A Carbon Atmosphere for the Cas A Neutron Star

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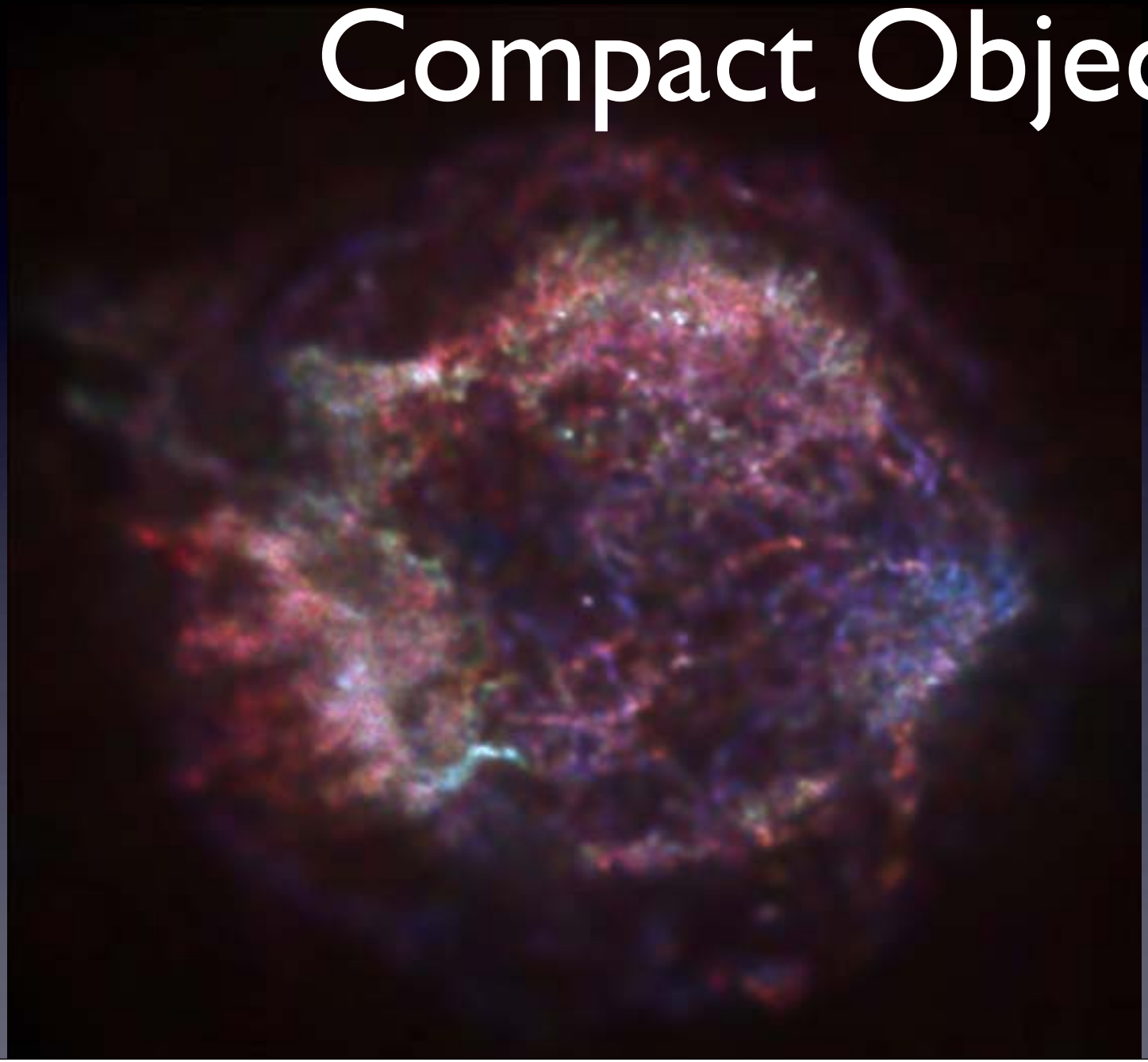
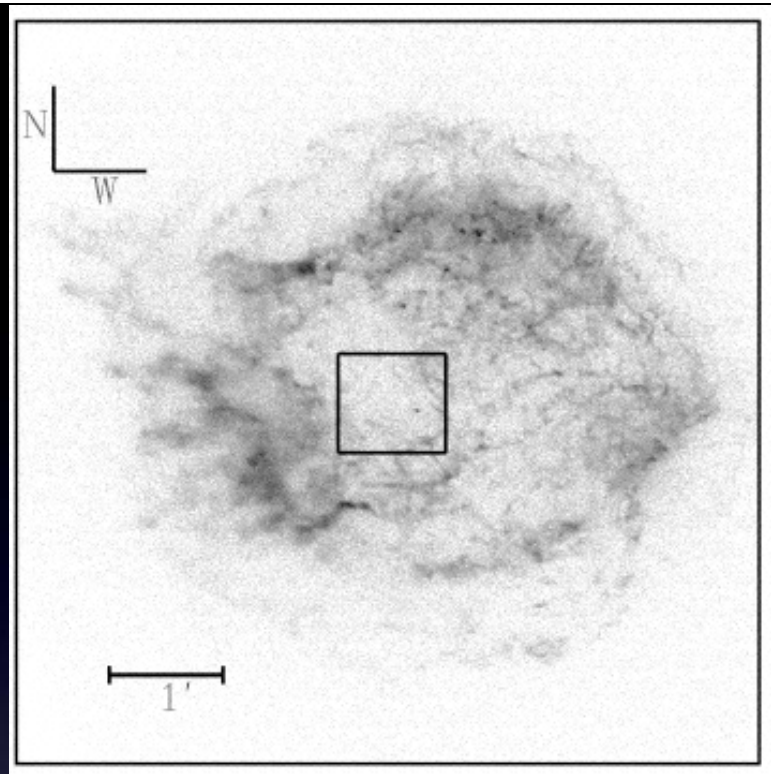
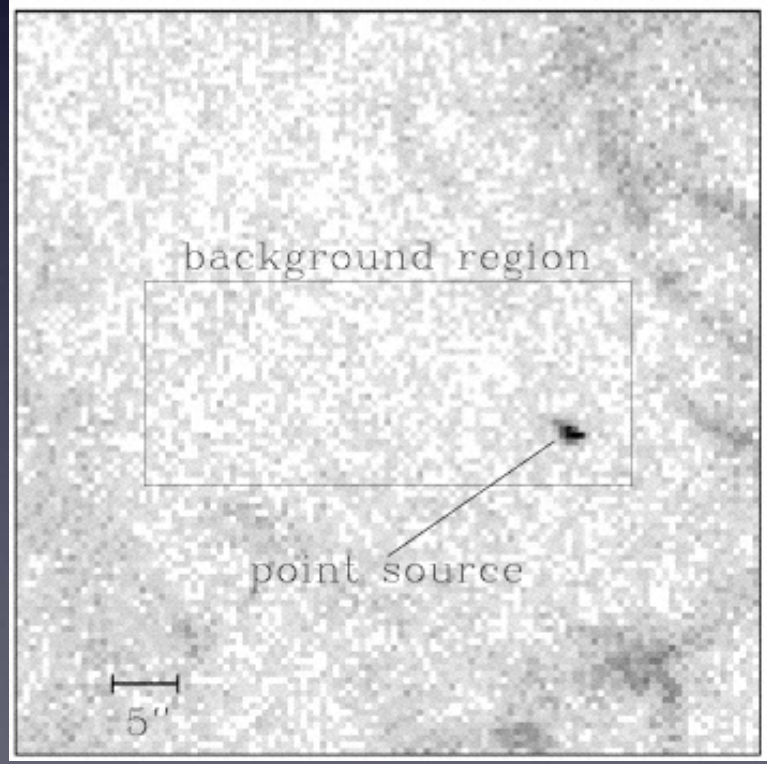
Ten Years of Science With Chandra, Boston 2009

