Testing Cosmic ray acceleration in young SNRs with Pass8

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for the Fermi-LAT collaboration

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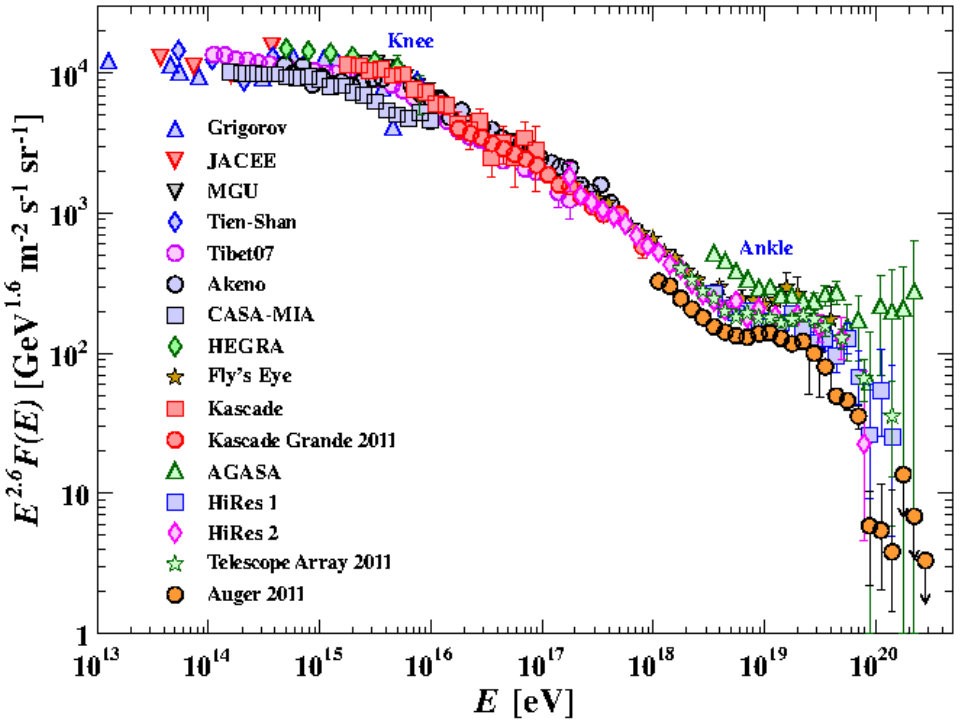
Outline

- **Supernova Remnants as Cosmic Ray accelerators in the Galaxy**

- **Two young SNRs: Tycho and Cassiopeia A**

- **Fermi-LAT data analysis and modeling**

Cosmic rays



Magnetic rigidity of the Galaxy implies a transition from galactic to extragalactic CRs at ~10^{18} eV

CR observed spectrum (below the *knee*)

$$N(E) \propto E^{-2.7}$$

$$N(E) = Q_{inj}(E)\tau_{esc}(E)$$

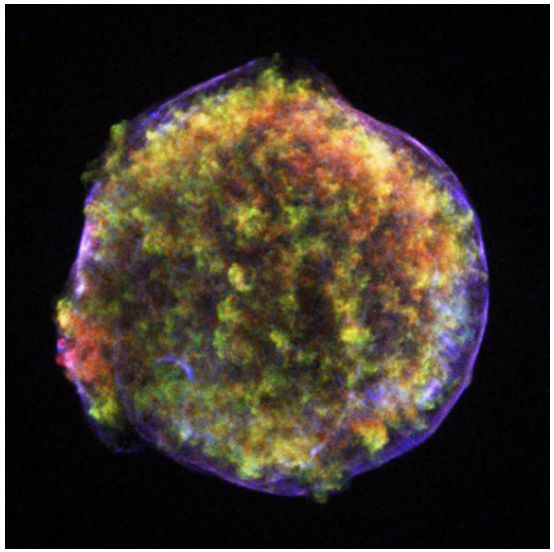
$$\tau_{esc}(E) \propto E^{-0.6 \div -0.3}$$

$$Q_{inj}(E) \propto E^{-2.1 \div -2.4}$$

from B/C ratio measurements

Close to test particle diffusive shock acceleration theory

Supernova Remnants



Tycho SNR in X-ray light
Chandra X-ray Observatory

- SN explosion energy E_{SN}~10^{51} erg
- Rate of explosion in the Galaxy R_{SN}~3 SN/century
- Confinement time of cosmic rays τ_e~10 Myr
- Cosmic-ray energy density ρ_{CR}~1 eV cm^{-3}

