



Ankara University  
Kreiken Observatory



# Surface Inhomogeneities of the Eclipsing Binary System ER Vulpeculae

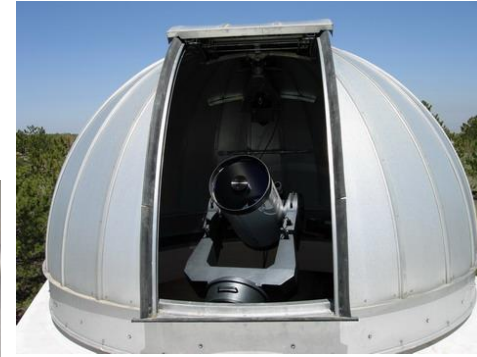
Observing Techniques, Instrumentation and Science  
For Metre-Class Telescopes II

Tatranská Lomnica, Slovakia  
September 24 - 28, 2018

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# Telescope and Instruments



## Kreiken Telescope (Meade LX200 16")

### Technical Specifications

**Diameter:** 406 mm

**Focal Ratio:** f/10

**Focal length:** 4064 mm

**Image scale:** 51 arcsec/mm

**Manufacturer:** Meade Instruments Corp.,  
California

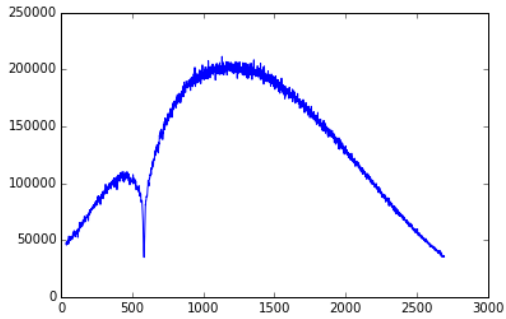
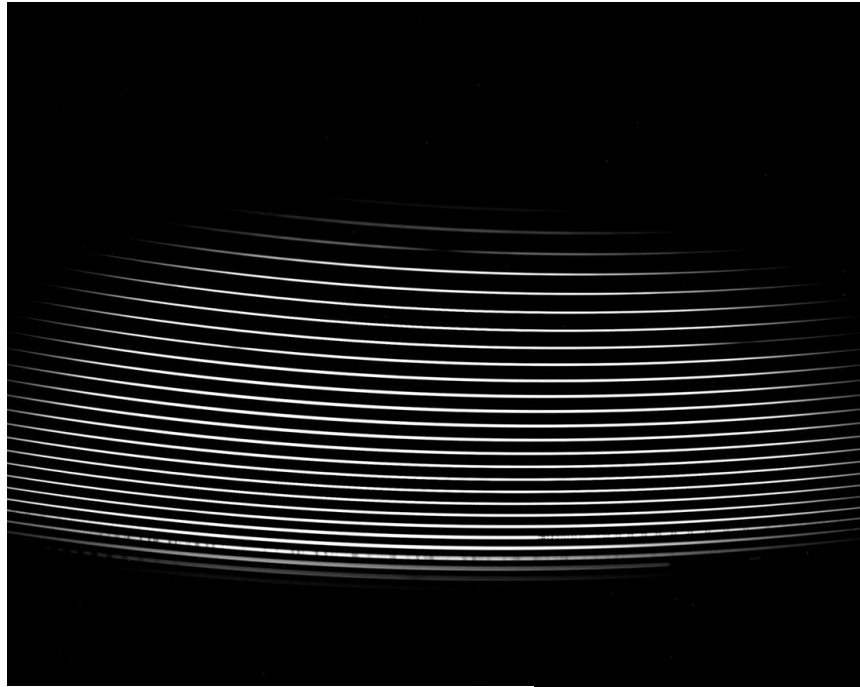
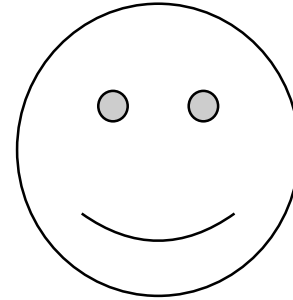


### Focal Plane Instruments

- eShel Spectrograph (Shelyak Instruments),  $R \sim 14000$ ,  
Wavelength Range: 4340-7400 Å, Brightness Limit  $V < 8.0$  mag
- Fiber Injection and Guiding Unit (f/6)
- Halogen, LED and Thorium-Argon lamp calibration unit
- QSI 660ws CCD camera
- 2758 x 2208 pixel 4.54 micron Sony ICX694 chip
- Autoguider system
- Various eye-pieces

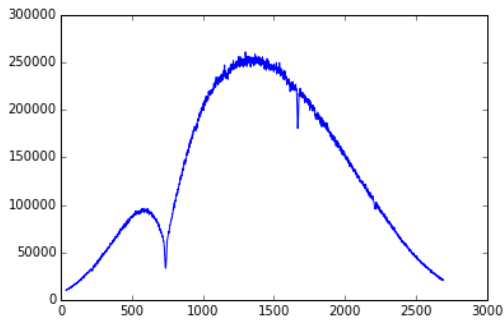


First Light  $\beta$  Leo  $m_v= 2.1 - 90$  Sec (06.04.2016)



Vega -  $H_{\beta}$

Vega -  $H_{\alpha}$



# Some of Our Studies From This Setup

THE ASTROPHYSICAL JOURNAL, 852:116 (5pp), 2018 January 10

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<https://doi.org/10.3847/1538-4357/aa9f14>

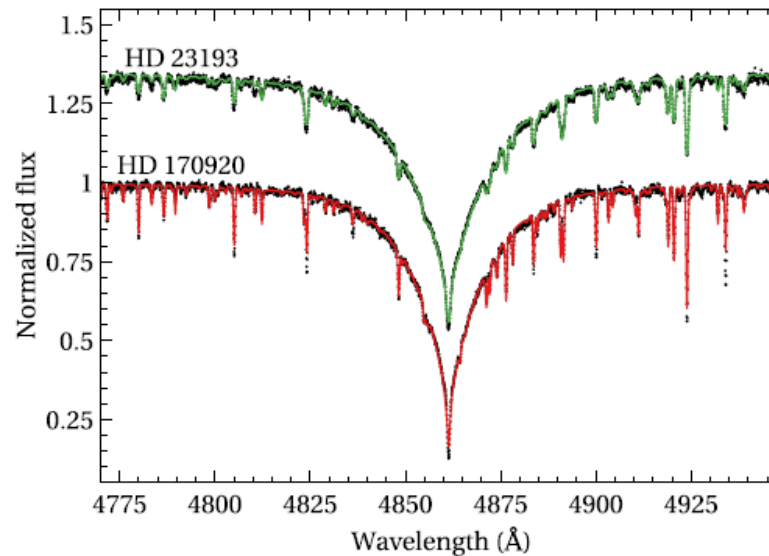


## Behavior of Abundances in Chemically Peculiar Dwarf and Subgiant A-Type Stars: HD 23193 and HD 170920\*

Tolgahan Kılıçoğlu, Şeyma Çalışkan<sup>1</sup>, and Kübraözge Ünal

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HD 23193 and HD170920 H<sub>β</sub> profiles and theoretical model

# Doppler Imaging and Chemical Abundance Analysis of EK Dra: Capabilities of Small Telescopes

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**SUMMARY.** We investigate the chromospheric and spot activity behaviour of the young Solar-like star EK Dra via Doppler Imaging and spectral synthesis methods, using mid-resolution spectroscopic spectra of the system. We also present the atmospheric parameters and elemental photospheric abundances of the star. The chemical abundance pattern of EK Dra supports the classification of the star as enriched by Boron, the Boron-to-Aluminum (B/A) ratio of EK Dra is higher than the solar value. The spot temperatures that may be cooler than 4000 K. In addition, we also show the capabilities of small telescopes (40 cm in our case) and medium resolution spectrographs in terms of Doppler Imaging and chemical abundance analysis.

## EK Dra: A Young Solar Analogue

- The first Doppler Imaging of EK Dra was performed by Strassmeier & Bos (1998) who used a spectra with R=120,000. They found that the poleward latitudes of the dark (apertured) regions are +40° and -70-90° (for the data taken in March 1993), and noted a large cool feature at 60°.
- Fabrichi et al. (2002) investigated the long term photometric variations of the star using Sonneberg Sky-Photo plates and detected a smooth decrease in the blue brightness (B<sub>v</sub>) of the star indicating a "superactivity".
- Jarvinen et al. (2008) found that the spots on EK Dra are grouped into two longitudes separated roughly 180° using the photometric data and the light curve inversion method. They also detected periodic variation of the total spot with a period longer than 40 years and with an additional period of 10.5 years.
- König et al. (2008) derived the mass of EK Dra for the primary component of the system and found 2.707 ± 0.008 solar masses in the radial velocity for the years 2001 and 2002.
- The surface temperature map of EK Dra were obtained by Jarvinen et al. (2007) who revealed that the spots are ~300 K cooler than the photosphere and moving in latitude in time.
- Ayres & Francis (2010) captured several very broad profiles of highly ionized C IV and Fe I indicating highly dynamic subsonic plasma as well as decreasing Si IV becoming quiet in the lower atmosphere.
- A new detailed Doppler Imaging and Zeeman Doppler Imaging of the star were finally performed by Waite et al. (2017).

