Reverse Shock Processing of Ejecta in Cassiopeia A

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Abstract

Cassiopeia A was observed with Chandra for 50 ksec in 2000 and 2002, and for 1 Msec in 2004. We note several X-ray knots located at the reverse shock which exhibit measurable intensity changes over the 4 years worth of observations. I will summarize the results from our spectral analyses of these regions and compare them to hydrodynamical models for reverse shock interactions with non-uniform ejecta.

Introduction

With an estimated explosion date of 1671±1 (Thorstensen et al. 2001) and a distance of 3.4±0.3 kpc (Reed et al. 1995), Cassiopeia A is currently the youngest known Galactic remnant of a core-collapse supernova. The remnant consists of an optical, infrared, and X-ray bright 4′ diameter (≈ 4pc) emission ring of reverse shock heated ejecta rich in O, Si, Ar, Ca, and Fe. In X-rays (Figure 1), the remnant's debris is seen as a bright ≈ 95″ radius ring dominated by thermal emission, surrounded by an emission ring of forward shock heated circumstellar material. While the forward shock has an estimated velocity of ~ 6000 km s^{-1} (Delaney & Rudnick 2003), the reverse shock velocity is estimated to be only ~ 1000 km s^{-1} (Laming & Hwang 2003), in contrast to that measured in the optical (~ 5000 km s^{-1}; Morse et al. 2004).

Results

Regions 1, 2, and 3 were fit to either metal-rich VNEI models with no H, He, C, and N, or VNEI models with no H and cosmic abundance He, C, and N (Figs. 2-4). Region 4 contains insufficient counts in the 2004 observations for an acceptable fit.

Table 1: Observed ACIS count rates

Region	114	1952	(4634–4637)[a]
1	0.495 ± 0.006	0.572 ± 0.006	0.298 ± 0.003
2	0.302 ± 0.005	0.349 ± 0.005	0.180 ± 0.002
3	0.193 ± 0.003	0.201 ± 0.003	0.096 ± 0.001
4	0.247 ± 0.003	0.224 ± 0.003	0.105 ± 0.001

[a] Observation IDs 4634-4637 were coadded and weighted using the CIAO tool *acisspec*.

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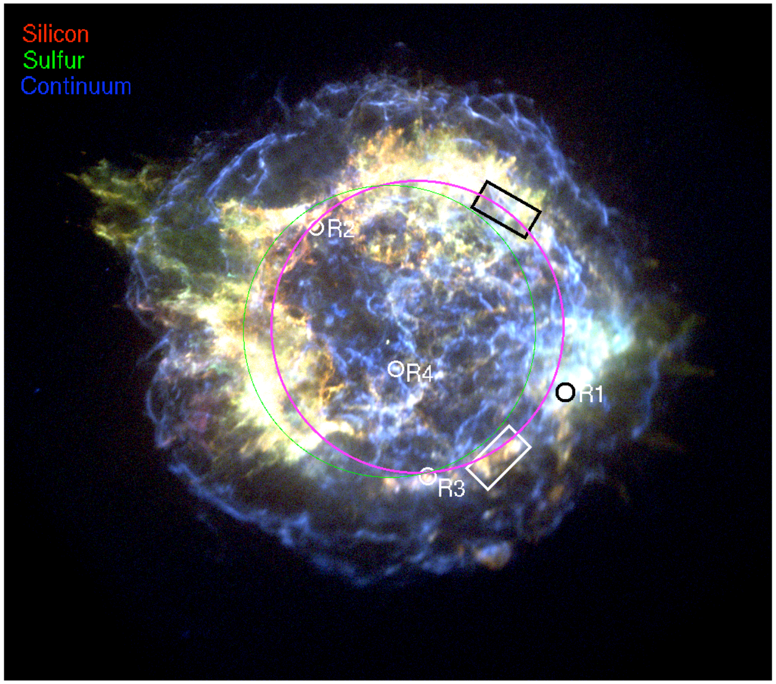

Figure 1: True color image of Cassiopeia A. The green circle marks the location of the reverse shock based on the center of expansion (Thorstensen et al. 2001). The magenta circle coincides with the reverse shock identification of Gotthelf et al. (2001). The circles mark regions which show significant flux changes between 2000 and 2004. The reverse shock locations identified by Morse et al. (2004) are marked with rectangular boxes.

