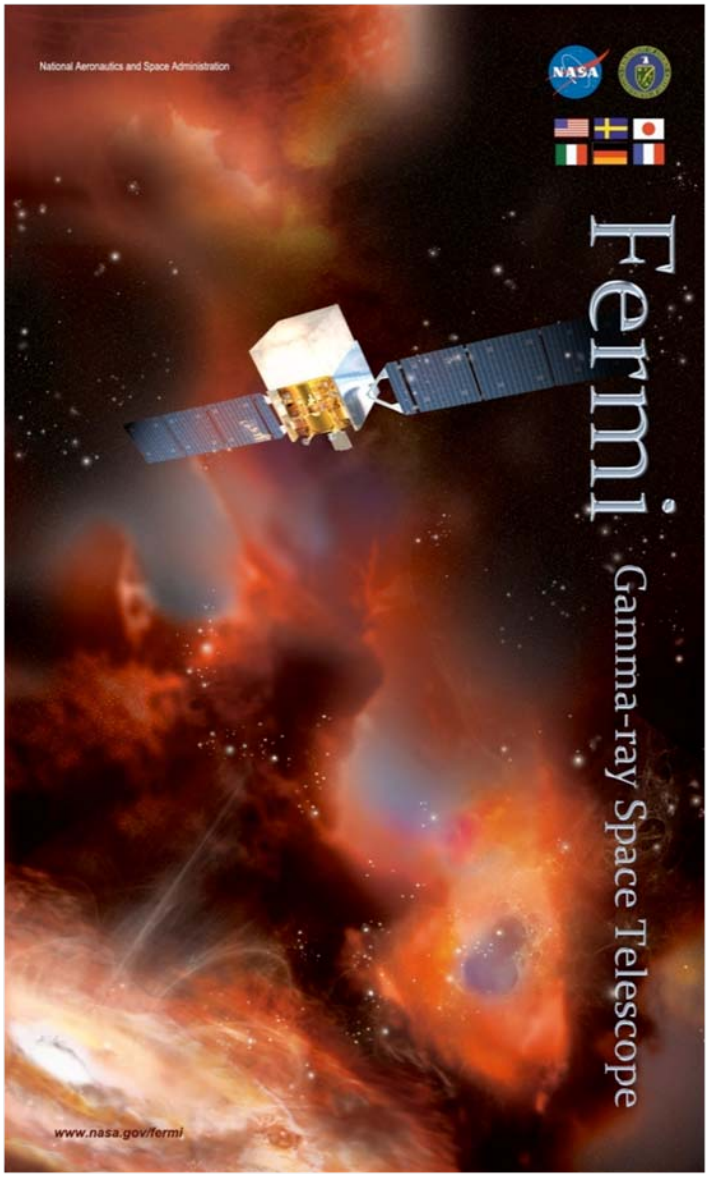


Fermi LAT Observations of GeV Gamma Rays from Supernova Remnants

Hide Katagiri
(Hiroshima Univ)
on behalf of Fermi LAT collaboration

Nov 16, 2010

Gamma-ray astronomy workshop@ICRR

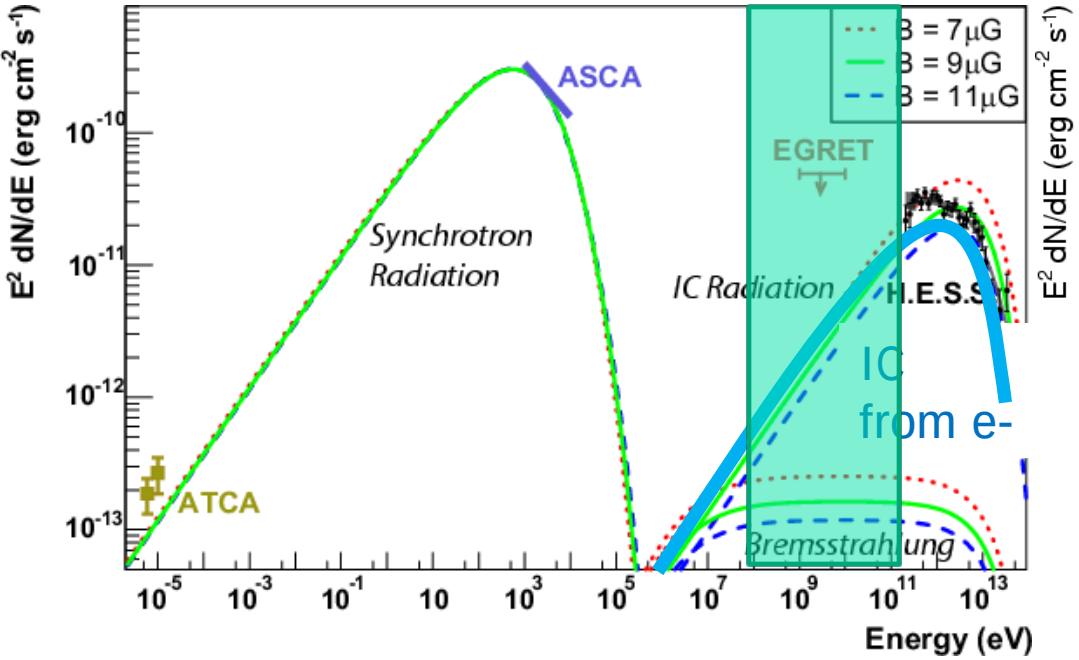
Observations of GeV gamma rays from SNRs

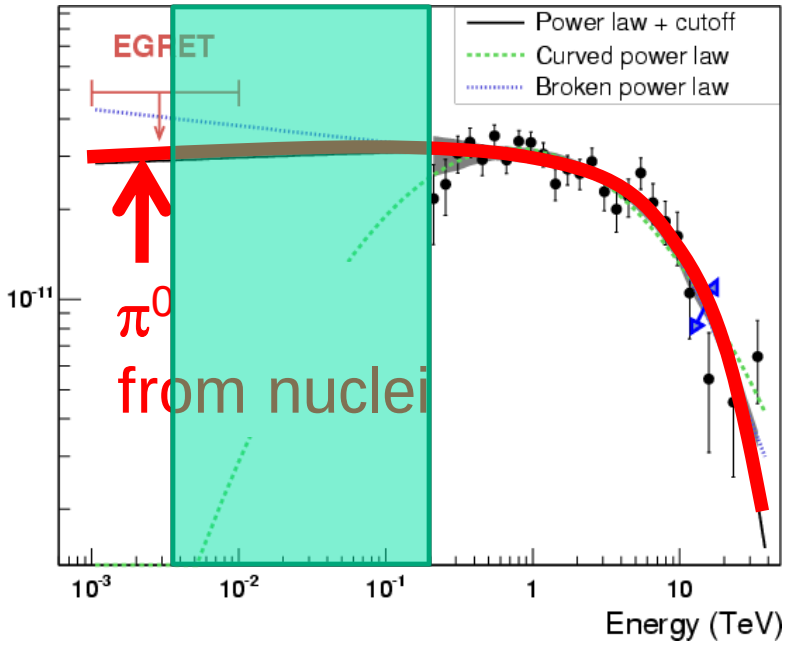
SNR RX J1713.7-3946

Aharonian et al. (2006)

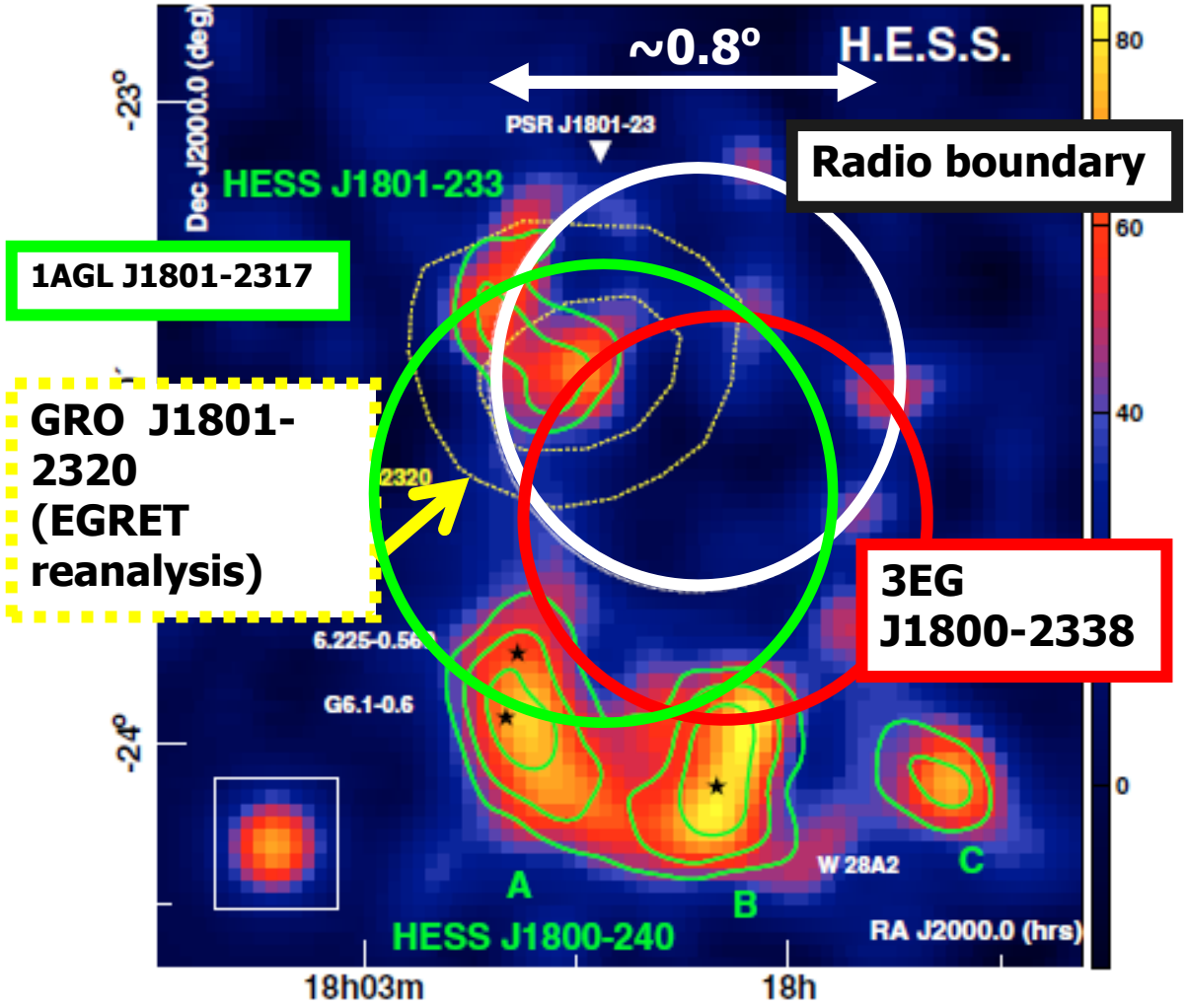
Leptonic model

Hadronic model





- **Observations of GeV gamma rays are crucial for study of cosmic-ray acceleration in SNRs**
  - **Parent particles, momentum spectrum, diffusion…**



