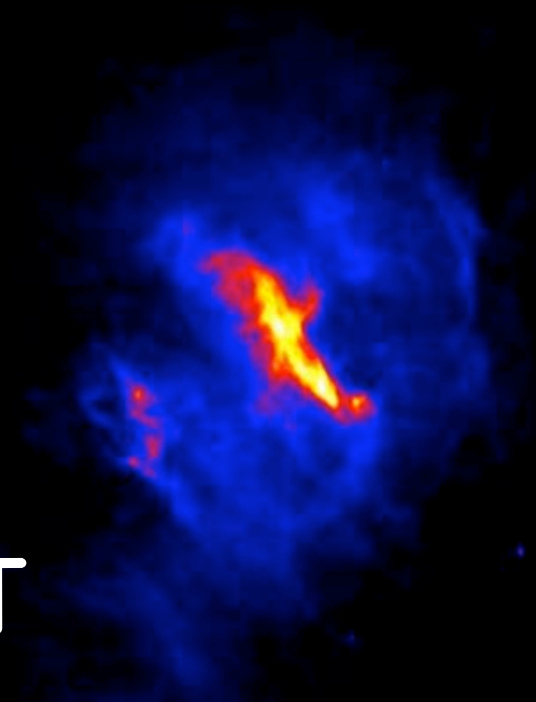
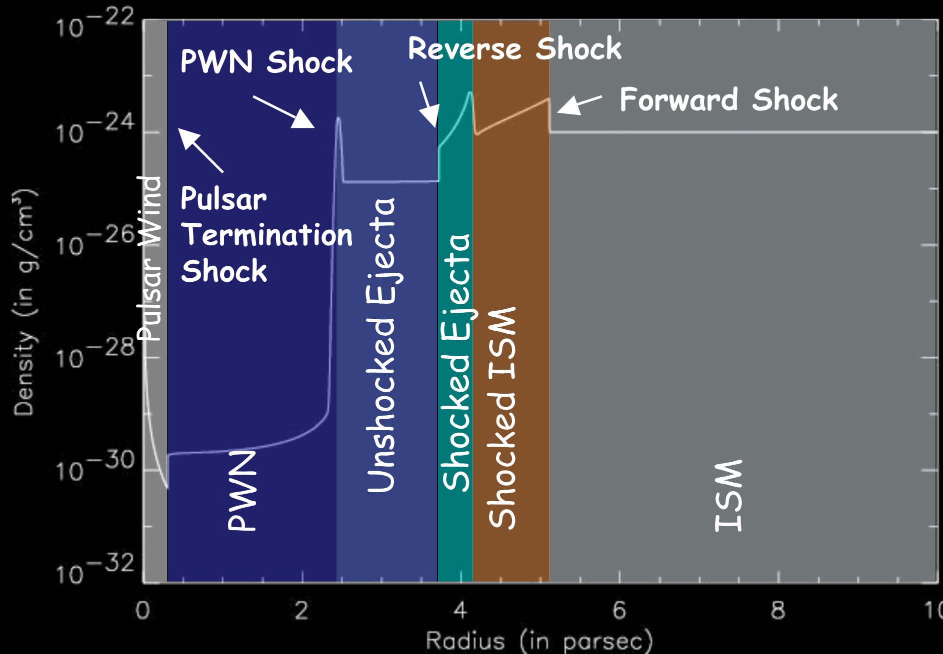
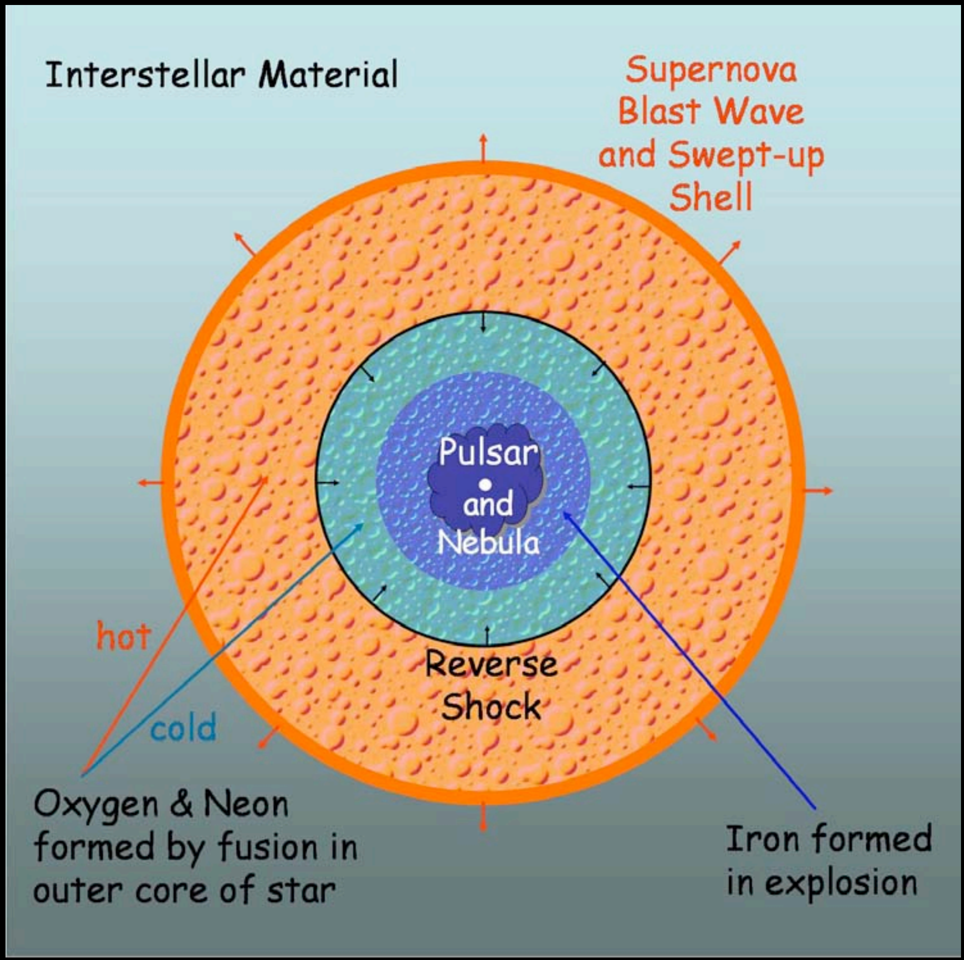
Supernova Remnants



and GLAST

SNRs: The (very) Basic Structure





- **Pulsar Wind**
  - sweeps up ejecta; shock decelerates flow, accelerates particles; PWN forms
- **Supernova Remnant**
  - sweeps up ISM; reverse shock heats ejecta; ultimately compresses PWN; particles accelerated at forward shock generate Alfven waves; other particles scatter from waves and receive additional acceleration

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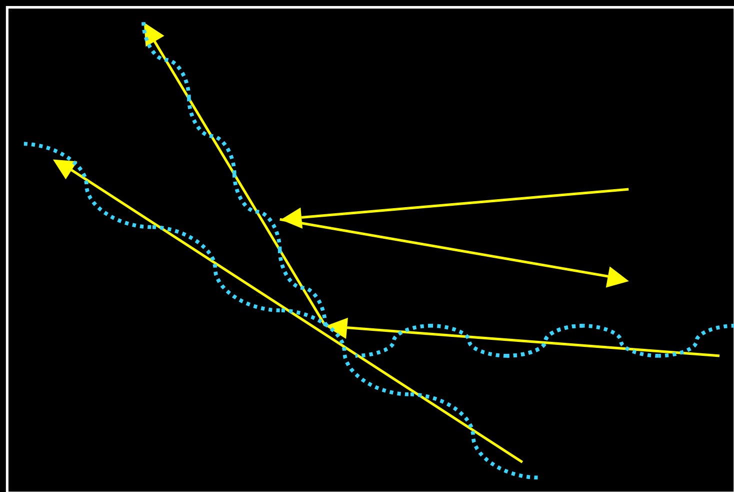

