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# Radial velocity study of the intermediate polar EX Hydrae

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**Abstract.** Intermediate Polars study from the canonical approach used for non magnetic systems is indeed controversial. Nevertheless, we present hereby high dispersion spectroscopic observations with simultaneous optical photometry of the intermediate polar EX Hya. A normalization method for doppler tomography throughout a complete observation run is introduced. We find rapid variations, orbital period averaged, in the H$\alpha$ emission line, with the capability to map the region where they come from in the velocity-space doppler tomogram. By applying the double-Gaussian method to the same line profile we determine a velocity semi-amplitude of the primary star $K_1 = 52 \pm 5$ km s$^{-1}$ which, even if suggests a lower value than recent results, is still within the error bars of the such estimations.

**Key words.** Stars: binaries: close – Stars: dwarf novae, cataclysmic variables – Stars: spectroscopy

## 1. Introduction

EX Hydrae is a short period intermediate polar (IP), the subclass of cataclysmic variables in which a magnetic white dwarf (WD) accretes from a surrounding gaseous ring (see Warner 1995, and references therein). It was first identified by Kraft (1962) as an eclipsing system with an orbital period $P_{orb} = 98 min$, a disk inclination $i = 78^o \pm 1$ and a second prominent period $P_{spin} = 67 min$ due to the rotation of the WD (Vogt et al. 1980; Kruszewski et al. 1981). The large $P_{spin}/P_{orb}$ ratio ($\approx$ 2/3) places the system out of the usual spin equilibrium rotation since most IPs have shown to attain it near $P_{spin}/P_{orb} \approx 0.1$ (King & Wynn 1999; Wynn 2000). Reports on the binary masses had been indeed controversial, until Beuermann & Reinsch (2008) unveiled narrow NaI and CaII lines from the secondary, accurately determining both component masses. However, there is still lack of visual spectroscopy of the system. In this paper we present a radial velocity study to determine the orbital parameters via a diagnostic diagram and doppler tomography analysis featuring an interesting normalizing method with the aim of a continuous analysis throughout the complete observation run.

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**Table 1.** Spectroscopy of EX Hya

| Date | HJD (start) [2454400+] | Time [hrs] | No. of spectra | Exp. [s] |
|---|---|---|---|---|
| 01.10.08 | 75.962341 | 1.58 | 20 | 240 |
| 01.11.08 | 77.027255 | 1.26 | 15 | 240 |
| 01.12.08 | 77.950838 | 2.65 | 32 | 240 |
| 01.13.08 | 78.942922 | 2.64 | 32 | 240 |

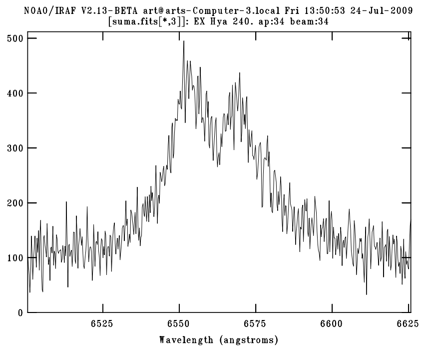


**Fig. 1.** Spectrum of the H$\alpha$ emission line with asymmetrical contribution on the wings of the profile (see section 4). Despite the fact of the low S/N ratio, the double gaussian method is still reliable.

## 2. Observations

EX Hydrae was observed in 2008 January 10–13 with the Echelle spectrograph at the f/7.5 Cassegrain focus of the 2.1 m telescope of the Observatorio Astrónomico Nacional at San Pedro Mártir, B.C., México. The SITe3 1024×1024 CCD was used to cover a spectral range from $\lambda$6850 to $\lambda$7100 Åwith a spectral resolution of R=12,000. An echellette grating of 300 l/mm, was used and the exposure time was 240 s during the four nights (hereinafter referred each of them as Night $n$, $n = 1, 2, 3, 4$). The main feature of the spectra is a weak H$\alpha$ emission line. Fig. 1 shows a typical spectrum with the double-peaked profile.

