Spectral Evolution of Recurrent Nova RS Ophiuchi

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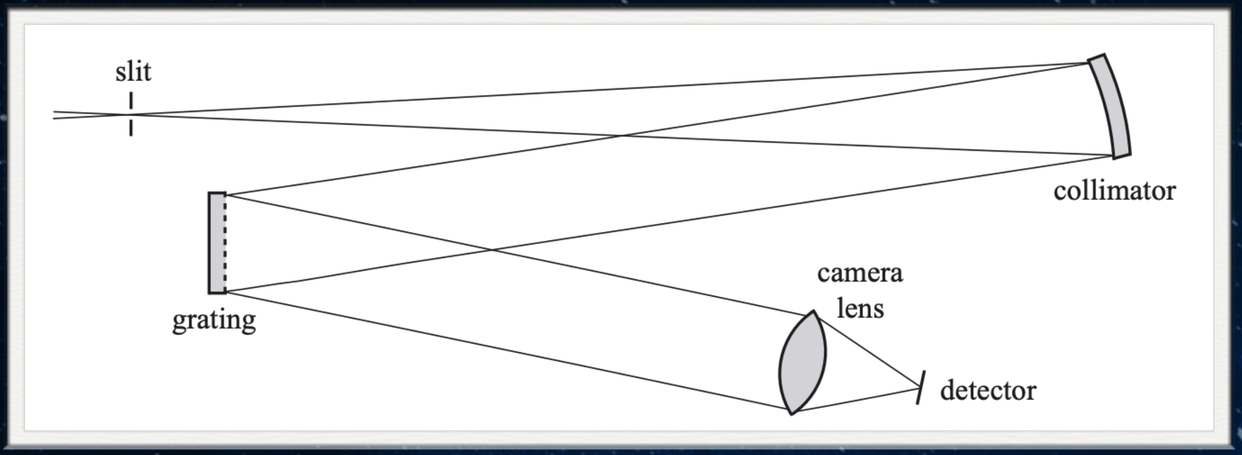


Figure: Basic Diagram of a CCD Spectrometer

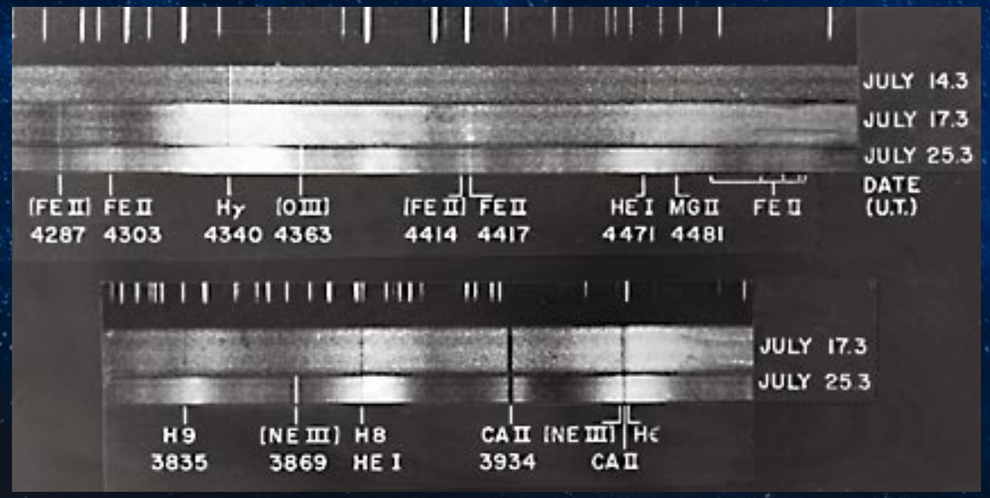


Figure: Historic Image of RS Oph's Spectra from 1958

WHAT IS SPECTRAL ANALYSIS

- Spectroscopy is the practice of breaking up incoming electromagnetic waves into its constituent wavelengths, via a diffraction grating and usually projected onto a CCD.
- This gives us insight into the physical and chemical properties of light emitting objects.
- This project utilizes archived data from the Stony Brook/SMARTS Spectral Atlas of Southern Novae

RS OPHIUCHI

- RS Oph is a recurrent nova, with 6 observed outbursts spanning the last 122 years.
- A binary system of a primary white dwarf and companion red giant star.
- Most recent outburst was February 12th 2006 after reaching a magnitude of 4.5, 21 years after the previous outburst.

