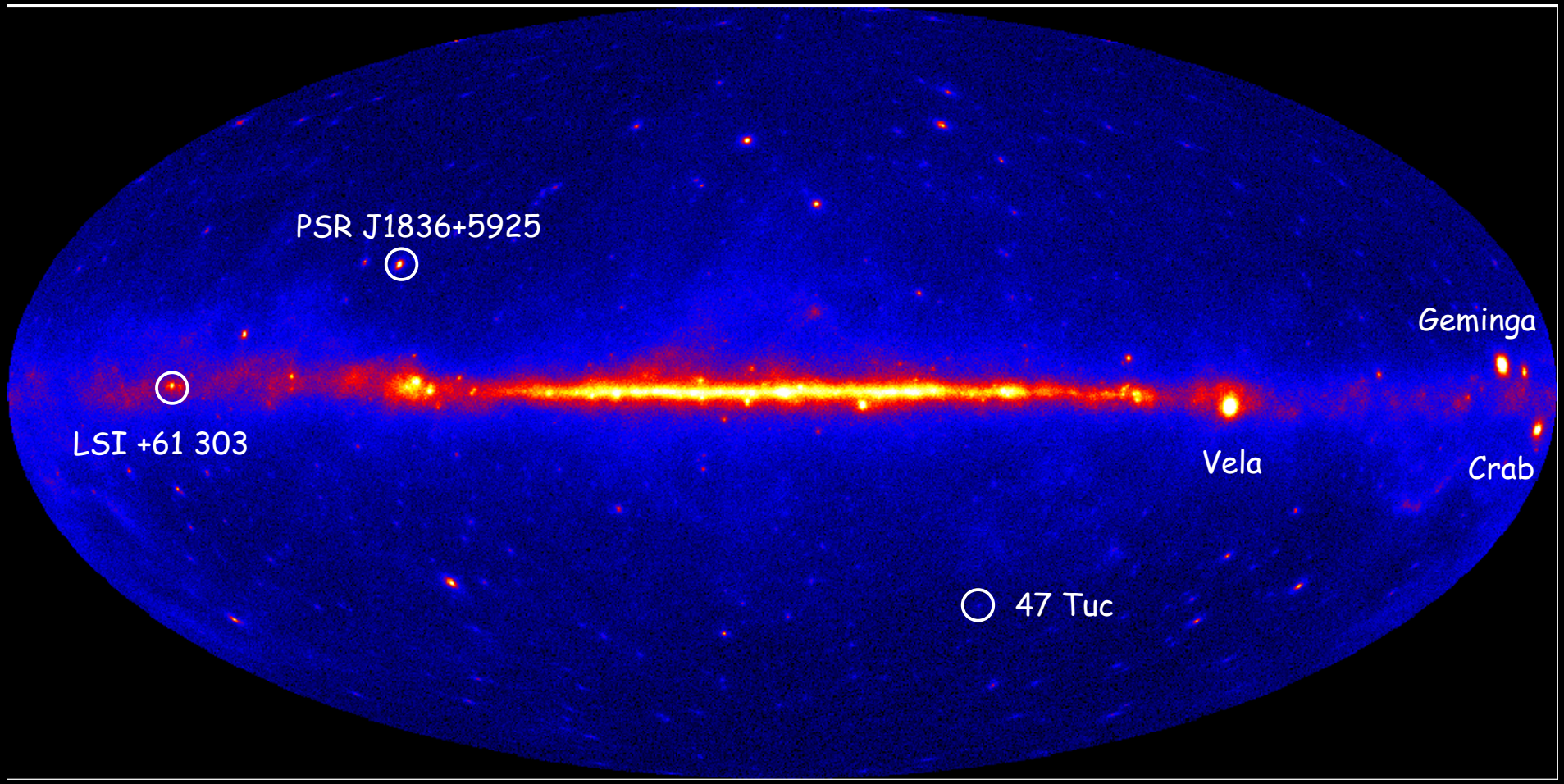
- LAT has already surpassed EGRET and AGILE celestial gamma-ray totals
- Unlike EGRET and AGILE, LAT is an effective All-Sky Monitor
  whole sky every ~3 hours