**Fundamental Par.**  
 M = 0.95 M<sub>⊙</sub>  
 v sin i = 16.4 km s<sup>-1</sup>  
 i = 60°  
 (Waite et al. 2017)  
 T<sub>eff</sub> = 5750 K  
 Logg = 4.40

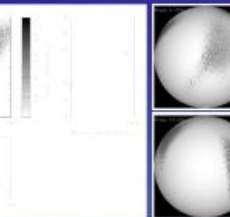


Fig. 1 Surface Map of EK Dra with latitudinal and longitudinal (l) distributions

## Observations

EK Dra was observed using the Swedish 1-m telescope mounted on a 40 cm telescope in Ankara University Mersin Observatory in 2017. 13 spectra were obtained with about 0.1 nm resolution. The spectra were obtained with a slit width of 0.1 arcsec. The spectra were obtained with a slit width of 0.1 arcsec. The spectra were obtained with a slit width of 0.1 arcsec.

## Methods

We used the Least Squares Deconvolution (LSD) technique (see Donati et al. 1997 for details) in order to enhance the S/N of EK Dra data. The input spectra of the LSD is obtained from the Vignera Atomic Line profiles - LSD (Vignera et al. 1999) by considering the surface gravity as well as the effective temperature of EK Dra. The S/N of the input spectra vary between 70 and 307, while the resulting LSD profiles have S/N values between 100 and 1100. During the LSD process we set the element pair grid to 50 km/s, depending on the resolution of our spectra data. The LSD profiles of the spectra that had more than 100 lines (1000-1100 Å and 1100-1200 Å) were used. The LSD profiles of EK Dra were also obtained in the same manner. The surface map of EK Dra was obtained using the Doppler Imaging code DOPIM (Donati 1997), which reconstructs the distribution of spots by the use of spot filling factor (S<sub>f</sub>) based on two - hemisphere model and Minimum Variance Method (MVM). The system parameters (mass, mass inclination) used during Doppler Imaging were taken from Waite et al. (2017). The resulting surface map of EK Dra in meridian projection map is shown in Fig. 1, while the surface images of the system at different phases are represented in Fig. 2. Modeling of the line profiles are also shown in Fig. 3.

Model atmospheres were calculated using ATLAS9 (Kurucz 1993), assuming a plane parallel geometry, a gas in hydrostatic and radiative equilibrium and LTE. Synthetic spectra were computed using SYNTHE (Hubeny & Lanz 1992). The model was first constructed from Kurucz grid data and then updated by using VALD, NIST and several publications. Hydroline structure was taken into account. The initial atmospheric parameters are derived from Strassmeier and Johnson photometric data of the star: T<sub>eff</sub> = 5750 K and log g = 4.40. The microturbulent velocity was derived by minimizing the scatter in the fit contributed from individual lines (Fig. 4). We fitted lines of the elements in the observed spectra with synthetic profiles to derive the elemental abundances using a best fitting method with Levenberg-Marquardt minimization procedure.

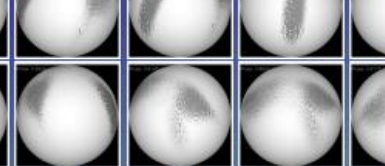


Fig. 2 Surface Images of EK Dra at different phases

## Results and Discussion

Our surface maps of EK Dra show these dark cool regions of intermediate-high latitudes. Figs. 1 & 2 emphasize how much bigger these spots are compared to sunspots (diameters < 1°). Strong absorption in FeO bandhead of 7000-7100 Å indicates T<sub>spot</sub> ≈ 4000 K.

We derive the abundances of EK Dra (Fig. 6) and find solar abundances except for Y and Ba which is clearly over-abundant. These initial results indicate that EK Dra may be a Boron dwarf. However, one needs to consider the isotopic structure of Ba and the effects of the magnetic field to clarify/reject this classification.

As EK Dra is G-type convective mixing dominants and surface composition should affect the stellar properties of birth, the reason for the enhanced Ba is a puzzle. We do not expect the atomic diffusion occurs in these stars, as the process has much longer timescale than that of convective motions.

We will obtain higher resolution spectra to reveal surface maps with higher spatial resolution, confirm our abundance measurements and check for a Si overabundance.

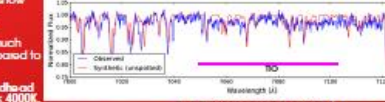


Fig. 3 Line profiles of EK Dra at 7000 Å

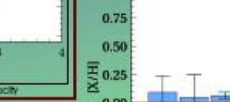


Fig. 4 Determination of the microturbulent velocity



Fig. 5 Line profiles of EK Dra at 7000 Å

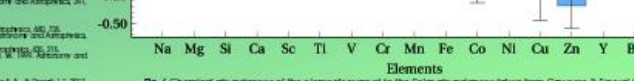


Fig. 6 Chemical abundances of the elements relative to the Solar abundances taken from Grevesse & Sauval (1998)

Imaging of Stellar Surfaces, March 5-9, 2018, ESO Garching, Munich, GERMANY

05 - 09 March 2018 ESO Garching Germany "Imaging of Stellar Surfaces" poster

(DOI: 10.5281/zenodo.1220763).

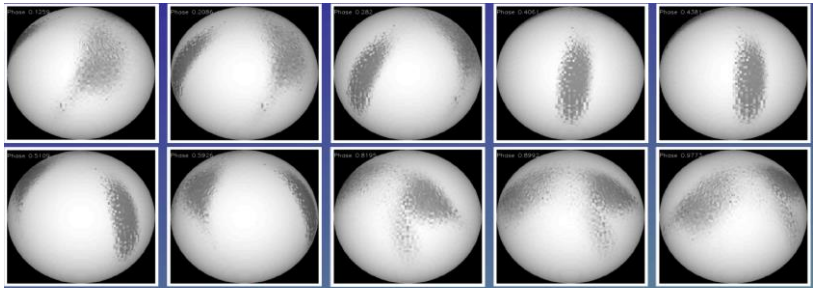


Fig. 2 Surface Images of EK Dra at different phases

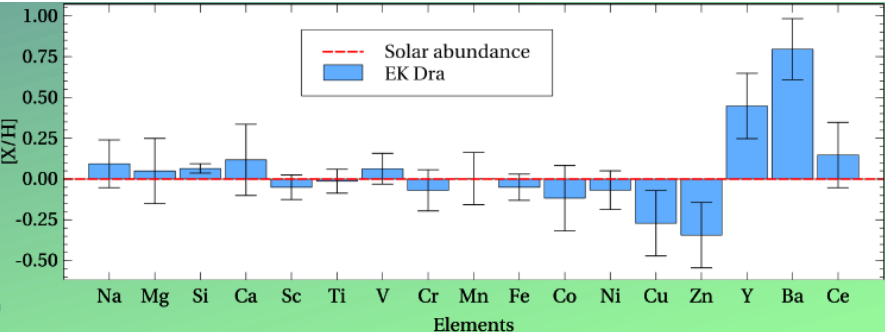
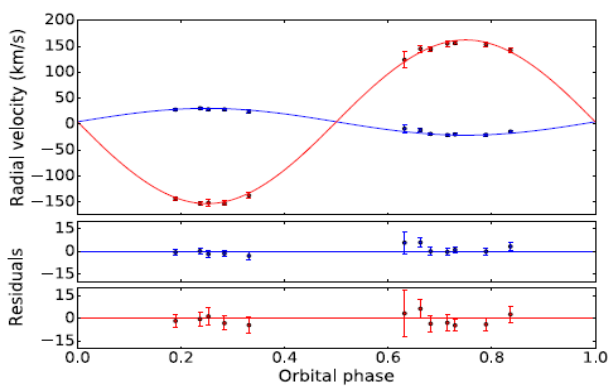


Fig. 6 Chemical abundances of the elements relative to the Solar abundances taken from Grevesse & Sauval (1998)

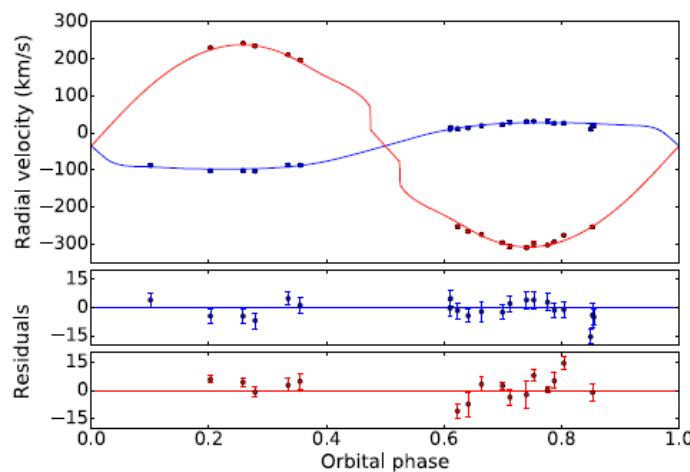
ACKNOWLEDGMENTS  
 This work is supported by the National Research Council of Turkey (TUBITAK) and Ankara University. We thank the referee for the constructive comments and the anonymous referee for the constructive comments.