Simultaneous CCD photometry was obtained during the same nights, using the 1.5 m and 0.84 m Telescopes with the Marconi and Thomson detectors, respectively. The Johnson V and Strömgren v filters were used

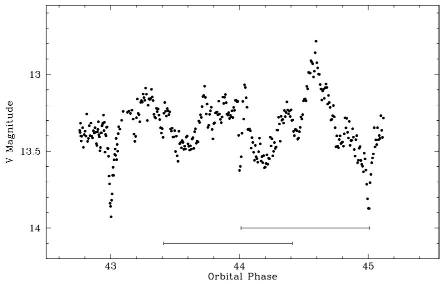


**Fig. 2.** Typical light curves of EX Hya featuring narrow eclipses, V Johnson filtered and plotted against orbital period. The bars under correspond to the simultaneous spectral coverage (see section 3.3).

simultaneously for the Nights 3&4 (see Table 2). A nearby comparison star with $m_V = 11.39$ was used to determine the V magnitude of EX Hya, while the Strömgren magnitude is only differential.

## 3. Results

### *3.1. Photometry*

The light curves of the object observed with both telescopes and different filters are well correlated, fact later used to correct the spectra for possible slit losses. Fig. 2 shows the V Johnson light curve during the Night 4. Narrow eclipses of $\Delta m_V \approx 0.5$ corresponding to the inferior conjunction are observed. The orbital phase was arbitrary set to zero on the first eclipse on January 10th and is taken as a reference for the rest of the nights. There is evidence of a perfect match of the eclipses throughout the season with the orbital period, which where computed using the linear ephemeris of Hellier & Sproats (1992). In some orbital phases, e.g. $\phi = 44$ in Fig. 2, the eclipses are almost vanished due to the intrinsic activity of EX Hya. The bars under the light curves indicate the simultaneous spectral coverage (see section 3.3).

Because of the longer coverage during Nights 3&4, it was possible to observe three

**Table 2.** Photometry of EX Hya

| Date (UT) | Tel | Filter | Exp. Time | HJD (start) | HJD (end) |
|---|---|---|---|---|---|
| Jan. 10, 2008 | 1.5m | V | 10s | 2454475.963844 | 2454476.010098 |
| Jan. 11, 2008 | 1.5m | V | 10s | 2454477.009960 | 2454477.009752 |
| Jan. 12, 2008 | 1.5m | v | 30s | 2454477.940522 | 2454478.057280 |
| Jan. 12, 2008 | 0.84m | V | 10s | 2454477.892149 | 2454478.060985 |
| Jan. 13, 2008 | 1.5m | v | 10s | 2454478.964090 | 2454479.062884 |
| Jan. 13, 2008 | 0.84m | V | 30s | 2454478.899026 | 2454479.059909 |

**Table 3.** Comparison night to night of the obtained Orbital Parameters

| Orbital Parameters | 10+11 Jan | 12 Jan | 13 Jan |
|---|---|---|---|
| $\gamma$ $(km/s)$ | 10 ± 3 | 15 ± 5 | 8 ± 3 |
| $K_1$ $(km/s)$ | 47 ± 5 | 70 ± 8 | 52 ± 5 |
| $\sigma$ | 20.5 | 31.7 | 18.6 |

eclipses in photometry and almost two orbital cycles in spectroscopy.

### 3.2. Diagnostic diagram for Hα

The H$\alpha$ emission line was measured using the standard double-Gaussian technique and its diagnostic diagrams as described in Shafter, Skody & Thorstensen (1986). We refer this paper for the details on the interpretation ouf our results.

We have used the *convolve* routine from the IRAF *rvsao* package, kindly shared with us by Thorstensen (private communication). We used a fixed width of 26 pixels for both gaussian profiles with the aim of tracing the wings of the double-peaked emission line. Running the double-Gaussian program for a range of the separations $a$ from 125 to 200 pix result in Fig. 3. The *Total Diagnostic Diagram* shows the results for the whole observation run, using the separation $a$ in Å by considering the conversion value 1 pix = 0.2341 Å for the corresponding detector.

