A non-spherical mass outflow from RS Oph during its 2006 outburst

A. Skopal, T. Pribulla
Astronomical Institute, Slovak Academy of Sciences, 059 60 Tatranská Lomnica, Slovakia

Ch. Buil
Castanet Tolosan Observatory, 6 Place Clemence Isaure, 31320 Castanet Tolosan, France

A. Vittone, L. Errico
INAF Osservatorio Astronomico di Capodimonte, via Moiariello 16, I-80 131 Napoli, Italy

Abstract. We present results of our modeling the Hα line profile along the 2006 RS Oph outburst. At day 1.38 the very broad component of the Hα profile was possible to fit by a bipolar wind model. The model corresponds to a very fast acceleration of the wind particles and the line luminosity of \( \sim 2900( d/1.6\text{ kpc})^2 L_\odot \) to the mass-loss rate of \( \sim (1-2) \times 10^{-4} M_\odot \text{ yr}^{-1} \). During days 10 – 30 the broad component shrank to \( FWZI \sim 1800 \text{ km s}^{-1} \). It could be associated with expanding ring and its satellite components at \( \sim \pm 2430 \text{ km s}^{-1} \) with bipolar jets. Later observations made at day 57 and 209 indicated a decrease in both the mass-loss rate (\( \sim 1 \times 10^{-5} - 1 \times 10^{-6} M_\odot \text{ yr}^{-1} \)) and the wind acceleration. During the quiet phase, emission bumps observed sporadically in the line wings could reflect clumpy ejections by the central star.

1. Introduction

RS Oph is a symbiotic recurrent nova, in which a high-mass white dwarf (WD) accretes material from a cool K7 III giant on a 456-day orbit (e.g. Bode 1987; Mürset & Schmid 1999; Fekel et al. 2000). Historically, 6 eruptions have been recorded unambiguously. The first one in 1898 and the last one on 2006 February 12.83 (Evans et al. 1988; Narumi et al. 2006). The recurrence period of approximately 20 years and a bright peak magnitude, \( V = 4 - 5 \), made RS Oph a good target for multifrequency observational campaigns from the beginning of its recent, 1985 and 2006, outbursts (e.g. Evans et al. 2007, and references therein). For example, they revealed a non-spherical shaping of the nova ejecta: (i) on the radio map (e.g. Taylor et al. 1989), (ii) by interferometric technique in the near infrared (e.g. Lane et al. 2007; Chesneau et al. 2007) and also (iii) by the HST imaging in the optical (Bode et al. 2007).

In this contribution we present evidences of the non-spherical mass outflow on the basis of the optical spectroscopy of RS Oph carried out from the first days of its 2006 outburst to the post-outburst quiet phase.
2. Bipolar wind at day 1.38

The Hα profile from day 1.38 consisted of a very broad component, triangular in profile, with $FWZI \sim 7600 \text{ km s}^{-1}$, a narrow emission component ($FWZI \sim 240 \text{ km s}^{-1}$) cut with a sharp absorption at $\sim -13 \text{ km s}^{-1}$ and a blueward-shifted absorption component at $\sim -4250 \text{ km s}^{-1}$ (Fig. 1).

We suggest that the broad triangular profile is due to kinematics of the photoionized and optically thin stellar wind from the WD. The narrow central absorption/emission components then could represent result of the radiative transfer in Hα through the optically thick fraction of the wind at the vicinity of the WD surface. The violet-shifted absorption could be associated with a dense material of the neutral wind from the giant swept off by the fast wind from the WD and accumulated into a shell at the front of the ejecta.

We tested the origin of the broad triangular component by the bipolar wind model as proposed by Skopal (2006). In this model a fraction of the wind from the central star is blocked by the disk at/around the WD’s equator, which thus creates bipolar geometry of the stellar wind. According to the model SED from the quiet phase (Skopal et al. 2008) we adopted the disk radius $R_D = 10 R_\odot$ and the disk thickness at its edge, $H = 3.3 R_\odot$. The resulting synthetic profile (Fig. 1, left) corresponds to the terminal velocity $v_\infty = (3800 \pm 100) \text{ km s}^{-1}$, the acceleration parameter $\beta = 0.56 \pm 0.02$ and the mass loss rate through the wind, $\dot{M}_W = (1 - 2) \times 10^{-4} \text{ M}_\odot \text{ yr}^{-1}$. The small value of $\beta$ reflects a very high acceleration of the wind particles (Fig. 1, right).
3. Bipolar jet-like collimated outflow during $\sim 10 - 30$ days

Here we present examples of H$\alpha$ line profiles we measured at day 12.4 and 15.3 (Fig. 2). Similar profile could still be recognized at day 28.3 (13/03/2006). The whole profile was shifted to the red part of the spectrum by $\sim 150$ km s$^{-1}$. The main emission core was triangular in profile with the peak $70 - 80$ times the continuum and the base of $FWZI = 1750 \pm 250$ km s$^{-1}$. In addition, the profile showed emission shoulders located bipolarly at $\sim \pm 2430$ km s$^{-1}$, expanding to $\sim \pm 3000$ km s$^{-1}$ (Fig. 2). Radial velocities of both the triangular emission core and the faint satellite components in the H$\alpha$ profile were very similar to those indicated by the AMBER/VLTI interferometric observations at day 5.5 (Chesneau et al. 2007): a slow expanding ring-like structure with $|v_{\text{rad}}| < 1800$ km s$^{-1}$ and a fast structure ($|v_{\text{rad}}| \sim 2500 - 3000$ km s$^{-1}$) in the direction that coincides with the jet-like feature seen in the radio. Accordingly, the triangular H$\alpha$ emission core could be associated with an expanding ring at the equatorial plane of the WD and the satellite components with bipolar jets ejected at/around the accretor. The latter, however, requires the presence of the inner disk, through which sufficient amount of mass is accreted to balance the outflow via the jets (note that $M_{\text{acc}} \gtrsim M_{\text{jet}}$, e.g. Livio et al. 2003).

4. Attenuation of the stellar wind and clumpy ejections

Figure 3 shows H$\alpha$ line profiles carried out at day 57 (10/04/2006) and 209 (09/09/2006) compared with synthetic profiles of the bipolar wind we introduced in Sect. 2. In the earlier case (left panel) the wind model fits only the very extended wings ($|\Delta RV| \gtrsim 1300$ km s$^{-1}$) of the observed profile. The model corresponds to $v_{\infty} \sim 3500$ km s$^{-1}$, $\beta \sim 1.7$ and the mass loss rate, $\dot{M}_{W} \sim 1.5 \times 10^{-5} M_{\odot}$ yr$^{-1}$ for $d = 1.6$ kpc. However, a significant fraction of the line
core does not obey the $\beta$-wind velocity law. The $FWHM \sim 420\,\text{km}\,\text{s}^{-1}$ is too large to be fitted by the wind. This reflects the presence of a bipolarly located emission within $|\Delta RV| \lesssim 1\,000\,\text{km}\,\text{s}^{-1}$ having probable cause in the expanding and diluting ring-like structure as discussed in Sect. 3.

At day 209 the H$\alpha$ flux decreased by a factor of $\sim 20$ and the profile became to be narrow ($FWHM \sim 100\,\text{km}\,\text{s}^{-1}$). The model fits well the profile for $|\Delta RV| > 200\,\text{km}\,\text{s}^{-1}$, but isolates an emission bump in the red wing. We interpret this feature as a result of a sporadic clumpy ejection from the accretor due to abrupt accretion from the re-creating large disk during the quiet phase (c.f. the SED in Fig. 1 of Skopal et al. 2008).

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