$$\rho_{CR} = R_{SN}\, E_{SN}\, \tau_e\, \epsilon$$

Acceleration efficiency required ε ~ 10%

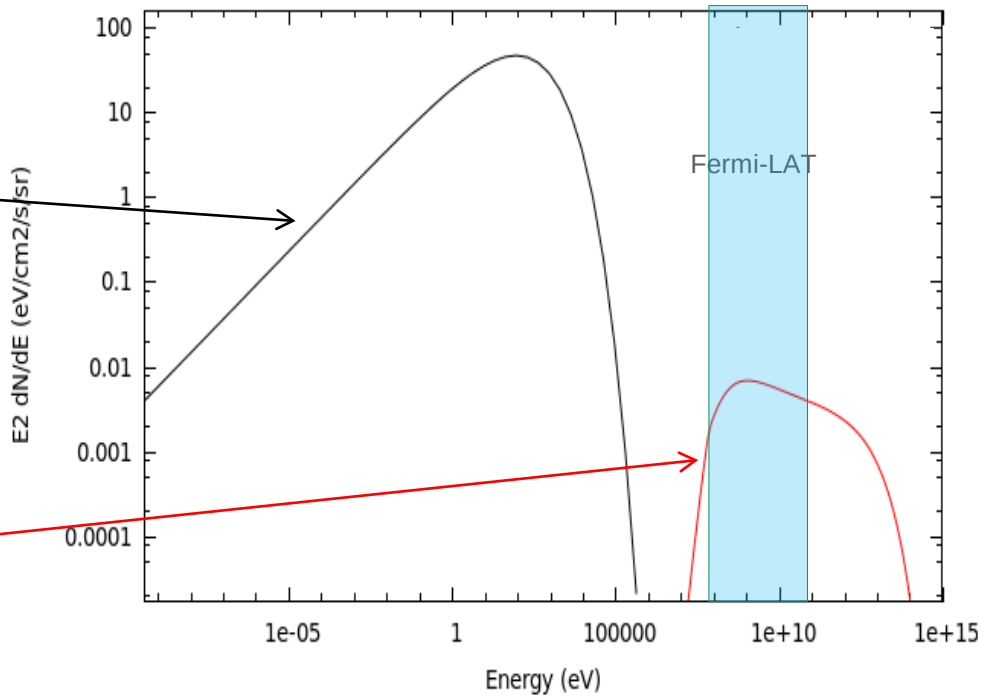
Maximum energy of acceleration ⟶ visible in young SNRs ?

$$\frac{dE}{dt} = \frac{\xi E}{T_{cycle}} \qquad E_{max} \approx 100\ TeV\ ?$$

Spectral energy distribution of SNRs

Radio to X-ray range
- Synchrotron peak

Three competitor processes for GeV-TeV energy range
- Inverse Compton
- Bremsstrahlung
- Pion decay



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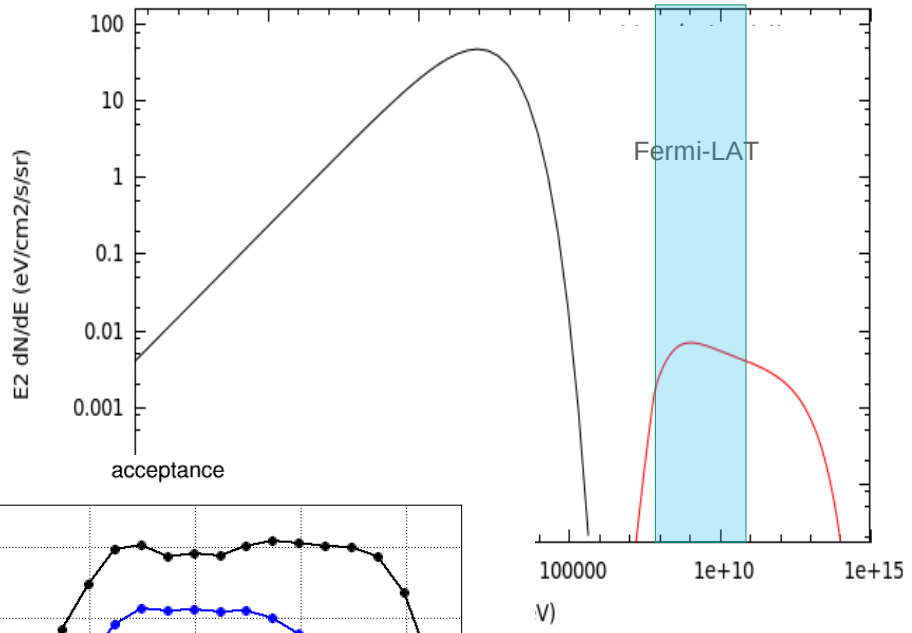
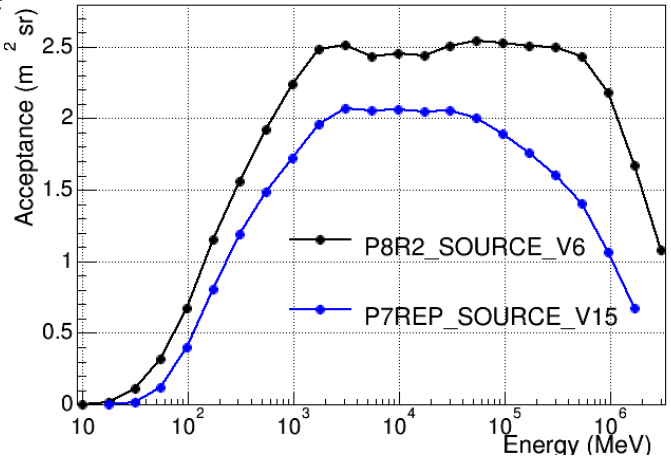
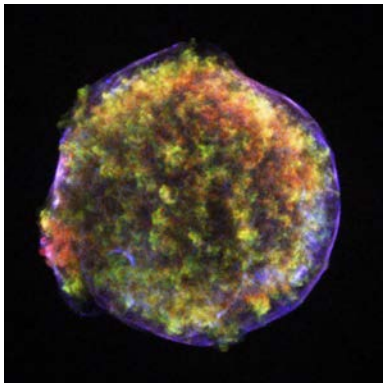


