5th Korean Astrophysics Workshop
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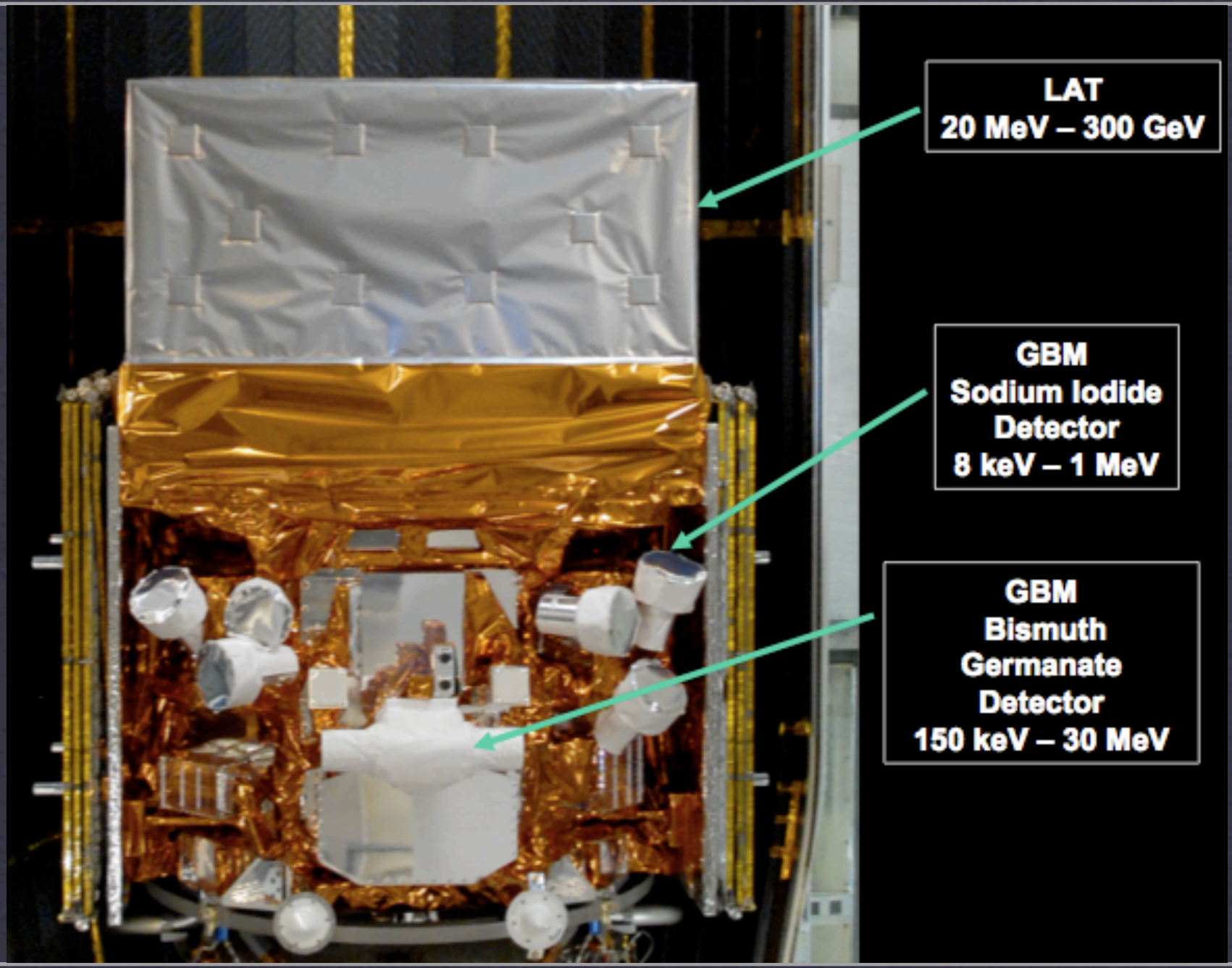
Gamma-ray Observations of SNRs with Fermi

Modified for online post

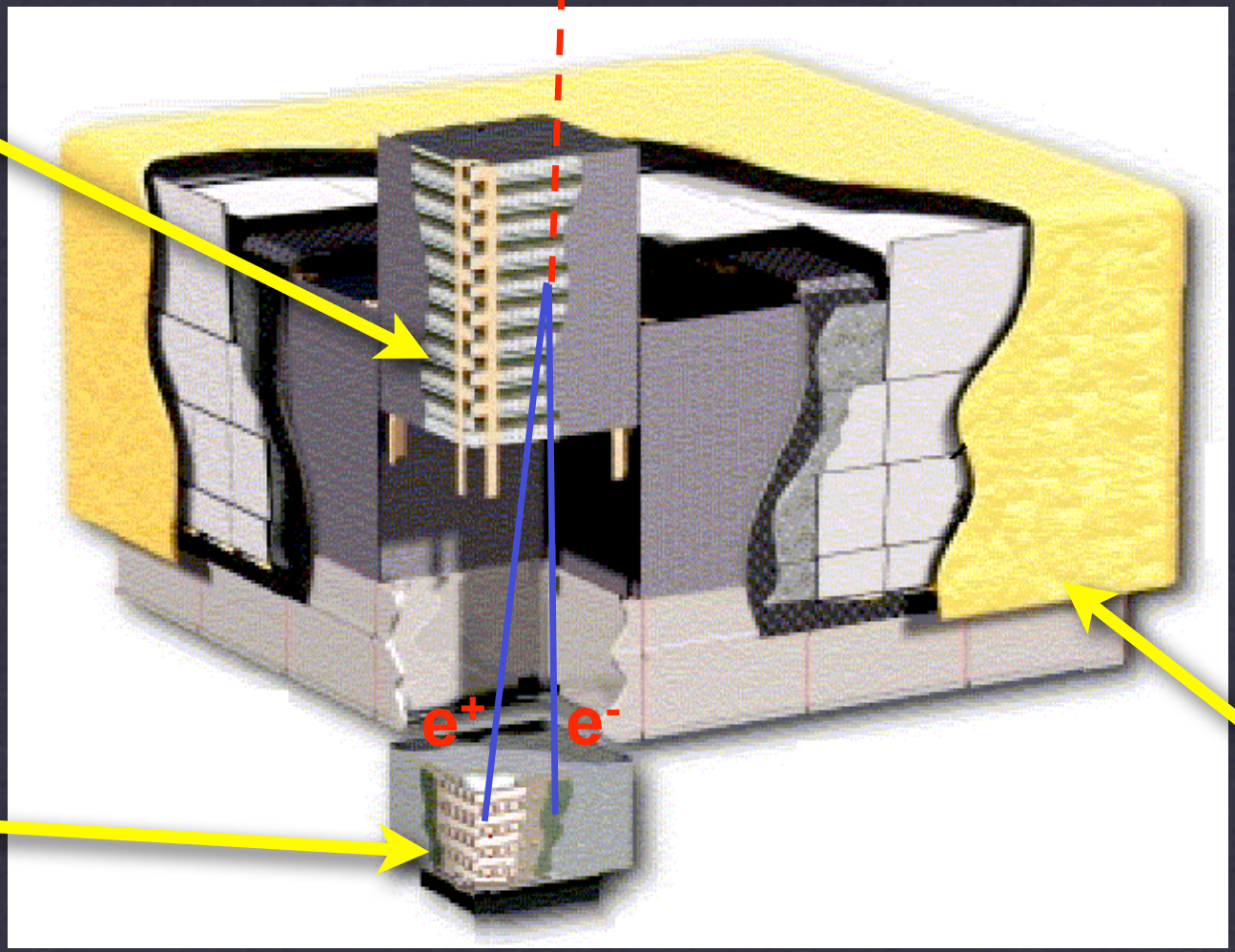
Yasunobu Uchiyama
(Panofsky Fellow of SLAC)
on behalf of the Fermi LAT collaboration

Launch!

* June 11, 2008
* Delta II Heavy launch vehicle
* Low-Earth orbit 565 km (96 min period)
* Inclination 25.6 deg



