

HOT GAS IN WIND-BLOWN BUBBLES

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ABSTRACT

Bubbles blown by massive stars should contain shocked fast winds at temperatures $\geq 10^6$ K that emit diffuse X-rays. Only two Wolf-Rayet bubbles have shown detectable diffuse X-rays – NGC 6888 and S 308. We have obtained *Chandra* and *XMM-Newton* observations of these two bubbles to study their hot interior gas. We further use the results to suggest an explanation for the lack of detectable diffuse X-ray emission from other bubbles blown by massive stars.

Key words: Bubbles; Stellar Winds; Wolf-Rayet Stars; X-rays.

Hot Gas in Wind-Blown Bubbles

Massive stars with fast stellar winds are expected to blow bubbles and the bubble interiors are expected to be filled with shocked fast winds that emit in X-rays (Weaver et al. 1977). However, no main sequence O stars are seen in visible bubbles. Only evolved massive stars, such as Wolf-Rayet (WR) stars and luminous blue variables, are frequently seen in visible bubbles. Most of the well-defined bubbles consist of stellar material and are called “circumstellar bubbles,” while the irregular ones are dominated by interstellar material and are called “interstellar bubbles”. Of all known single-star bubbles, only two WR bubbles show detectable diffuse X-ray emission: S308 and NGC 6888. Both are circumstellar bubbles.

We have obtained *Chandra* ACIS-S observations of NGC 6888 and *XMM-Newton* EPIC observations of S 308. Figure 1 compares these X-ray images with optical [O III] $\lambda 5007$ images and show the spectra of diffuse X-ray emission. These images confirm the presence of limb-brightened X-ray emission with high angular resolution, and reveal a noticeable offset between the X-ray and optical shell rims in S 308, but not in NGC 6888. Both show soft X-ray spectra consistent with plasma temperatures of $2-3 \times 10^6$ K in NGC 6888 and 1×10^6 K in S 308.

Why are S 308 and NGC 6888 different? We have used high-dispersion $H\alpha$ and [O III] spectroscopic observa-

tions of S 308 to study its bubble dynamics. The kinematics of S 308’s dense shell show (1) a shell of swept-up red supergiant wind, (2) an outer envelope of undisturbed red supergiant wind, and (3) an outermost shell of shocked red supergiant wind. This structure indicates that S 308 is a textbook example for a circumstellar bubble in an early evolutionary stage with the hot gas from shocked fast winds confined within a shell of swept-up red supergiant wind. NGC 6888, on the other hand, has swept-up all the red supergiant wind into a shell that has fragmented and allow the fast wind to break out. This corresponds to a later evolutionary stage than S 308.

Why Is Diffuse X-ray Emission Rarely Seen in Bubbles?

ROSAT, *Chandra*, and *XMM-Newton* have been used to make deep observations of Anon(MR16), M1-67, NGC 2359, NGC 3199, NGC 6164-5, NGC 7635, and RCW 58; however, no diffuse X-ray emission has been detected. This is most likely caused by a combination of large absorption columns and low plasma temperatures that produce easily-absorbed soft X-ray emission.

With a distance of 1.5 kpc and a galactic $b = -10^\circ$, S 308 has the smallest absorption column density among all known bubbles (Chu et al. 2003). If it were located at the position of any other Galactic WR star, the foreground absorption would have prohibited its detection. Therefore, if the other bubble interiors have interior gas as cool as S 308, interstellar absorption will prevent the detection of their X-ray emission. NGC 6888 has a slightly higher plasma temperature, so its X-ray emission is harder and can be detected through a larger absorption column. If the other bubbles emit like NGC 6888, then RCW 58 and NGC 6164-5 should have been detected by their *XMM-Newton* observations (see Table 1).

