Chandra and Spitzer Constraints on the Evolution of G54.1+0.3 and 3C 58

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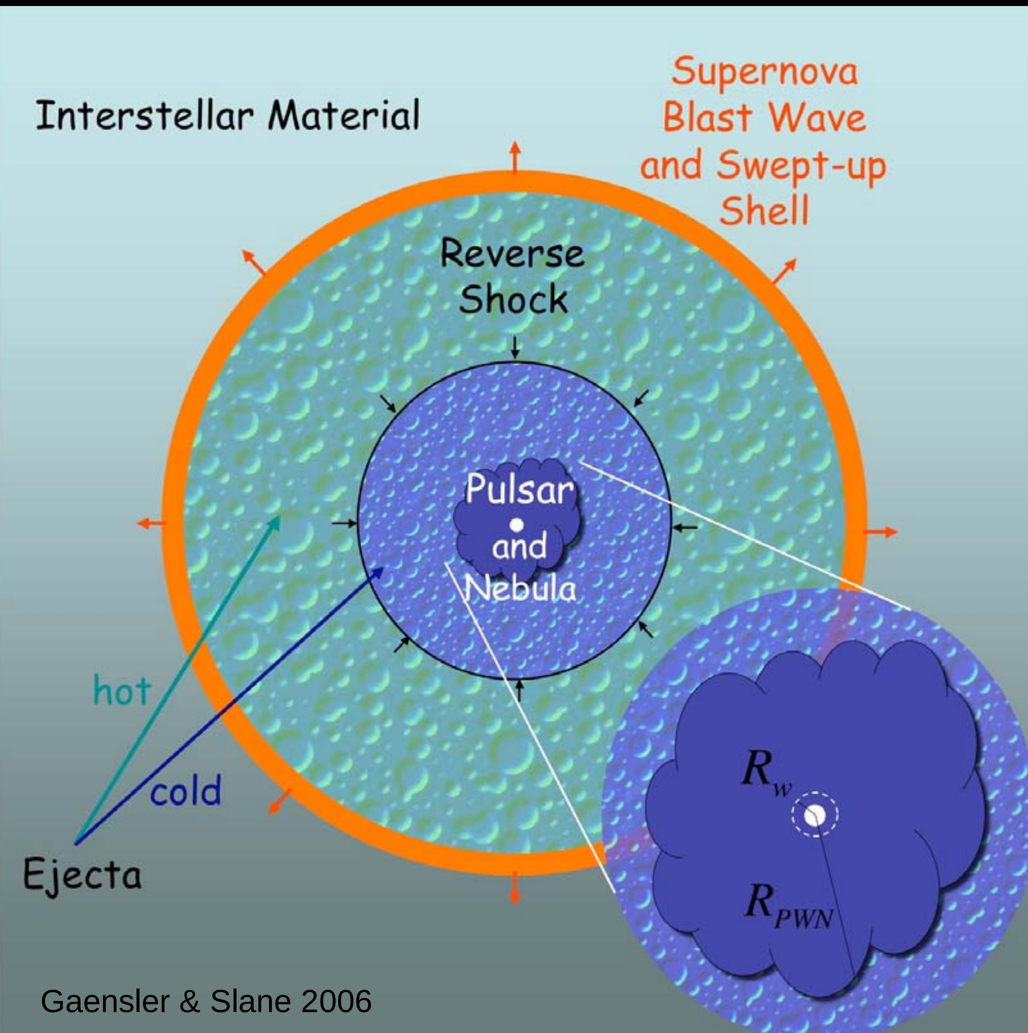
Environments of Pulsar Wind Nebulae



Gaensler & Slane 2006

- Rapidly expanding ejecta from SN explosion sweeps up CSM/ISM in blast wave
  - forms thermal shell with solar abund.
- As forward shock decelerates, reverse shock is driven into ejecta
  - forms metal-enriched thermal emission
- Young NS powers a particle/magnetic wind that expands into SNR ejecta
  - toroidal magnetic field results in axisymmetric equatorial wind
  - forms pulsar wind nebula, with jet/torus structure
  - nebula sweeps up surrounding ejecta, forming filamentary shell