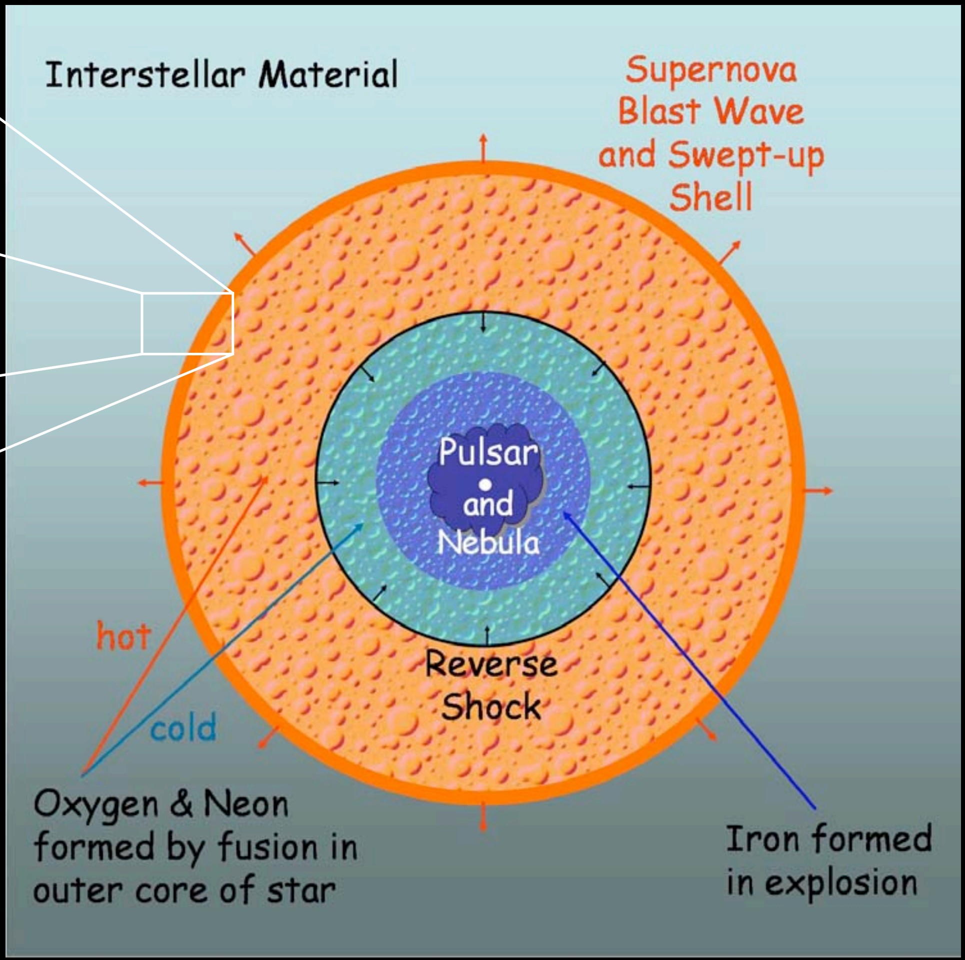

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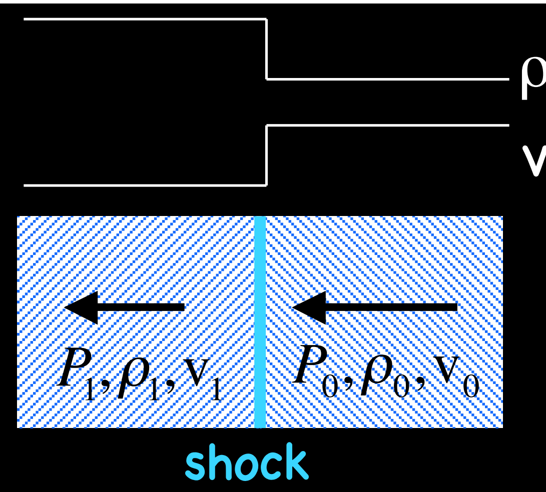
Shocks in SNRs



- Expanding blast wave moves supersonically through CSM/ISM; creates shock
  - mass, momentum, and energy conservation across shock give (with γ=5/3)

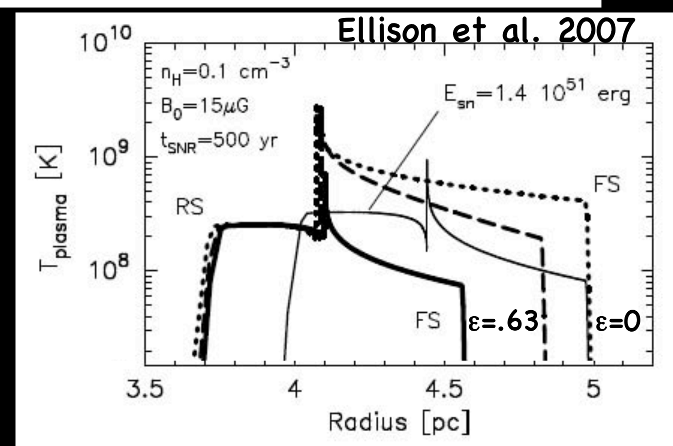
$$\rho_1 = \frac{\gamma + 1}{\gamma - 1}\rho_0 = 4\rho_0$$

$$v_1 = \frac{\gamma - 1}{\gamma + 1} v_0 = \frac{v_0}{4}$$

$$T_1 = \frac{2(\gamma - 1)}{(\gamma + 1)^2}\frac{\mu}{k} m_H v_0^2 = 1.3 \times 10^7 v_{1000}^2 \text{ K}$$

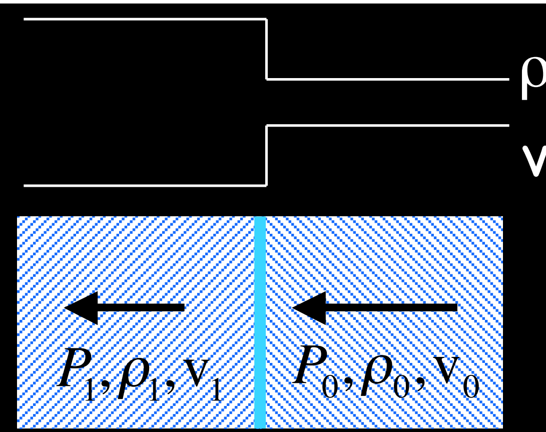
$$v_{ps} = \frac{3v_s}{4}$$

X-ray emitting temperatures



- Shock velocity gives temperature of gas
  - can get from X-rays (modulo NEI effects)
- If cosmic-ray pressure is present <u>the temperature will be lower than this</u>
  - radius of forward shock affected as well

Shocks in SNRs



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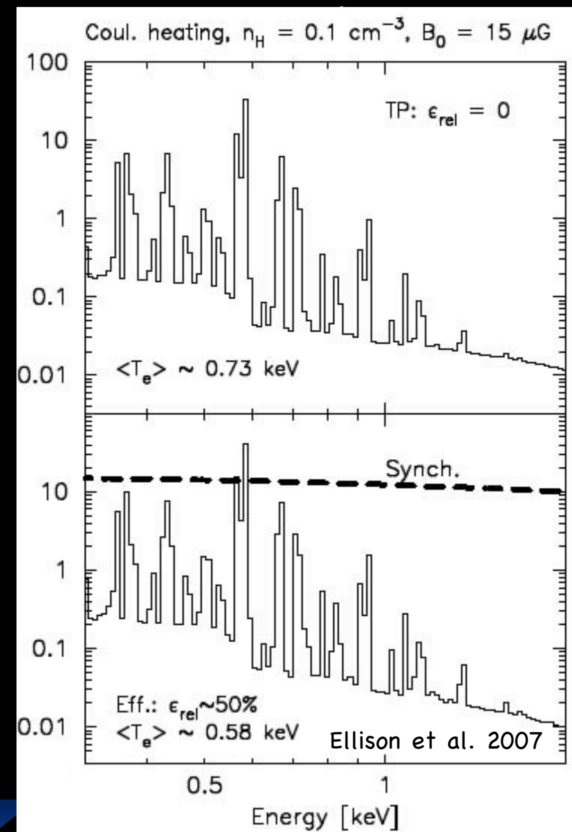
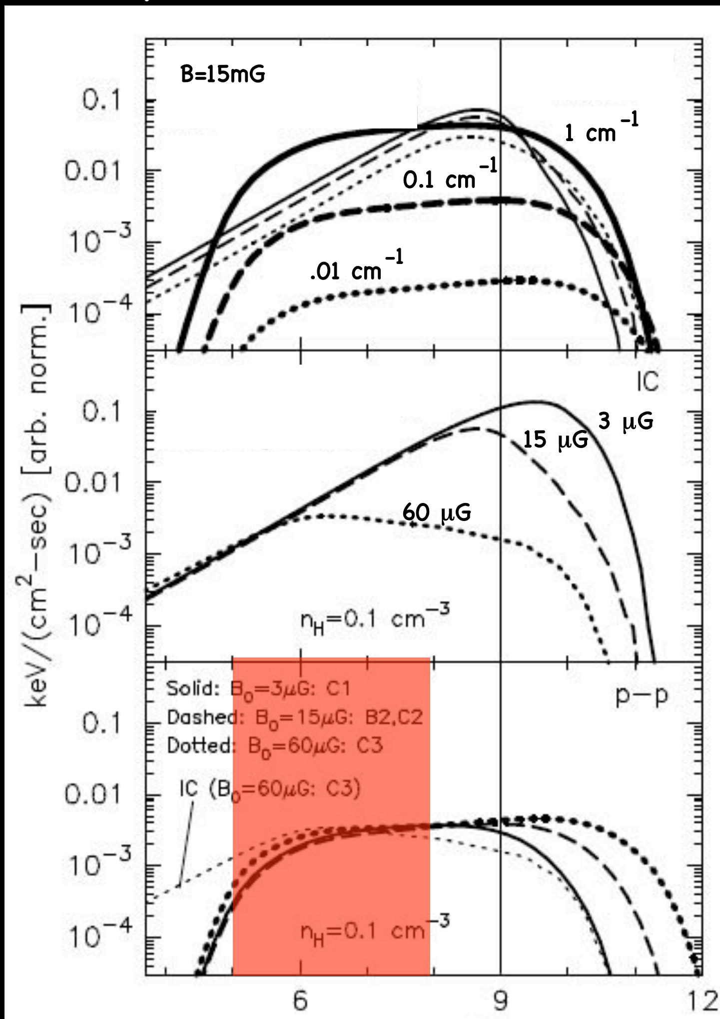