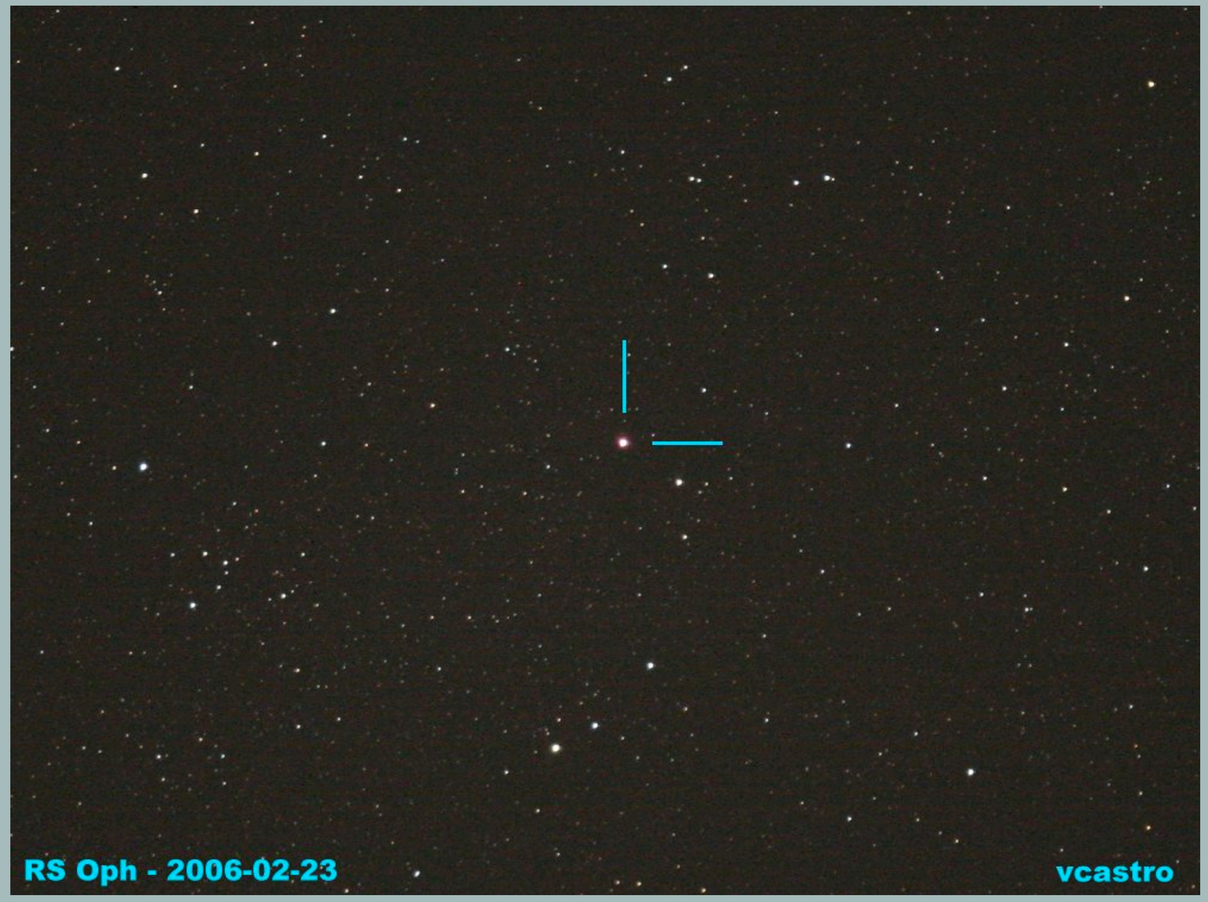


Figure: Image of RS Oph taken 11 days after 2006 outburst.

