Primary Spin Up by Devouring Mass from Secondary – in the Massive Algol Binary RY Persei

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Abstract

We present an investigation of the Hα emission line variations observed in the massive Algol binary, RY Persei. We used the observed optical spectra to calculate new radial velocity data for the secondary and high dispersion UV spectra for the primary. We present the revised orbital elements and an estimate of the primary's projected rotational velocity. We used a Doppler tomography algorithm to reconstruct the individual primary and secondary spectra in the region of Hα, and the latter was subtracted from each of our observations to obtain profiles of the primary and its disk alone. Our Hα observations of RY Per show that the mass gaining primary is surrounded by a persistent but time variable accretion disk. The outside-of-eclipse profile has weak, double-peaked emission flanking a deep central absorption. It was found that these properties can be reproduced by a disk model that includes the absorption of photospheric light by the band of the disk seen projected against the face of the star. We developed a new method to reconstruct the disk surface density distribution from the ensemble of Hα profiles observed around the orbit, and this method accounts for the effects of disk occultation by the stellar components, the obscuration of the primary by the disk, and flux contributions from optically thick disk elements. The resulting surface density distribution is elongated along the axis joining the stars, in the same way as seen in hydrodynamical simulations of gas flows that strike the mass gainer near the trailing edge of the star. This type of gas stream configuration is optimal for the transfer of angular momentum, and we show that rapid rotation is also found in other Algols that have passed through a similar stage.