# A simultaneous spectroscopic and photometric study of two eclipsing binaries: V566 Oph and V972 Her

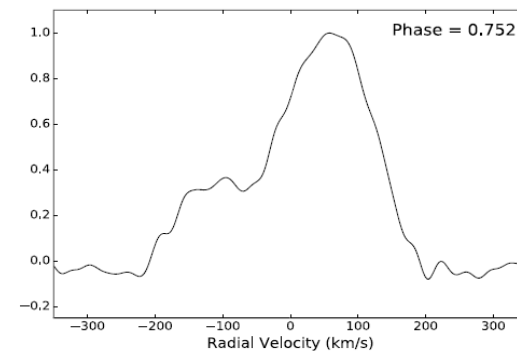
S.O. Selam<sup>1,2</sup> · E.M. Esmer<sup>1,2</sup> · H.V. Şenavcı<sup>1,2</sup> · E. Bahar<sup>1,2</sup> · O. Yörükoğlu<sup>1,2</sup> · M. Yılmaz<sup>1,2</sup> · Ö. Baştürk<sup>1,2</sup>



Radial velocity curve and theoretical model of V972 Her



Radial velocity curve and theoretical model of V566 Oph



V972 Her's Broadening Function (phase= 0.752 )

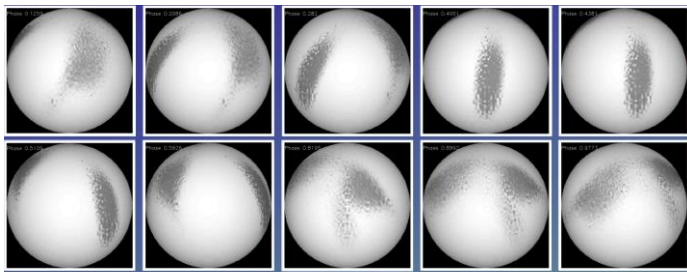
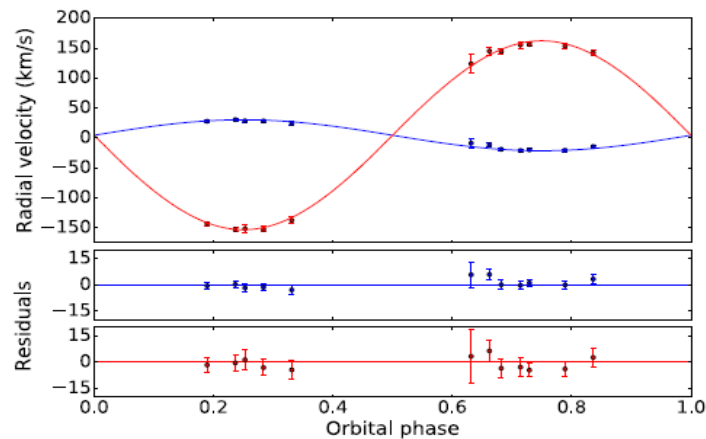
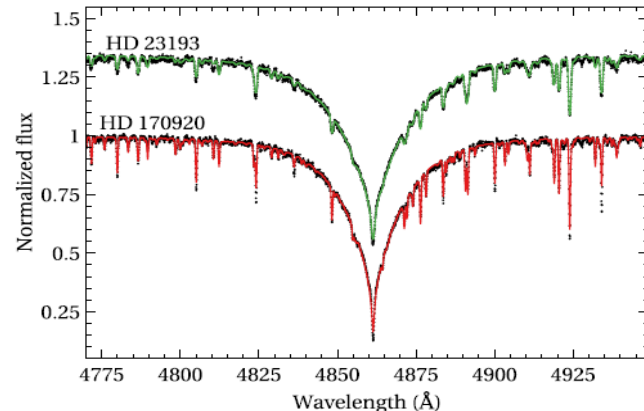
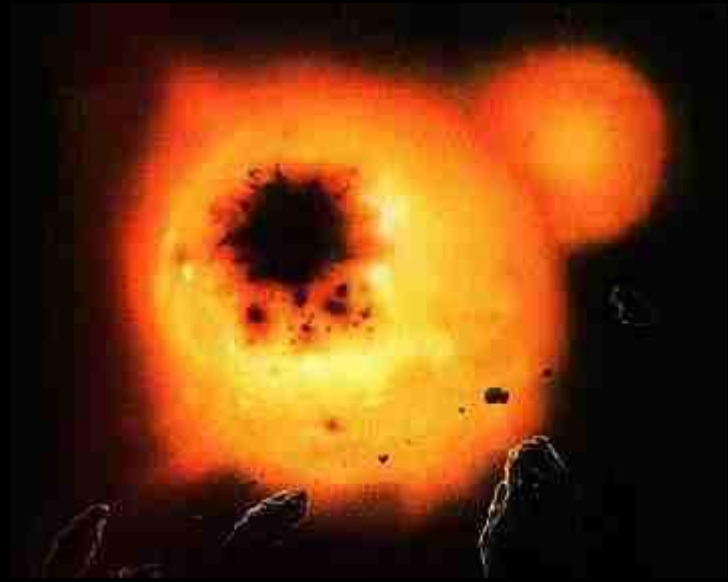


Fig. 2 Surface images of EK Dra at different phases



# Why ER Vul ?



Credit: Martin Tsarev  
(<http://www.sv-cam.smolyan.info/rscvn.html>)

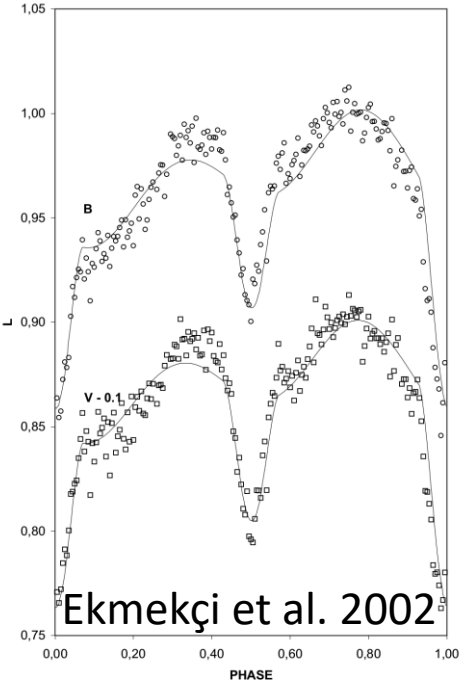
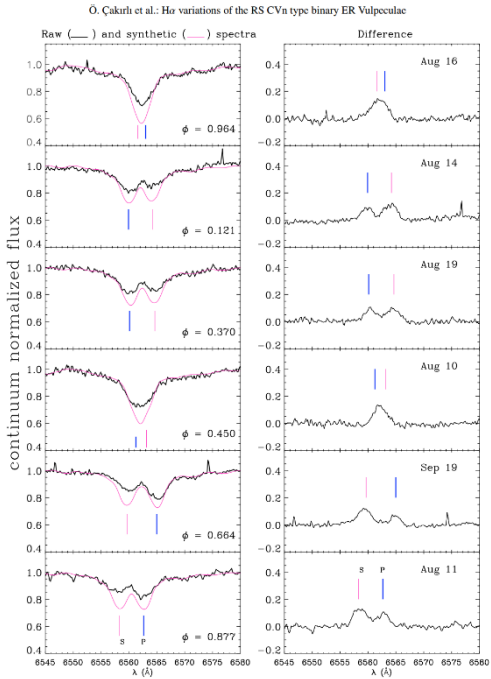
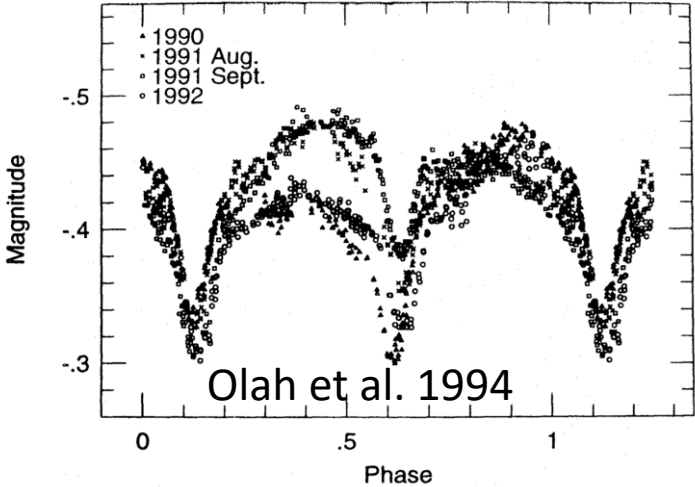
- Convenient for our setup (brightness) and is known to be magnetically active.
- Sun-like stars, G0V primary and G5V secondary
- Short-period ( $\sim 0.7^d$ ) RS CVn-type binary system.
- Primary star nearly fills its Roche lobe, but the binary system is still detached (Duemmler et al. 2003) .
- ER Vul is identified as a pre-contact binary system (Dryomova, Perevozkina & Svechnikov 2005)



