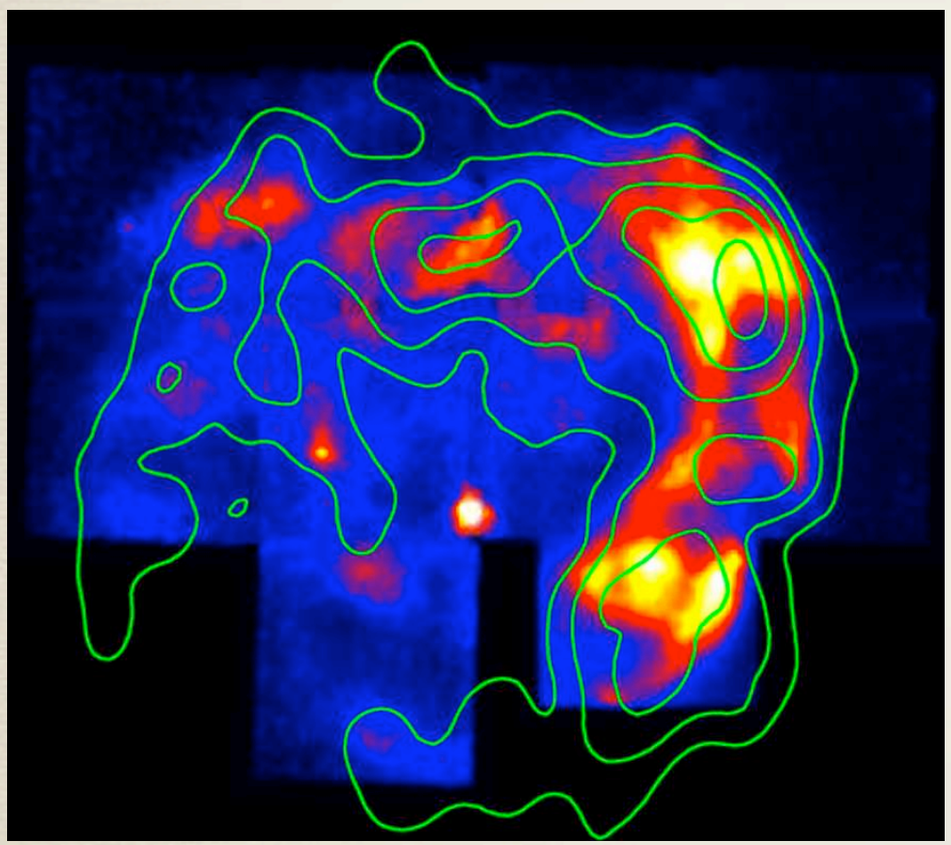
FERMI-LAT STUDY OF SUPERNOVA REMNANTS

Y. Uchiyama (SLAC)
on behalf of the Fermi LAT collaboration

CR Acceleration in Young SNRs

- **Diffusive Shock Acceleration** (1st order Fermi Acceleration) at expanding supernova shells is the most-favored explanation for **the origin of galactic cosmic rays (CRs).**
- Significant progress in recent years by **keV** and **TeV** observations of **young** SNRs.

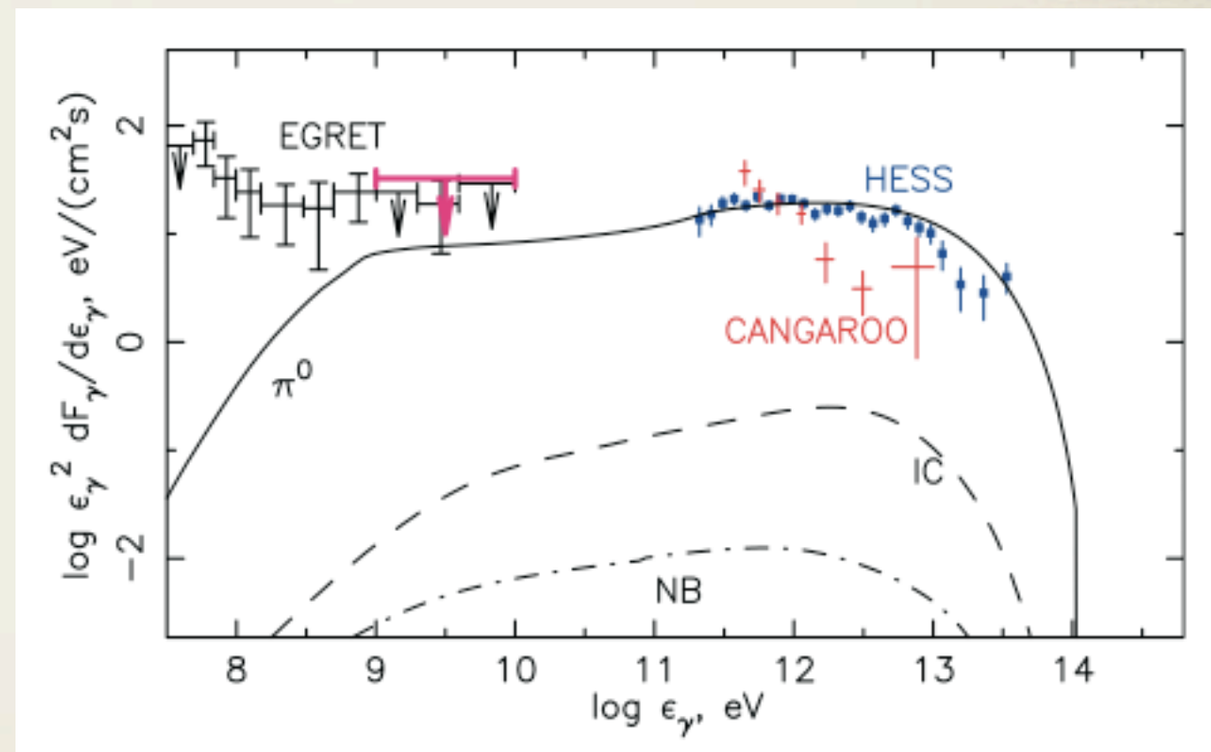
SNR RXJ1713.7-3946



X-ray (Suzaku) vs TeV (HESS)
Tanaka+2008

Non-linear Acceleration

Berezhko&Völk 2006

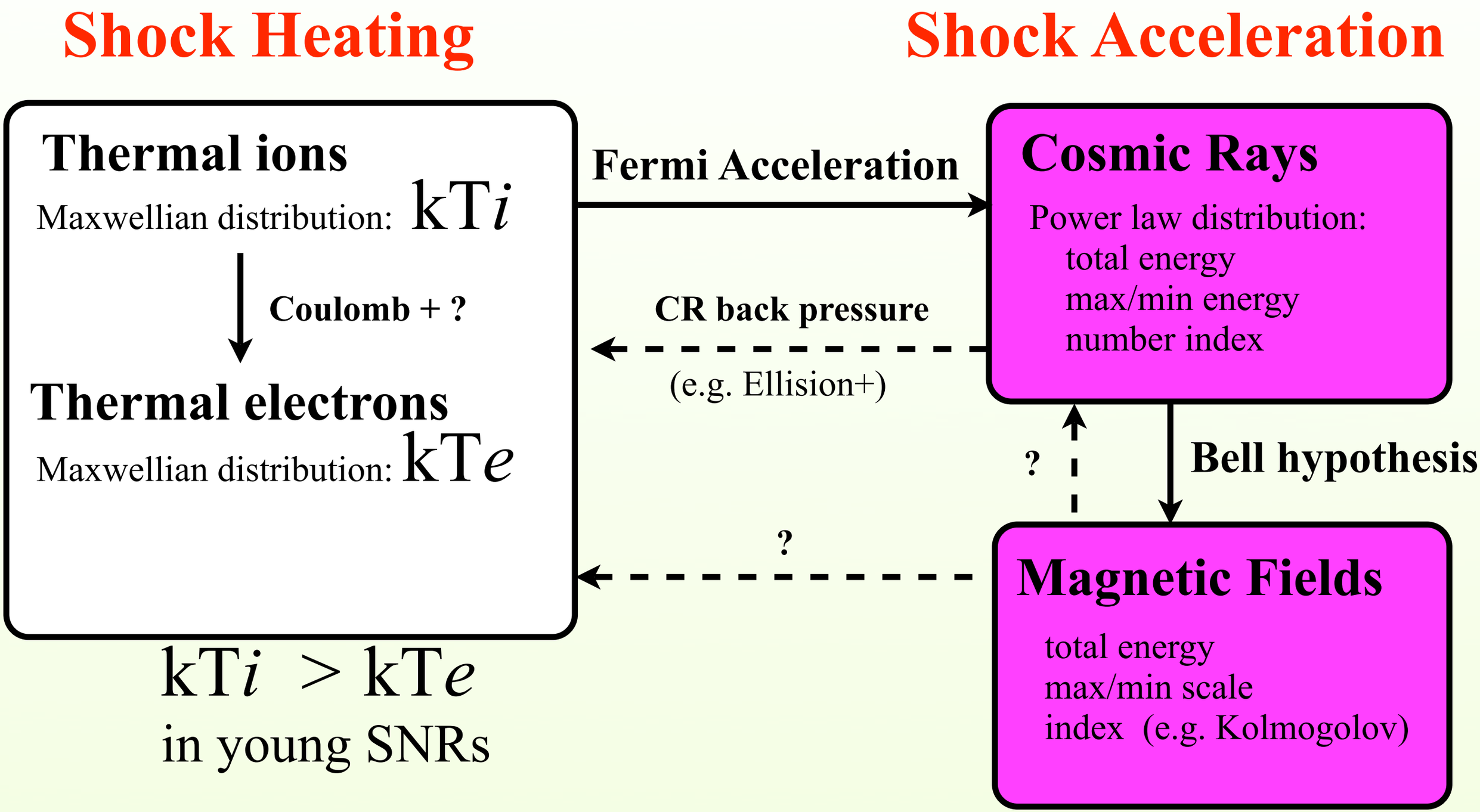


Synchrotron X-ray variability : B ≈ 0.1 - 1 mG
Uchiyama+2007

Filament width : B ≈ 0.1 mG

Gamma-ray emission mechanism is under active debate.

Collisionless Shock in SNRs



$kTi > kTe$

in young SNRs

Calculations from "first principle": not available

We need Experiments (Observations)!!