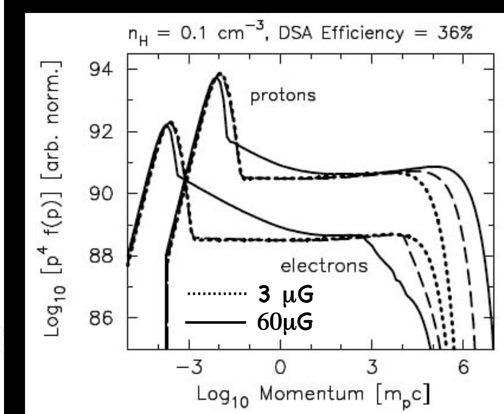
γ-ray Emission from SNRs

t=500y, ε=36%



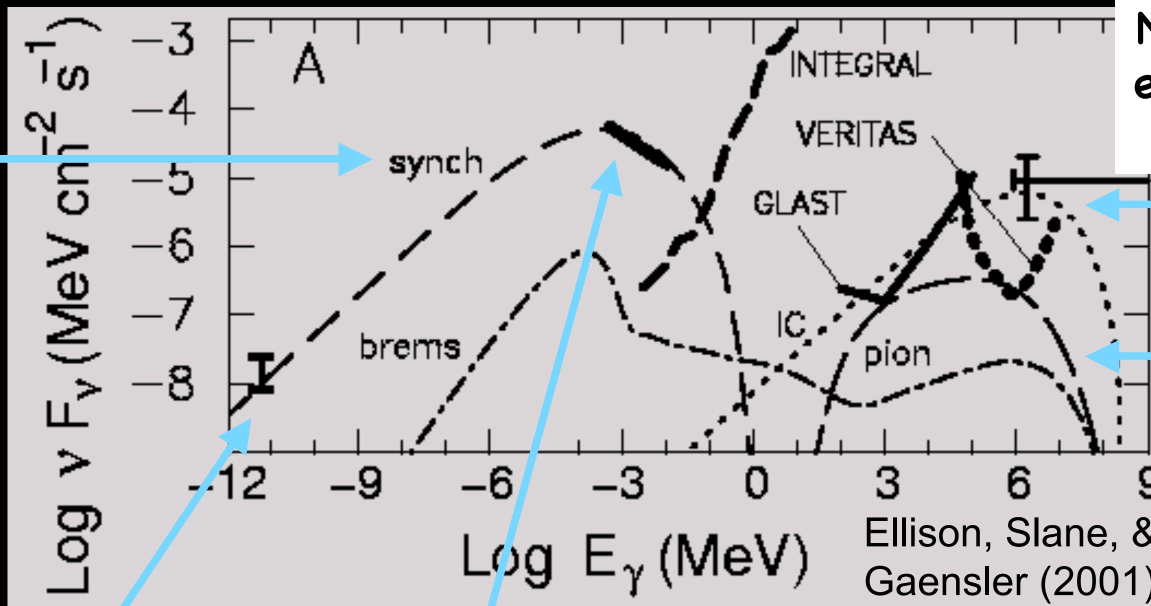
Ellison et al. 2007

- Neutral pion decay
  - ions accelerated by shock collide w/ ambient protons, producing pions in process: $\pi^o \longrightarrow \gamma\gamma$
  - flux proportional to ambient density; SNR-cloud interactions particularly likely sites
- Inverse-Compton emission
  - energetic electrons upscatter ambient photons to γ-ray energies
  - CMB, plus local emission from dust and starlight, provide seed photons



- High B-field can flatten IC spectrum; low B-field can reduce E_{max} for π^o spectrum
  - difficult to differentiate cases; GLAST observations crucial to combine with other λ's and dynamics

Broadband Emission from SNRs



Note that typical emission in GLAST band is faint!

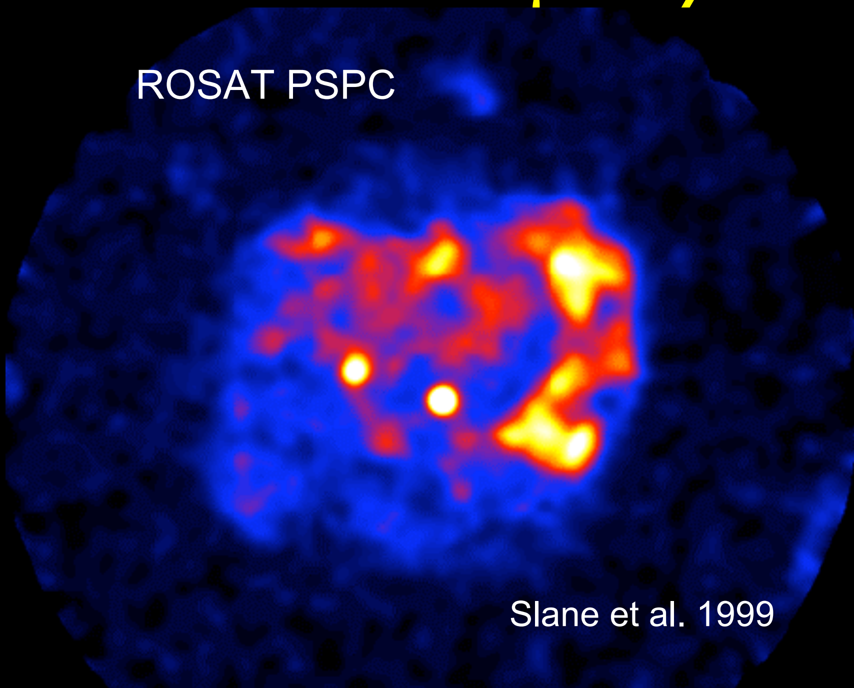
- synchrotron emission dominates spectrum from radio to x-rays
  - shock acceleration of electrons (and protons) to > 10^{13} eV

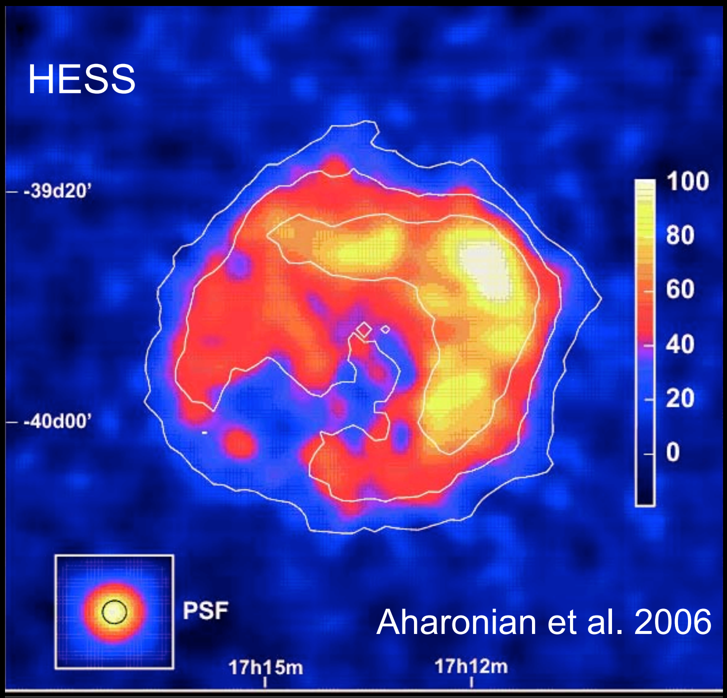
E_{max} set by age or energy losses
- observed as spectral turnover

- inverse-Compton scattering probes same electron population; need self-consistent model w/ synchrotron

- pion production depends on density
  - GLAST/TeV observations required

γ-rays from G347.3-0.5





- X-ray observations reveal a nonthermal spectrum everywhere in G347.3-0.5
  - evidence for cosmic-ray acceleration
  - based on X-ray synchrotron emission, infer electron energies of ~50 TeV

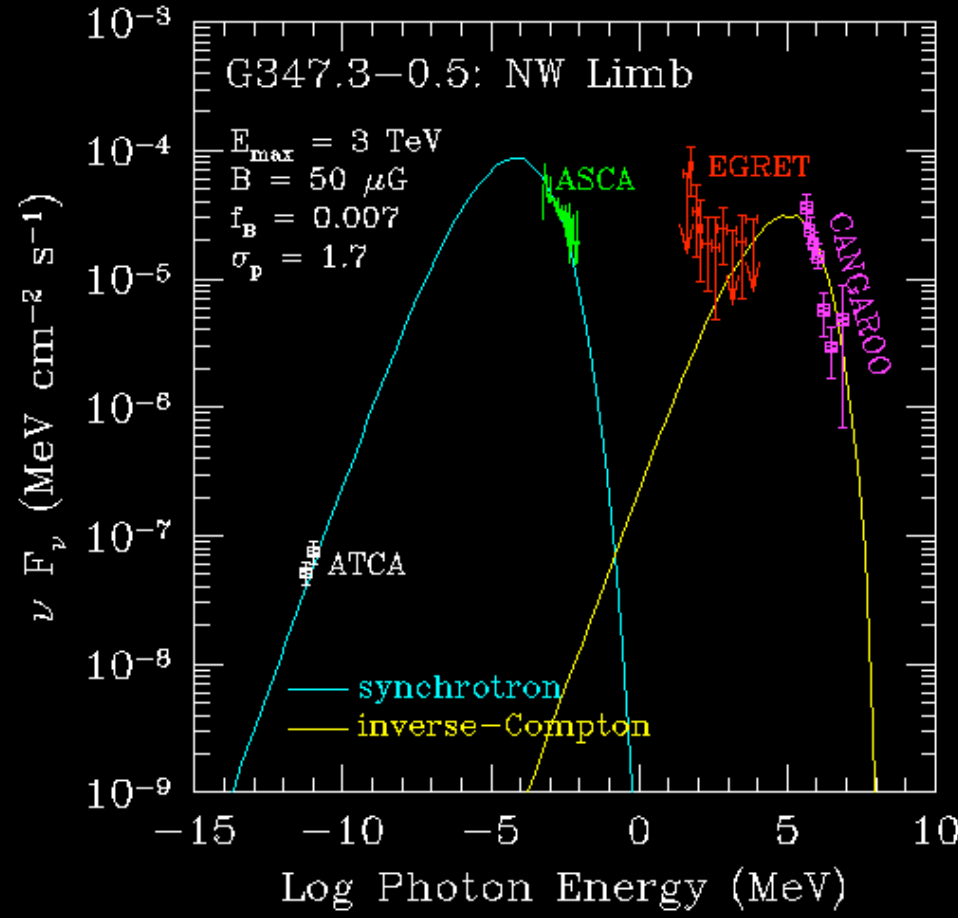
- This SNR is detected directly in TeV gamma-rays, by HESS
  - γ-ray morphology very similar to x-rays; suggests I-C emission
  - spectrum seems to suggest π^0-decay

WHAT IS EMISSION MECHANISM?