Before the Fermi-LAT ~ SNR W28 case

- Green contours: 4, 5, 6 sigmas of the HESS TeV emissions

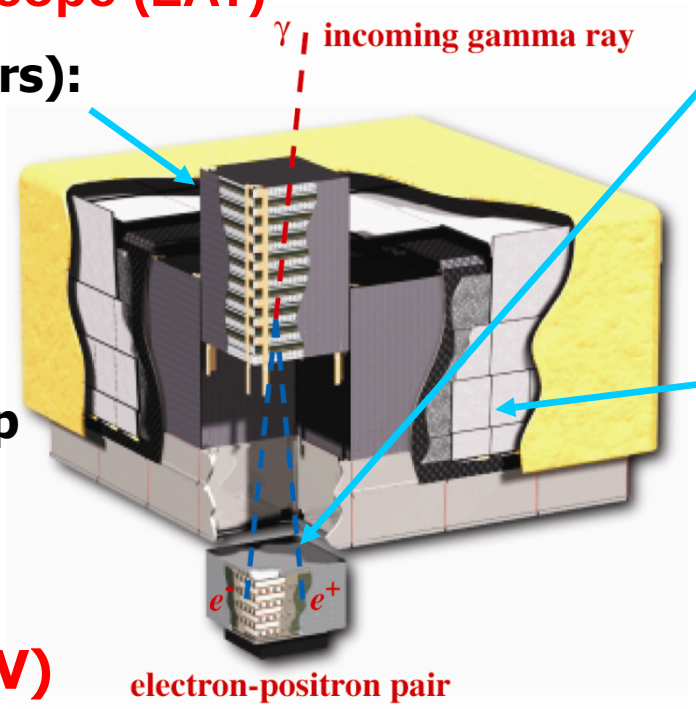
- The uncertainty of position determination accuracy ~ 1deg. due to degree-scale PSF and low statistics
- Point-source or extended?
- Spectral studies at > a few GeV are limited due to the small effective areas.

Fermi Gamma-ray Space Telescope

- International collaboration between US, Europe, and Japan
- Launched on June 11 2008 (its science data is public now)
- Consists of LAT and GBM

Large Area Telescope (LAT)

Tracker (16 towers):
- Pair conversion telescope
  → Tungsten conversion foils
- Measures e^-/e^+ track with Si-strip detectors



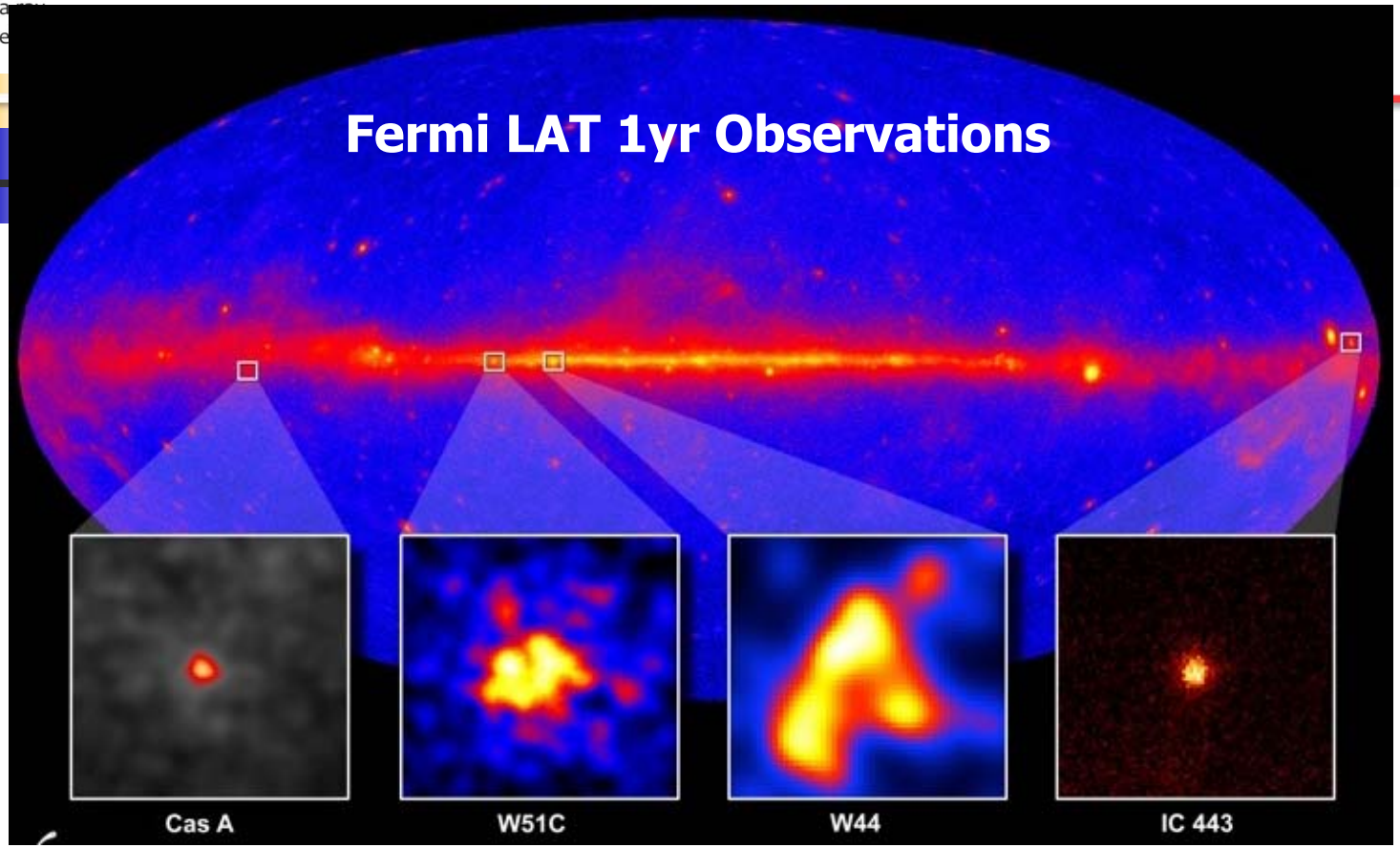
Calorimeter:
-1536 CsI crystals
-Measures photon energy

Anti-coincidence detector:
- Segmented
- Vetos CR background

- Better PSF (~0.6°@1GeV)
- Large Eff. Area & 2.4 sr FoV
- ~20 MeV < E < ~300 GeV

→
- Source ID & extension
- Emission mechanism

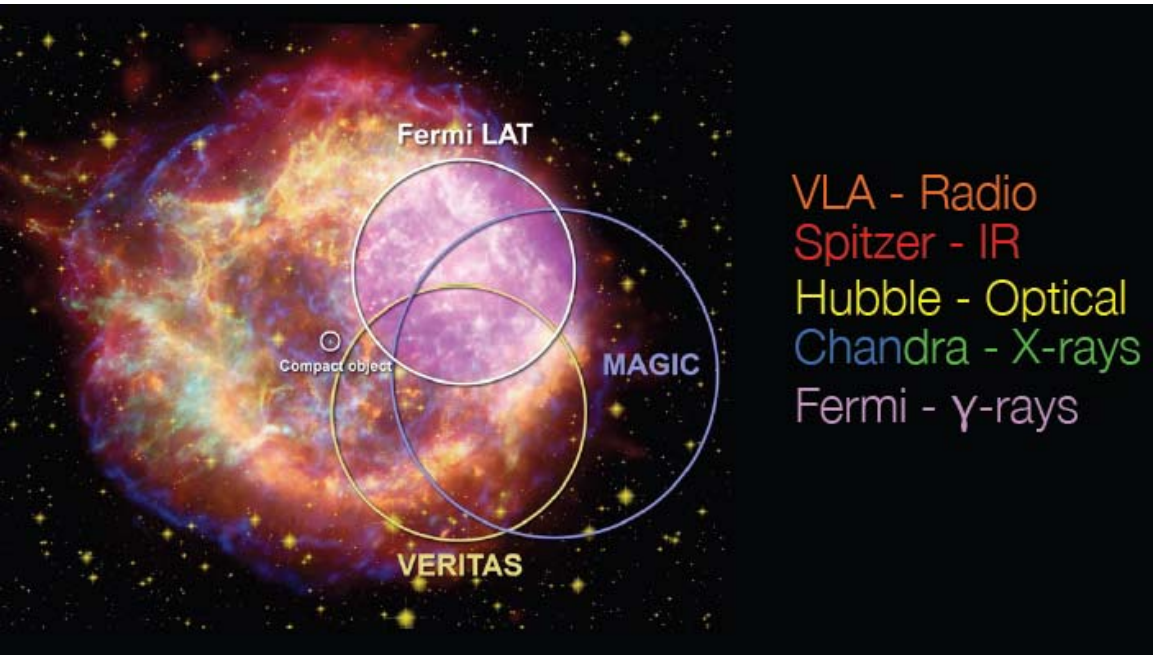
GeV-emitting SNRs



- 10 SNRs so far (W28, W49B, RX J1713-3946, G8.7-0.1, …)
- Two categories
  - Young (<~2000yr) SNRs (Cas A, RX J1713-3946)
  - Relatively old SNRs with molecular clouds (W28, W44, W49B, W51C, IC443, etc.)