3

Indirect Evidence of CR Dominance

SNR RCW 86 (The remnant of SN AD 185)

Helder+2009

VLT (Hα filaments)

Line width gives a post-shock temperature of

2.3±0.3 keV

Chandra (Synchrotron X-ray)

Proper motion predicts a post-shock temperature of

42 - 70 keV

CR pressure seems comparable to thermal pressure

Large amount of shock energy goes to CRs

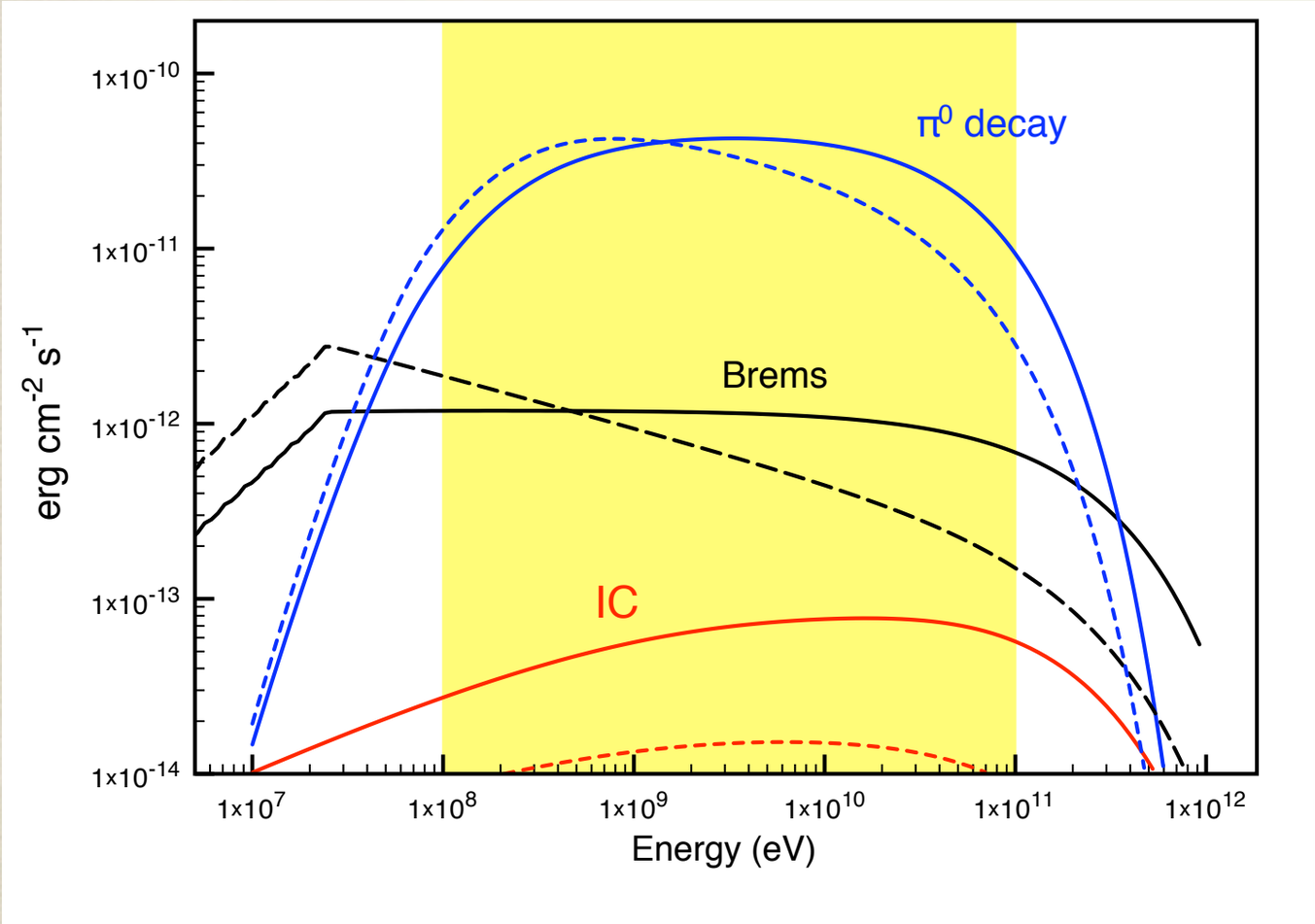
→ Fermi-LAT observations will be able to test this.

Y. Uchiyama, TeVPat 2009

Fermi Study on SNRs

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

(Typical) Gamma-ray Spectrum



- D = 3 kpc
- n = 100 cm^{-3}
- $W_p = 10^{49}$ erg
- $W_e = 10^{47}$ erg
- $E_{p,max} = E_{e,\,max} = 0.5$ TeV
- Particle index = 2.0 (solid)
- Particle index = 2.3 (dashed)

Interaction with molecular cloud enhances Pion-decay/ Bremsstrahlung.

Y. Uchiyama, TeVPat 2009

Fermi-LAT Study towards 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 **51 σ**)

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 **39 σ**)

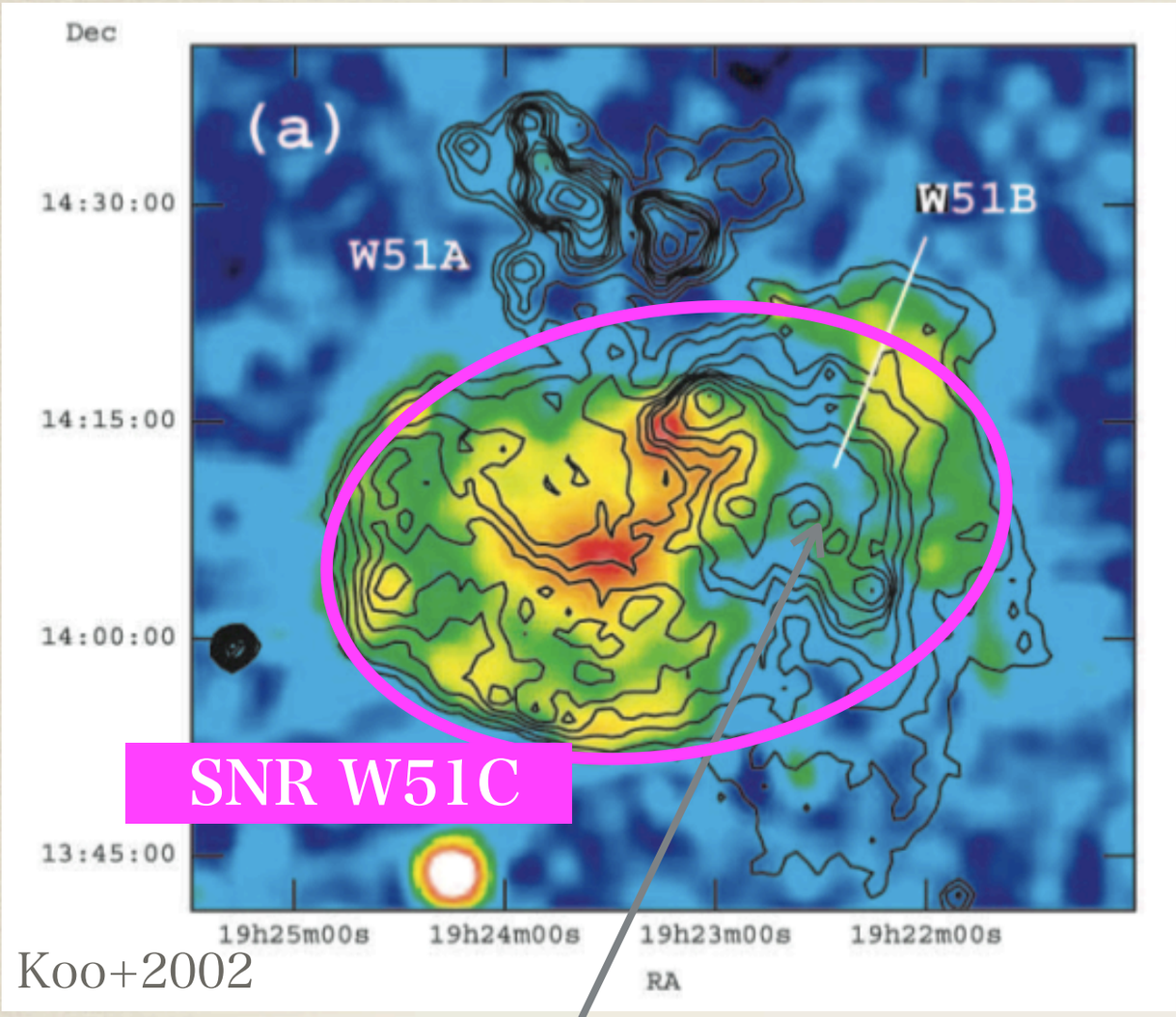
W51C: (Y. Uchiyama on behalf of Fermi LAT at 31st ICRC)