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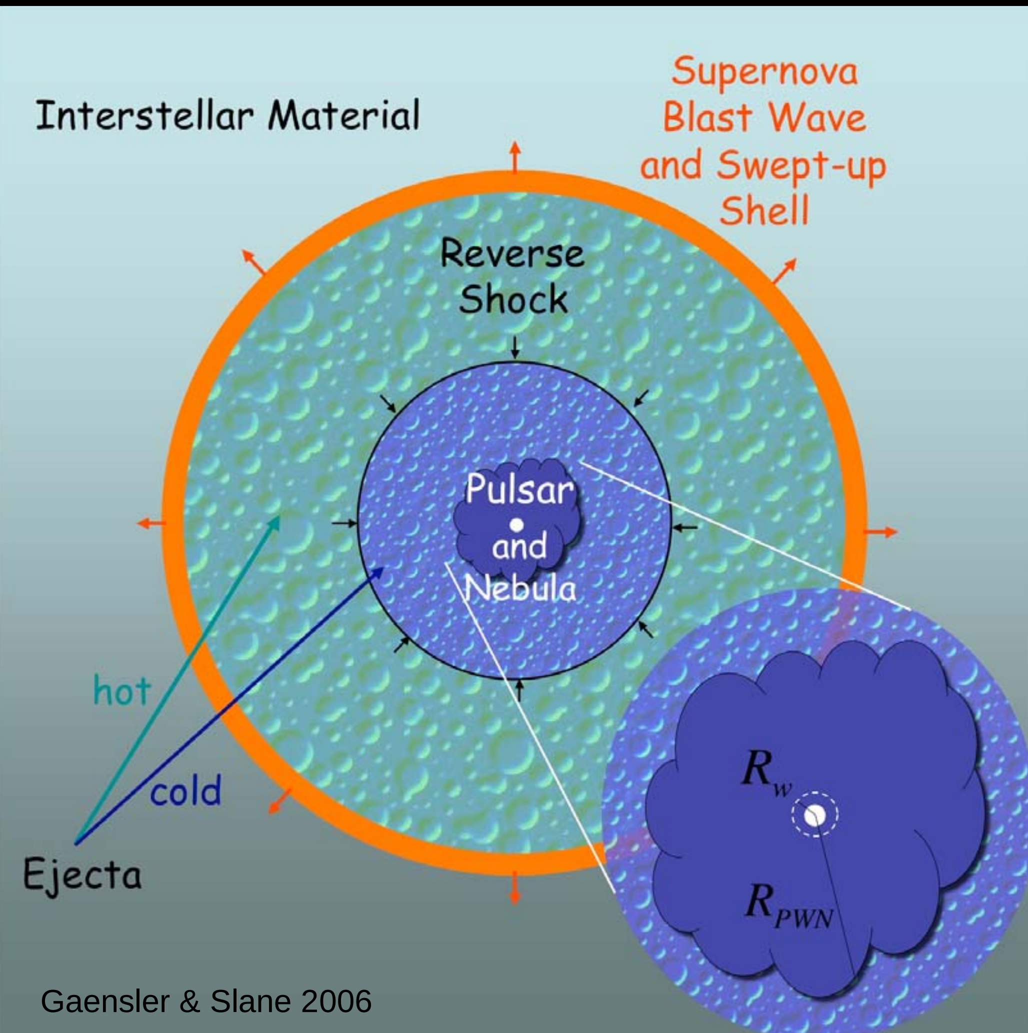

