A neutron star with a carbon atmosphere in the Cassiopeia A supernova remnant

Wynn C. G. Ho1 & Craig O. Heinke2

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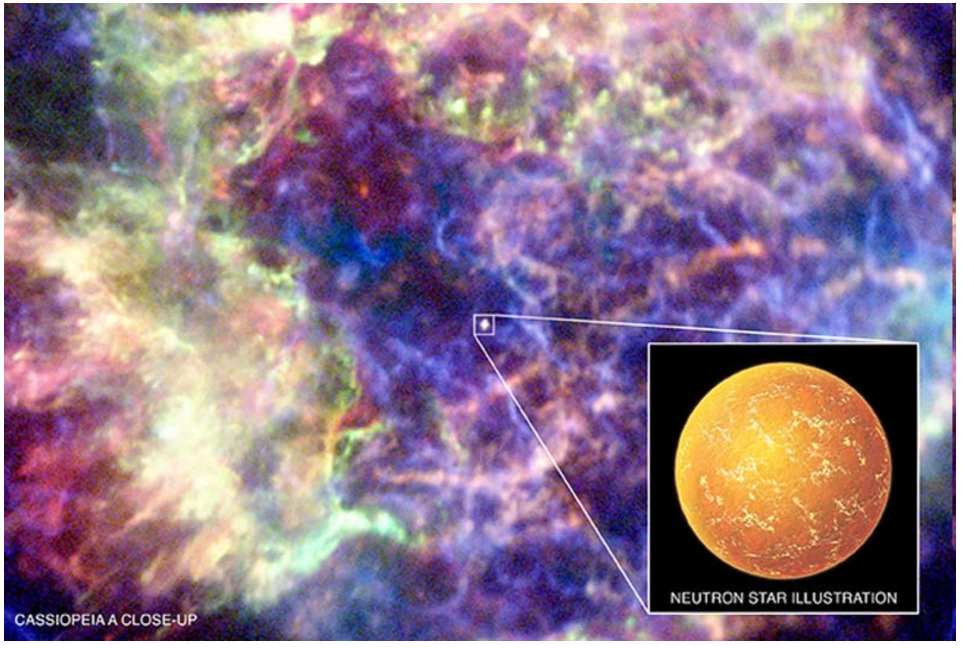
Kao, Kai-Wei
Institute of Astronomy, NTHU

An artist's impression of the carbon-cloaked neutron star
Illustration: NASA/CXC/M.Weiss



Cassiopeia A is one of the youngest-known supernova remnants in the Milky Way and is at a distance of d$\fallingdotseq$3.4 kiloparsecs (kpc) from the Earth.

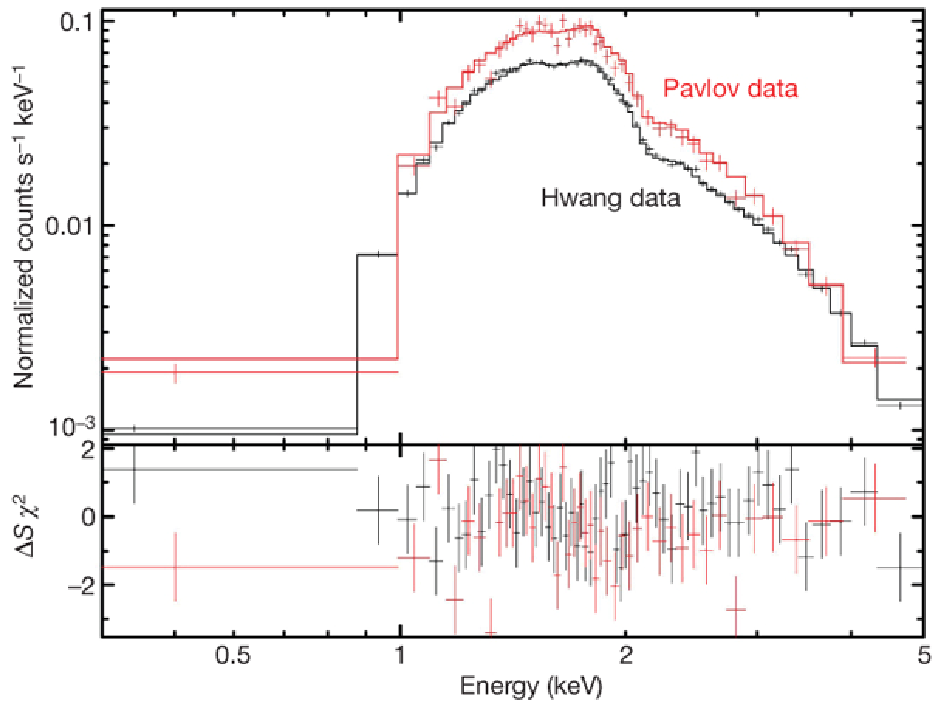
- **Here they report an analysis of archival observations of the compact X-ray source in the centre of the Cassiopeia A supernova remnant. They show that a carbon atmosphere neutron star (with low magnetic field) produces a good fit to the spectrum.**

