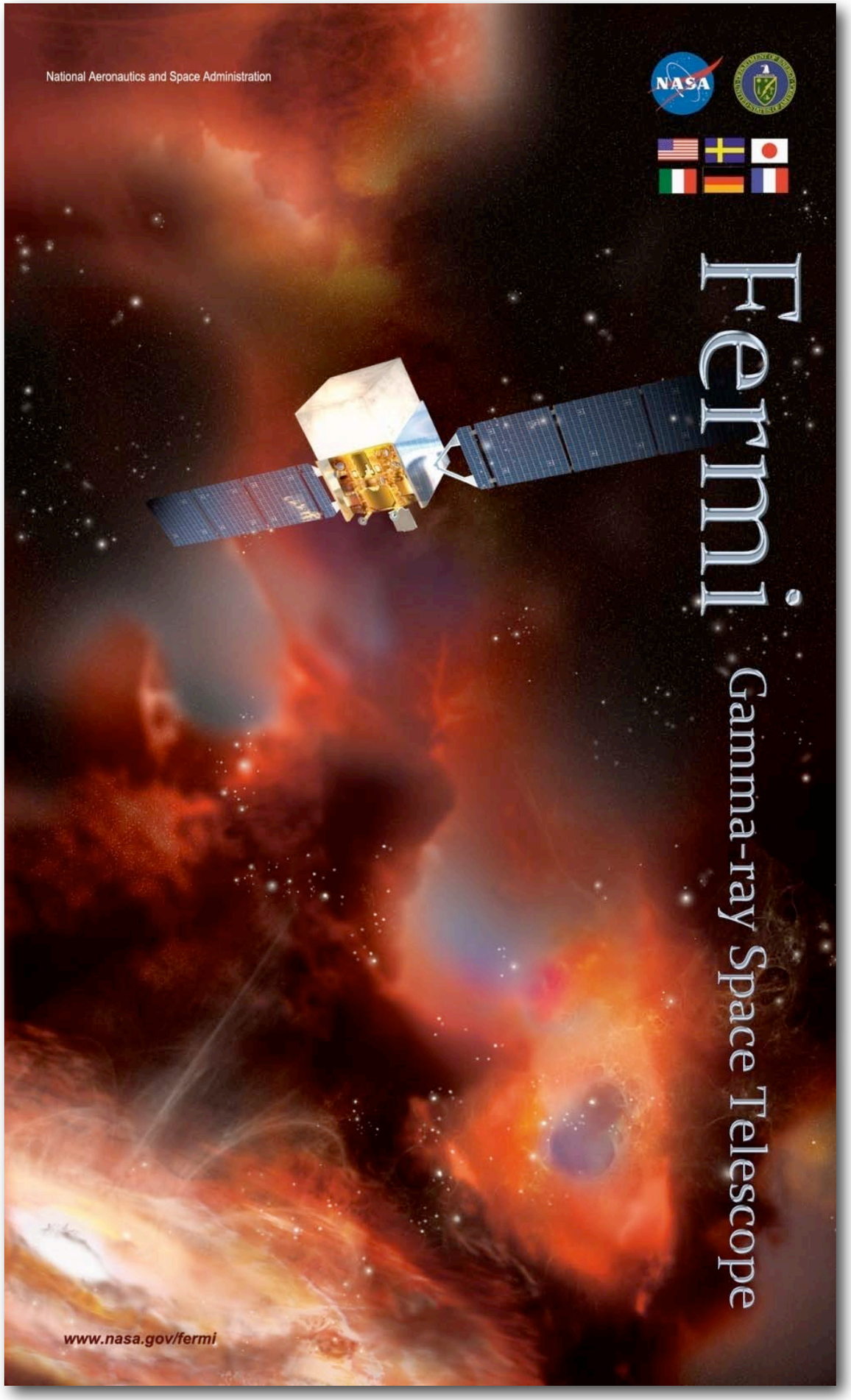


Galactic Sources as Seen by Fermi-LAT

田中孝明 (KIPAC/SLAC)

on behalf of the Fermi-LAT collaboration

JPS Meeting @ Konan University (09/12/2009)

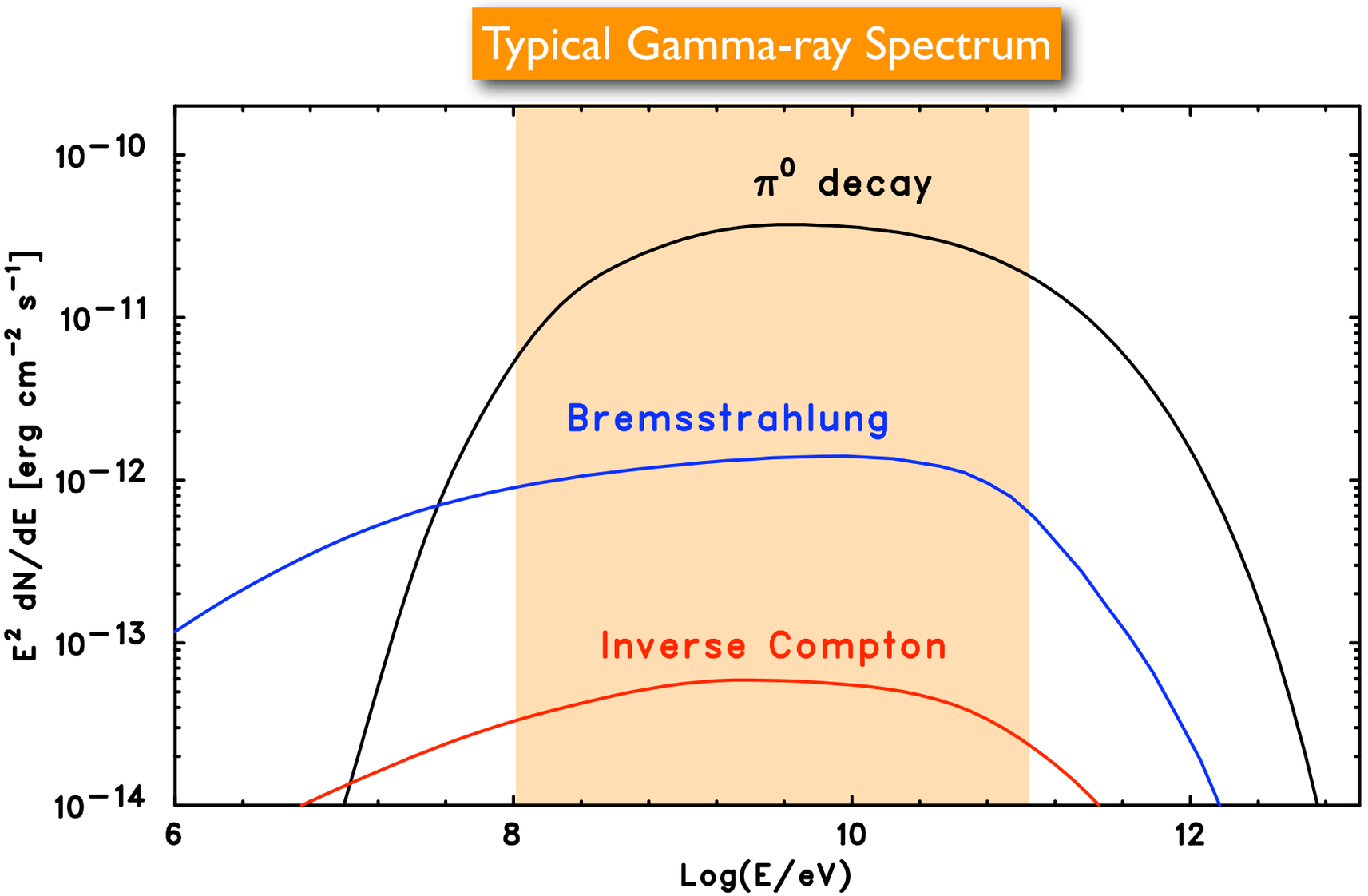
Outline of the Talk

One-year Fermi LAT observations of

- Supernova remnants
  - W44
  - W51C
- Pulsar wind nebula
  - Crab nebula
  - Vela X
- Binaries
  - LS I +61° 303
  - LS 5039

SNRs in GeV

- Key issues to be addressed by **Fermi LAT**:
  - Searching for **π^0-decay** signatures,
  - Measuring total **CR energy content** per SNR,
  - Measuring **CR spectrum**,
  - Learning how CRs are **released** into ISM.



- D = 3 kpc
- n = 100 cm^{-3}
- $W_p = 10^{49}$ erg
- $W_e = 10^{47}$ erg
- $E_{p,max} = E_{e,max} = 2.0$ TeV
- Particle index = 2.0
- Constant injection over 1.0×10^4 yr

Interaction with molecular cloud enhances Pion-decay/ Bremsstrahlung

Fermi-LAT SNRs

IC 443: (A. Rodriguez on behalf of Fermi LAT at 31st ICRC)

- Middle Age, Mixed Morphology SNR, Distance 1.5 kpc
- Interactions with Molecular Clould
- EGRET, AGILE, MAGIC, VERITUS
- **Fermi-LAT** (0FGL J0617.4+2234: **3 months** data yield **51σ**)

W44: (T. Tanaka on behalf of Fermi LAT at 31st ICRC)

- Middle Age (20000 yr), Mixed Morphology SNR, Distance 3 kpc
- Interactions with Molecular Cloud
- EGRET
- **Fermi-LAT** (0FGL J1855.9+0126: **3 months** data yield **39σ**)

W51C: (Y. Uchiyama on behalf of Fermi LAT at 31st ICRC)

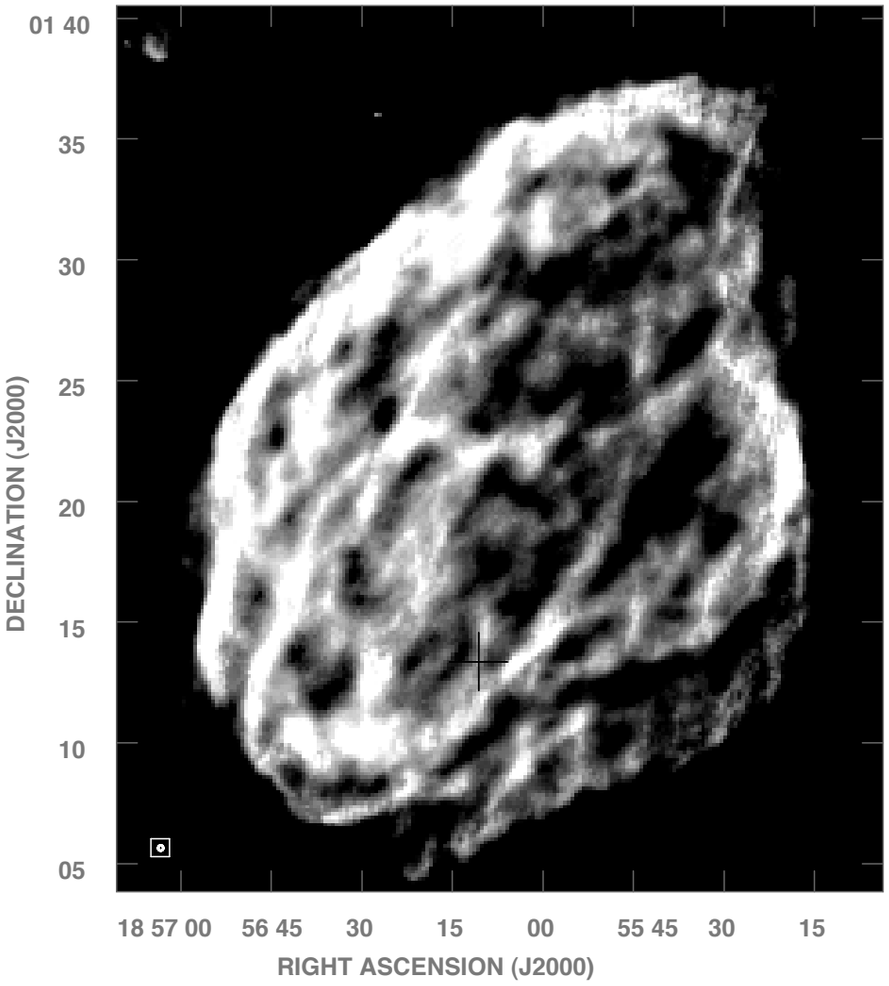
- Middle Age (20000 yr), Distance 6 kpc
- Interactions with Molecular Cloud
- HESS (No spectrum)
- **Fermi-LAT** (0FGL J1923.0+1411: **3 months** data yield **23σ**)

+ W28: (H. Katagiri on behalf of Fermi LAT at this meeting)