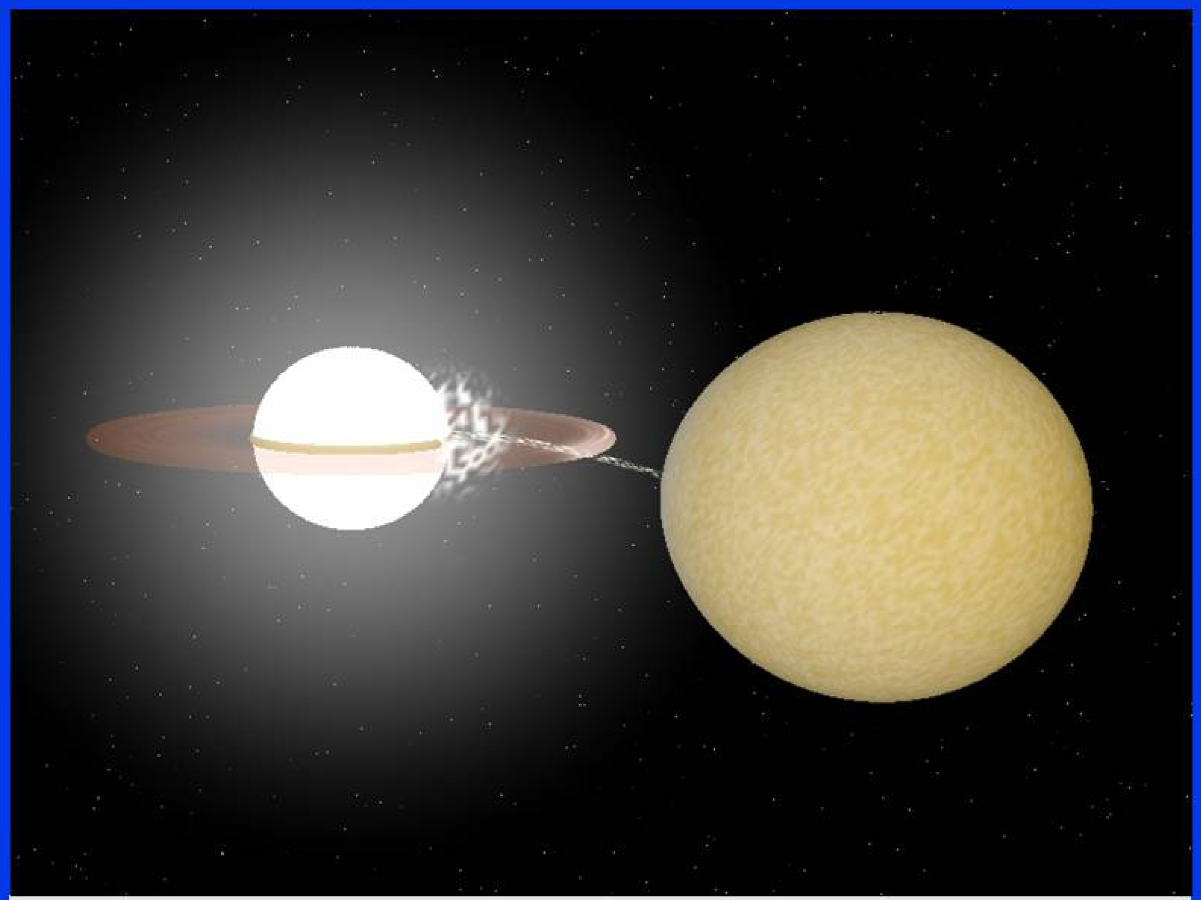

Fig 1. – Simulated image of RY Persei – Algol binary star pair. Gas stream from the cooler secondary (bigger star at right) strikes the hot primary near it's trailing edge, causing it to spin up.

Using software '*Binsim*' by Dr. Robert Hynes of UT Austin

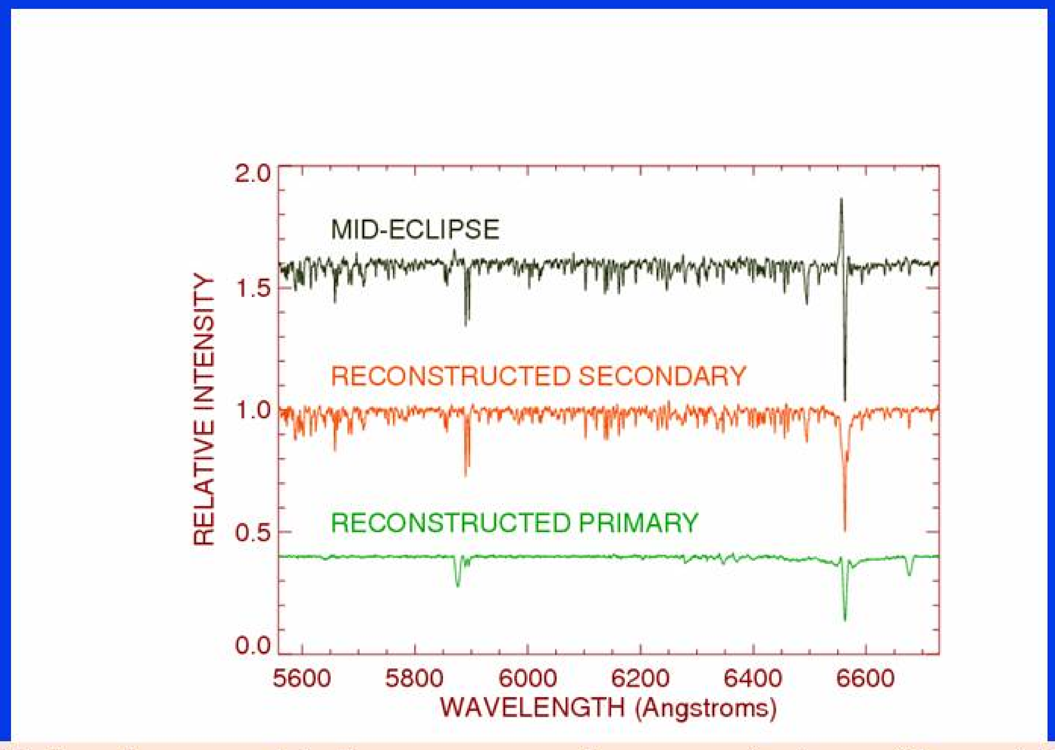

Fig 2. – Tomographically reconstructed spectra of primary (*bottom*) & secondary (*middle*) based on out-of-eclipse spectra and rectified to a unit continuum. *Upper* plot shows single spectrum at mid eclipse when flux is entirely from secondary (except disk emission at Hα).