# Some Light Curves of ER Vul

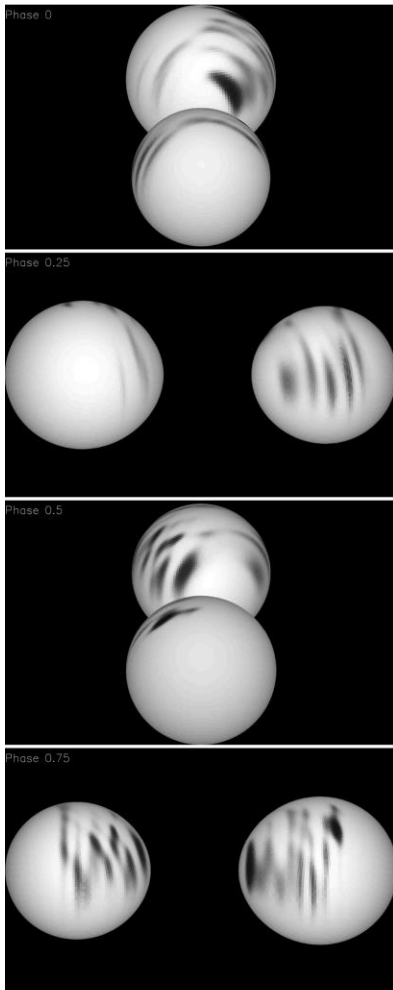
ER Vul V 1990-91-92

- Hall (1976) → RS CVn type
- Olah et al. (1994), Ekmekçi, et al. (2002) and Wilson & Raichur (2011) → Light curve
- Çakırlı et al. (2003) → the secondary star is more active than the primary one.

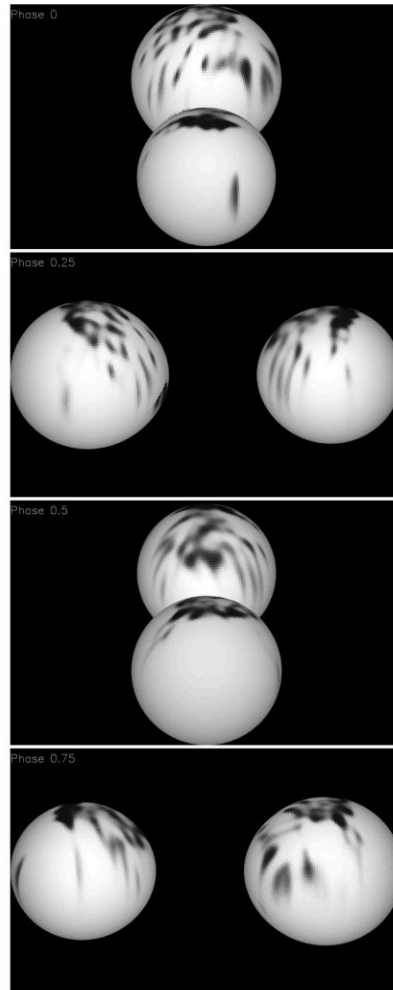


Piskunov → 1996, 2001 and 2008 and performed Doppler imaging

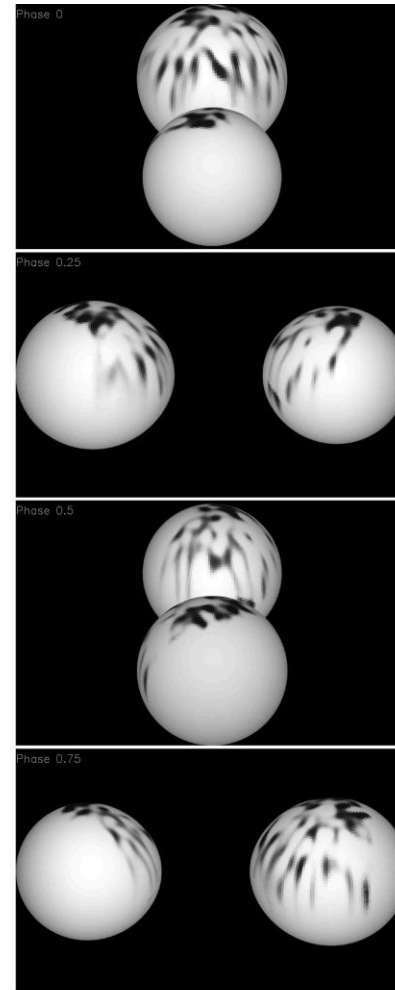
Xiang 2015 → the most recent Doppler imaging



(a)



(b)



(c)