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

Y. Uchiyama, TeVPat 2009

SNR W51C

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



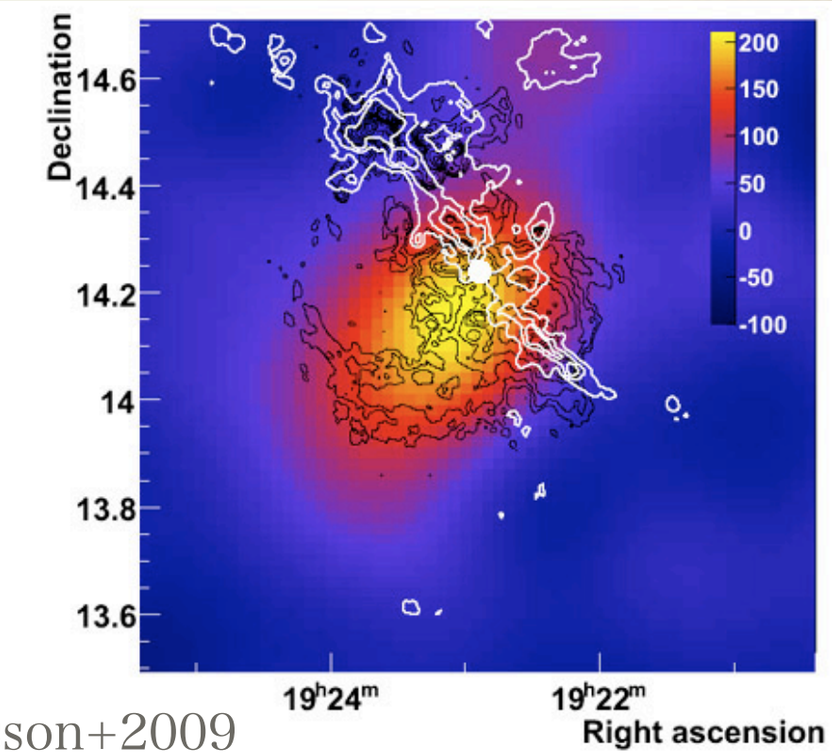
Koo+2002

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



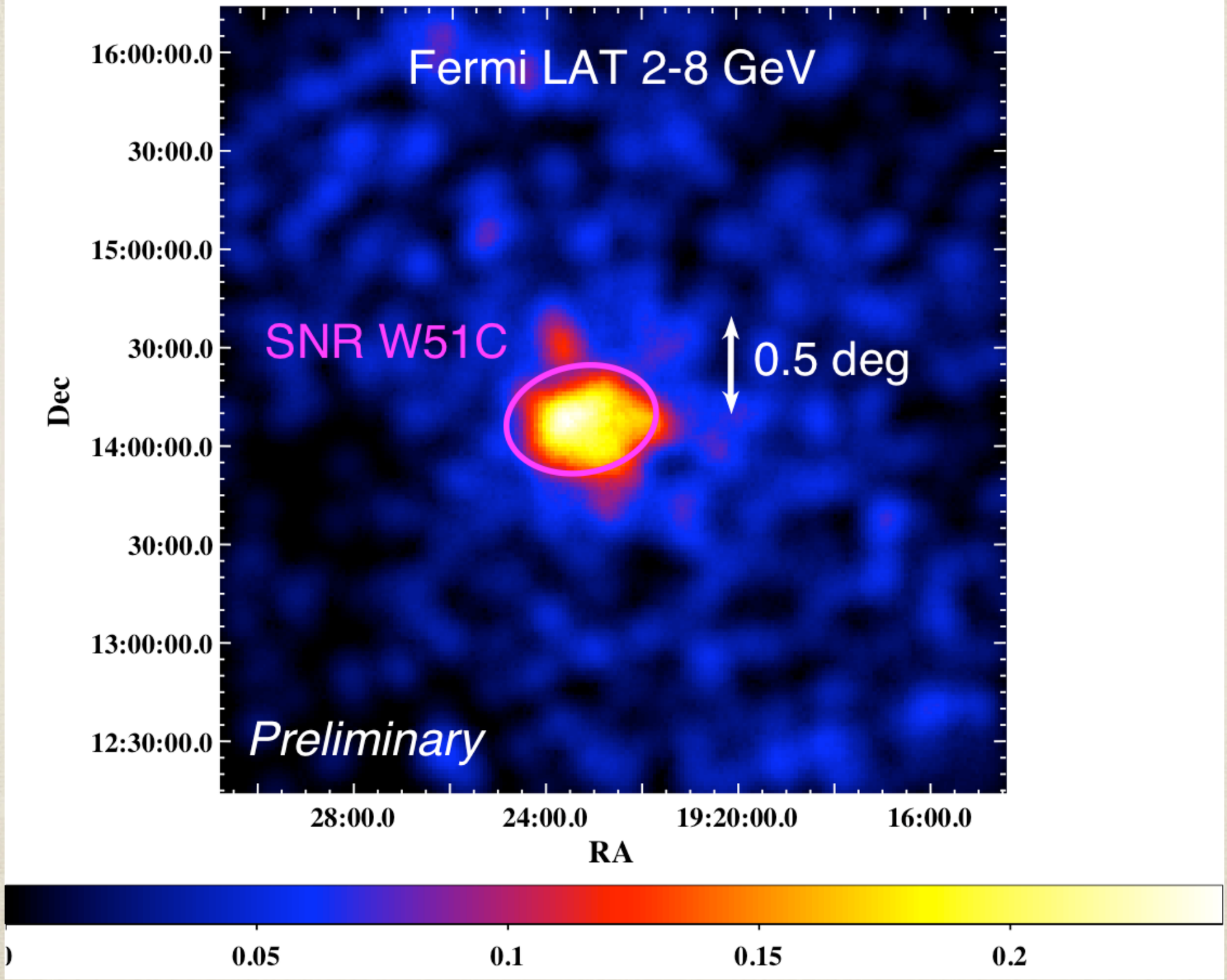
Fiasson+2009

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).

Y. Uchiyama, TeVPat 2009

Fermi View on W51C Region

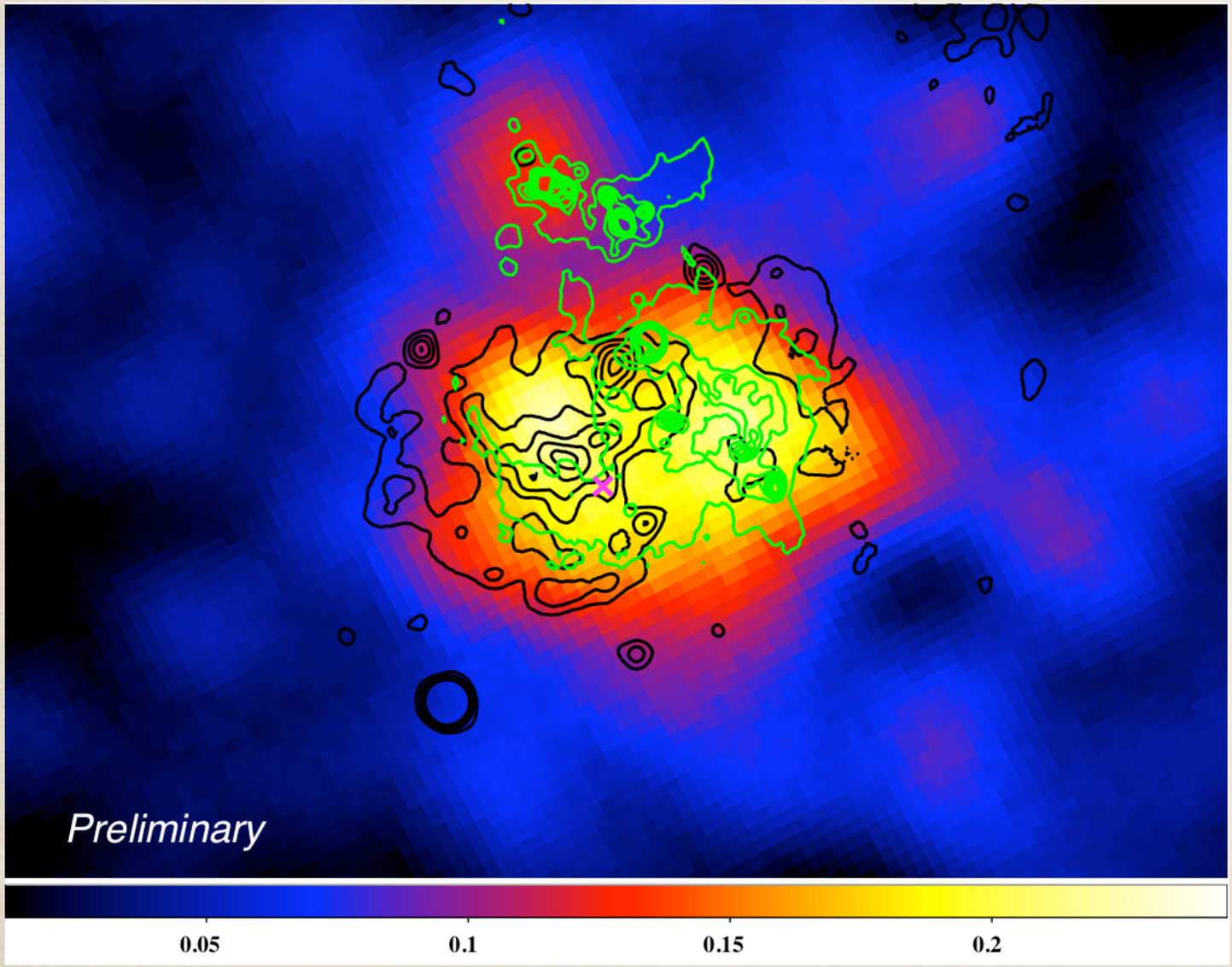
Fermi LAT counts map: very bright (>40 σ) gamma-ray source



Y. Uchiyama, TeVPat 2009

Close-up View on W51C Region

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)
- Cental region due to cloud evapolation?

Radio:

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

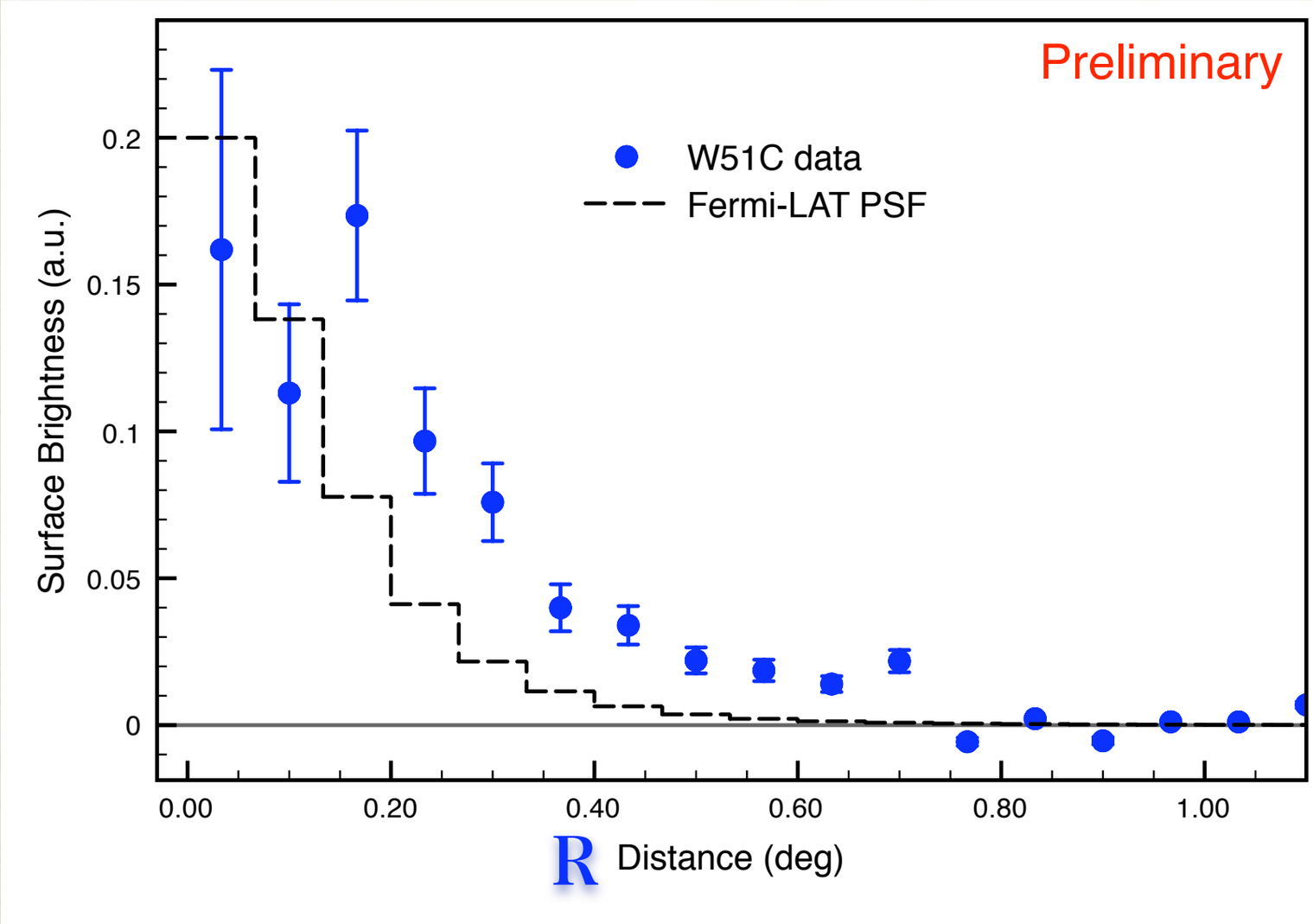
GeV Gamma-ray:

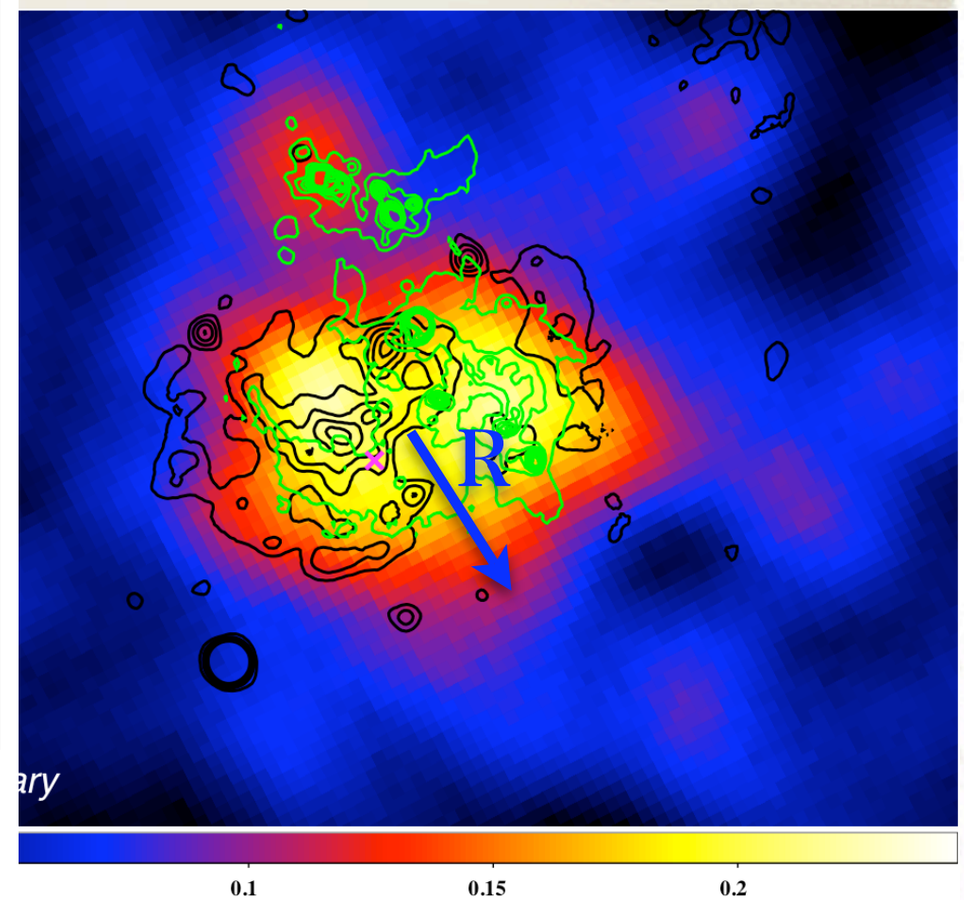
- Origin?
- Very large luminosity (~4×10^{35} erg/s) using 6 kpc

Y. Uchiyama, TeVPat 2009

The Fermi Source is "Extended"

- 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)





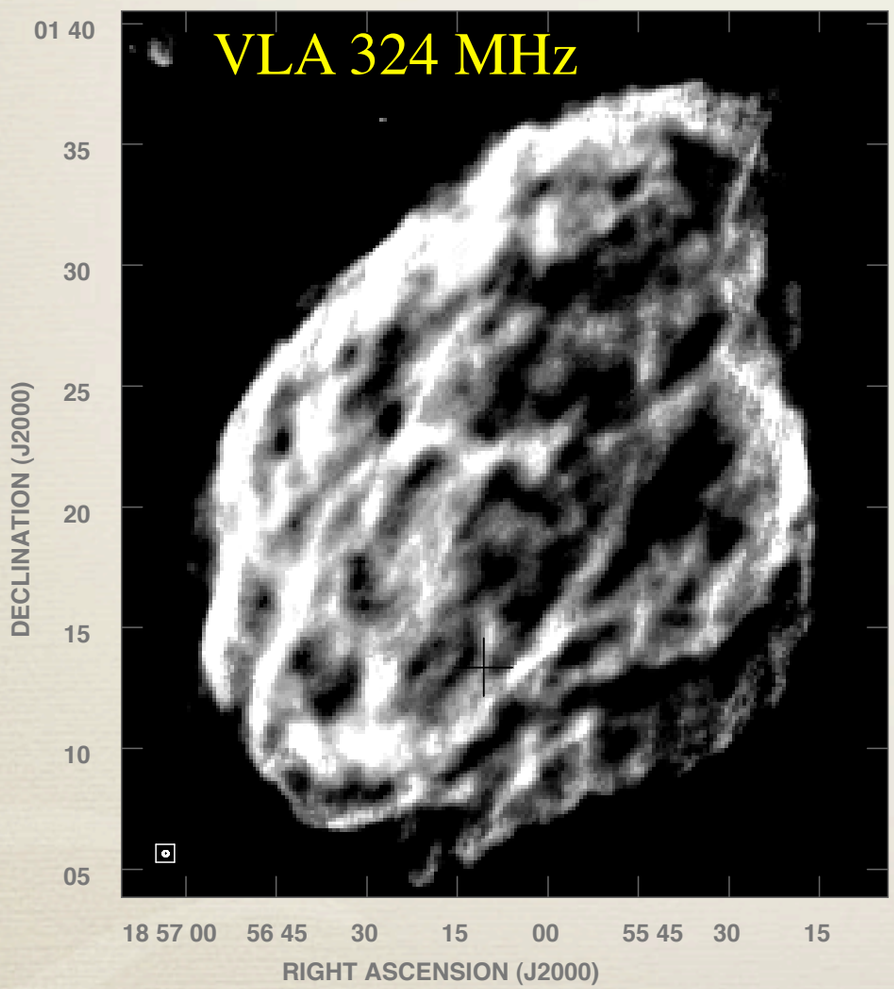
(NOTE) PSF of Fermi LAT depends heavily on energy. The PSF shape is obtained by taking account of energy distribution.

SNR W44

- Middle-aged (~ 2.0×10^4 yr)
- Mixed-morphology SNR (radio: shell, thermal X-ray: centerly filled)
- Distance: ~ 3kpc
- Spatial extent: ~ 35 arcmin × 26 arcmin