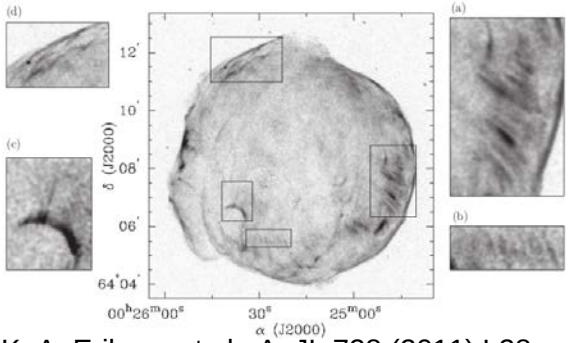


Fermi-LAT Pass8:
increased sensitivity

Tycho Supernova Remnant



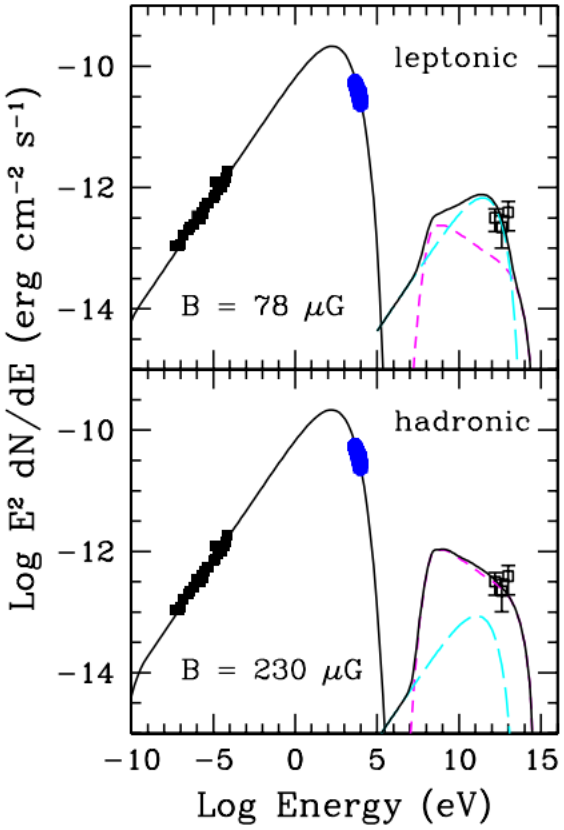
Tycho SNR observed by Chandra X-ray Observatory



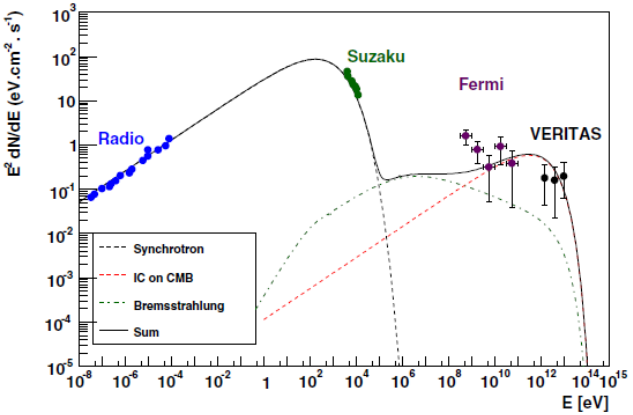
K. A. Eriksen et al., ApJL 728 (2011) L28.