Orbital Element	Result
P (days)	6.863569
T_P (HJD-2,400,000)	51467.15 ± 0.10
T_S (HJD-2,400,000)	51466.97 ± 0.13
e	0.036 ± 0.005
ϖ_P (deg)	255
ϖ_S (deg)	75 ± 7
K_P (km / s)	47.3 ± 3.9
K_S (km / s)	174.5 ± 0.9
V_P (km / s)	13.8 ± 2.9
V_S (km / s)	-6.0 ± 0.6
rms_P (km / s)	8.4
rms_S (km / s)	3.4
M_P ($M_\odot$)	6.24 ± 0.24
M_S ($M_\odot$)	1.69 ± 0.23
a ($R_\odot$)	30.3 ± 0.6

Introduction & Basic Spectroscopic Analysis

- ***RY Persei*** (HD 17034 = HIP 12891) – B4 V gainer & F7 II-III loser
- ***Observation***:
  Optical spectra – KPNO 0.9-m Coude Feed Telescope – 4 runs: 1999 Oct 12 – 18, Nov 09 – 15, Dec 04 – 09, & 2000 Oct 02 – 04.
- ***Radial velocities***:
  - Secondary:
    - Cross correlate each observed spectrum with a mid eclipse spectrum (HJD 2,451,463.804).
    - Velocities made absolute scale using HD 216228 as RV standard (-14.2 ± 0.7 km s^{-1}).
  - Primary:
    - Use spectra recorded by IUE in range 1240 – 1850 Å.
    - Cross correlate with narrow-lined spectrum of ι Her (-20 km s^{-1})
- ***Revised Orbital Elements***:
  - Adopt P from VHW, Calculate other elements
- ***Projected Rotational Velocity of Primary***:
  - Using width of ccf as measure of photospheric line broadening due to rotation
  - $V \sin i$ = 213 ± 10 km s^{-1}