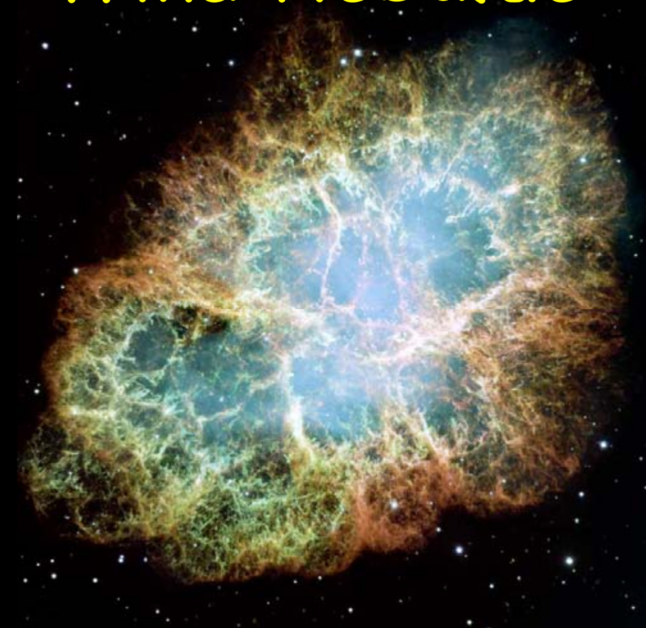

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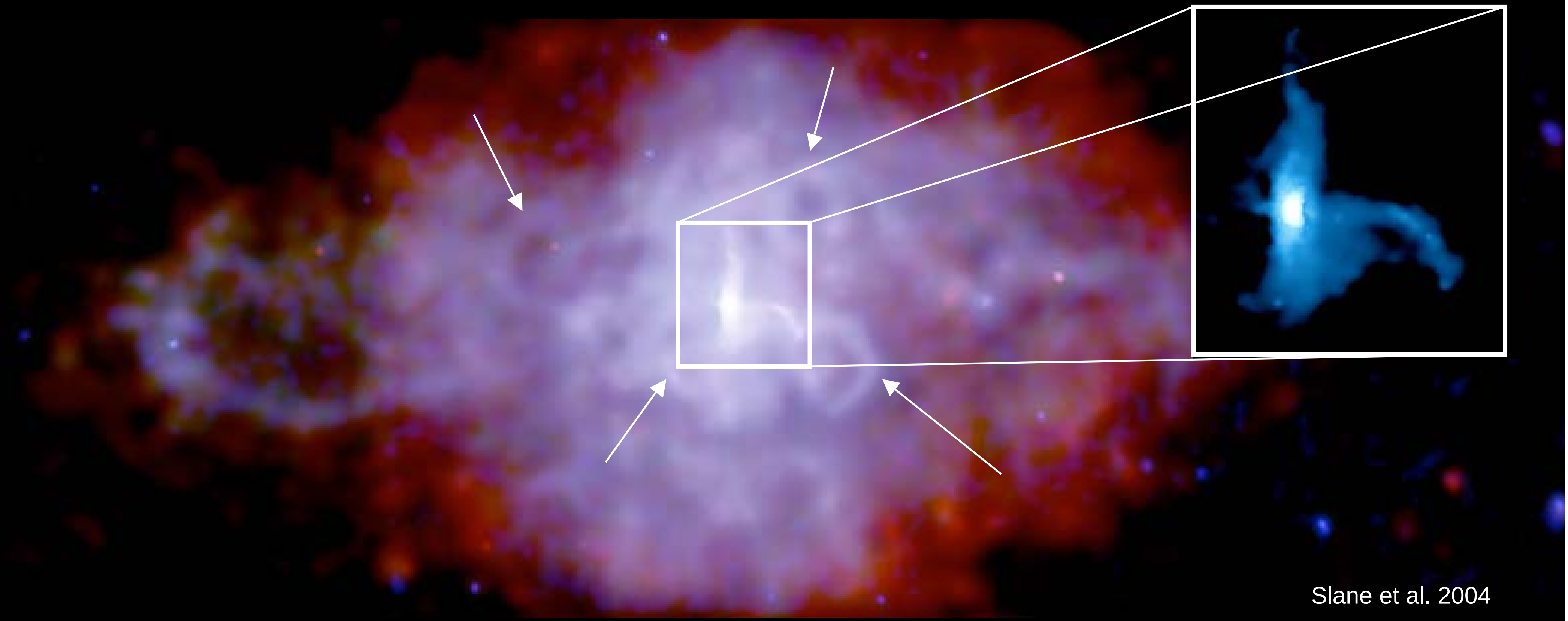
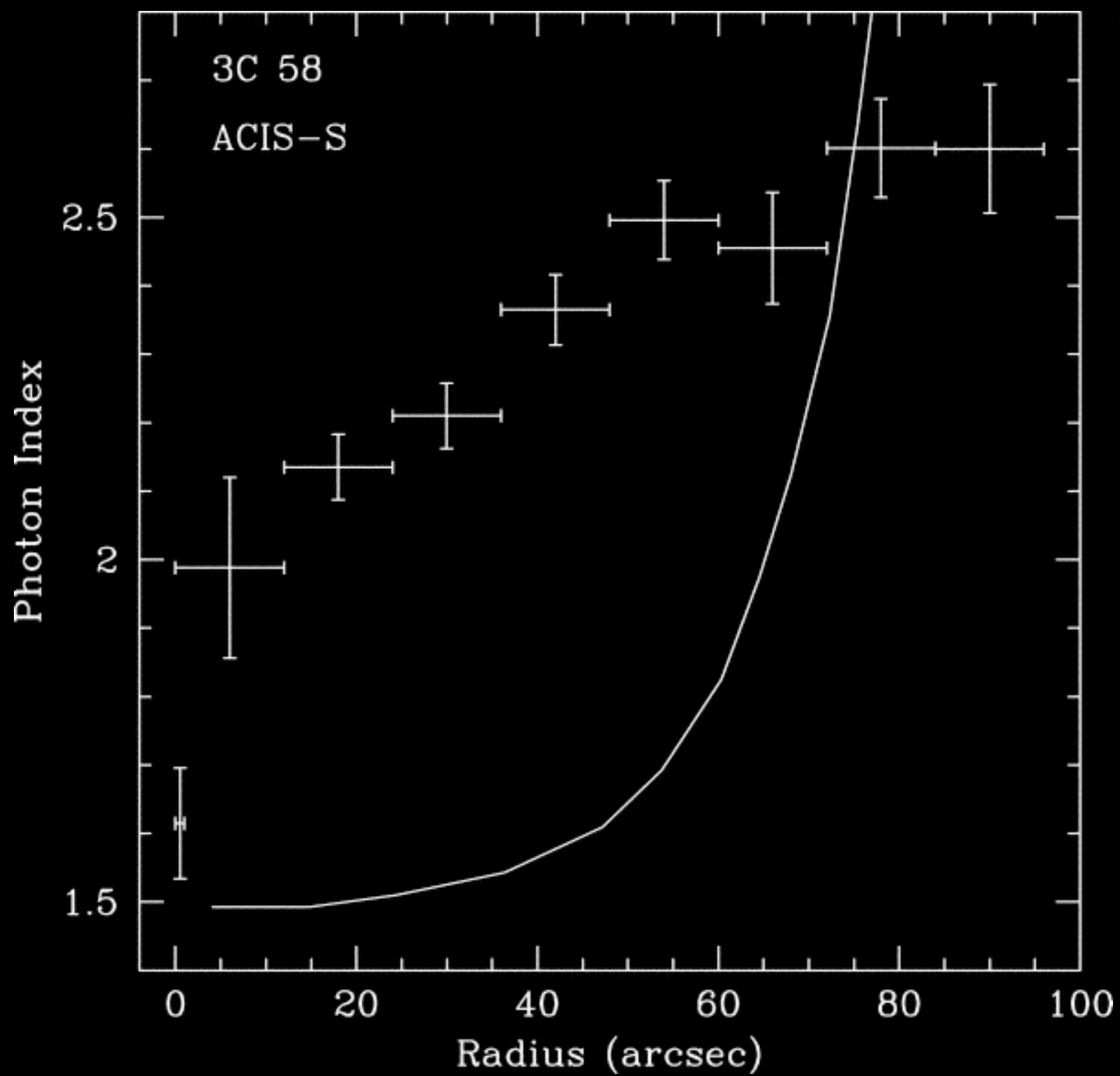
Structure and Evolution of 3C 58