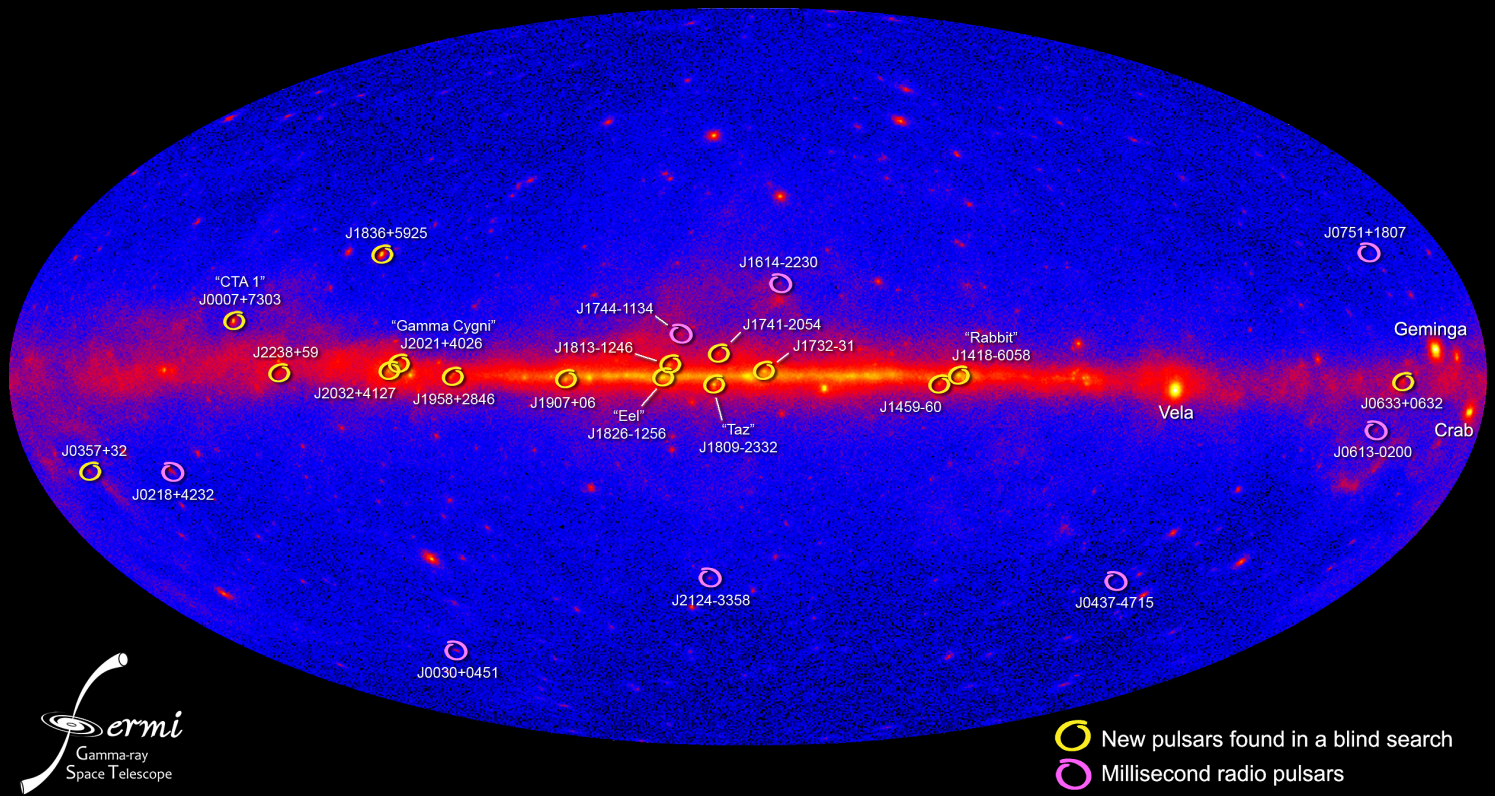
9-month all-sky survey

Fermi-LAT reveals best ever view of the gamma-ray sky !



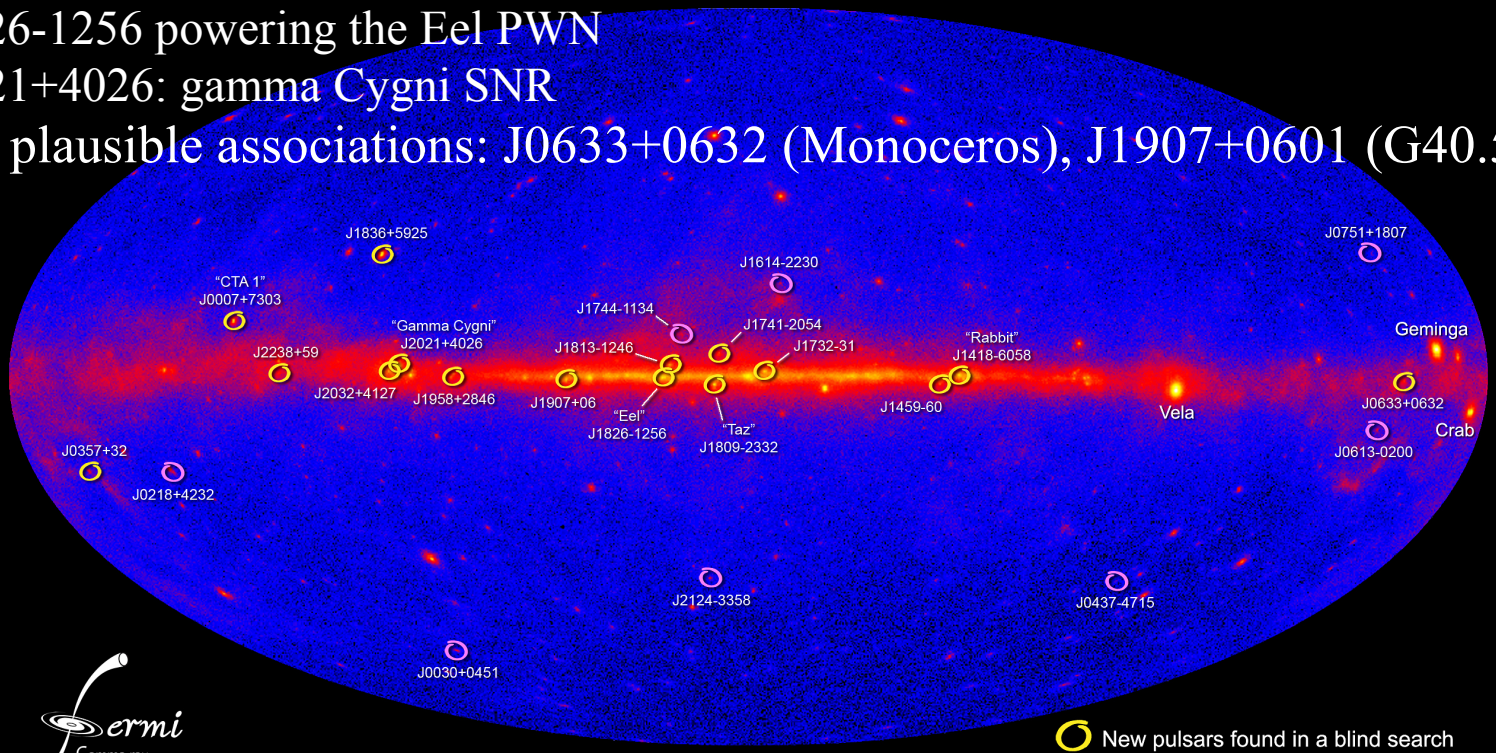
Fermi detects slew of new pulsars

The Fermi Telescope has found 16 previously unknown pulsars (yellow). It also detected gamma-ray emissions from known radio pulsars (magenta for the 8 MSPs), and from known or suspected gamma-ray pulsars.



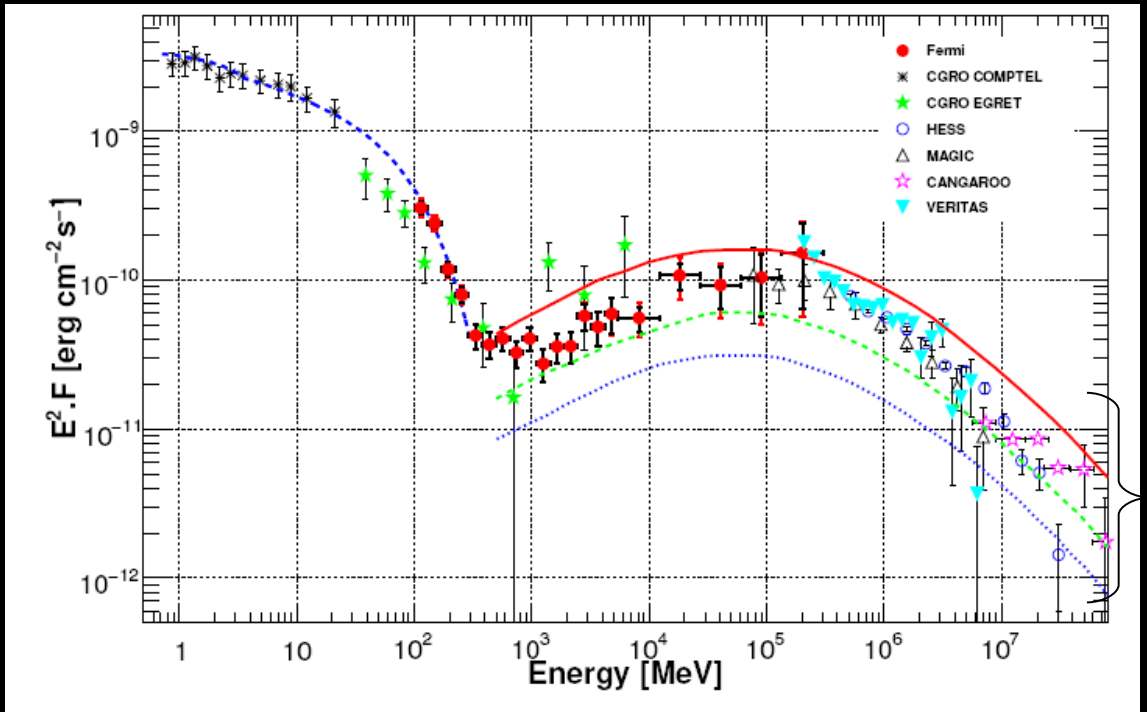
Fermi blind search pulsars: the link to SNRs and PWNe