Cassiopeia A's Central Compact Object



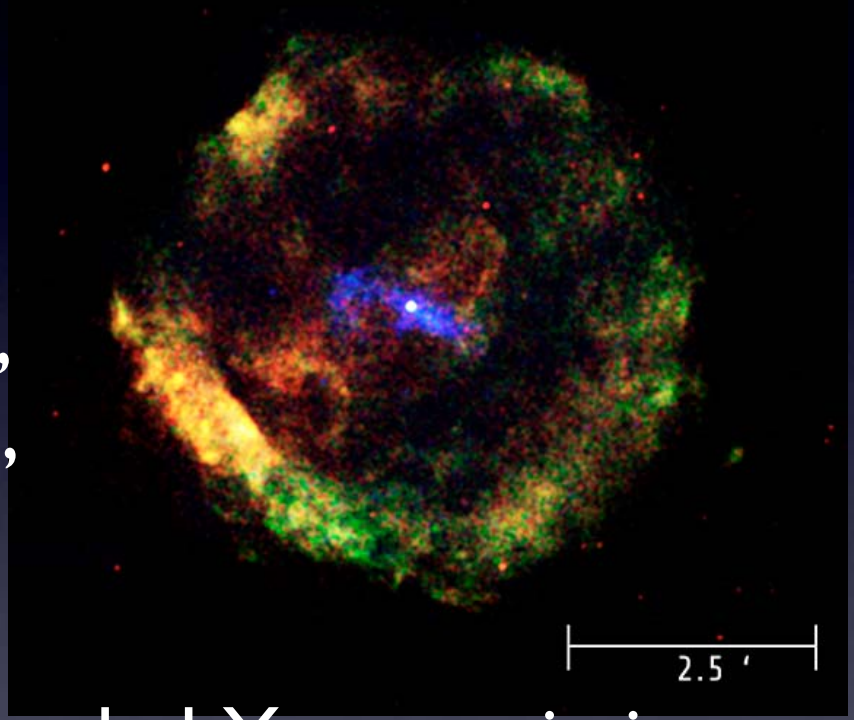
1999:
Chandra's
First Light





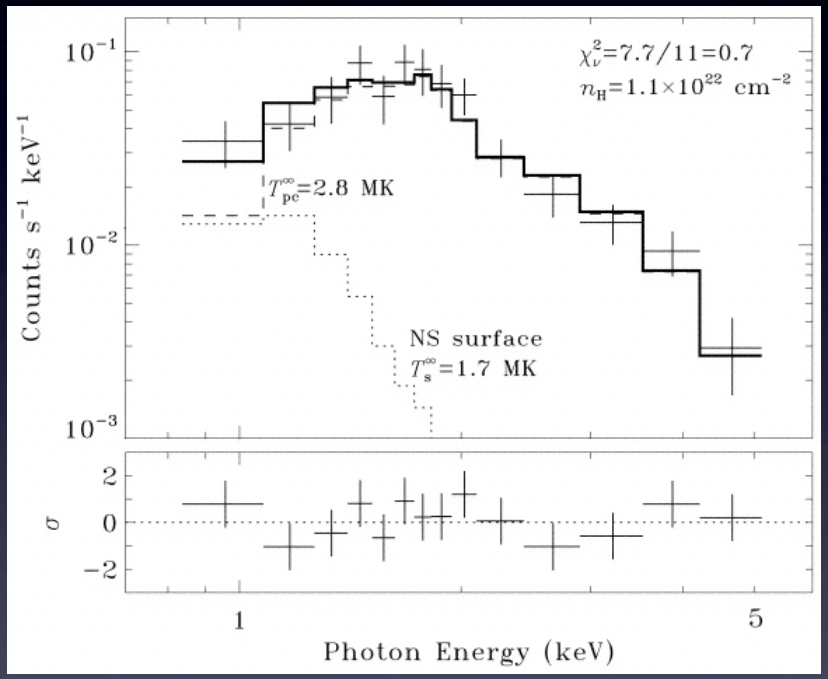
Is it a pulsar?