SNR W44

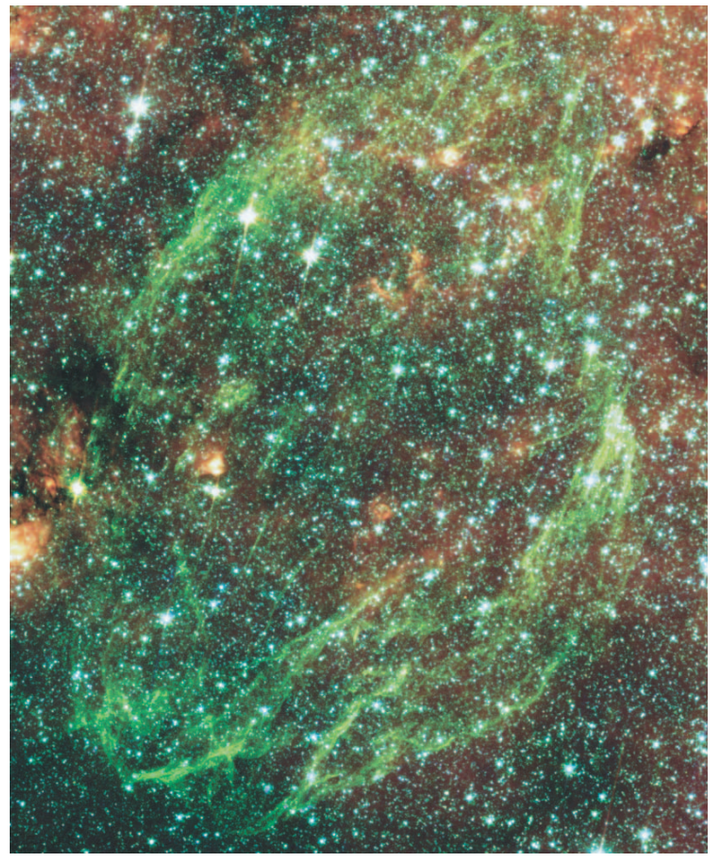
Middle-aged (~ 2.0 × 10^4 yr) & mixed-morphology SNR (radio: shell, thermal X-ray: centrally filled)
Distance: ~ 3kpc
Spatial extent: ~ 35 arcmin × 26 arcmin
Spatially coincident with 3EG J1856+0114

Bright radio source (S_{1GHz} ~ 230 Jy)
Filamentary shell structures



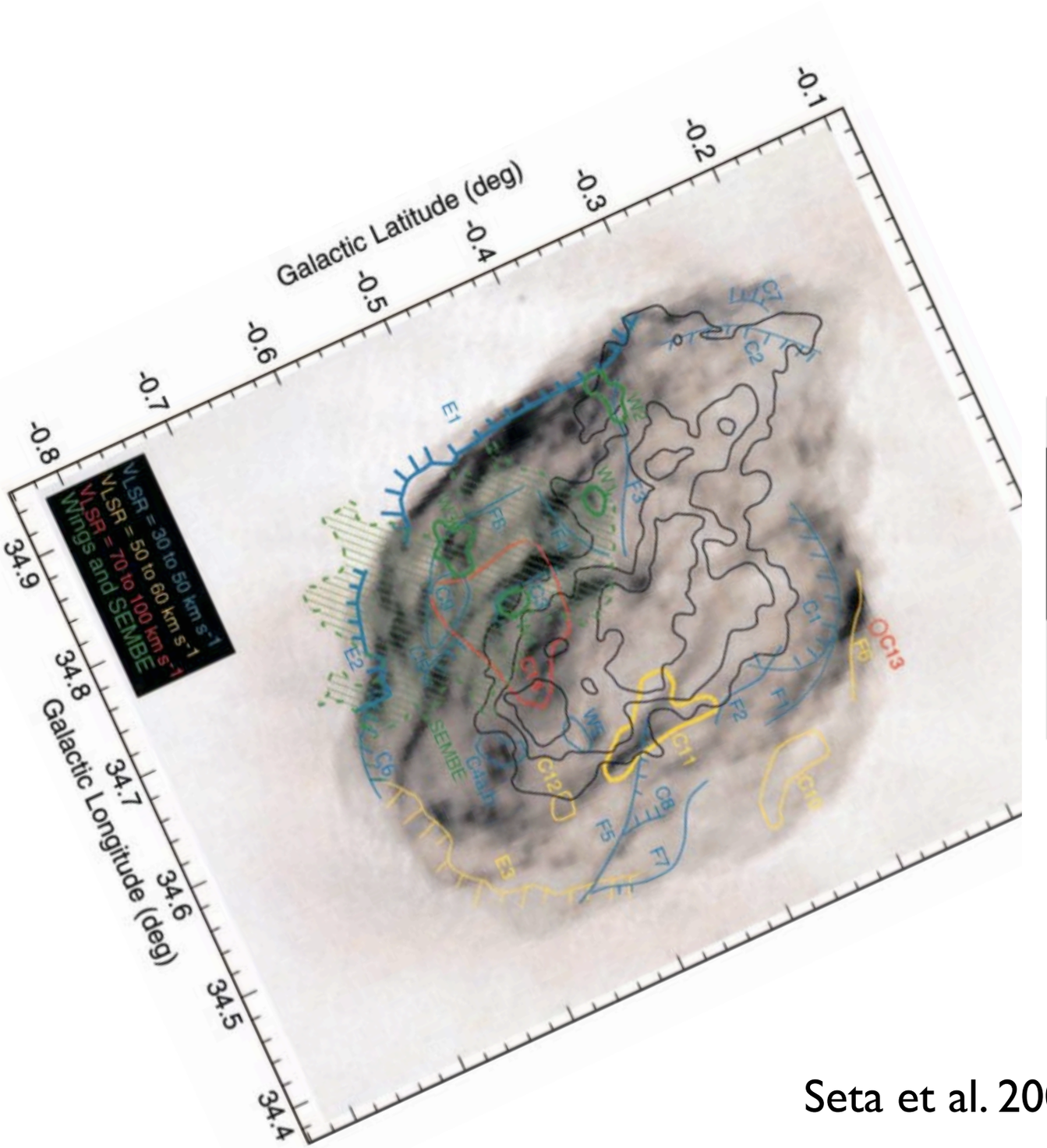
VLA 324 MHz
Castelletti et al. (2007)

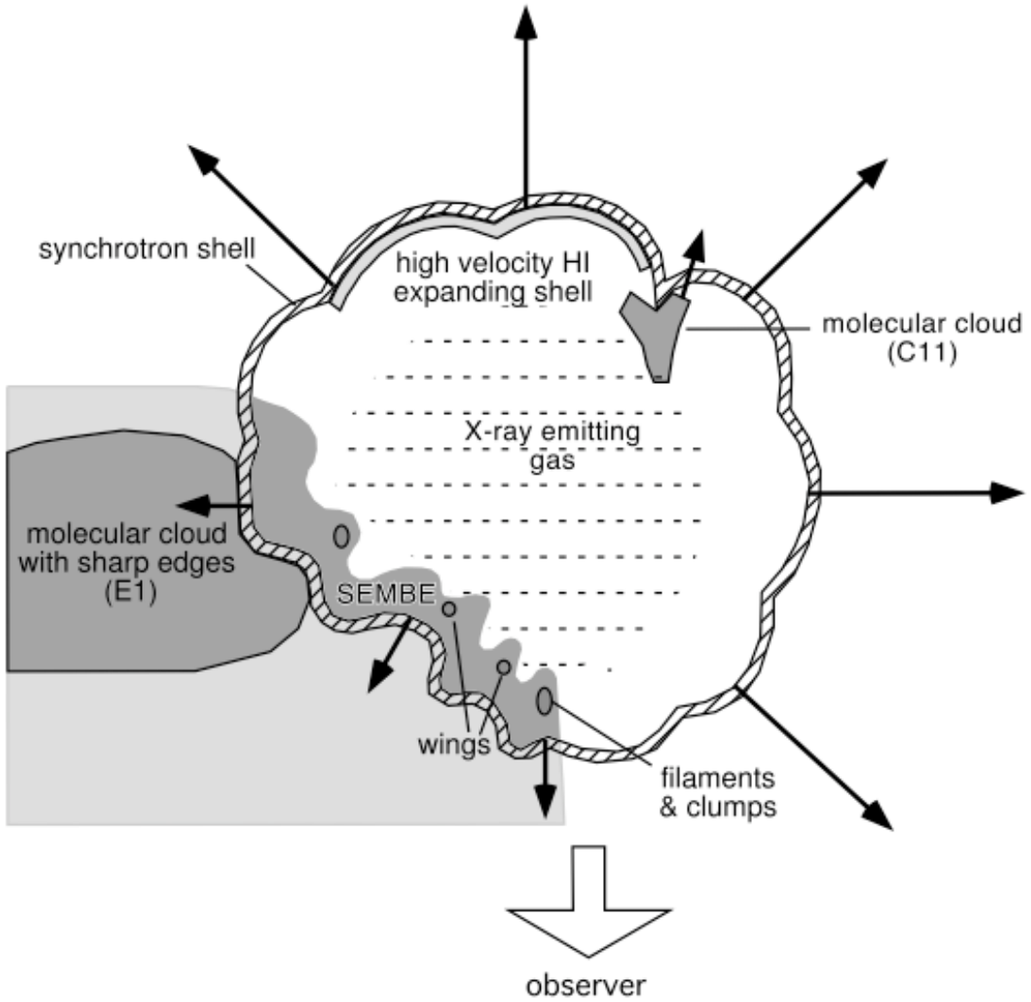
Cloud-shell interactions
CO (Seta et al. 2004), OH maser (1720 MHz: Hoffman et al. 2005), mid-IR(traces shocked H_2; Reach et al. 2006)



Green: Spitzer IRAC channel 2 (4.5 μm)
Reach et al. (2006)

SNR W44





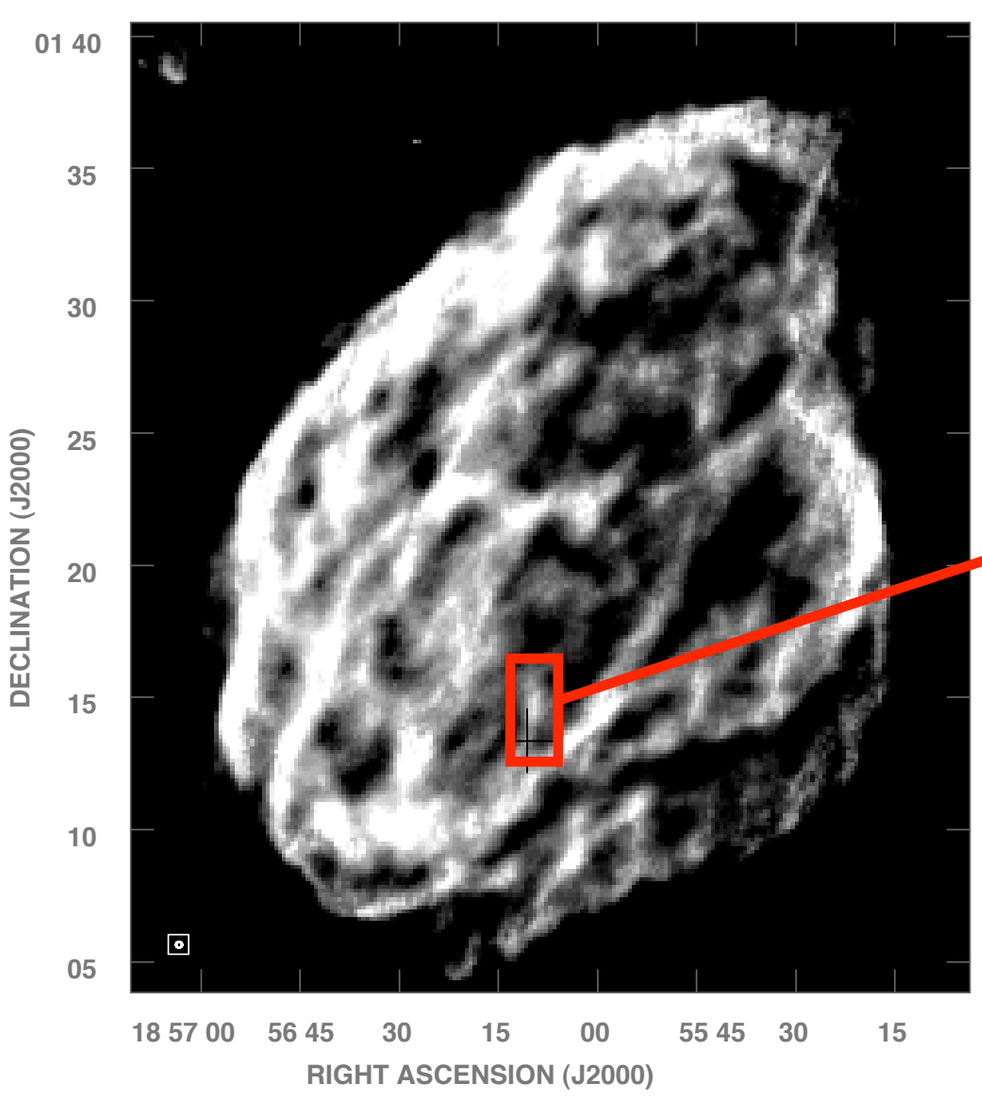
Seta et al. 2004

Pulsar & PWN in W44

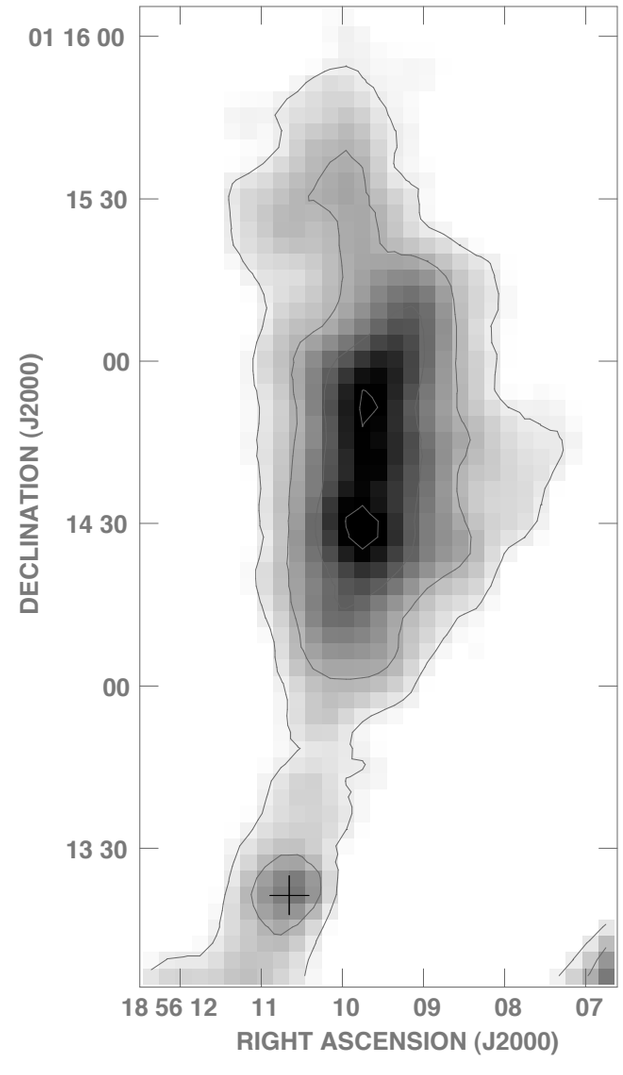
Associated pulsar: PSR B1853+01(Wolszczan et al. 1991)