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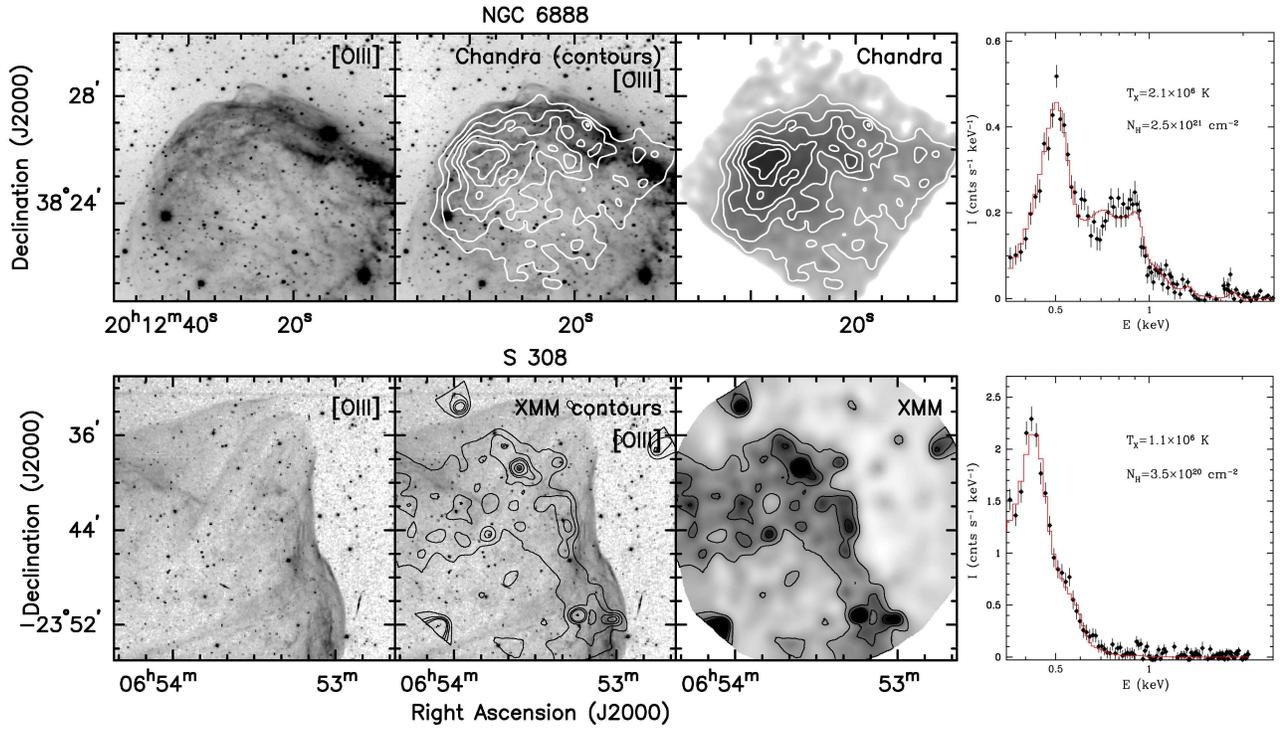


Figure 1. Top: $[O\ III]\ \lambda 5007$ image and Chandra ACIS-S image and spectrum of NGC 6888. Bottom: $[O\ III]\ \lambda 5007$ image and XMM-Newton EPIC image and spectrum of S 308.

Table 1. Bubbles Blown by Single Massive Stars

Nebula Name	Star Name	Spectral Type	Distance (kpc)	Bubble ¹ Type	Angular Size	Diameter (pc)	Emitting Like	
							S308 XMM-Newton EPIC/pn (cnt s ⁻¹ arcmin ⁻²)	NGC 6888 XMM-Newton EPIC/pn (cnt s ⁻¹ arcmin ⁻²)
Anon (WR16)	HD 86161	WN8	2.4	CSB	8'	5.6	8.6×10^{-5}	1.1×10^{-2}
M 1-67	209 BAC	WN8	3.4	CSB	1.4'	1.4	5.0×10^{-6}	1.5×10^{-3}
NGC 2359	HD 56925	WN4	3.7	ISB	4.4'	4.7	5.3×10^{-5}	7.6×10^{-3}
NGC 3199	HD 89358	WN4	2.2	ISB	20'	12.8	2.7×10^{-5}	4.7×10^{-3}
NGC 6164-5	HD 148937	O6.5f	1.3	CSB	6.3' × 3.6'	2.4 × 1.4	8.6×10^{-5}	1.1×10^{-2}
NGC 6888	HD 192163	WN6	1.3	CSB	18'	6.8	1.0×10^{-4}	1.2×10^{-2}
NGC 7635	BD+60 2522	O6.5III	3.5	ISB	3'	3.0	7.3×10^{-5}	9.5×10^{-3}
RCW 58	HD 96548	WN8	2.3	CSB	9.4'	6.3	1.7×10^{-4}	1.7×10^{-2}
S 308	HD 50896	WN4	1.5	CSB	40'	17.5	1.2×10^{-3}	6.6×10^{-2}

¹ CSB - circumstellar bubble, ISB - interstellar bubble.