L: Cas A (Chakr.+01),
R: G11.2-0.3,
M. Roberts



- No extended X-ray emission (Chakrabarty+01, Pavlov+09)
- No radio pulsations

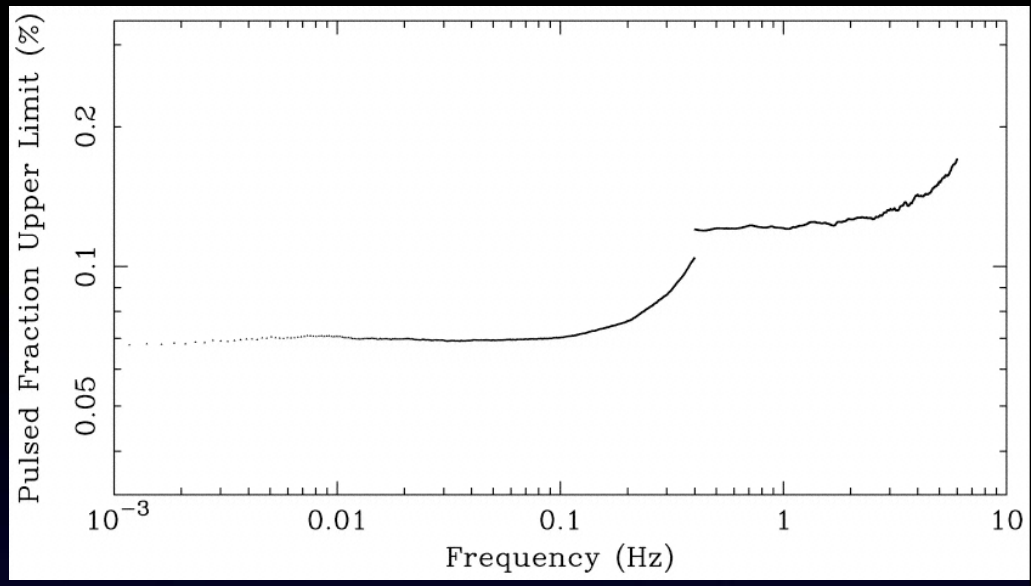
Spectrum of Cas A CCO



Pavlov+99

- Consistent with blackbody
- Distance to SNR ~3.4 kpc (Reed+95)
- Inferred BB radius 0.2-0.5 km; hot spots on a NS?

Timing Tests



XMM limits on pulsed fraction of Cas A, Mereghetti+02

- No variability on long, short timescales (Teter+04), excluding accretion
- No pulsations observed by Chandra HRC (PF<30%, Murray+02), XMM (PF<13% for P>0.3s, Mereghetti+02)
- Deeper HRC pulsation search by Chakrabarty, 2009

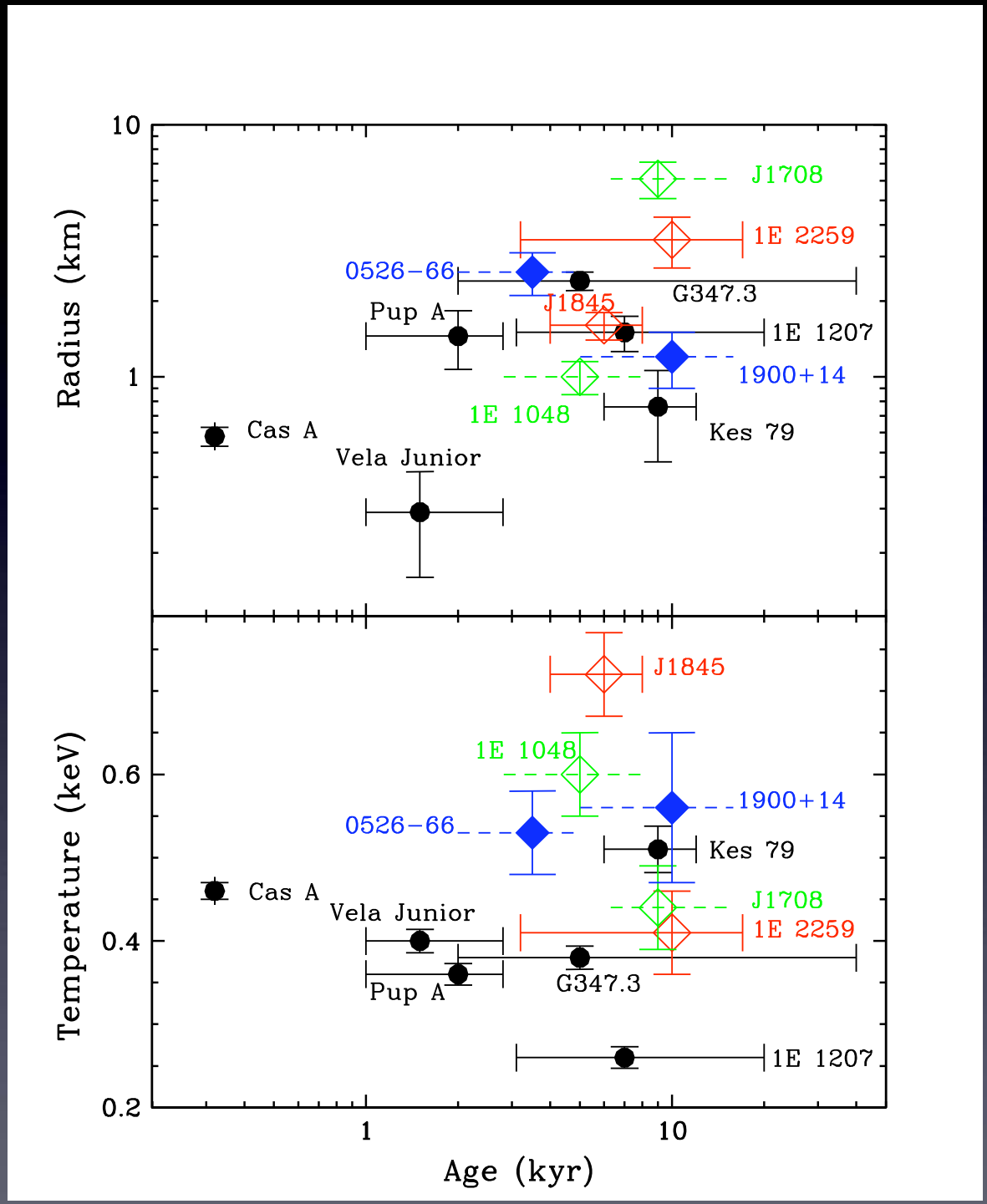
Other CCOs

- About 8 other CCOs
- Most show BB-like spectra, no long-term variability (e.g. Pavlov+03)
- Likely neutron stars, not radio pulsars. Why?