- Detection of 16 new gamma-ray pulsars through blind frequency search: Abdo et al. , Science Express, 2nd July 2009
- 5 pulsars likely associated with PWN/SNR:
  - J0007+7303: CTA1
  - J1418-6058 (Kookaburra complex): G313.3+0.1, the Rabbit
  - J1809-2332 (Taz PWN): mixed-morphology type SNR G7.5-1.7
  - J1826-1256 powering the Eel PWN
  - J2021+4026: gamma Cygni SNR
- 2 more plausible associations: J0633+0632 (Monoceros), J1907+0601 (G40.5-0.5)



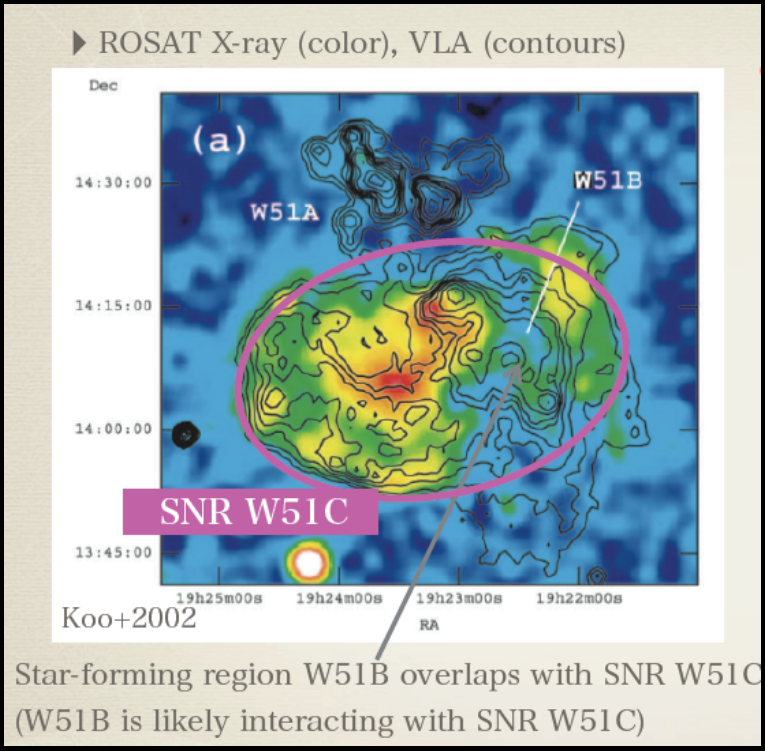
Fermi view of the Crab Nebula

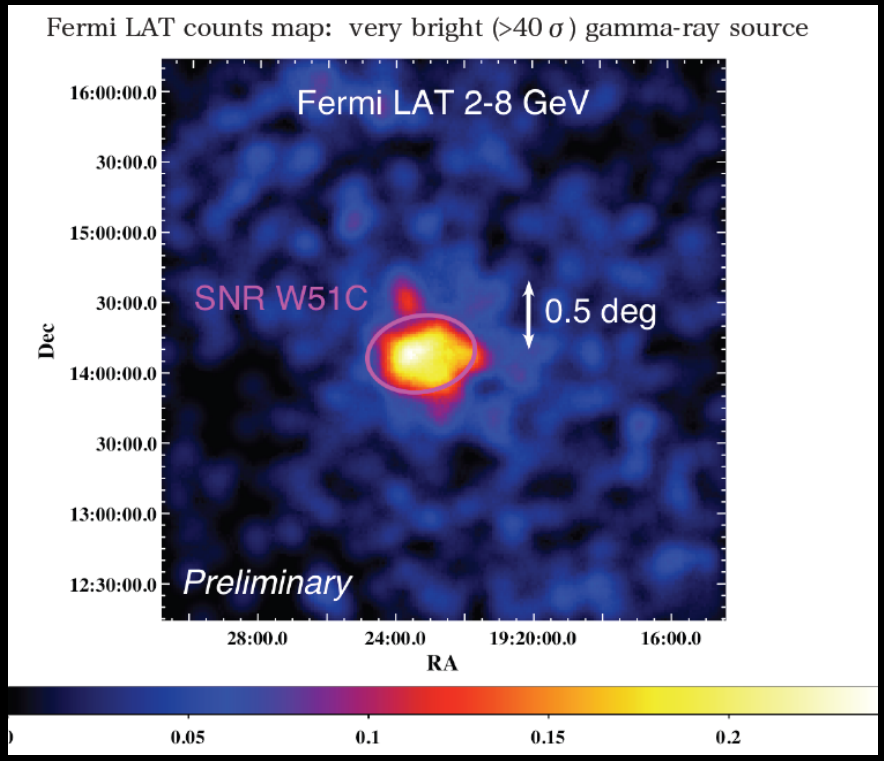
- Synchrotron component fit with COMPTEL + LAT => cut-off at ~100 MeV
- No cut-off seen with LAT data only for the IC component
- LAT high energy and Cherenkov spectra link up naturally
- Overlaying predictions of *Atoyan, A.M. and Aharonian, F.A., 1996, MNRAS, 278, 525* for different nebular mean magnetic fields, the results obtained by the LAT and ground based telescopes are consistent with 100 μG < B < 200 μG, indicating a magnetic field well beyond the equipartition field in the Crab nebula (300 μG)