Slane et al. 2004

- X-ray emission shows considerable filamentary structure; origin unknown
- Radio structure is remarkably similar, both for filaments and overall size; low magnetic field
- Outer region rich in thermal X-rays; spectrum is metal-rich
  - PWN is sweeping up ejecta; dynamical considerations suggest an age of 2500-5000 yr; not SN 1181?
- Energetic young pulsar with jet/torus structure powers nebula

Broadband Spectrum of 3C 58



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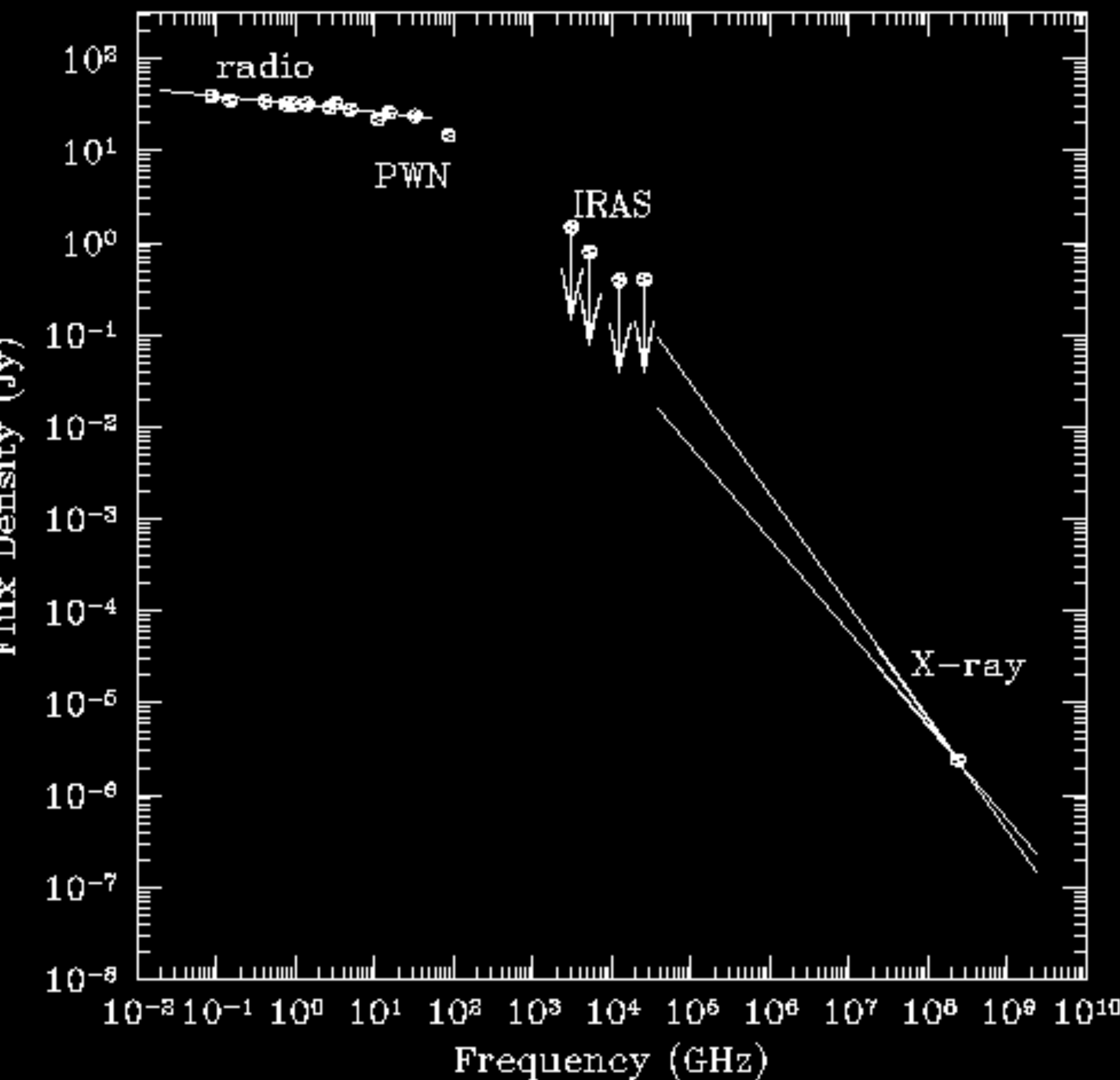