Puppis A, ROSAT

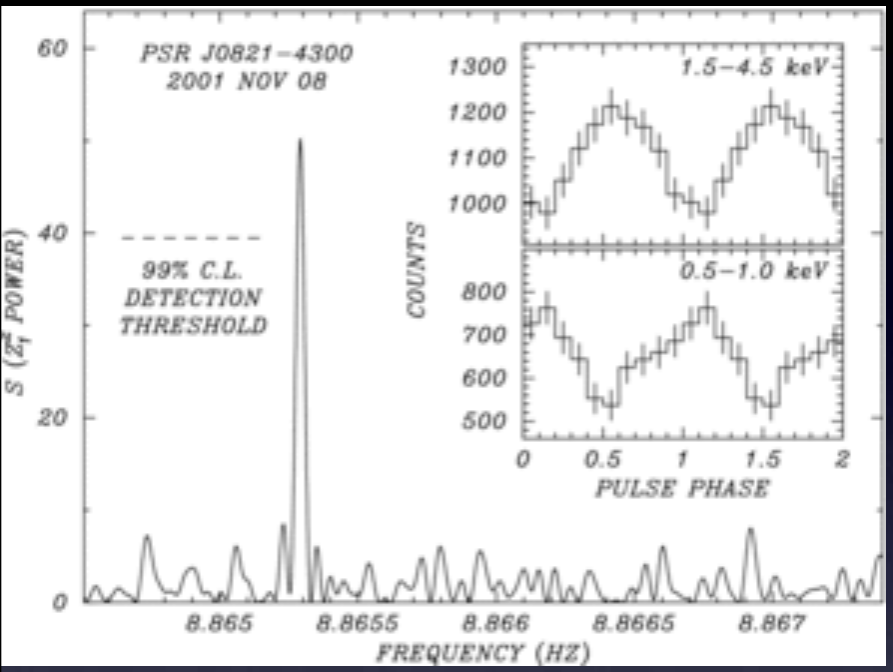
Magnetars?

- Inferred radii of CCOs increase with age (Pavlov+03)
- Inferred radii similar to magnetars, but temps lower, cooling



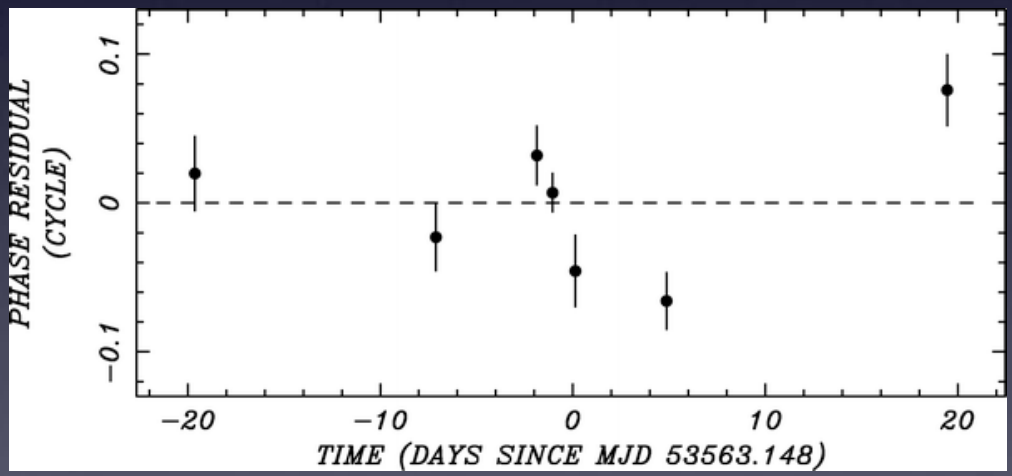
Pavlov+03

Low B--anti-magnetars?



Gotthelf+09, Pup A

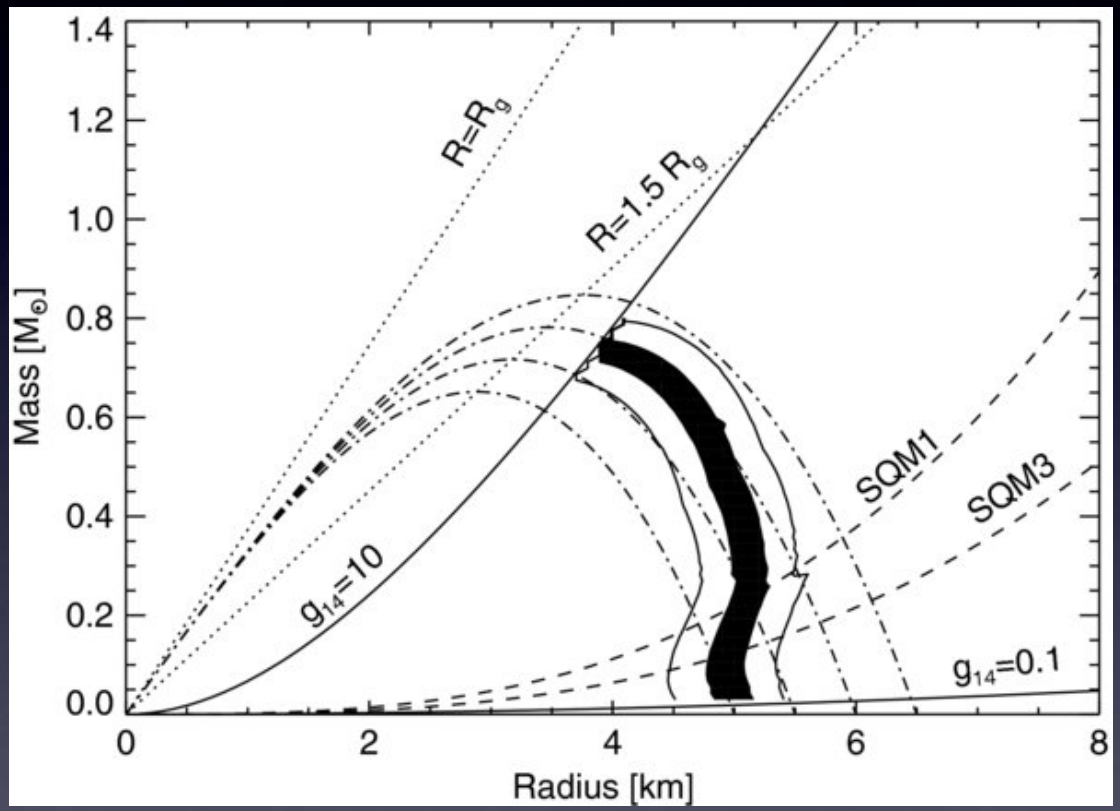
- Several CCOs pulse, P~0.1-0.5 s
- Strict limits on $\dot{P}$, $B<10^{12}$ G (Halpern+07, Gotthelf+07, Gotthelf+09)