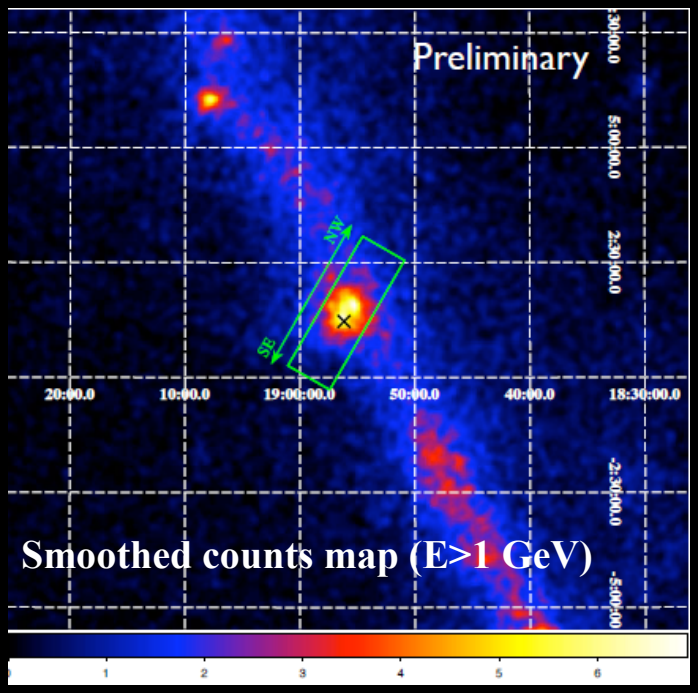
An extended source in the W51C region

- D ~ 6kpc, Age ~20000 yrs
- Molecular cloud interactions
- SNR diameter ~30 arcmin
- Very recent HESS detection
- **Detection with Fermi-LAT ! Extended emission beyond the LAT PSF; very large luminosity using 6kpc (~4×10^{35} erg/s)**

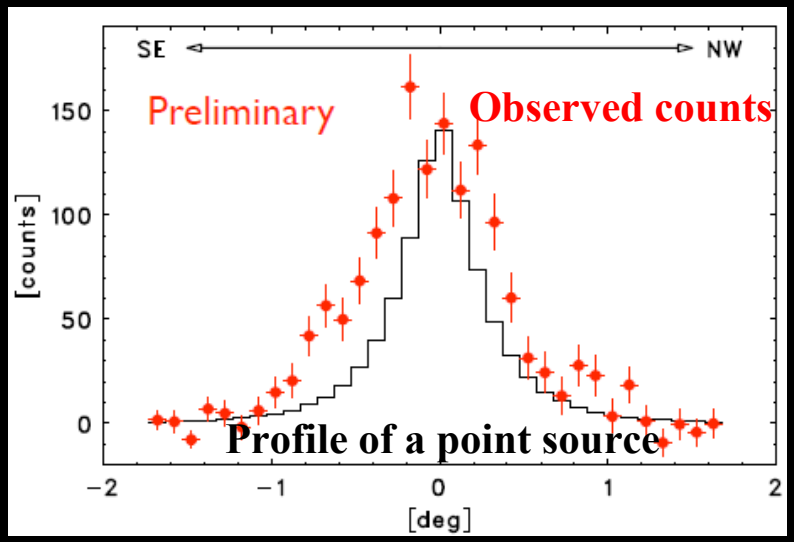


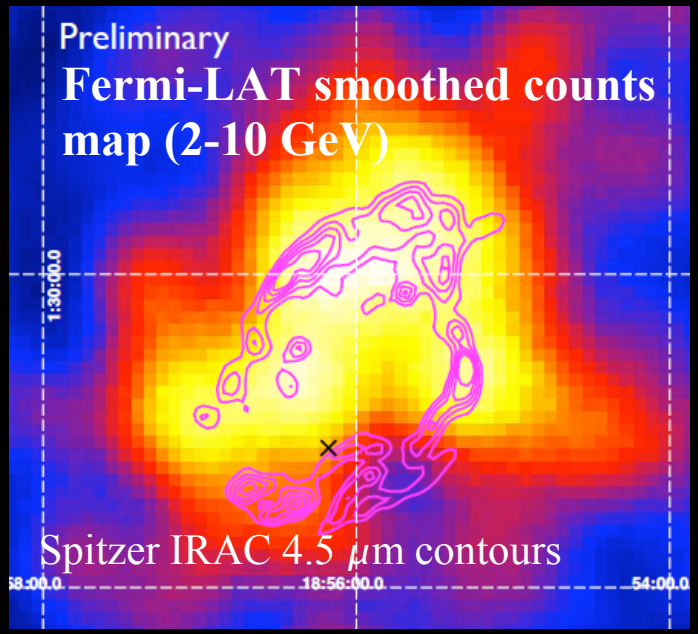


The W44 region as viewed by Fermi-LAT



- D ~ 3kpc, Age ~20000 yrs
- Molecular cloud interactions
- Spatial extent ~35 arcmin x 26 arcmin
- Spatially coincident with 3EG J1856+0114 but large error circle
- **Detection with Fermi-LAT ! Extended emission beyond the LAT PSF**





Detection of a source in the Vela X region

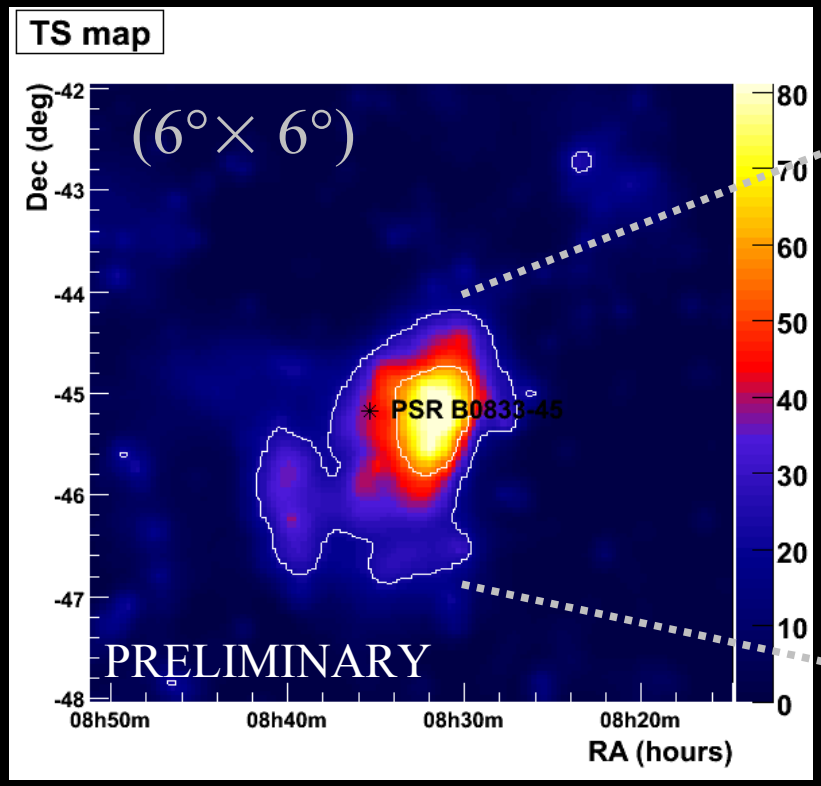
Using 9 months of survey data with Fermi-LAT and the off-pulse events:

TS ~80 (i.e ~9σ) for E > 800 MeV: significant detection

Good positional agreement with Vela X as seen with 8.4 GHz Parkes radio data

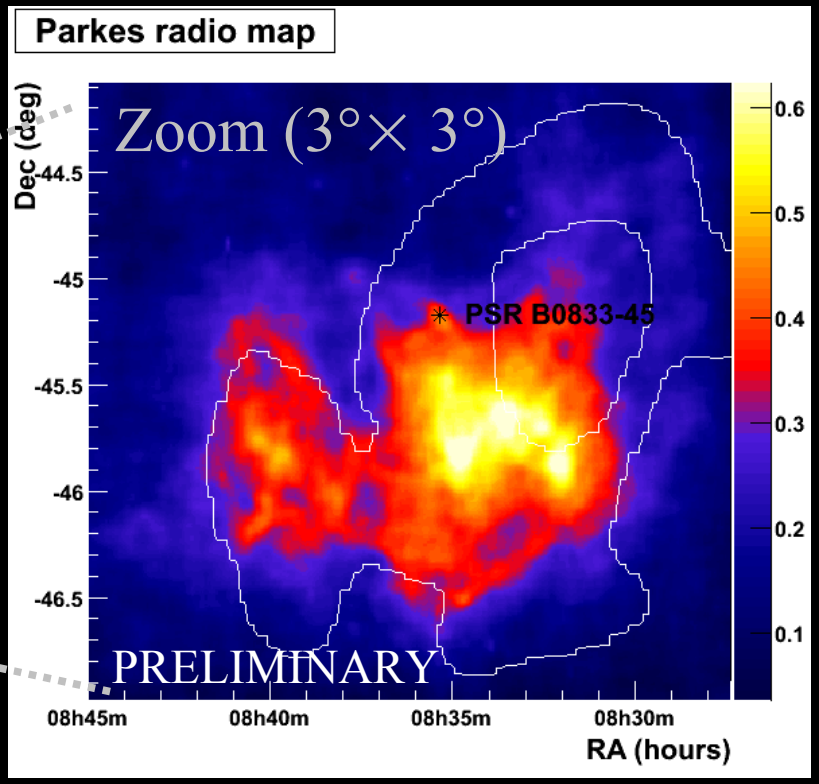
Fermi-LAT TS map (E > 800 MeV)

Fermi-LAT TS contours superimposed (white)



Parkes radio map at 8.4 GHz

Fermi-LAT contours superimposed (white)



Summary

Fermi detects tons of Pulsars !

Clear identification of the Crab Nebula; study of both the synchrotron and inverse compton peaks in the frame of a simple SSC model => magnetic field smaller than the equipartition field

Fermi-LAT detected significant gamma-ray emission spatially coincident with W51C, W44 and Vela X:

- The gamma-ray sources are extended beyond the Fermi-LAT PSF
- Detailed spectral analysis, morphological studies (precise measure of extension) as well as multi-wavelength modeling are underway

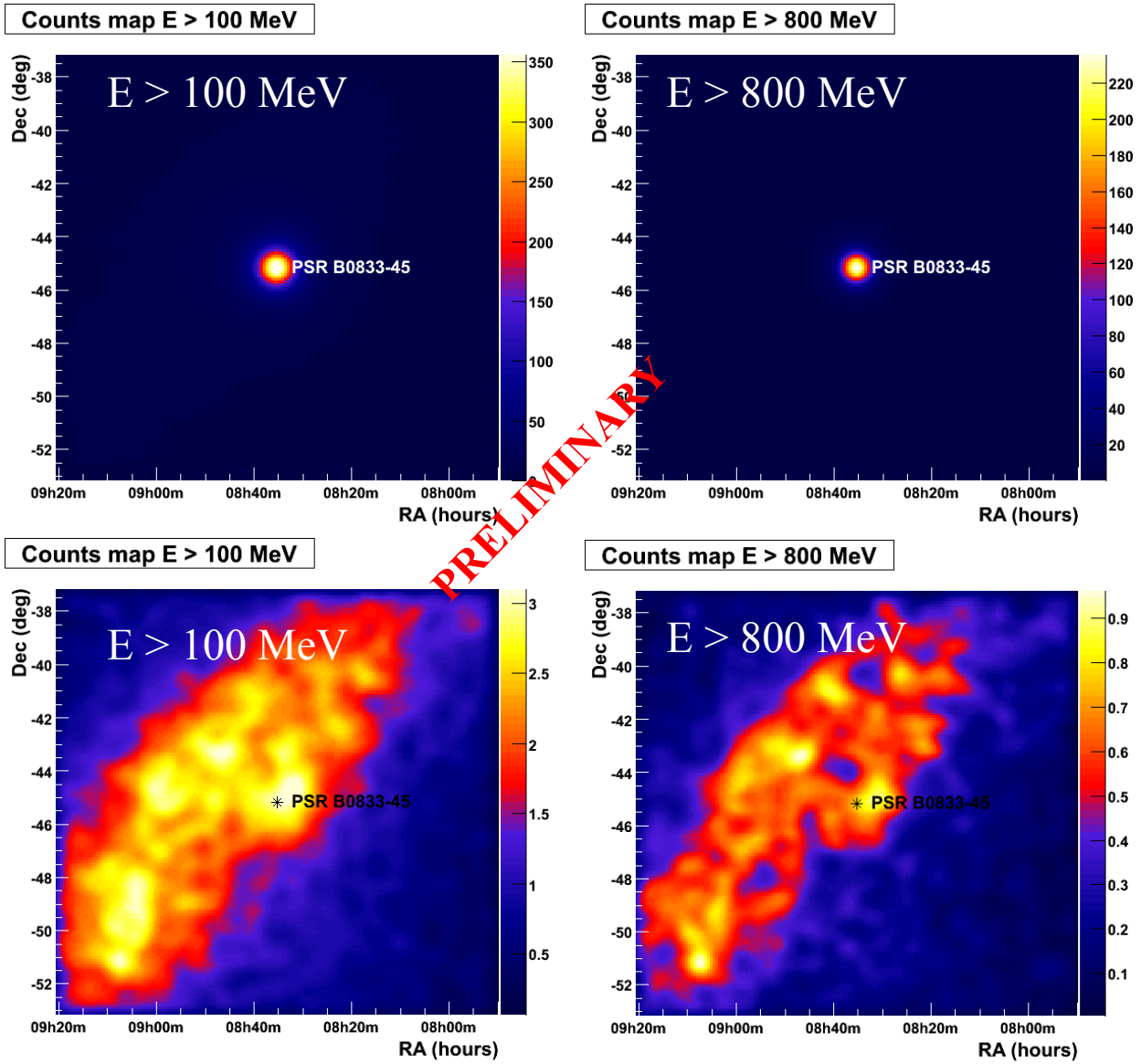
All detailed results will be reported in the upcoming papers

Back-up

Vela X: directly located in the Galactic Plane !