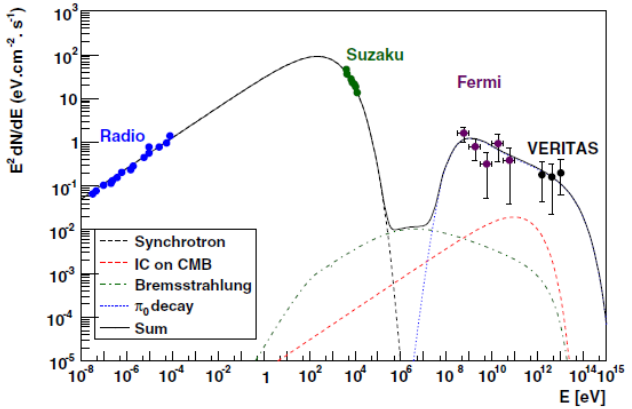
X-ray stripes observed by Chandra support acceleration of protons up to the ‘knee’ of CRs

Gamma-ray detection



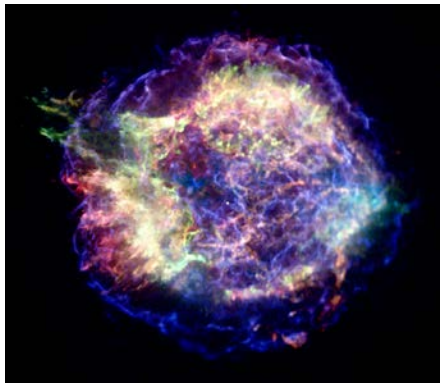
V.A. Acciari et al., ApJL 730 (2011) L20



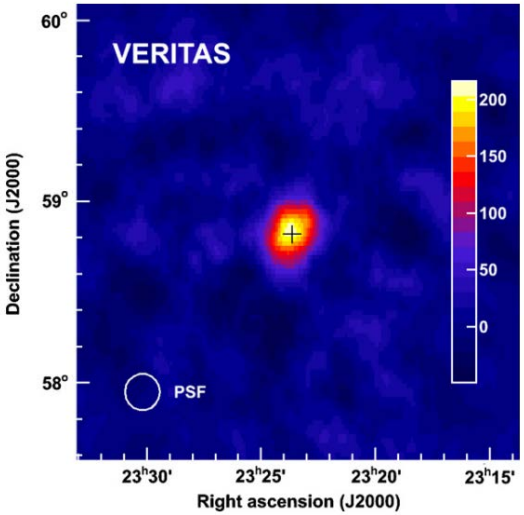


F. Giordano et al., ApJL 744 (2012) L2

Cas A Supernova Remnant



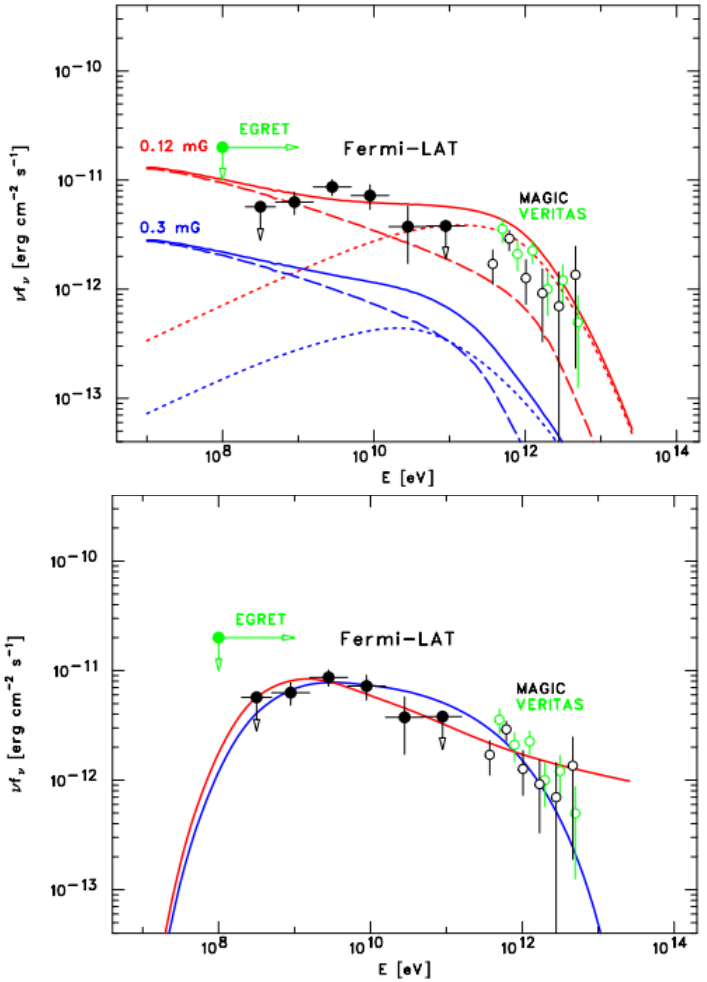
Cas A SNR observed by
Chandra X-ray Observatory