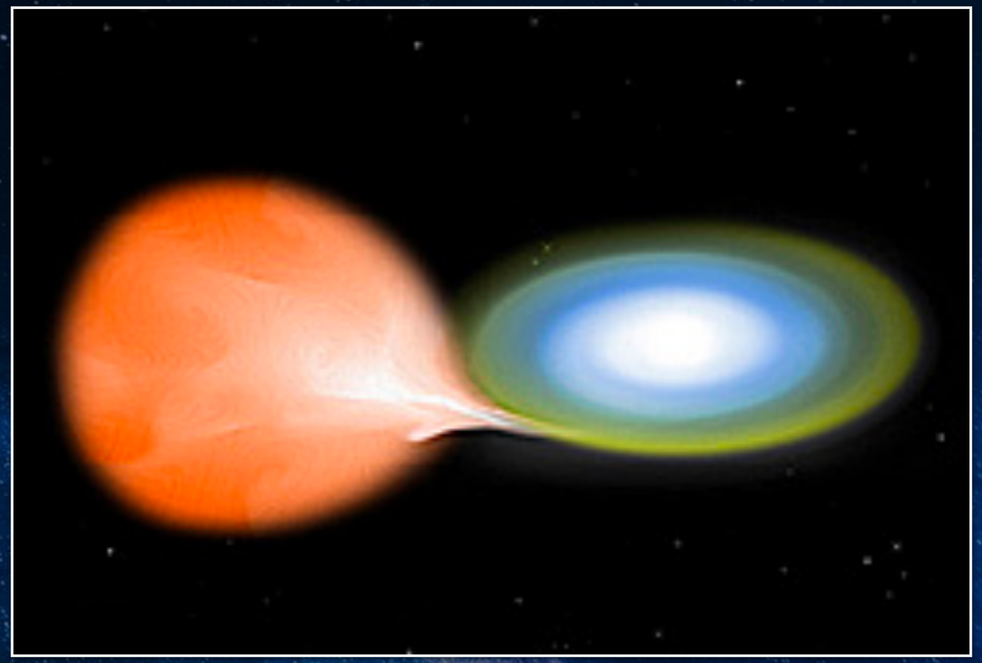


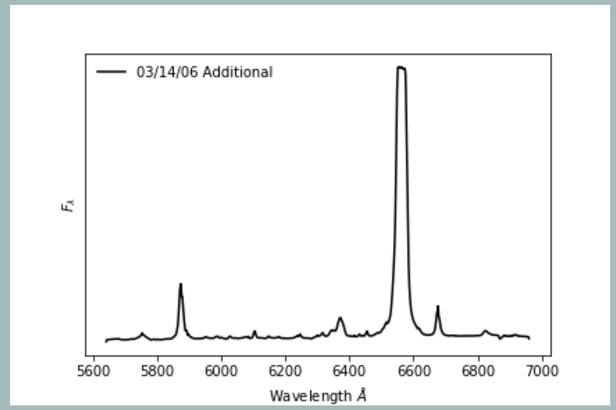
Figure: Concept art of a White Dwarf accreting mass from a companion red giant star

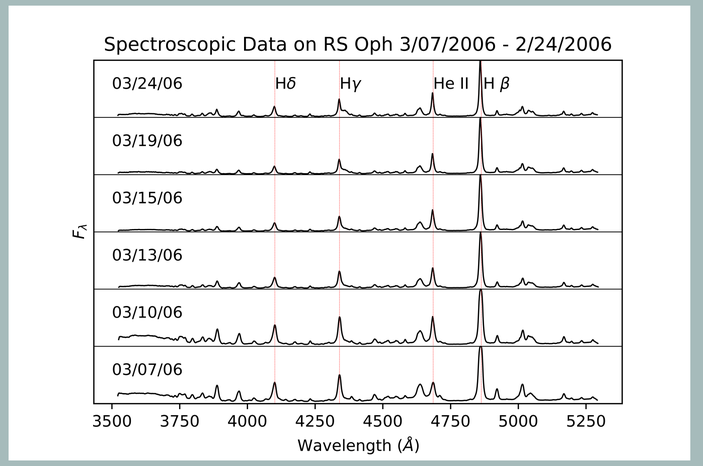
RECURRENT NOVAE

- The process of a recurrent nova is similar to that of a classical nova with WD accreting a surface layer of hydrogen from the companion.
- Outbursts occur on a very frequent timescale.
- Rs Oph is a very fast nova, rapidly decreasing from its photometric maximum. This classification of recurrent novae places them in a middle ground between classical novae and dwarf novae depending on magnitude variations and periodicity.
- There are not many known recurrent novae.

