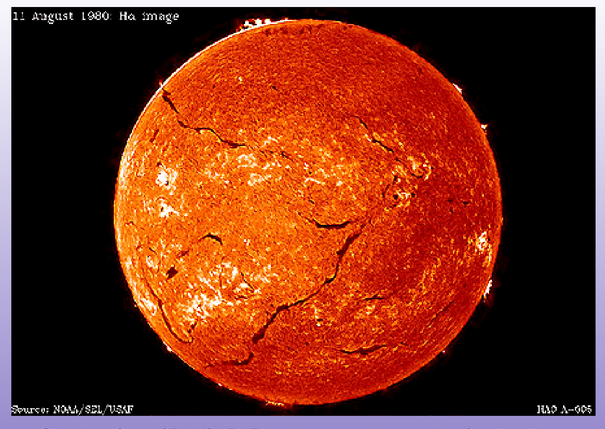

Credit: NOAA/SEL/USAF *"The chromosphere of the Sun (Ha)"*

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

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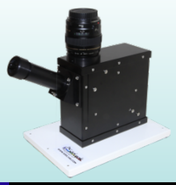
SUMMARY. We investigate the chromospheric and spot activity behaviour of the young Solar-like star EK Dra via Doppler imaging and spectral synthesis methods, using mid-resolution time series spectra of the system. We also present the atmospheric parameters and elemental photospheric abundances of the star. The chemical abundance pattern of EK Dra suggests the atmosphere of the star is enriched by Barium. The Titanium Oxide (TiO) bandheads at 7000 - 7100 A region also give clues about the spot temperature 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.



Observations

EK Dra was observed using the Shelyak eShel spectrograph mounted at 40 cm telescope in Ankara University Kreiken Observatory in 2017. 13 spectra were obtained with about 0.1 phase steps to cover overall phase of the star for Doppler Imaging. The spectra cover 4340-7800 Å wavelength interval with a with a medium resolving power, i.e., R~12000.

EK Dra: A Young Solar Analogue

- The first Doppler Imaging of EK Dra were performed by Strassmeier & Rice (1998) who used a spectra with R=120 000. They found that the preferred latitudes of the dark (spotted) regions are +40° and ~+70-90° (for the data taken in March 1995), and noted a large cool feature at 45°.
- Fröhlich et al. (2002) investigated the long term photometric variations of the star using Sonneberg Sky-Patrol plates and detected a smooth decrease in the blue brightness (B_T) of the star indicating a "superactivity".
- Jarvinen et al. (2005) 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 45 years and and with an additional period of 10.5 year.
- König et al. (2005) derived the mass of 0.9 $M_\odot$ for the primary component of the system and found 2.767 ± 0.005 days periodic variation 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 ~500 K cooler than the photosphere and moving in latitude in time.
- Ayres & France (2010) captured several very broad profiles of highly ionized C, Si, and Fe, indicating highly dynamic subcoronal plasma as well as accreting Si IV bearing gas onto 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 $M_\odot$
vsini = 16.4 km s^{-1}
***i* = 60°**
(Waite et al. 2017)
T_{eff} = 5750 K
Log*g* = 4.40

Methods

We used the Least Squares Deconvolution (LSD) technique (see Donati et al. 1997 for details) in order to enhance the SNR of EK Dra data. The linelist required by the LSD is obtained from the Vienna Atomic Line database – VALD (Kupka et al. 1999), by considering the surface gravity as well as the effective temperature of EK Dra. The SNR of the input spectra vary between 78 and 307, while the resultant LSD profiles have SNR values between 704 and 1146. During the LSD process, we set the increment per pixel to 8.0 km/s, depending on the resolution of our spectral data. The LSD profiles of the template stars that represent the photospheric (HD217813 – G1V) and spot (HD16160 – K3V) temperatures of EK Dra were also obtained in the same manner. The surface map of EK Dra was obtained using the Doppler imaging code DoTS (Collier-Cameron 1997), which reconstruct the distribution of spots by means of spot filling factor (f_s), based on two – temperature model and Maximum Entropy Method (MEM). The system parameters (vsini, mass, inclination) used during Doppler imaging were taken from Waite et al. (2017). The resultant surface map of EK Dra in mercator 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 1979), assuming a plane parallel geometry, a gas in hydrostatic and radiative equilibrium and LTE. Synthetic spectra were computed using SYNSPEC48 (Hubeny & Lanz 1992). The linelist was first constructed from Kurucz's gfall.dat, and then updated by using VALD, NIST and recent publications. Hyperfine structure was taken into account. The initial atmospheric parameters are derived from Strömgren and Johnson photometric data of the star: T_{eff} = 5750 K and log *g* = 4.40. The microturbulent velocity was derived by minimizing the scatter in (Fe/H) computed 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 minimisation procedure.