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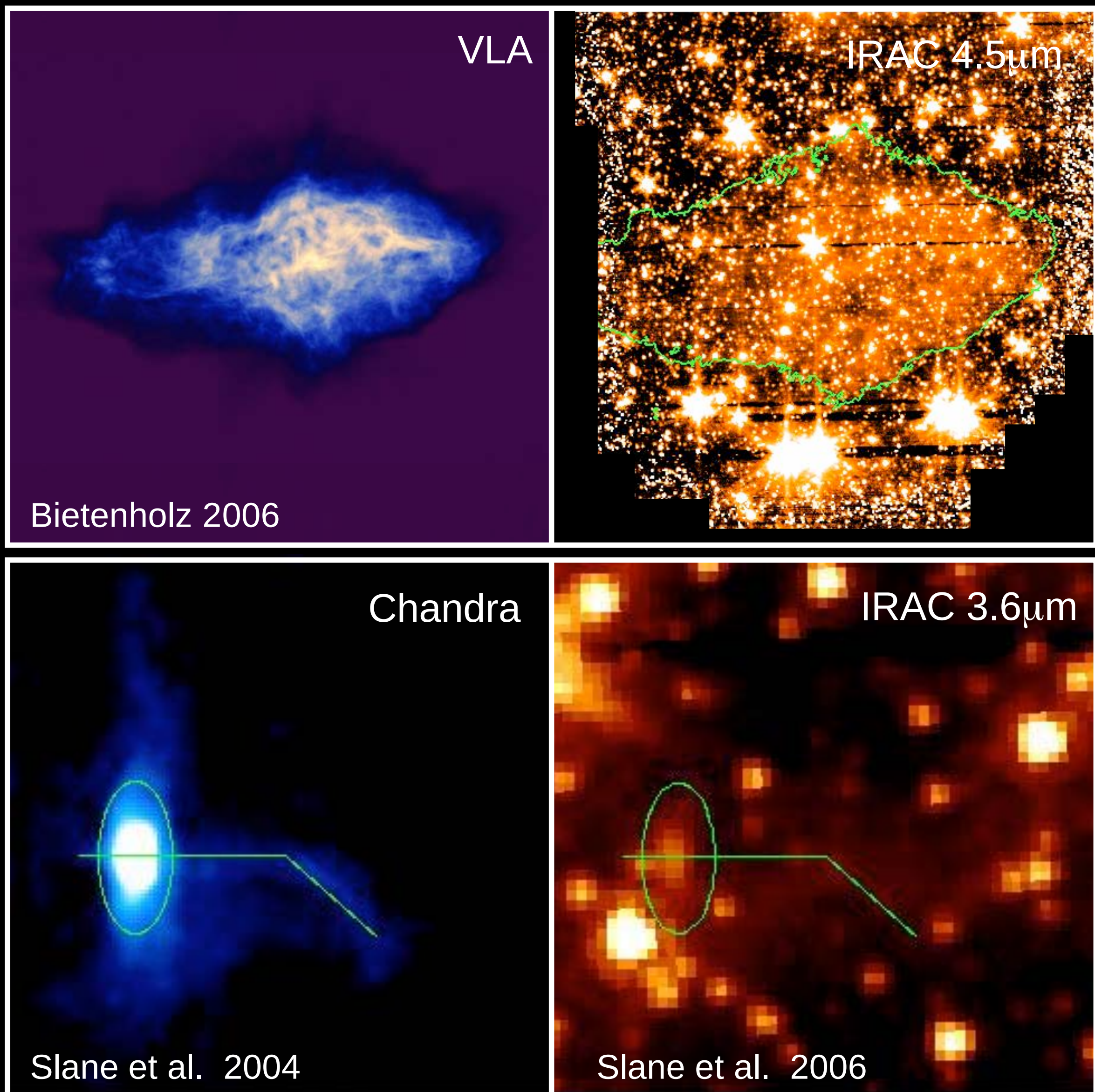
- Radio and X-ray data require low frequency spectral break
  - IRAS limits indicate break is below IR band
  - much too low for synchrotron break unless B is huge
  - radio and X-ray size of nebula are same => B is not huge…
- Several other PWNe also show breaks at low frequencies
  - modeling efforts currently unable to explain this in the context of evolution of pulsar and nebula