V.A. Acciari et al., ApJ 714 (2010) 163

New Veritas measurements: see poster by T.B. Humensky

Fermi-LAT detection



A.A. Abdo et al., ApJL 710 (2010) L92

Data selection

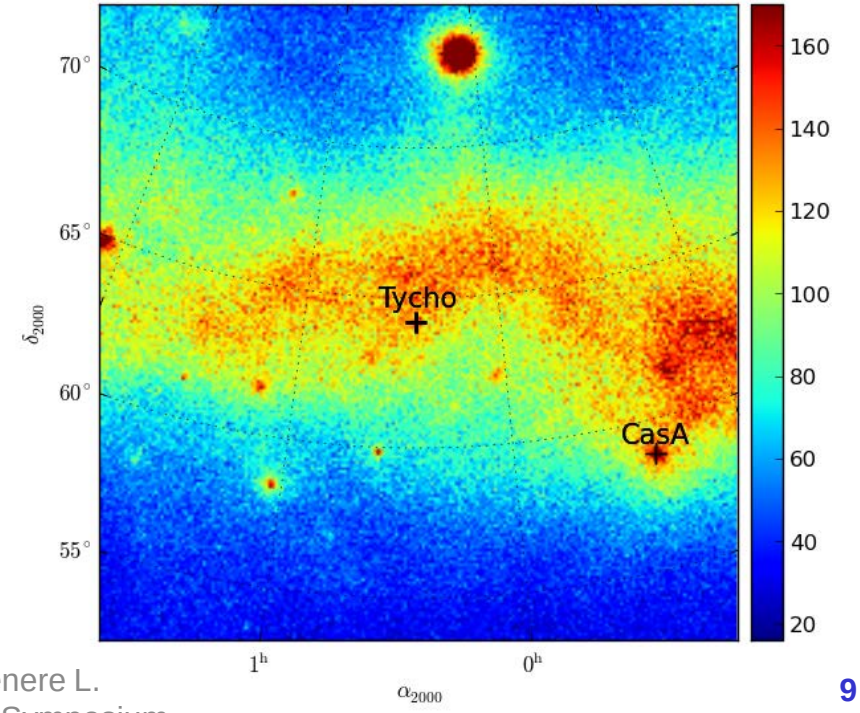
Data selection

- Pass8 data
- 78 months of data
- Energy range: 100 MeV - 100 GeV
- Two separate 15° ROIs for Tycho and Cas A

