The 2006 Outburst of the Recurrent Nova RS Ophiuchi - Multiwavelength Observations

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RS Ophiuchi

- *Interacting binary system with an accreting white dwarf primary and an M2-3 giant secondary with an orbital period of 455.72 days (Dobrczycka et al 1994; Feckel et al 2002). Distance=1.6kpc, E(B-V)=0.73*
- *Recurrent nova that had suffered five recorded outbursts in 1898, 1936, 1958, 1967, 1985 (Rosino 1986)*
- *Fast nova, t_3= 8-10 days (Rosino 1986)*
- *Optical light curve and spectral evolution very similar during outbursts.*
- *The radio, X-ray and the coronal lines arise in a region that is shock heated as the ejected*

The 2006 Outburst

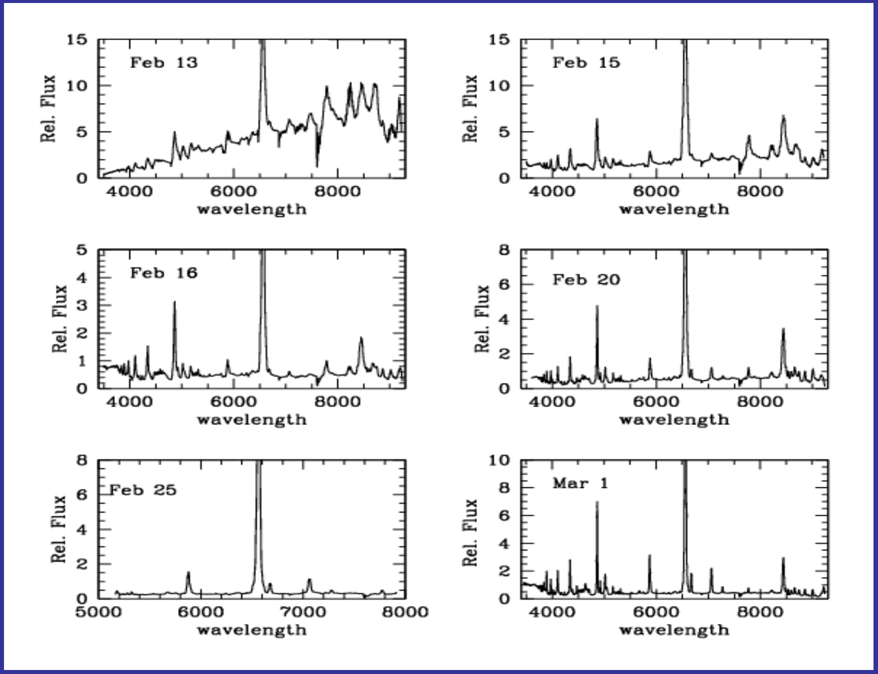
- *RS Oph discovered in outburst again, after a gap of 21 years, on 2006 Feb 12.83, at a magnitude of 4.4.*

OBSERVATIONS

- *Optical monitoring using the 2.3m Vainu Bappu Telescope and the 2m HCT started from Feb 13.9, one day since the discovery.*

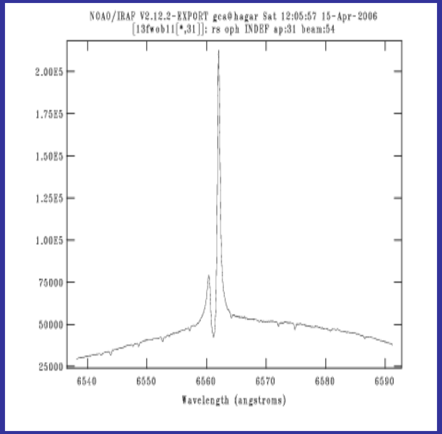
  Low resolution spectra obtained using HCT and occasionally with VBT. Immediate post-maximum high resolution (R~ 30,000) echelle spectra obtained using VBT.
- *Low frequency radio observations in the 0.240, 0.325 and 0.610 GHz using the Giant Meterwave Radio Telescope began ~ 14 days since outburst.*

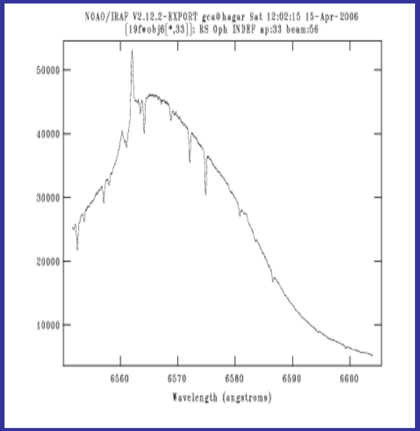
Evolution of Optical Spectrum



Feb 13.9 (t=+1.0) - Broad emission lines with P Cyg profiles; Lines due to H, N, Ca II (IR), Na I and O I. Narrow P-Cyg with velocity ~20 km/s originating in the red giant wind. Wind emission dominated by Fe II emission. Na I D interstellar and several diffuse interstellar absorptions clearly seen