LAT and GBM onboard Fermi

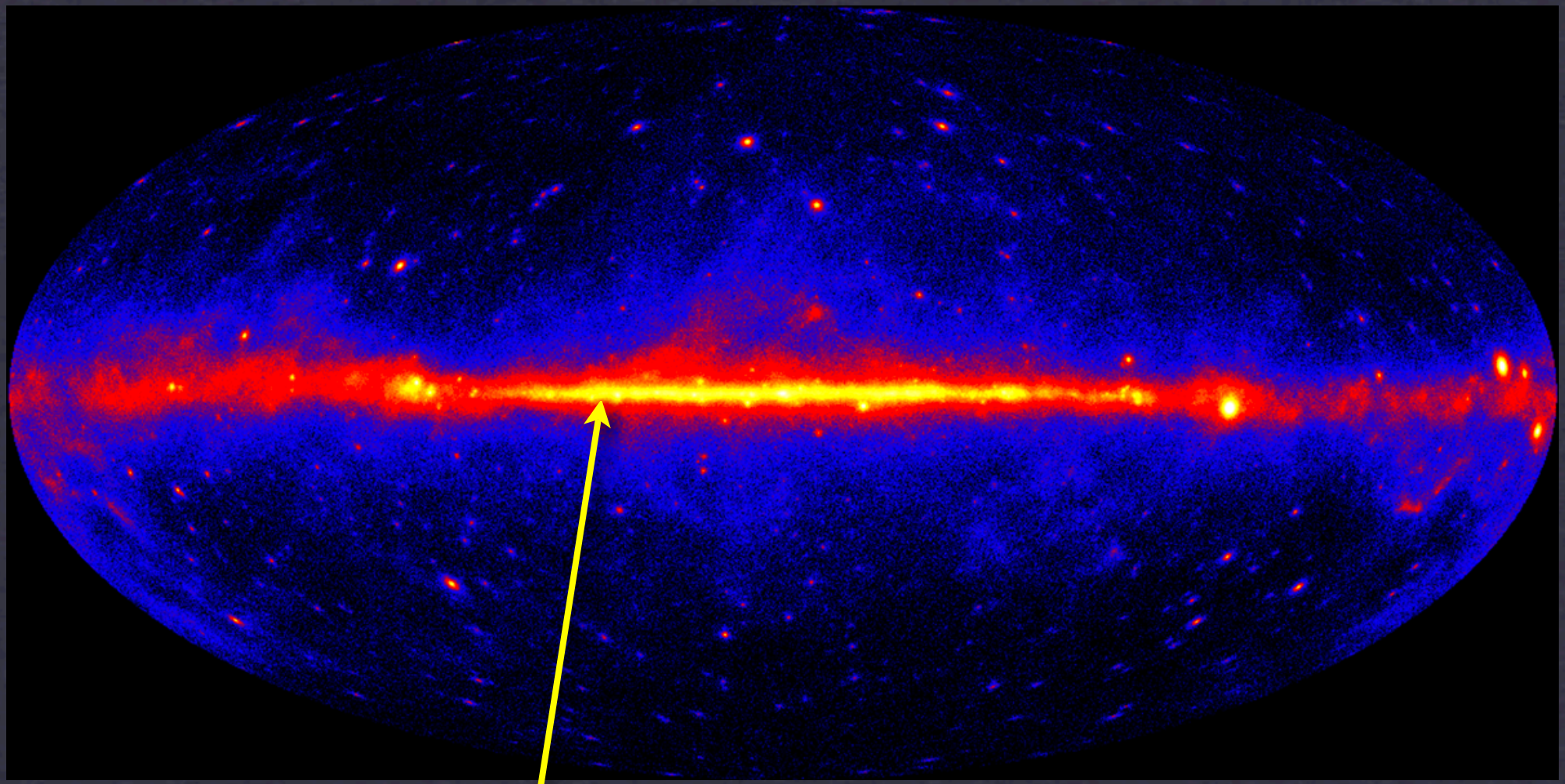


LAT: 4x4 modular array
3000 kg, 650 W

Large Area Telescope (LAT)

LAT All Sky Map (1 yr)

> 1000 LAT sources

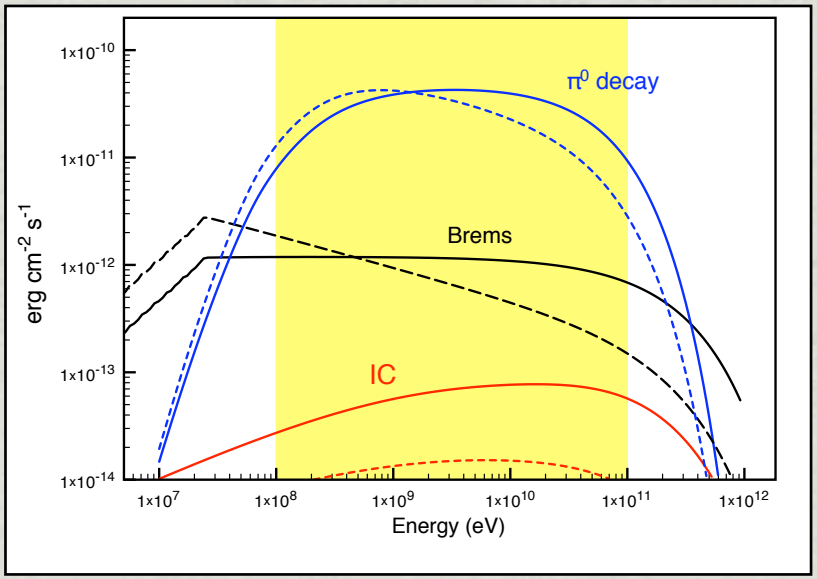


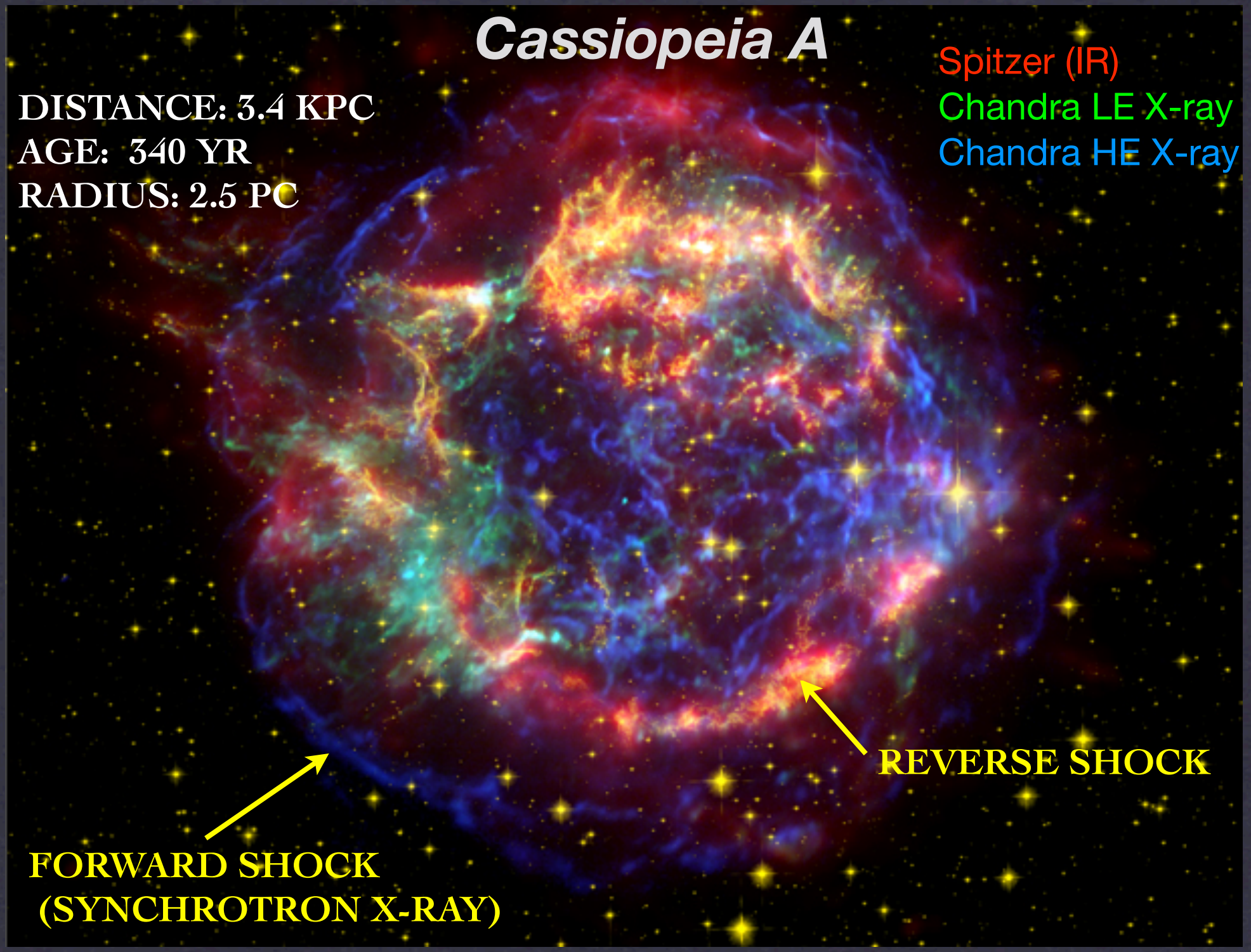
Milky Way (Galactic Cosmic Rays)

Contents

Fermi-LAT Detections of Shell-type SNRs

- **Young SNRs**
  - Cas A
  - RXJ1713.7-3946
- **Middle-Aged SNRs with Molecular Cloud Interactions**
  - W51C
  - W44
  - (IC443)
  - (W28)
  - (W49B)
  - etc




Cassiopeia A
DISTANCE: 3.4 KPC
AGE: 340 YR
RADIUS: 2.5 PC
Spitzer (IR)
Chandra LE X-ray
Chandra HE X-ray
REVERSE SHOCK
FORWARD SHOCK
(SYNCHROTRON X-RAY)

Cassiopeia A: Variable Filaments

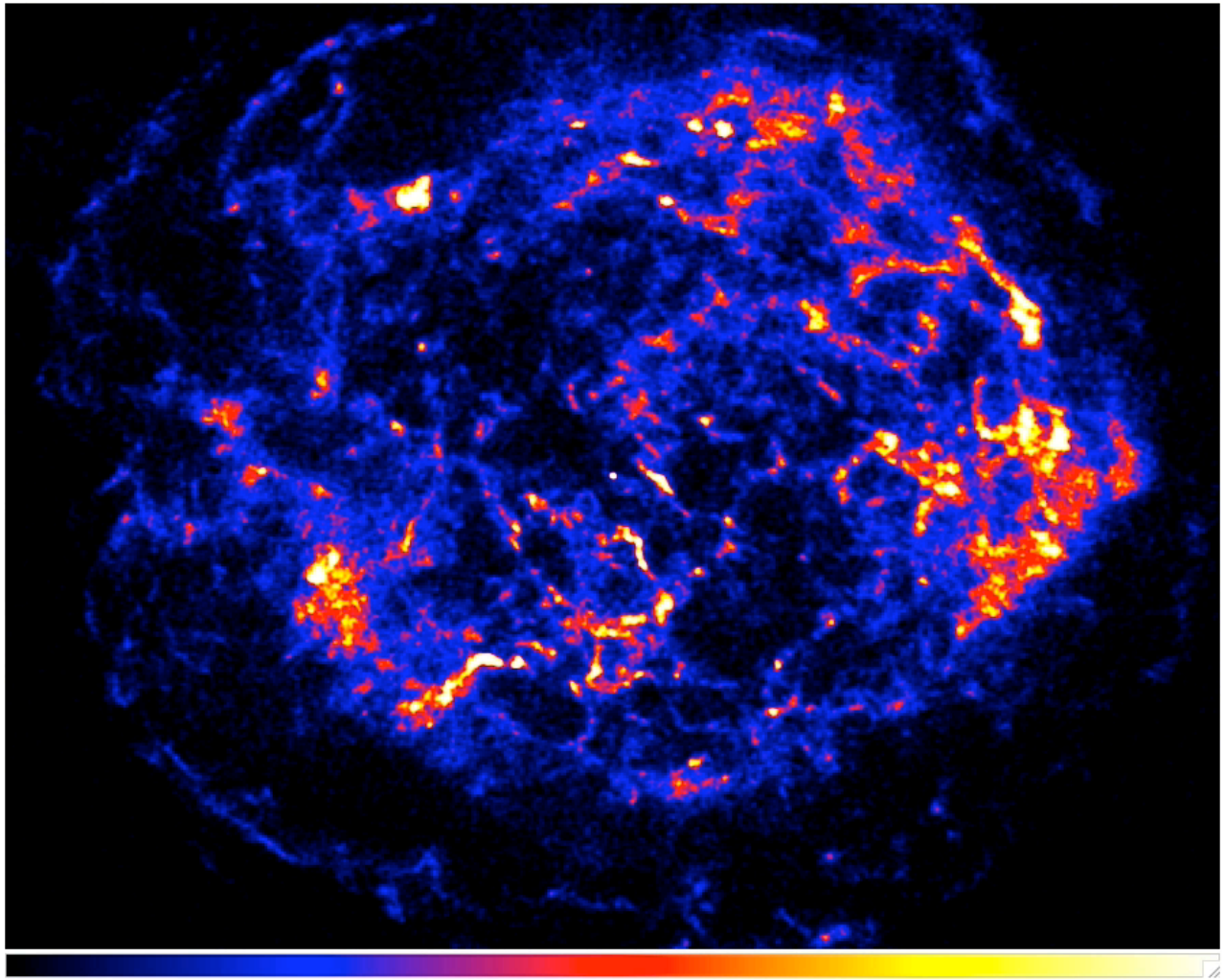
Continuum (4-6 keV) year-scale variability