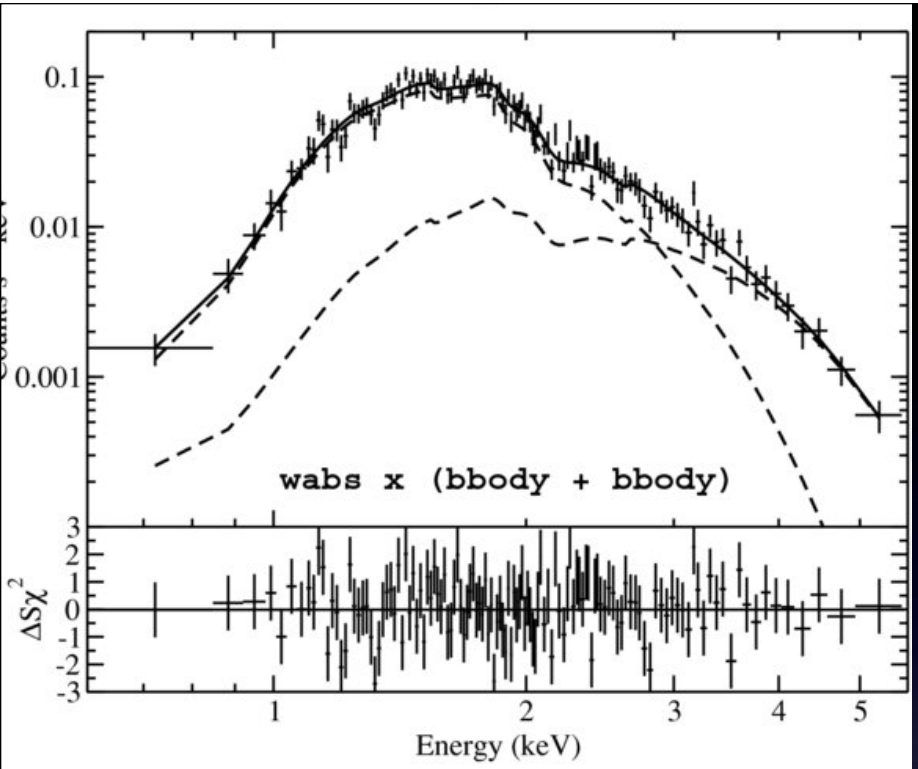
Gotthelf+07, 1E1207-52 timing

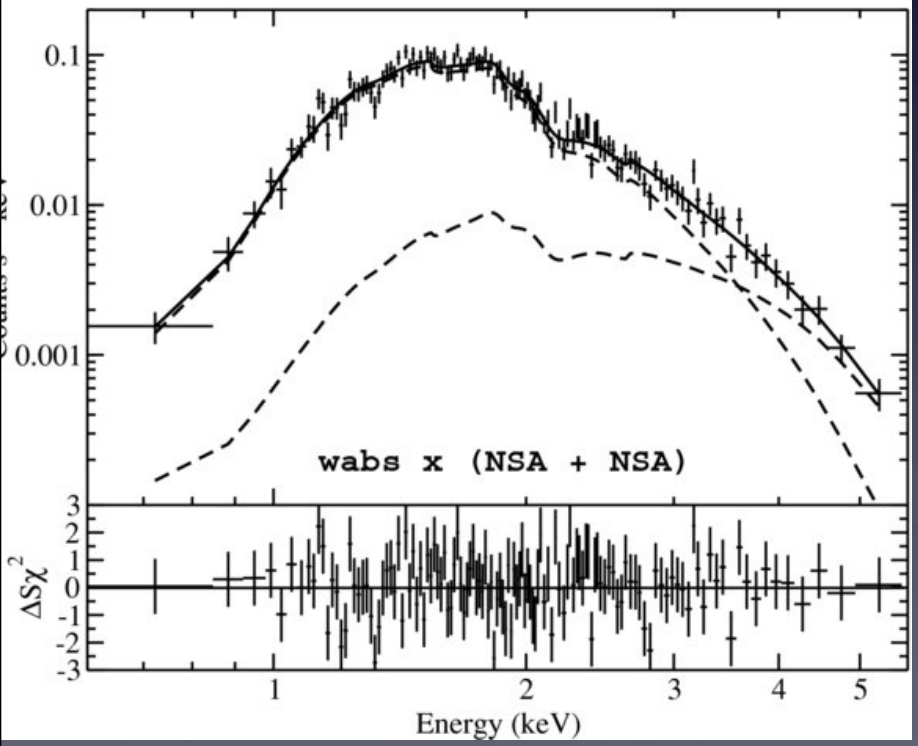
Low-B H atmosphere?