Young SNR ~ Cas A

- Historical supernova: age=330yr
- The brightest radio source in our Galaxy
  -> efficient particle acceleration
- TeV gamma rays detected by HEGRA, MAGIC, VERITAS



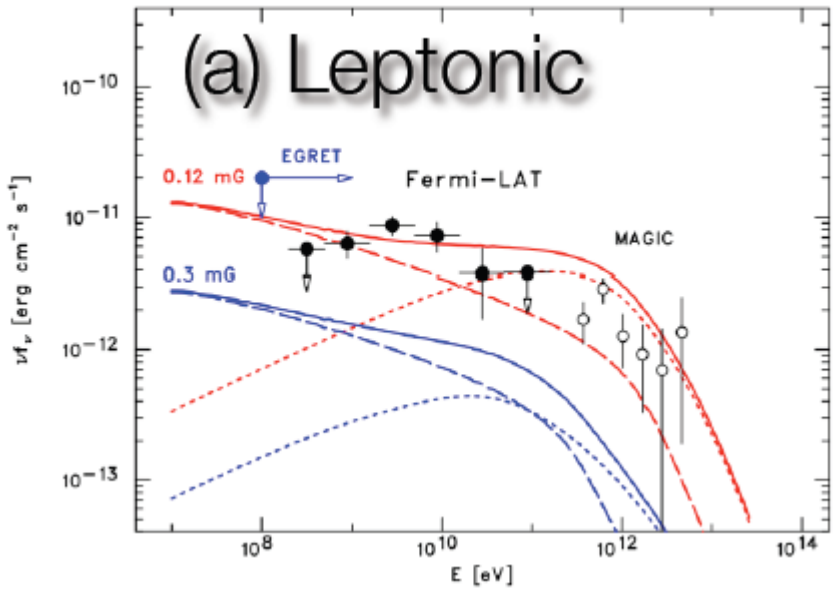
- Cannot be distinguished on positional grounds
- No gamma-ray pulsation, no time variability
- No pulsar-like cutoff on the spectrum

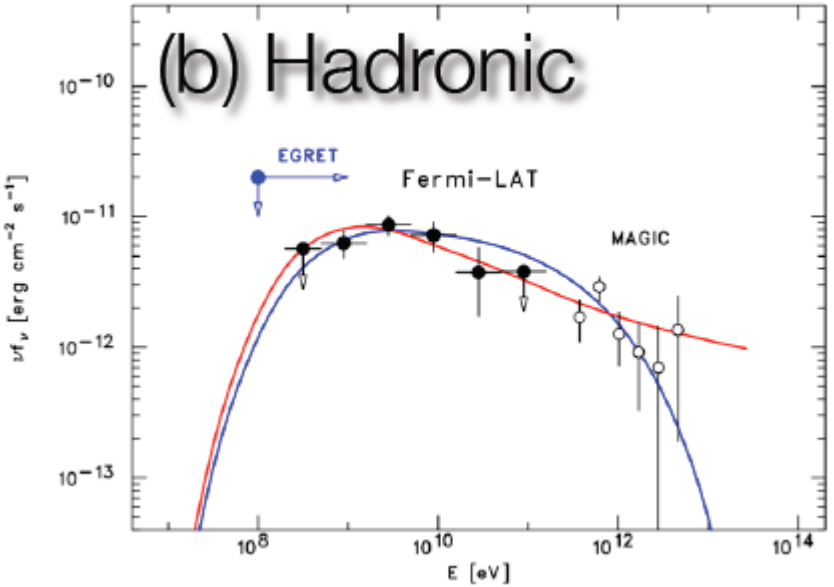
GeV gamma rays
~ from the SNR shells.

5’

Abdo et al. (2009)
Corresponding Authors (CAs): Funk, Uchiyama

Spectrum of Cas A

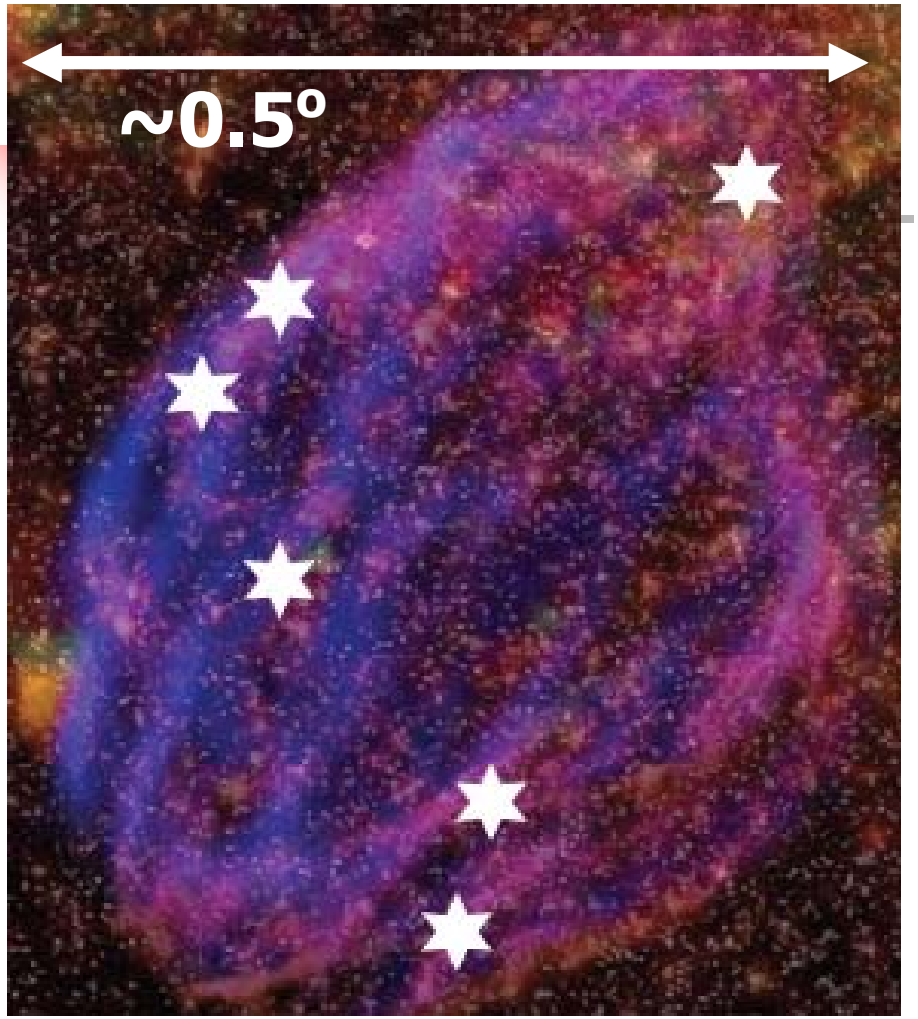




- **Leptonic scenario (Brems + IC):**
  - **B = 0.12 mG, We=1×10^{49} erg**
- **Hadronic scenario (π0 decay):**
  - **B > 0.12 mG, Wp=3×10^{49} erg**
  - **Good fit with proton spectral index ~2.3**
  - **(red) or ~2.1 (blue) with cut-off at 10 GeV**

- **The hadronic scenario can better fit the data (but not conclusive due to the systematics)**
- **$W_{CR(e+p)}$=1-4×10^{49} erg regardless of the parent particles.**
- **B > 0.12 mG -> B amplification at the shock**

