

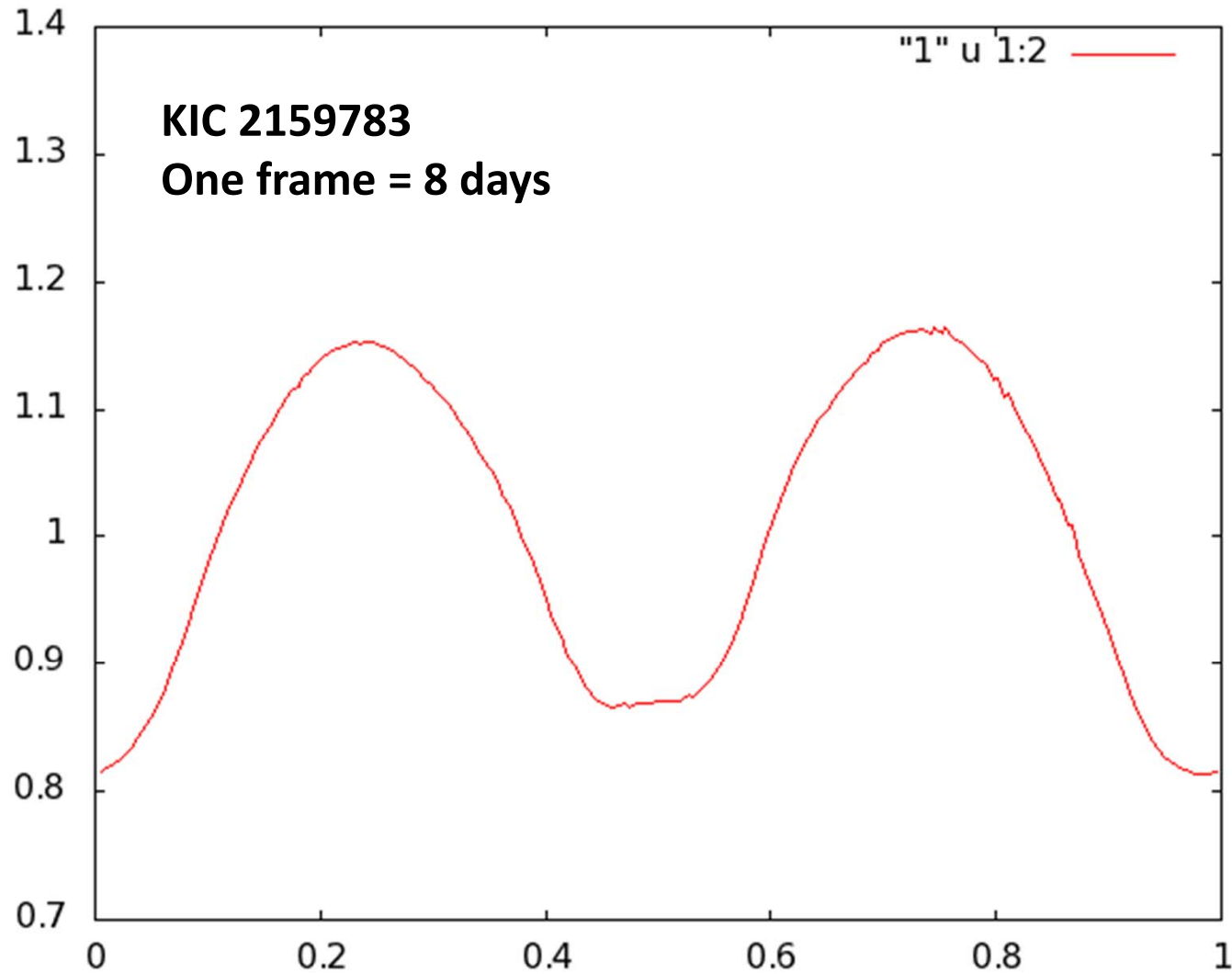
Starspots on an extremely close binaries: Spectroscopy vs continuous photometry

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- ✓ Kepler Mission: about 500 `contact binaries`
- ✓ Light curves evolve intrinsically in a timescale of weeks, months
- ✓ The LC variations are caused by a changing photospheric activity
- ✓ Evolving starspots! Stationary and migrating starspots!