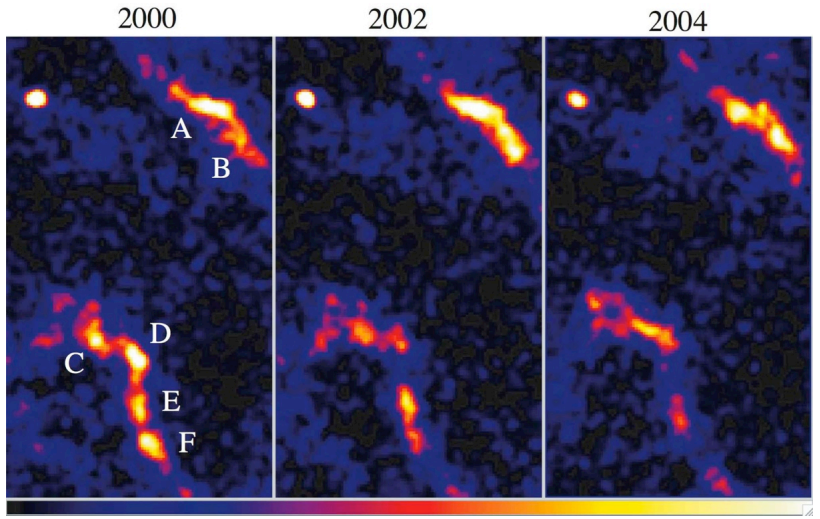
thermal bremsstrahlung from shock-heated ejecta

+ **synchrotron** component: knots/filaments brightening/decaying 10%/yr

(Uchiyama & Aharonian 2008)

see also Patnaude & Fesen 2009

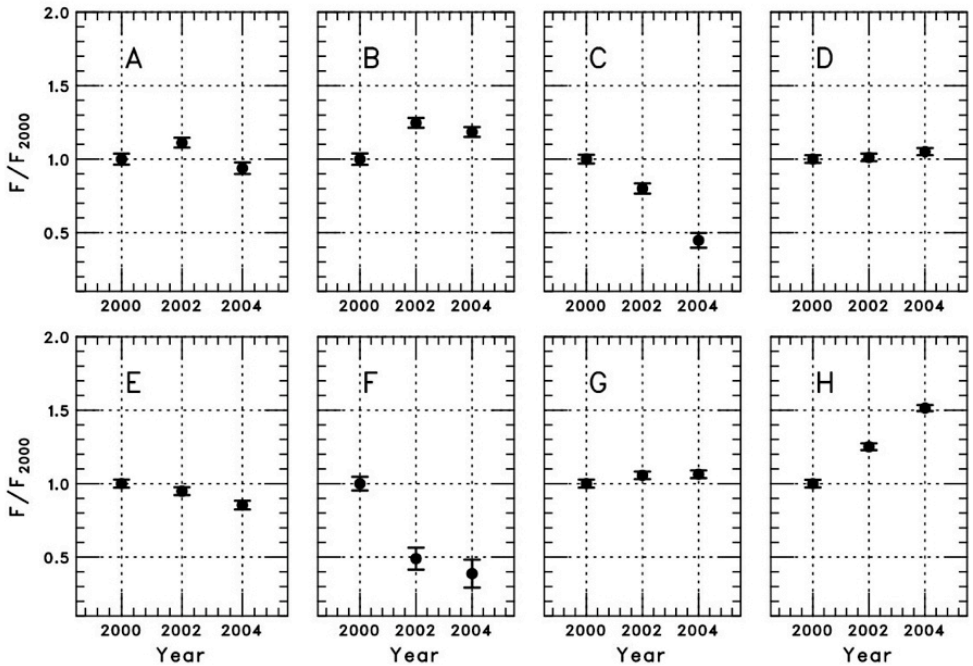




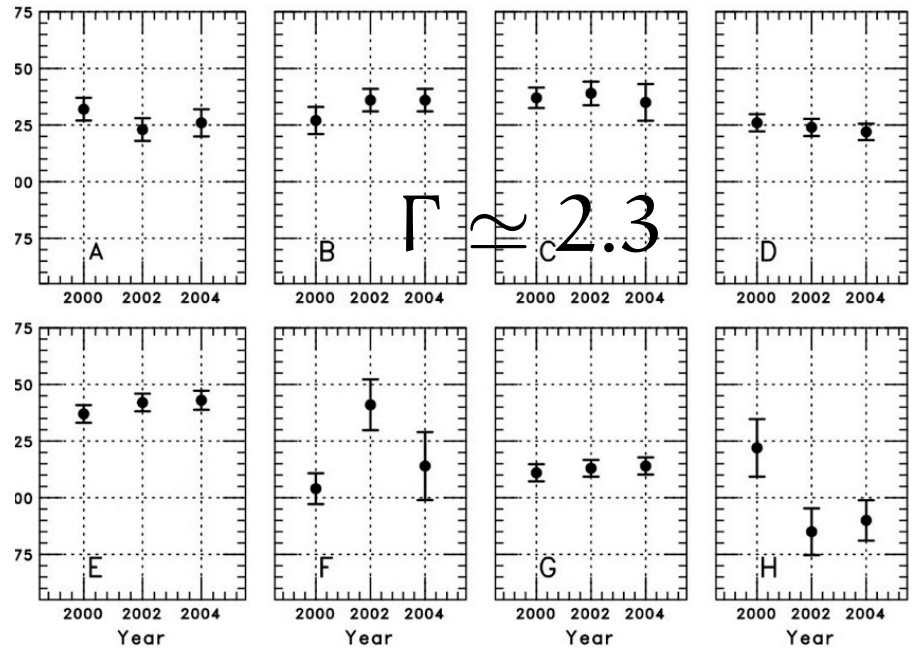
Chandra Observations in 2000, 2002, and 2004

(Back up) Cas A: Spectra of Variable Filaments

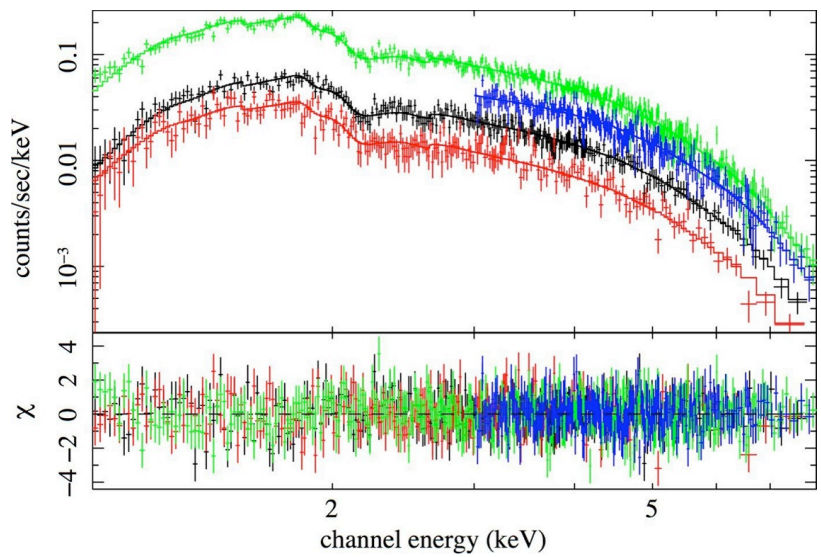
Flux changes



Index changes



(Uchiyama & Aharonian 2008)



X-ray spectra
are consistent
with a synchrotron model

Cas A: Variability Timescales

- ***Synchrotron X-ray Variability:***

(Uchiyama & Aharonian 2008; Patnaude & Fesen 2009)

Decaying = Synchrotron Cooling

$$t_{\rm sync} \sim 1.5 \left(\frac{B}{\rm mG}\right)^{-1.5} \left(\frac{\epsilon}{\rm keV}\right)^{-0.5} \ {\rm year} \longrightarrow B \sim 1 \ {\rm mG}$$

Brightening = Acceleration of Fresh Electrons

$$t_{\rm acc} \sim 1 \ \eta \left(\frac{B}{\rm mG}\right)^{-1.5} \left(\frac{\epsilon}{\rm keV}\right)^{0.5} \left(\frac{V_s}{3000 \ {\rm km \ s^{-1}}}\right)^{-2} \ {\rm years} \longrightarrow B \sim 1 \ {\rm mG}, \ \eta \sim 1$$