Characteristic age: ~ 2.0×10^4 yr

PWN: Observed in Radio & X-ray (extends ~ 2 arcmin in radio)
(Frail et al. 1996, Harrus et al. 1996, Petre et al. 2002)



Black cross: location of PSR B1853+01



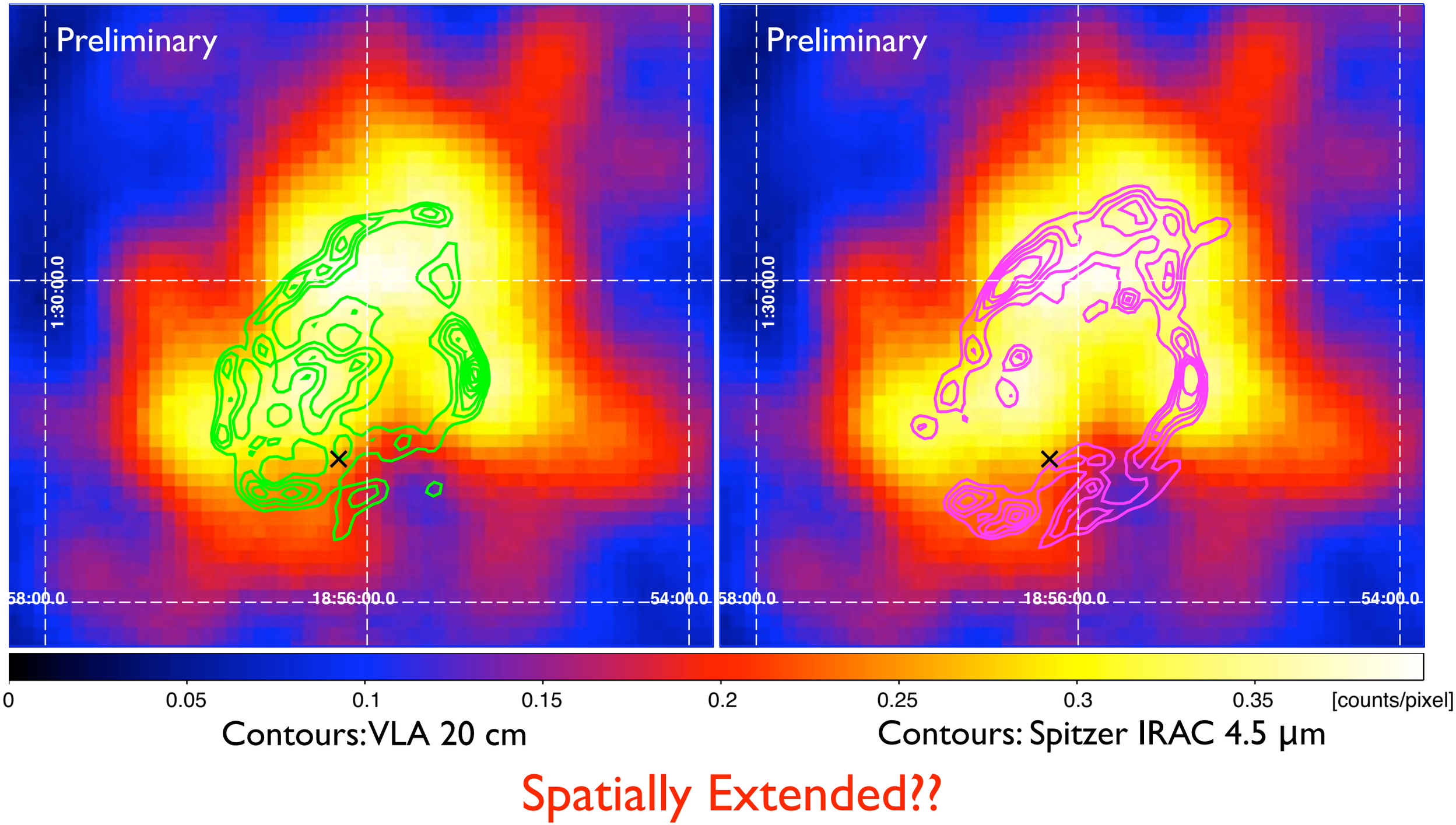
VLA 324 MHz
Castelletti et al. (2007)

W44 Image

Fermi-LAT Smoothed Count Map (Front Events; 2–10 GeV)

The source corresponds to 0FGL J1855.9+0126 (BSL: Abdo et al. ApJS 2009)

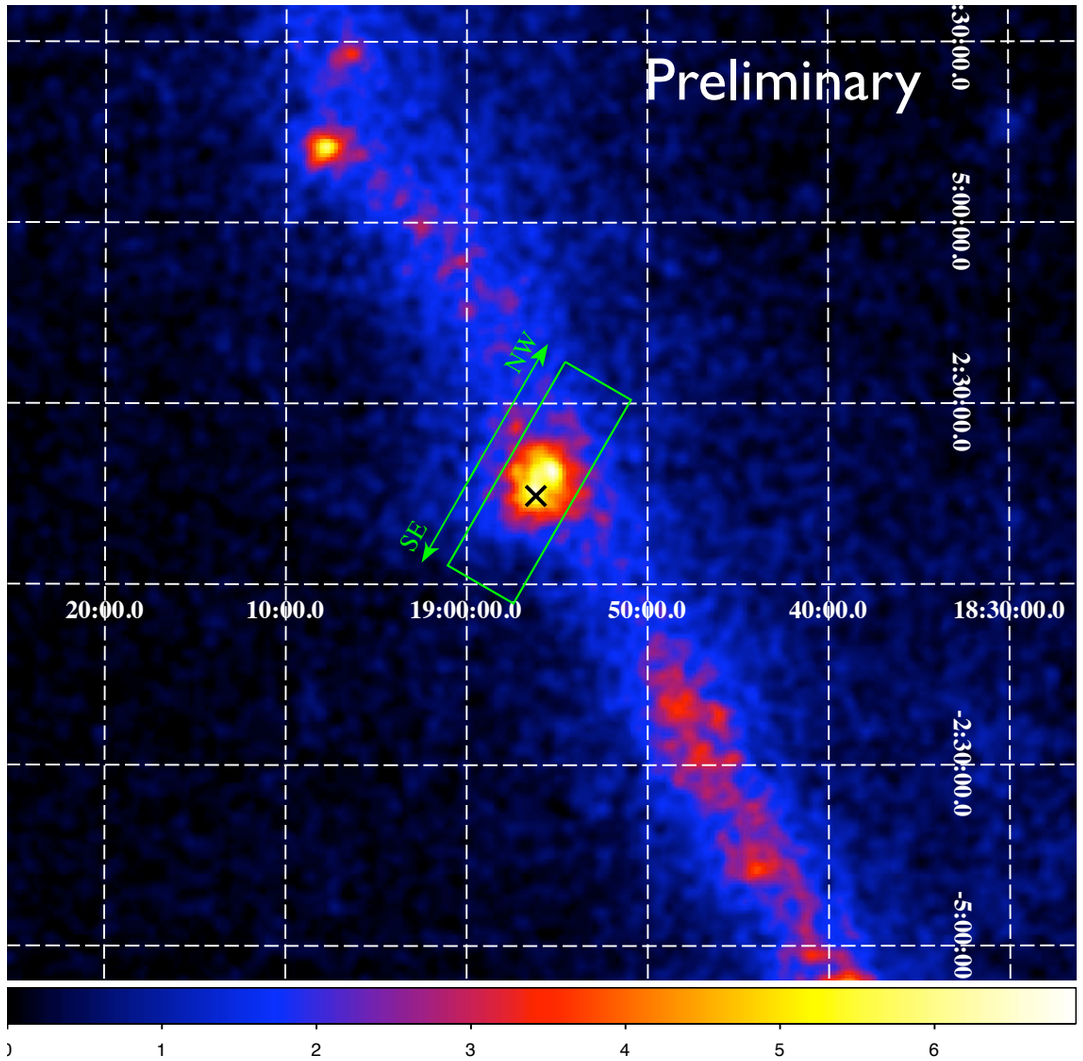
Black cross: location of PSR B1853+01



Spatially Extended??

Spatial Extent?

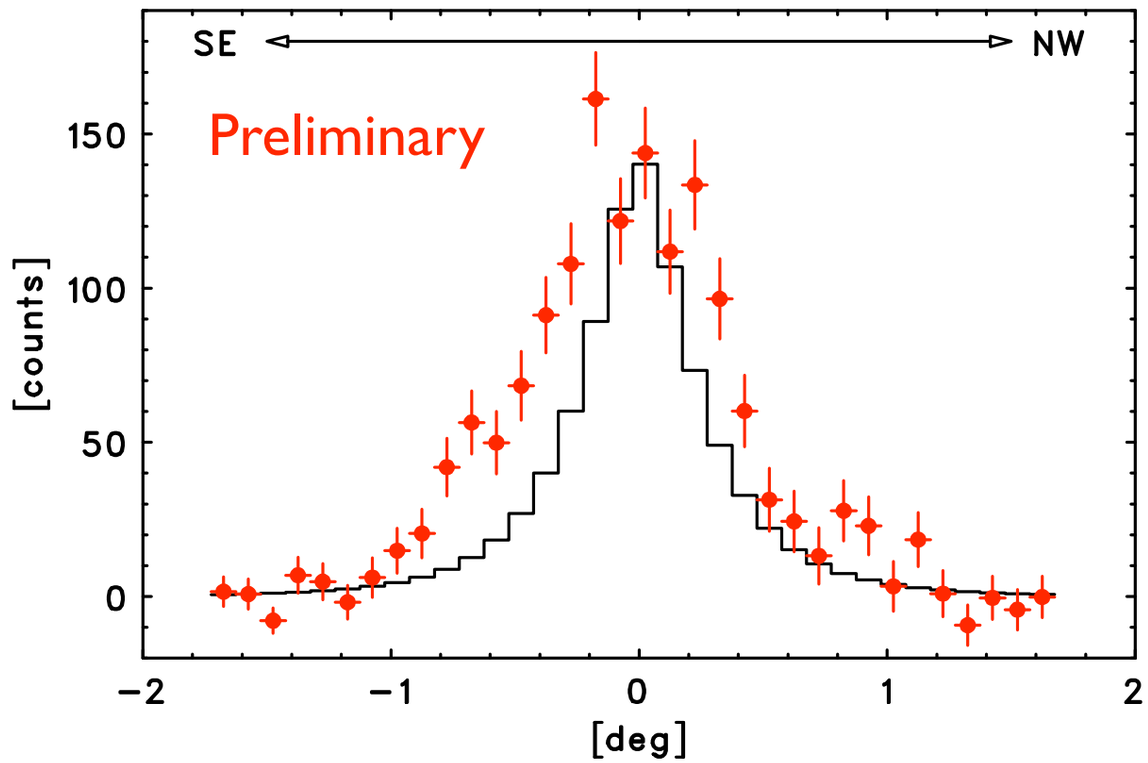
Smoothed Count Map (> 1GeV)



