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

A. Skopal(1), T. Pribulla(1), Ch. Buil(2), A. Vittone(3), L. Errico(3)

(1) Astronomical Institute, Slovak Academy of Sciences, 059 60 Tatranska Lomnica, Slovakia
(2) Castanet Tolosan Observatory, 6 Place Clemence Isaure, 31320 Castanet Tolosan, France
(3) INAF Osservatorio Astronomico di Capodimonte, via Moiariello 16, I-80 131 Napoli, Italy

---

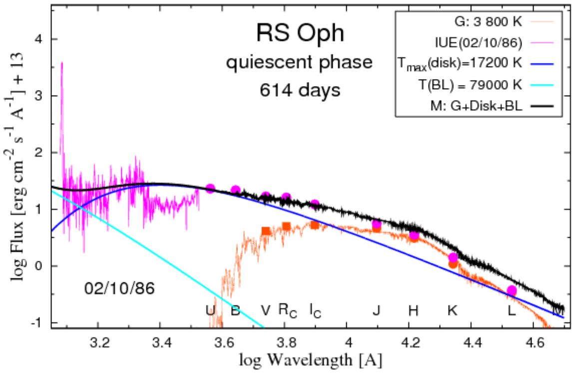
Absatract:

We present results of our modeling the Hα (Hβ) line profiles along the 2006 RS Oph outburst. The extreme broad base of the Hα line at 1.38 days after the eruption was possible to fit by a bipolar wind model. The successful model requires a very fast acceleration of the wind particles ($\beta = 0.56$ in the β-wind velocity law). The line luminosity of 2900(d/1.6kpc)**2 solar units corresponded to the mass-loss rate of (1-2)E-4 solar masses per year. Comparison of the modeled and the observed profile revealed additional faint emission components at/around +/-1000 and +/-2500 km/s. At the day 12 and 15, satellite components to the central emission of the Hα line developed at +/- 2450 km/s. This suggested ejection of bipolar jets collimated within an opening angle of 7 – 14 degrees. Later observations made at 57, 111 and 209 days indicated a gradual decrease of the mass-loss rate, to about 0.8 – 2.0E-6 solar masses per year, and a slower wind acceleration ($\beta \sim 1.8$).

Disk-like structure of the hot component causes a bipolar shaping of the mass outflow.

Observed and modeled SED during quiescence.

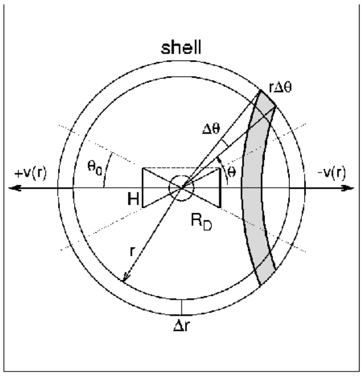
A disk model:

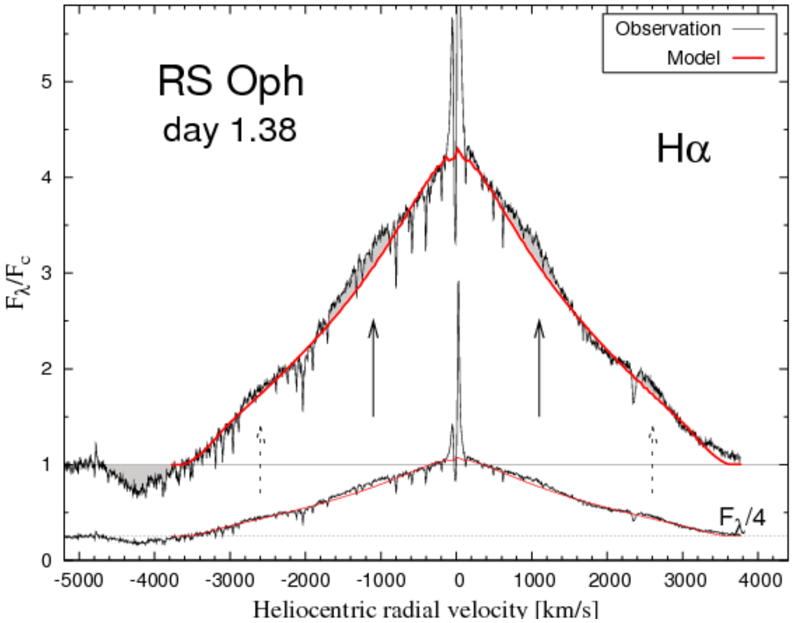


$$F_\lambda = F_\lambda(AD) + 0.6 \times \pi B_\lambda(T_{BL})$$

$$R_h^{eff} \approx 9\ Ro,\ \ T_D(max) \approx 17\ 000\ K,\ \ T_{BL} \approx 79\ 000\ K$$