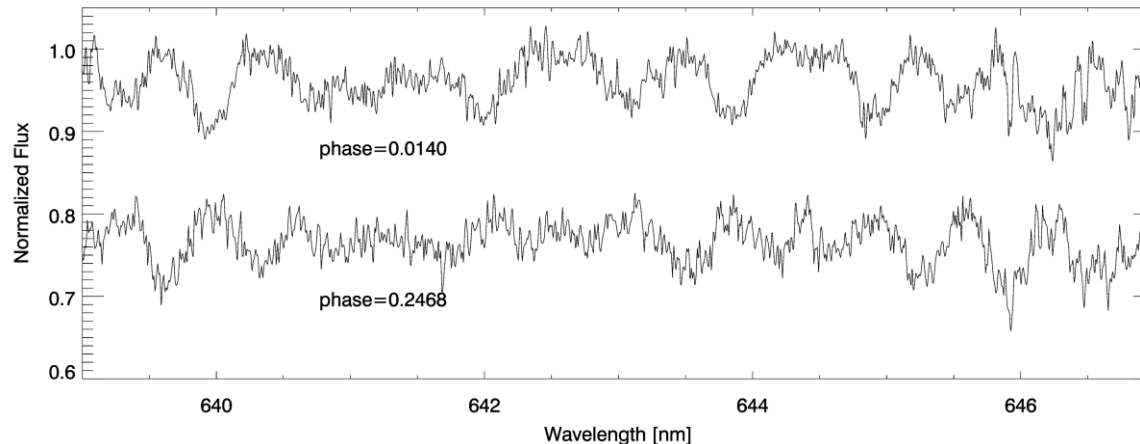
# Observations

**Table 1.** Log of spectroscopic observations.

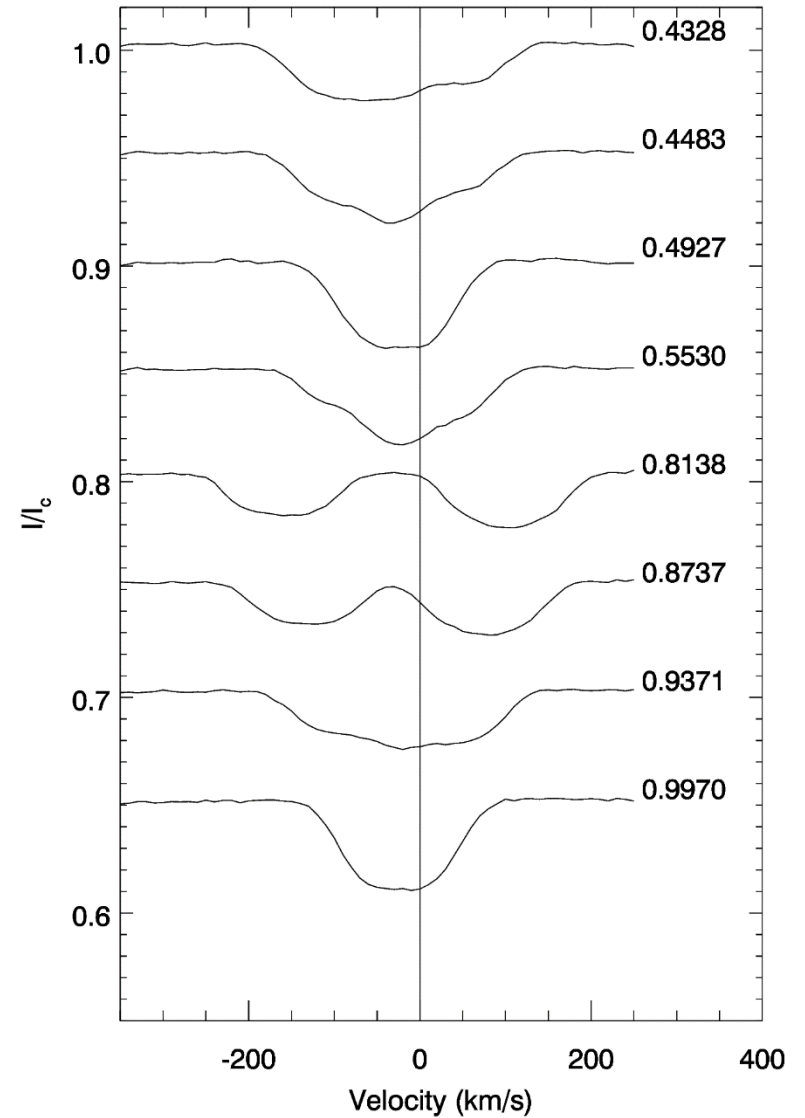
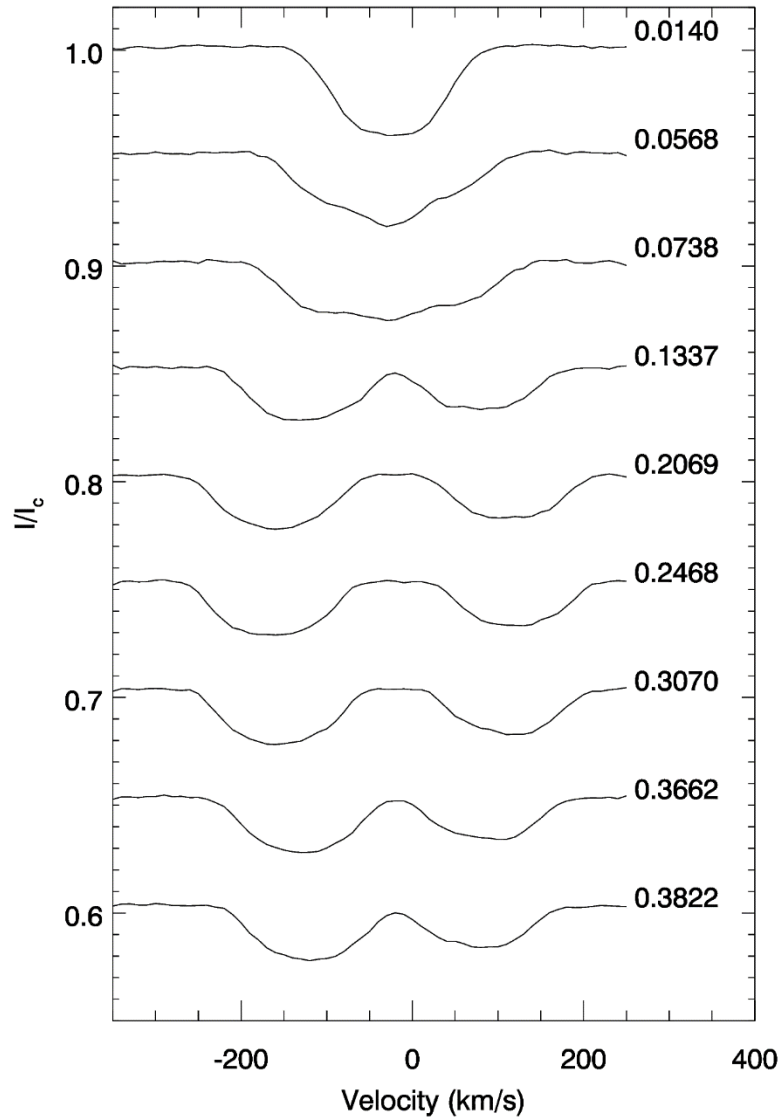
| Date     | HJD-2400000<br>Mid Time | Phase  | SNR Input | SNR LSD |
|----------|-------------------------|--------|-----------|---------|
| 01/07/18 | 58301.3235              | 0.0140 | 77.78     | 1588    |
| 01/07/18 | 58301.3653              | 0.0738 | 71.22     | 1641    |
| 01/07/18 | 58301.4071              | 0.1337 | 58.76     | 1532    |
| 01/07/18 | 58301.4582              | 0.2069 | 94.86     | 1922    |
| 04/07/18 | 58304.3618              | 0.3662 | 84.55     | 1857    |
| 04/07/18 | 58304.4083              | 0.4328 | 80.16     | 1766    |
| 04/07/18 | 58304.4501              | 0.4927 | 75.07     | 1603    |
| 04/07/18 | 58304.4922              | 0.5530 | 67.67     | 1610    |
| 06/07/18 | 58306.3727              | 0.2468 | 77.72     | 1756    |
| 06/07/18 | 58306.4147              | 0.3070 | 99.14     | 1781    |
| 06/07/18 | 58306.4672              | 0.3822 | 77.06     | 1806    |
| 06/07/18 | 58306.5134              | 0.4483 | 62.39     | 1686    |
| 17/07/18 | 58317.3260              | 0.9371 | 85.31     | 1732    |
| 17/07/18 | 58317.3678              | 0.9970 | 65.51     | 1549    |
| 17/07/18 | 58317.4096              | 0.0568 | 58.35     | 1508    |
| 19/07/18 | 58319.3342              | 0.8138 | 86.46     | 1834    |
| 19/07/18 | 58319.3760              | 0.8737 | 81.13     | 1771    |

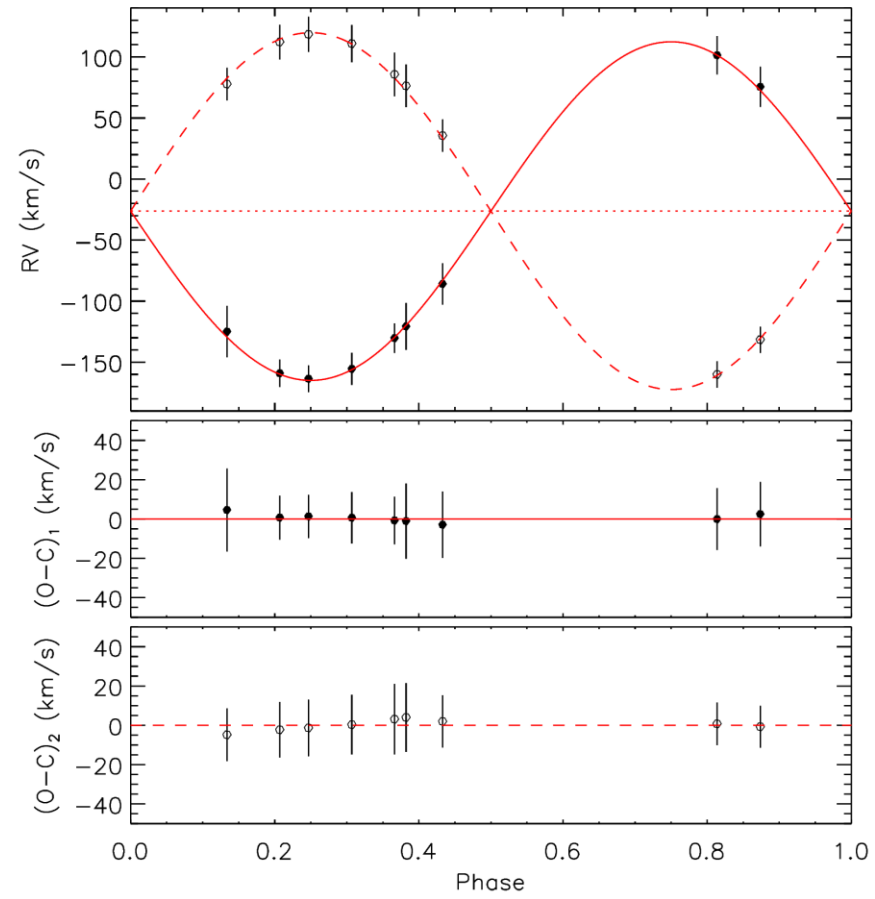
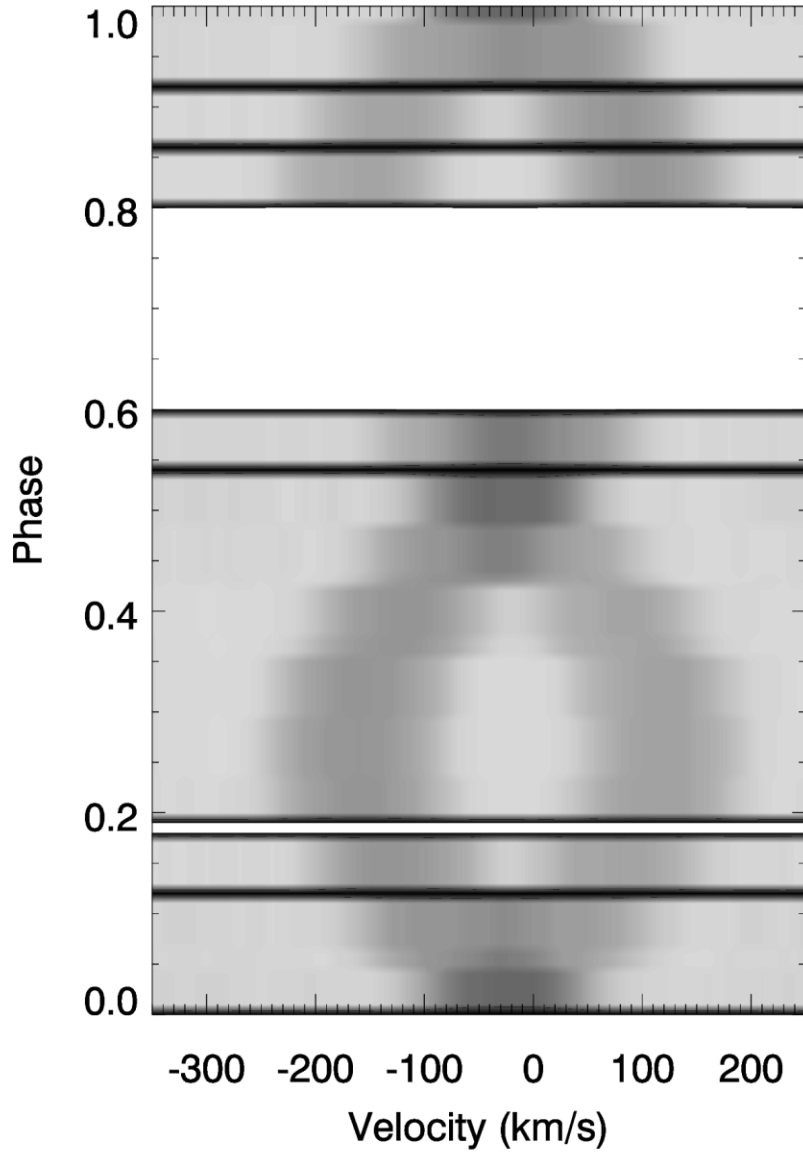
Because the two-temperature model is used in our image reconstruction, we also observed several inactive slowly rotating template stars by using the same instrument setup.