Black Cross: Pulsar (PSR B1853+01) location

Profile along the rectangle

Contributions from the diffuse backgrounds and nearby sources are subtracted



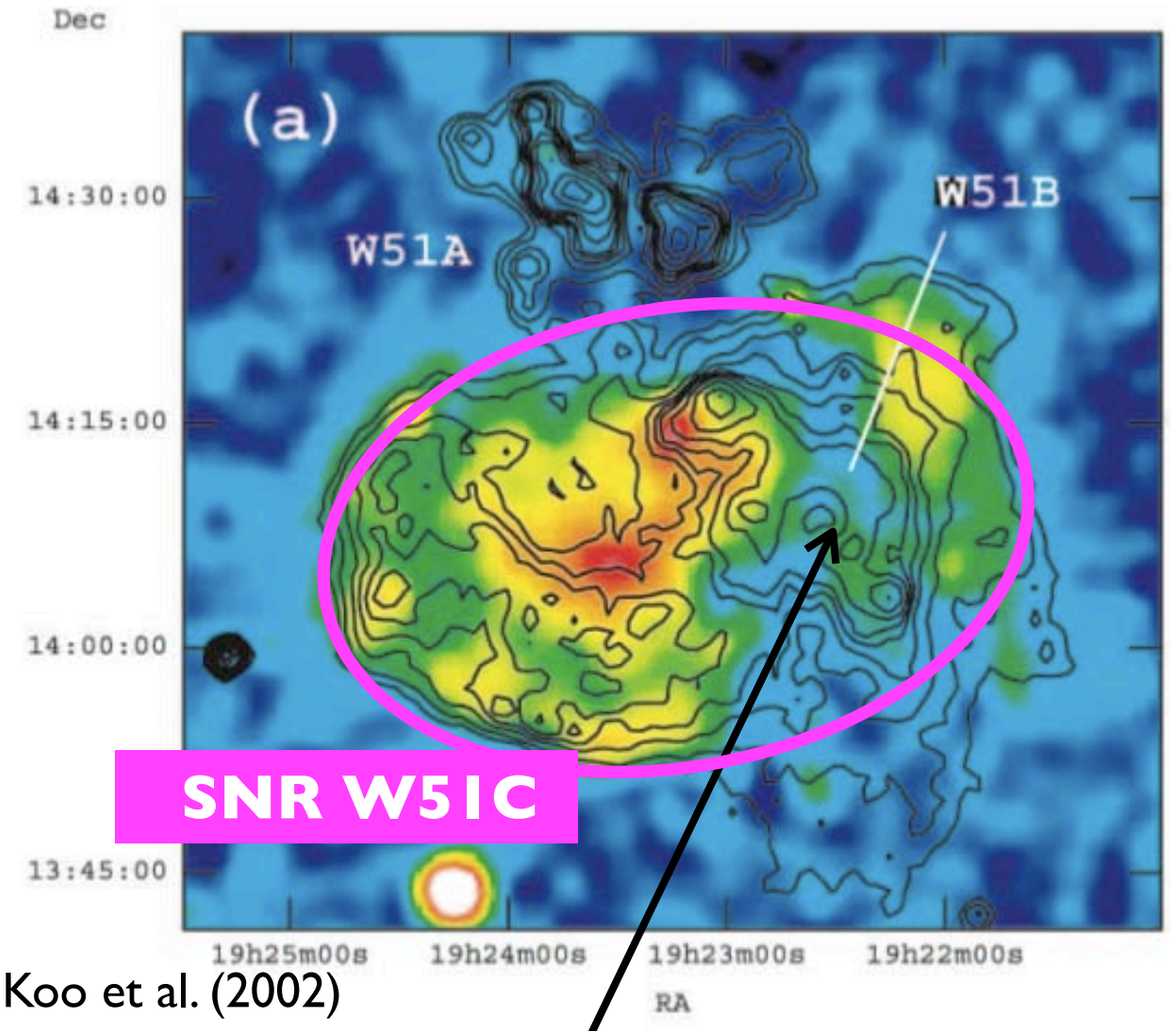
Red: Observed Counts

Black: Expected Profile for a Point Source

Spatially Extended!!

SNR W51C

- ROSAT X-ray (color), VLA (contours)



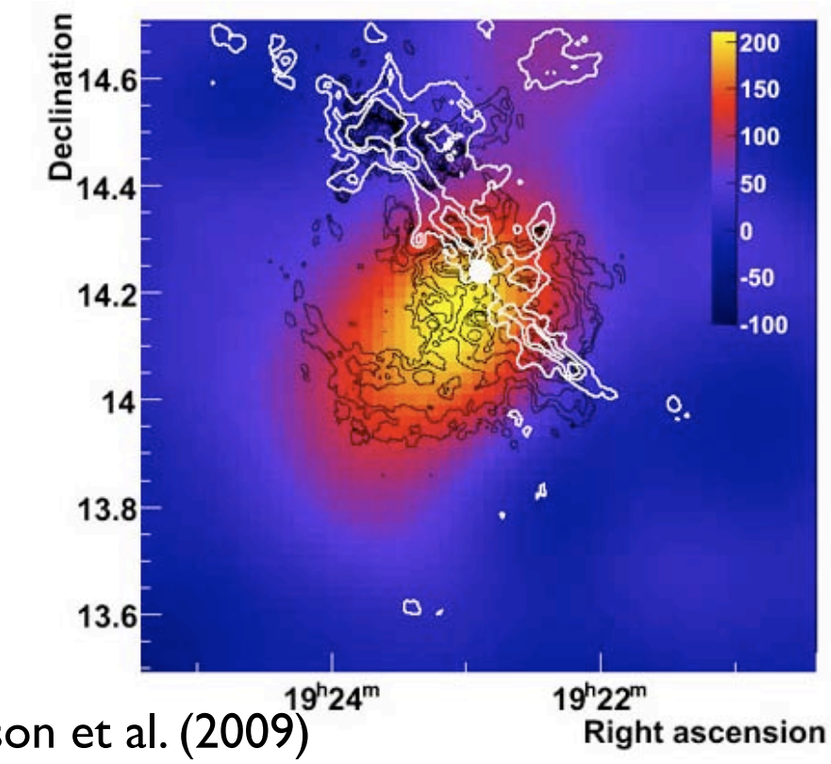
Koo et al. (2002)

Star-forming region W51B overlaps with SNR W51C
(W51B is likely interacting with SNR W51C)

Supernova exploded in the vicinity of
star-forming regions (?)

- D ~ 6 kpc, Age ~ 20000 yrs
- Molecular cloud interactions
- SNR diameter ~ 30 arcmin
  ... may be extended for LAT at high energies
- very large: 90 pc x 70 pc

- Very recent **HESS** detection

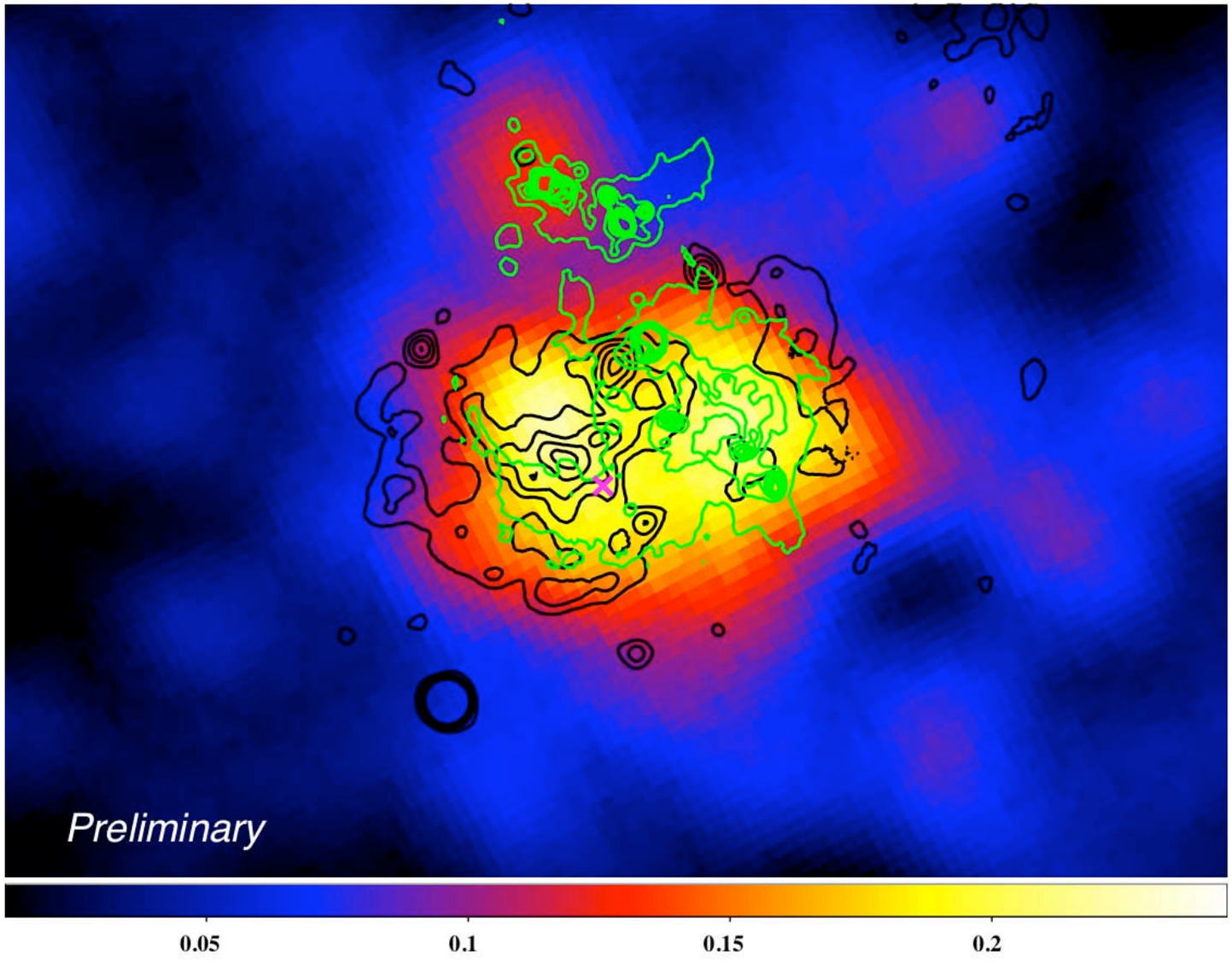


Fiasson et al. (2009)

Fig. 2: *VHE gamma ray image, with the 11 cm radio contours superimposed in black (from Moon & Koo 1994), and 13CO radio emission contours tracing molecular clouds superimposed in white (from Jackson et al. 2006). The filled white circle shows the location of OH maser emission (Green et al. 1997).*

W51C Image

Color: Fermi LAT counts map (2-8 GeV)
Black contours: ROSAT X-ray map (0.1-2.4 keV)
Green contours: VLA 1.4 GHz



X : CXOJ192318.5+140305 (a neutron star?)

X-ray:

- Thermal emission by shock-heated plasma (kT=0.2 keV)
- Central region due to cloud evaporation?

Radio:

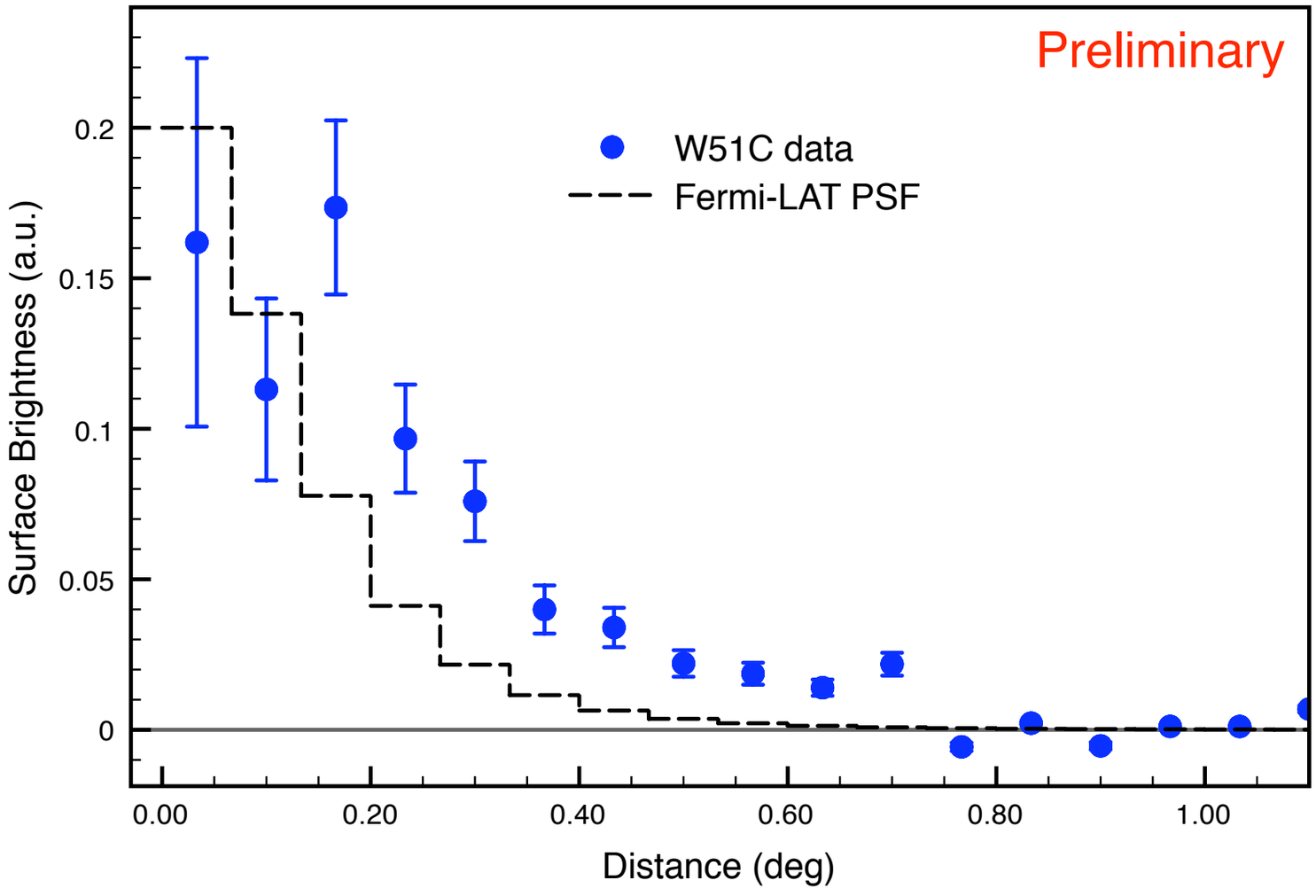
- Peaks are HII regions
- Synchrotron radiation of SNR W51C is well matched with thermal X-ray emission

