Studying active stars on different timescales

Theses

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1. Background

Stellar activity originates from strong magnetic fields, which are created and maintained by dynamo mechanisms. The exact working of these dynamos is not completely understood even today. It is well known, however, that differential rotation and meridional flows play key roles. The strength of the magnetic field depends strongly on the rotation rate of the stars: those with faster rotation are known to produce stronger magnetic fields, thus showing many signs of activity (star spots, flares). Beside the rotation rate, the stellar structure also has an important impact on the properties of magnetic fields. Solar-like stars possess a radiative core and a convective envelope. The transition region between these, known as the tachocline, is supposed to play an important role in the generation of the magnetic field. Stars less massive than $\sim 0.35\mathfrak{M}_\odot$ are probably fully convective, the magnetic fields in these stars are thought to be maintained by a distributive dynamo. Tracking the activity signatures can help to reveal the nature of the dynamos. By continuous monitoring evolution of the stellar surface – birth and decay of spots, even activity cycles – can be observed. Eclipsing binaries have a particular significance: by analysing their light curves, the parameters of the system and its components (e.g. masses, radii) can be exactly determined, which is not possible in the case of single stars.

The main topic of my dissertation is the study of ultrafast-rotating M-dwarfs: EY Draconis, V374 Pegasi, and V405 Andromedæ. M-dwarfs despite being faint, represent about two third of the stars of the Galaxy, and contribute about 20% to its total mass. The dwarf stars studied have a rotation rate of $\sim$ 0.5 days, so they are very active. Changes happen on a short (daily, i.e., rotational) time scale, making them ideal targets of observations. As their signs of activity is similar to that observed on the Sun, by studying these active stars we could get nearer to understanding the behaviour of the Sun.

Beside the M-dwarfs, we have analysed two active giant stars: UZ Libræ, and σ Geminorum. The aim of this work was to investigate the surface flows (differential rotation and meridional flows) of the objects.

2. Methods

Most of the results is based on photometry obtained by instruments of the Konkoly Observatory, Hungary – the 60cm telescope at Svábhegy, and the 1m telescope at Piszkéstető. I participated in the observations of EY Draconis and V405 Andromedæ at the 60cm telescope at Svábhegy. Beginning with 2007 I started an independent programme at the Piszkéstető Mountain Station of the Konkoly Observatory with the aim of studying active stars. Using these instruments we managed to collect long-term time series with a good coverage. Reduction of the CCD frames and photometry was done using standard IRAF packages. In most cases I used aperture photometry, except TYC 2627-638-1, where the two close components of the system could be separated only by PSF photometry.

For modelling the light curves I used SpotModel. This software can fit the light curves using maximum three circular spots with the same temperature, making possible to determine the spot positions and sizes. Using this method, the spot longitudes can be recovered relatively well, but the light curves have only very limited information on spot latitudes. In the case of the RS CVn-type V405 Andromedæ I used an iterative method to find the light curve solution: the effects of binarity and spottedness were treated separately. The effects of binarity were modelled by PHOEBE (PHysics Of Eclipsing BinariEs), a software based on the Wilson–Devinney code that can handle our four-colour photometry and the radial velocity data together.

Photometric mapping techniques can be used with Hungarian instruments, and long time series can be easily obtained. However, these methods have some disadvantages. By current photometric accuracy spot latitudes cannot be determined. Spot modelling can give better fits if multiple spots are used in the model with the cost of non-unique solutions due to the higher number of free parameters. Better and more stable results can be achieved using Doppler-imaging, based on spectroscopic measurements. Doppler-imaging is based on the fact that star spots, being cooler than the surrounding photosphere appear in a spectral line as small emission bumps. From the position and intensity of this bump the size, position, and temperature of the spot can be determined. From the spectra of UZ Libræ and σ Geminorum, we created time-series of Doppler-maps using the TEMPMAP code. By cross-correlating these maps it is possible to determine the position changes of the spots. These cross-correlation maps can be used to measure differential rotation of the stellar surface.