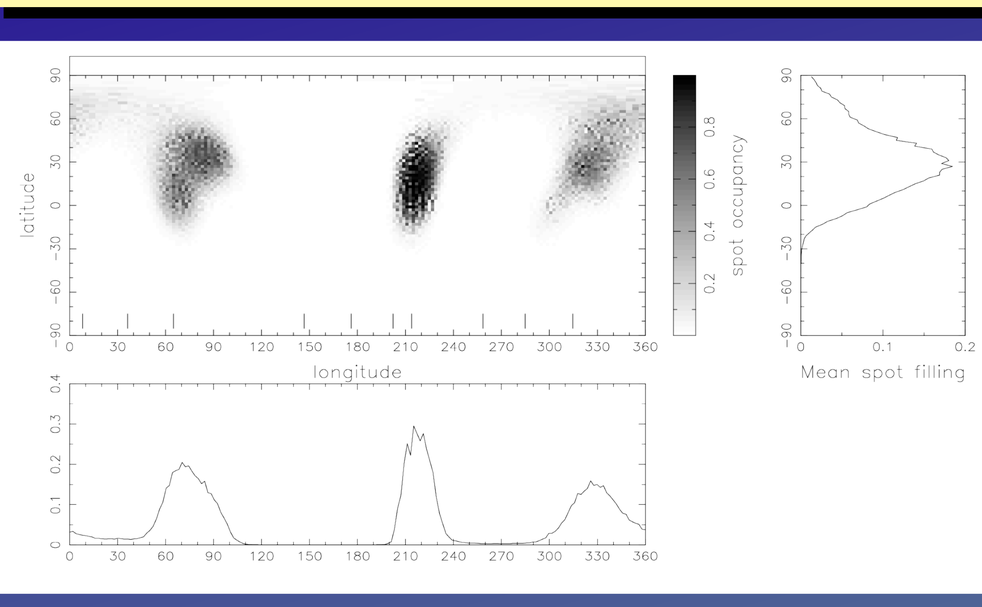


Fig. 1 Surface Map of EK Dra with latitudinal and longitudinal f_s distributions

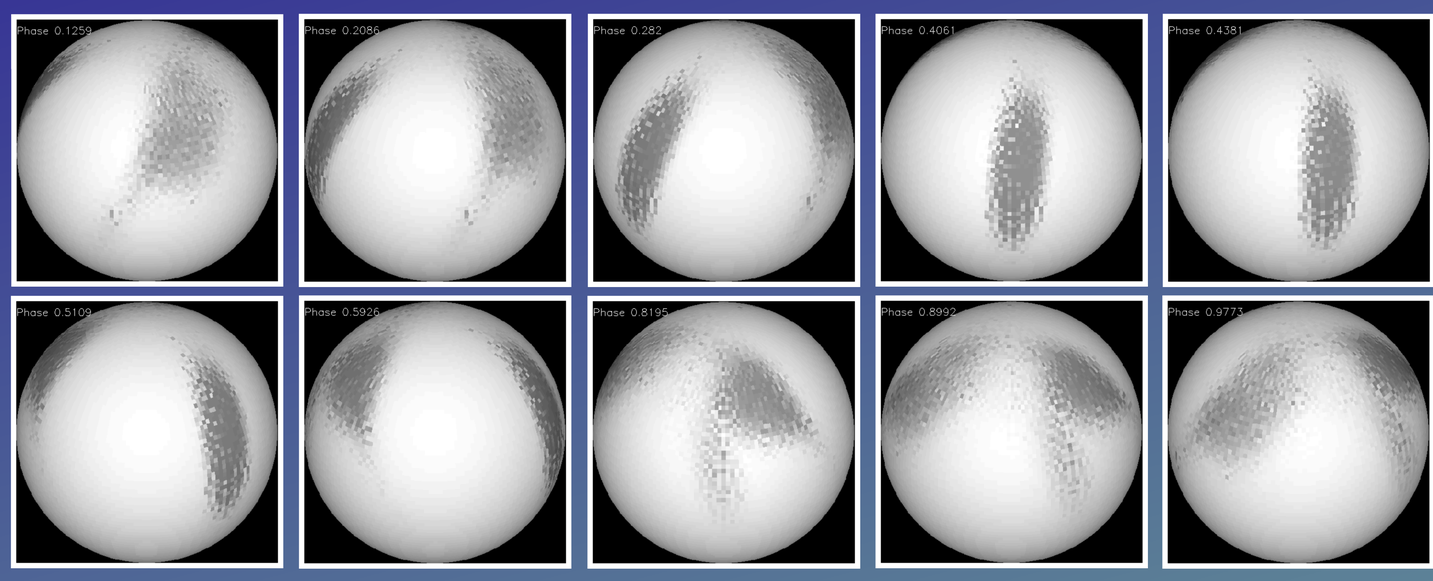


Fig. 2 Surface images of EK Dra at different phases

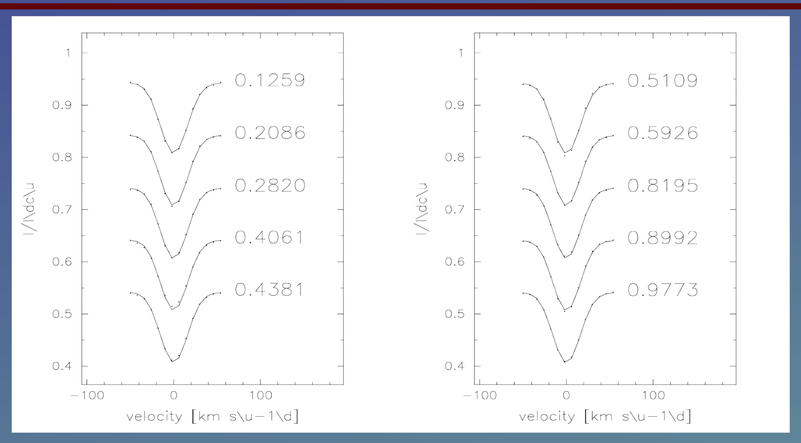


Fig. 3 Time series LSD profiles of EK Dra

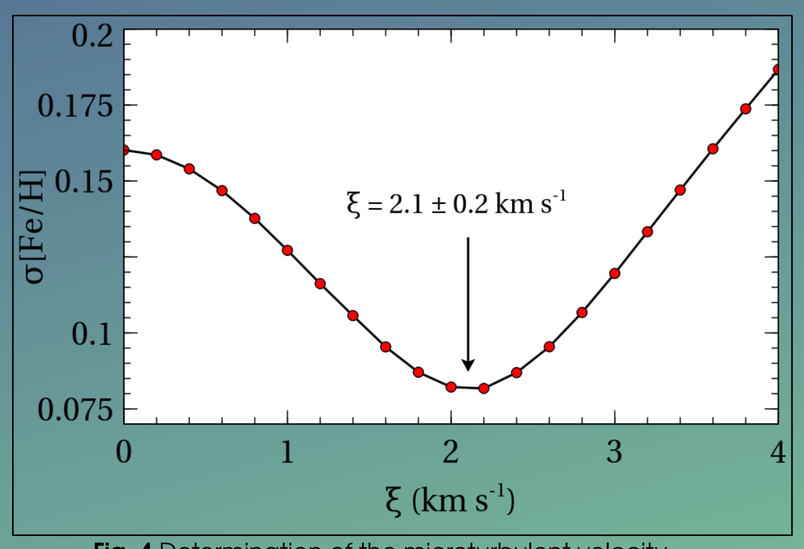


Fig. 4 Determination of the microturbulent velocity

Results and Discussion

- Our surface maps of EK Dra show three dark cool regions at **intermediate-high latitudes.**
- Figs. 1 & 2 emphasise how much bigger these spots are compared to sunspots (diameters < 1°).
- Strong absorption in **TiO bandhead** at 7000-7150A indicates **T_{spot}< 4000K.**