- Low-B H atmosphere good fit to Cas A CCO
- Inferred radius ~ 5 km, permitting only tiny quark stars (Pavlov & Luna 09)
- Some older CCOs consistent with single H-atm, NS radius (Zavlin +98, Pavlov+03)



Constraints for uniform H atmosphere, Pavlov+09





Nonuniform H atmospheres?

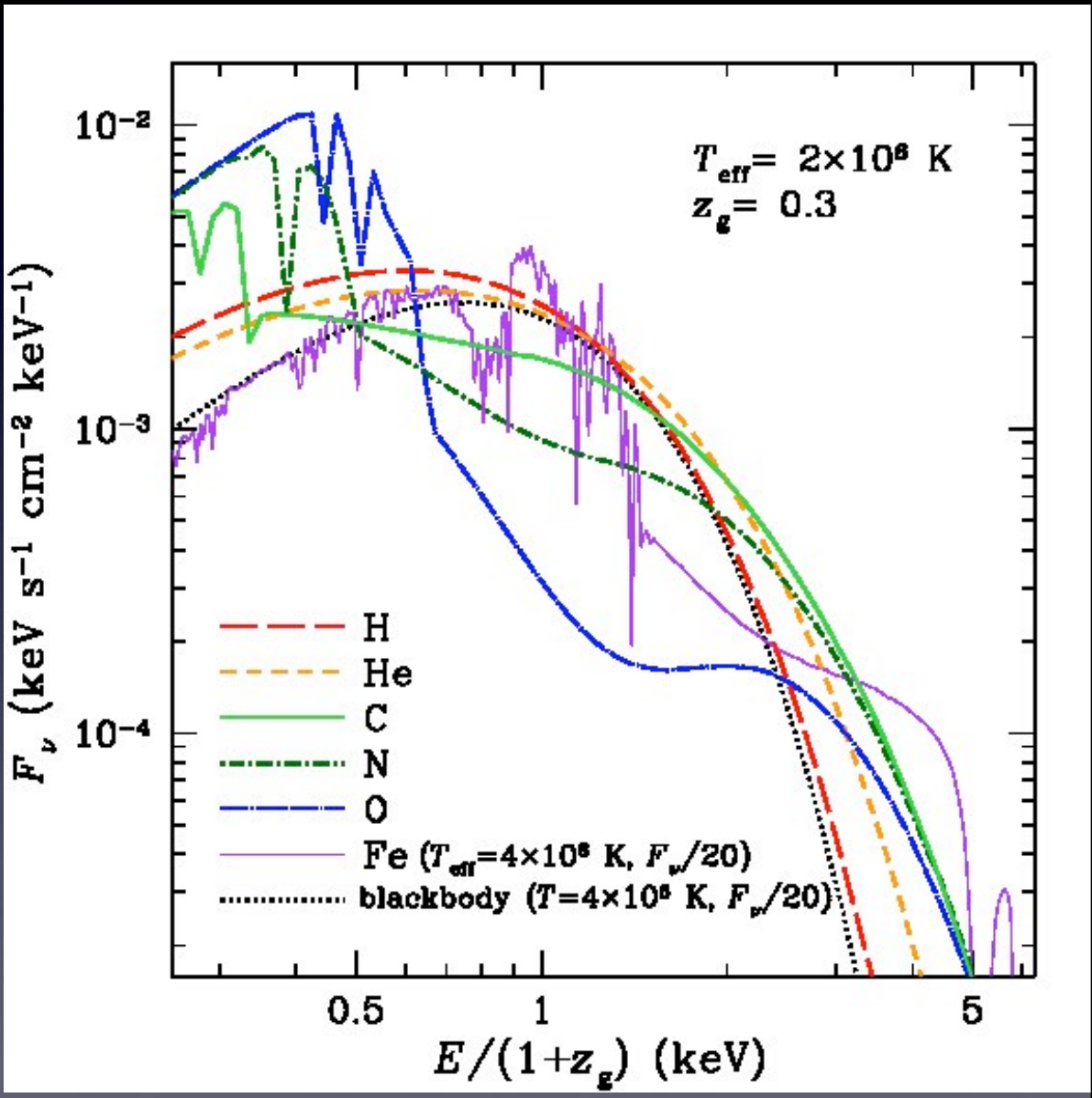
- Two low-B components give acceptable fit, allow R~12 km
- Should produce strong pulsations, not yet detected
- Difficult to explain origin of ~0.4 km hot spot

Cas A fits, Pavlov+09

Alternative atmospheres

- Variety of low-B NS atmospheres, using Opacity Project
- N, O, Fe produce major features
- C somewhat harder than H, He