A geometrical model of the bipolar wind





Hα line observed at the day 1.38 after the eruption. Observation was carried out at the Castanet Toloson Observatory with resolution of 0.115 A/pixel.

$$F_c = 2.61 \times 10^{-11}\ erg\, cm^{-2}\, s^{-1}\, A^{-1}$$

Modeling the Hα wings

(Skopal, 2006, A&A, 457, 1003, in detail)

$$R_D = 10\ Ro,\ \ H = 3\ Ro\ \ (H/R_D \equiv 0.3)$$

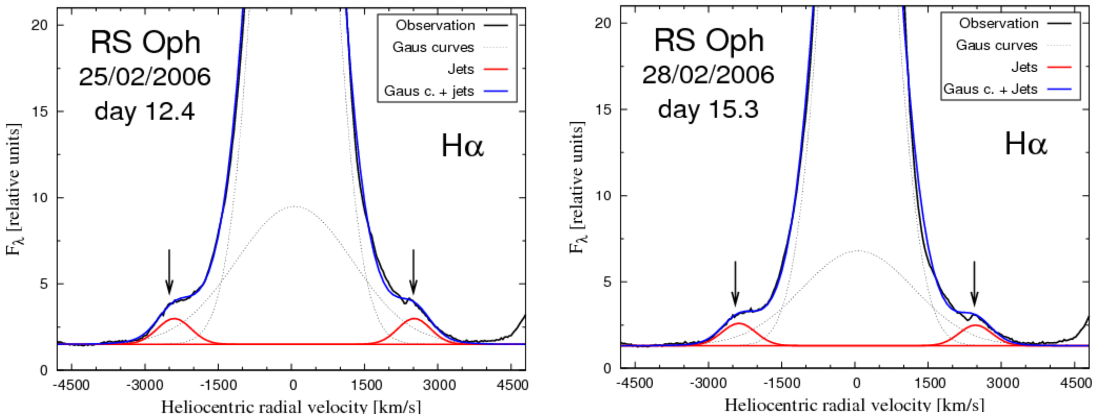
$$v_\infty = 3\,800\ km/s$$

$$\beta = 0.56$$

$$L(H\alpha) = 2900(d/1.6\,kpc)^2\ Lo$$

$$(dM/dt) \approx 1.5 \times 10^{-4}\ Mo\, yr^{-1}$$

A bipolar jet-like collimated outflow detected to the day 28



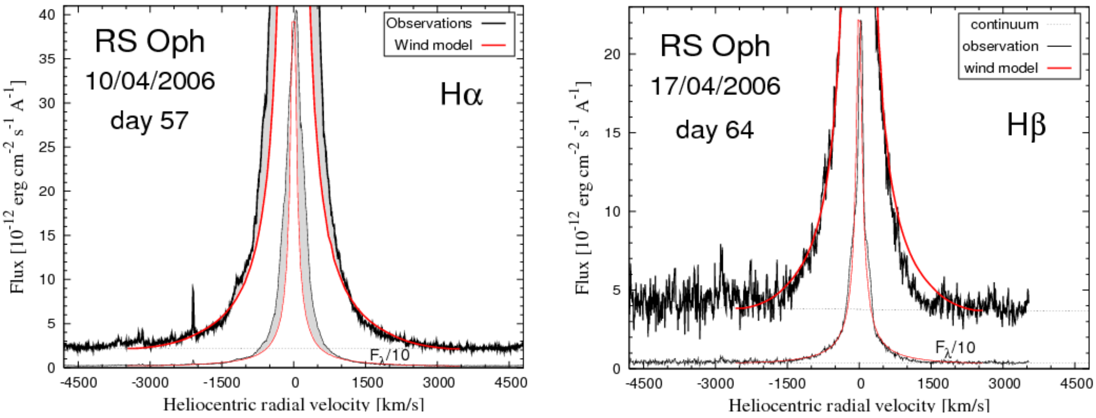
Hα line observed at the day 12.4 and 15.3 after the eruption. Observation were obtained at the Castanet Toloson Observatory and have resolution of 0.74 A/pixel. High-velocity satellite components to Hα, Hβ and HeI5876 were detected to 13/03/06 (day 28). F(cont) = 2.2 and 1.8E-11 erg cm-2 s-1 A-1; Fα = 3560 and 3200 Lo, respectively.