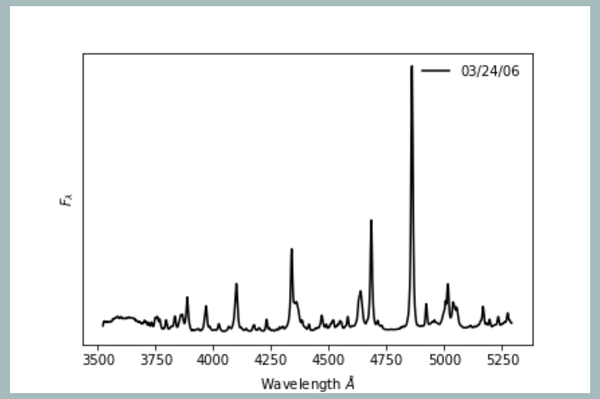
DATA PROCESSING

- Spectroscopic data is presented in the form of an ascii file.
- Extracted the files into python and produce plots of Flux vs Wavelength.
- Due to varying exposure times and flux scales, the fluxes are normalized for comparison.
- Plots are layered over each other to show progression and changes in spectral lines following the outburst.





Figures: Examples of normalized spectral lines used in the analysis extracted via Python.



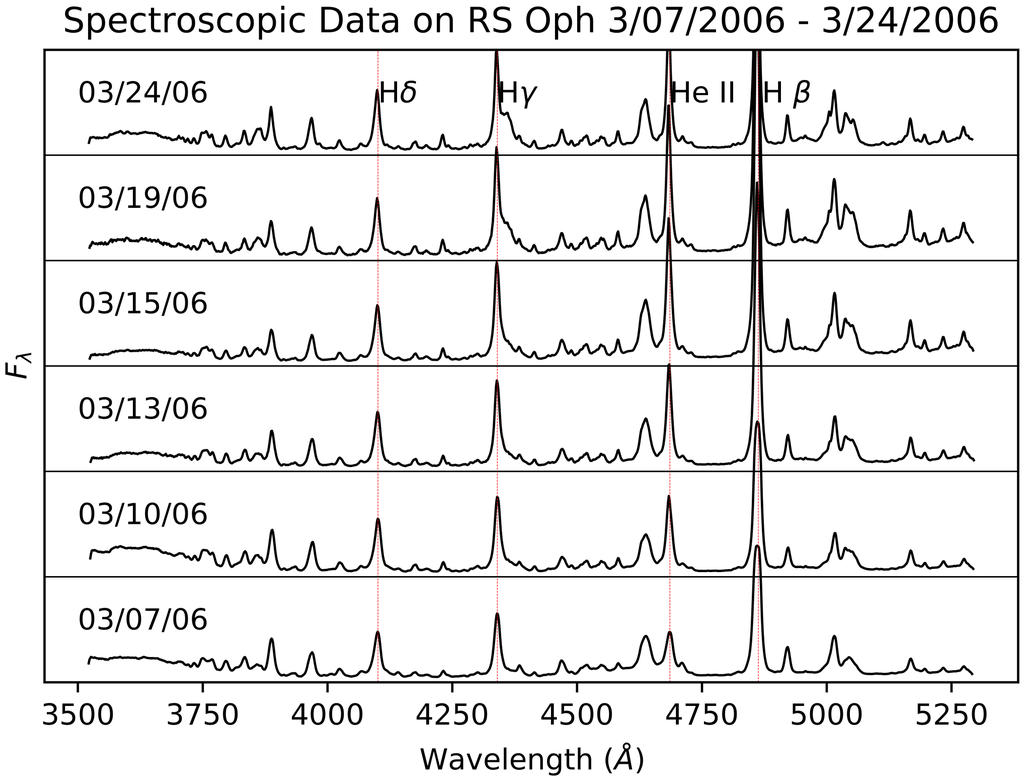


Figure: "Blue" Wavelengths for Rs Oph from 3/7/06 - 3/24/06 (Days 23 to 41 after outburst)

BLUE WAVELENGTH DATA (EARLY PHASE)