Spitzer Observations of 3C 58



- PWN detected in 3.6, 4.5 μm bands
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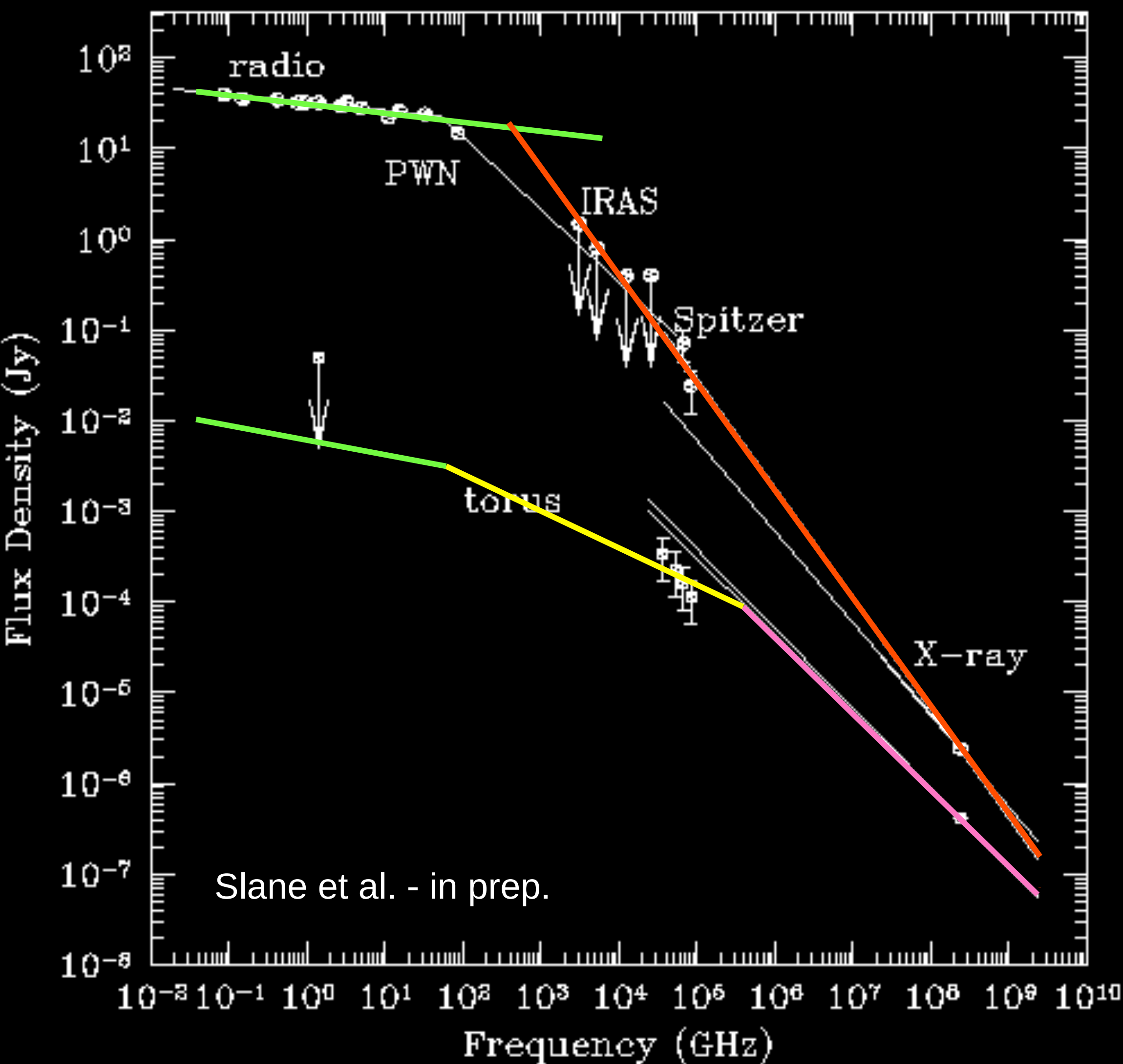

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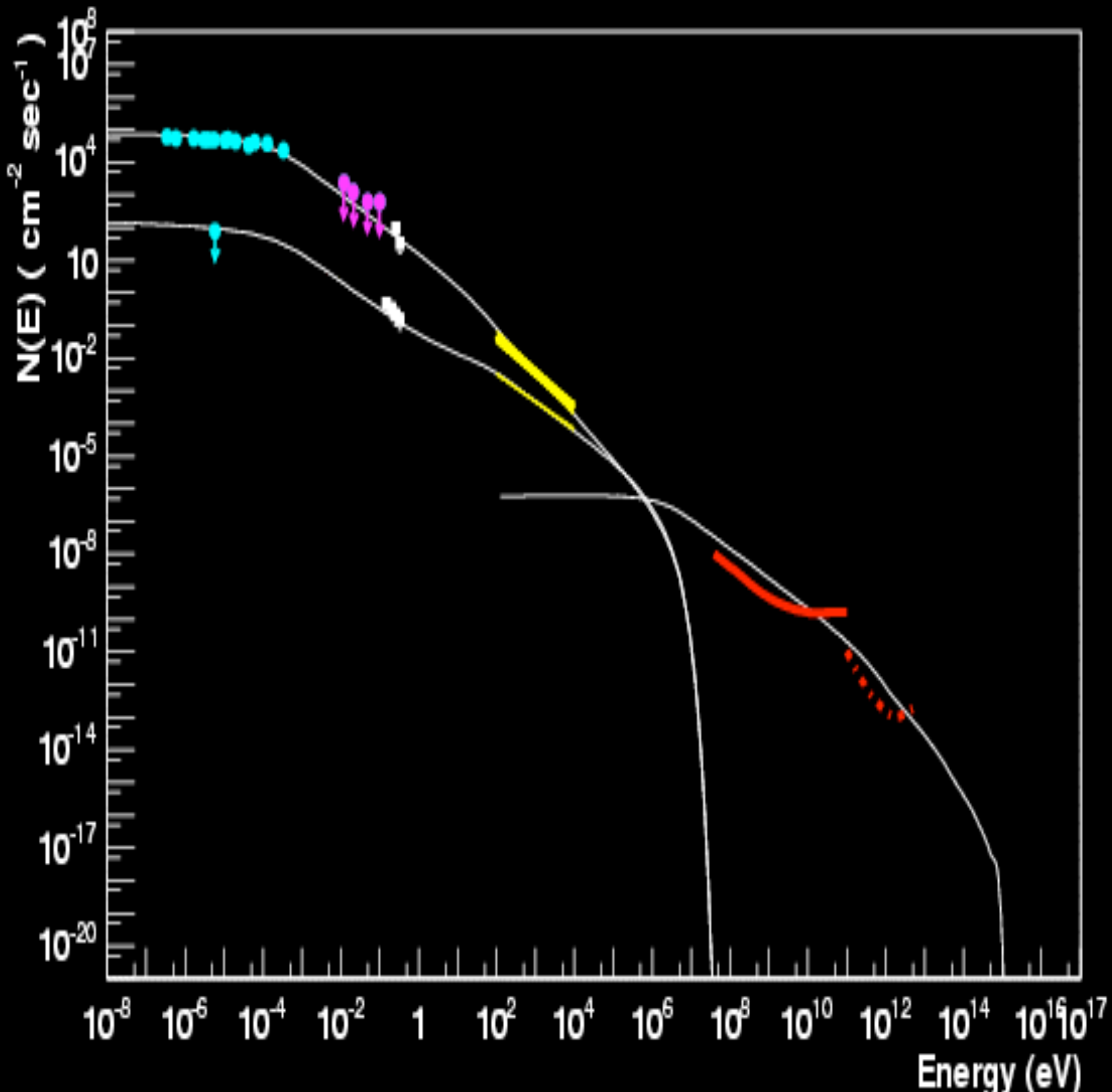