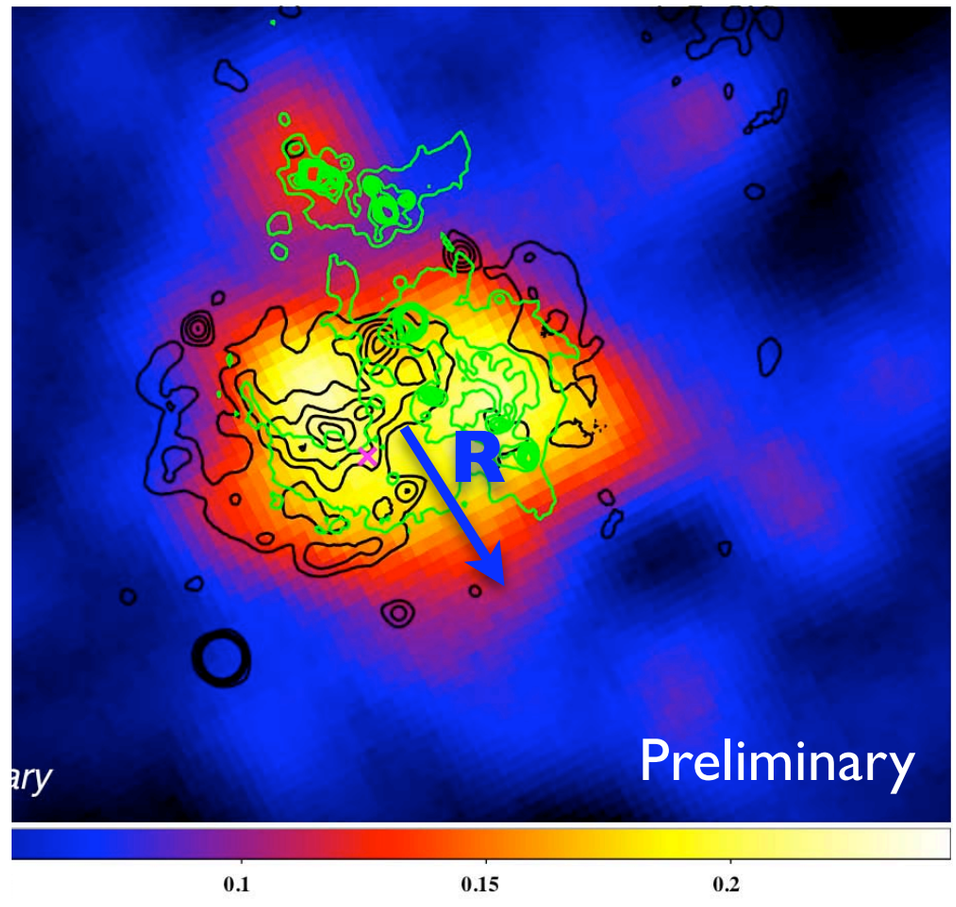
GeV Gamma-ray:

- Origin?
- Very large luminosity (~ 4×10^{35} erg/s) using 6 kpc

Spatial Extent?

- 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)





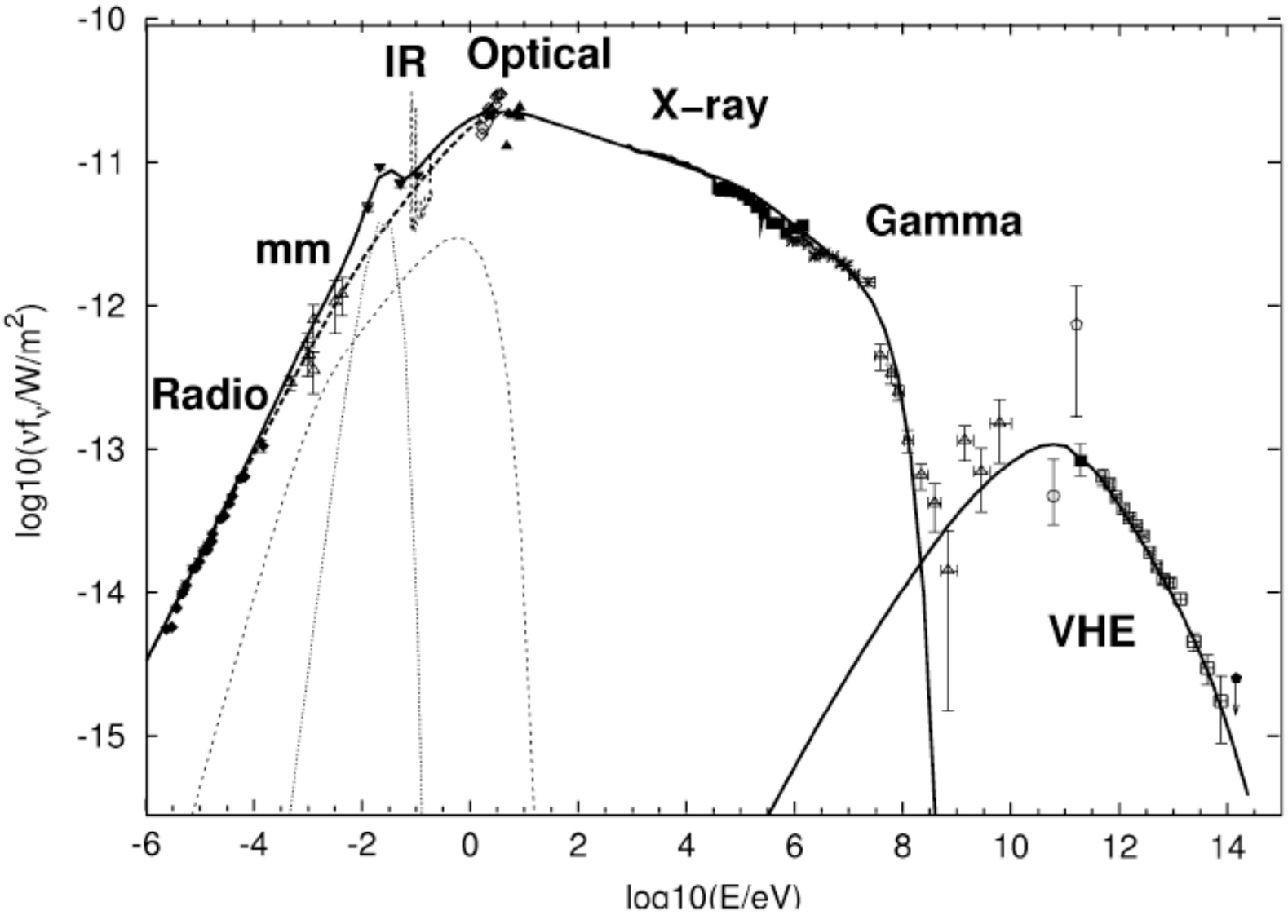
(NOTE) PSF of Fermi LAT depends heavily on energy. The PSF shape is obtained by taking account of energy distribution.

Spatially Extended!!

Crab Nebula

EGRET observations of synchrotron/ inverse Compton spectrum in the 70 MeV–30 GeV energy band

Large uncertainties on the spectral shape for both components



Spectral energy distribution of the Crab nebula
Horns & Aharonian (2004)

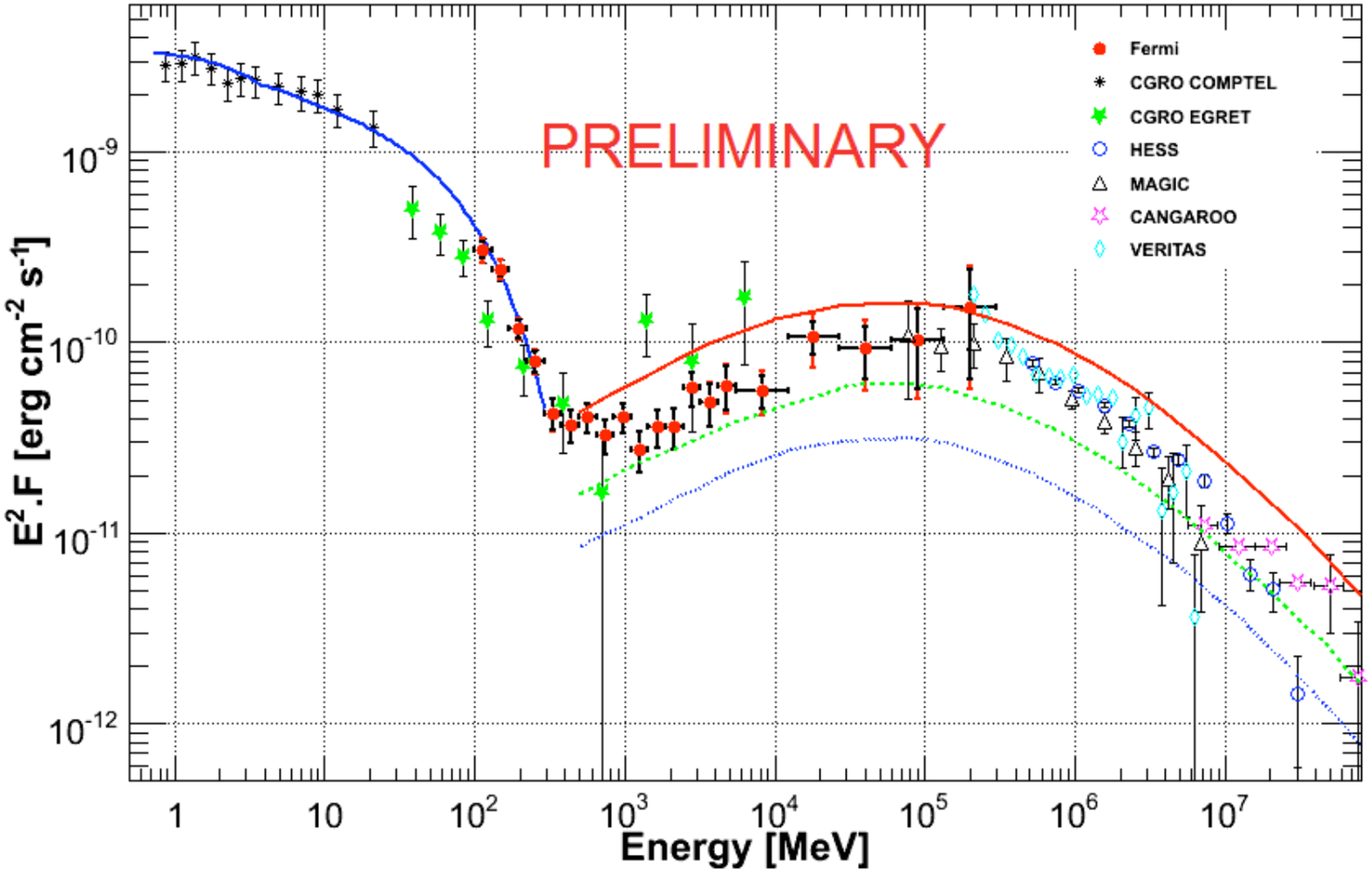
Crab Nebula

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 & Aharonian (1996) for different nebular mean magnetic fields, the results obtained by the LAT and ground based telescopes are consistent with 100 μG < B < 200 μG

Joint fit (using LAT and Cherenkov results) could be performed with more data



Prediction
by Atoyan & Aharonian (1996)