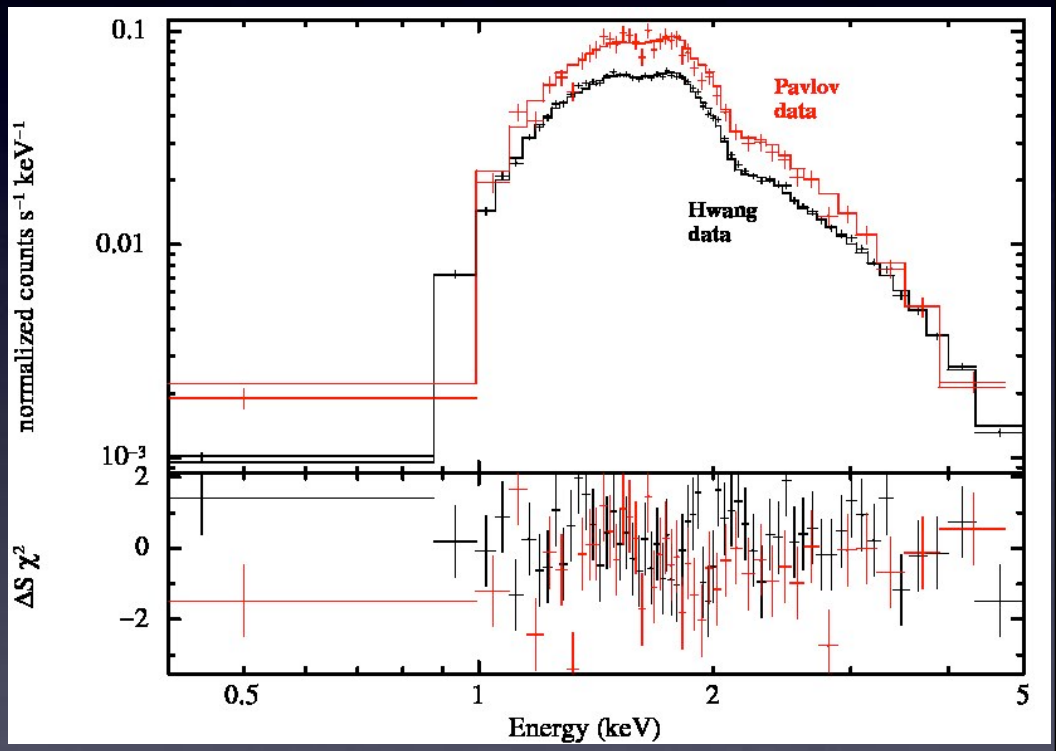
Ho & Heinke 09



Carbon atmosphere fit

- Fit megasec Hwang data, dedicated Pavlov data
- Slightly better χ^2 from C
- C atm fit only one consistent with NS radii

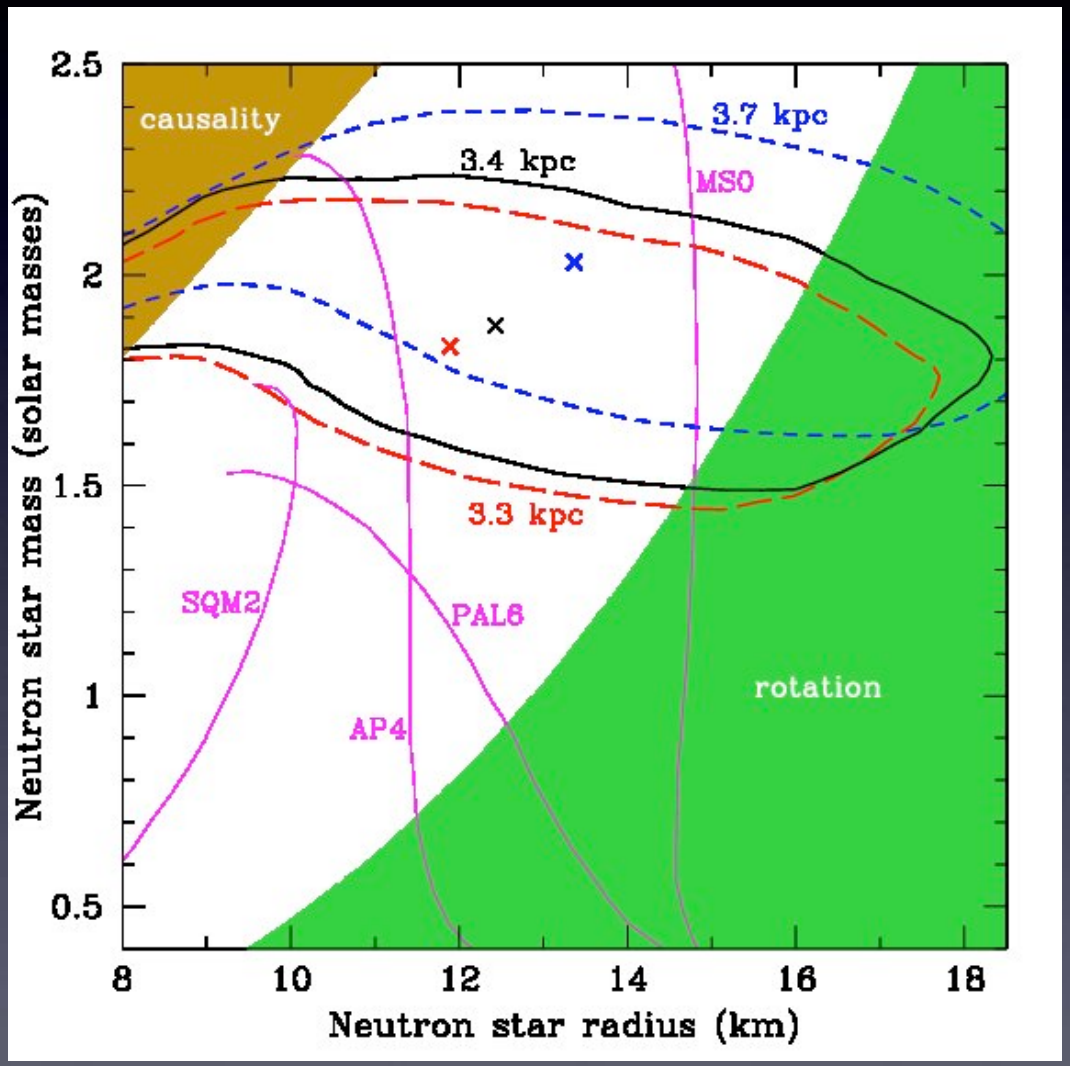
Model	Norm	χ^2/dof	nhp
H	0.18(3)	106.3/99	29%
He	0.22(5)	112.4/99	17%
C	1.8(5)	105.3/99	31%
N	1.18	388/99	0%