Chandra X-ray spectra of Cas A.

They considered archival Chandra X-ray Observatory data from two studies of Cas A, both using the ACIS-S charge-coupled device.

A series of Chandra observations, totalling 1 megasecond, was performed in 2004 to study the supernova remnant; these are referred to here as the Hwang data.

A shorter (70 kiloseconds) observation in 2006 was designed to study the compact source, here referred to as the Pavlov data.



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Spectra from the Hwang (black) and Pavlov (red) observations and fits with their C spectral model. Error bars are 1 s.d. The lower panel shows the fit residuals, $\triangle S_{\chi^2}$ in units of s.d.

- Previous works found poor fits to the data using magnetic ($B \geqq 10^{12}$ G) H atmosphere spectra.

- Timing measurements suggest that they have (dipolar) magnetic fields of $B << 10^{12}$G.

  Neutron stars have weakly magnetic fields at birth. (Gotthelf et al. 2009)

- When $B=2.35\times10^{9}\times Z^{2}$ G ($\sim 8\times10^{10}$ G for carbon), magnetic-field effects on the radiation transport and atoms in the atmospheric plasma are negligible. (Rajagopal et al. 1996 ; Zavlin et al. 1996)

- If the magnetic field of Cas A is ~(1–5) $\times10^{11}$ G, then a spectral feature due to the electron cyclotron resonance may appear in the Chandra energy range, but this has yet to be detected. The lack of a visible pulsar wind nebula and no indication of magnetospheric activity like those seen in classical pulsars (with $B \geqq 10^{12}$ G), also **suggest the magnetic field is low**.

Table 1 | X-ray spectral fitting of Cas A

Atmosphere model	N_H (10^{22} cm^{-2})	kT (eV)	Normalization	χ^2/d.o.f.	Null hypothesis probability (%)
Hydrogen	$1.65^{+0.04}_{-0.05}$	241^{+7}_{-6}	$0.18^{+0.03}_{-0.03}$	106.3/99	29
Helium	$1.62^{+0.04}_{-0.05}$	228^{+9}_{-8}	$0.22^{+0.05}_{-0.04}$	112.4/99	17
Carbon	$1.73^{+0.04}_{-0.04}$	155^{+7}_{-6}	$1.84^{+0.56}_{-0.42}$	105.3/99	31
Nitrogen	1.37	172	1.18	388/99	0
Oxygen	1.03	234	0.20	2,439/99	0
Blackbody model	$1.46^{+0.04}_{-0.04}$	$kT^{\infty} = 387^{+7}_{-6}$ eV	$R^{\infty} = 1.0^{+0.1}_{-0.1}$ km	134.2/98	11

Joint fitting results to the Hwang and Pavlov data with neutron-star atmosphere and blackbody models that are modified by photoelectric absorption N_H (using the Tuebingen–Boulder absorption routine TBABS with Wilms model abundances in the X-ray spectral fitting package XSPEC; see http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/index.html), dust scattering[23], and corrections for pile-up[24] (the grade migration parameter of the pile-up algorithm is allowed to float freely and is 0.36 for the best-fit C model). Chandra data with such high statistics reveals systematic uncertainties in the Chandra calibration[13], so we added a systematic uncertainty of 3% in quadrature. All parameter errors are given at 90% confidence. Errors are not reported when the reduced $\chi^2 > 2$. The normalization refers to the fraction of the neutron star surface emitting radiation (for a 10 km stellar radius and 3.4 kpc distance). The null hypothesis probability is the probability that one realization of the model fit to the data would have a reduced χ^2 greater than that obtained; less than 5% indicates a poor fit. $T^{\infty} = T/(1+z_g)$ and $R^{\infty} = R(1+z_g)$ are the temperature and radius measured by an observer at infinity and d.o.f. is the number of degrees of freedom.