Diffusive shock acceleration

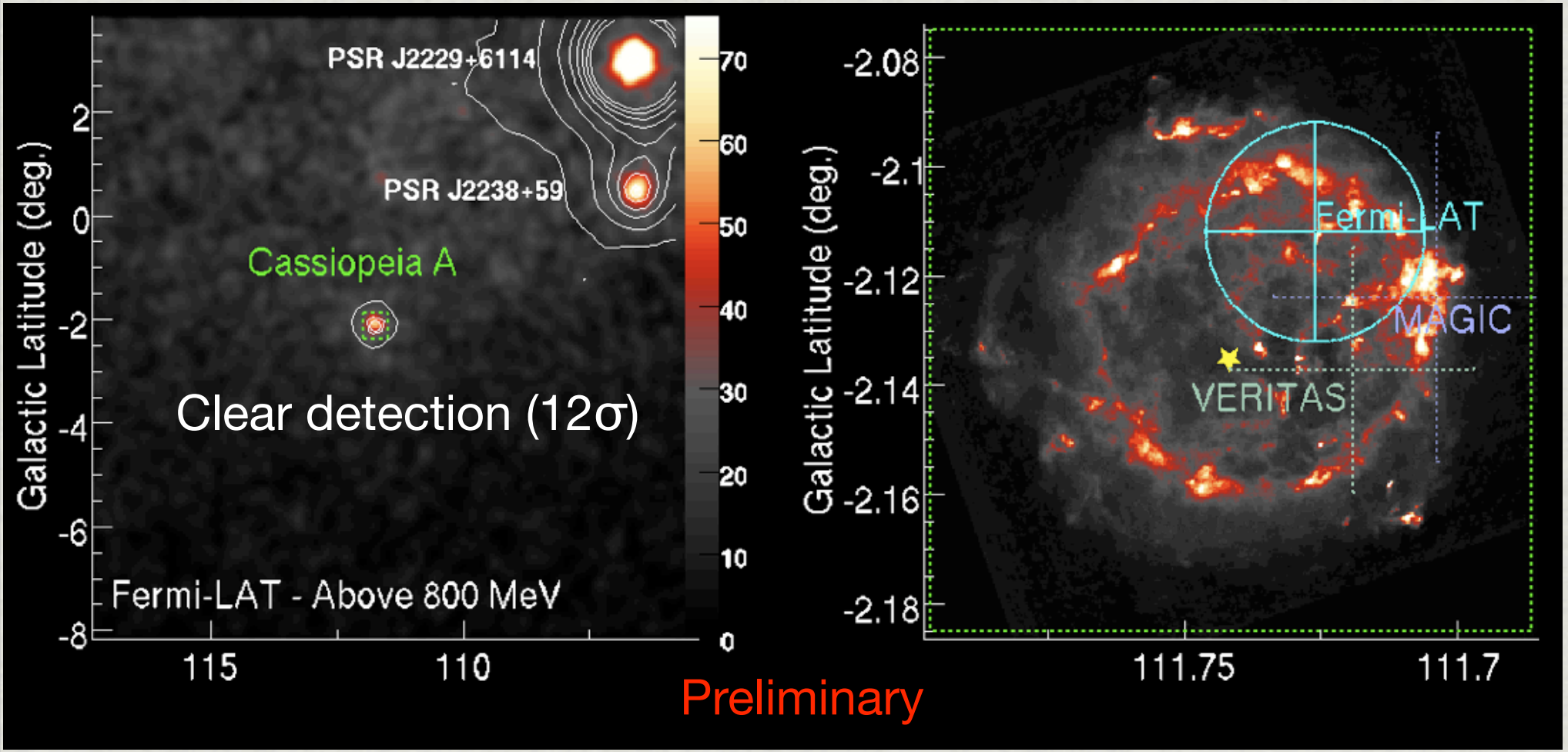
$$\eta \equiv \left(\frac{\delta B}{B}\right)^2$$

"gyro-factor"

Fermi-LAT Detection of Cas A

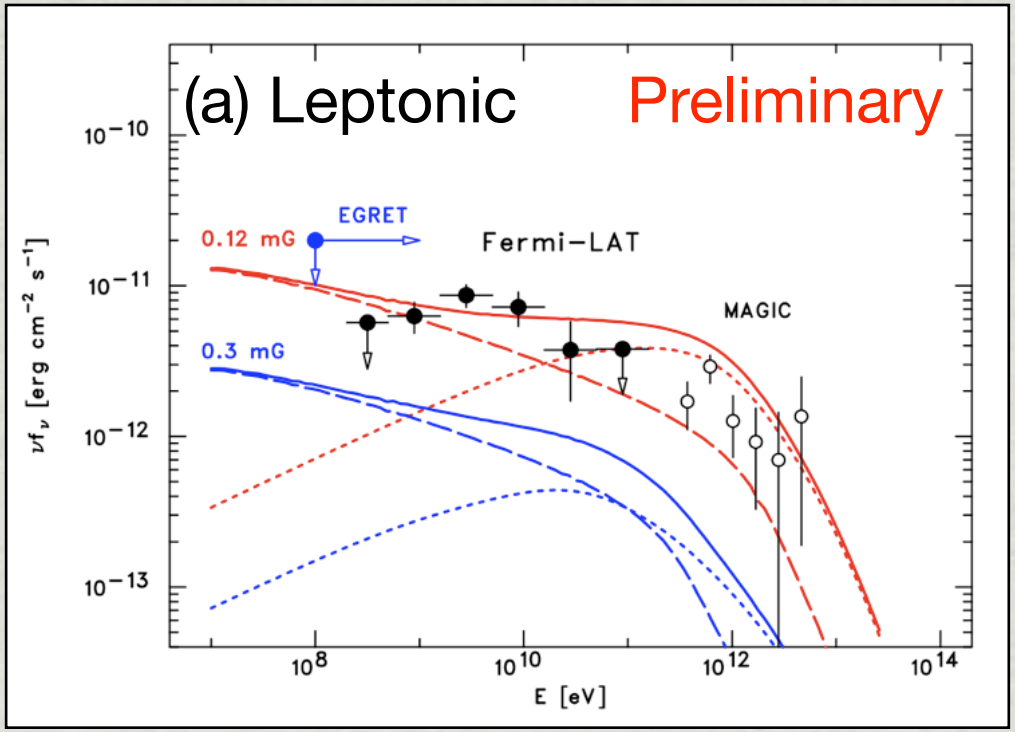
Fermi-LAT (>0.8 GeV)

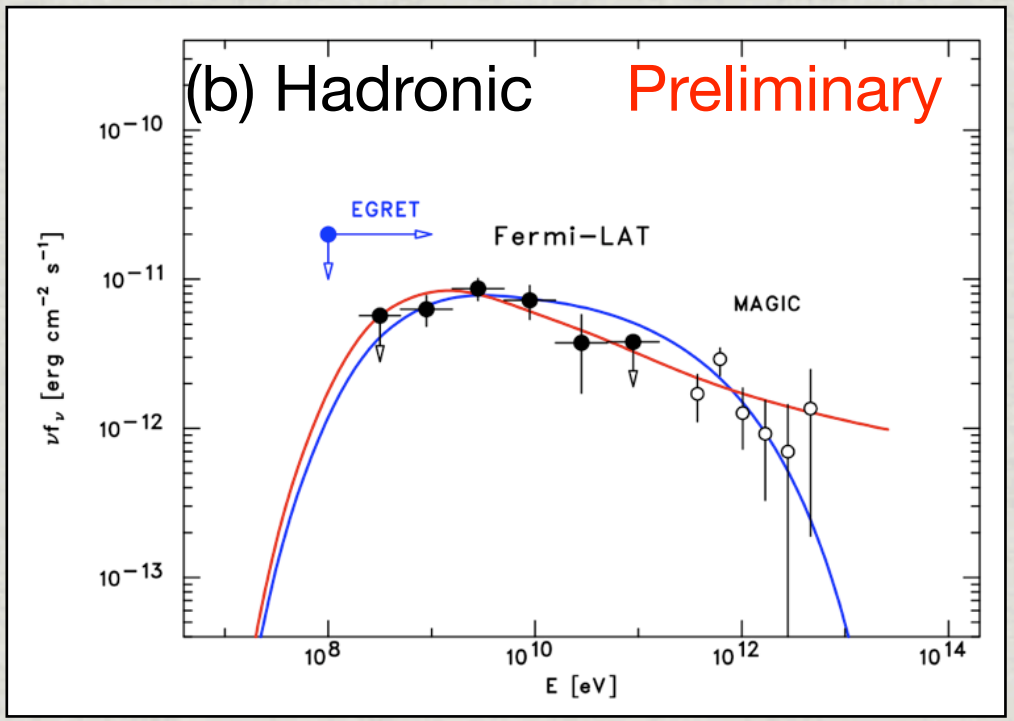
VLA radio map



First clear detection of historical SNR

The position does not match with CCO (neutron star)





Cas A GeV/TeV Spectrum

(a) Leptonic (Bremsstrahlung + IC)

B = 0.12 mG

We = 1×10^{49} erg

(total electron energy content)

(b) Hadronic (π^0 decay)

B > 0.12 mG

Wp = 5×10^{49} erg

(total proton energy content)

B-field amplification

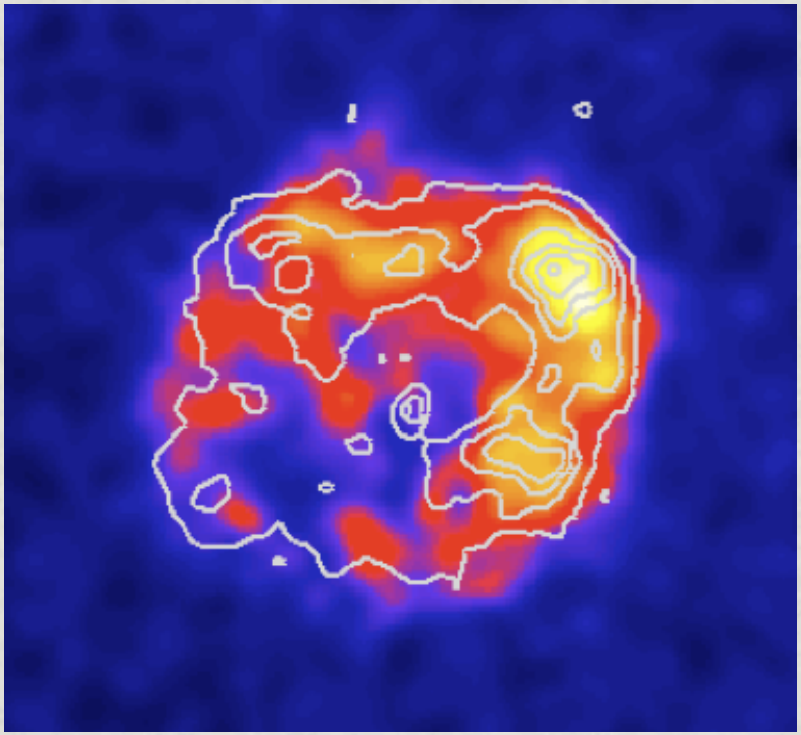
CR content: 2% of E_{SN}

SNR RXJ1713.7-3946: Brightest keV/TeV sources

TeV Gamma: Hadronic or Leptonic origin?