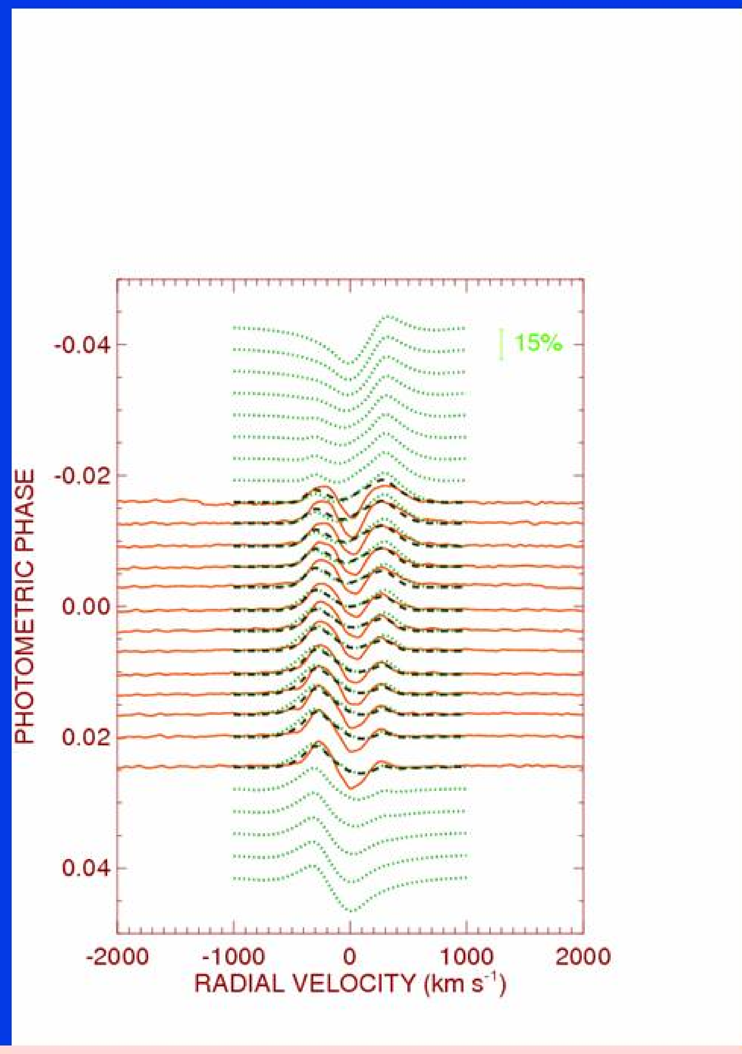

Fig 3. – Secondary subtracted Hα profiles for the eclipse observed on 1999 Oct 12 (plotted in velocity frame of gainer). Each spectrum aligned so that continuum level is set at orbital phase of observation. *Dotted*: Model predictions for eclipses of axisymmetric disk. *Dashed*: Model spectra derived from reconstruction of disk surface density.

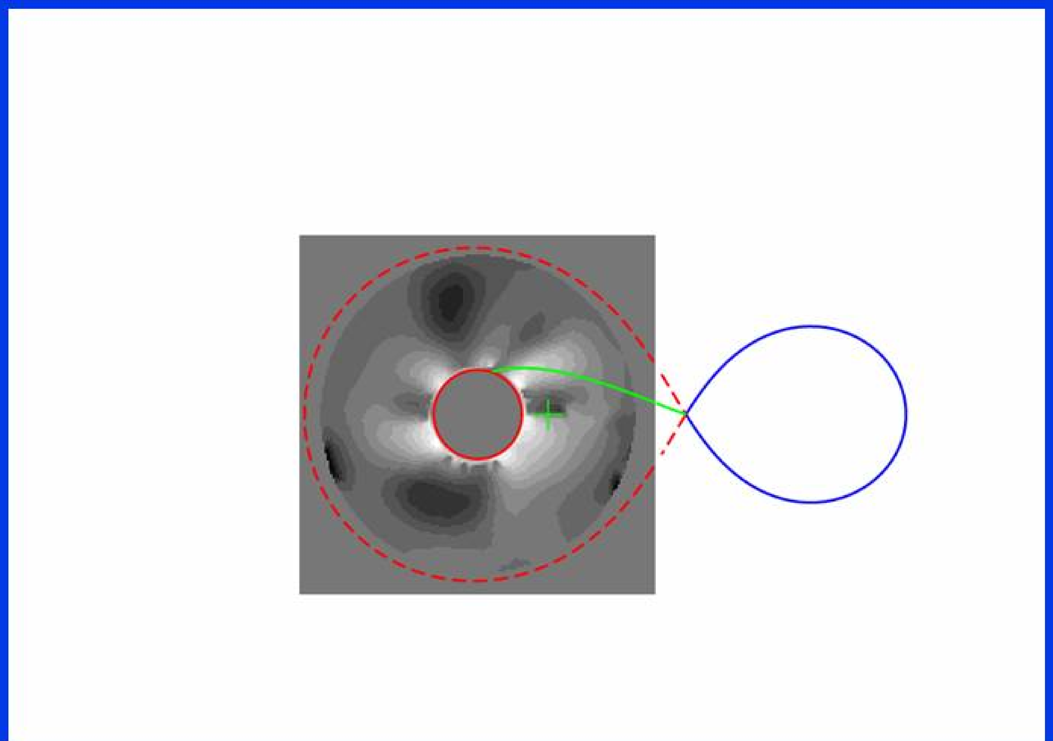

Fig 4. – Grayscale (16 level) depiction of the logarithm of the disk surface density in a spatial diagram, as viewed from above orbital plane. Roche filling secondary's outline is shown at right, with the primary is at center of disk. *Dashed* line: Roche limit of primary; *Dotted* line: Ballistic trajectory of gas stream from secondary.