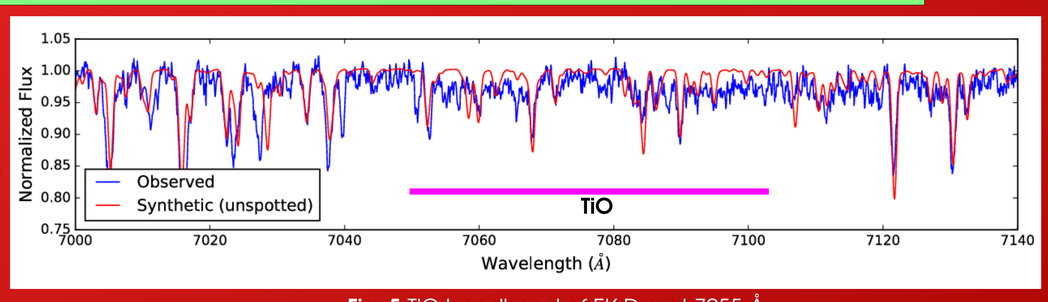


Fig. 5 TiO bandhead of EK Dra at 7055 Å

- 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 indicates that EK Dra may be a **Barium dwarf.** However, one needs to consider the isotropic structure of Ba and the effects of the magnetic field to clarify/reject this classification.
- As EK Dra is G-type convective mixing dominates and surface composition should reflect the stellar properties at 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 Sr overabundance.

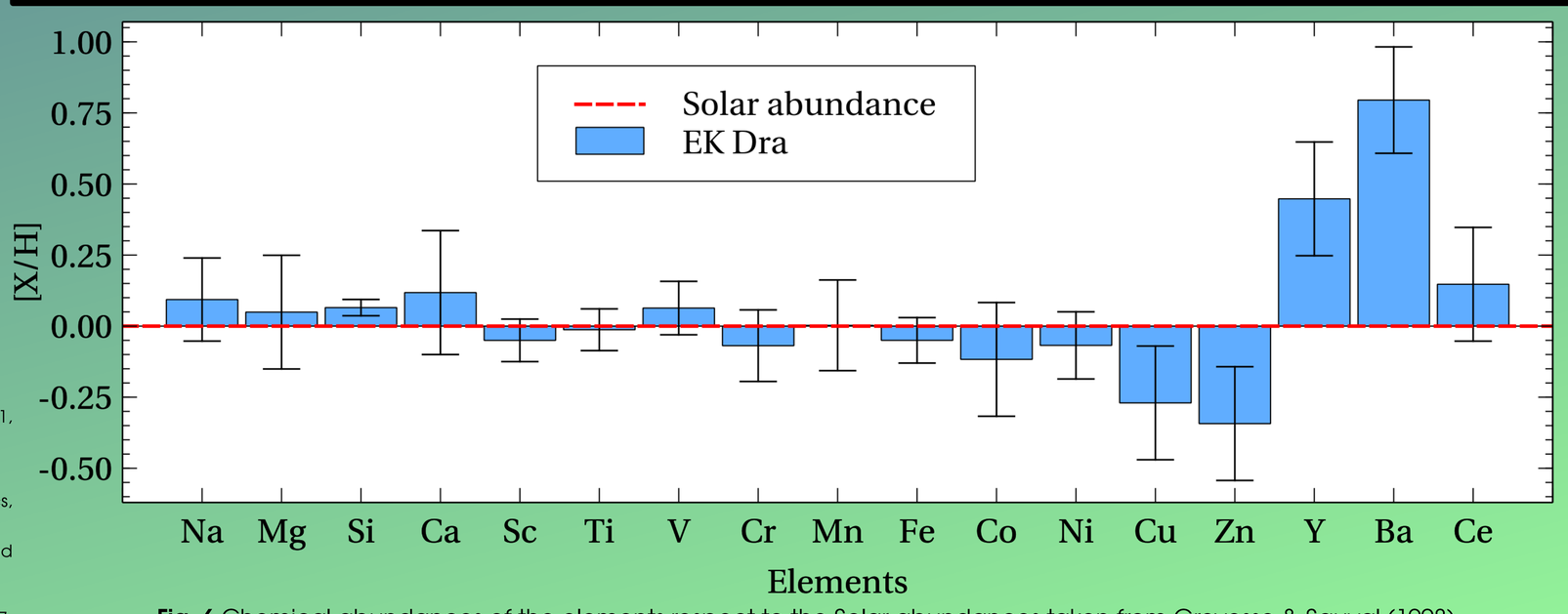


Fig. 6 Chemical abundances of the elements respect to the Solar abundances taken from Grevesse & Sauval (1998)

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