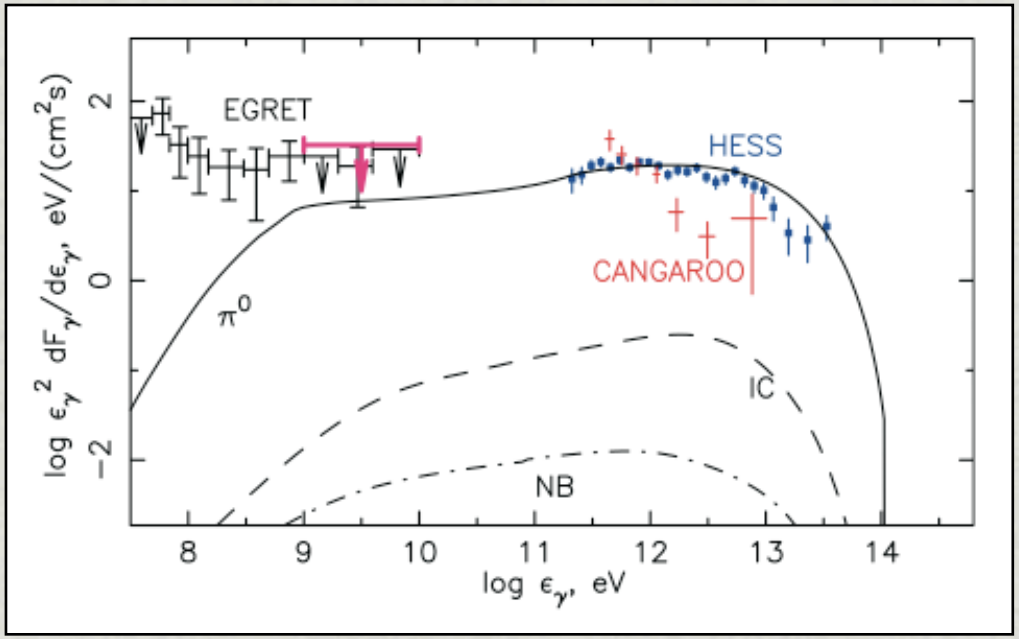
Gamma-ray emission mechanism is under active debate.

SNR RXJ1713.7-3946



X-RAY (ASCA) VS TEV (HESS)

NON-LINEAR ACCELERATION Berezhko&Völk 2006

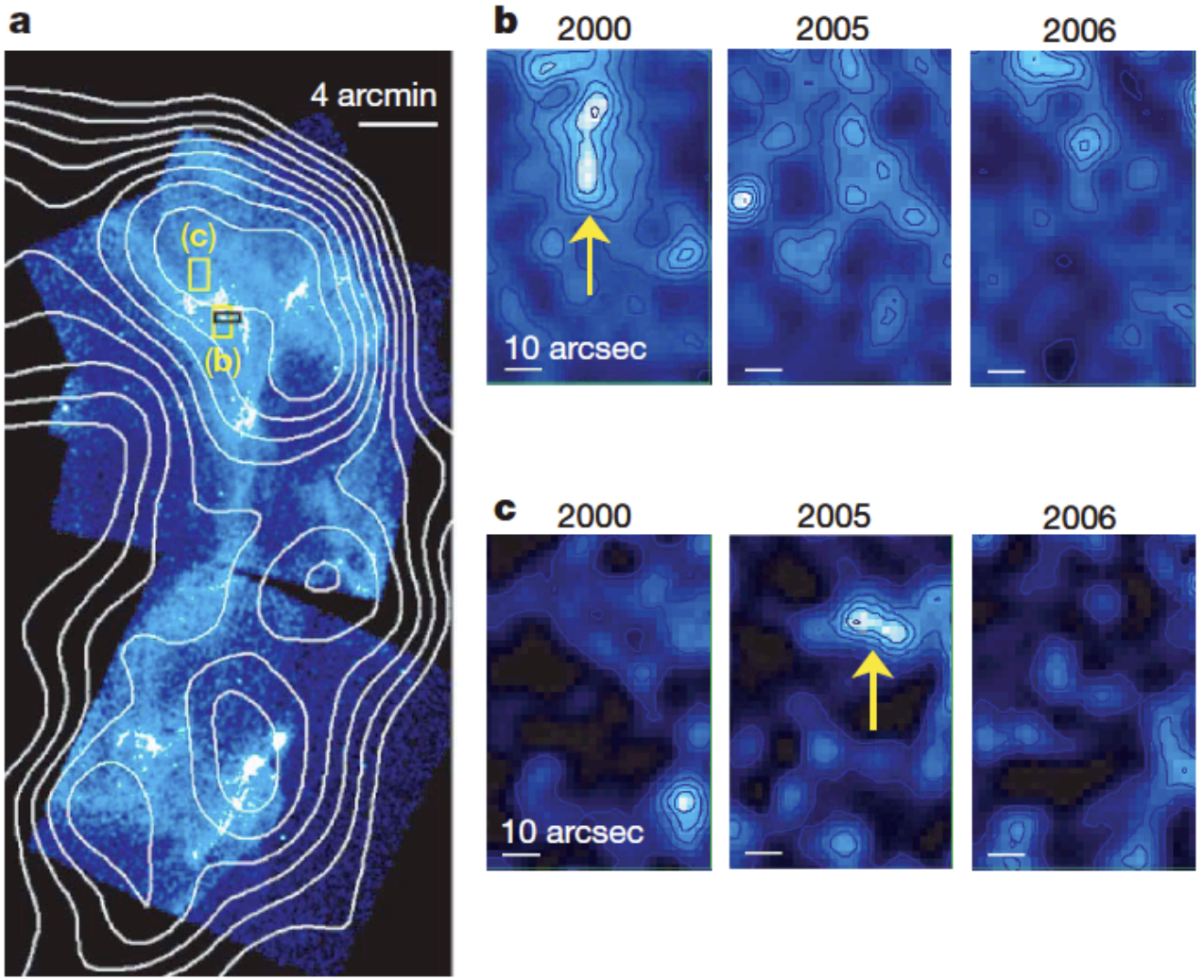


Synchrotron X-ray variability : B ≈ 0.1 - 1 mG

Uchiyama+2007

RXJ1713.7-3946: Chandra X-ray Monitoring

Uchiyama et al. (2007)



Chandra (color)
HESS (contours)

Most filaments (spatially extended) are variable in time!!

X-ray spectra:
a power law with photon index ~2

Timescale ~ 1 year

$\longrightarrow \quad B \sim 1$ mG

$\eta \sim 1$

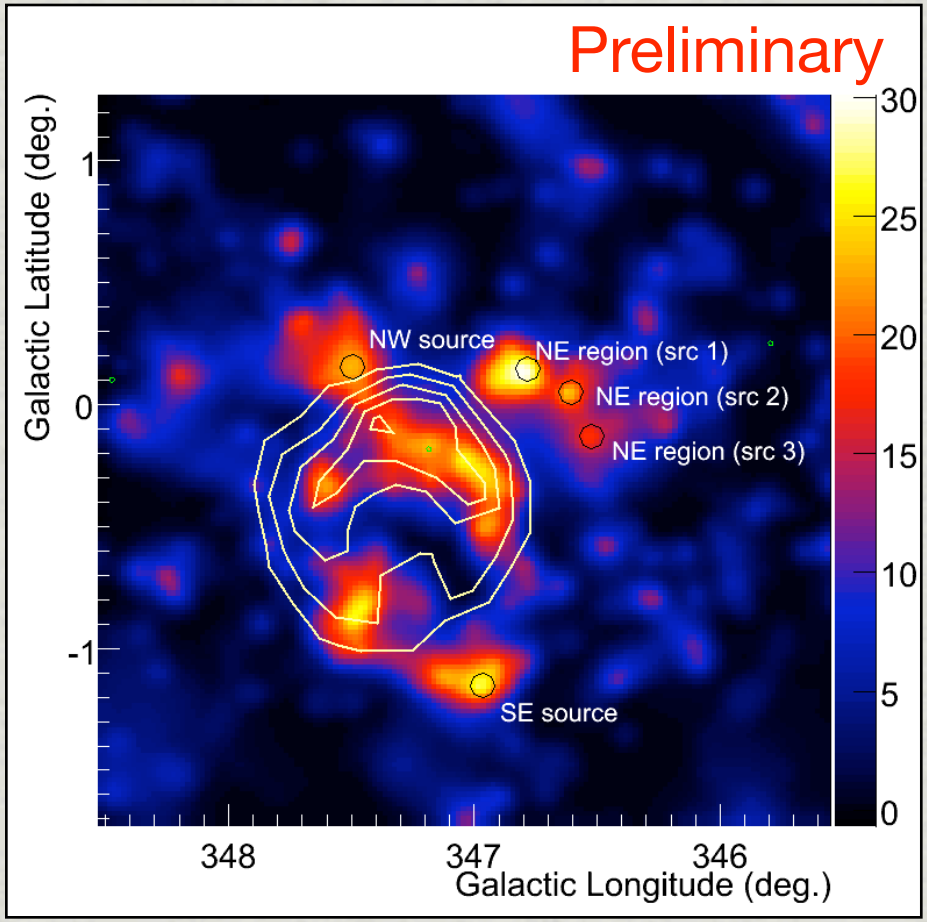
Uchiyama et al. (in prep.)