- Primary photosphere temp (6000 K) ==> HD 143761
- Secondary photosphere temp (5750 K) ==> HD 139777
- Spot temp (5000 K) ==> HD 32147



- In order to increase the S/N of the observed spectra, we used the Least - Squares Deconvolution technique (LSD; Donati et al. 1997)
- This technique to combine all available photospheric lines in each spectrum.
- The line list for ER Vul and standard stars were obtained from Vienna Atomic Line Database (VALD; Kupka et al. 1999).



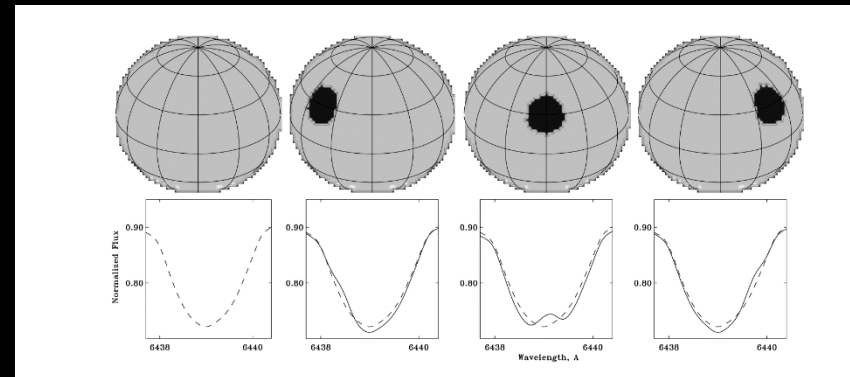
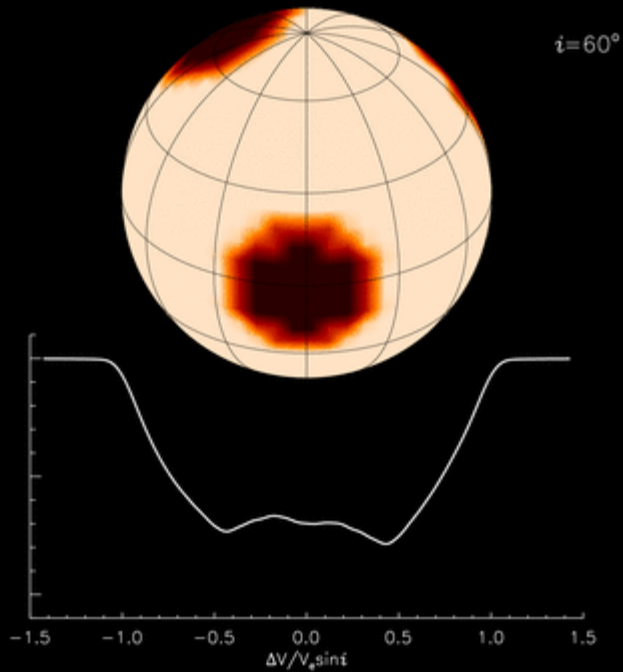


**Table 2.** Some parameters of ER Vul.

| Parameter                    | Value             | Reference <sup>1</sup> |
|------------------------------|-------------------|------------------------|
| $q = M_2/M_1$                | $0.949 \pm 0.056$ | This Study             |
| $K_1(\text{km/s})$           | $138.67 \pm 6.18$ | This Study             |
| $K_2(\text{km/s})$           | $146.13 \pm 8.70$ | This Study             |
| $i$ [°]                      | 66.63             | a                      |
| $V_\gamma$ [km/s]            | $-26.26 \pm 3.72$ | This Study             |
| $T_0(\text{HJD})$            | 2445220.40964     | This Study             |
| $P(\text{d})$                | 0.698095          | This Study             |
| $T_{\text{eff},1}(\text{K})$ | 6000              | a                      |
| $T_{\text{eff},2}(\text{K})$ | 5750              | a                      |

