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Multiwavelength Monitoring of the Be/X-ray Binary X Persei - Evidence for Multiple Disk Structures

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Abstract. We present optical photometry and high resolution optical spectra of the Be star X Persei/HD 24534, the counterpart to the X-ray pulsar 4U0352+30, obtained over the past ~10 years. These spectra show a variety of behaviour, ending with the onset of a strong V/R cycle. Observations of the He I 6678 line suggest several episodes of discrete disc forming. This data forms part of a major long-term multiwavelength monitoring programme ($UBVRIJHKL$ photometry plus optical and UV spectroscopy).

1. Introduction

X Persei/HD 24534 is the prototypical persistent low luminosity Be/X-ray binary system. The Be star has recently been reclassified as a B0 Ve at a distance of around 700-800 pc. Recently the system has undergone two episodes of dramatic disk loss, during the mid-1970's and the 1980's, and following the latter event was seen to display unusual He I 6678 line profiles. Here we present optical data obtained over the period 1987 to 1998, covering the entire disk loss period and the unusual multi-component line behaviour.

Most of the data presented here was obtained from the Crimean Astrophysical Observatory, Ukraine, 2.6 m Shain telescope, Coude focus with CCD, resolution ~25,000. Photometry was obtained with the Sternberg Astronomical Institute 0.60 m and the Univ. of St. Petersburg 0.74 m IR telescopes, both also located at Crimea, Ukraine.

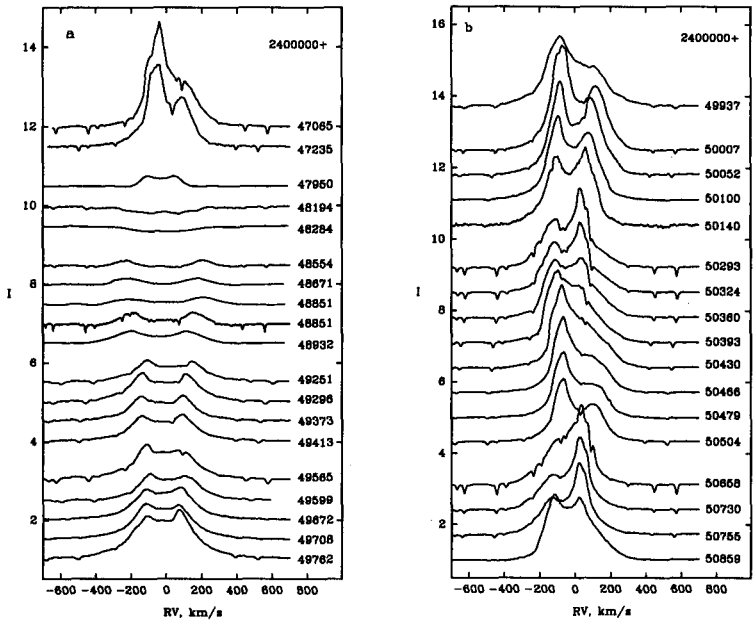

Figure 1. The Hα spectra of X Per covering the period 1987-1998.

2. Behaviour of the Hα and He I 6678 lines.

Figure 1, panels *a* and *b* show the Hα line of X Per. Figure 3 (left panel) displays the observed parameters of the Hα line taken from the spectra in Figure 1. Figure 2 panels *a* and *b* show the behaviour of the He I 6678 line. Figure 3 (right panel) displays the observed line parameters of the He I 6678 line from the spectra shown in Figure 2.

Phase 1 (TJD∼46500-47700): covers bright state prior to Extended Low State (ELS), showing double-peaked structure (see Phase 3), followed by rapid fading to minimum brightness ($\Delta V \sim 0.6^m$ in ∼400 days)

Hα: Region is poorly covering spectroscopically, but our data shows that the Hα line is bright (EW ∼10 Å), with double-peaked structure (V>R). There may be some evidence for to suggest we are seeing possible V/R variations. Small peak separation (∼140 km s^{-1}).

(No He I 6678 data for this phase)

Phase 2 (TJD∼47700-49100)): star in extended low state, with very low amplitude photometric variations, possible increasing in size towards end of this period.

Hα: Starts as weak, double-peaked emission line, falling to photospheric absorption line for a short period (∼20-30 days). Rapid EW decrease, but lagging behind V decrease by about 400-500 days. After absorption line seen, weak emission returns with large peak separation (∼500 km s^{-1}). Intensity of the line gradually increases. As EW increases almost linearly, peak separation decreases. No V/R variability observed.