Modeling the Emission

- Joint analysis of radio, X-ray, and γ-ray data allow us to investigate the broad band spectrum
  - data can be accommodated along with EGRET upper limits, with no contributions from pion decay
  - large magnetic field is required, with relatively small filling factor
- However… HESS spectrum is completely inconsistent with that reported by CANGAROO
  - broader spectrum suggests pion origin, but implied densities appear in conflict with thermal X-ray upper limits
- BUT… strong magnetic field can flatten inverse-Compton spectrum
  - ORIGIN NOT YET CLEAR; NEED GLAST

Lazendic et al. 2002



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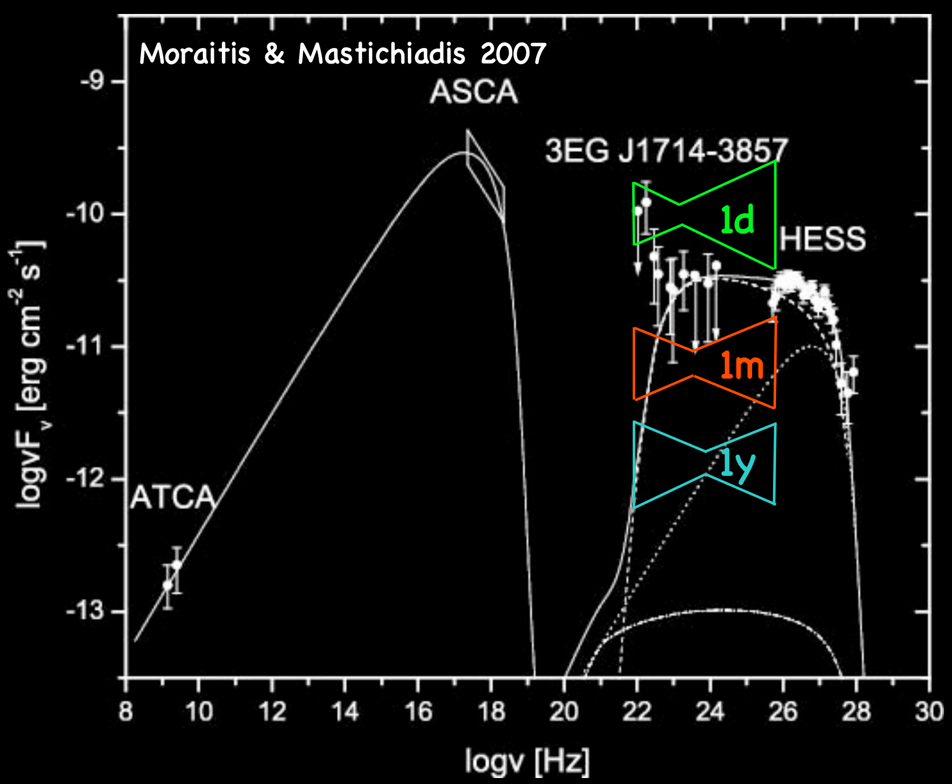
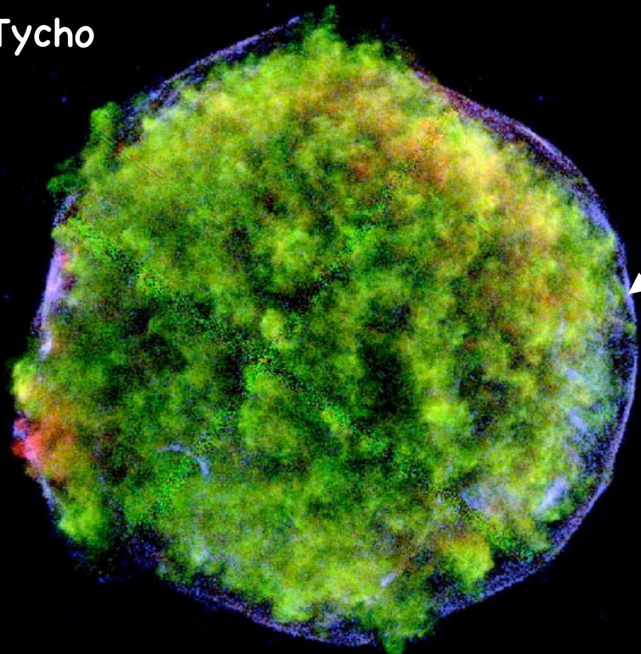
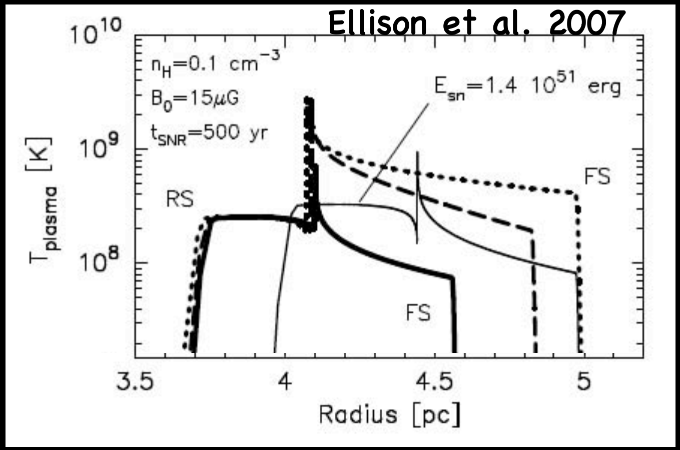


Aside: Evidence for CR Ion Acceleration



Warren et al. 2005



- Efficient particle acceleration in SNRs affects dynamics of shock
  - for given age, FS is closer to CD and RS with efficient CR production
- This is observed in Tycho's SNR
  - "direct" evidence of CR ion acceleration

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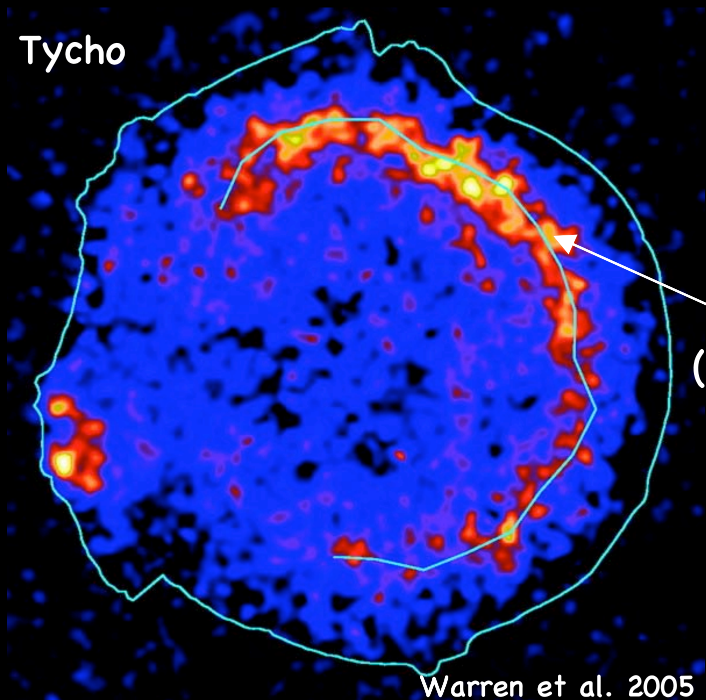

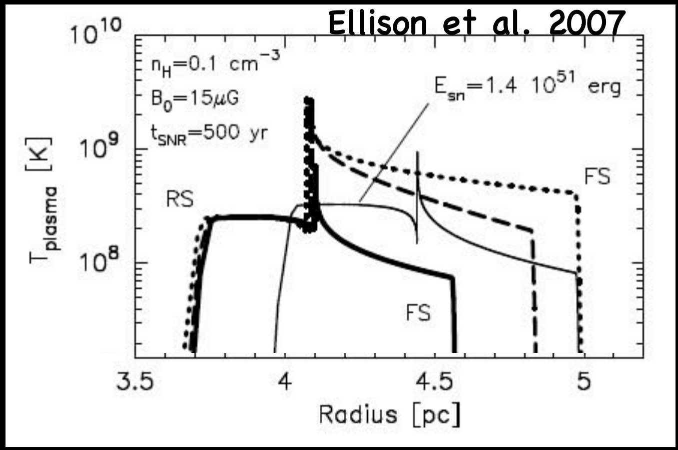

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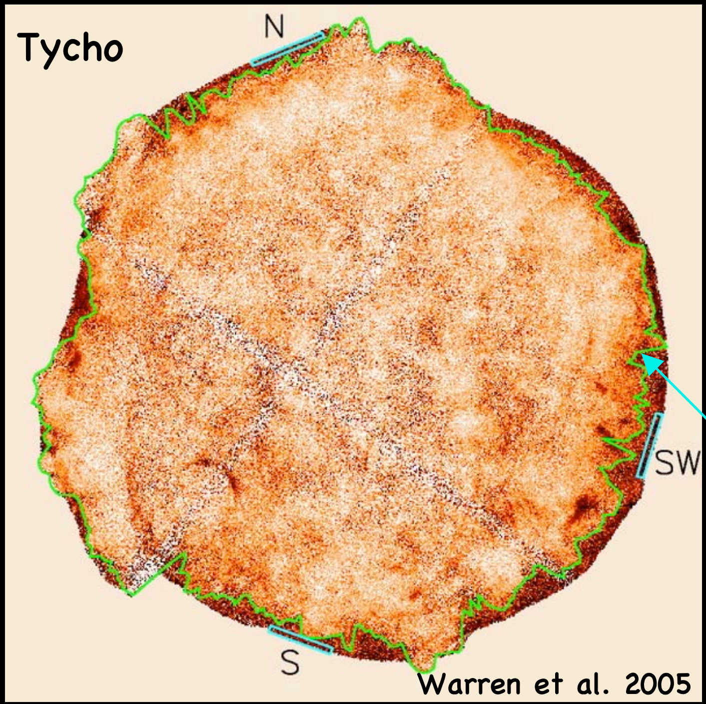
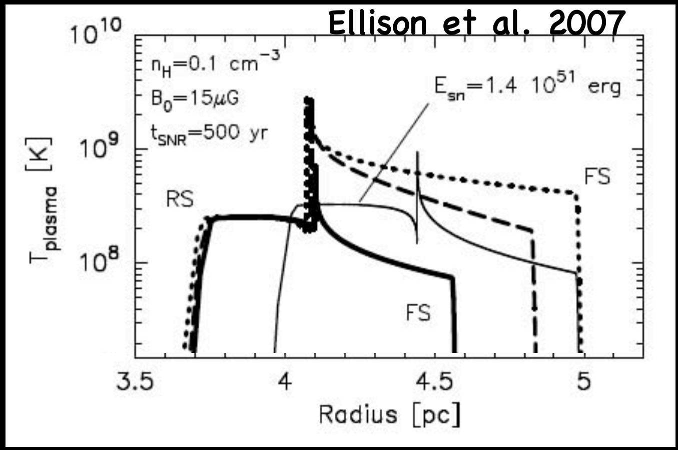
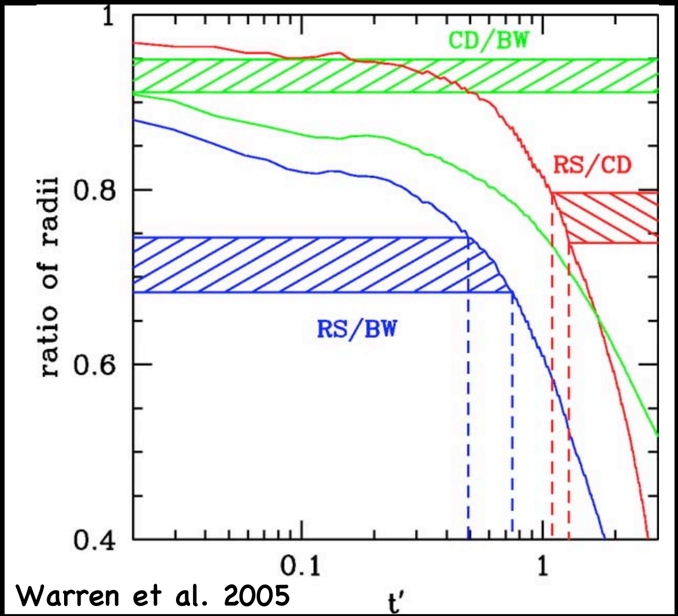