Castelletti+07



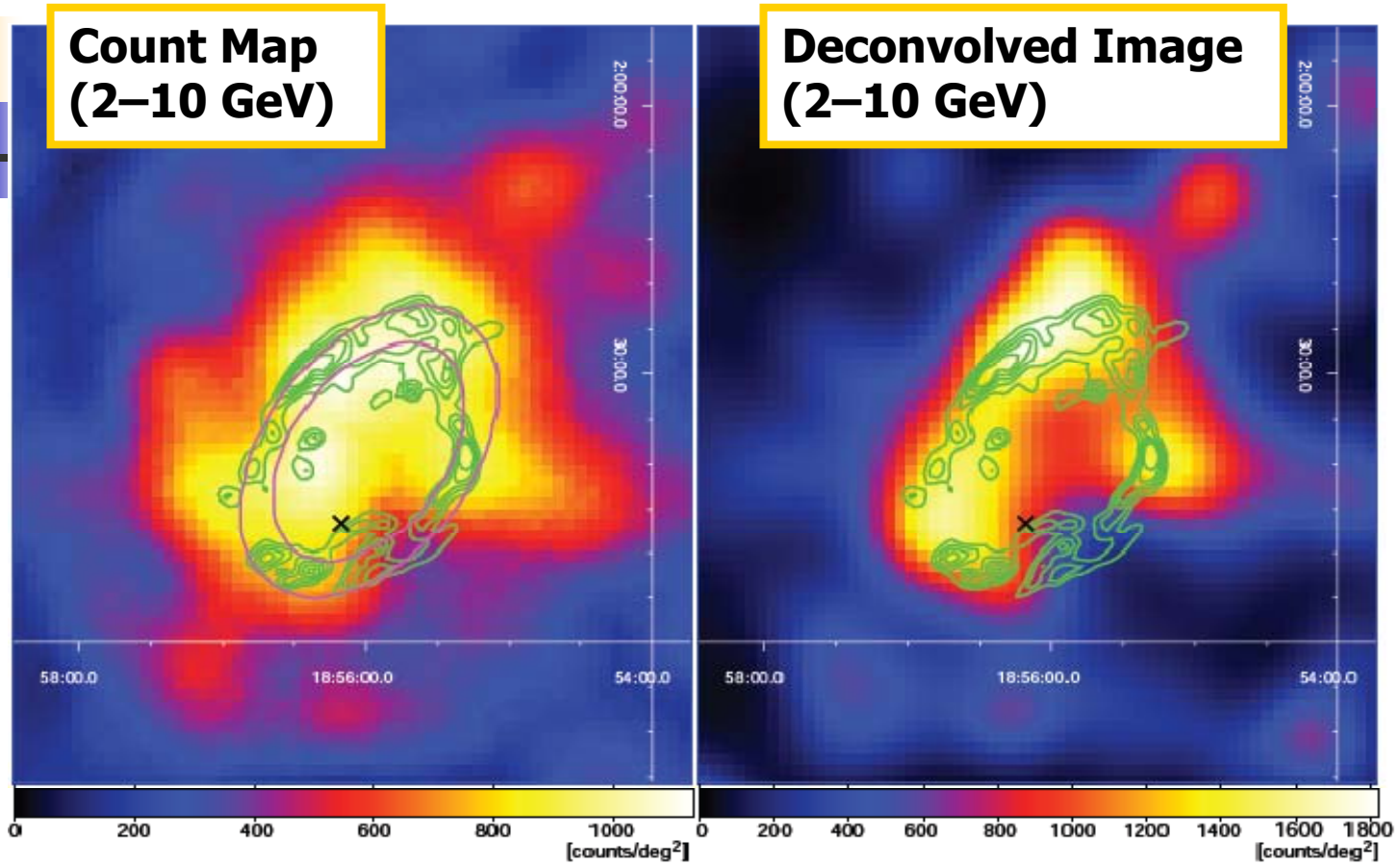
W44

- Mixed morphology SNR
- Age ~2 x 10^4yr
- Distance ~3kpc
- Interactions with molecular clouds

Lines from H2 gas (Spitzer)
Radio synchrotron (VLA)
★ OH masar spots

LAT view

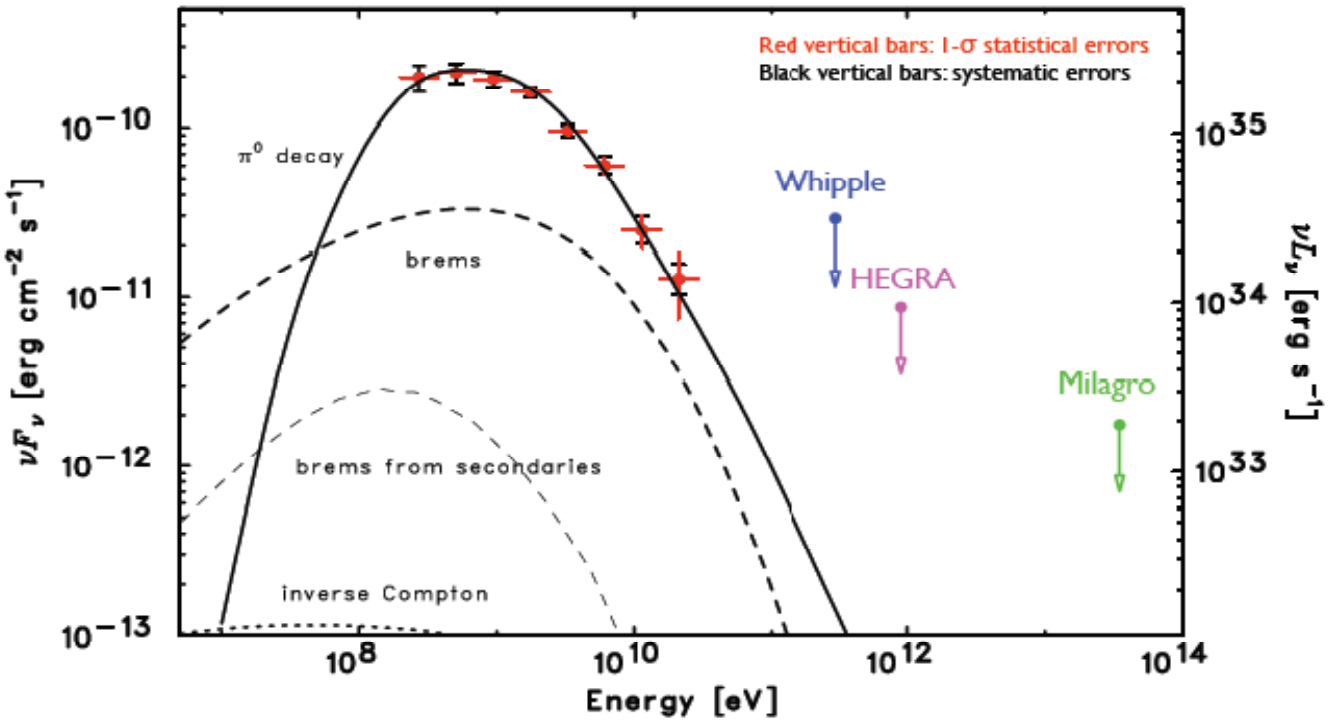
Abdo+10
(CAs: Tanaka, Uchiyama, Tajima)



Black cross: location of PSR B1853+01, Green contours: Spitzer IRAC 4.5 μm

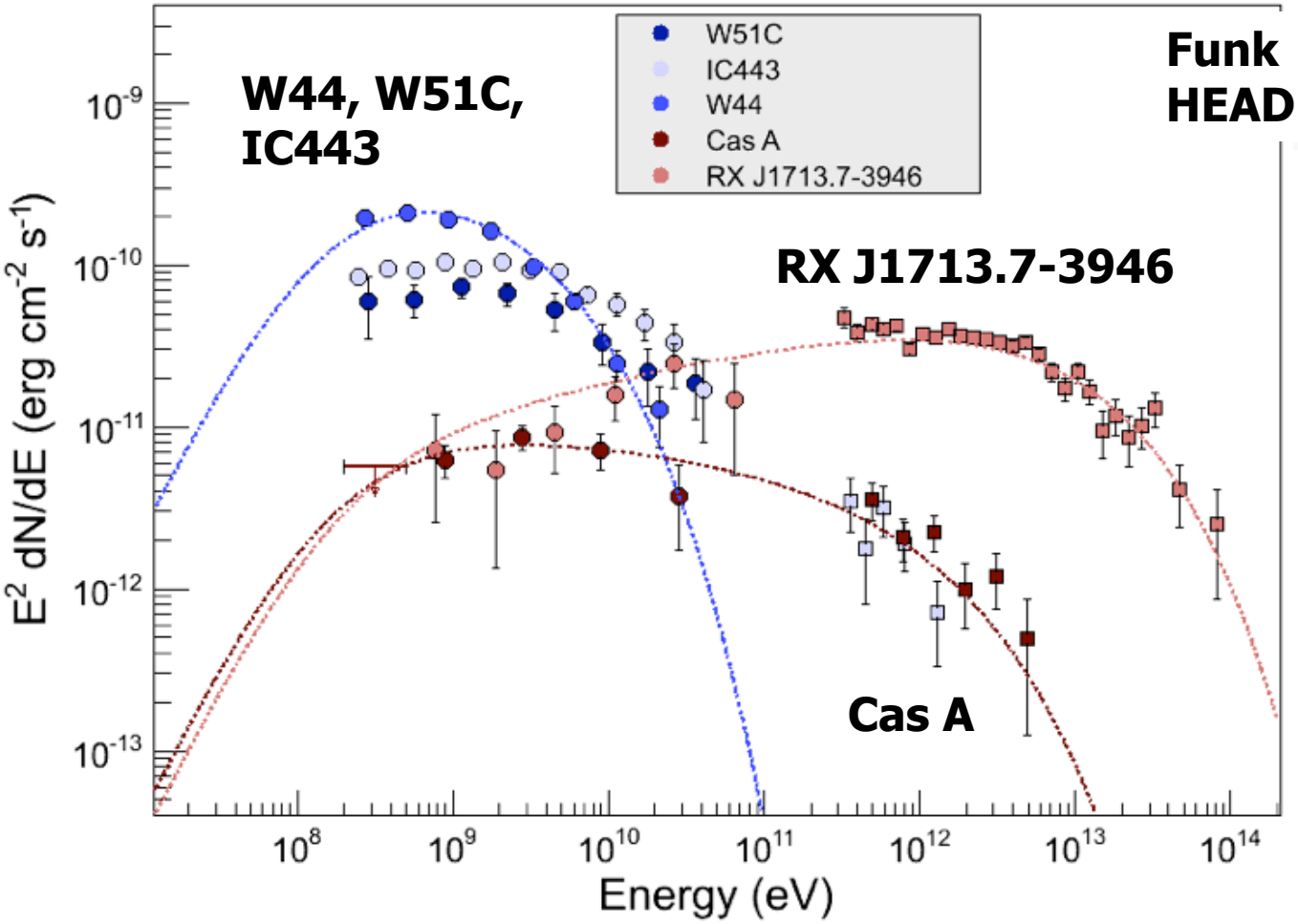
- Results of maximum likelihood analysis also prefer ring-like morphology rather than centrally filled morphology (> 8 σ)