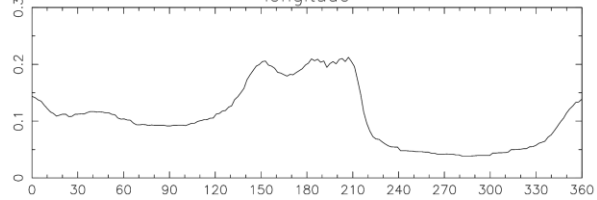
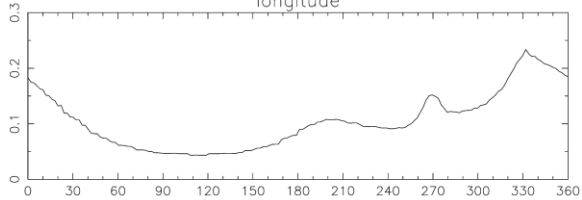
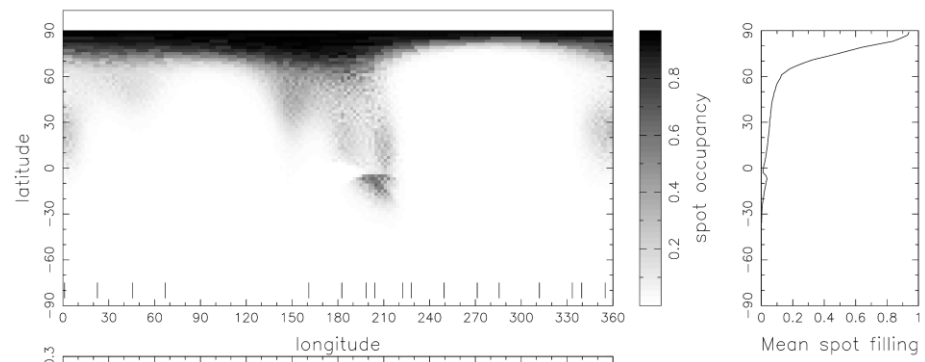
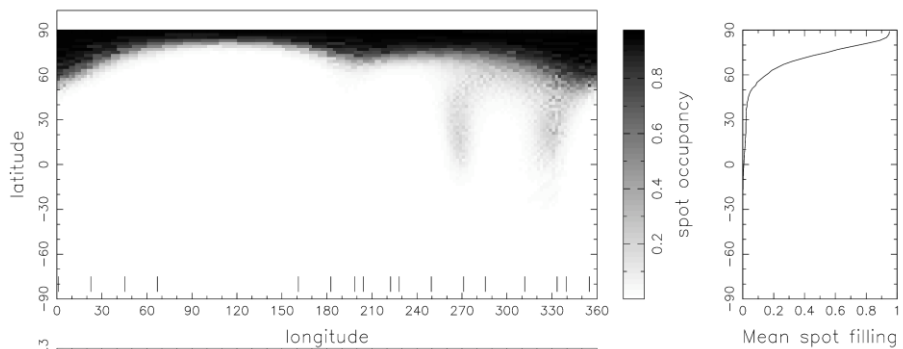
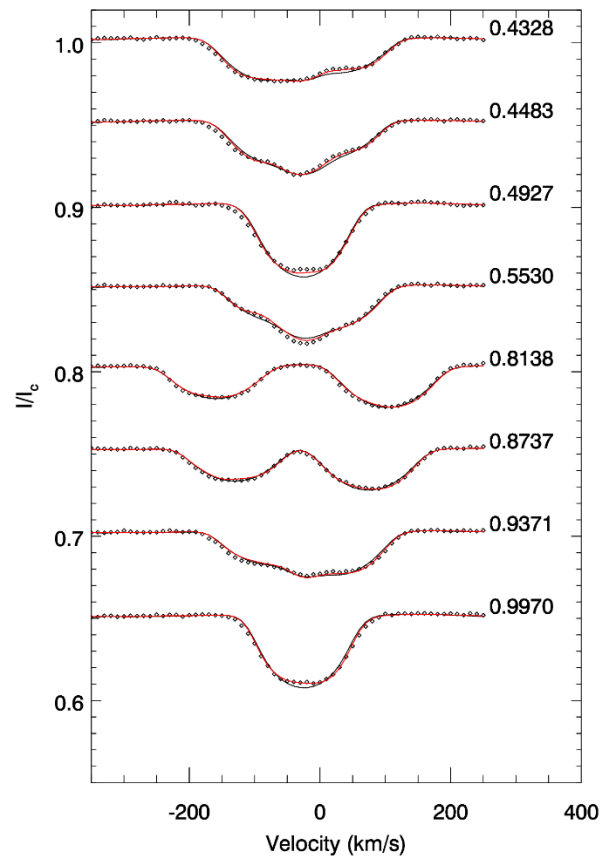
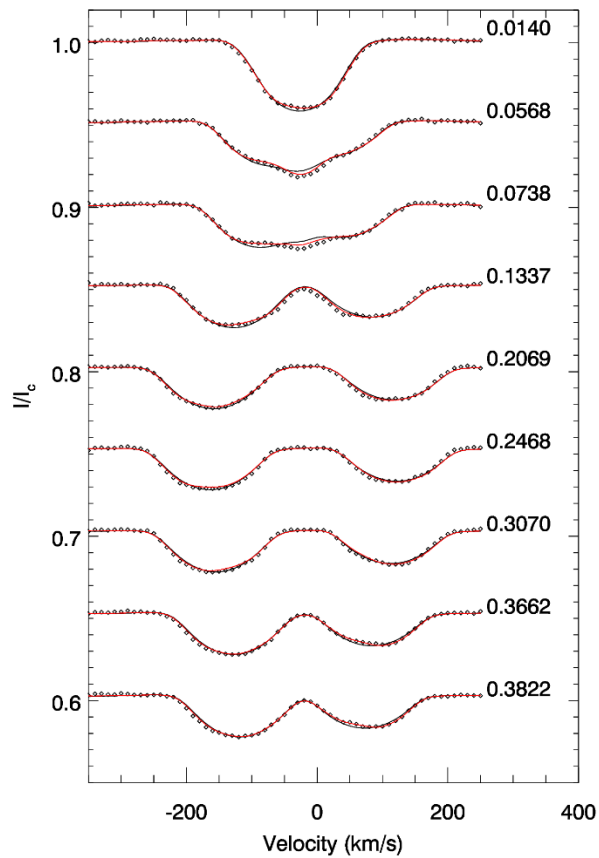
Reference: a. Harmanec et al. (2004).

# Doppler Imaging



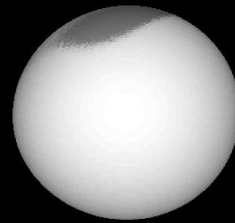
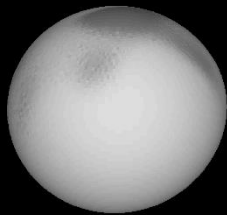
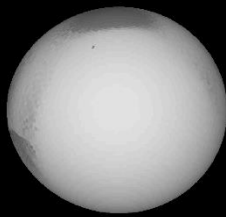
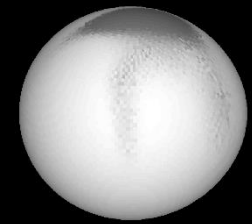
Berdyugina 2005

[http://www.astro.uu.se/~oleg/di\\_scheme\\_a.html](http://www.astro.uu.se/~oleg/di_scheme_a.html)



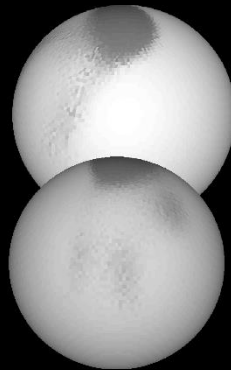
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Phase 0.8138

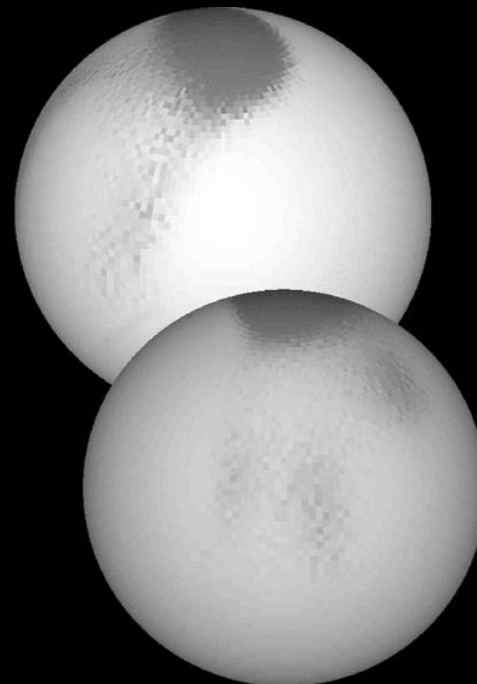


Phase 0.4927

Phase 0.997



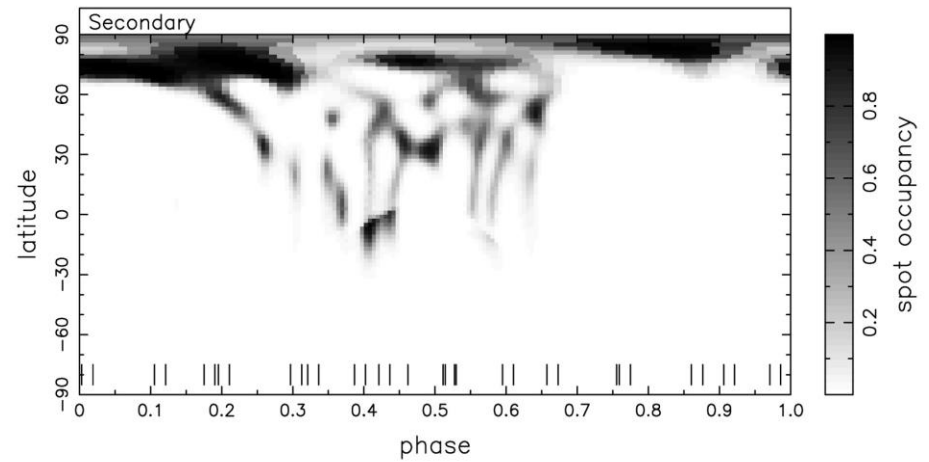
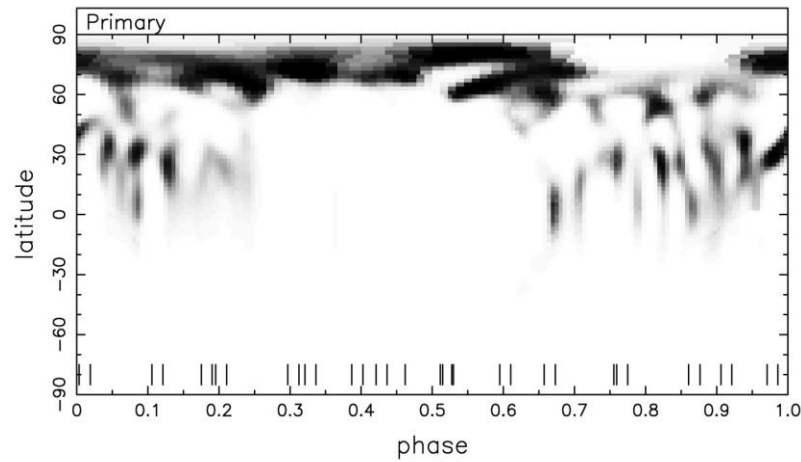
Phase 0.014