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

Filamentary shell structures



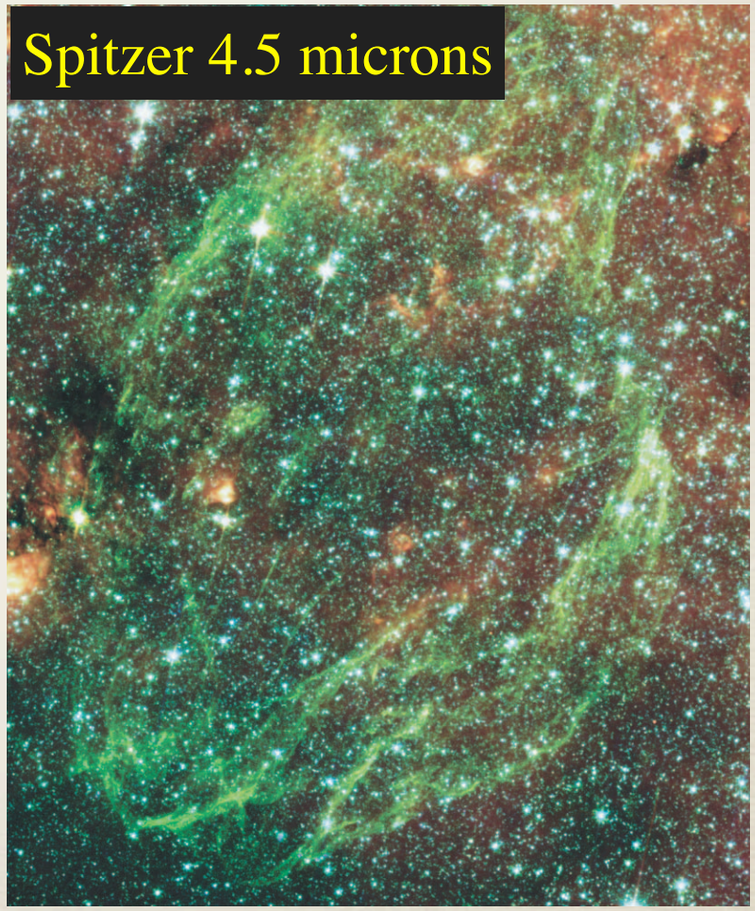
Castelletti+2007

Interactions with a giant molecular cloud

CO (Seta et al. 2004),

OH maser (1720 MHz: Hoffman et al. 2005),

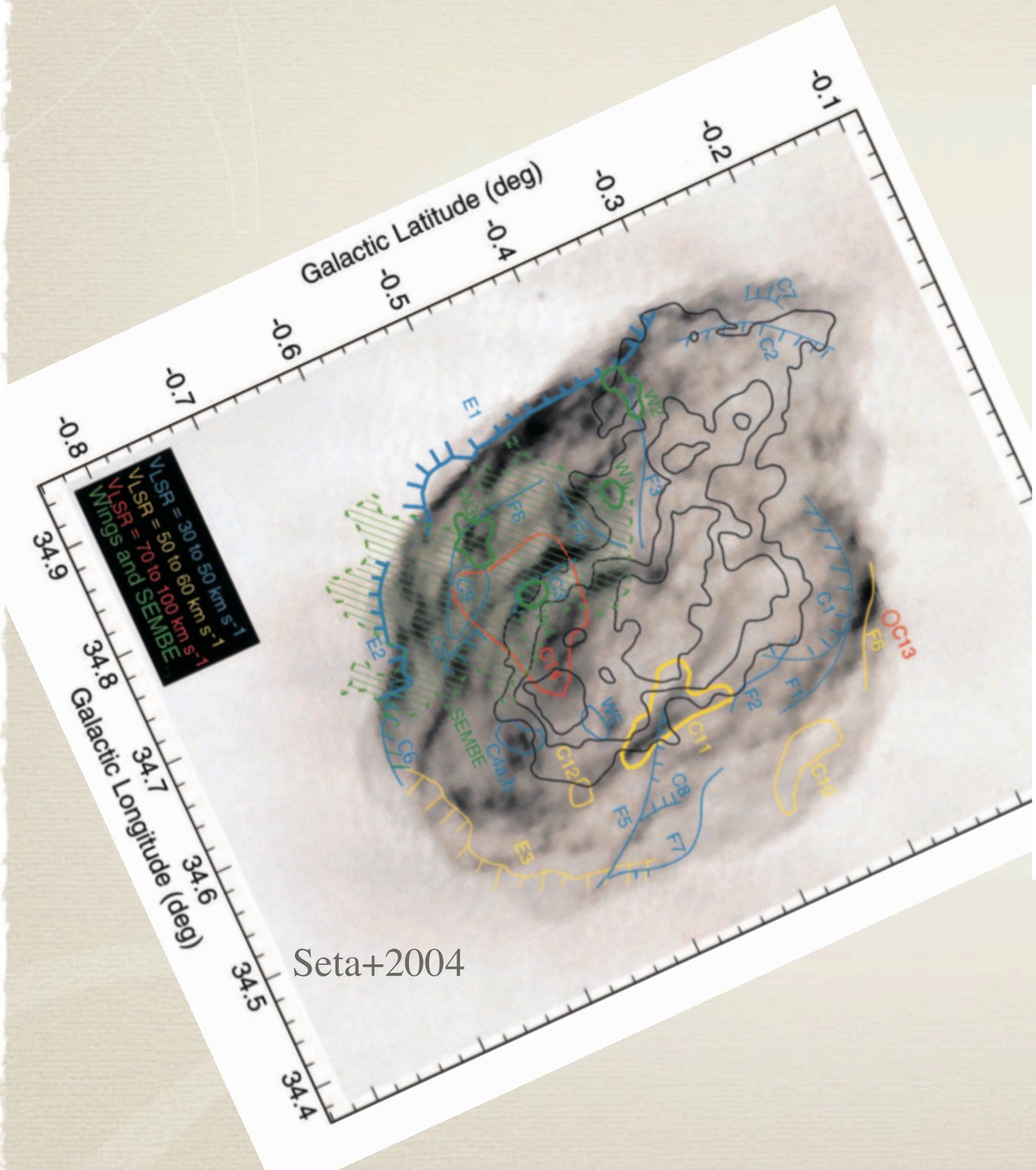
IR(shocked H_2; Reach et al. 2006)