LAT spectrum & modeling



- π^0-decay model can explain the data well
  - Leptonic scenarios have difficulties
    - Brems: difficult to reconcile with the radio data
    - IC: large amount of electrons ($\sim 10^{51}$ergs)
- Protons need to have a spectral break at ~ 10 GeV/*c*
  - Possible explanation:
    Fast escape of high energy particles with damping of magnetic turbulence due to the dense environment (e.g. Ptuskin & Zirakashvili 2003)

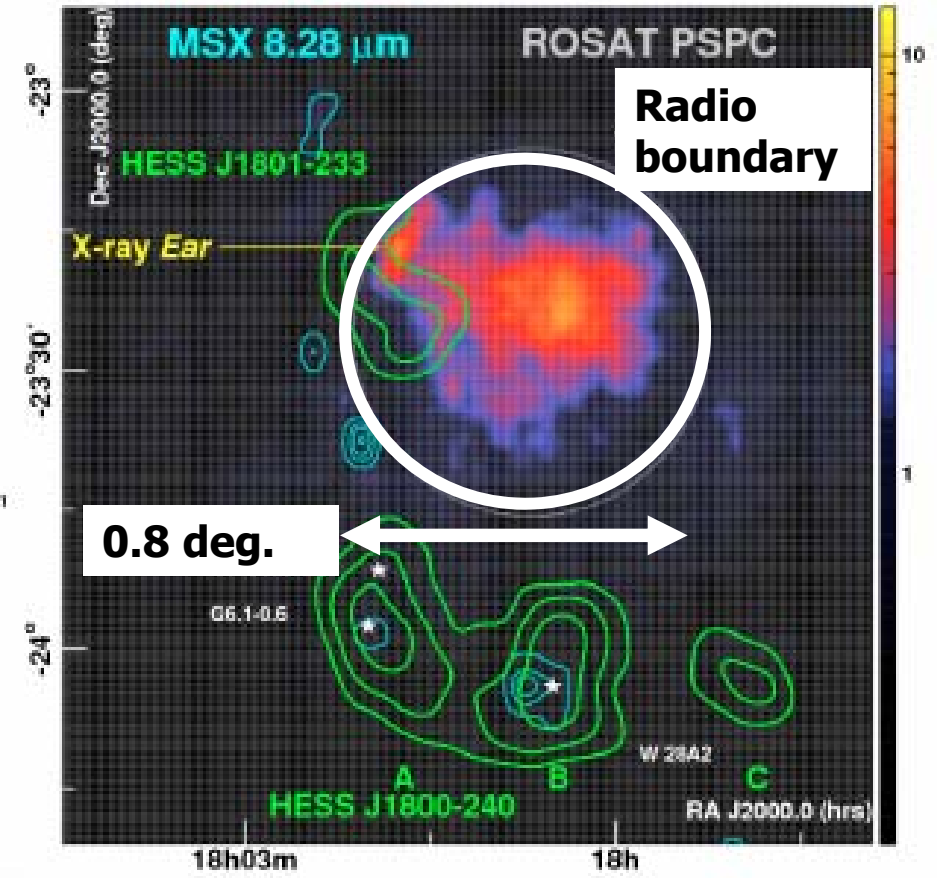
Comparison of energy spectra



- **Different evolutionary stages allows us to probe how particles are accelerated and later released into the Galaxy**

W28 (G6.4-1.0)

ROSAT X-ray images
with HESS TeV contors

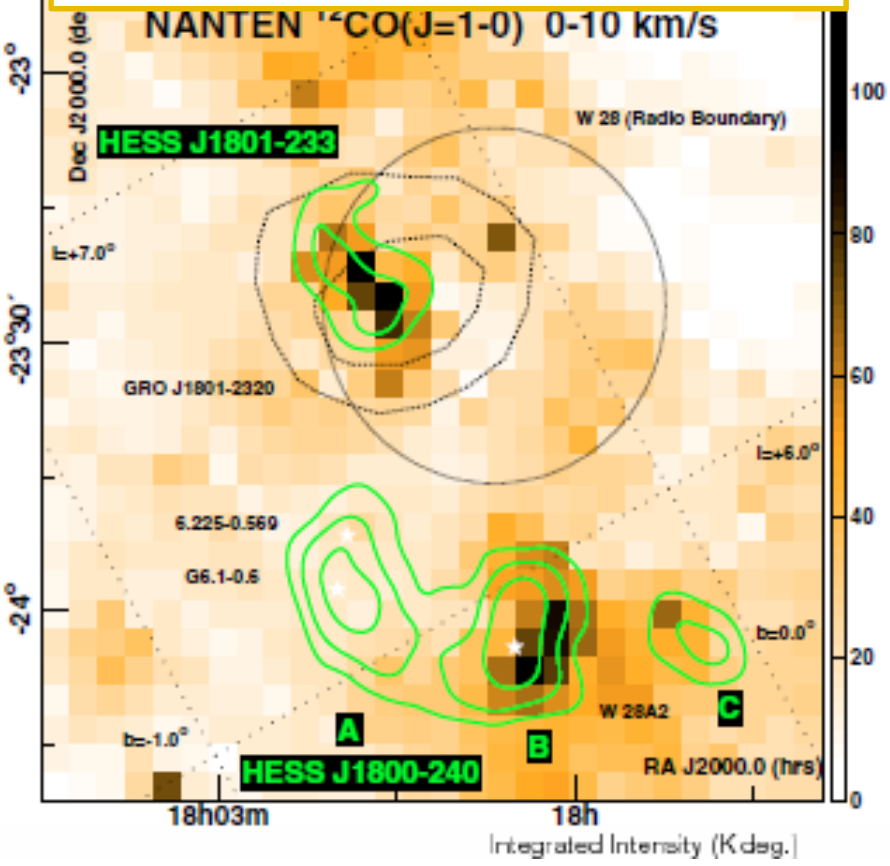


- **Mixed-morphology SNR**
- **Old age ~35000-150000yr**
- **Distance 1.8-3.3kpc**
- **TeV detected by HESS**
- **South TeV sources are spatially coincident with star forming regions.**

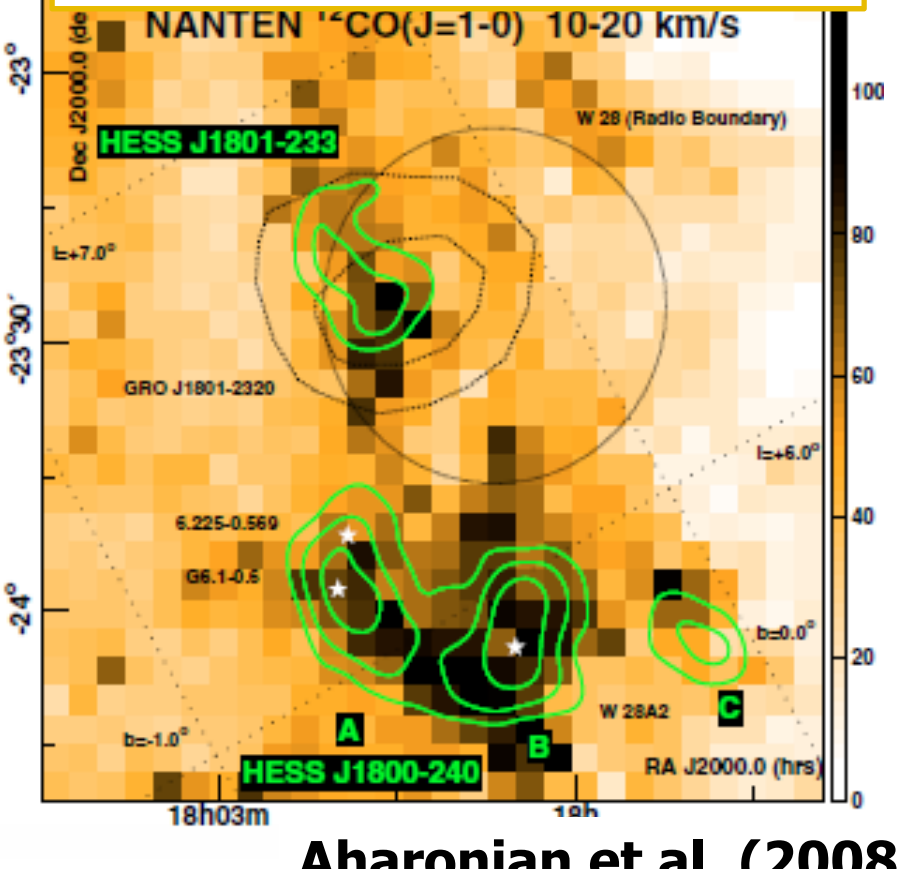
Aharonian et al. (2008)

Association with molecular clouds

NANTEN 12CO(J=0-1) 0-10km (0 – 2.5 kpc)



NANTEN 12CO(J=0-1) 10-20km (2.5 – 4 kpc)