Disk Modeling

- Spectral region - Hα emission (6563 Å) from disk
- Reconstruct Primary & Secondary components from composite out-of-eclipse spectrum – Doppler Tomography algorithm (Bagnuolo et al. 1994)
- Composite – Secondary = Flux from Primary + Disk
- Axi-symmetric disk model – Hummel & Vrancken (2000) semi-analytical method to model Hα emission profile
  - Successfully gives overall time averaged Hα profile
  - Can not account for temporal variations in disk emission
- Reconstruction of Disk Surface Density
  - Secondary subtracted Hα profile for out of eclipse phases – Photospheric profile = Disk Hα emission
  - Back projection tomographic reconstruction using algorithm by Thaller et al. (2001)
  - → Doppler tomogram
- New method to model gas distribution in disk
  - Use analytical line formation method (axi-symmetric disk) – accounting for geometrical occultation & optical depth effects
  - Correction scheme – Revisions to assumed disk surface density distribution
  - Compute disk surface density based on observed Hα profile
  - Fig. 4 – Use 9 iterations; Gain, γ = 0.02

Conclusions

- RY Persei –
  - Algol-type binary
  - Mass gainer surrounded by time variable accretion disk
  - Double-peaked emission with strong central absorption in Hα
- Fit mean Hα profile using line modeling method, applicable for Be shell stars
- New method of tomograpic reconstruction to derive map of disk surface density.
  - Density map similar to hydrodynamical simulations of gas flows in Algols.
  - → Incoming gas stream deflected at impact site into elongated trajectories creating density enhancements along axis joining stars.
- Rapid rotation in primary –
  - Result of accretion of gas with high angular momentum.
  - Gas stream strikes gainer very close to it's trailing edge (favorable condition for angular momentum transfer from gas stream to primary)
- Angular momentum gain of primary increases, as system evolves to lower ***q*** (Mass ratio decreases) .
- ∴ Pronounced spin up of mass gainers at peak of efficiency curve.
  - Eg. of other algol systems (Fig. 6).
  - → RY Per shows how massive stars can be spun up by mass & angular momentum transfer in close binaries.