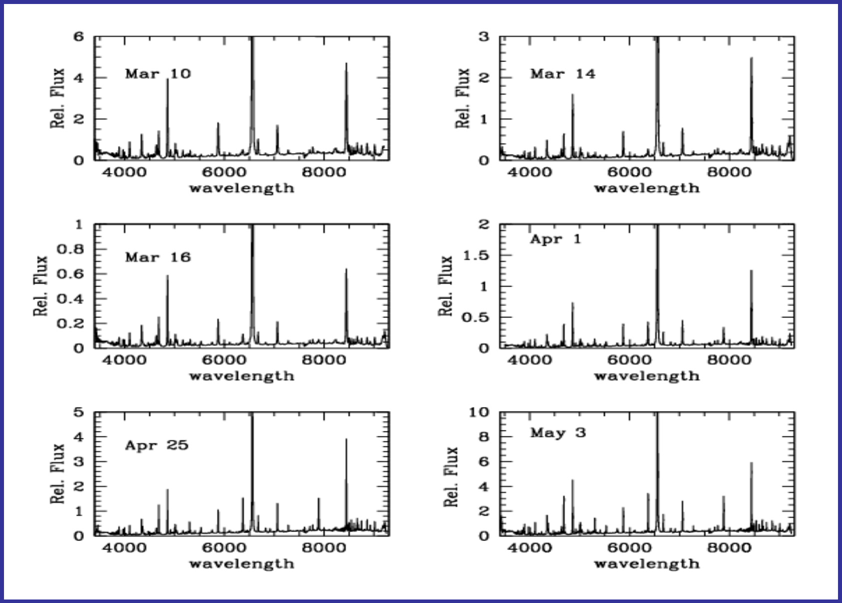
Feb 15-16 (t=+3-4) P Cyg absorption absent, emission lines narrower; Prominent lines due to H and Fe II. [AX] 5535 A could be weakly present. OI 8446 line strength increased while Ca II IR decreased. Circumstellar P-Cyg decreased.

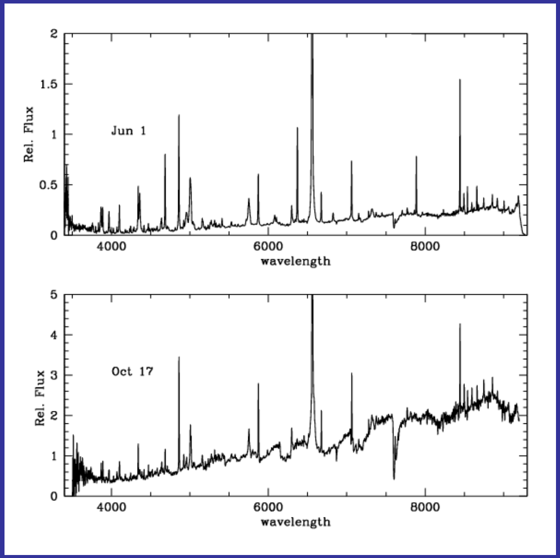


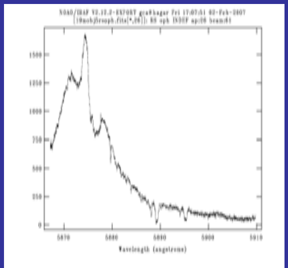


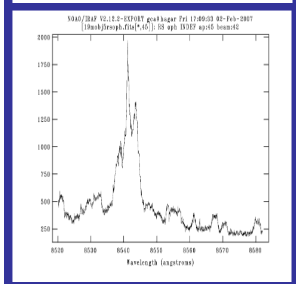
Fe II lines fade with time; He I lines develop and strengthen with time. By ~ day 15, spectrum dominated by H and He I lines. OI 8446 stronger than OI 7774 (Bowen fluorescence)

Evolution of optical spectrum (contd)









Mar 10 (t~+25): Spm dominated by hydrogen and helium (I,II) lines. OI 8446 strengthened further. No coronal lines due to Fe present.