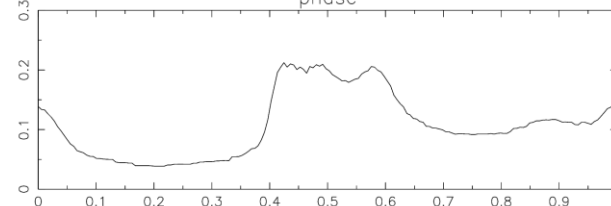
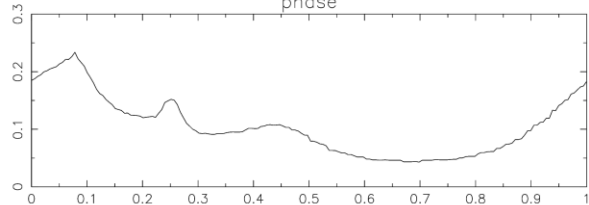
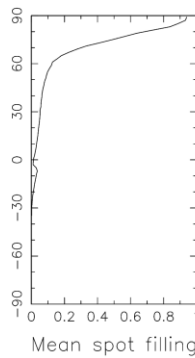
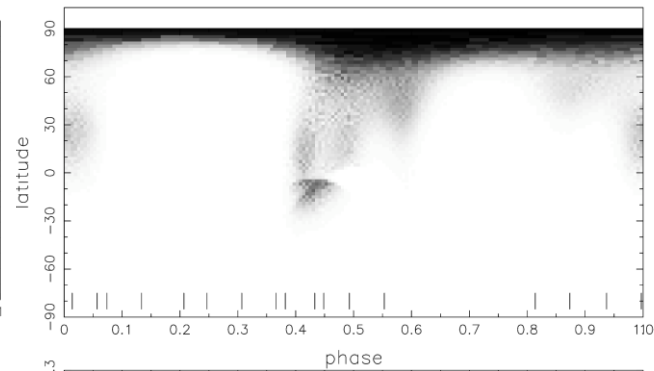
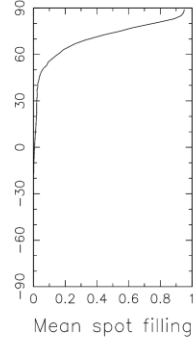
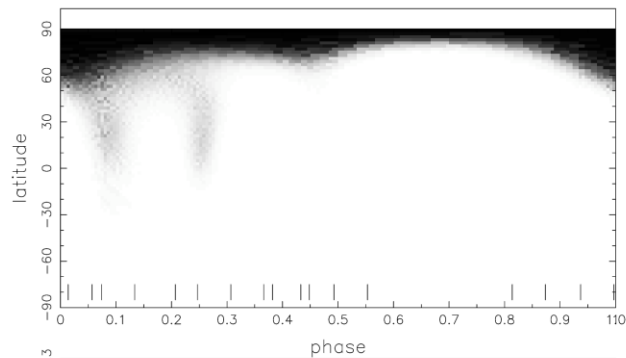


# Comparison with latest surface maps from literature

Xiang et al. 2015

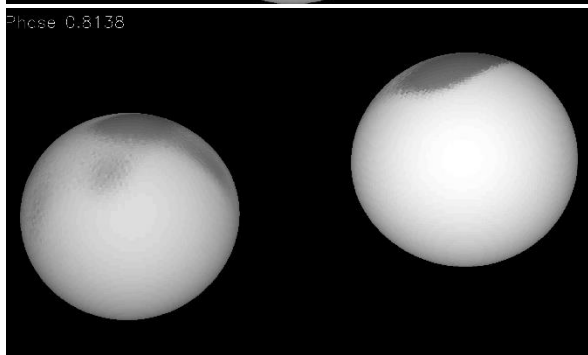
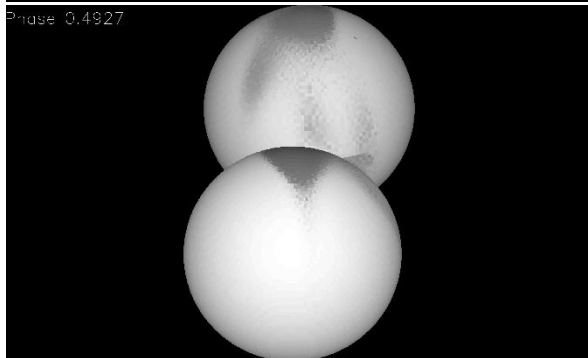
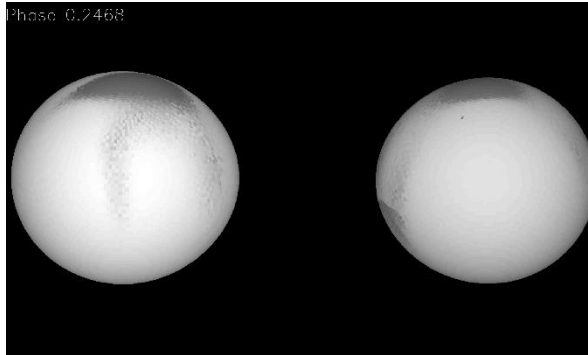
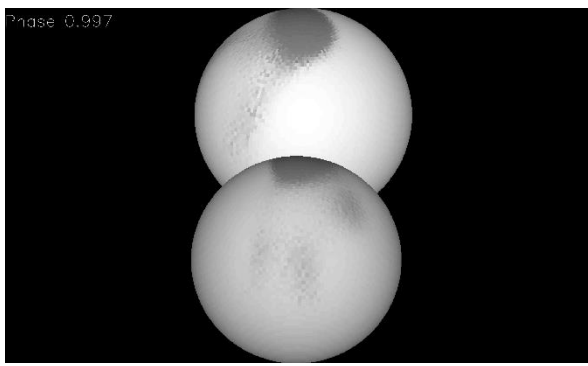


(a)

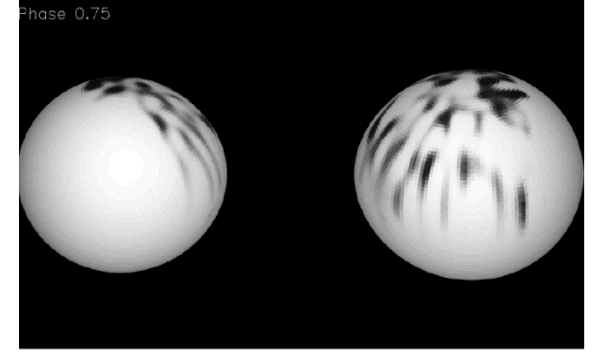
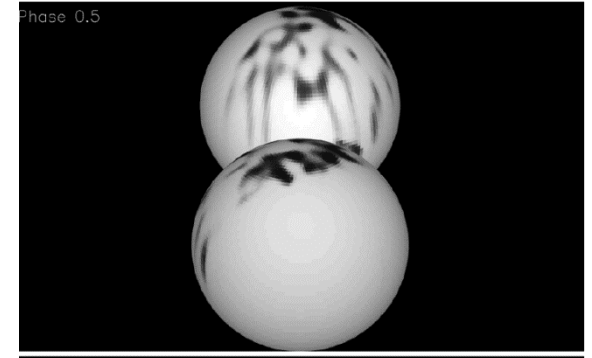
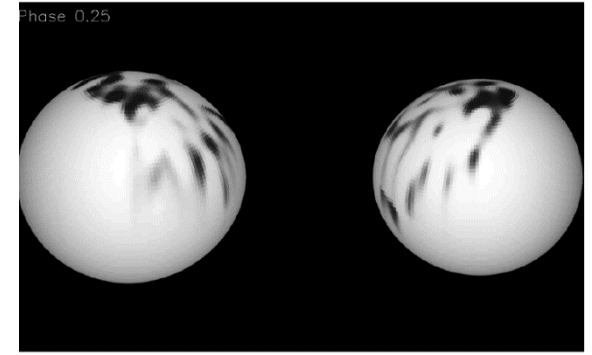
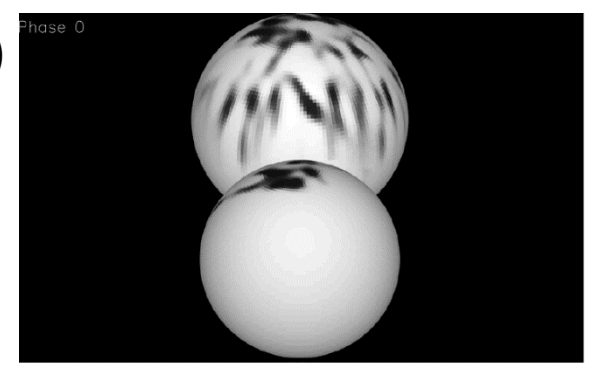


This study

This Study



Xiang et al. (2015)



Thank you very much for your patience...



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