Contact Discontinuity





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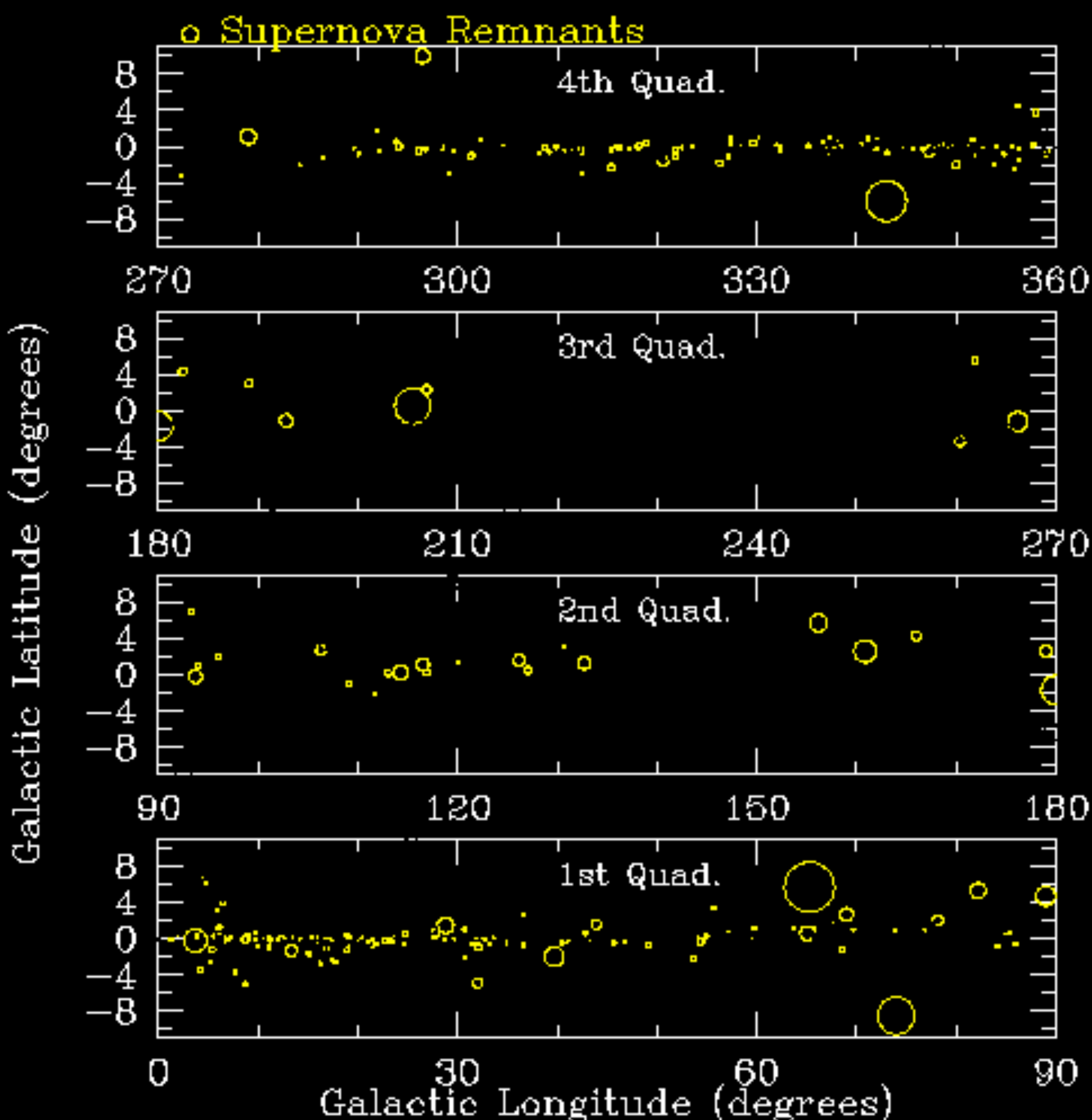
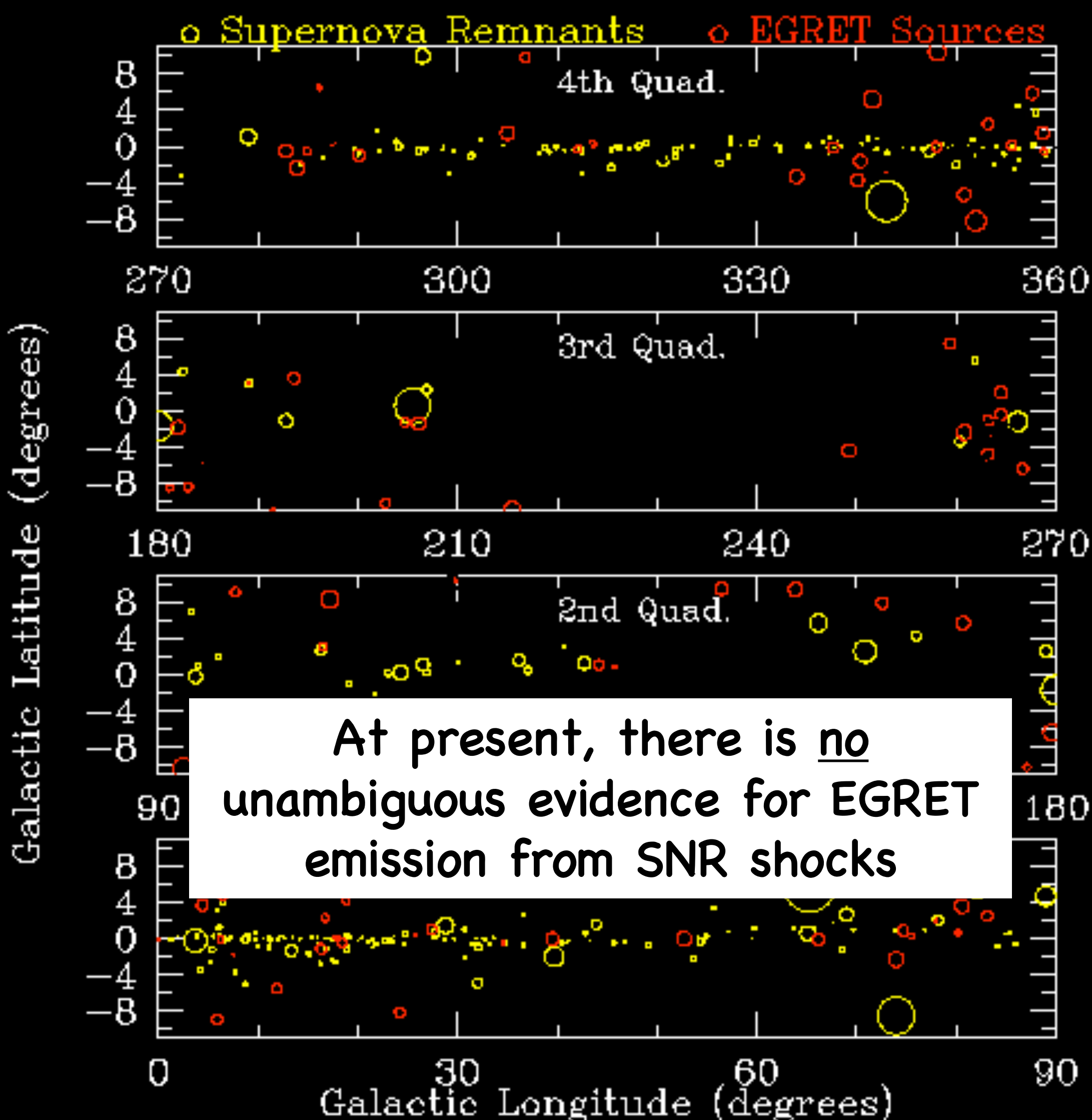
EGRET Results on SNRs/PWNe



- SNRs are natural candidates for the production of γ-rays
  - pulsars in SNRs are young and probably active; pulsars form a known class of γ-ray sources
  - shock acceleration of particles yields γ-rays through a variety of processes
  - interactions with molecular clouds enhance emission
- Establishing a direct association between SNRs and γ-ray sources is tricky
  - SNRs are large, as are EGRET error circles
  - SNRs distributed like other potential γ-ray populations