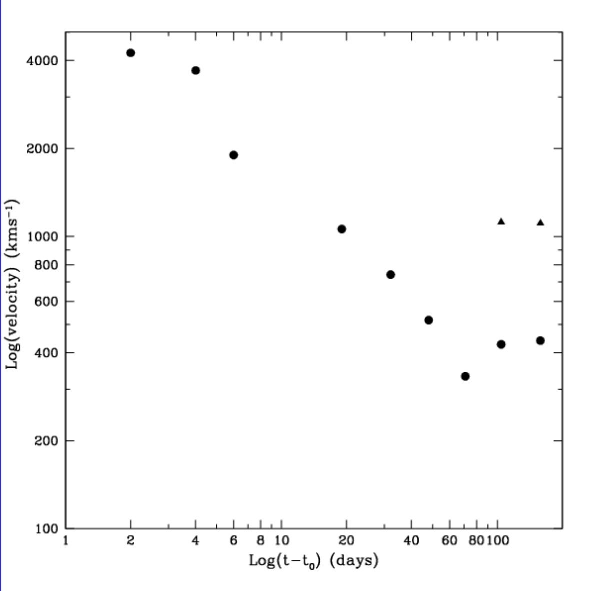
Coronal lines due to [FeX], [FeXI] and [FeXIV] developed by Mar 14 (t~+30), and strengthened with time. OI 8446 continues to be strong. Line profiles show multiple component.

Nebular phase began by day 100, and nova was well into nebular phase by Jun 01 (t~+135). Broad nebular lines seen together with narrow recombination lines. Secondary begins to contribute. Oct 17 spectrum shows clear signature of secondary. TiO absorption bands clearly seen, continuum redder. TiO absorption indices indicate secondary spectral type M2-M3. Nebular line strengths decreased by Oct.

Emission line velocities

- *The emission line widths narrow with time, indicating the following velocities: 4200 km/s (+1); 3800 km/s (+3); 2000 km/s (+5); 1060 km/s (+18); 740 km/s (+31); 332 km/s (+70).*

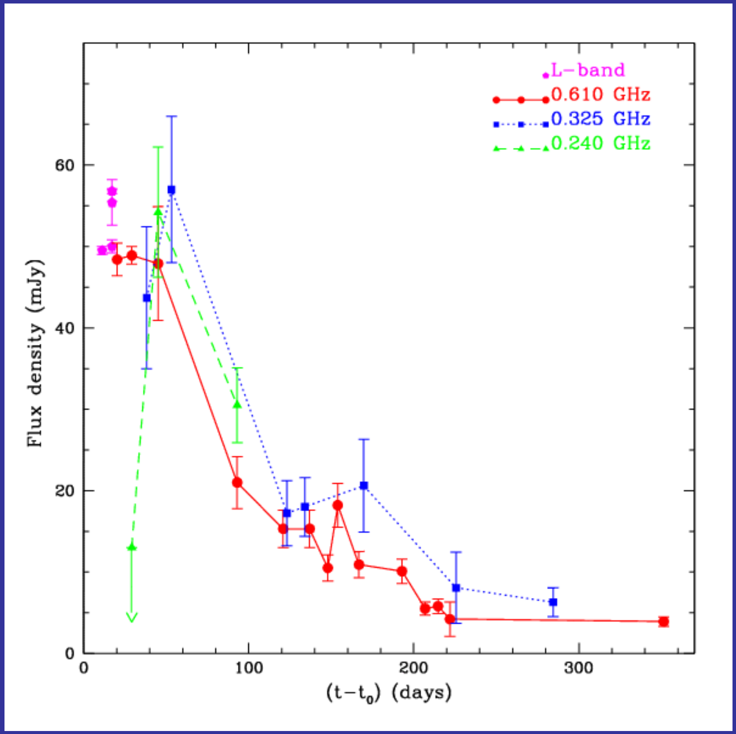
- *A slight increase in emission line width of the*
- *recombination lines is seen after day +80.*
- *The nebular lines are broader than recombination lines, with a velocity v~1500 km/s compared to v~400 km/s for the recombination lines.*
- *The velocities varied as $t^{-0.4}$ for t<5 days and $t^{-0.66}$ during t=+5-70 days.*



Interstellar extinction

The interstellar Na I D and K I lines imply an E(B-V) ~ 0.7, consistent with the HI absorption and UV 2200 bump estimates made during the 1985 outburst (Hjellming et al. 1987, Mason et al. 1987)