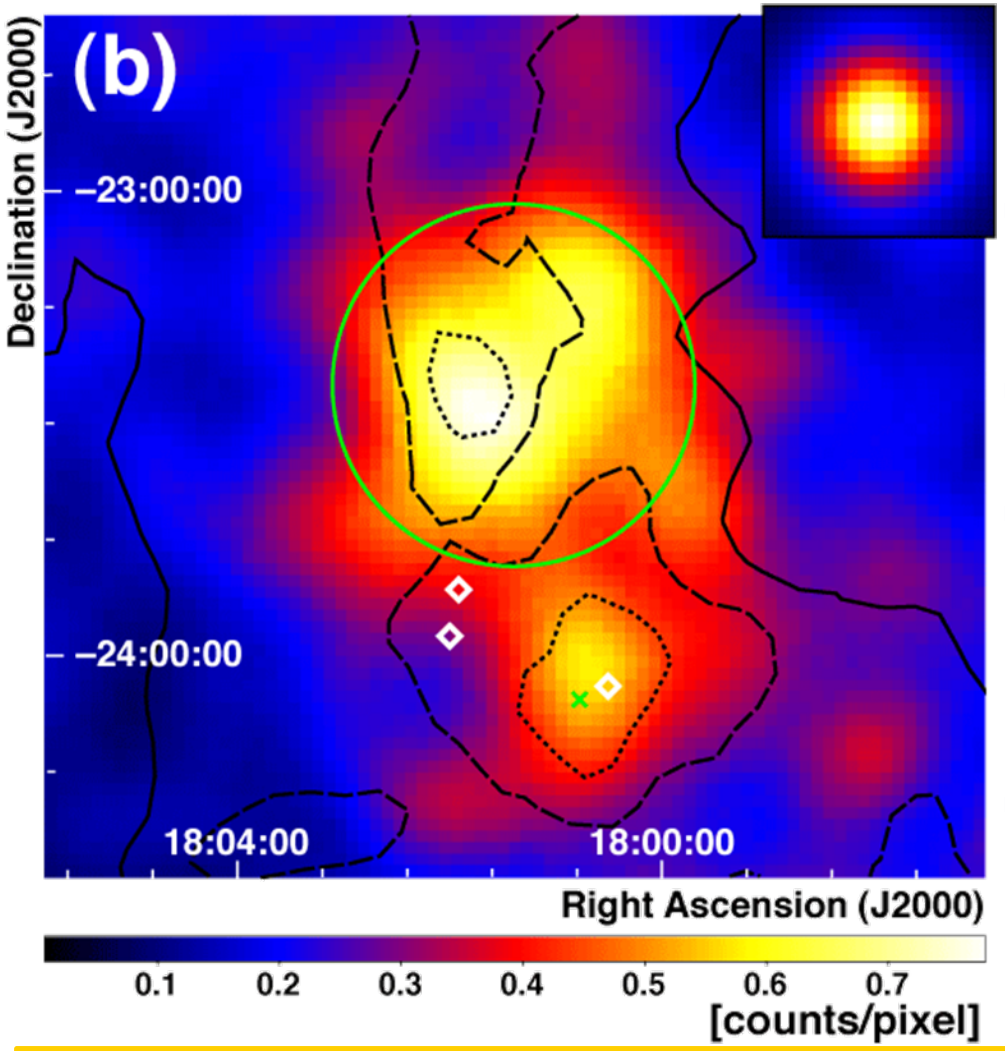


Aharonian et al. (2008)

Most outstanding in the gamma-ray (HESS) – CO correlation among SNRs.

LAT view

2-10GeV with NANTEN CO(J=1-0) contours

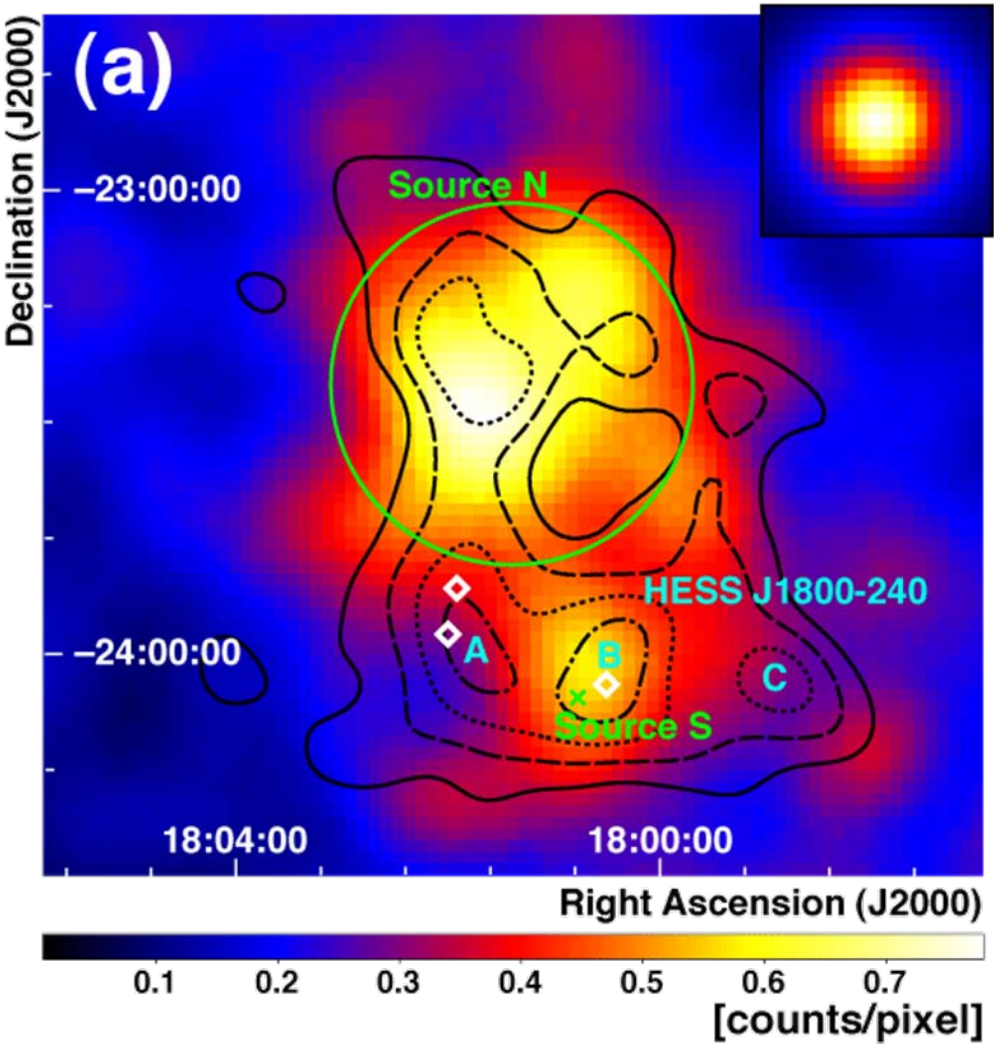


Abdo+10 (CAs: Katagiri, Tajima, Tanaka, Uchiyama)

- **The GeV emission is extended, overlapping with molecular clouds**
- **Spectral steepening with a break ~1GeV.**
- **π^0-decay in dense molecular gas provides a reasonable explanation for the broadband gamma-ray spectrum (similar to W44, etc.).**
- **The compact HII region W28A can be a possible energy source with extremely high density (~10^7/cc).**

•Mosaic: FERMI(1pixel=0.025deg. Smoothing Gaussian kernel=0.2deg.)
•Contours: NANTEN (CO J=1-0) v=0-20km/s (25, 50,75%)
•Diamonds : HII regions

2-10GeV with HESS contours



Comparison with TeV

- **Upper limits in the GeV band on HESS J1800-240A, C**

•Mosaic: FERMI(1pixel=0.025deg. Smoothing Gaussian kernel=0.2deg.)
•Contours: HESS excess map (20, 40, 60, 80%) with smoothing (Gaussian kernel=0.1deg.)
• A,B,C=HESS J1800-240A,B,C , Diamonds : HII regions

Runaway CRs?

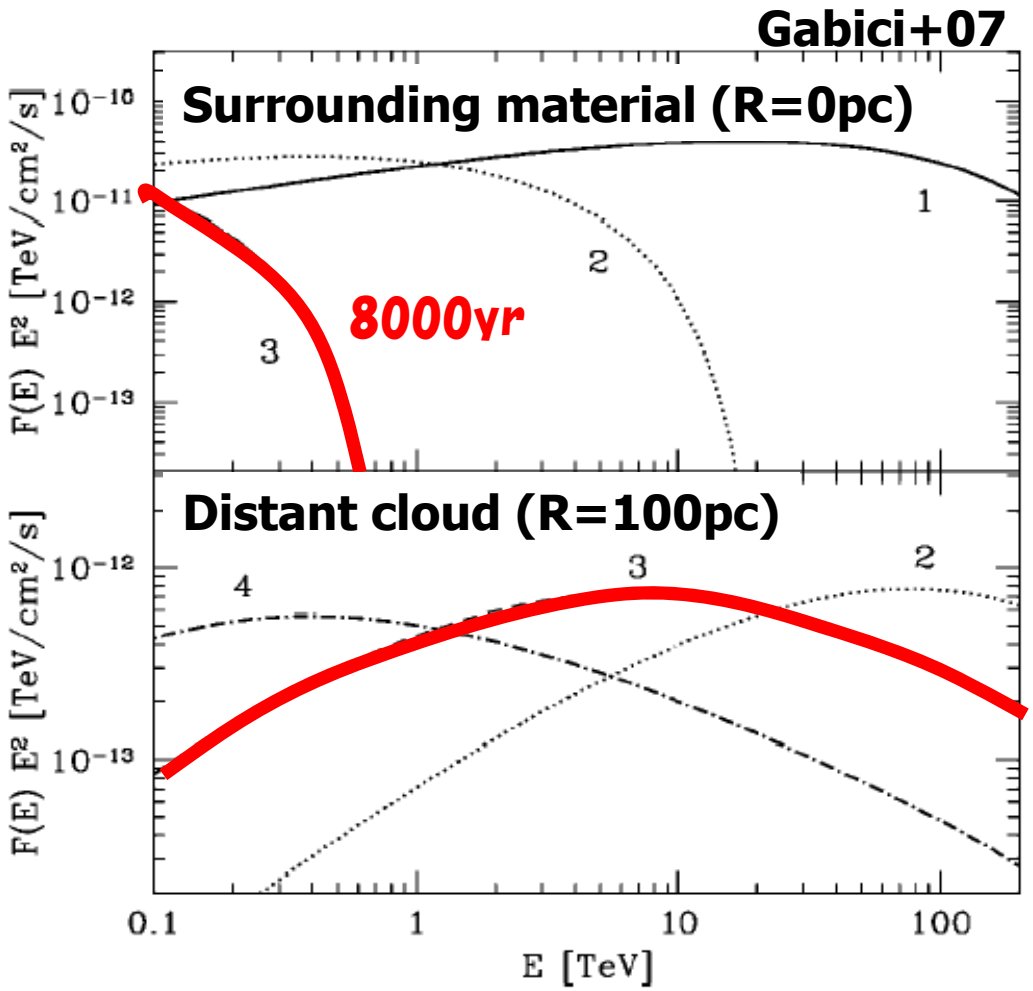


FIG. 1.—Gamma-ray spectra from the SNR (*top*) and from a cloud of $10^4\ M_\odot$ located 100 pc away from the SNR (*bottom*). The distance is 1 kpc. Curves refer to different times after the explosion: 400 yr (*curve 1*), 2000 yr (*curve 2*), 8000 yr (*curve 3*), and 3.2×10^4 (*curve 4*) yr.