Need GLAST resolution + multi-λ

EGRET Results on SNRs/PWNe



At present, there is no unambiguous evidence for EGRET emission from SNR shocks

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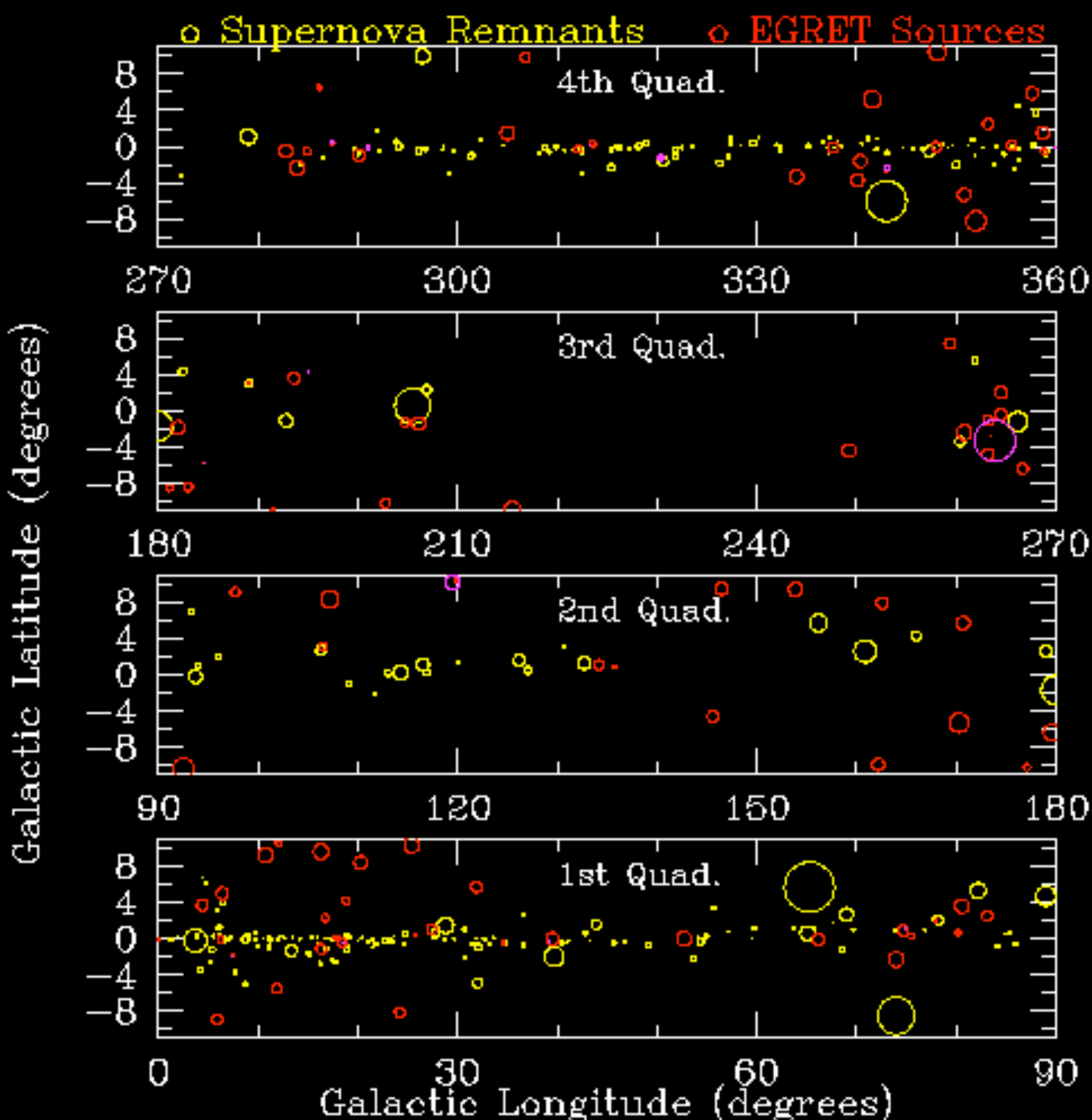

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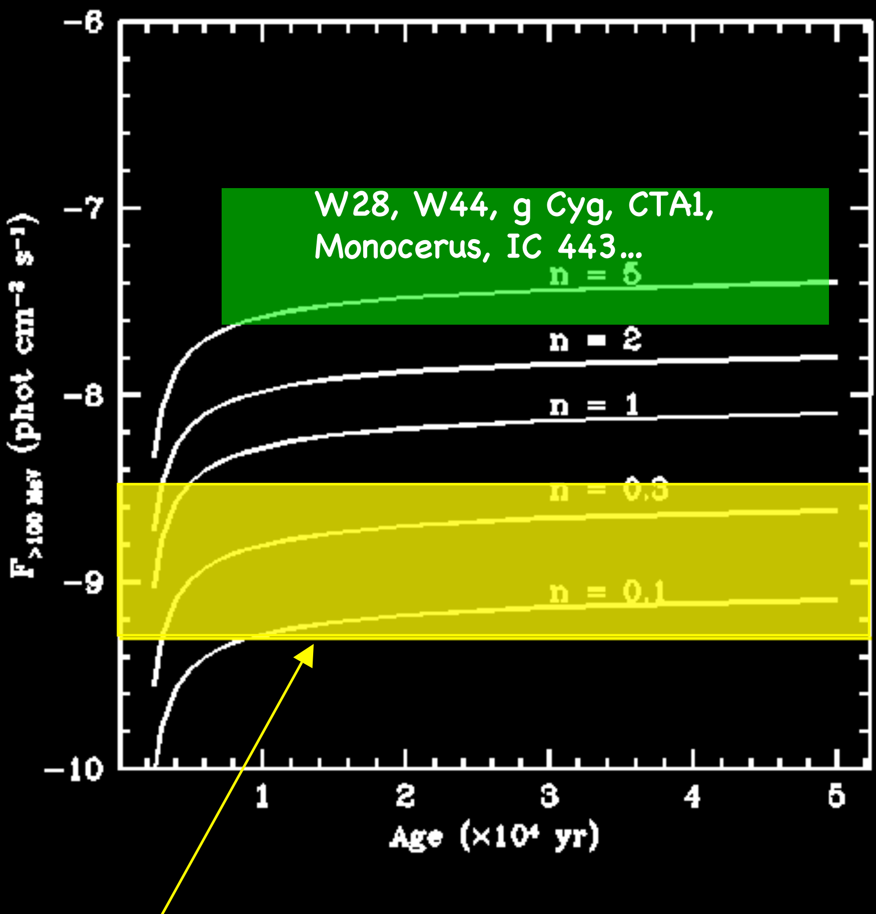
GLAST Sensitivity for SNRs



1 yr sensitivity for high latitude point source

- The expected $\pi^0 \longrightarrow \gamma\gamma$ flux for an SNR is

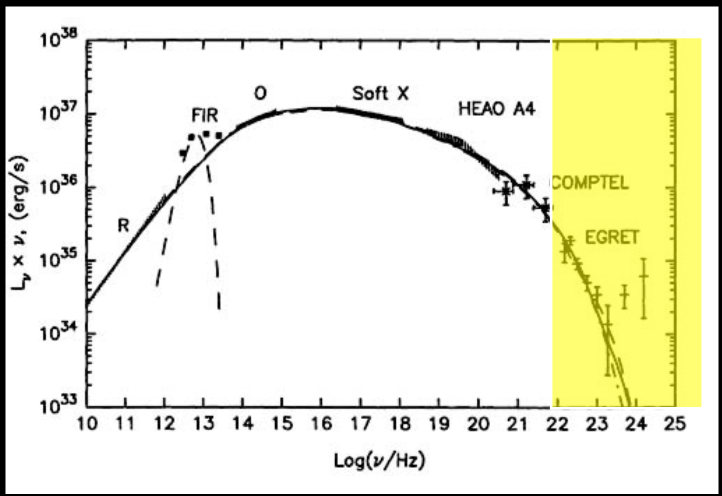
$$F(>100MeV) \approx 4.4\times10^{-7}\theta E_{51} d_{kpc}^{-2} n \text{ phot cm}^{-2}\text{ s}^{-1}$$

  where θ is a slow function of age (Drury et al. 1994)
  - this leads to fluxes near sensitivity limit of EGRET, but only for large n

- Efficient acceleration can result in higher values for I-C γ-rays
  - SNRs should be detectable w/ GLAST for sufficiently high density; favor SNRs in dense environments or highly efficient acceleration
  - expect good sensitivity to SNR-cloud interaction sites