New observations in 2009:
SNR expansion with V~4000 km/s

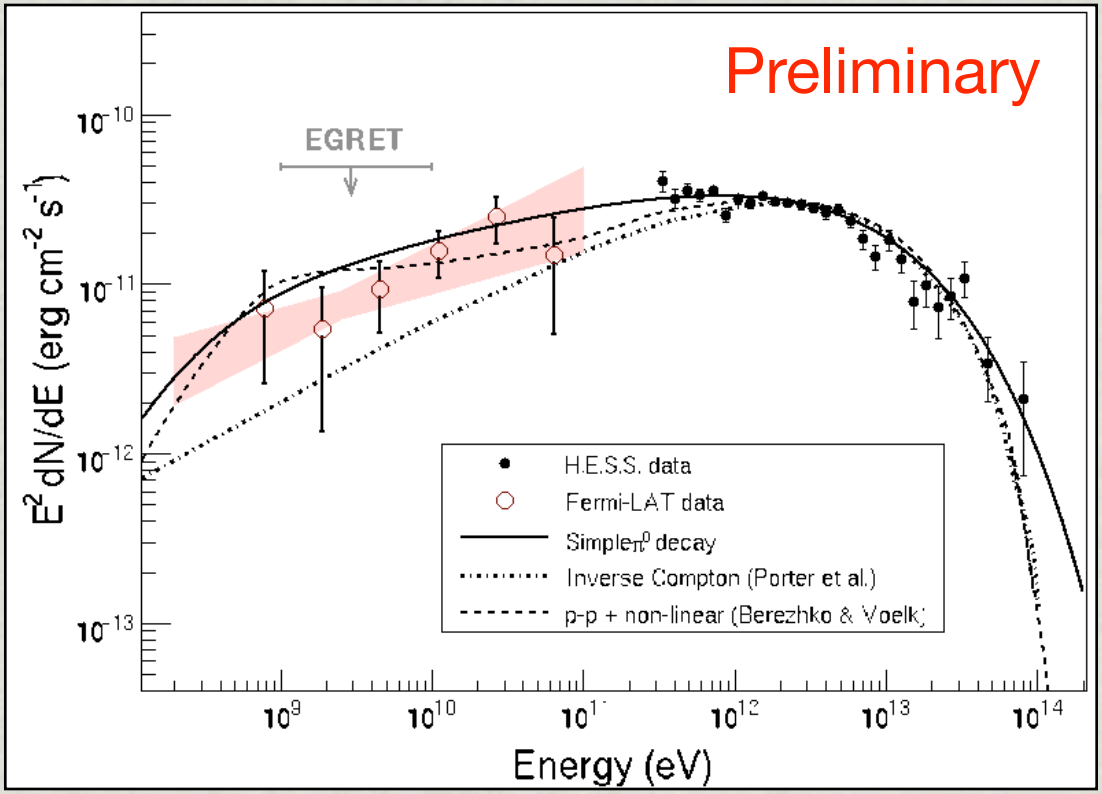
Young SNR!

SNR RXJ1713.7-3946
Fermi LAT Results (Preliminary)

Fermi-LAT (significance map)

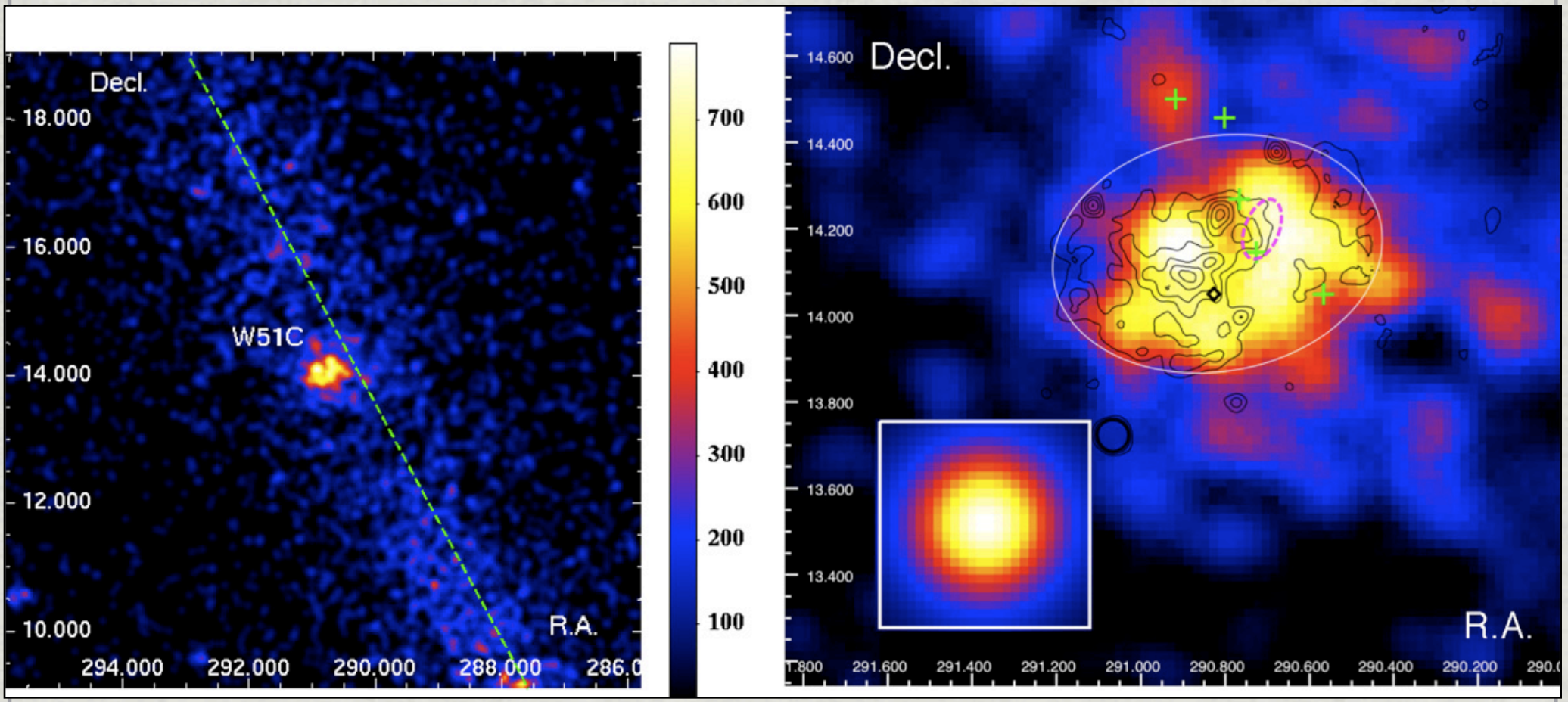


LAT + HESS Spectrum



SNR interacting with Molecular Cloud: (1) SNR W51C

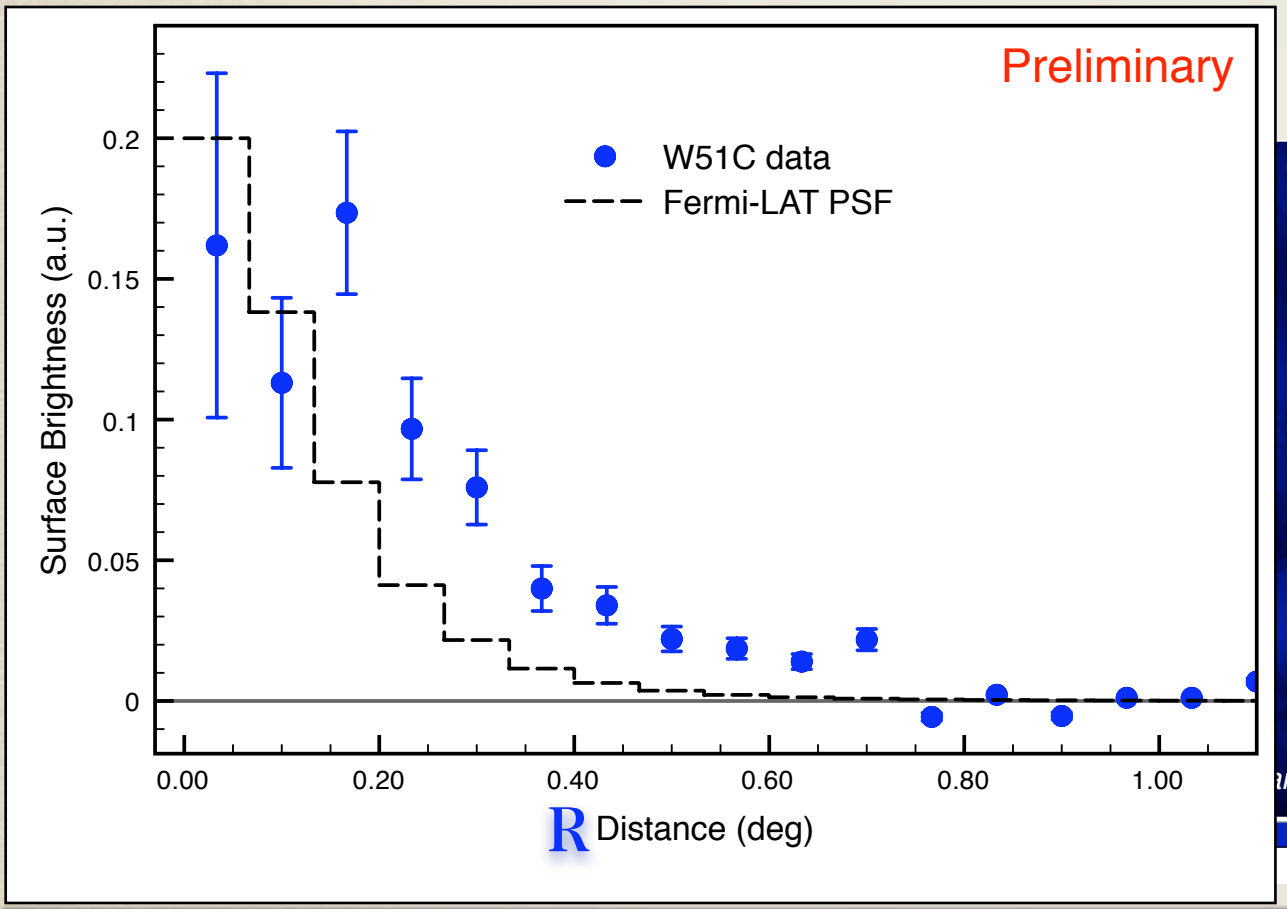
- Middle-aged (~ 3×10^4 yr) Distance: ~ 6 kpc
- Radio shell, thermal X-ray (black contours)