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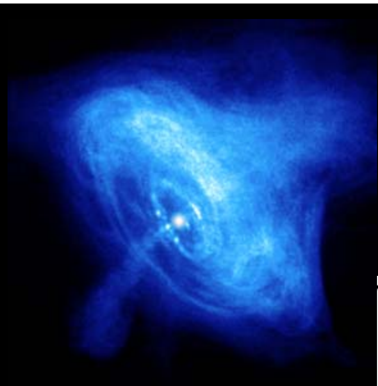
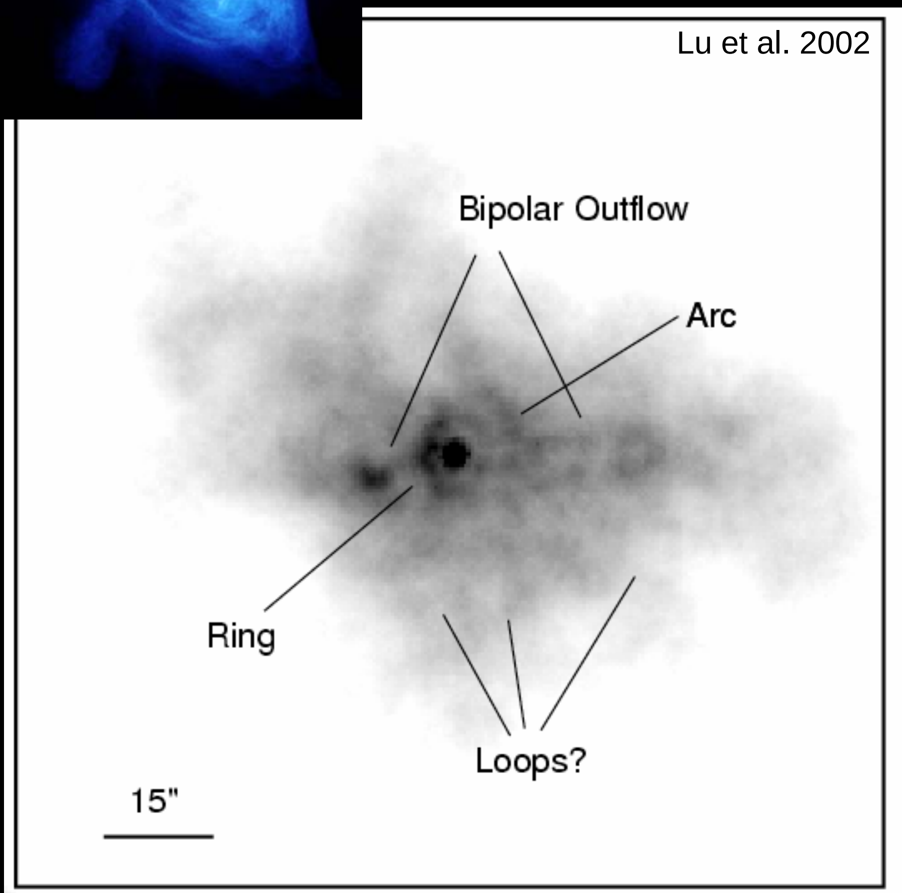
X-ray Emission from G54.1+0.3