Contributions from PWNe

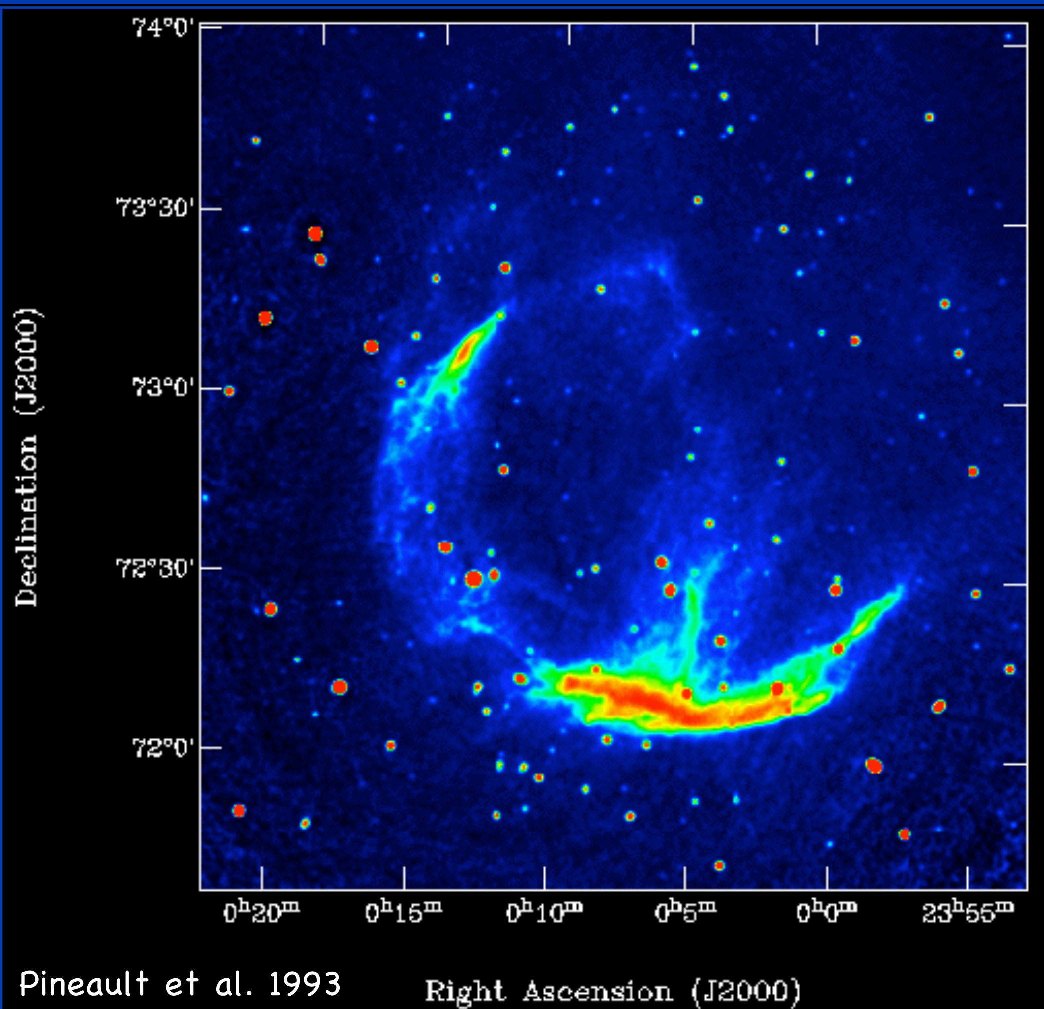
- Unshocked wind from pulsar expected to have $\gamma = 10^6$
  - X-ray synchrotron emission requires $\gamma > 10^9$
  - acceleration at wind termination shock
- GLAST will provide sensitivity to measure γ_{max}



- X-ray/radio observations of EGRET sources have revealed a handful of PWNe (e.g. Roberts et al. 2006)
  - γ-ray emission appears to show variability on timescales of months; constraints on synchrotron age (and thus B)?

GLAST survey mode ideal for investigating this

G119.5+10.2 (CTA1)



Pineault et al. 1993

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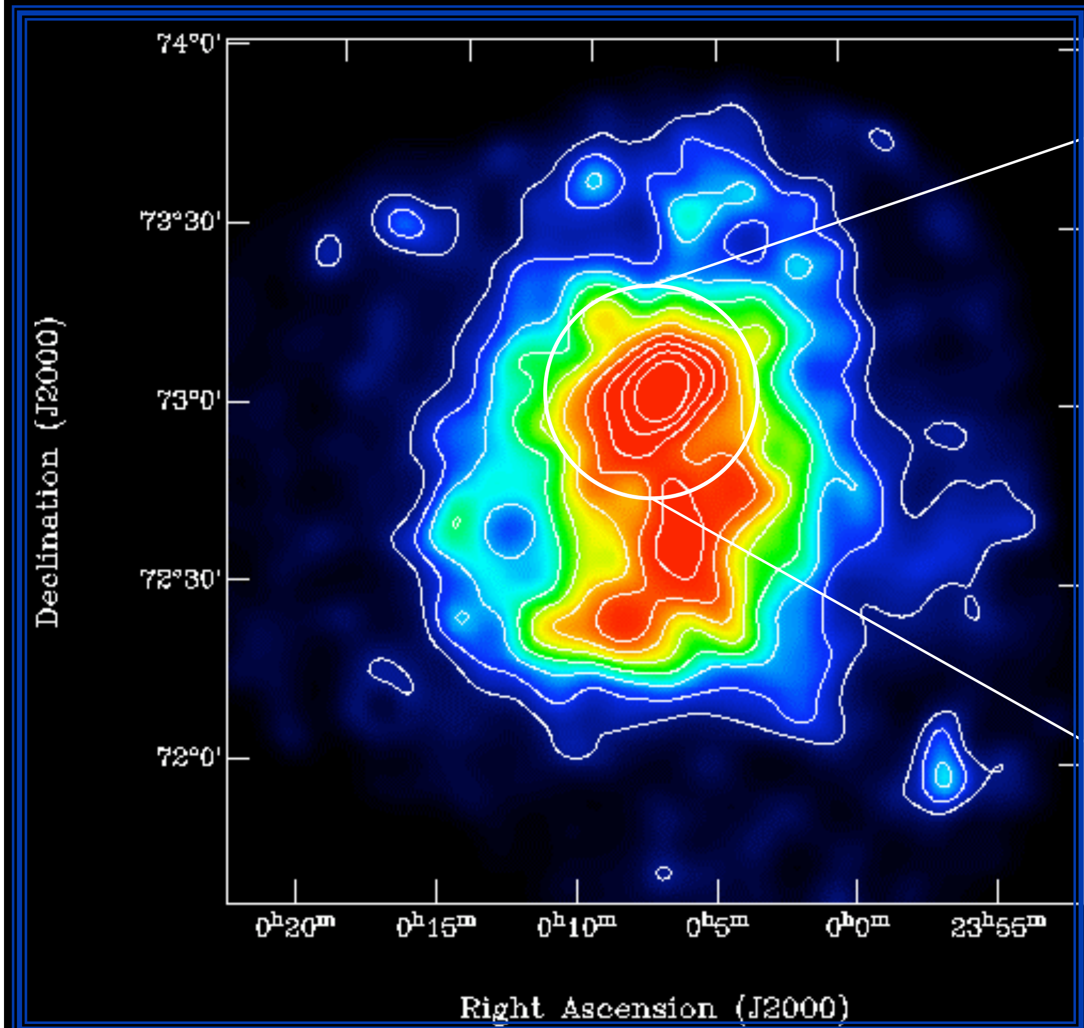
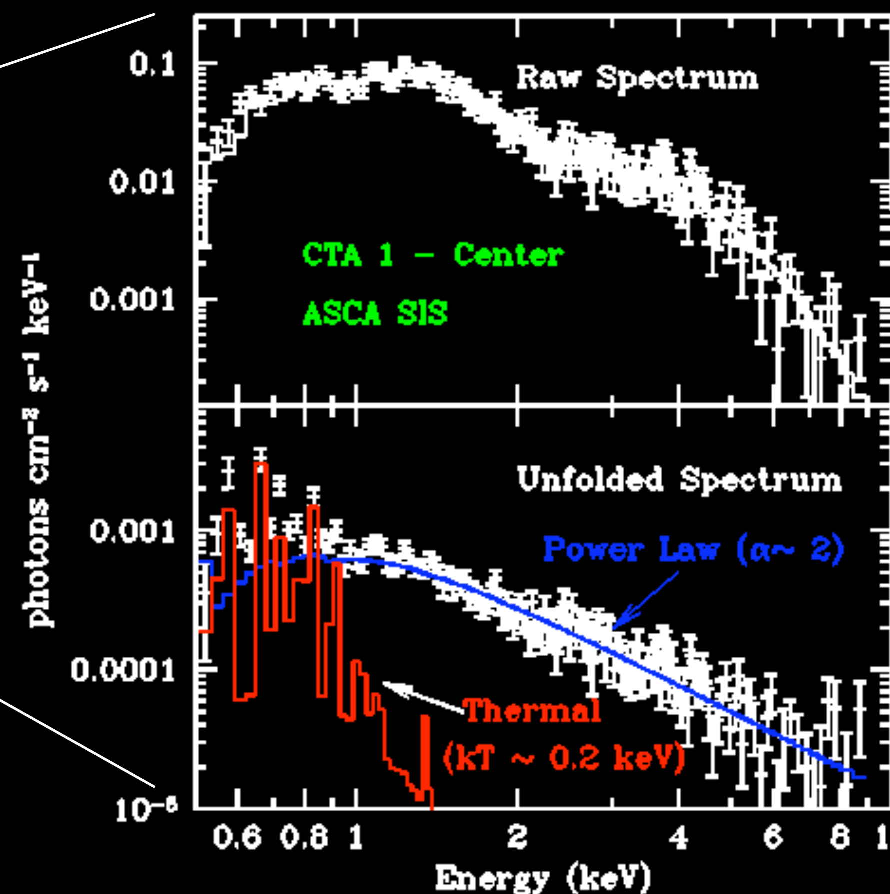
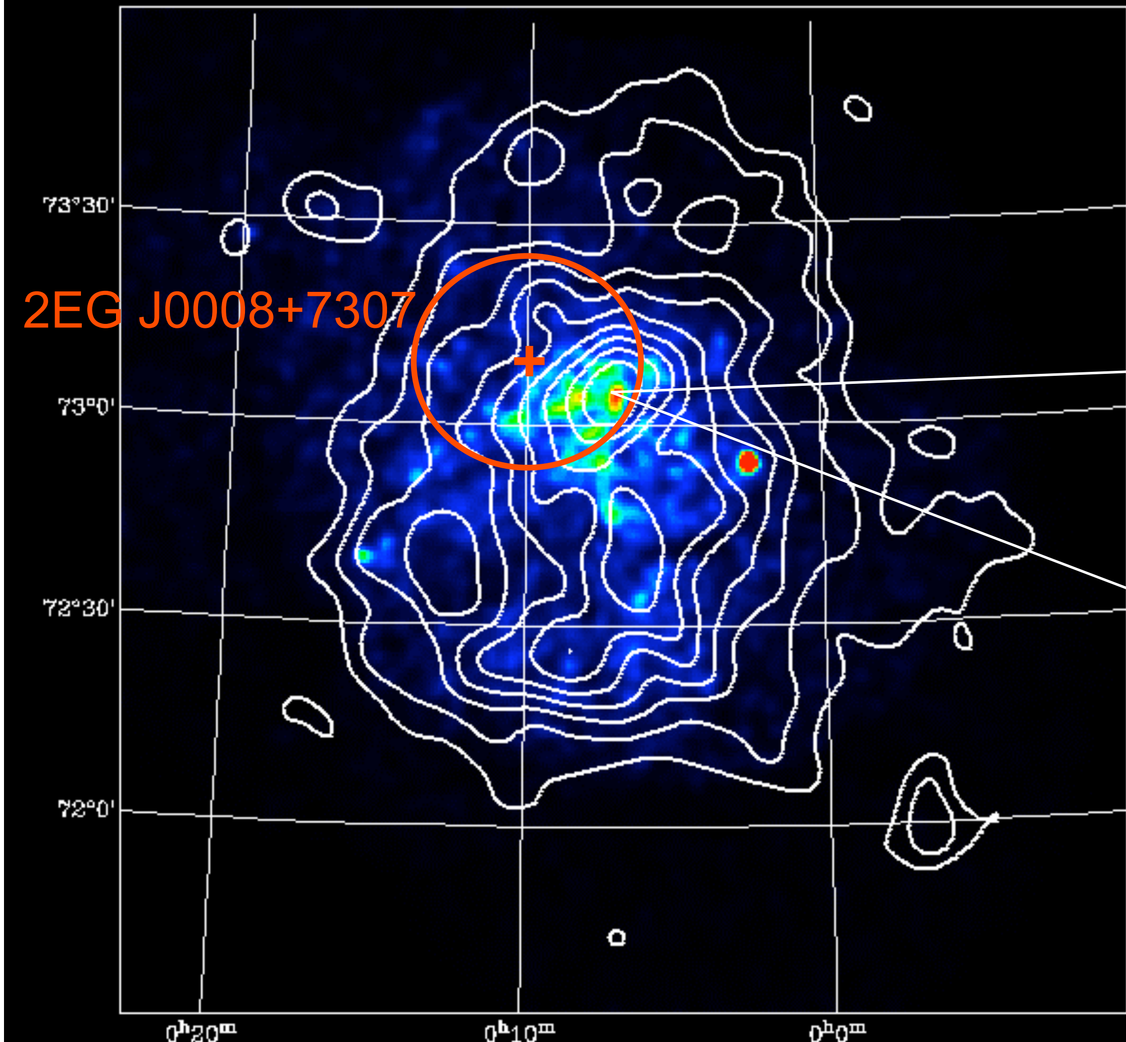