- Early phase spectra is dominated. By H and He (I and II). As well as the other Balmer lines.
- The Balmer emission lines are also narrowing.
  - Ex. H-β lines narrows by nearly 9.601Å between 3/7 and 3/24.
- H II lines are seen to strengthen through early evolution

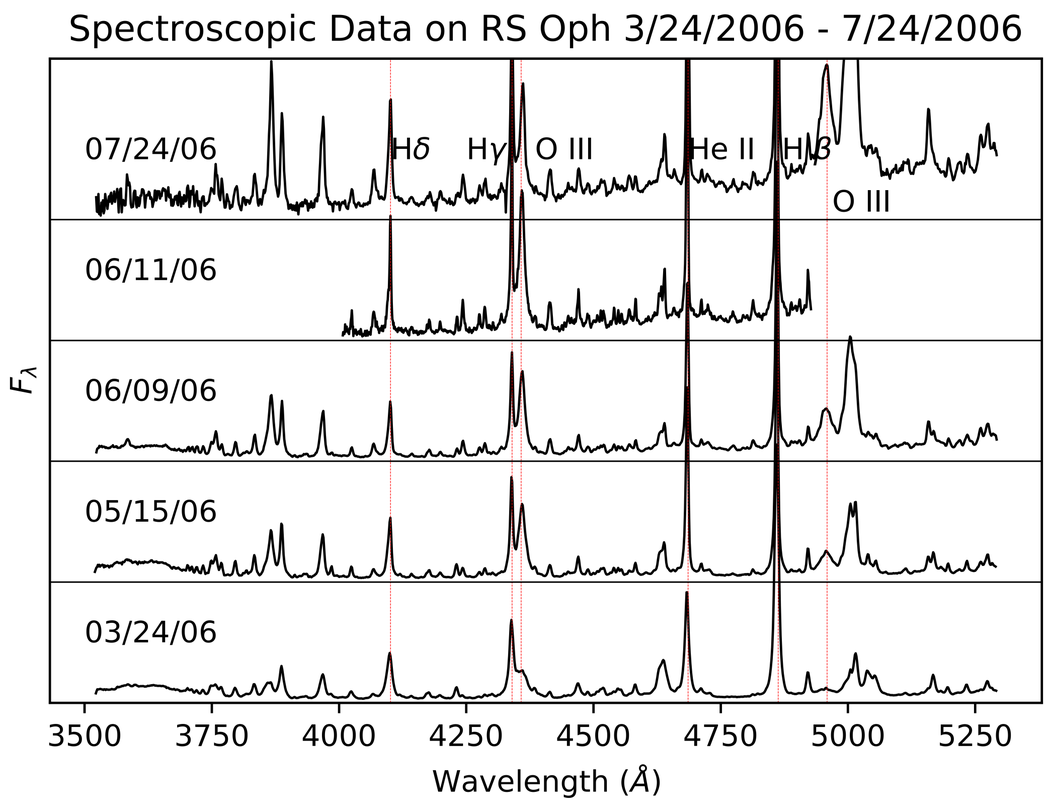


Figure: "Blue" Wavelengths for Rs Oph from 3/24/06 - 7/24/06 (Days 41 to 163 after outburst)

BLUE WAVELENGTH DATA (LATE PHASE)

- The emission lines are much narrower in the later stage evolution.
- Still dominated by Balmer, He II, coronal, and high excitation lines
- The O III [4959Å] line shows a significant strengthening
  - The shorter wavelength O III line is also see to strengthen, nearly matching the H-γ line.
  - These higher ionization lines indicate the shell is becoming thinner and higher ionization lines are now visible

RED WAVELENGTH DATA

- H and He lines still dominate in this range of wavelengths.
- The Fe X line strengthens quickly starting on 3/9.
- The H-α narrows significantly over the span of these measurements.
  - FWHM decrease of about 11.57Å
- The Raman scattering line and Ar XI line appear suddenly around 3/10 and strengthen.