Radio emission

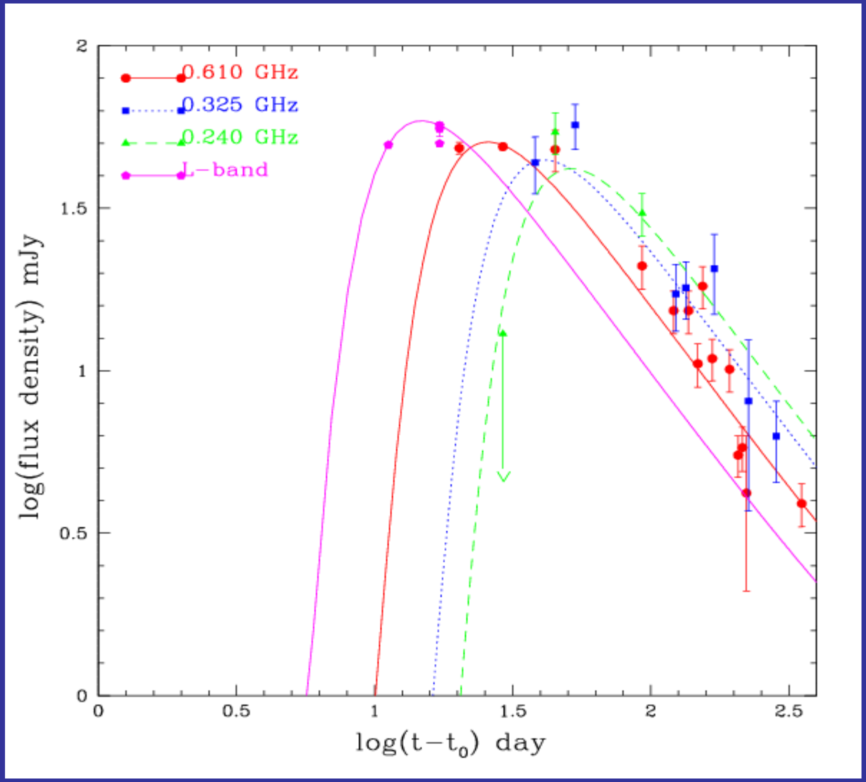


Radio emission turned on early, 3 days since outburst, compared to ~14 days since outburst in 1985.

Radio emission detected in the low frequencies for the first time - detected at 0.61 GHz on day 20 with a flux density of ~48 mJy and at 0.325 GHz on day 38 with a flux density of 44 mJy. This is in contrast with the 1985 outburst when it was not detected at 0.327 GHz even on day 66.

The light curves indicate a steep rise in the flux density, followed by a relatively flat maximum and a subsequent decay. While the different frequencies seem to become visible and peak at different epochs, which is clear from our upper limit at 240 MHz around day 25 and subsequent detection around day 45; the post-maximum decay at all the frequencies is fairly similar. The flux decays as $t^{-1.4}$. The observed spectral index ($S_\nu \propto \nu^\alpha$) varies from α ~ -0.1 around maximum to α ~ -1.0 around day 220.

Light Curve Model



The emission at low radio frequencies is clearly non-thermal and is well-explained by a synchrotron spectrum $S \propto \nu^{\alpha}$, with α=-0.53, suffering foreground absorption due to the pre-existing, ionized, warm red giant wind whose optical depth τ decreases as $(t-t_0)^{-2.9}$.

The light curves also indicate the presence of more than one emission component, consistent with the VLBI and MERLIN images at higher frequencies (O'Brien et al. 2006).

Comparison with 1985 outburst

RS Oph detected early in the radio in 2006; detected in low frequency radio during 2006. Although early evolution different, the late time evolution (>+60 days) very similar during both outbursts (and at all frequencies). This suggests that the early difference is primarily due to differences in the foreground absorption. A simple estimate based on the observed fluxes at the two epochs implies that the foreground absorption was less by about 25% during 2006.

Summary

- *The evolution of the optical spectrum is very similar to previous outbursts and indicates interaction of the nova shell with the circumstellar material due to the red giant wind that is ionized by the outburst. This interaction gives rise to the coronal lines and the non-thermal synchrotron radio emission.*
- *The emission line velocity evolution indicates that the remnant was in the adiabatic phase for a very brief period and quickly moved to the radiative cooling phase by t~+5 days, consistent with the findings of Bode et al. (2006) based on X-ray observations. This is in contrast with the 1985 outburst when the remnant was in the adiabatic phase for nearly 30 days.*
- *The nebular lines originate in a region closer to the WD while the recombination lines originate in the decelerating material.*
- *Radio light curves indicate the presence of multiple components. Light curve modelling indicates that the foreground absorption was about 25% less during 2006 compared to 1985.*

Collaborators:

- Optical Observations - S. Muneer, G. Pandey, G. Selvakumar (VBT)

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- Radio – N.G. Kantharia, T.P. Prabhu, S. Ramya, S.P. Eyres, M.F. Bode, T. J. O’Brien

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RS Oph