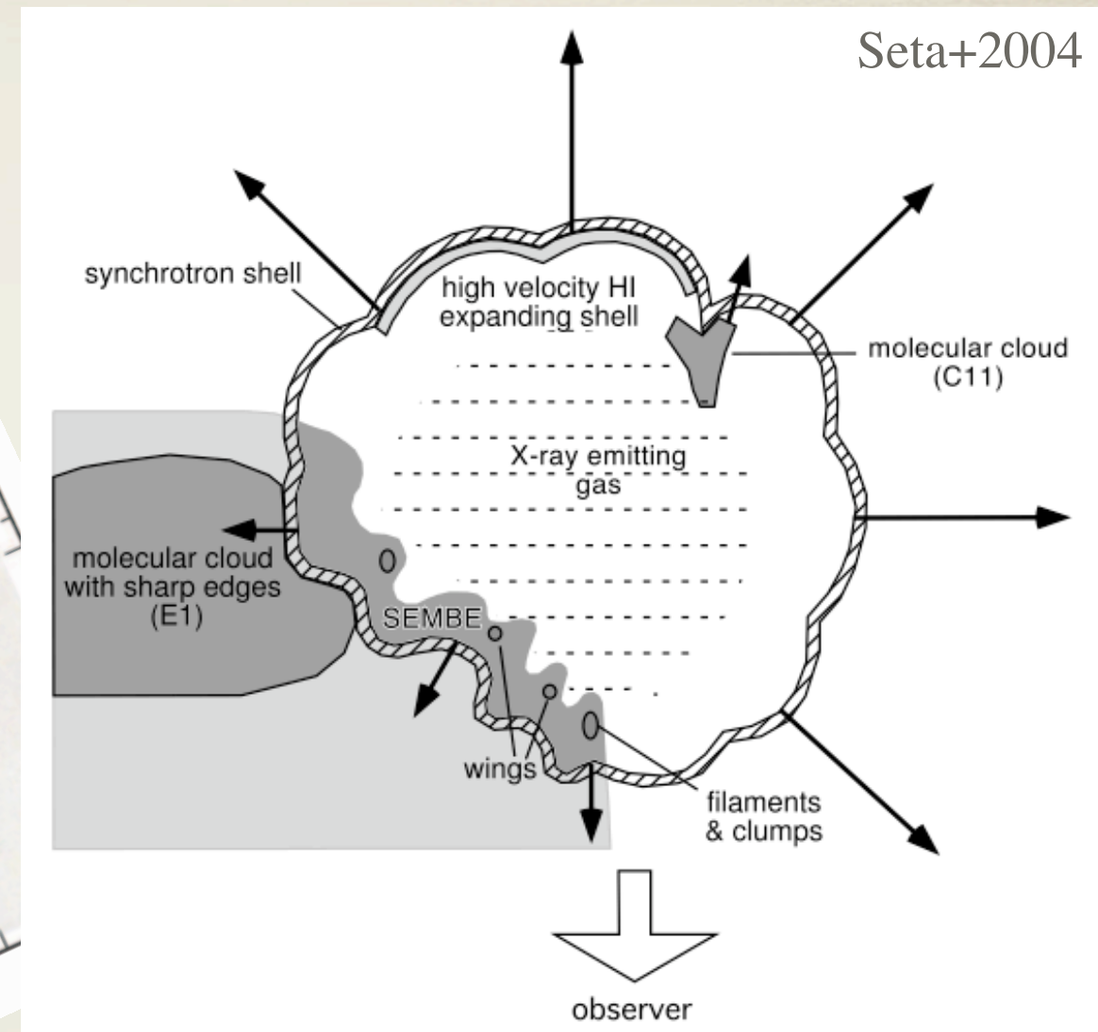
Reach+2006

SNR W44

Interactions with a giant molecular cloud



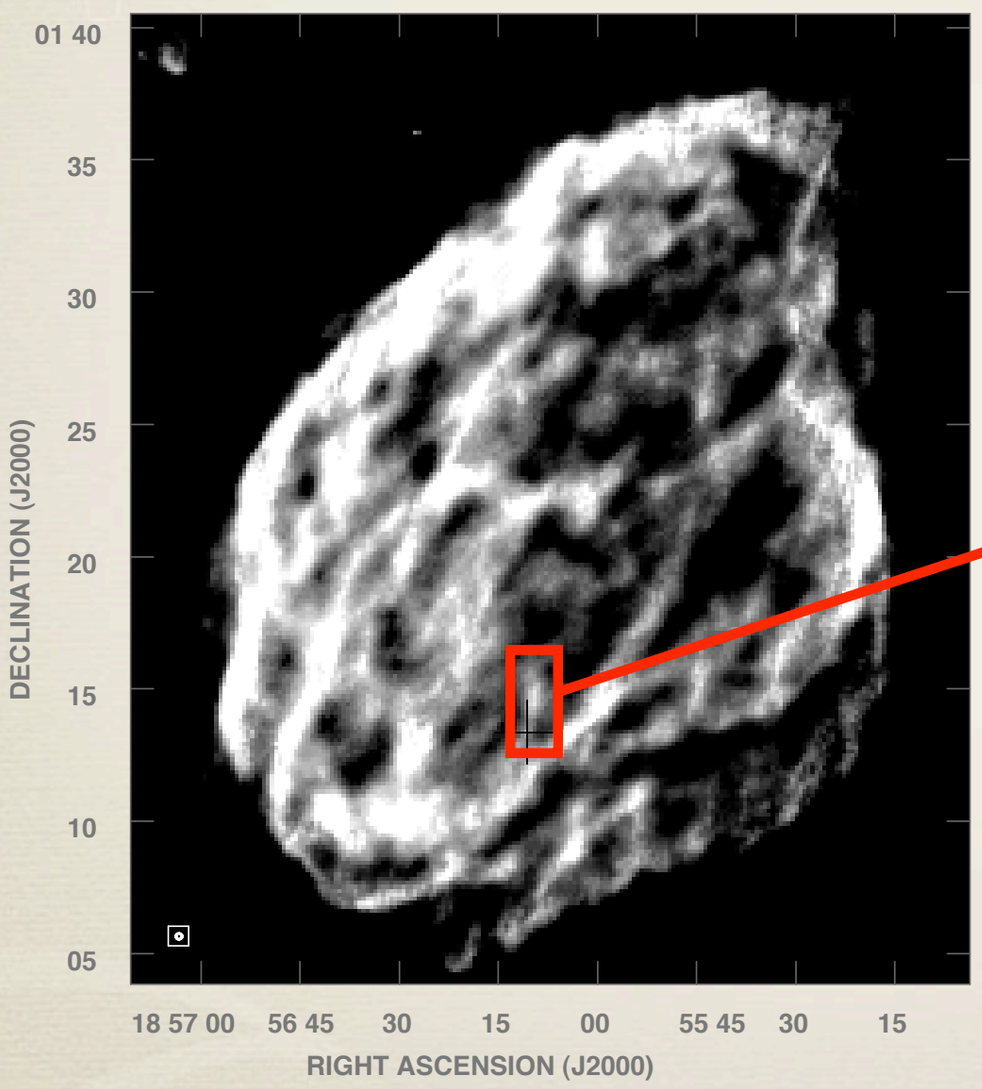
Seta+2004



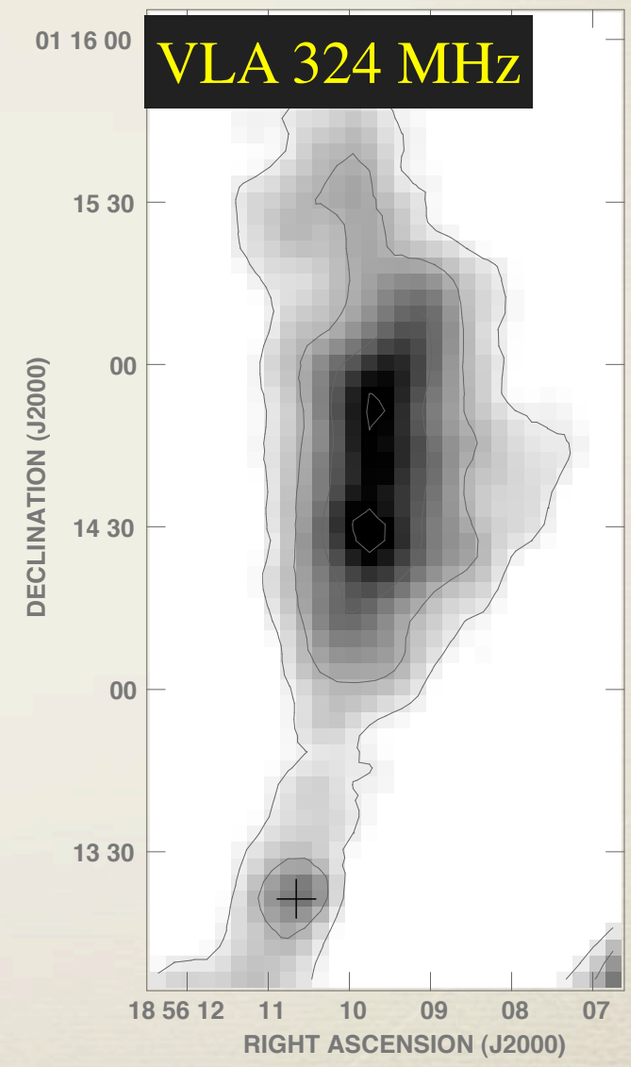
Seta+2004

Pulsar & PWN in W44

- Associated pulsar: PSR B1853+01(Wolszczan+1991)
- Characteristic age: ~ 2.0×10^4 yr
- PWN: Observed in Radio & X-ray (extends ~ 2 arcmin in radio) (Frail+1996, Harrus+1996, Petre+2002)



Black cross: location of PSR B1853+01



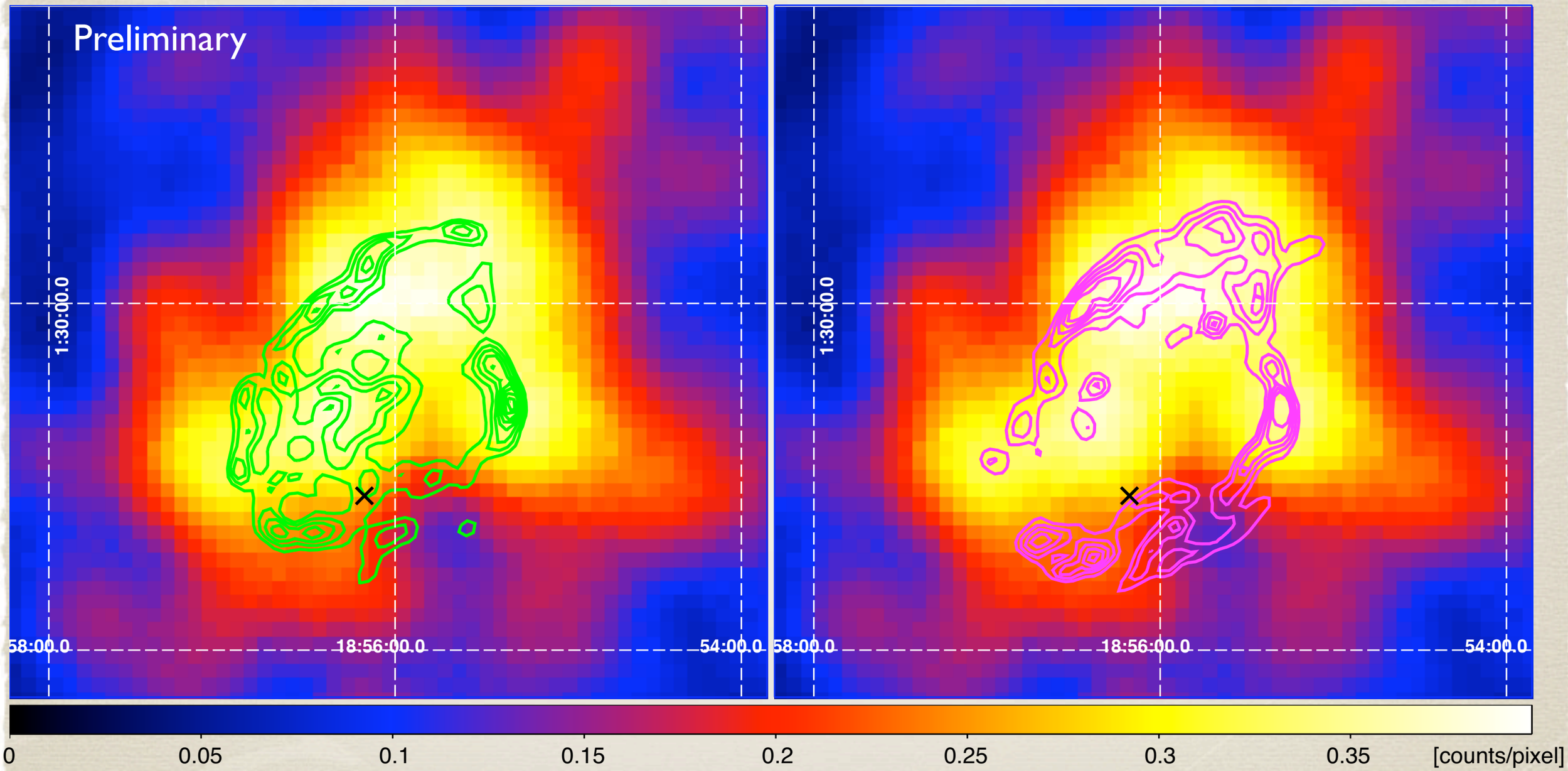
Castelletti+2007

W44 Region: Fermi-LAT 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: PSR B1853+01 (**No evidence of pulsed gamma-rays**)

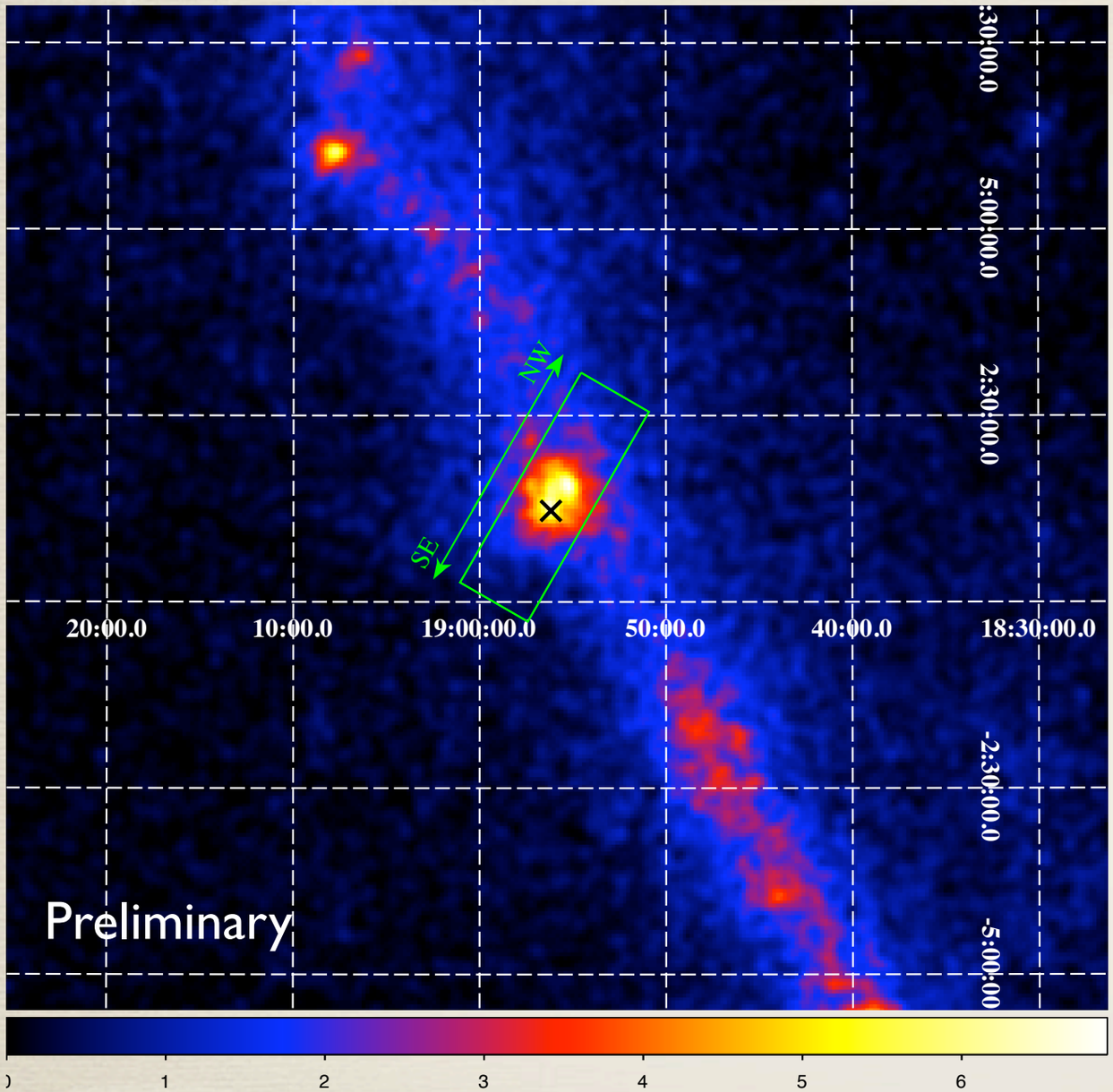


Contours: VLA 20 cm

Contours: Spitzer IRAC 4.5 μm

Spatial Extention (1)