100 μG

200 μG

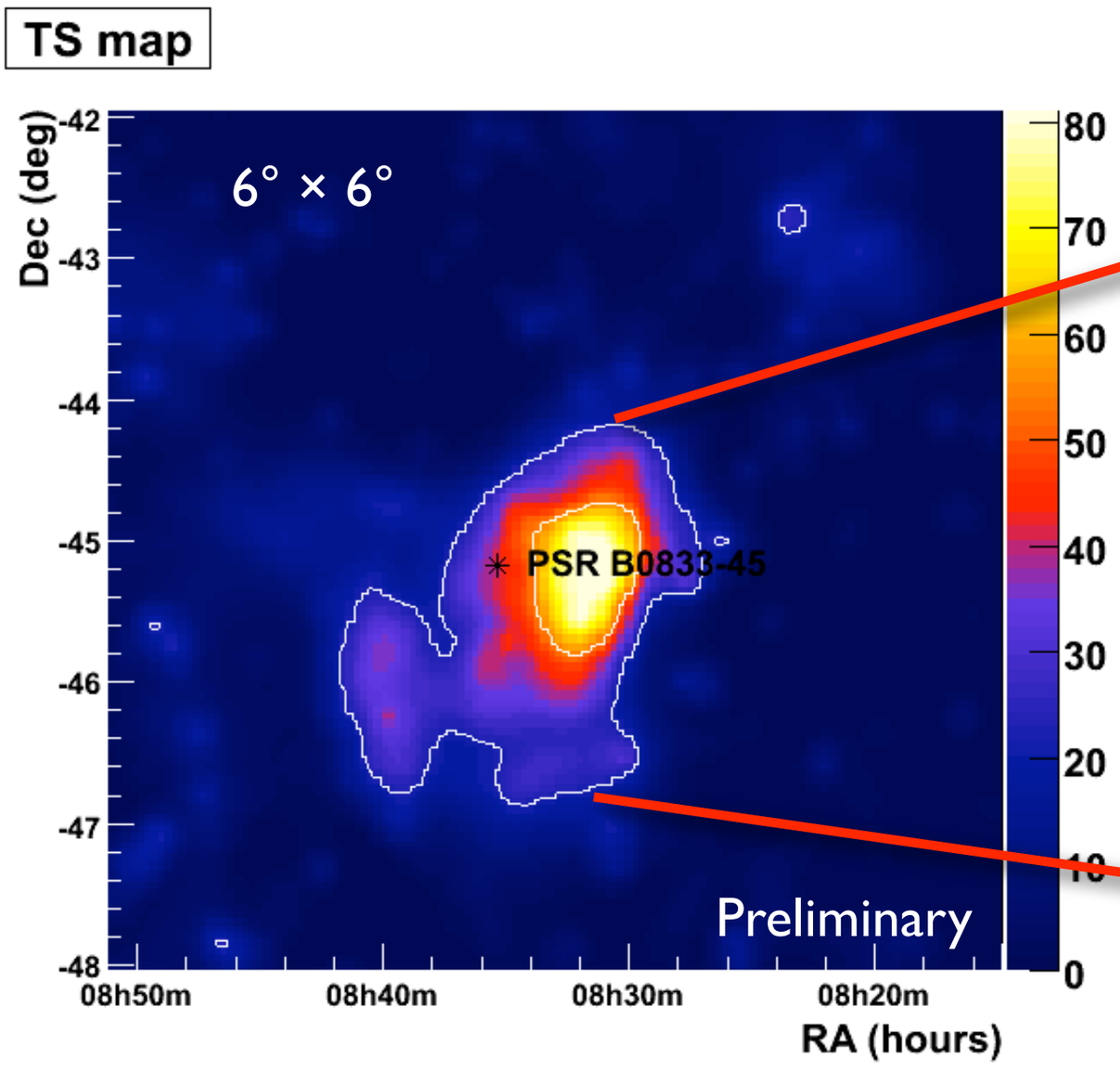
300 μG

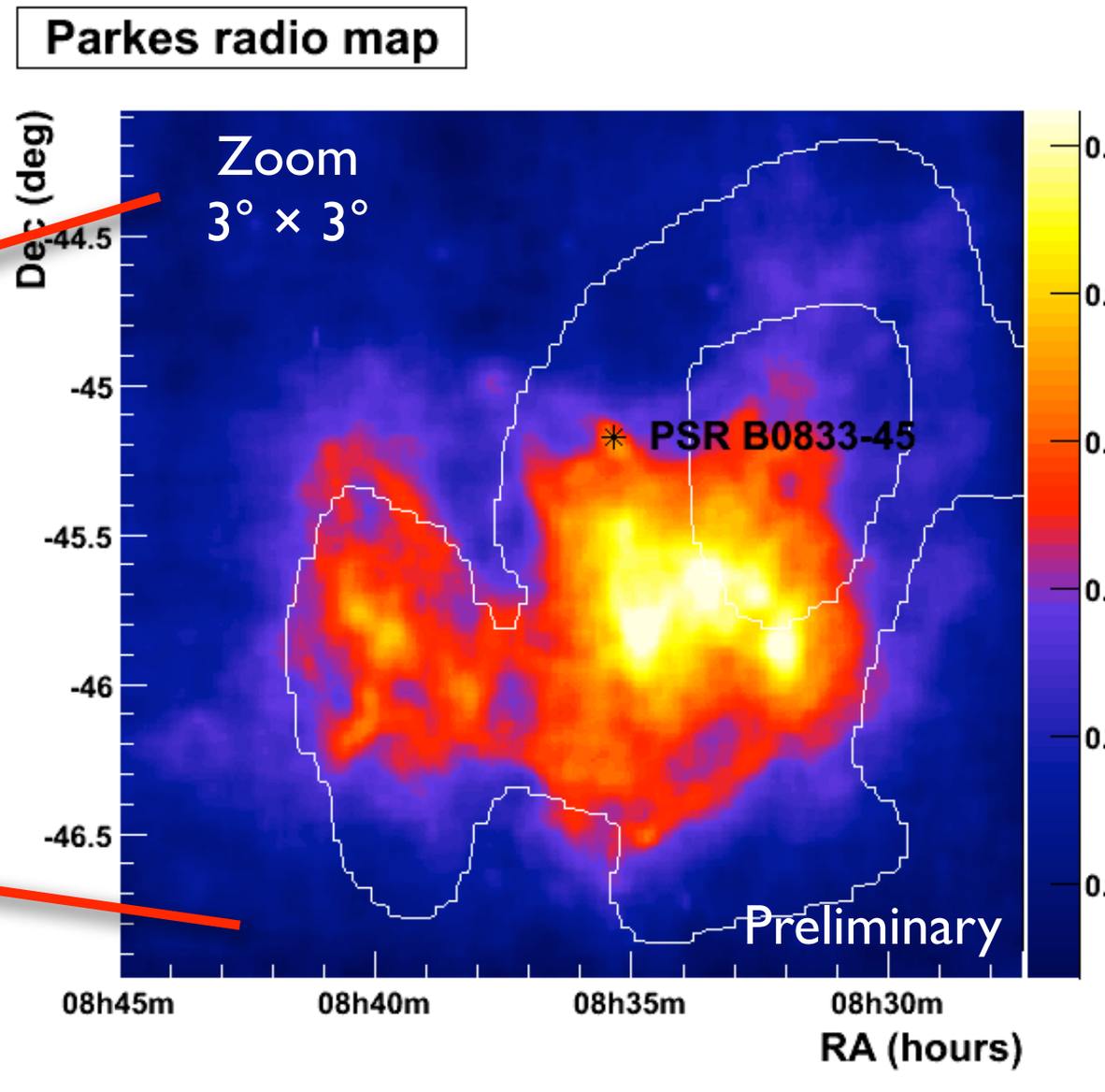
Vela X Region

Using 9 months of survey data with Fermi-LAT and the off-pulse events:
TS ~80 (i.e ~9 sigma) 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)

Parkes radio map at 8.4 GHz
Fermi-LAT contours superimposed (white)

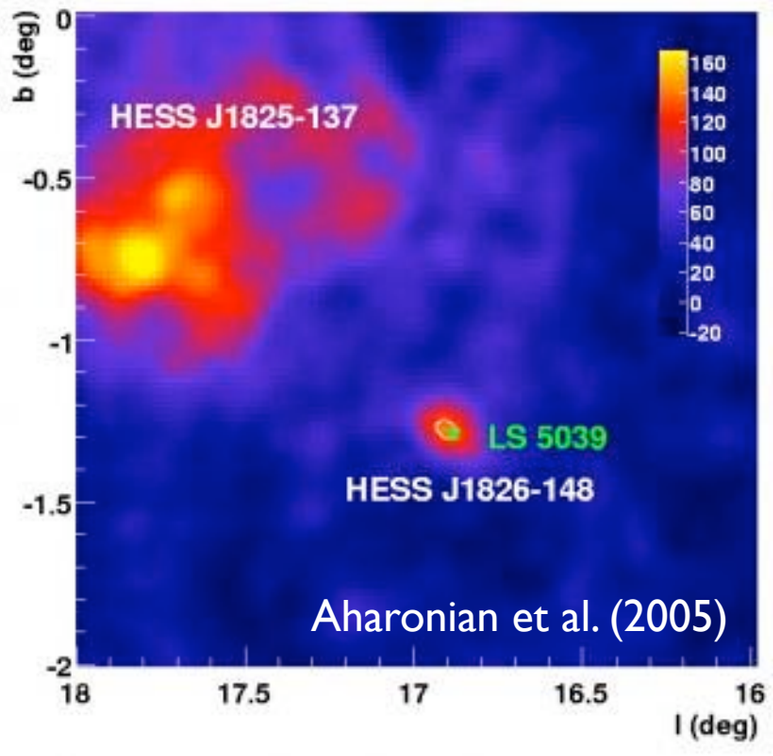




Gamma-ray Binaries

Four X-ray binaries are claimed as TeV emitters
(LS 5039, LS I +61° 303, PSR B1259–63, Cyg X-1)
+ HESS J0632+057?

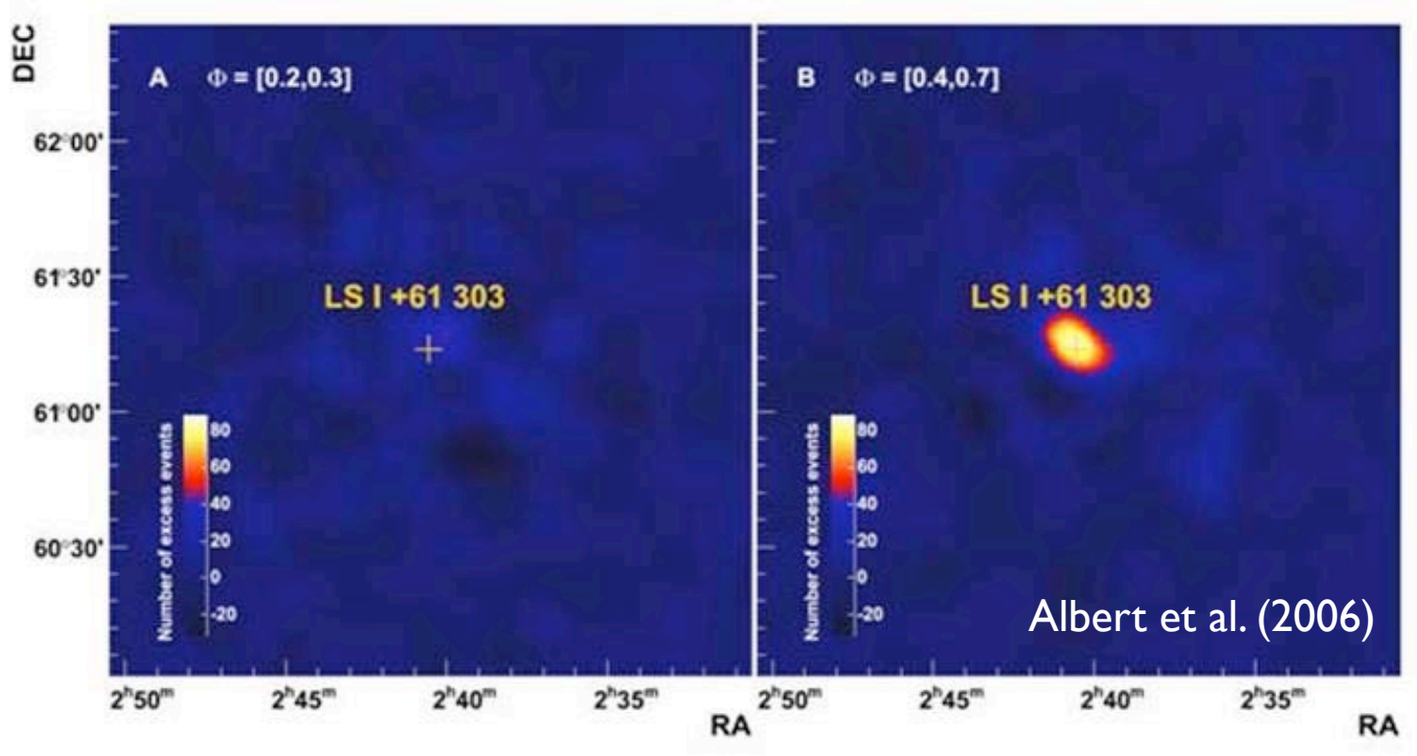
LS 5039



Aharonian et al. (2005)

O star + ?
H.E.S.S. detected
Periodicity

LS I +61° 303



Albert et al. (2006)