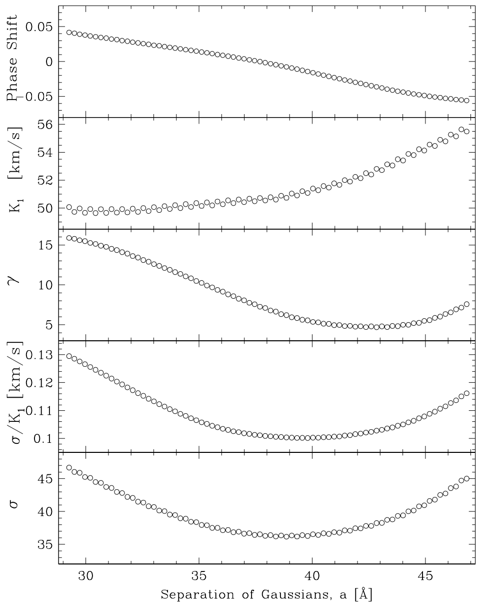


**Fig. 3.** Diagnostic Diagram revealing the best orbital parameters for EX Hya, in this case for all available spectra (see section 3.2 for details).

The large dispersion obtained on the Total Radial Velocity Curve after using the orbital parameters pushed us to analyse night by night the behaviour of EX Hya, resulting in a strange variation, up to this point, of the semi-amplitude of the primary (Table 3). Data from Nights 1&2 were added in order to work on similar samples. From the three results, the fit