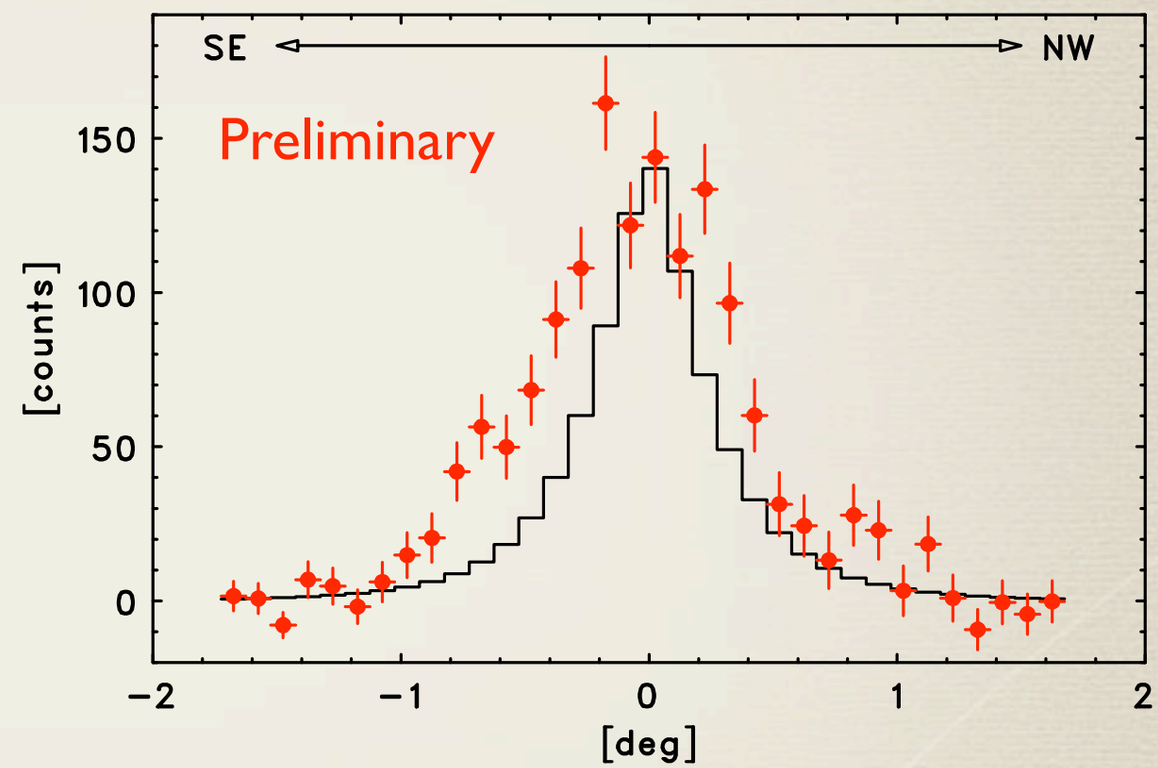
Smoothed Count Map (> 1GeV)



Black Cross: Pulsar (PSR B1853+01) location

Profile along SE-NW

Contributions from the diffuse backgrounds and nearby sources are subtracted



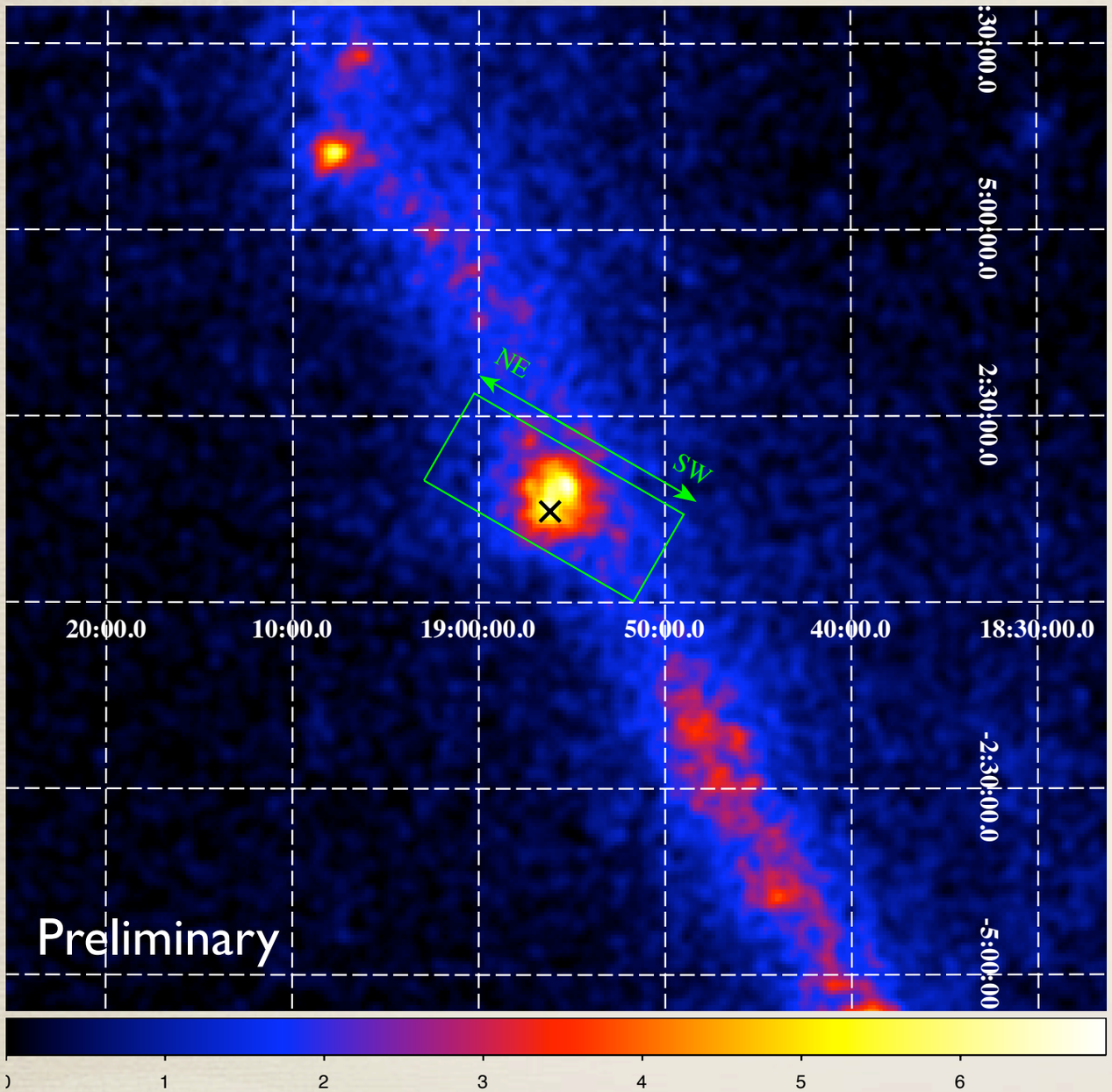
Red: Observed Counts

Black: Expected Profile for a Point Source

Spatially Extended

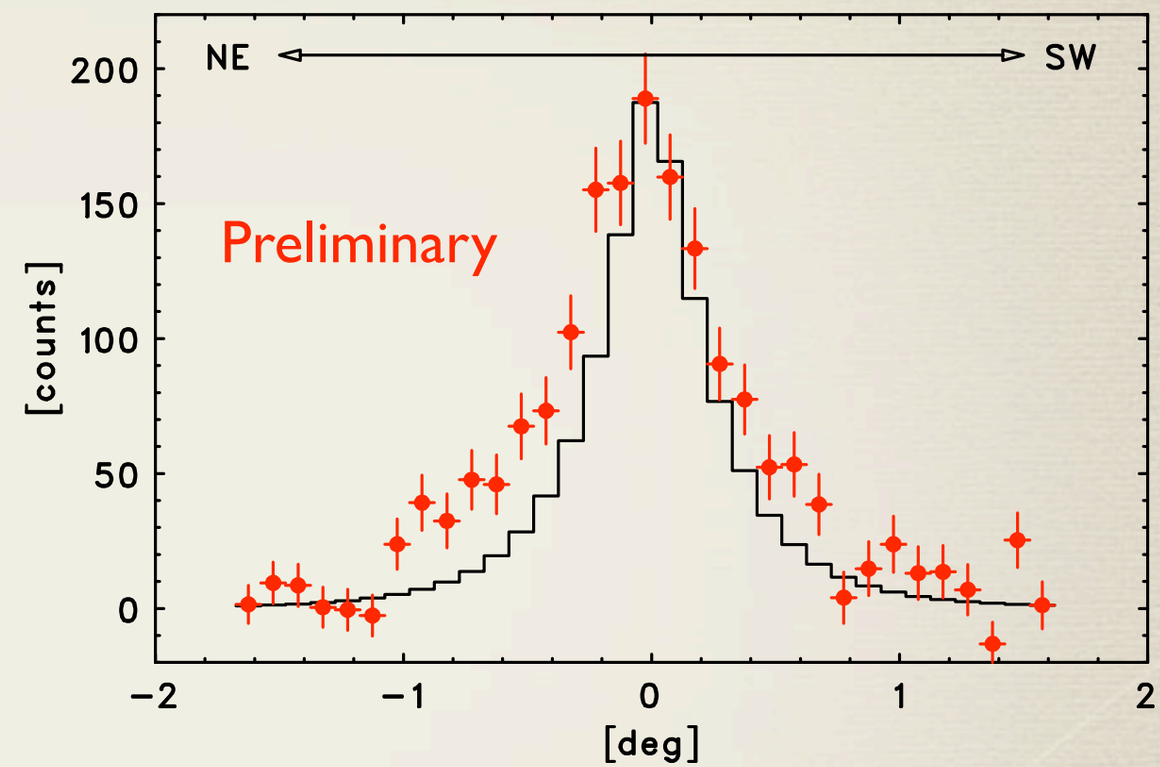
Spatial Extention (2)

Smoothed Count Map (> 1GeV)