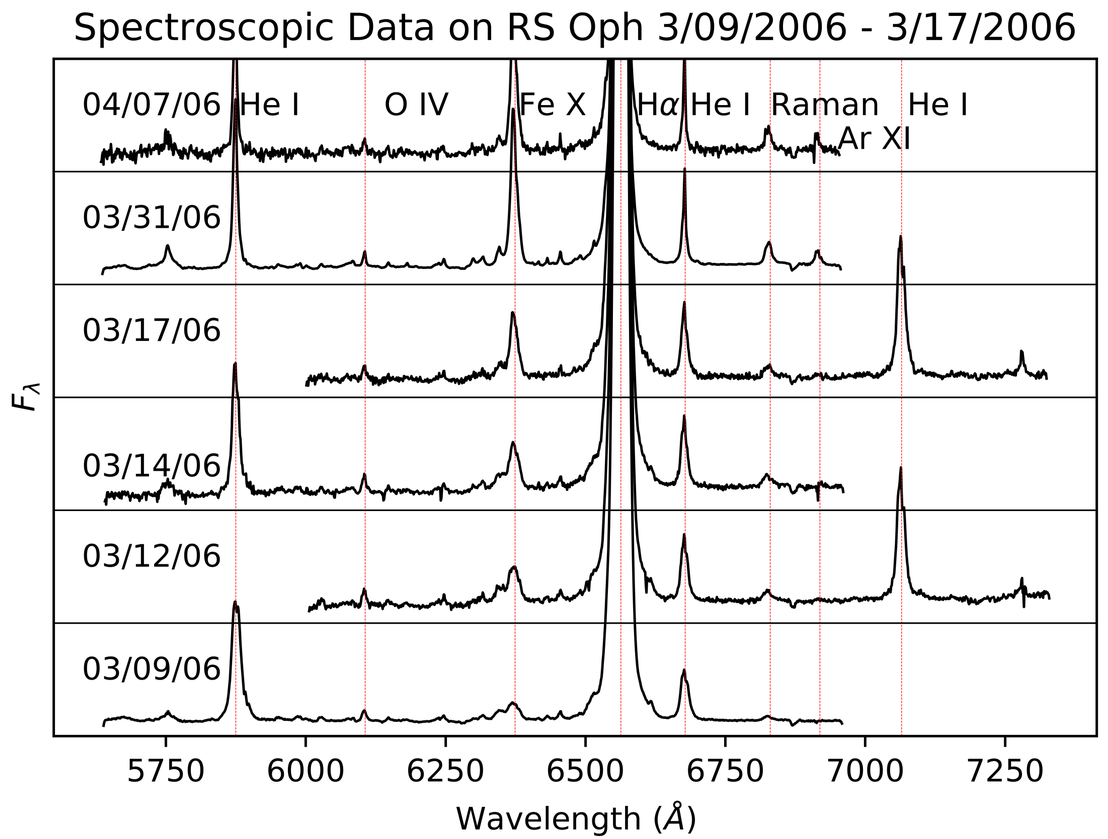


Figure: "Blue" Wavelengths for Rs Oph from 3/7/06 - 3/24/06 (Days 25 to 54 after outburst)