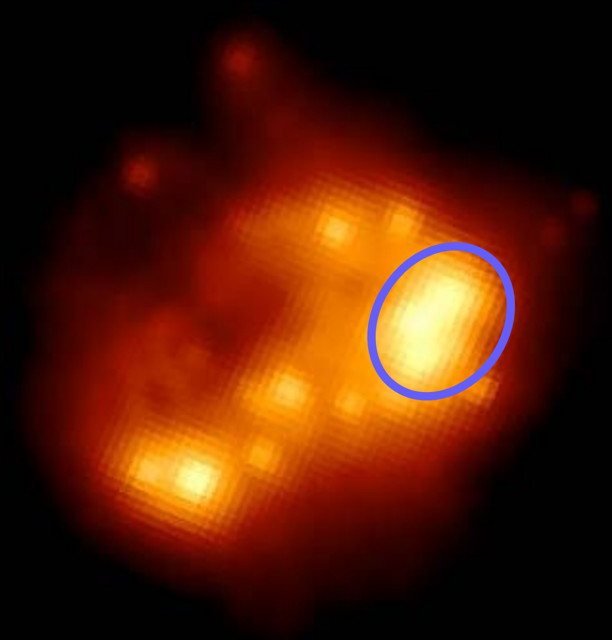
- X-ray observations of G54.1+0.3 reveal an extended nebula powered by a young pulsar
  - Doppler-brightened torus surrounds pulsar, identifying termination shock
    - -> brightness profile implies xx deg inclination
  - faint arc observed beyond ring; is this a Crab-like torus?
    - -> why so much fainter?
    - -> bright on "wrong" side for Doppler beaming

- Evidence for bipolar outflow suggests powerful X-ray jet
  - much brighter relative to torus than in Crab
  - appears to terminate in a limb-brightened structure, including circular knot at end

- No evidence for SNR shell or filamentary radio structure; where is the ambient medium?
  - spectrum softer in outer regions: faint shell?
  - loop-like structure observed: ejecta?

An IR Shell Around G54.1+0.3

MIPS 24 μm



Slane et al. - in prep.

- Spitzer observations reveal IR shell of emission from G54.1+0.3
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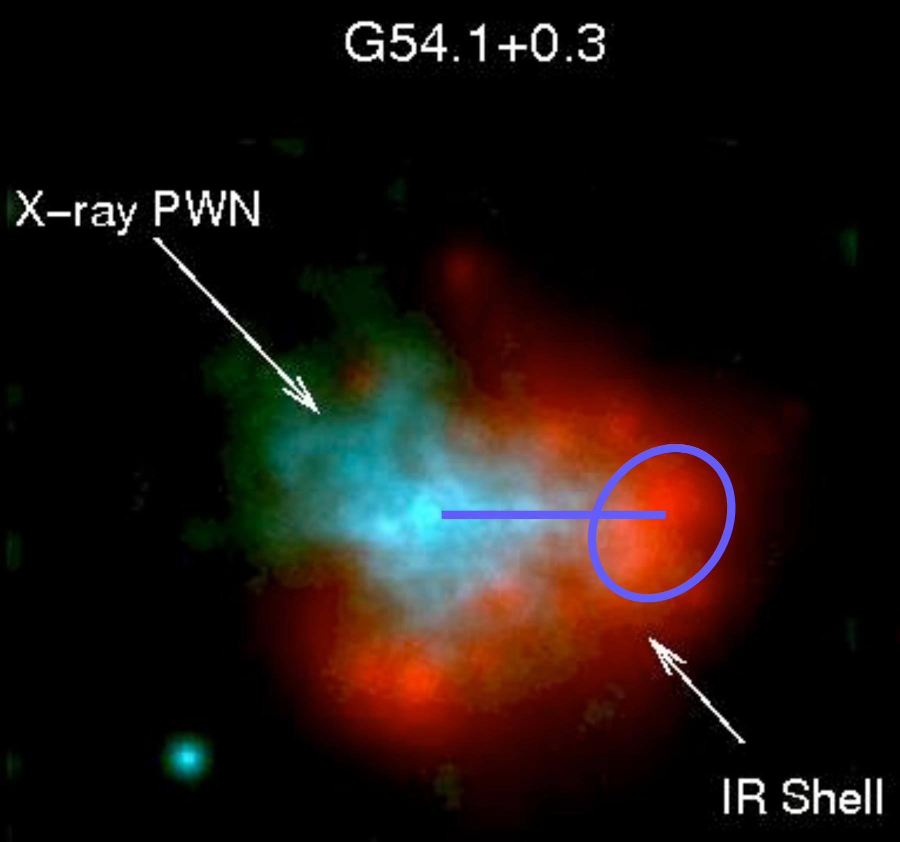

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- X-ray PWN fills shell cavity
  - may represent ambient dust swept up and heated by expanding PWN, or shock-heated stellar ejected that has encountered PWN
  - deep X-ray observations required to search for thermal emission from shell

- X-ray jet terminates at brightest IR region
  - is this region excited by jet interaction?
  - IR spectroscopy needed

- Chandra Large Project and Spitzer IRS observations approved in next Cycle; stay tuned!

Conclusions

- 3C 58 is powered by an energetic young pulsar whose injection spectrum drives the evolution of the nebula
  - jet/torus structure identifies particles near termination shock
  - broadband spectrum shows low frequency break
  - Spitzer observations reveal nebula and torus in mid-IR
  - spectrum of nebula consistent with single break in sub-mm band
  - torus spectrum implies break in injected particle spectrum; this will be crucial for overall models of nebula emission

- G54.1+0.3 reveals complex X-ray structure
  - emission seen from ring/torus, jets, and nebula
  - structure in nebula suggests interaction with surrounding material, or magnetic structures like in 3C 58
  - deep X-ray observations underway to probe detailed structure and search for thermal emission

- Spitzer observations reveal shell of emission encompassing PWN
  - may be from dust or ejecta; brightest emission aligned with jets
  - IRS observations will reveal nature of emission