$$L^{v}_{jet} = L^{r}_{jet} = 32.0\,Lo\,,\quad FWHM_{jet} \simeq 800\,km\,s^{-1} \qquad L^{v}_{jet} \sim L^{r}_{jet} = 26.5\,Lo\,,\quad FWHM_{jet} \simeq 800\,km\,s^{-1}$$

$$RV_{jet} = \pm 2450\,km\,s^{-1} \qquad RV_{jet} = \pm 2420\,km\,s^{-1}$$

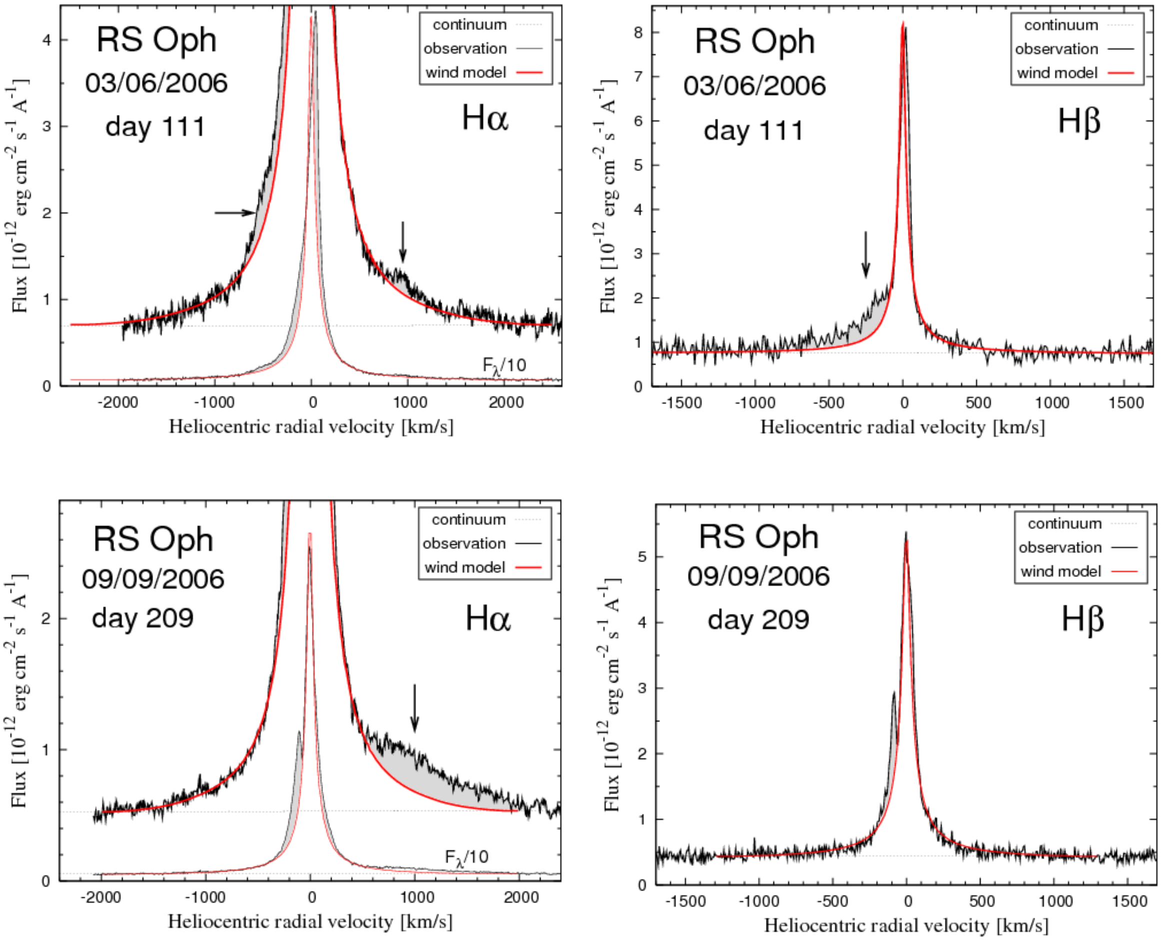
$$\theta_0 \approx 7-14^{o} \quad for \quad i \approx 79-68^{o} \quad (RV_{jet} = v_{esc} - 0.5\times v_{esc}\,,\quad v_{esc} \approx 13100\,km/s)$$