All phase Smoothed Counts map (σ=0.3°)

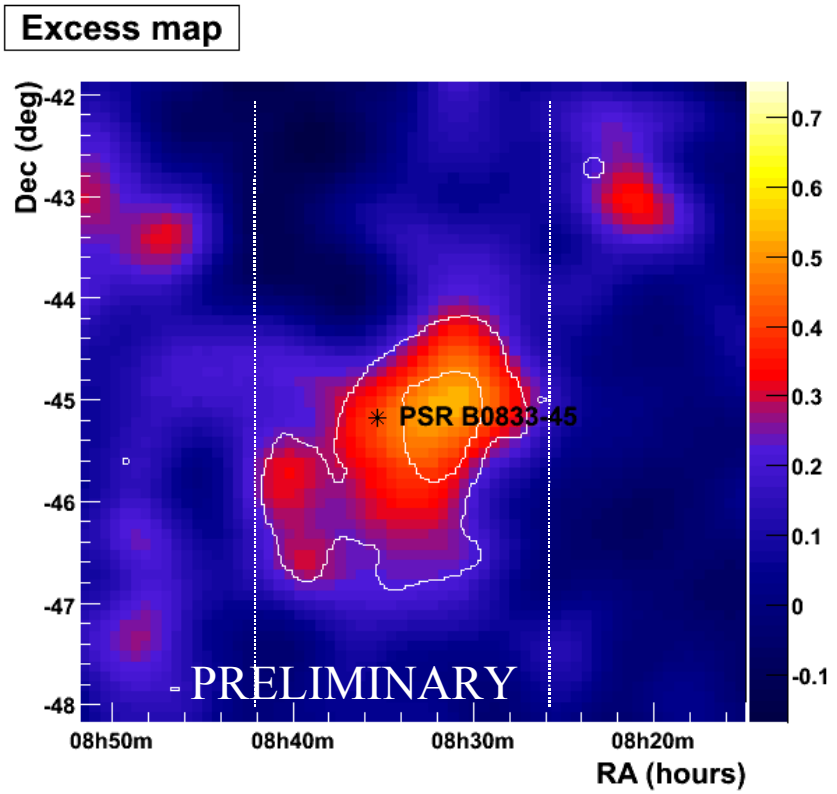
Off-pulse Smoothed Counts map (σ=0.3°)



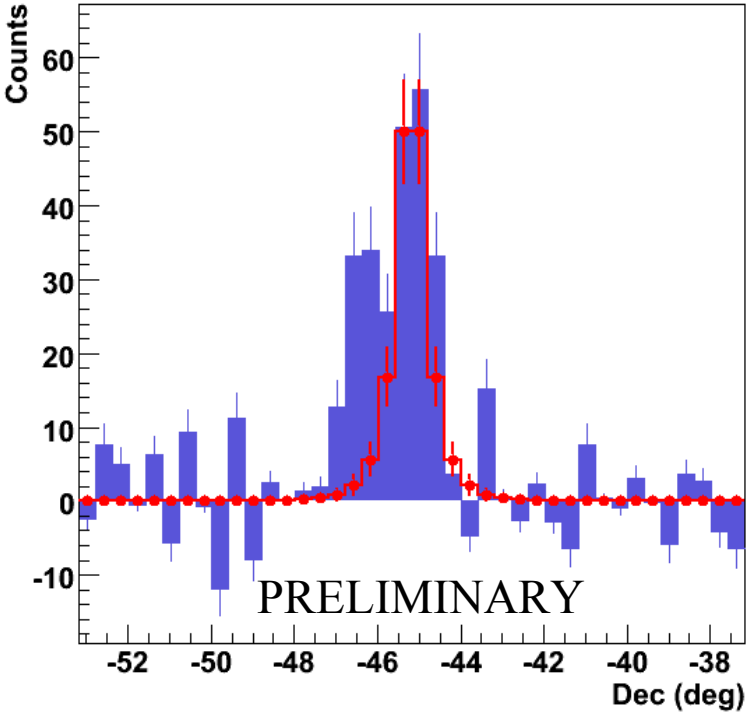
An extended source

Spatially extended !

Smoothed excess map (σ = 0.3°)
E > 800 MeV
Fermi-LAT TS contours (white)



Profile along the Declination axis
Blue: observed counts
Red: Point source simulated at the position of the Vela PSR



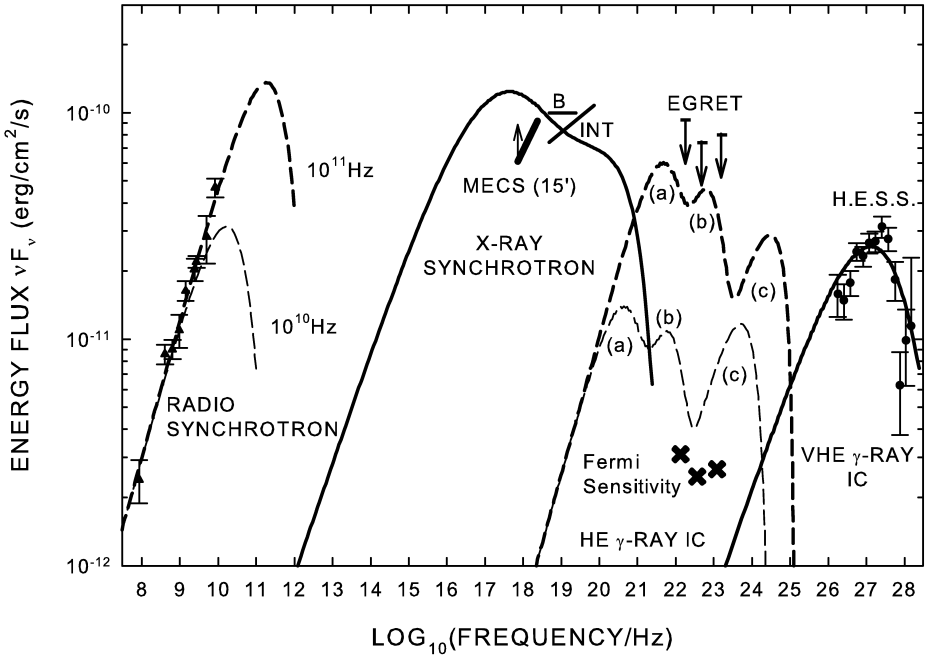
Vela X: perspectives

Radio, VHE spectrum and Fermi-LAT data for entire PWN suggests presence of two distinct electron populations

- radio-emitting particles may be relic population; higher energy electrons injected by pulsar