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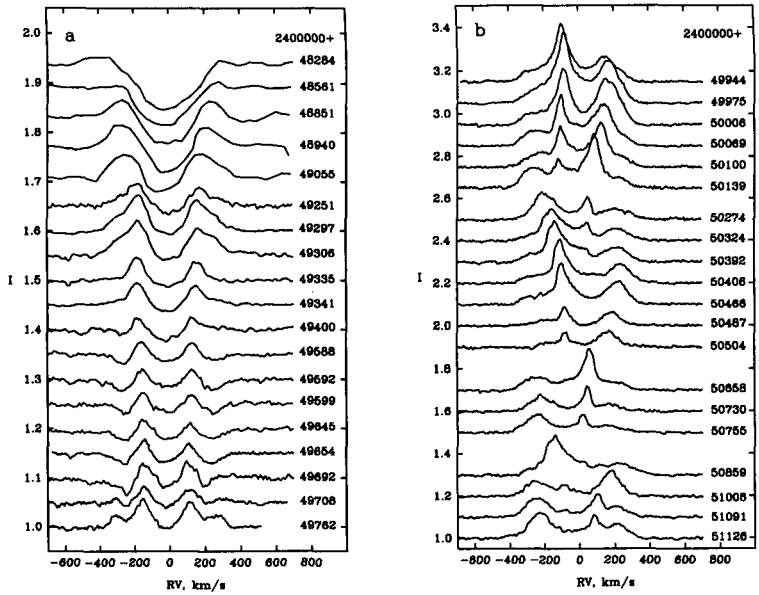

Figure 2. The He I 6678 line spectra covering the period 1991-1998.

He I 6678: First observation is in absorption, line gradually moves into emission with widely separated peaks and central absorption component.

Phase 3 (TJD~49100-49650): ELS ends with rapid brightening in V ($\Delta V \sim 0.6^m$ in 550 days), again shoving double-peaked structure as for previous maximum (Phase 1).

Hα: EW reaches plateau (whilst V still increasing), some low amplitude, irregular V/R variability, peaks continue to move closer at same rate as in Phase 2.

He I 6678: Peak intensity decreases, separation decreases, photospheric wings appear at edge of the emission peaks. EW variability more pronounced than for Hα, reaching a local minimum when star is at maximum brightness (end of Phase 3).

Phase 4 (TJD~4965-5000): rapid fading in V magnitude ($\Delta V \sim 0.55^m$ in 350 days).

Hα: During this period, the Hα line profile shows large global changes in structure, remaining strong and double-peaked throughout. EW begins to increase again (anti-correlated with V changes), and we see the onset of the long-term V/R cycle, which begins near maximum brightness (amplitude increasing with time). Peak separation decreases at much slower rate.

He I 6678: Disappearance of photospheric wings, replaced by additional emission components at high velocity (four peak structure). EW behaviour as for Hα (increases while V decreases), peak separation remains unchanged for main (inner) components.

Phase 5 (TJD~50000-50800): minimum of light curve at $V \sim 6.7^m$, slightly

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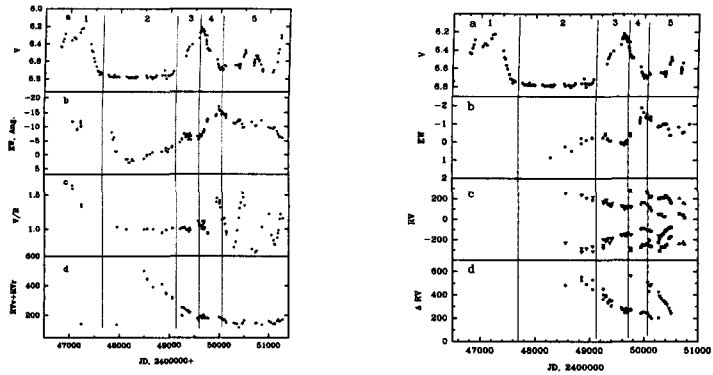

Figure 3. Time variability of the parameters of the Hα (left panel) and He I 6678 (right panel) lins.

brighter than in ELS ($V{\sim}6.8^m$) suggesting some overall long-term brightening. Some small brightening episodes ($\Delta V{\sim}0.1 - 0.2^m$), but poor coverage.
Hα: Pronounced profile variability, in classical Be star V/R cycle form. V/R variability increasing in amplitude with period ~550 days – suspiciously close to the proposed 580 day orbital period. EW decreases slightly, and peak separation reaches minimum, as seen in Phase 1 ($\sim 100\,\mathrm{km\,s^{-1}}$).
He I 6678: Multi-component structure shows strong variability in both intensity and radial velocity, for all peaks. Pairs of peaks converge (Figure 3, right panel), and EW decreases to pre-plateau level (start of Phase 3).

3. Discussion

We find a V/R cycle which starts around the time of the optical maximum in 1994/95, with a short period (~550 days). Throughout this V/R cycle we see the disk expanding. The Hα observations show that the disk reforms close to the stellar photosphere (peak separation $\sim 500\,\mathrm{km\,s^{-1}}$) reaching a size comparable to that seen in the late 1980's around ~5-6 years later (peak separation $\sim 180\,\mathrm{km\,s^{-1}}$).

The system displays spectroscopic behaviour typical of classical Be stars (Phases 1-3; disk loss and recovery), although the amplitude of the associated photometric variability is unusually large ($\Delta V{\sim}0.6^m$). This period is followed by unusual activity which appears to correspond to complex structural changes in the evolution of the disk. We previously proposed that this might represent a multi-component disk structure (a "double disk"), and this additional data appears to support the interpretation. Observations of the He I 6678 line show what could be three separate disc components forming over a period of ~7 years.

A full analysis of the observations presented here will be published in Roche et al. (in prep.).

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