ROI model

- Pass8 scaled diffuse models
- 3FGL point sources

PRELIMINARY



Tycho analysis

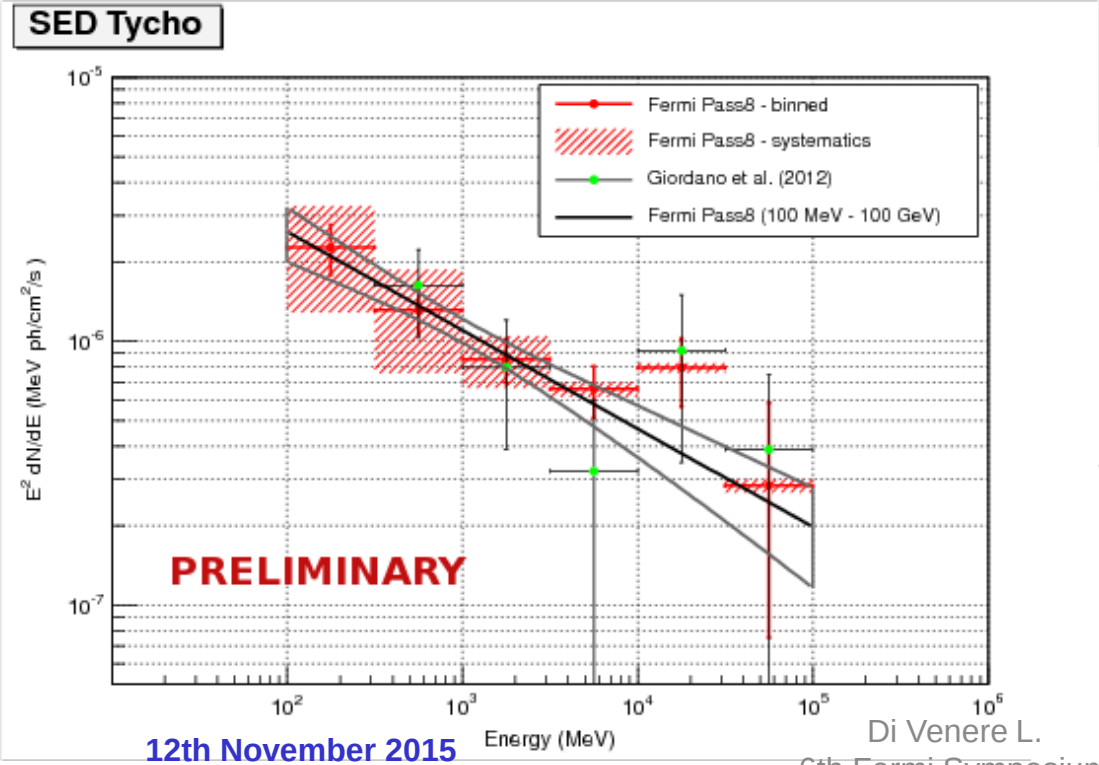
Binned analysis

- **2 bins per decade**
- **Systematics evaluated using different diffuse models** (de Palma et al. ICRC2015)

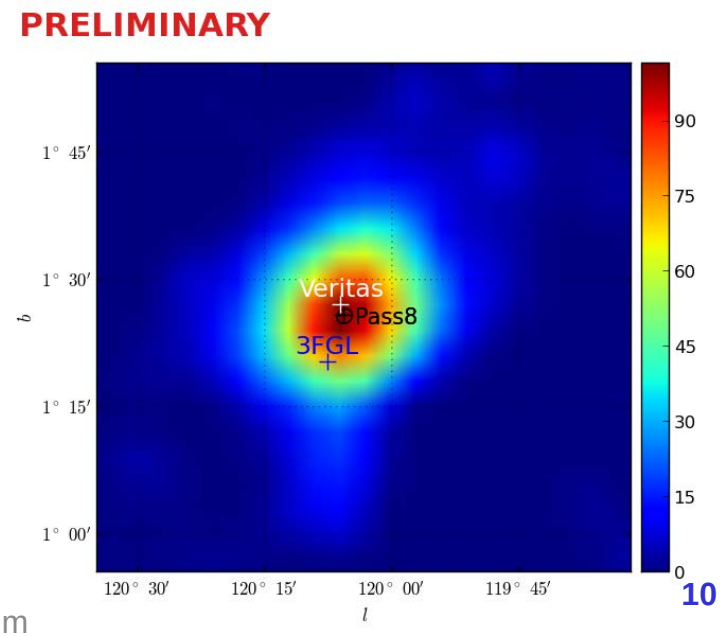
Full range analysis

- **Butterfly plot includes statistical uncertainty only for Pass8 fit**

Flux (100MeV – 100 GeV) = $(1.9 \pm 0.4) 10^{-8}$ ph cm^{-2} s^{-1} Index = -2.37 ± 0.09



TS map (E>1GeV)