C atm fit; Ho & Heinke 09

Mass/radius constraints

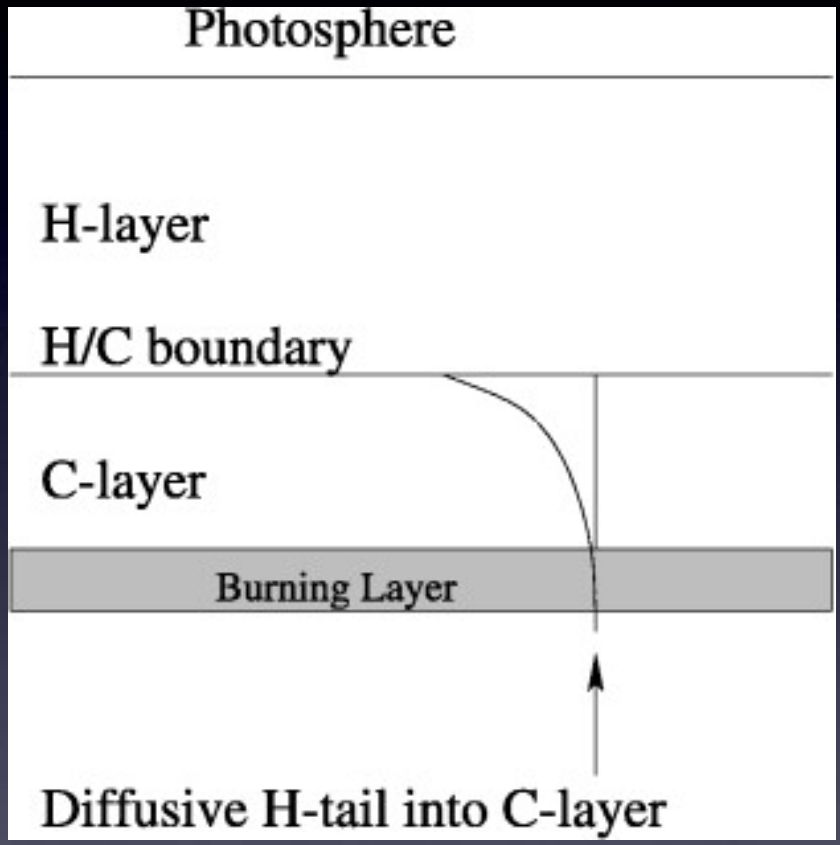
- Cas A fit to a grid of models in mass, radius
- 90% confidence contours suggest stiff NS structure
- Constraints subtly affected if B~10^{11} G



Ho & Heinke 09 (in press)

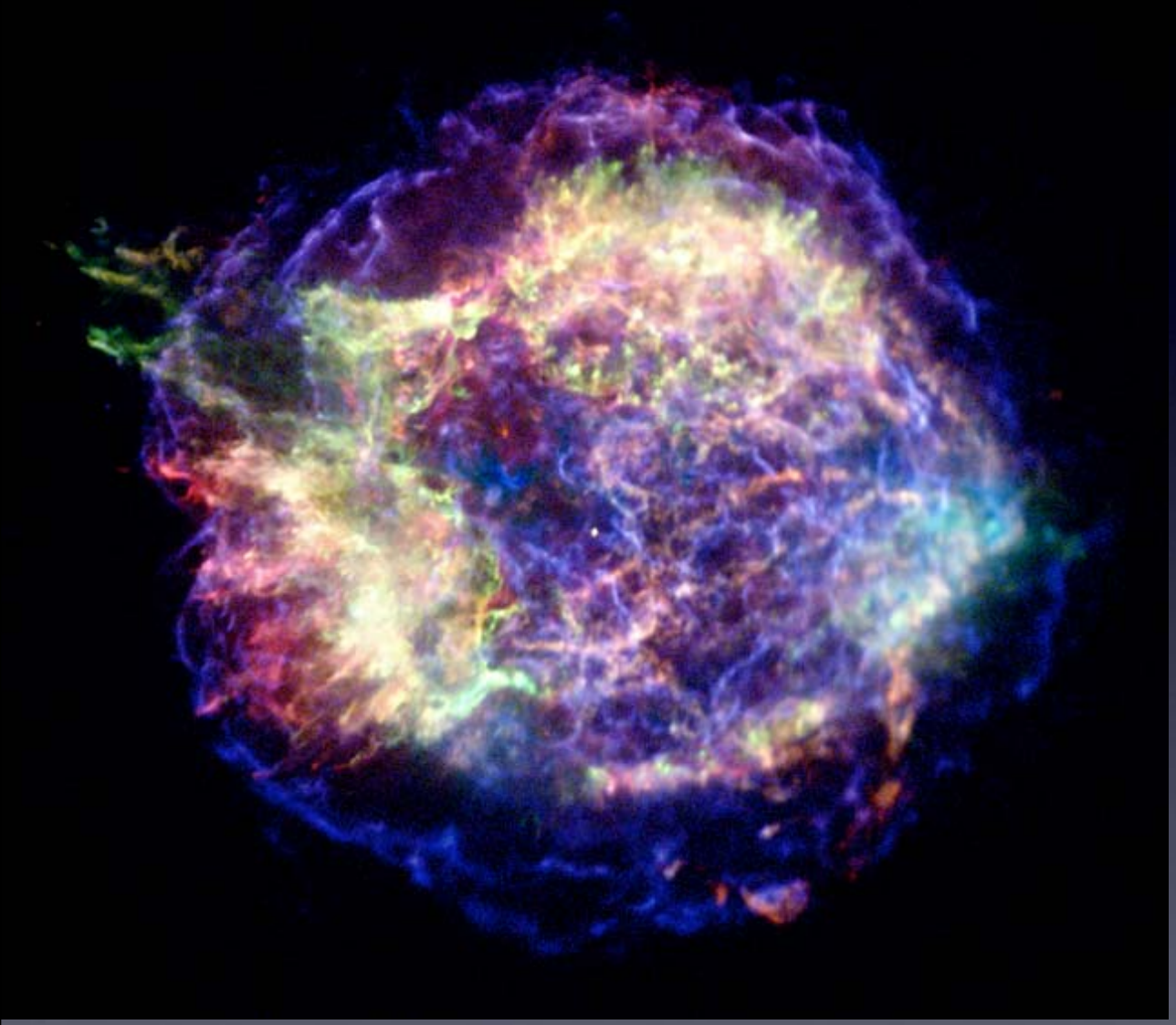
Why a C atmosphere?

- Cas A is youngest known NS
- Interiors of SNR contain dissociation products (H, He), likely accrete onto NS
- H, He diffuse down, can be burned to C (Chang+03)
- Low-B NSs burn away H, He for first 1000 years? Then H atm?



Chang+03

10-year mystery resolved?



- Cas A CCO is a NS
- Indicates evolution of NS surface
- Cooling behavior in line with theory
- Do any other CCOs show C atms?

Cas A, Hwang