Be star + ?
MAGIC & VERITAS detected
Periodicity

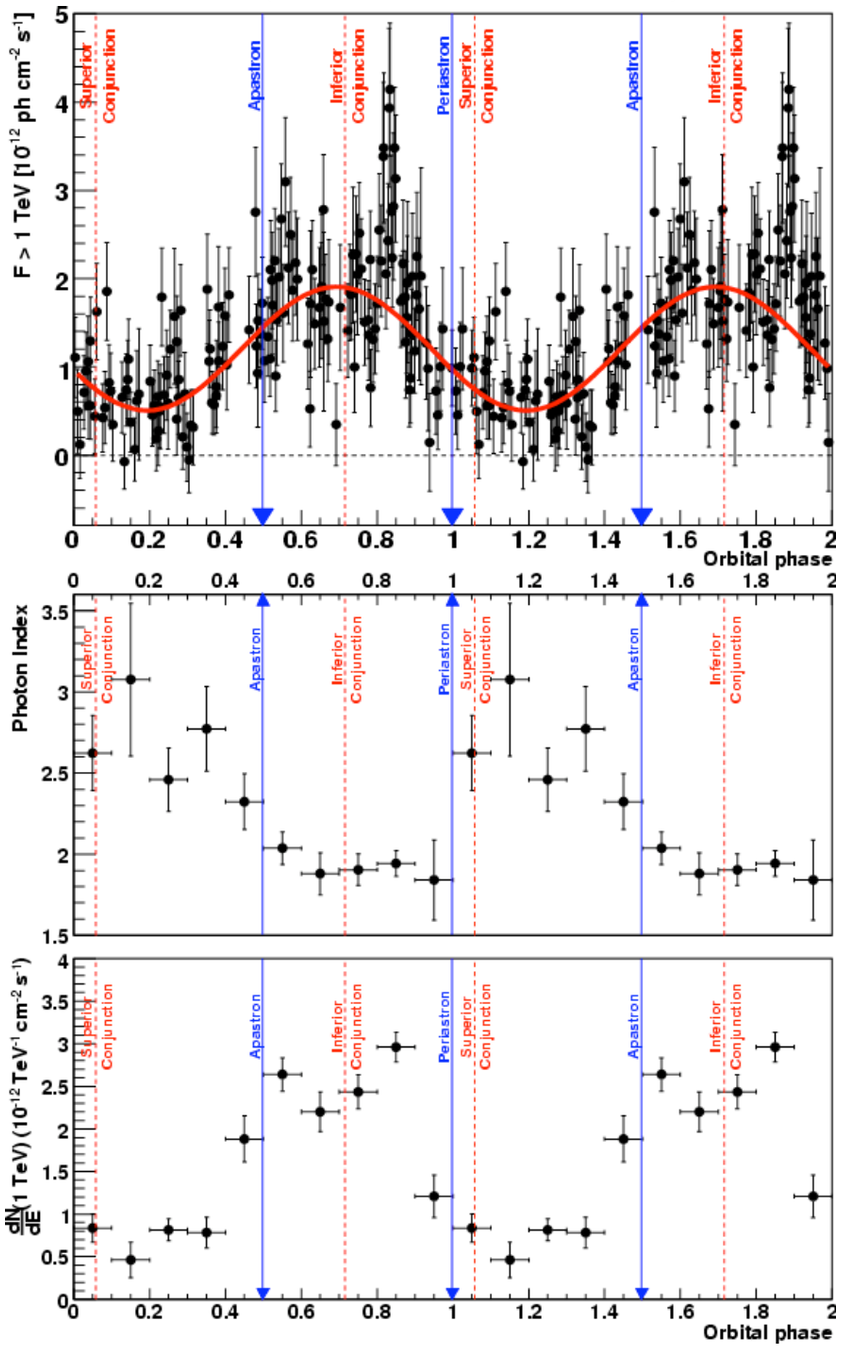
Periodic Behavior in TeV

Gamma-ray Space Telescope

LS 5039

P = 3.9 days

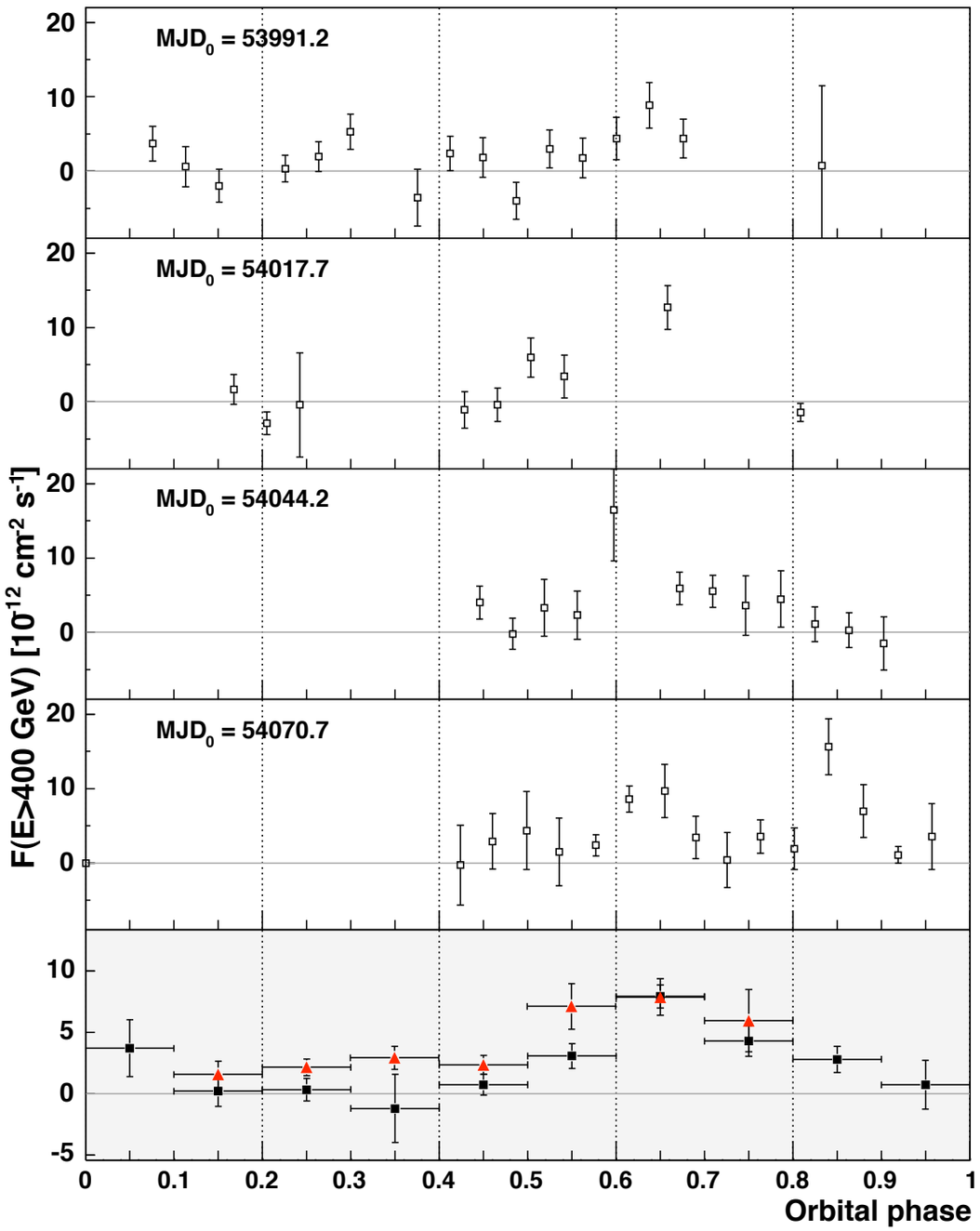
H.E.S.S. (Aharonian et al., 2006)



LS I +61° 303

P = 26.5 days

MAGIC (Albert et al., 2008)

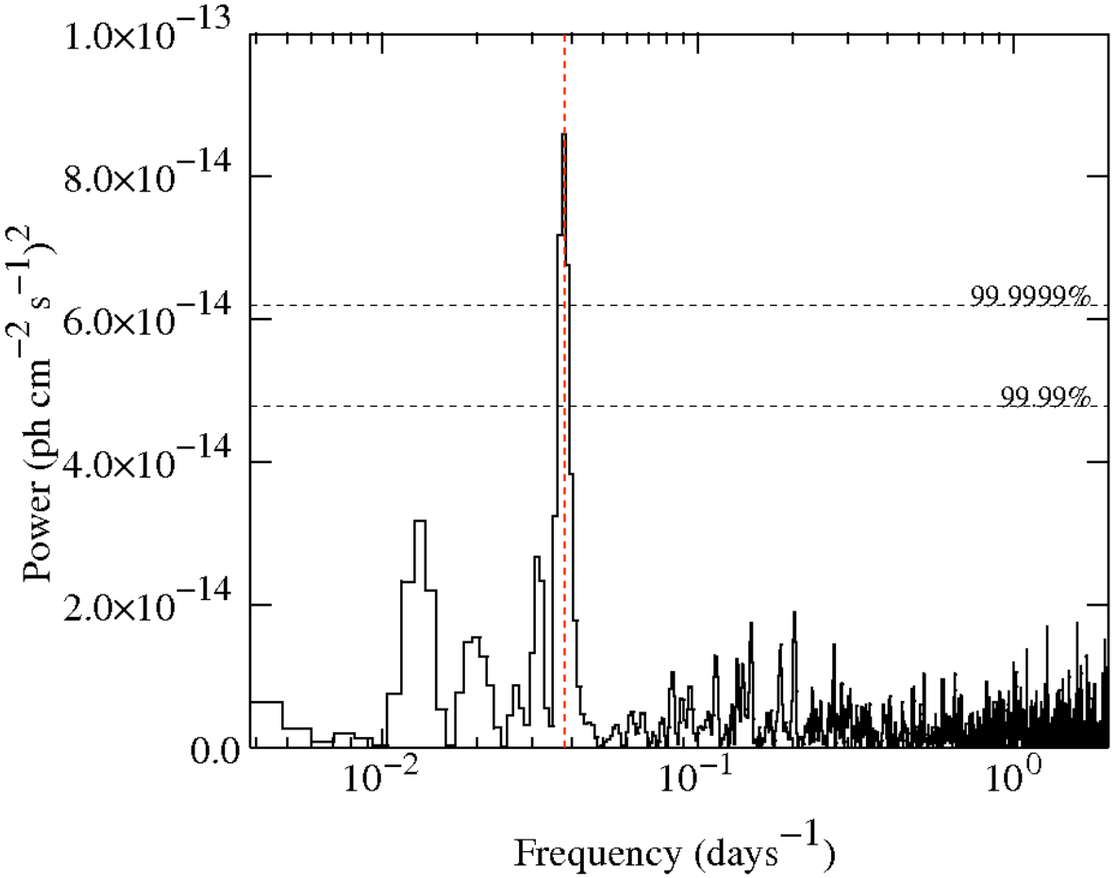


Periodic behaviors reflect geometry & physical processes in the binary systems

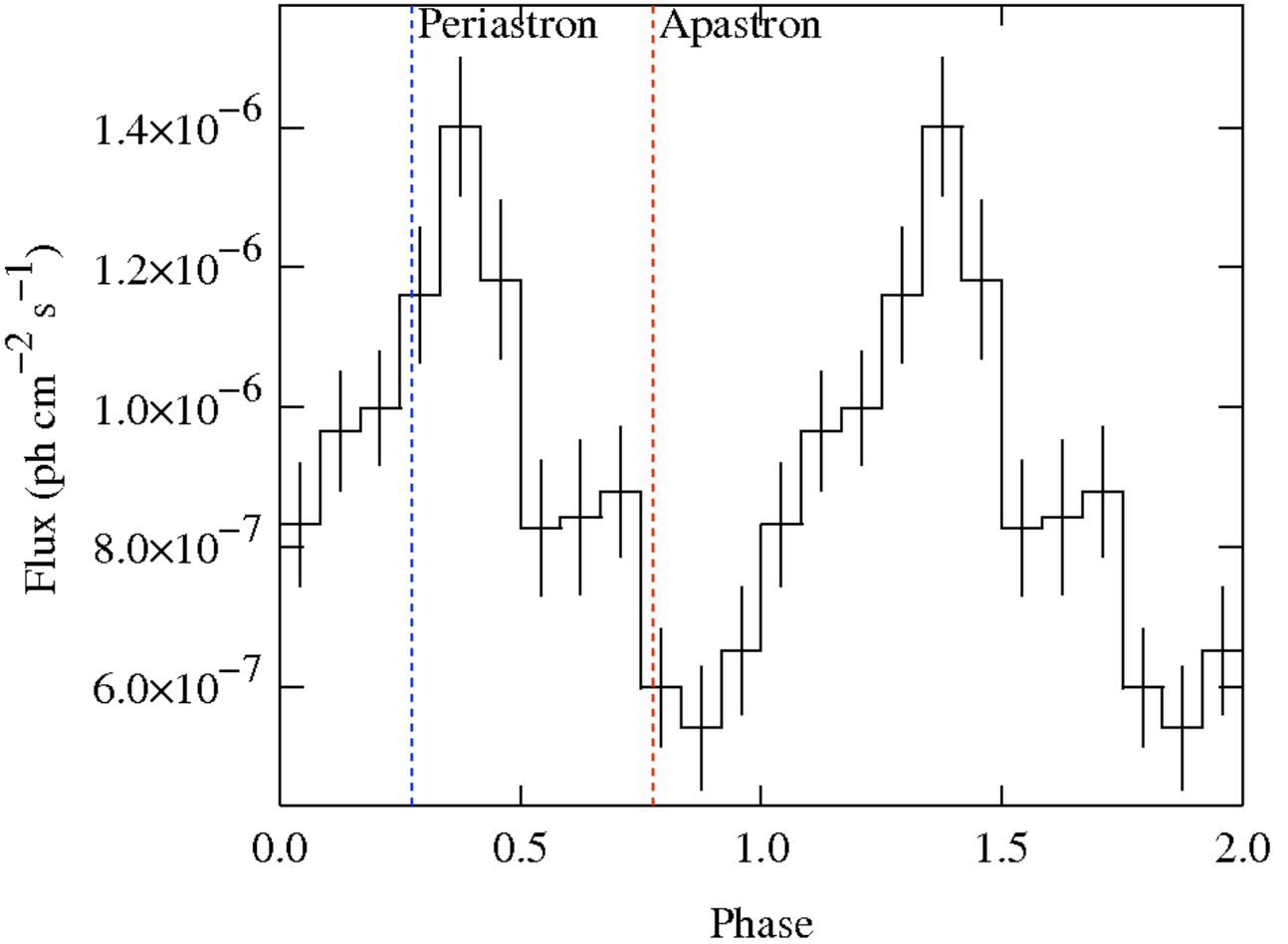
LS I +61° 303

- First detection of orbital periodicity in GeV
- Period = 26.6 ± 0.5 days (consistent with know period; Gregory et al. 2002)
- Highest flux around periastron
- Spectral shape does not significantly change across the orbit