Maximum energy of radio-emitting electrons not well-constrained

- this population generates IC emission in GLAST band (consistent with positional agreement and extension)
- upcoming observations will provide strong constraints on this electron population

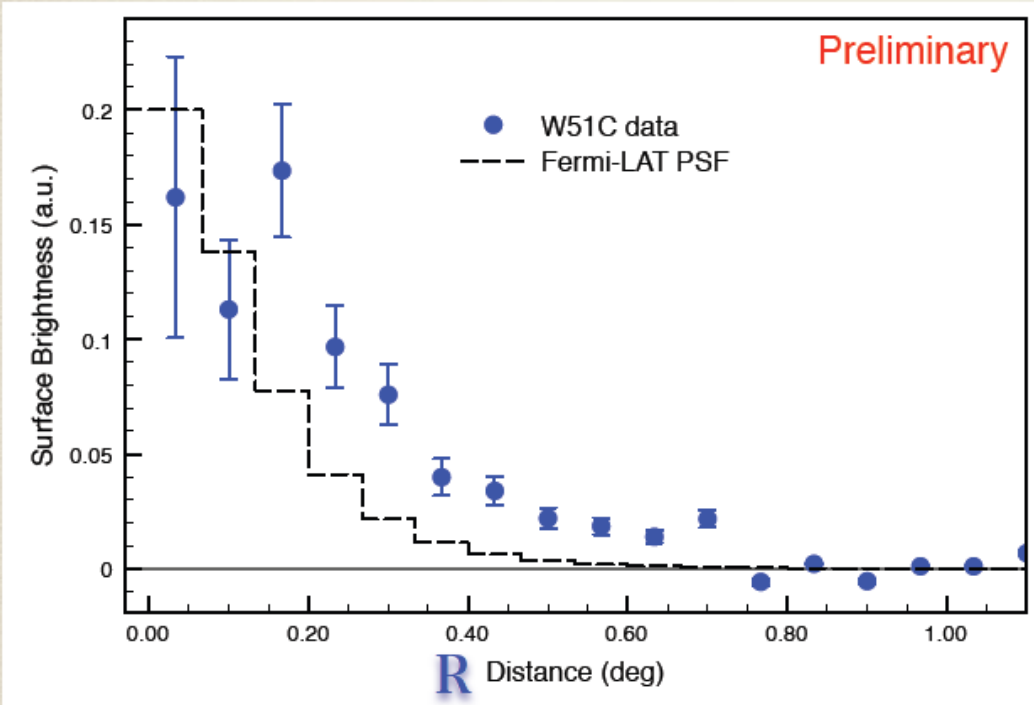


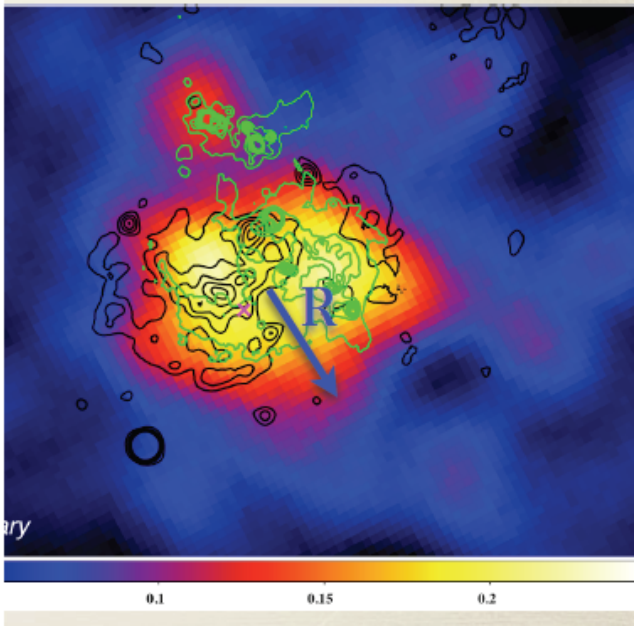
Spectral energy distribution of Vela X assuming an extension for the nebula

(De Jager et al, ApJ 689:L125, 2008)

W51C: an extended source

- Mean surface brightness (2-8 GeV) as a function of distance from the SNR center vs Fermi-LAT PSF (using the energy spectrum obtained with maximum likelihood technique)





Cosmic-ray accelerators ?

60 arcmin

RX J0852.0-4622

SNRs in our Galaxy: 231(Green et al. 2001)

with non thermal X-ray emission - ~10

best candidates - young SNRs with non thermal synchrotron X-rays

SN1006

Tycho

Kepler

Cas A

30 arcmin

d30m

d00m

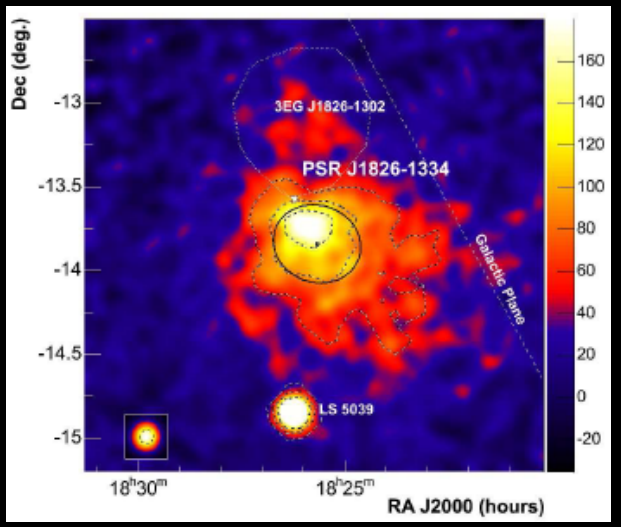
SNR RX J1713.7-3946

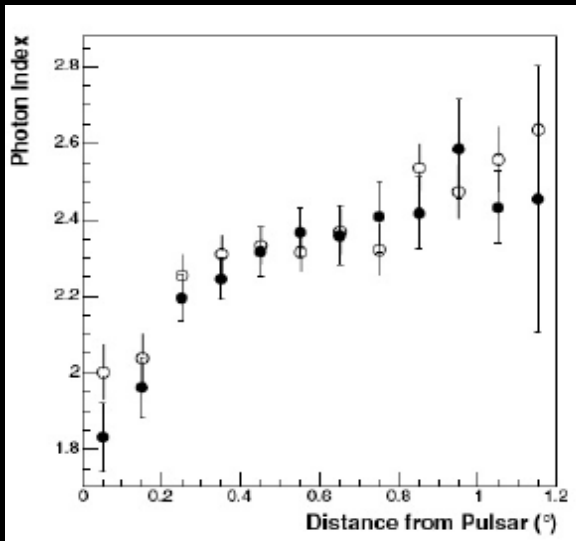
H.E.S.S. PSF

TeV emission

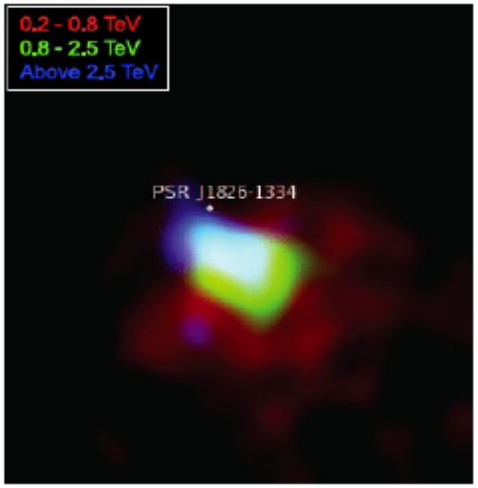
Established PWNe from the TeV properties