- **Nearby clouds (surrounding material)**
  - **GeV > TeV**
- **Distant clouds**
  - **GeV < TeV**

GeV-TeV spectrum allow us to study CR diffusion.

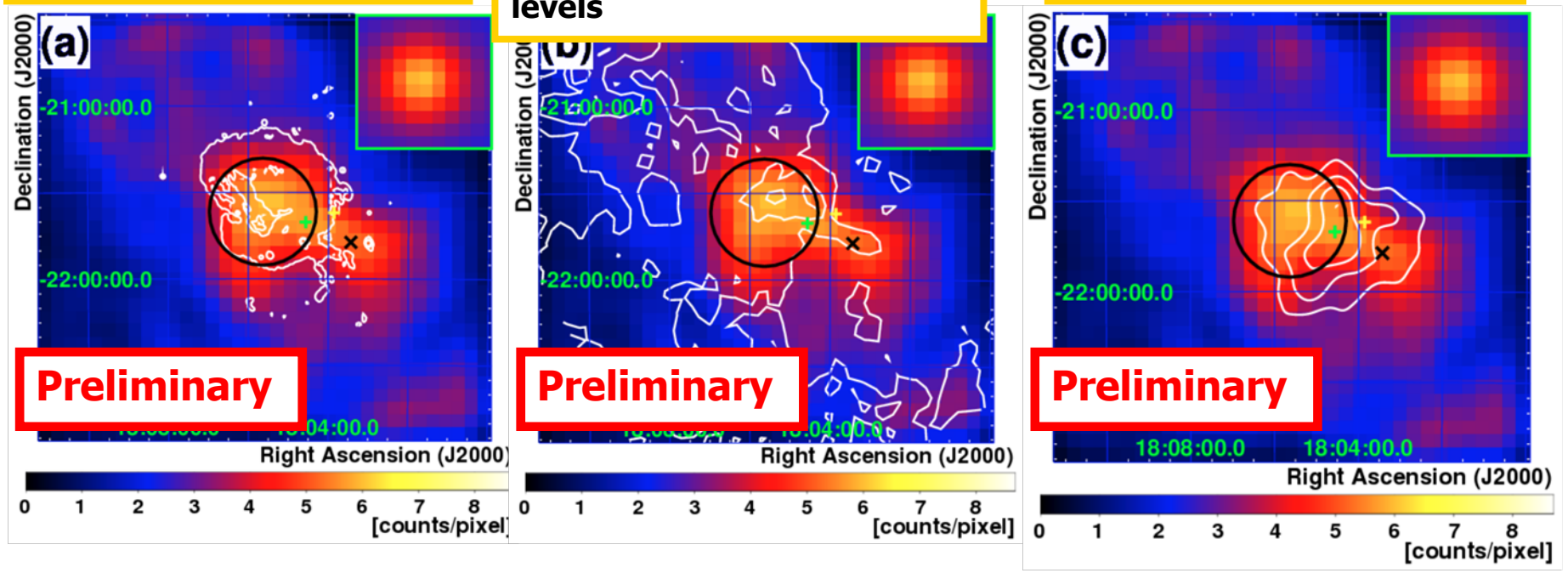
SNR with TeV & MCs ~G8.7-0.1

Abdo et al. (CAs: Hanabata, Katagiri), to be submitted

VLA 90cm contours with 5, 15 and 25% levels

NANTEN CO (J=1-0) 20-30 km/s with 25, 50 and 75% levels

HESS contours with 25, 50 and 75% levels

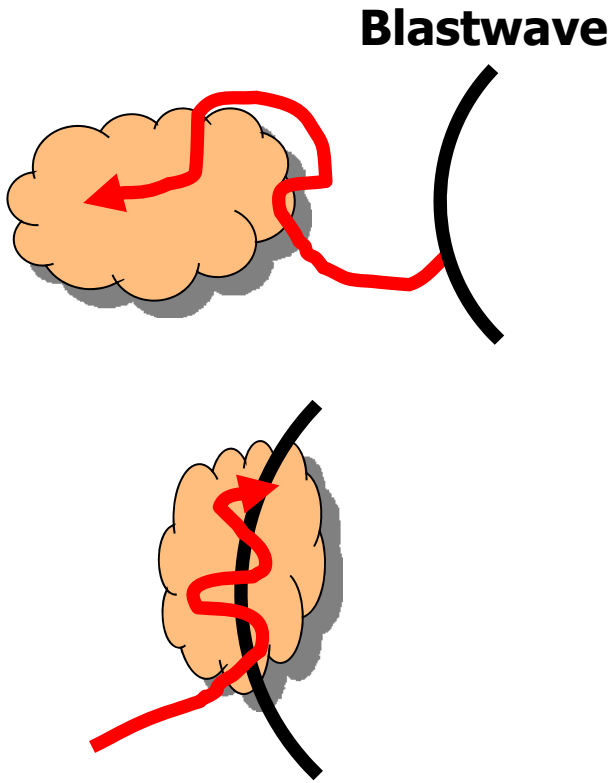


- Yellow cross: PSR J1803-2137
- Green cross: Suzaku J1804-2140

- **Extended GeV emission**
- **Spatially associated with some molecular clouds**
- **With relatively bright TeV emission (~25% Crab)**

Theoretical activities

- **Runaway CRs (e.g., Fujita+10, Ohira+10)** See Ohira-san's talk
  - CRs escaping from SNR and colliding with nearby MCs
- **"Crushed cloud" scenario (Uchiyama+10)**
  - Gamma rays coming from "cloud shock" (CRs and MC simultaneously compressed)
  - Spectral break:
    Ion-neutral collision → Damping of Alfvén wave
  - Radio-GeV correlation naturally explained
- **Etc.**



Summary of the LAT SNRs

Compiled by Uchiyama

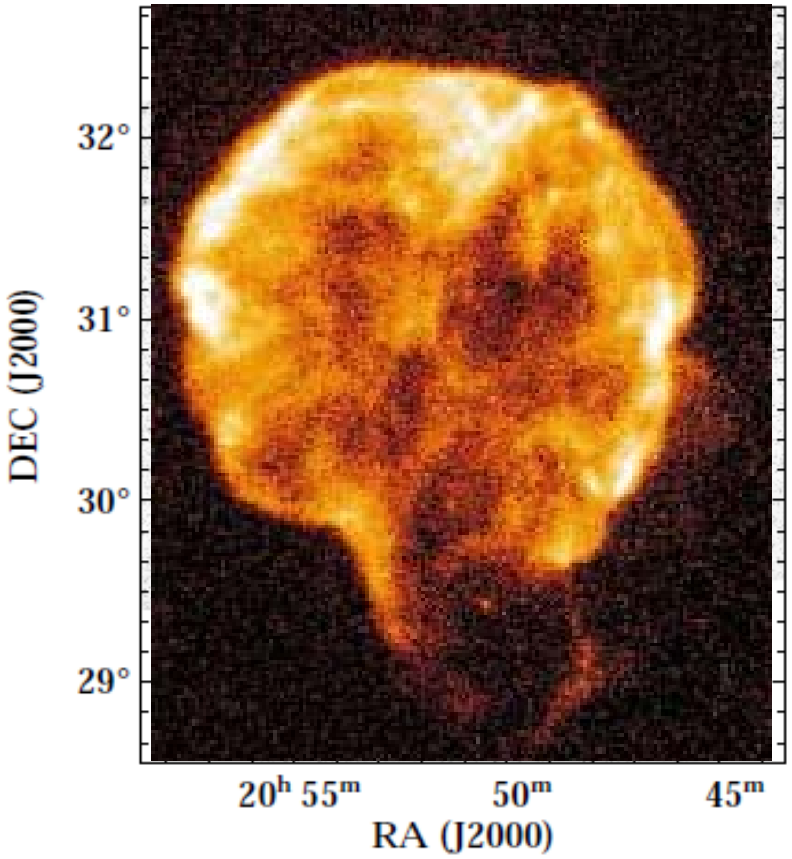
Object	Diameter	Age	Cloud Interaction	L_γ 1-100 GeV
Cas A	5 pc	330 yr	No	4×10^{34} erg/s
W49B	10 pc	~3000 yr	Yes	9×10^{35} erg/s
3C 391	15 pc	~6000 yr	Yes	6×10^{34} erg/s
G349.7+0.2	17 pc	~6000 yr	Yes	9×10^{34} erg/s
IC 443	20 pc	~10000 yr	Yes	8×10^{34} erg/s
W44	25 pc	~10000 yr	Yes	3×10^{35} erg/s
W28	28 pc	~10000 yr	Yes	9×10^{34} erg/s
CTB 37A	50 pc	~20000 yr	Yes	9×10^{34} erg/s
G8.7-0.1	63 pc	~30000 yr	Yes	8×10^{34} erg/s
W51C	76 pc	~30000 yr	Yes	8×10^{35} erg/s