Light curve continuous evolution



single filter photometry

- Starspot existence
- Migration of starspots
- Evolution of a stationary spot
- Which component is more massive
- Timescale of magnetic activity
- Activity cycles!
- Constraints on starspot size, temperature, latitude

Ordinary modeling: days/weeks
LC Morphology analysis: **half an hour**
Need for **spectroscopic confirmation**
BEFORE the beginning of missions like WFIRST, PLATO, TESS...

Starspots on an extremely close binaries: spectroscopy vs continuous photometry



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Introduction

We developed a fast method of studying the evolution of stellar activity in close binaries. The Light Curve Morphology Analysis (LCMA) allowed us, inter alia, to determine the presence of a starspot migration in a systems, put constraints on spots size and latitude and trace the direction of such a migration. All this has been obtained analyzing one-color, continuous, long-time photometry provided by the Kepler mission. Some newest findings, presented here, need spectroscopic confirmation.

The Light Curve Morphology Analysis focuses on the evolution of light curve extrema over many orbital periods. For this work we used lightcurves stored in the Kepler Eclipsing Binaries Catalogue (KEBC). Kepler mission not only unveiled the power of a long-period photometry, but also provides data of unprecedented accuracy. Because of that it is possible to measure the fine changes in location (in flux heights/depths and position in phase) of brightness minima and maxima. One of the most interesting parameters is the distance between the brightness of primary and secondary maximum. Here the primary maximum is the one occurring after the primary minimum, while the primary minimum is normally chosen as the deeper one. Our findings in the maxima separation are shown below. Furthermore, LCMA focuses on the O'Connell effect, evolution of the brightness minima and correlations between some evolving parameters of the lightcurve. The observational data have been confronted with a series of simulations we performed using the modified Wilson-Devinney code. We invite the reader to meet our editions in following sections.

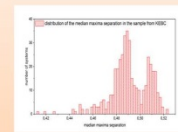


Figure 1: The histogram of median maxima separations in our sample taken directly from KEBC. The apparent bimodal distribution is caused by randomly attributed primary minima.

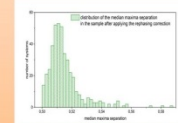


Figure 2: The histogram of median maxima separations after rephasing the binaries. Now primary minima are chosen in such a way that the median maxima separation is larger than 0.5 ph.

Median Maxima Separation (MMS)

Keywords: mass ratio, primary of components, brightness maxima

Brightness maxima in contact and near-contact binaries are shaped primarily by the mass and temperature ratios of a system components, the fill-out factor, limb darkening and gravitational brightening and stellar activity. All these factors influence not only the heights of the maxima, but also their position in phase, hence the separation between them. The net result is that the maxima separation is noticeably larger than 0.5 of orbital phase. The only factor that changes over time is the stellar activity, which manifest itself with starspots that evolve over timescale of months or years. Such a photospheric phenomenon can introduce large shifts in the position of the brightness maxima. On the other hand, such a large and troublesome starspots can live long enough to migrate longitudinally at least once over the stellar surface. In such a case the light curve deformation due to the starspot shall average itself over time and become a second-order effect. Knowing that we can expect that the long-term observations shall return a median maxima separation larger than 0.5 of orbital phase. That is, if we name the components of the system in a correct order.

The upper left histogram shows a distribution of the Median Maxima Separation in our sample of binaries from KEBC. The maxima separation were calculated using element provided in the same catalogue. The distribution of MMS's seems to be bimodal, with two sets of binaries distributed symmetrically in reference to 0.5 orbital phase. We propose that the cause behind the MMS's distribution lower than 0.5 lies in a wrong choice of a primary star in the systems, indeed, if we rephase given systems choosing the second component as now a primary one, the two distributions overlap with each other with a peak around 0.512. This 'corrected' histogram of our sample is depicted on the lower left hand.

Since the MMS larger than 0.5 seems to be always attributed to the binaries with a mass ratio lower than 1.0, we can use it for a proper 'naming' of the components. This leads to an interesting conclusions that we are able to find out when the more massive star is being eclipsed using only a quick analysis of relative positions of brightness maxima in a long run of continuous photometry. Such hypothesis needs to be tested by producing radial velocity curves of exemplary binaries.

In brief: choose the primary minimum, so that the median maxima separation would be higher than 0.5 of orbital phase.