Tycho SED modeling

Leptonic model

Atoyan & Dermer 2012

- **Bremsstrahlung dominated**
- **Two-zone model**

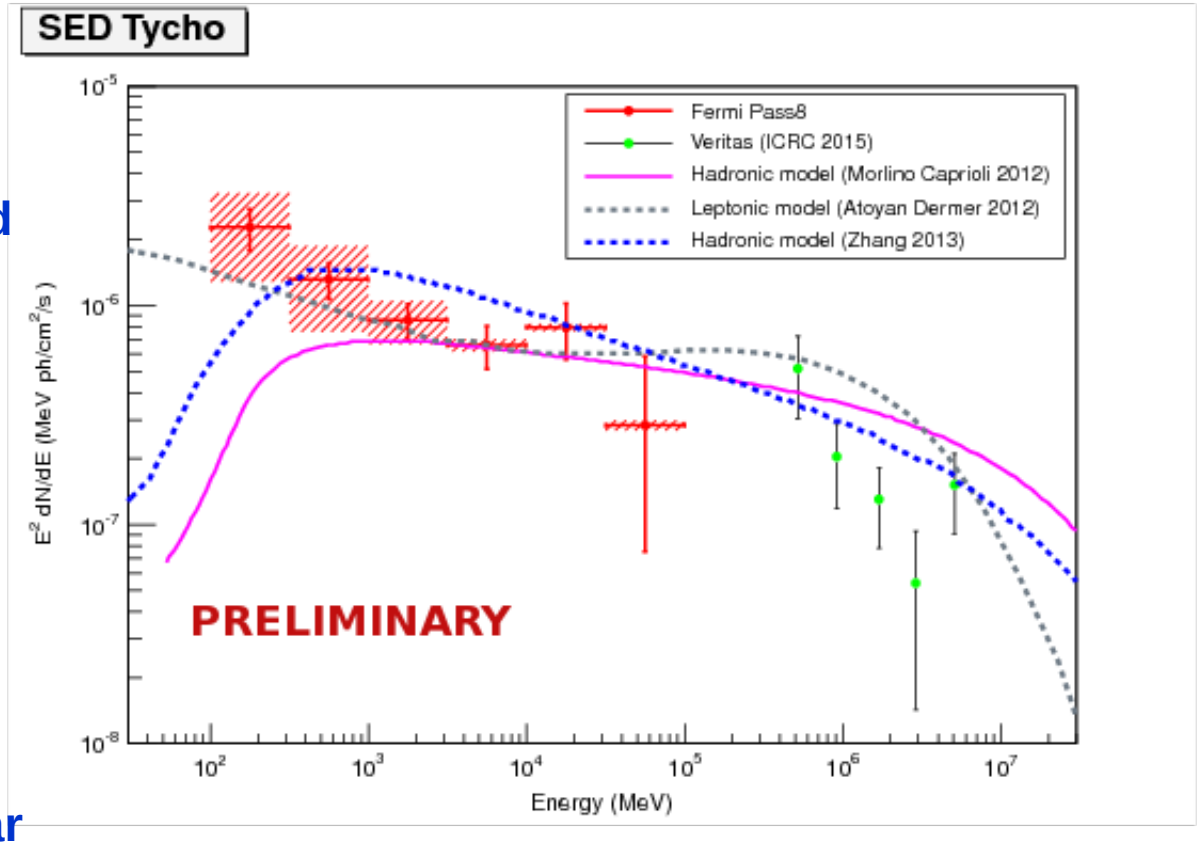
Hadronic models

Morlino & Caprioli 2012

- **Uniform low density ambient**

Zhang et al. 2013

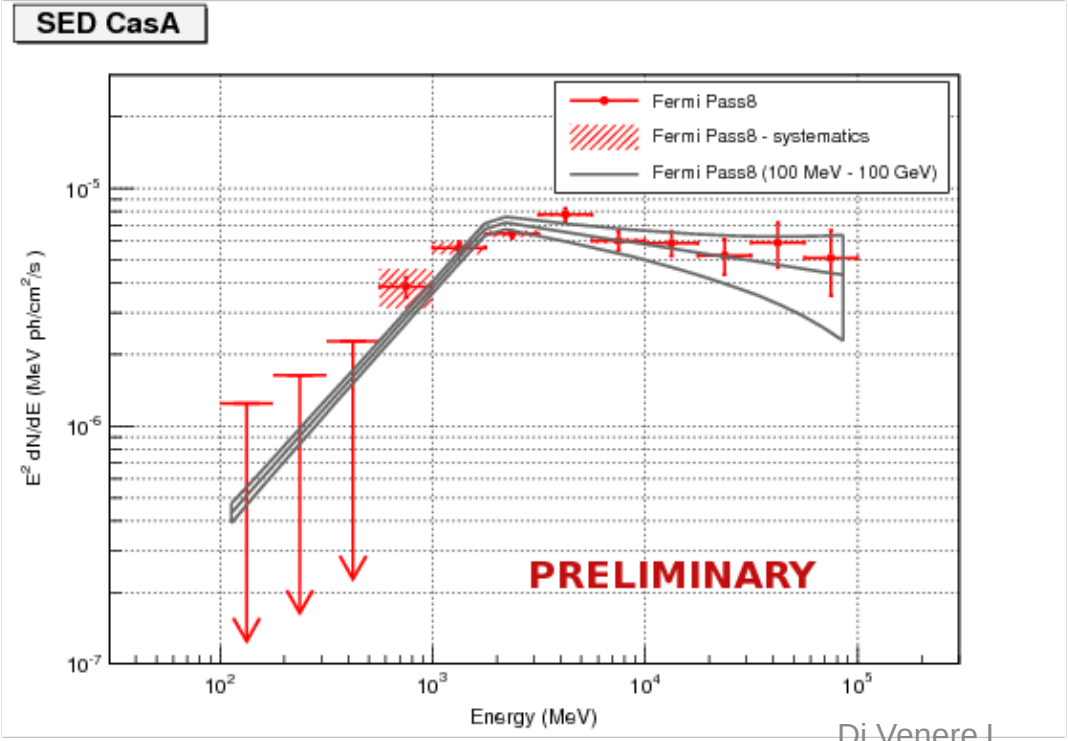
- **Interaction with a molecular cloud**