- **HESS J1825-137**, nebula of PSR B1823-13
  - Large TeV source, offset from the pulsar
  - Smaller X-ray extension
- TeV gamma-ray spectral steepening with distance away from pulsar
  - Consistent with radiative losses of $e^{\pm}$ accelerated near the pulsar



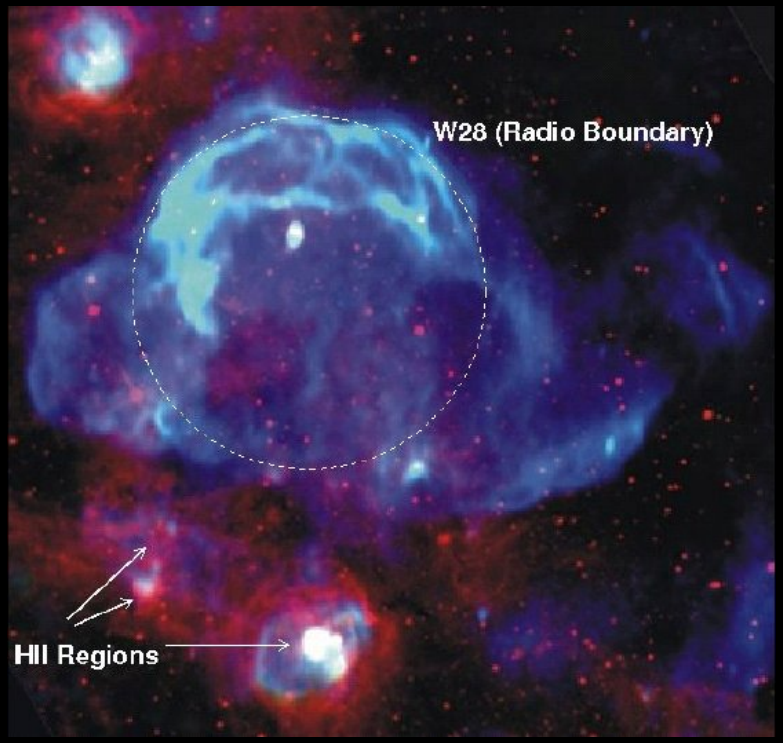


A&A **460**, 365 (2006)



Funk et al. 2007

SNR interacting with molecular clouds the example of W28

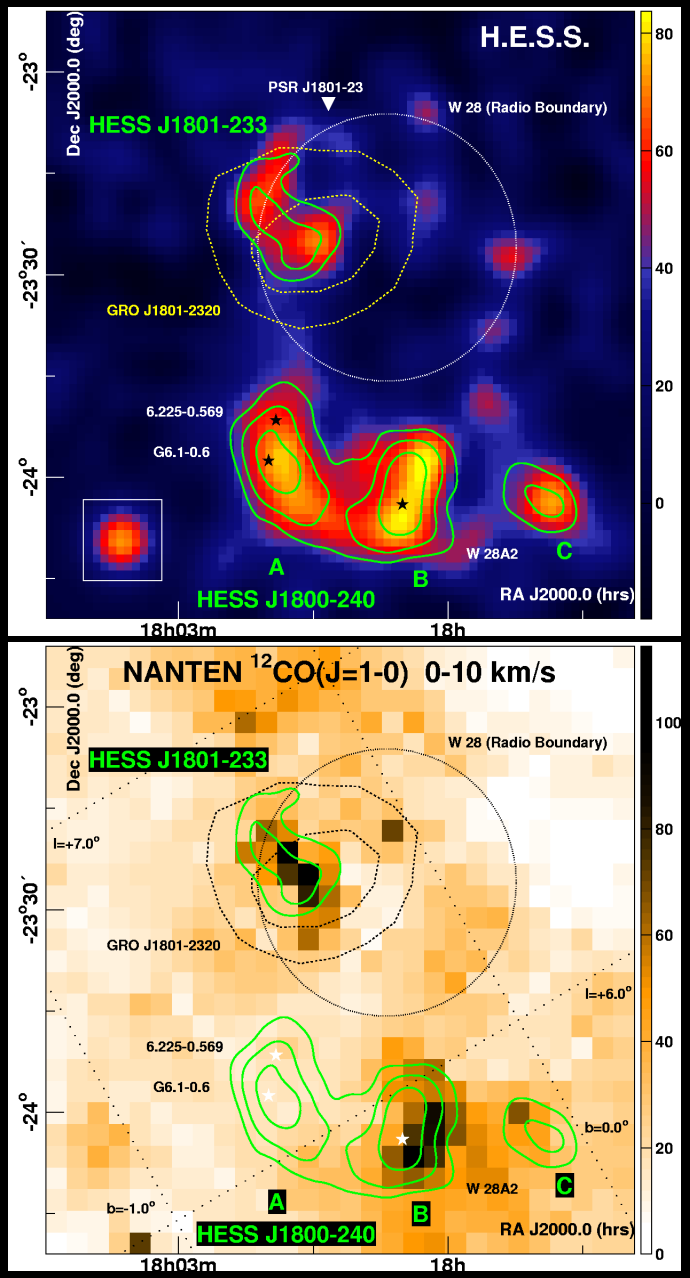


VLA 90cm radio emission

- Mixed morphology SNR
- Distance between 1.8 and 3.3 kpc (Goudis 1976, Lozinskaya 1981)
- Very old remnant: 35 000 to 150 000 years old
- Interaction with a molecular cloud (Wootten 1981) along its North and North-Eastern boundaries

H.E.S.S. results on W28

- Interaction of the remnant with a dense molecular cloud seen in NANTEN CO (J=1->0) observations
  - Presence of OH masers
  - Energetics compatible with CRs accelerated within the SNR and interacting with the cloud
- Molecular clouds seen also in coincidence with the southern excesses
  - Distances compatible with the SNR
  - Hadronic scenario also possible
- Alternative scenarios possible for the southern emission:
  - Other SNRs, young stars, open stellar cluster



F. Aharonian et al., A&A, 481, 401 (2008)