Periodogram



Folded Light Curve



LS I +61° 303

Phase-averaged Spectrum

Simple power law rejected

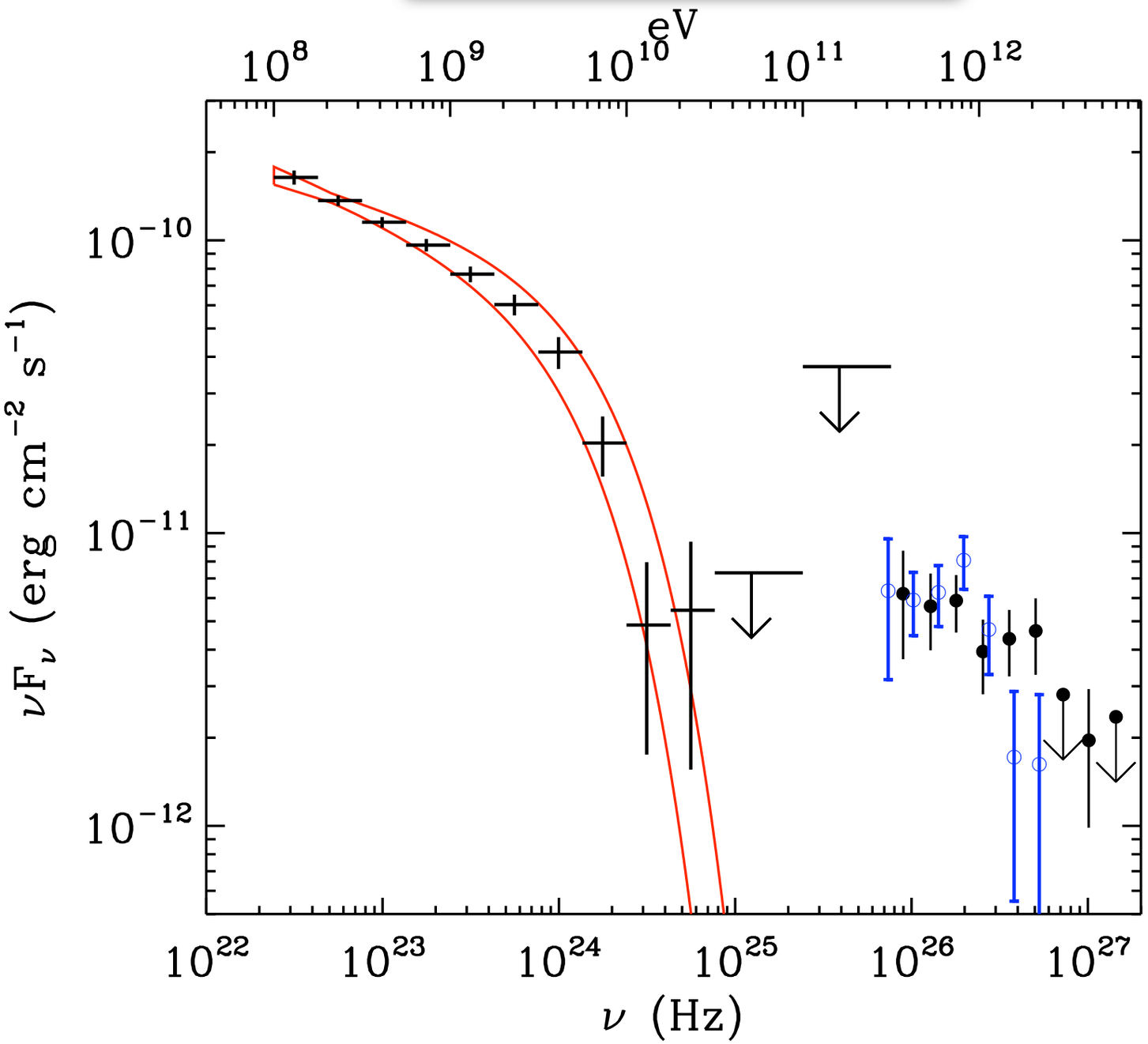
Results of fit with exponential cutoff PL fit:

$$dN/dE = A\ E^{-\Gamma} \exp(-E/E_c)$$

Flux (> 100 MeV) = (0.82 ± 0.03 (stat) ± 0.07 (sys)) × 10^{-6} [ph cm^{-2} s^{-2}]

Γ = 2.21 ± 0.04 (stat) ± 0.06 (sys)

Ec = 6.3 ± 1.1 (stat) ± 0.4 (sys) [GeV]

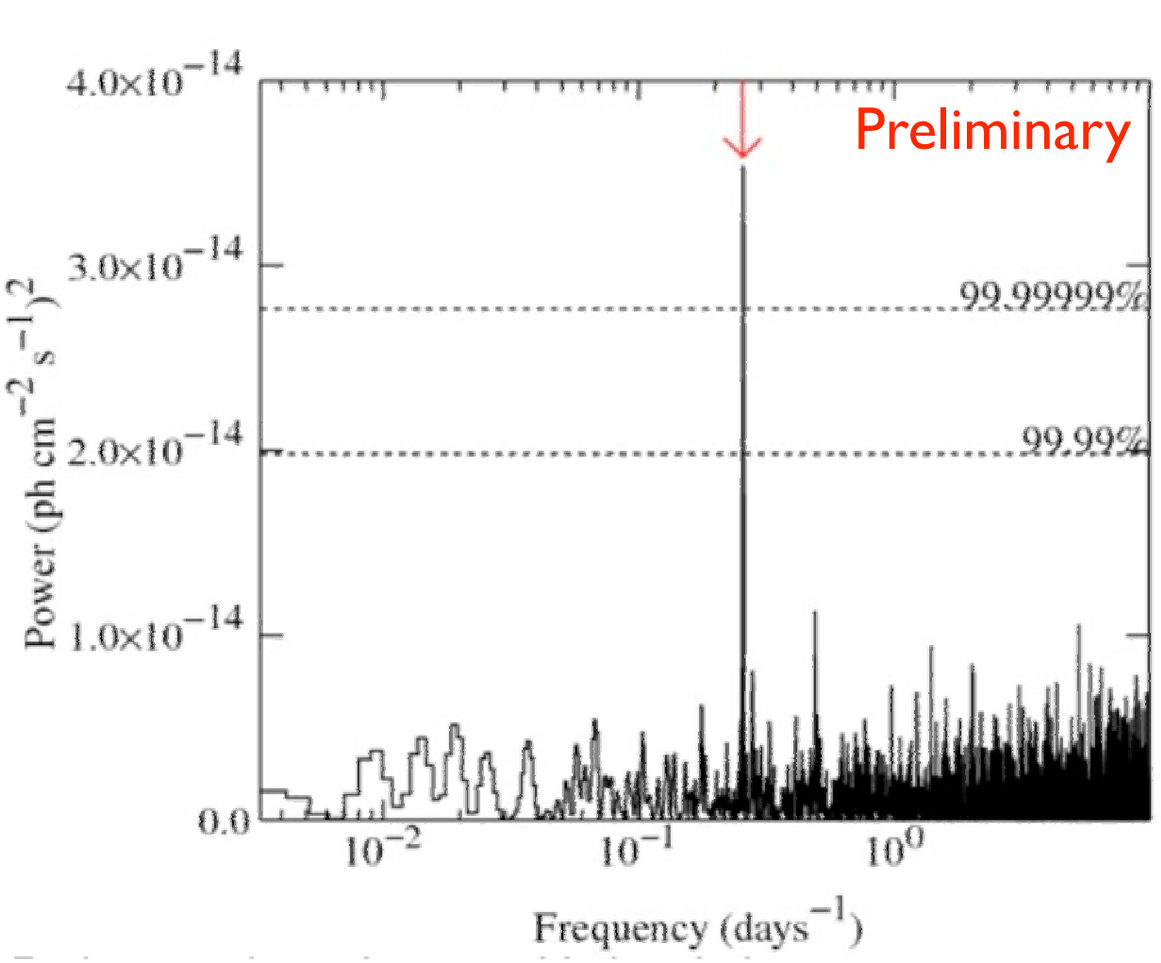


TeV data points:
VERITAS (black circle; phase 0.5–0.8)
MAGIC (blue; phase 0.5–0.7)

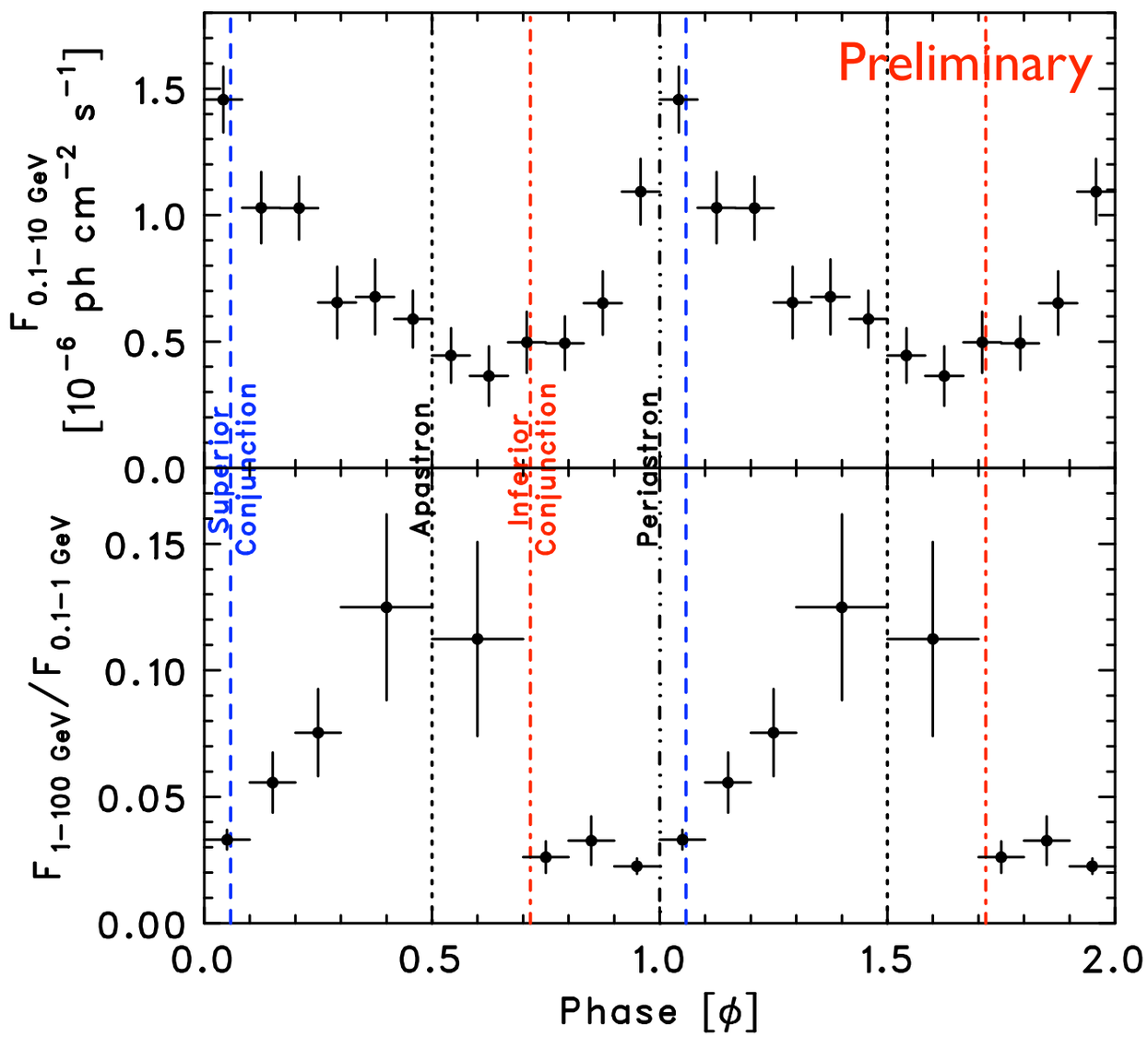
LS 5039

- Detection of orbital periodicity
- Period = 3.903 ± 0.005 days (consistent with know period; Casares et al. 2005)
- Highest flux around periastron
- Spectral shape changes across the orbit

Periodogram



Folded Light Curve



Summary

- Fermi-LAT detected spatially extended emission from SNRs (W44, W51C, & IC 443)
- Detailed spectral study of Crab nebula between 100 MeV and 300 GeV, covering both synchrotron and inverse Compton components
- Spatially extended emission from the Vela X region
- Detection of periodicity from two gamma-ray binaries
- Many papers have been or will soon be submitted