Black Cross: Pulsar (PSR B1853+01) location

Profile along NE-SW



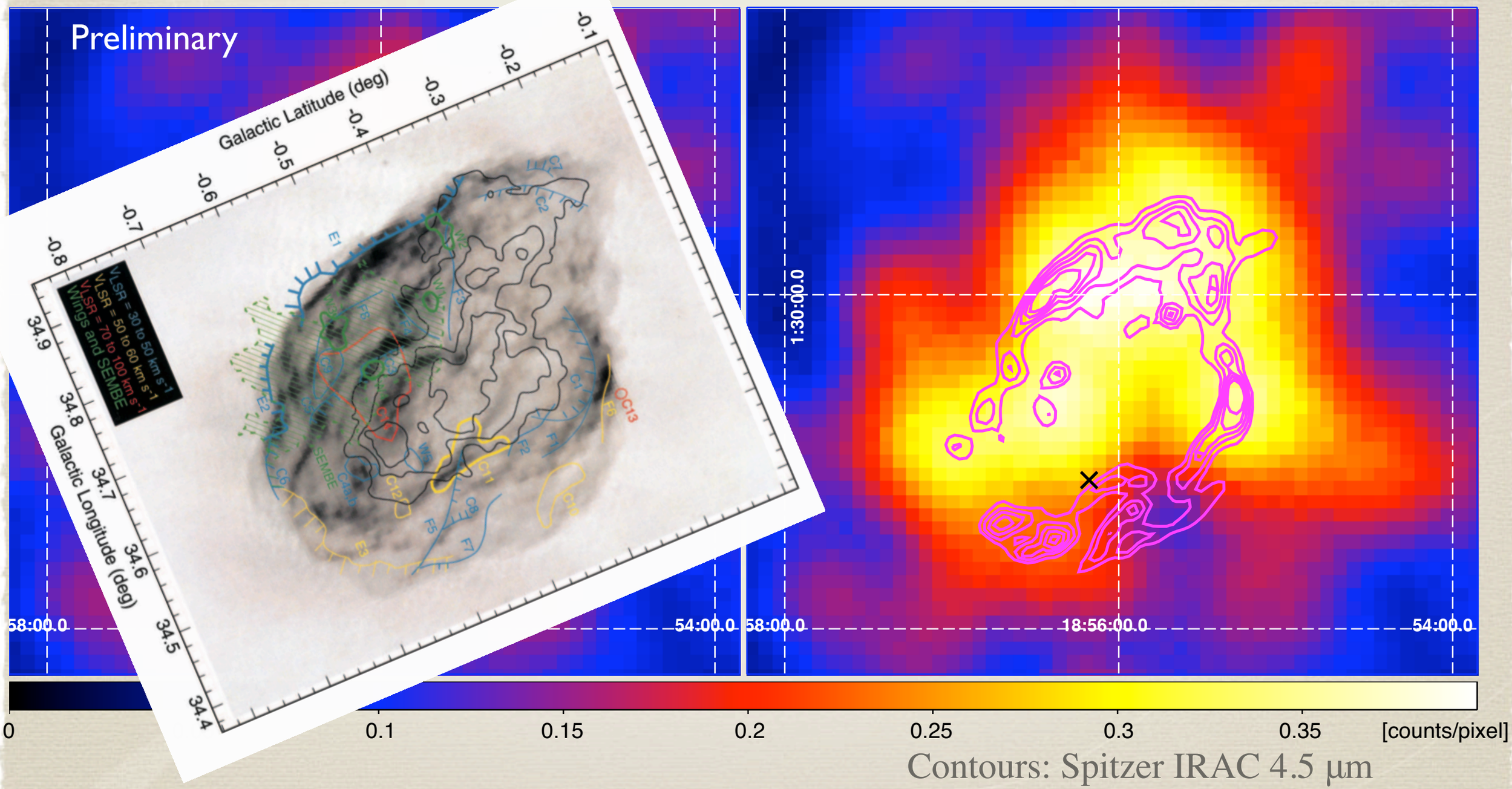
Red: Observed Counts

Black: Expected Profile for a Point Source

W44: Fermi-LAT Image

Fermi-LAT has started to reveal spatial structures of some bright gamma-ray sources.
We can obtain even better images by applying a kind of maximum likelihood technique.

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



Contours: Spitzer IRAC 4.5 μm

Y. Uchiyama, TeVPat 2009

EGRET Study on SNRs

Esposito+1996

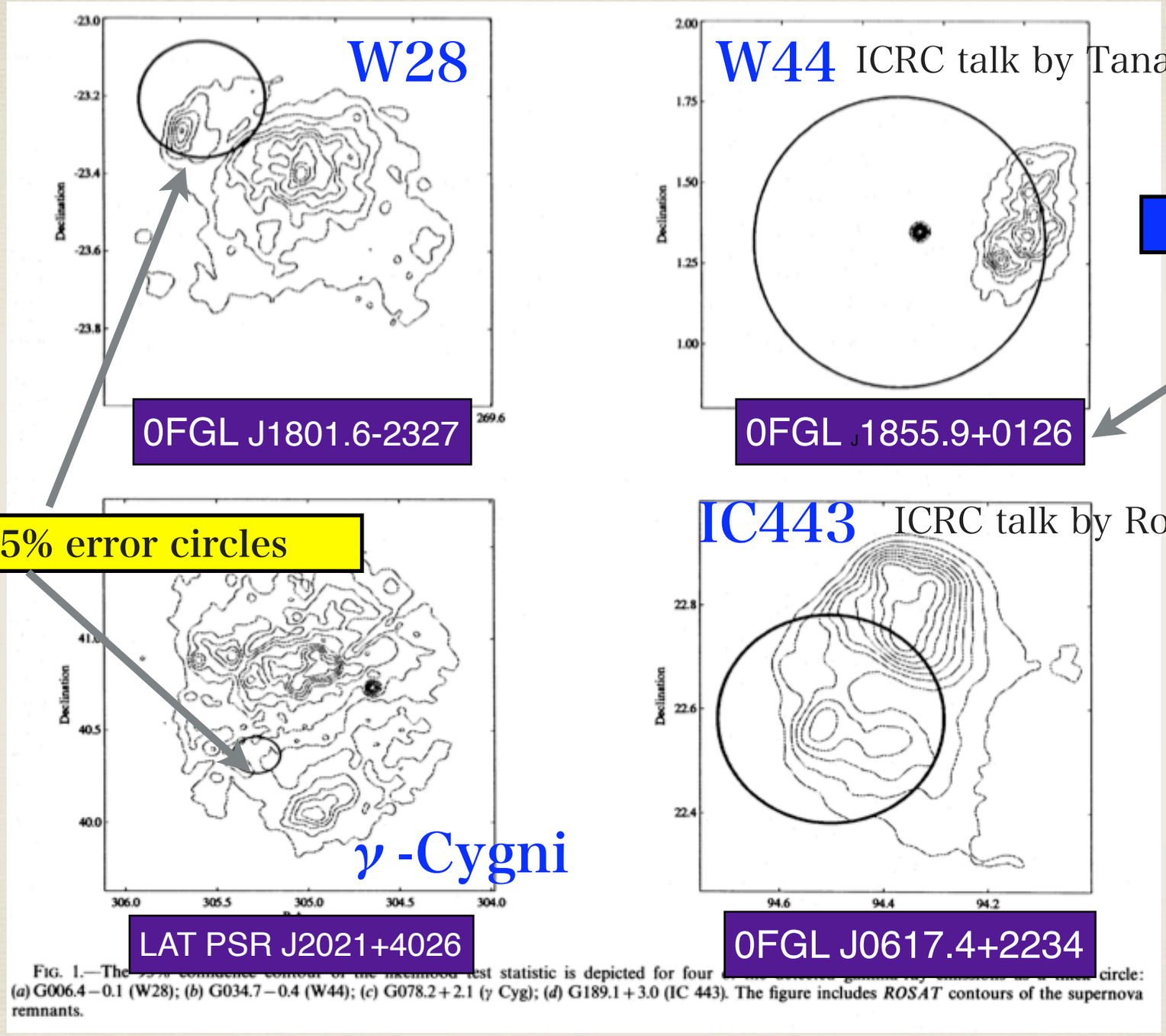


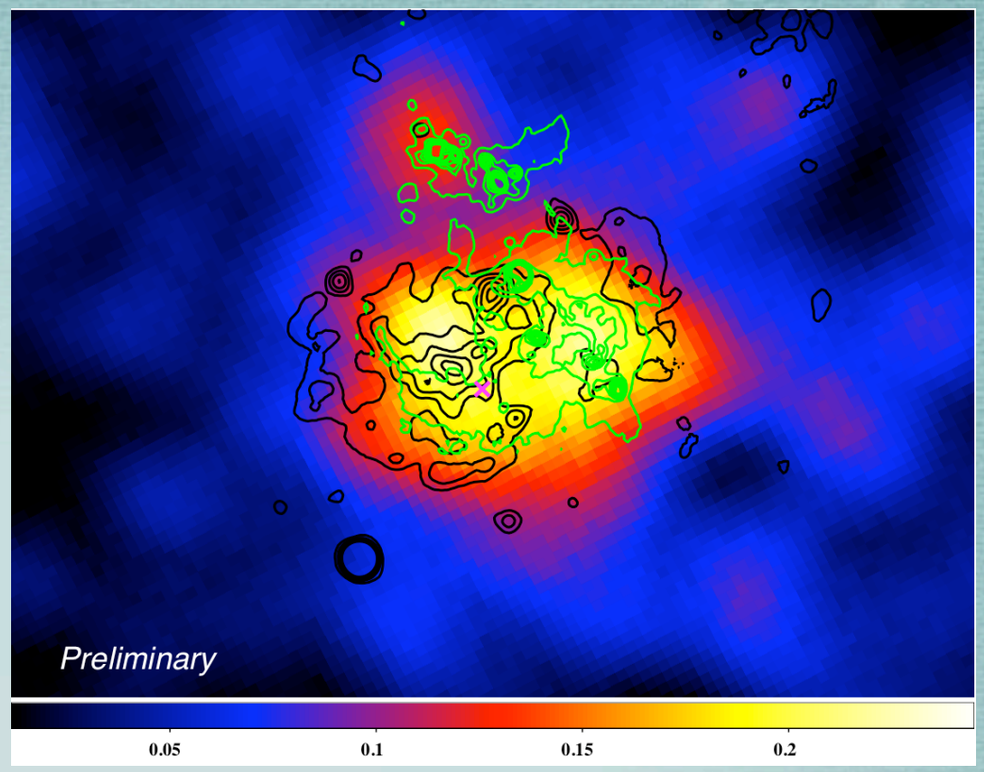
FIG. 1.—The 95% confidence contour of the likelihood test statistic is depicted for four [illegible] circle: (a) G006.4−0.1 (W28); (b) G034.7−0.4 (W44); (c) G078.2+2.1 (γ Cyg); (d) G189.1+3.0 (IC 443). The figure includes *ROSAT* contours of the supernova remnants.

Despite its brightness at GeV enegies, the Fermi source in the W51C region does not have EGRET counterpart(s).

Summary

- Results of Fermi-LAT observations of the W44/W51C regions are presented
- Gamma-rays are spatially "extended"
- Positionally coincident with SNRs
- Gamma-ray luminosity is found to be very large (e.g. ~4×10^{35} erg/s for W51C):
  - One of the most luminous extended gamma-ray sources in the Galaxy
- Spectral analysis will be presented in a refereed journal

W51C region (Fermi LAT)



W44 region (Fermi LAT)