Note that the first point is 1.7σ away from the lowest hadronic model

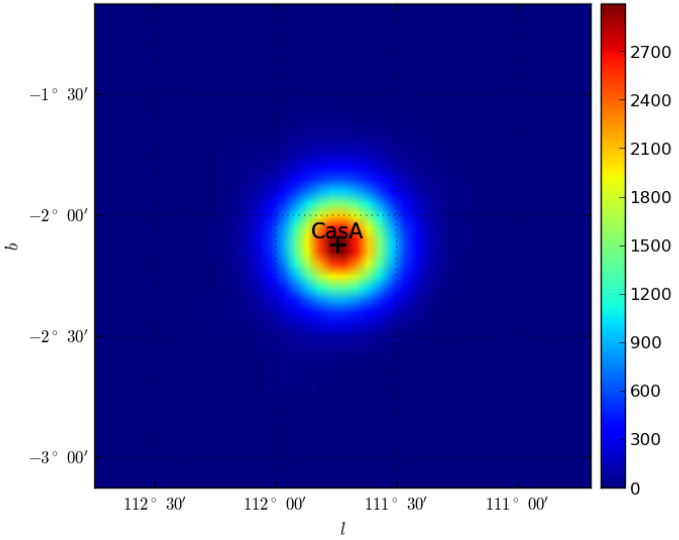
Cas A analysis

- **Binned analysis**
- **4 bins per decade**
- **Upper limits calculated @ 95% C.L. using the profile of the likelihood**
- **No systematic errors reported for upper limits**
- **Full range analysis**
- **Broken power-law preferred to simple power-law** $2(\log \mathcal{L}_{BPL} - \log \mathcal{L}_{PL}) = 174$



TS map (E>1GeV)

PRELIMINARY



Fermi and Veritas position overlap

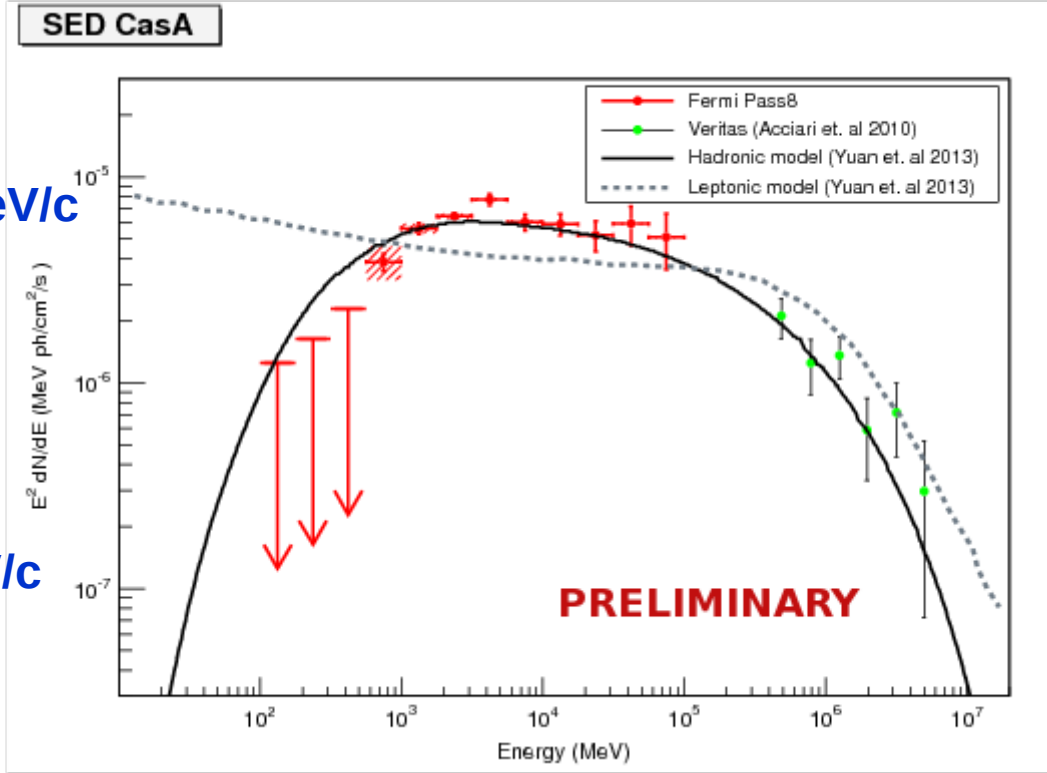
CasA SED modeling

Leptonic model

- Bremsstrahlung + Inverse Compton dominated
- Magnetic field 0.12 mG
- Electron index = -2.34
- Electron cut-off momentum = 40 TeV/c

Hadronic model

- Proton index = -2.1
- Proton cut-off momentum = 10 TeV/c



Conclusions

- **Young SNRs are interesting targets to be studied both in GeV and TeV range**

- **In Tycho SNR there is no clear evidence that it is dominated by hadronic gamma-ray emission**

- **In Cas A SNR hadronic model favoured thanks to the increased sensitivity and statistics**