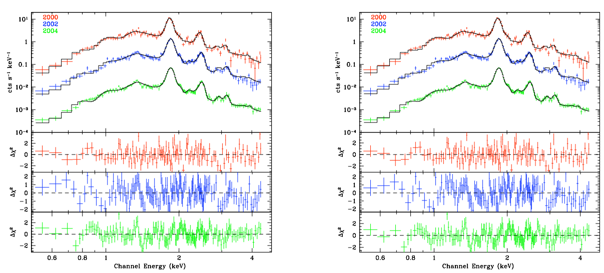

Figure 2: Spectra and model fits for Region 1. *Left:* Metal rich models. *Right*: Models with a continuum component. Between 2000 and 2004, the fitted temperature increases from ~ 1.4 to 2.3 keV in the metal rich models and from 1.6 to 2.9 keV in the metal+continuum models. $n_e t$ is seen to decrease from 2000-2004.

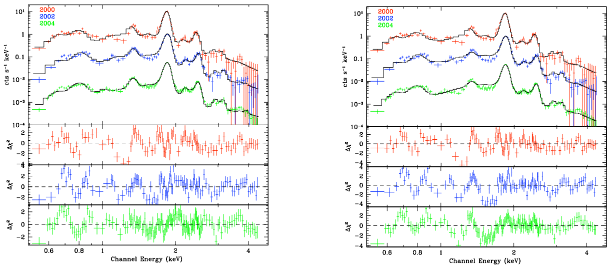

Figure 3: Spectra and model fits for Region 2. *Left:* Metal rich models. *Right*: Models with a continuum component. Between 2000 and 2004, the fitted temperature increases from ~ 1 to 2.2 keV in the metal rich models and is nearly constant in the metal+continuum models. $n_e t$ is seen to remain constant from 2000-2004 in both sets of models.

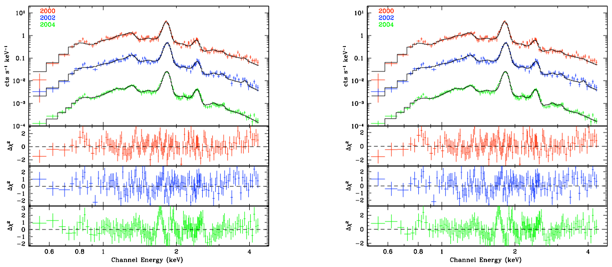

Figure 4: Spectra and model fits for Region 3. *Left:* Metal rich models. *Right*: Models with a continuum component. Between 2000 and 2004, the fitted temperature decreases from ~ 1 .1 to 0.9 keV in the metal rich models and from 1.3 to 1.1 keV in the metal+continuum models. $n_e t$ is seen to decrease from 2000-2004.

Discussion

Optical images of the reverse shock suggest a "swiss-cheese" density structure whereby dense optical clumps are interspersed in lower density, hot gas. If the ejecta were uniform, a single ionization timescale would be sufficient for all three epochs. However, the large observed changes in the X-ray temperature and fitted abundances (Patnaude & Fesen 2005), combined with the changes in $n_e t$ suggest that the ejecta crossing the reverse shock is not uniform. These X-ray measurements are currently being combined with HST ACS images of Cassiopeia A (Morse et al. 2004) and hydrodynamical models for metal rich ejecta in order to understand the ejecta profile in a core collapse supernova. The models being employed use a self-similar solution for the SNR reverse shock in conjunction with a smooth, hot ejecta density profile populated by cold dense clumps.

References

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