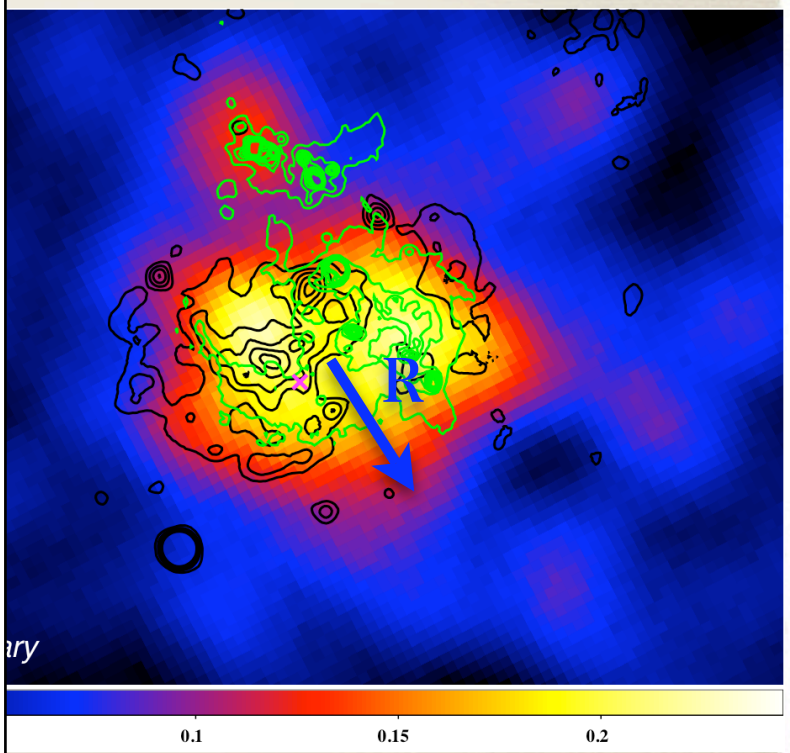


Fermi-LAT Count Map (Front Events; 2–10 GeV)

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)



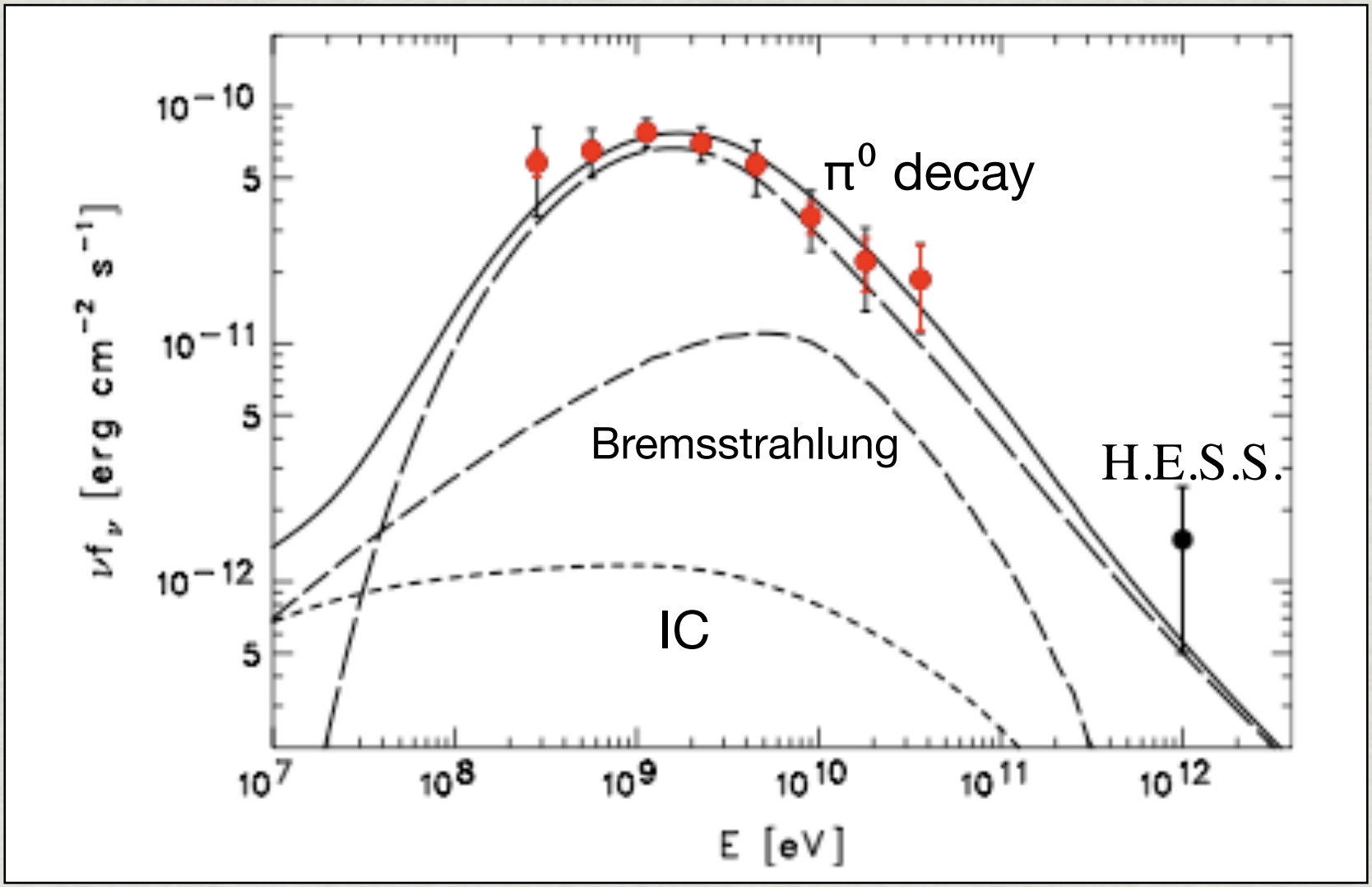


(NOTE) PSF of Fermi LAT depends heavily on energy. The PSF shape is obtained by taking account of energy distribution.

SNR W51C

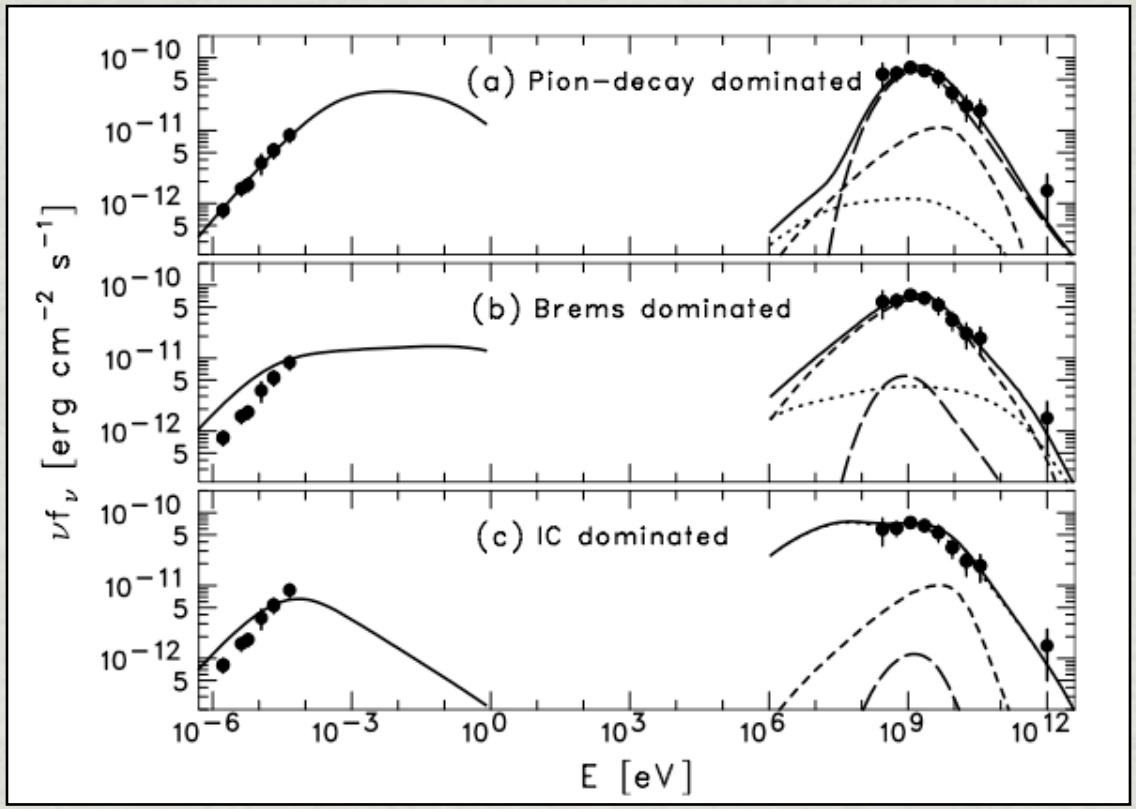
CR proton sources are finally found?