H → R ≒ 4km
He → R ≒ 5 km
C → R ≒ 12~15 km

R_{NS} ≒ 10 km~14 km.

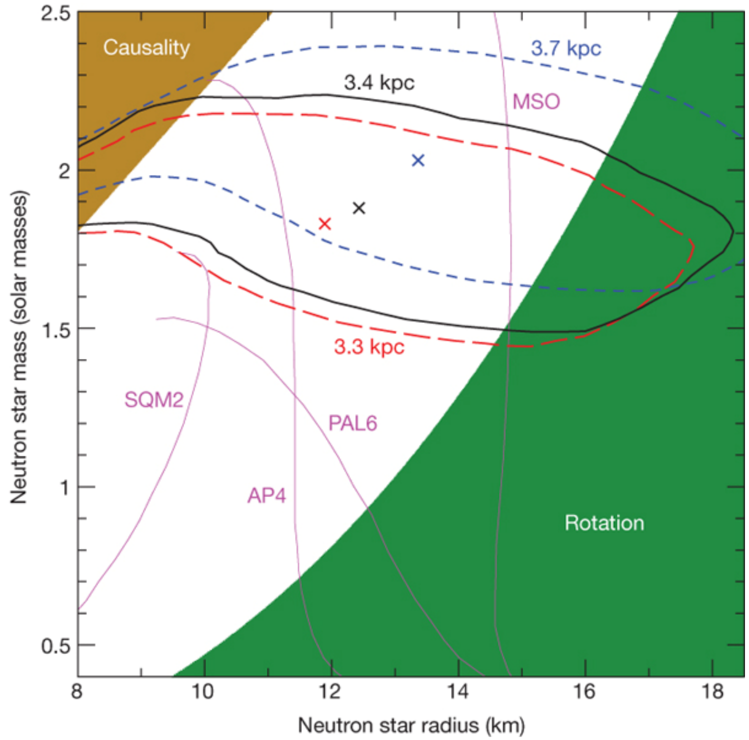
Thus we conclude that Cas A is consistent with a low-magnetic field carbon-atmosphere neutron star of mass $1.4M_{Sun}$, radius 12–15 km, and surface temperature $T=1.8\times10^6$ K.

- The derived sizes of the emission region R for H and He are much smaller than the theoretical size of a neutron star $R_{NS.}$ This would suggest the emission region is a hot spot on the neutron-star surface, which would probably result in X-ray pulsations as the hot spot rotated with the star. However, these pulsations have not been detected.

the X-ray observations are detecting emissionfrom the entire stellar surface, and therefore the emission would not necessarily vary as the star rotates

Neutron star mass and radius.

Interpreting the size of the emission region to be the true neutron-star radius ($R=R_{NS}$), we can constrain the neutron-star mass M_{NS} and radius R_{NS} by using a range of surface gravity models. If we fix $M_{NS}=1.4M_{Sun}$ and the distance to Cas A as d=3.4 kpc ,then we find a surface effective temperature of $T_{eff} \fallingdotseq 1.61\times10^{6}$K and emission size $R \fallingdotseq 15.6$ km.



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90% confidence contours of χ^2around the best-fitting Cas A mass and radius (crosses) for distances of 3.3 kpc (red long-dashed line), 3.4 kpc (thick black solid line), and 3.7 kpc (blue short-dashed line).

The upper-left and lower-right regions are excluded by constraints fromthe requirement of causality and fromthe fastest-rotating neutron star known.

- the compact source as a very young (330-year-old) neutron star.

- Because the next-youngest neutron stars for which surface thermal emission has been measured have ages exceeding a few thousand years, Cas A serves as a valuable window into the early life of a passively cooling neutron star.

Thank you

Reference:

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(http://www.nature.com/nature/journal/v462/n7269/pdf/nature08525.pdf)

Carbon atmosphere discovered on neutron star (http://www.astronomy.com/asy/default.aspx?c=a&id=8771)