Slane et al. 1997

2EG J0008+7307: An Association with CTA1?

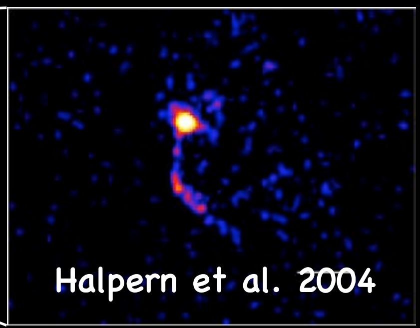


Slane et al. 1997 Brazier et al. 1998

- CTA1 contains a faint x-ray source J000702+7302.9 at center of PWN
  - for a Crab-like pulsar spectrum,

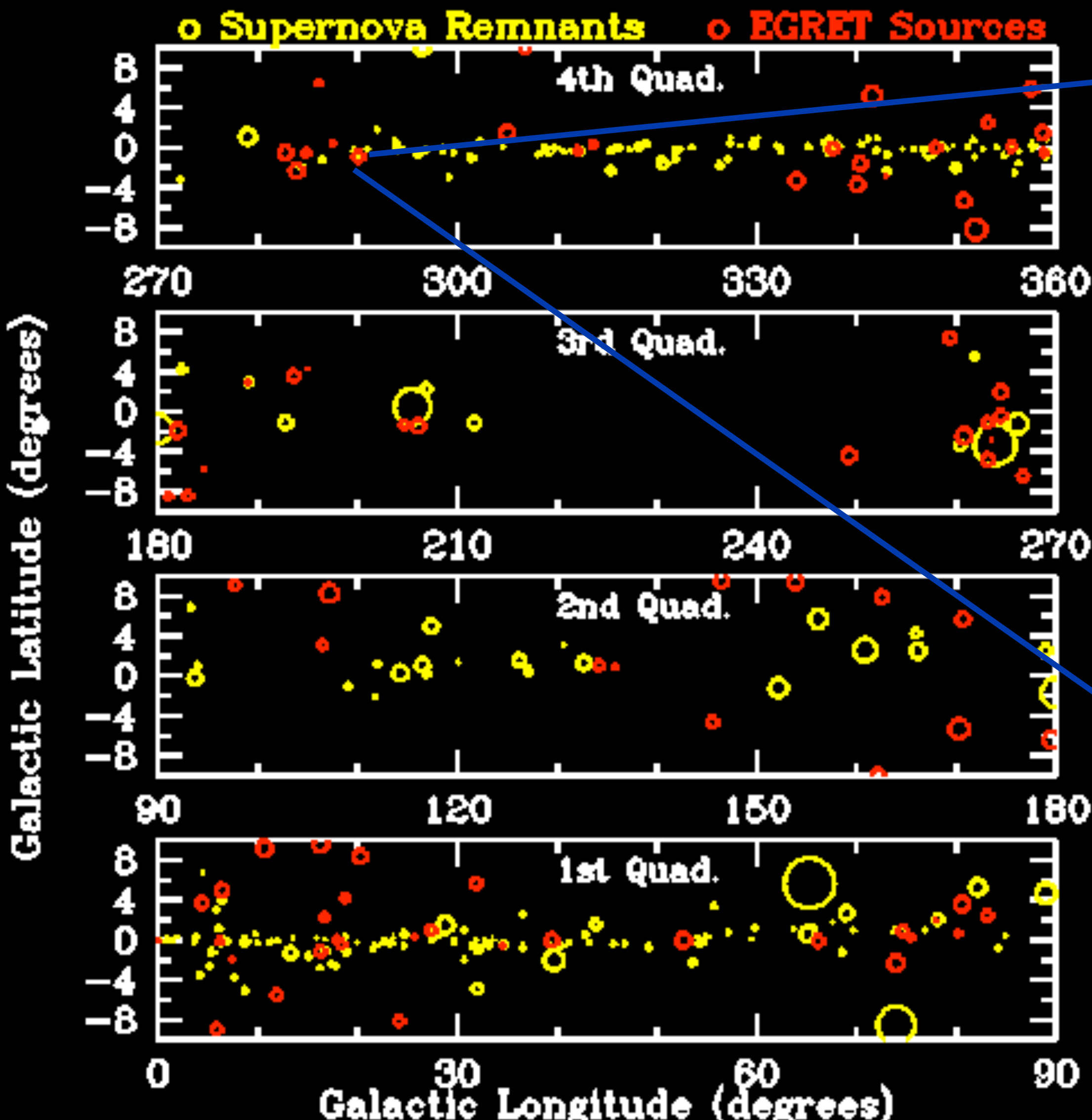
$$L_x = 4.3 \times 10^{31} d_{1.4}^2 \text{ erg s}^{-1}$$

  - this extrapolates to EGRET flux

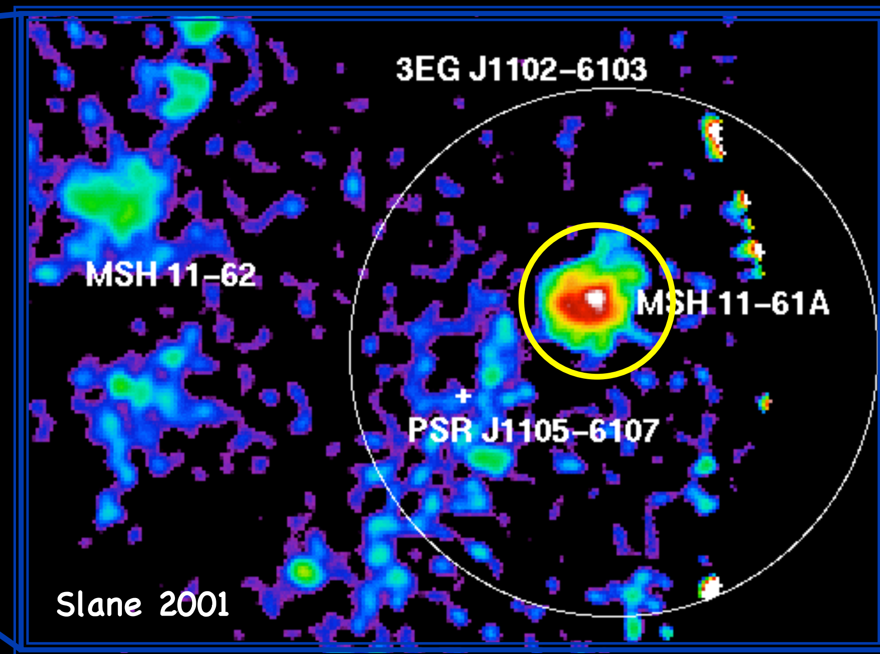


Halpern et al. 2004

- Chandra observations jet structure from compact source
  - definitely a pulsar, though pulses not yet detected
  - is EGRET source associated with the pulsar? the PWN? GLAST will isolate emission



3EG J1102-6103



- EGRET source initially identified with MSH 11-62 (composite SNR)
- Error circle contains young pulsar (J1105-6107) and SNR MSH 11-61A (which appears to be interacting with a molecular cloud). Which source is it? GLAST resolution will provide answer

Summary

- SNRs are efficient accelerators of cosmic ray electrons and ions
  - expect production of γ-rays from $\pi^0 \longrightarrow \gamma\gamma$ and I-C processes
  - GLAST sensitivity can detect SNRs in dense environments and those for which particle acceleration is highly efficient
  - spectra can provide crucial input for differentiating between emission mechanisms
- SNRs are in confused regions
  - GLAST resolution will provide huge improvement in identifications
  - may find many new PWNe
- GLAST survey mode provides exceptional capabilities for detecting faint SNRs and for studying variability in PWNe