Fermi-LAT Spectrum



Molecular cloud interaction enhances π^0 -decay emission

SNR W51C: SED modeling



π^0 decay : OK

brems : unlikely but not fully excluded

IC : very unlikely (energetics)

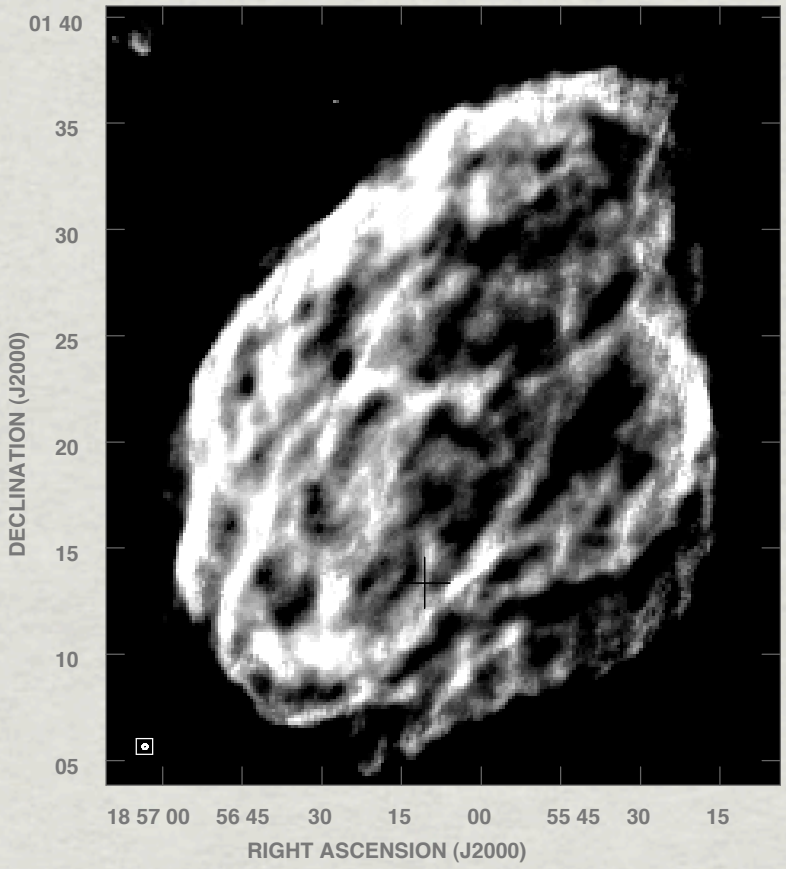
Model	Parameters					Energetics	
	a_e/a_p	Δs	p_{br} (GeV c^{-1})	B (μG)	$\bar{n}_H$ (cm^{-3})	W_p (10^{50} erg)	W_e (10^{50} erg)
(a) π^0 decay	0.02	1.4	15	40	10	5.2	0.13
(b) Bremsstrahlung	1.0	1.4	5	15	10	0.54	0.87
(c) Inverse Compton	1.0	2.3	20	2	0.1	8.4	11

Notes. Seed photons for IC include the CMB ($kT_{CMB} = 2.3 \times 10^{-4}$ eV, $U_{CMB} = 0.26$ eV cm^{-3}), infrared ($kT_{IR} = 3 \times 10^{-3}$ eV, $U_{IR} = 0.90$ eV cm^{-3}), and optical ($kT_{opt} = 0.25$ eV, $U_{opt} = 0.84$ eV cm^{-3}). The total energy content of radiating particles, $W_{e,p}$, is calculated for $p > 10$ MeV c^{-1}.

SNR interacting with Molecular Cloud: (2) SNR W44

- Middle-aged (~ 2.0×10^4 yr) Distance: ~ 3 kpc
- Mixed-morphology SNR (radio: shell, thermal X-ray: center filled)

VLA 324 MHz

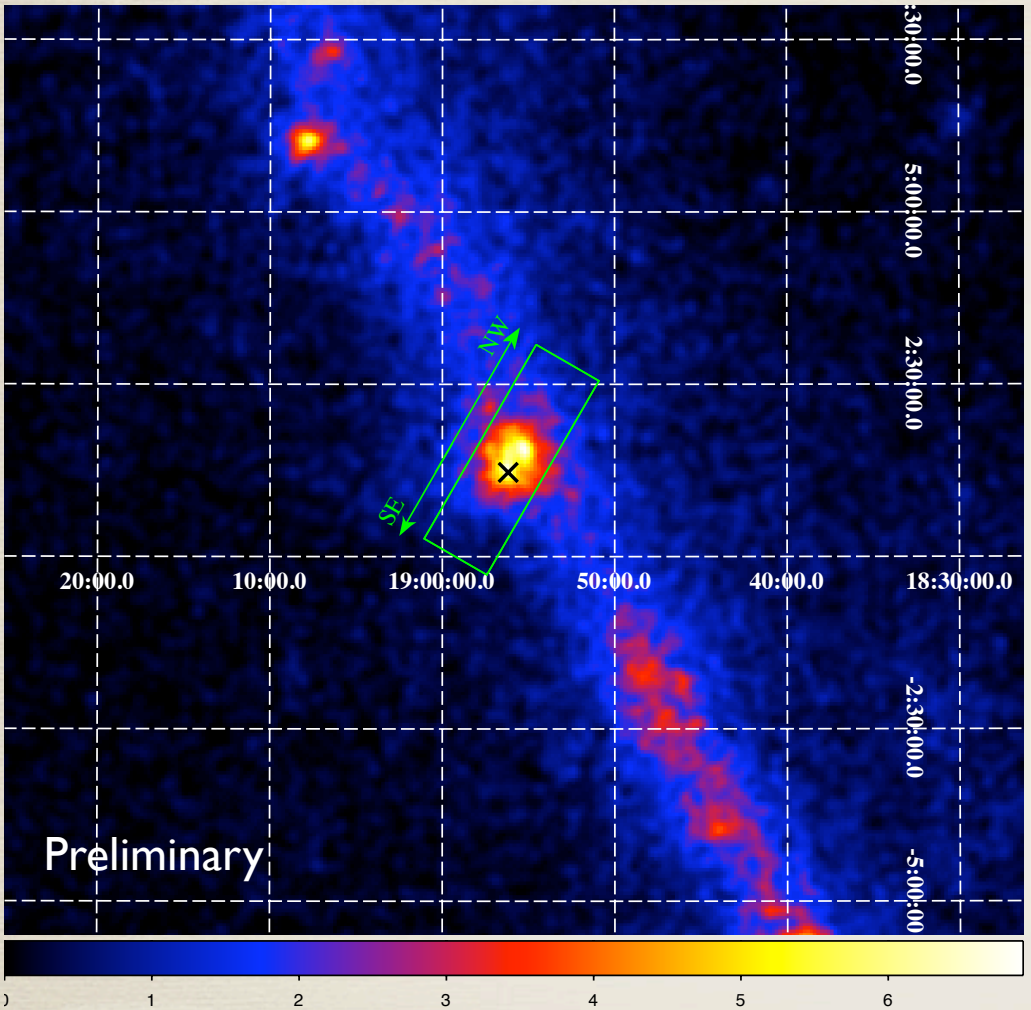


Spitzer 4.5 um

(shocked molecular gas)

Spatial Extension

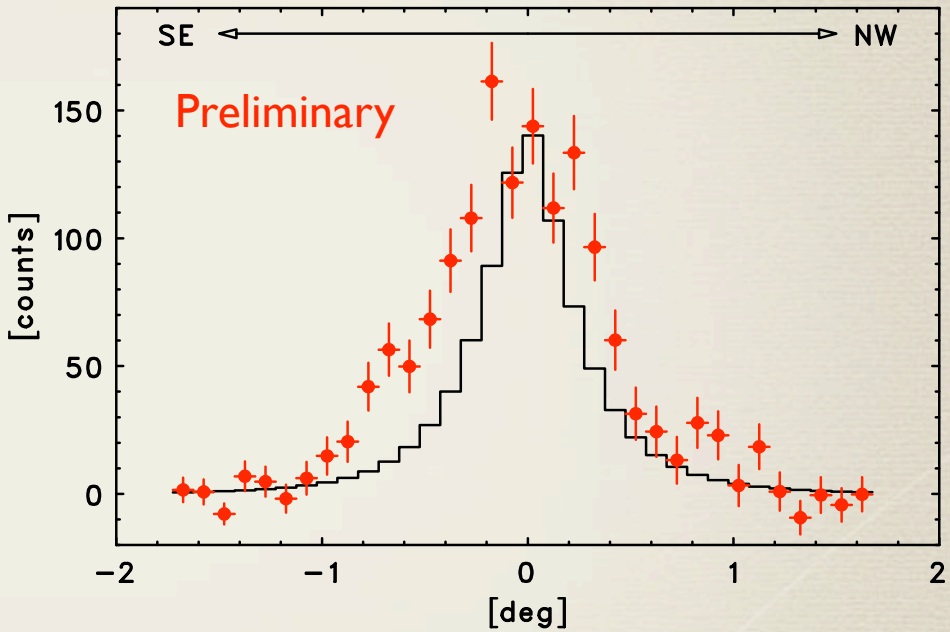
Smoothed Count Map (> 1GeV)



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

Summary

- **Young SNRs**
  - Cas A
    - Magnetic field: B>0.12mG
    - CR contents: (1-5)x10^{49} erg
  - RXJ1713.7-3946
    - Hard gamma-ray spectrum
- **Middle-Aged SNRs with Molecular Cloud Interactions**
  - W51C
    - Large luminosity 1x10^{36} erg/s
    - Likely of hadronic origin
    - Spectral steepening (escape? wave damping?)
  - W44
    - Similar to W51C
    - Shell-like is suggested