Direction of the starspot migration

Keywords: minimum depth, minimum location

The direction of the migration can be traced by comparing the signals of changes in the secondary minimum location and depth. This dependence is easily visible in case of a flat-bottom minima, because the amplitude of minima shifts are large due to the geometry of the lightcurve. If a starspot is located on a primary star and migrates descending along the longitude, then the drop of secondary minimum depth follows its leaning towards later orbital phase. In the case of KIC 6118779 we found the exact manifestation of such a phenomenon. As seen on a diagram below, observational data strongly suggest that the direction of a starspots migration in KIC 6118779 is descending in the longitude (Debski, Zola, Baran 2014). This can be tested with an intense campaign of spectroscopic observations that will lead to a series of Doppler imaging solutions. The timescale of one migration cycle for this object is about 5 months.

In brief: the longitudinal migration of a starspot is traceable by comparing the evolution of the minimum depth and the changes in its location.

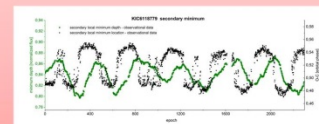


Figure 3: The evolution of the secondary minimum of KIC 6118779 (black dots) superimposed with the changes of its depth in a timespan of almost three years. If the minimum gets deeper during the ascension in phase location, it implies that a dark starspot migrates in the direction of the descending longitude.

Starspot migration

Keywords: O'Connell effect, maxima separation

A starspot that migrate in the stellar longitude will affect the height and position of the brightness maxima. During the one migration cycle (360° around the star) the maxima will be varying up and down one another. Thus the changes of the maxima heights will be negatively correlated (please see Figure 5). In the same time, the separation of the maxima will be highest when spot reach the back of the star and smallest for a spot sitting just between the stars. The separation, however, will evolve with a relatively small amplitude. The diagram of the O'Connell effect vs maxima separation (Figure 4) set with a similar scales on both axes shall display very flattened circle, resembling a horizontal line. In fact, we found that most objects in our sample manifest the signal attributable to the migrating starspot. It is possible to test those correlations performing simultaneously photometry (for LCMA) and spectroscopy (for Doppler imaging).

In brief: Changes in the O'Connell effect and the evolution of the maxima separation allows to select binaries with the ongoing starspot migration.

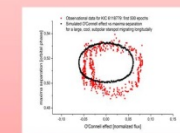


Figure 4: Relation between the changes of the O'Connell effect and the variations of maxima. Observations are in red. Data on modeled large spot, which moves closely around the pole are presented in black.

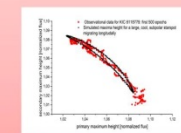


Figure 5: The longitudinal migration of a starspot will affect the brightness maxima consecutively changing their heights. It is visible as the negative correlation in maxima heights diagram. Observations are in red, model is in black.

Summary: the ongoing development

The key to the understanding what happens on the surface of the eclipsing close binary is hidden in the evolution of its lightcurve. The typical timescale of surface activity in short-period binaries last from several up to a few hundreds of orbital periods. Just because of that, it is crucial to conduct continuous observations lasting months or years to gather the information about a complete process. The LCMA has been tested for contact binaries and is extrapolated for the close, detached systems. In this poster we are showing some interesting correlations between the working parameters of the lightcurve. Beside current promising results, this method is still based on a single-color photometry only. Our findings should be verified by a joint venture of spectroscopic observations and continuous multicolor photometry. Kepler field is mostly non-observable from the southern hemisphere, but contact binaries reachable from the observatories located south to the equator are abundant. E.g. objects observed from the Kohnen station in Antarctica. In the following decade ESA and NASA will release new spacecrafts which will observe several millions of stars in a fashion similar to the Kepler mission (TESS, WFIRST, PLATO and other missions already accepted). Fast determination of the primary of the companions in would-observed binaries will give large advantage for modelers in near future. Because of that, our further efforts will focus on spectroscopic determination of binary parameters, e.g. mass ratio, and repeatedly conducted Doppler imaging of several most promising binaries.

Acknowledgements

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References

- Claret, A.; Bloemen, S.: 2011, ARA, 579, A75
- Debski, B.; Baran, A.: 2014, CoRoT, 43, 427
- Wilson, R.E.; Devinney, E.J.: 1971, AJ, 166, 605
- Wilson R.E.: 1979, ApJ, 23, 1054