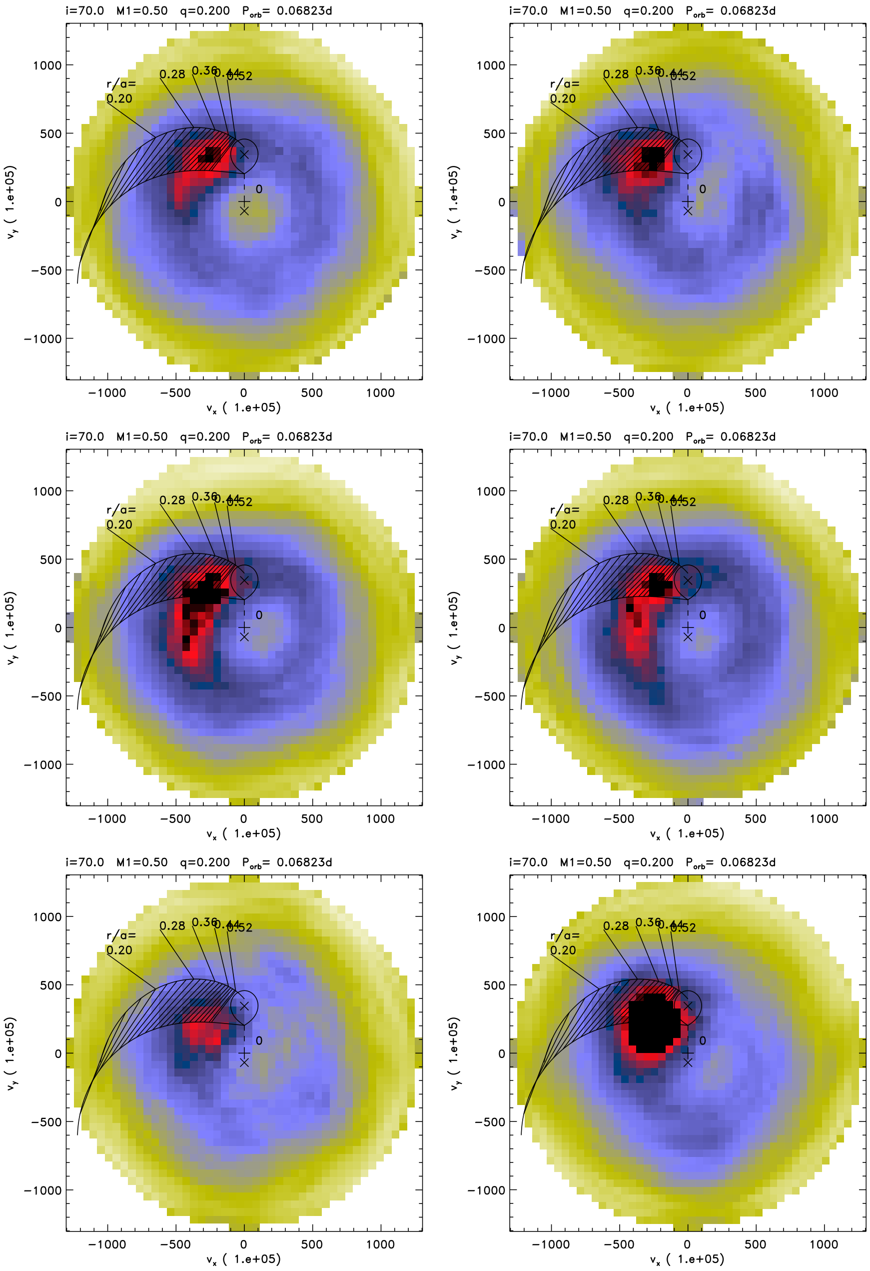


**Fig. 4.** Tomograms of EX Hya per night, per orbital period. Top left – Night 1. Top right – Night 2. Middle – Night 3, first and second covered orbital periods. Bottom – Night 4, first and second covered orbital periods.

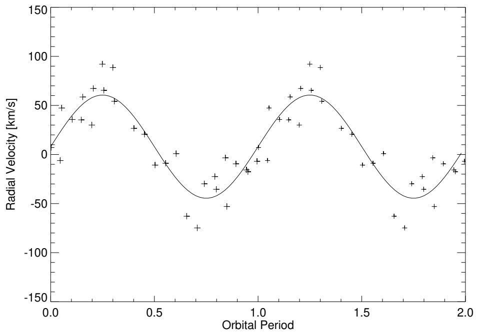


**Fig. 5.** Radial Velocity Curve for the 13 Jan in correspondence to the orbital parameters in Table 3.

from the Night 4 has the least *rms* value, corresponding to $K_1 = 52 \pm 5$ km s$^{-1}$.

### 3.3. Doppler tomography

On behalf of the study of the material orbiting around the WD, the gas stream coming from the companion, as well as emission regions arising from the last, Doppler Tomography turns out to be a useful technique. For further details we refer to Marsh & Horne (1988).

Six tomograms were computed by considering sufficient data for a single orbital period, therefore spectra from Nights 3&4 were split into two overlapping time intervals, indicated by the bars under, e.g. in Fig. 2 for Night 4. We performed an additional normalization throughout all the nights by considering the different amount of data available for each tomogram, namely the lack of it in Night 2 (see Table 1). Just after this method is applied we are in conditions to follow the behavior and evolution of the regions where H$\alpha$ is arising from. There is clear evidence of an accretion truncated disk around the WD and moreover a hot spot which appears sometimes smeared (Night 3) strongly correlated to the intrinsic activity shown by the photometry, probably evidence of ring overflows. Intensity suddenly increase of the hot spot in the second cycle of Night 4 is remarkably associated to the glitch in the light curve around $\phi \approx 44.6$. Ongoing analysis of such an interesting behavior is still taking place.

## 4. Conclusions

Simultaneous spectroscopic and photometric coverage made possible to correct the spectra. Becoming of great significance in the latter when normalizing the doppler tomograms for a single analysis of the whole data. This method causes still some controversy when applied to IPs, specially in the case of EX Hya, where it inherently carries some difficulties when describing the inner part of the truncated disk because of the *unconfortable* ratio $P_{spin}/P_{orb} \approx 2/3$. On the semi-amplitude determination, even though our best value is within the error bars of the most accurate values so far, the variation night to night is thought to be an spurious result coming from the asymmetry in the wings of H$\alpha$. Connected to the fact that working on higher radial velocities implies dealing with the inner region of the disk of an IP system. Finally, but not less important to consider, is the accretion curtain corotation and ring overflow effects described by Mhlahlo et al. (2007).

## 5. Discussion

**DAVID BUCKLEY's Comment:** Since EX Hya has both orbital and spin modulated radial velocities (RV), this poses problems in determining orbital tomograms and RV curves from just four nights of spectroscopy. Removing the effect of the spin modulation of $2/3P_{orb}$ could be difficult to do on a short time base (few days)

**KLAUS REINSCH:** In Intermediate Polars a basic assumption of Doppler Tomography is violated namely that we are not dealing with material in a 2-D velocity field. Material in the accretion curtain has a velocity component perpendicular to the orbital plane and contributes a significant fraction to the line emission.

**ABDIEL RAMIREZ-TORRES** We are now considering, instead of applying the double gaussian method to the wings, fit closer to the peaks and therefore get rid of the spurious contributions coming from the accretion curtain.

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