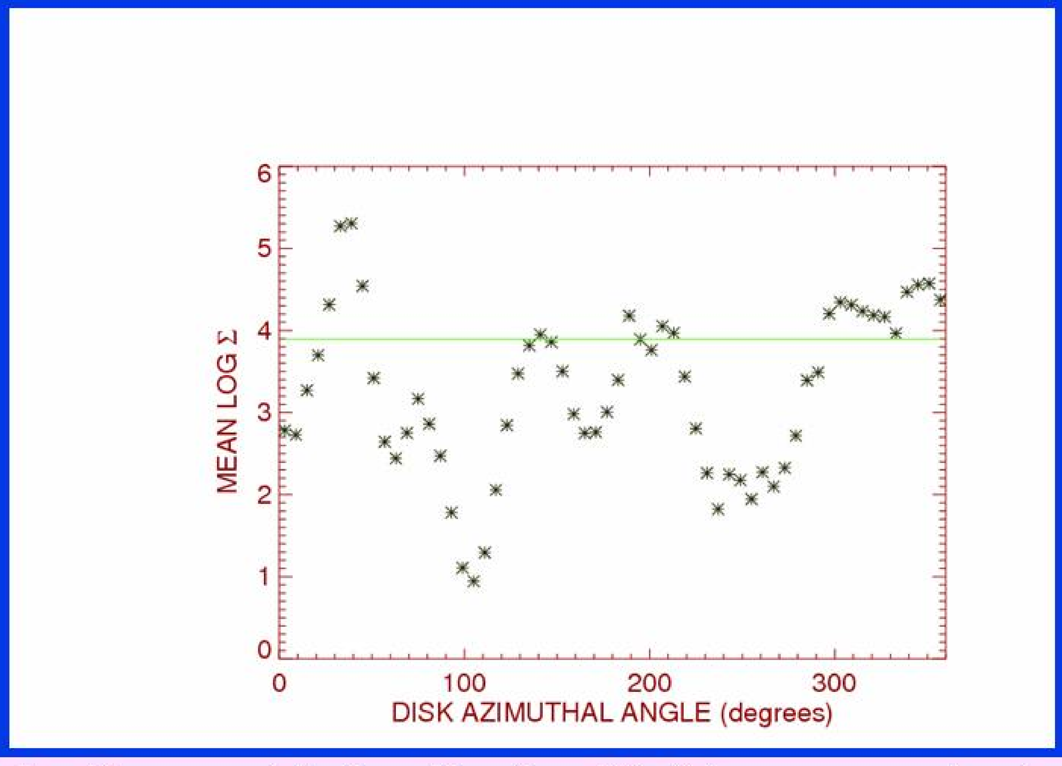

Fig. 5. – The mean of the logarithm (base 10) of the reconstructed surface density (number of neutral H atoms in the n=2 state per cm^2) along each radial arm of disk; plotted against disk azimuthal angle, φ (*plus signs*). *Solid line* is default value from axisymmetric disk model.

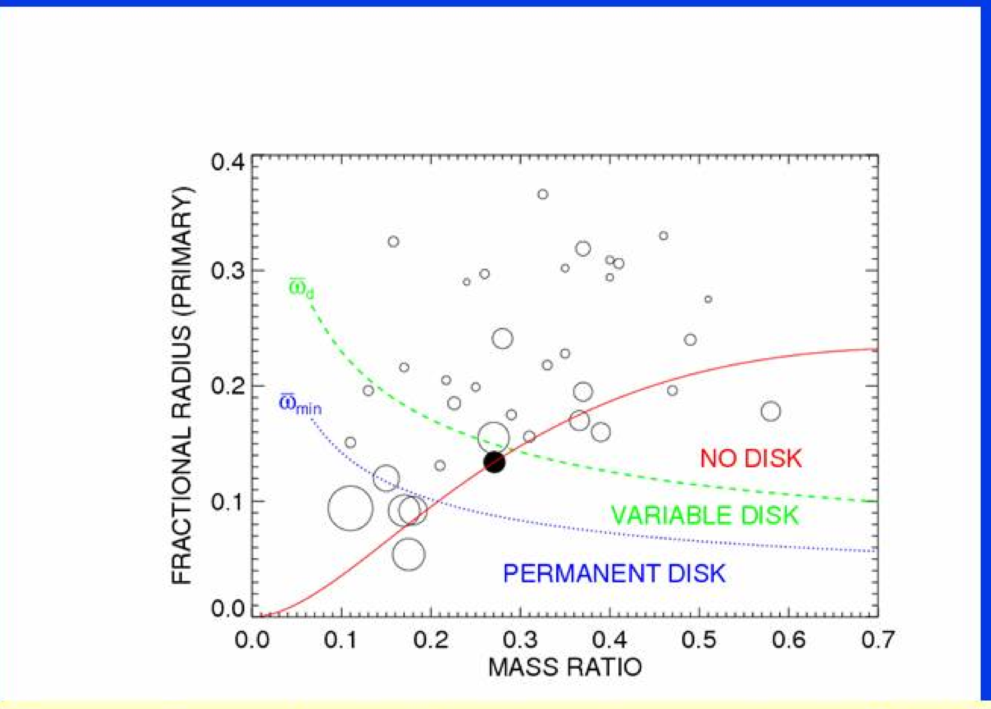

Fig 6. – An *r, q* diagram showing locations of mass gainers in Algol binaries (*open circles*) and RY Per (*solid circle*) . Area of each circle ˜ Ratio of the gainer's angular velocity compared to the synchronous rate. *Solid line* – Evolutionary path of RY Per for conservative mass transfer. *Dotted curve* (ϖ_{min}) – Minimum distance between gas stream & center of gainer. *Dashed curve* (ϖ_d) – Fractional outer radius of a disk where orbital velocity at stream-disk intersection matches vector component of stream in same direction.

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http://xxx.lanl.gov/abs/astro-ph/0309734

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