Death of Massive Stars: Supernovae and Gamma-Ray Bursts
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An X-ray study of mass-loss rate and wind acceleration of massive stars

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Abstract. By monitoring WC7 and the O5.5 binary WR 140 with the *Suzaku* telescope, we demonstrate a new method to measure the mass loss rates of both stars. By using the absorption column density, we found a mass-loss rate for the WC7 component : $\dot{M}_{\rm WC7} \approx 1.2\times10^{-5}{\rm M}_\odot{\rm yr}^{-1}$. We also measured the mass-loss rate of the companion O component using a luminosity variation in phases: $\dot{M}_{\rm O5.5} \approx 5\times10^{-7}{\rm M}_\odot{\rm yr}^{-1}$.

Keywords. Massive star, GRB progenitor, mass-loss rate

1. Introduction

Evolution of massive stars is critical to understand the explosion of the gamma-ray burst (GRB). The stellar wind is also helpful to understand the afterglow of the GRB. However, fundamental parameters of massive stars such as stellar mass and mass-loss rate are not easy to be derived. Therefore, understanding of these parameters still remains an unresolved issue in astronomy.

WR 140 is a wide colliding wind binary system of WC7+O5.5. Its orbit has been well determined with $P_{\rm orb}$ = 2896.35 days, i = 119.6°, and e = 0.8964 by detailed optical monitoring (Monnier *et al.* 2011). We pursued this via *Suzaku* monitoring during the periastron passage in 2009, which includes broad band X-ray spectra. A full paper of the results will be published as Sugawara *et al.* (2012). In this proceeding, we introduce measurements of mass loss rates of both stars from Sugawara *et al.* (2012).

2. Wind acceleration and mass-loss rate

We estimate the mass-loss rate of the WC7 star using the observed column density $N_{\rm He}$. We found the column density obtained at around the periastron passage can be explained by $\dot{M}_{\rm WC7} \sim 1.2\times10^{-5}$ ${\rm M}_\odot{\rm yr}^{-1}$. Fahed *et al.* (2011) also estimated $\dot{M}_{\rm WC7}$ $\sim 3\times$ $10^{-5}{\rm M}_\odot{\rm yr}^{-1}$ that is larger by a factor of three than our value.

According to Stevens *et al.* (1992), the X-ray luminosity of the colliding wind zone can be written as

$$L_{\rm X} \propto D^{-1}(1+A)/A^4 \tag{2.1}$$

where the wind momentum flux ratio, $A = ((\dot{M}_{\rm WC7}\ v_{\rm WC7}(r))/(\dot{M}_{\rm O5.5}\ v_{\rm O5.5}(r)))^{1/2}$. We also adapted a simple beta law for the wind acceleration as

$$v(r) = v_\infty(1-R/r)^\beta. \tag{2.2}$$

Table 1. Summary of wind-acceleration parameter β and mass-loss rate $\dot{M}$.

$\dot{M}_{O5.5}$ / $\dot{M}_{WC7}$	$\dot{M}_{O5.5}$	$\dot{M}_{O5.5}$ $[M_\odot yr^{-1}]$	$\dot{\beta}_{WC7}$	$\dot{M}_{WC7}$ $[M_\odot yr^{-1}]$
0.2	3	2×10^{-6}	any	1.2×10^{-5}
0.1	2	1×10^{-6}	any	1.2×10^{-5}
0.04	1	5×10^{-7}	any	1.2×10^{-5}

Here, v_∞ and R are the terminal wind-velocity and stellar radius, respectively. We used the value of $v_{\infty,WC7}$=2860 km s^{-1} (Williams *et al.* 1990), $v_{\infty,O5.5}$=3100 km s^{-1} (Setia Gunawan *et al.* 2001), R_{WC7} = 2 R$_\odot$ and $R_{O5.5}$ = 26 R$_\odot$ (cf. Williams *et al.* (2009)). The mass-loss rate from the O5.5 star can be solved as a function of mass-loss rate ratio $\dot{M}_{O5.5}$ / $\dot{M}_{WC7}$ as summarized in Table 1. Since it is widely believed that β for O stars is about unity, we conclude $\dot{M}_{O5.5}$ to be $\sim 5 \times 10^{-7}$ M$_\odot$yr^{-1}.

3. Discussion

Using the direct imaging technique of the stars and the shocked cone combined with the optical spectroscopy, the mass of the O5.5 star was measured as 41 ± 6 M$_\odot$ (Fahed *et al.* 2011 and reference therein). Vink *et al.* (2001) theoretically gave a recipe (eq. 24) to calculate the mass-loss rate and predict for the O5.5 star (log$L_{O5.5}$ = 6.18, $T_{\rm eff,O5.5}$ =44,000 K) to be $\sim 6 \times 10^{-5}$ M$_\odot$yr^{-1} that is two orders of magnitude larger than our mass-loss number of $\dot{M}_{O5.5} \sim 5 \times 10^{-7}$ M$_\odot$yr^{-1}.

If we assume that the WC7 star had the same mass loss rate for ∼ 2 M yr, the initial mass of the WC7 star can be calculated as ∼40 M$_\odot$. The initial mass of the WC7 star should be much larger than the present mass of the companion O5.5 star if we assume that both stars were born at the same age. The WC7 star may then prefer a longer lifetime in the WR phase. A longer solution for the WR life in the solar metallicity is predicted for the case of fast-rotation (Meynet & Maeder 2005). If it is true, the WC7 star could be a progenitor of a future GRB event.

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