Beside photometric measurements, we performed spectroscopy of EY Draconis and V374 Pegasi during the *NEON Observing School* at the Nordic Optical Telescope and the Isaac Newton Telescope (La Palma, Spain). Later, I reduced these data. Using these medium resolution Hα spectra possible changes in the stellar chromospheres can be detected.

3. Theses

1. Between 2005 and 2008 we obtained photometric measurements of EY Draconis and I reduced the data. Using Fourier-analysis of the dataset, I have determined the rotational period, and the presence of an activity cycle with a length of ~ 350 days. This cycle, similar to the 11-year long solar cycle, is the shortest one found for an active star. Spot modelling revealed two active regions, whose temperature is about 500K cooler than the surrounding photosphere. During the observations the longitude of these spots change only slightly, but their dominance switches suggesting a flip-flop mechanism, which can give indications on the properties of the stellar dynamo.

   Besides photometry, during the *NEON Observing School* we have obtained Hα spectra of the object with good phase coverage. The equivalent width of the line and the light curve show an anticorrelation, indicating solar-like activity. According to the colour index changes the active regions are spot-dominated. [1, 2, 6, 7]

2. We obtained photometric measurements of the RS CVn-type V405 Andromedæ at the 60cm telescope at Svábhegy, I made further observations using the RCC telescope at Piszkéstető and reduced these data. I have determined the light curve solution using an iterative method, in which the effects of spottedness and binarity are handled separately. I have determined the physical properties of the system. The fully convective secondary component seems to fit well the theoretical mass–radius relation, but the radius of the primary consisting of a radiative core and a convective envelope is significantly larger than the theoretical value. This result further confirms the dependence of stellar structure on magnetic fields.

   Besides photometry, I have downloaded spectral data from the ELODIE database (Haute-Provence, France). According to the Hα spectra, both components are active. The changes of the Hα line indicate plage-regions in the chromosphere. Two flares have been found in the spectroscopic data, and one in the photometric data, I presented the analyses of these events. In the photometric data I have found a brightening which lasted for days, which was probably caused by an eruption on a coronal loop. [4, 5]

3. In 2008, I started a campaign to observe V374 Pegasi with the 1m RCC telescope at Piszkéstető Mountain Station, and reduced the photometric data. Using Fourier-analysis I have determined the exact rotational period of the star. During the observations two major active regions are found on the surface separated by 140–160° in longitude. The spot structure does not change significantly during one season of measurements, in good agreement with previous observations reporting a stable, dipole-like magnetic field, which contradicts the predictions of current dynamo theories. In the same time, the star shows small variations on a nightly (thus rotational) time scale, which is probably similar to the birth and decay of spots in solar active nests. Large amount of flares are detected on the object, many of them are found around one of the active regions which could indicate a connection between the flares and the spot. The object shows flaring and quiet periods changing on a monthly time scale. [9]

4. I studied the surface flows of UZ Libræ. I found a weak, anti-solar differential rotation on the star. This result was confirmed by two independent methods: ACCORD (Average Cross-correlation of Contiguous Doppler-images) and LCT (local correlation tracking). We have not found clear signs of meridional flows. For the analysis we used the ACCORD-code, which can detect differential rotation and meridional flows on stellar surfaces using cross-correlation of time series of Doppler-maps. [3]

5. I participated in the observations of TYC 2627-638-1 at the 60cm telescope at Svábhegy, later I obtained further four-colour photometry with the 1m RCC telescope at Piszkéstető. I carried out PSF-photometry of the data from Piszkéstető, and later from the Nordic Optical Telescope (La Palma, Spain), which made possible to study the two components separately. Both components are active stars:

component A shows two close periods (3.5 and 3.7 days), which is probably caused by differentially rotating two spots on the stellar surface. Our observations proved, that this component has a substellar companion with mass $\leq 5\mathfrak{M}_{\mathrm{Jupiter}}$. The brightness of the B component shows a period of ~ 60 days, which is probably caused by a circumstellar dust disk. [8]

4. Publications related to the theses

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2. Vida, K.:
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3. Vida, K., Kővári, Zs., Švanda, M., Oláh, K., Strassmeier, K. G., Bartus, J.:
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5. Other publications related to the topic of the dissertation

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