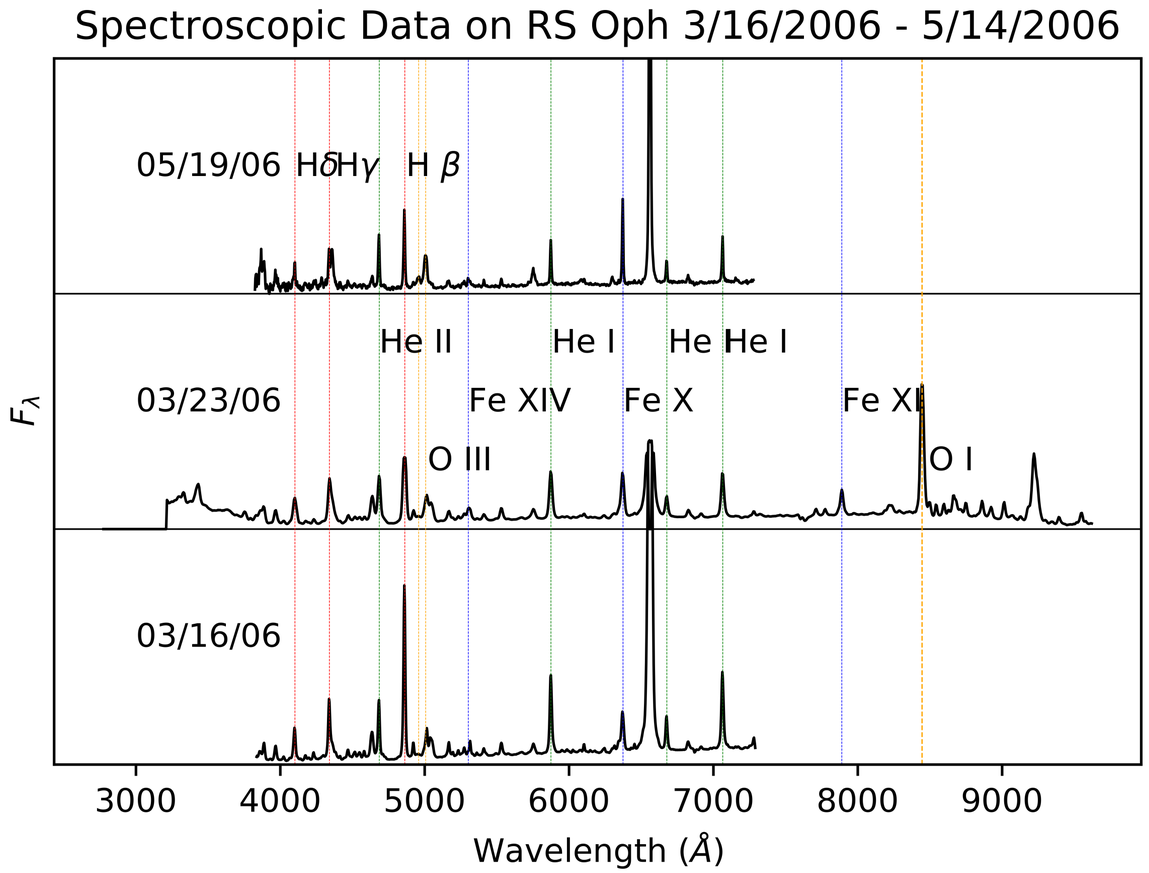


Figure: Total Spectra Wavelengths for Rs Oph from 3/16/06 - 5/14/06 (Days 33 to 93 after outburst)

TOTAL SPECTRA

- Many marked lines, but this plot is to show the evolution from low ionization lines to higher ionization lines.
- Specifically note the strengthening of Fe X and He I.
  - He I approaching the intensity of H-β
- Additionally the data from 3/23 is the only observation containing the O I 8446Å line, which should have began to strengthen and surpass He I around day 26.
- Note O III by May 19th is slightly stronger than H-δ and around H-γ

SUMMARY

- The rapid shift from the low ionization and the O III line increase tells us that the ejecta most likely surpassed the red giant wind and dispersed within 93 days after the outburst.
- This eruption of Rs Oph was one of the most well studied and covered outburst.
- The optical spectra seems to be reasonable consistent between the previous outbursts in 1985 and 1933.

- Bouns:
  - Although not utilized in this project, upon studying other papers and analysis of RS Oph's spectrum, X-ray measurements of quiescent burning on the surface of the WD further support the Raman scattering lines and strong ionization lines in later evolution.

REFERENCES

- [1]Mondal, A., Anupama, G. C., Kamath, U. S., Das, R., Selvakumar, G., and Mondal, S., “Optical spectroscopy of the recurrent nova RS Ophiuchi - from the outburst of 2006 to quiescence”, Monthly Notices of the Royal Astronomical Society, vol. 474, no. 3, pp. 4211–4224, 2018. doi:10.1093/mnras/stx2988.
- [2]Walter, F. M., Battisti, A., Towers, S. E., Bond, H. E., and Stringfellow, G. S., “The Stony Brook/SMARTS Atlas of (mostly) Southern Novae”, Publications of the Astronomical Society of the Pacific, vol. 124, no. 920, p. 1057, 2012. doi:10.1086/668404.
- [3]Somero, A., Hakala, P., and Wynn, G. A., “High-resolution optical spectroscopy of RS Ophiuchi during 2008-2009”, Monthly Notices of the Royal Astronomical Society, vol. 464, no. 3, pp. 2784–2795, 2017. doi:10.1093/mnras/stw2551.