References: Abdo+2009, 2010a, 2010b, 2010c, Castro & Slane 2010

- **Some of their emissions are well-explained by pi0 decay by making detailed discussion (spectral modeling , association, etc.).**
- **Observationally biased to SNRs with clouds so far.**
- **Deeper observation would provide less-biased samples.**

Fainter SNRs with deeper observations ~ Cygnus Loop

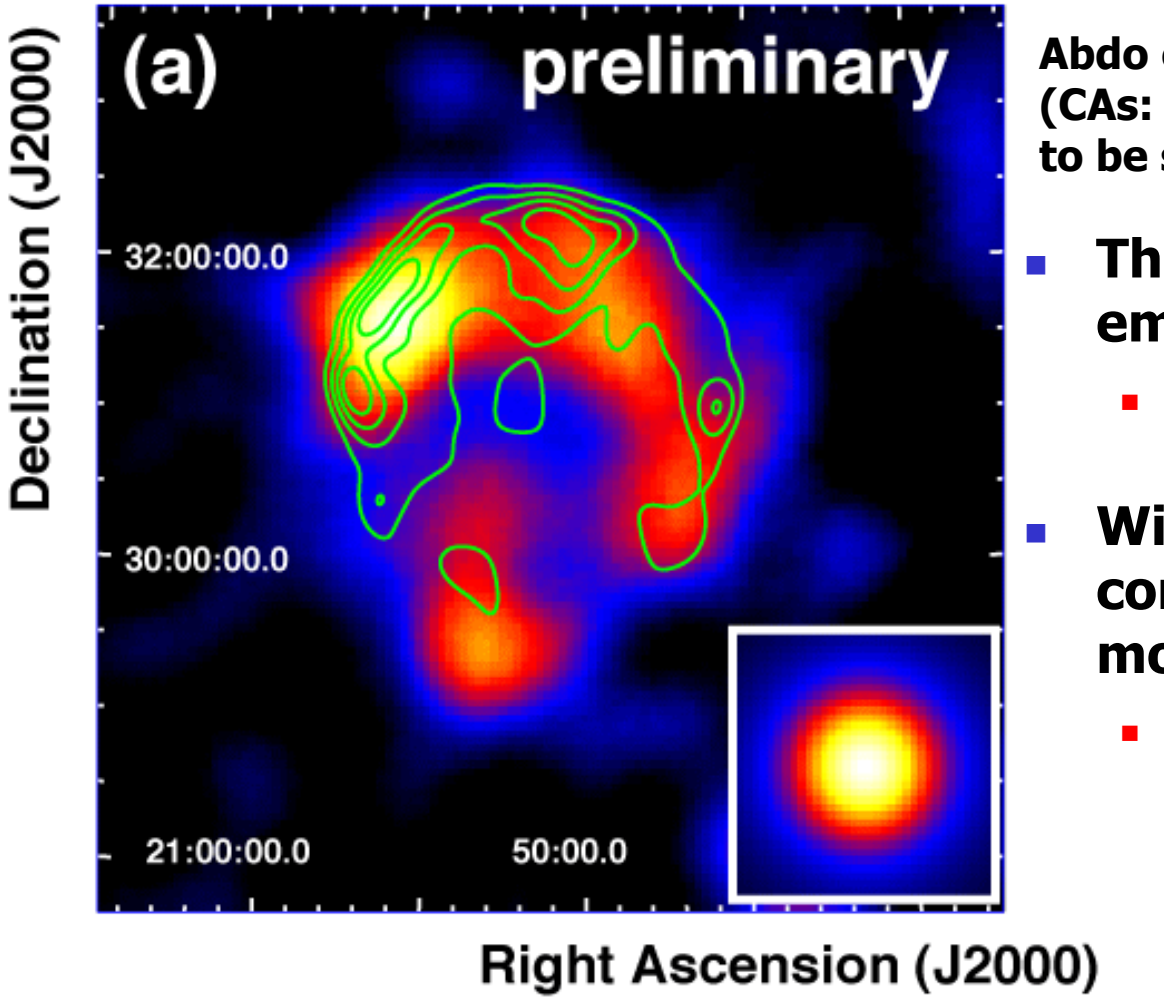
ROSAT X-ray (Aschenbach+99)



- Middle-aged shell-type SNR
- Large offset from the Galactic plane -> shock regions well-studied by IR/optical/UV
- Large size ~ 3°
  - Can be easily compared with other waveband data to study particle acceleration.
- Nearby SNR ~540pc; well-determined by optical filaments (Blair+05)
  - Could leave a unique feature in the CR electron spectrum of 1-2 TeV in the vicinity of the Earth (Koboyashi'03).

0.5-10GeV with ROSAT X-ray contours

LAT view



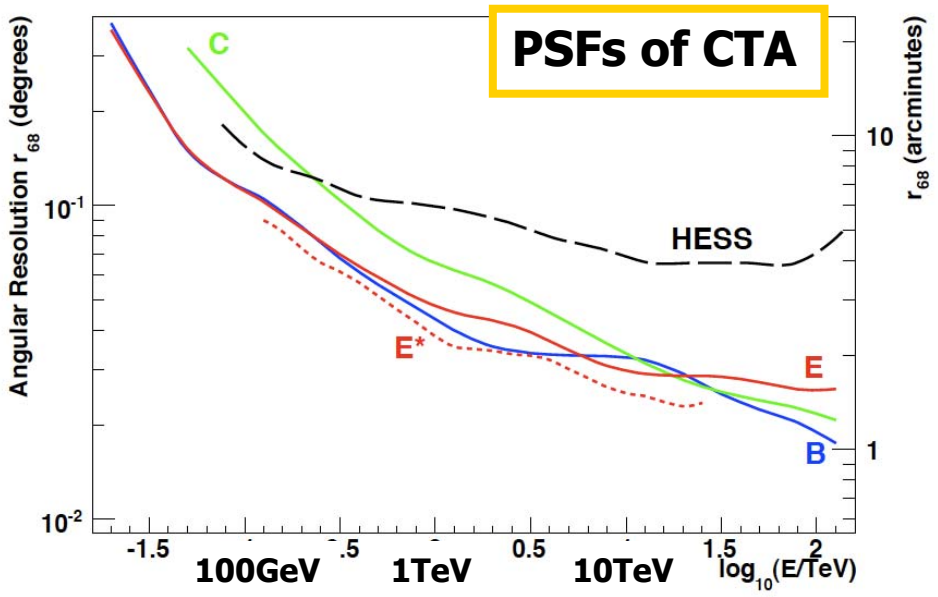
Abdo et al.
(CAs: Katagiri, Tibaldo),
to be submitted

- **The largest gamma-ray-emitting SNR**
  - **Detailed morphological study**
- **Without clear correlation with dense molecular clouds**
  - **A valuable sample for a particle acceleration**

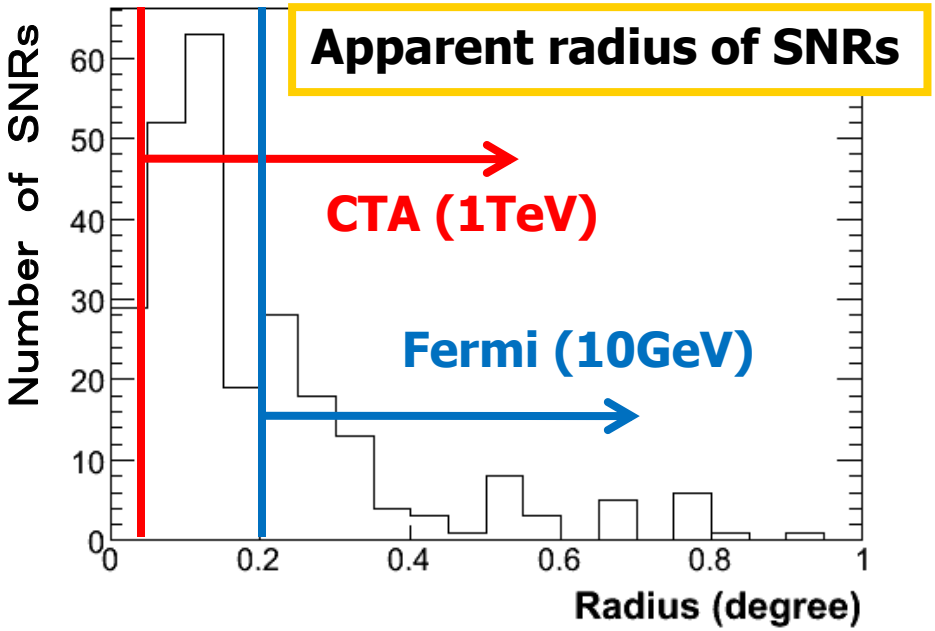
Fermi to CTA

- **Better source identifications by extension with better PSF (2′ at 1TeV)**
  - **Extension is a useful to constrain a pulsar/PWN hypothesis.**
  - **Associations with molecular clouds, shells, etc.**
- **Sensitivities of current TeV experiments are not sufficient to search for all SNRs in our Galaxy.**
  - **Most of SNRs would have a steep spectrum, except for young ones.**

See Bamba-san's talk (including some quantitative estimations)



*** C, B, E are configurations of telescope arrays.**



Summary

- **The Fermi-LAT detected GeV gamma rays from ~10SNRs with 2yr data.**
- **Two types:**
  - **(1)Young SNRs, (2) relatively old SNRs with MCs.**
- **Basically gamma rays are naturally explained by π^0 decay with surrounding material or molecular clouds.**
- **CR diffusion & environment in acceleration region can be also investigated.**
- **Deeper observations would provide less-biased samples for study of CRs.**
- **The CTA will extend detailed studies of CR acceleration to much more SNRs in our Galaxy with better angular resolution & sensitivity.**