An attenuation of the stellar wind: day 57 - 111

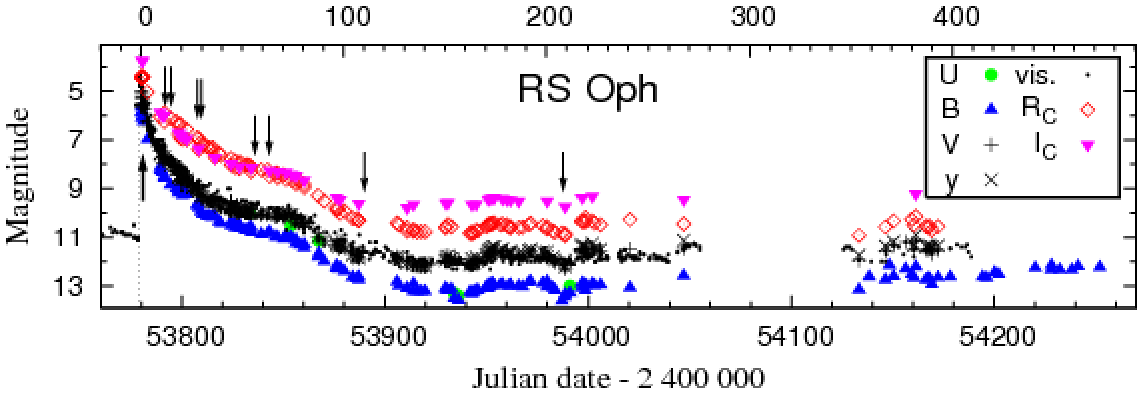


Hα and Hβ lines taken at the David Dunlop Observatory with a resolution of R=12000 and 8000, respectively. Comparison between the modeled and observed profile shows a large amount of a bipolarly located emission in the Hα core (left, FWHM(Hα) ~ 420 km/s, FWHM(Hβ) ~ 150 km/s). The wind model fits the Hβ profile for |RV| > 200 km/s, but suggests the presence of a redward shifted absorption. The models correspond to the terminal velocity, v(infty) = 3500 and 2600 km/s for Hα and Hβ, respectively, acceleration β = 1.65 and the mass-loss rate of about 1.5E-5 Mo/yr. Line luminosities decreased by a factor of about 10, to Lα = 370 Lo and Lβ = 93 Lo.

Asymmetric outflows during the post-outburst minimum



Hα and Hβ lines taken at the Asiago Astrophysical Observatory with a resolution of R=25000 and 17000, respectively. Comparison between the modeled and observed profile isolates emission bumps located asymmetrically with respect to the reference wavelength. Their origin is thus different from the hot stellar wind. A good fit of the model to a part of the observed broad wings suggests a significant contribution from the ionized wind. Models correspond to the terminal velocity, v(infty) ~ 2200 and 1500 km/s for Hα and Hβ, respectively, acceleration β ~ 1.8 and the mass-loss rate of about 0.87 - 2E-6 Mo/yr. Line luminosities decreased to Lα = 18 and 10 Lo, Lβ = 1.6 and 1.1 Lo on 03/06/06 and 09/09/2006, respectively (i.e. during the post-outburst minimum).



Light curves of RS Oph as collected by the VSOLJ observers, Kiyota, Kubotera, Maehara and Nakajima. Arrows denote the times of our optical spectroscopic observations.