# Starspot Trek

## The Motion Picture


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## Teaser trailer


**This is a study of the intrinsic variability of light curves** provided with the long timebase photometry. This work is focused primarily on the starspot migration in **contact binary stars of the W Uma-type.**

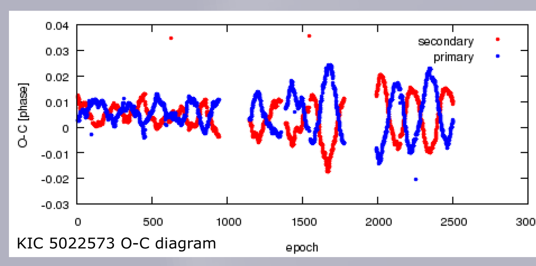
With the power of the **Light Curve Morphology Analysis** applied to the data from Kepler Spacecraft it was possible to easily **trace the spot migration** in our sample of objects with the EW- and EB-type light curves, as well **as obtain the unique insight into the physical properties** of the studied binary systems. Here we show some of the findings: the search for the primary minimum, automatically detecting the spot migration, tracing the spot migration and its latitude, learning the direction of the migration, the relative temperature of the migrating spot, and much more.

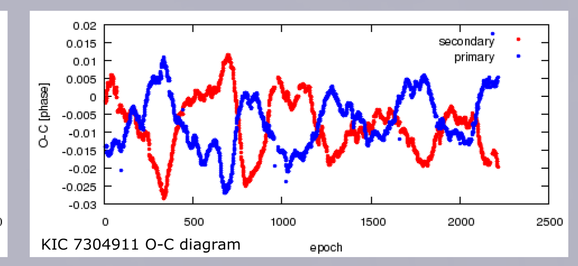
*Feel free to visit the Web page under the QR code – it contains more examples, explanations and results, as well as animations and this poster in the PDF format.*


### (1) The road so far

Contact binaries of the W Uma-type are peculiar systems in which two stars share a common convective envelope of a nearly uniform termperature. The light curves of contact binaries feature the minima of nearly equal depths and can experience a massive intrinsic variability, which is thought to be caused by the photospheric phenomena – starspots.

An early attempt to study the spot migration in the long time series photometry of Kepler Spacecraft is presented in Debski (2012), where some approaches are tested. Tran et al. (2013) published a study of the anticorrelation in the O-C diagrams of the Kepler binaries. They concluded that the best explanation is that the binaries experience a spot migration and the spots must be located far from the equator.



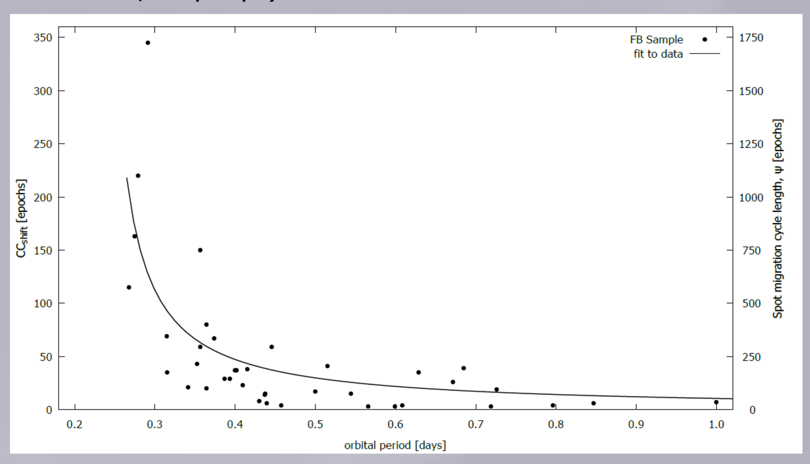




Balaji et al. (2015) published a study if the spot migration tracing. They found that in most studied binaries spots are migrating in the direction of the descending longitudes, if we assume the spots are cool.

### (5) Direction & rate of the migration

The cross-correlation between the secondary minimum timing and its depth variations provides the information on the direction and rate of the spot migration. The direction, however, is dependent of the assumed spot temperature (if it's a cool or a hot spot). The LCMA can provide the temperature of a spot by studying the relation between the minima depths (details in Debski 2019, in prep.).

Interestingly, it seems that the spot migration in all studied binaries is happening in the direction of descending longitudes. No matter, if the spot is cool or hot.




In general, the shorter the orbital period, the longer one migration cycle lasts (one full rotation, 360° in longitude).

### The summary

The light curve evolution analysis opens a range of new possibilities:

1) To ensure mass ratio q < 1, follow the recipy of the maxima separation S < 0.5 Φ
2) Hotter secondary components in contact binaries are virtually nonexistent
3) Starspot migration is detected by anticorrelation of the maxima heights
4) Spot migration is traced with the evolution of both the O'Connell effect and the maxima separation
5) Starspots are large and located around poles, rather than equators.
6) The spots can exist on both poles of the primary star simultaneously
7) The spot migration is following descending longitudes for both cool and hot spots
8) The shorter the orbital period, the slower rate of the spot migration

The LCMA could be easily applied to the binaries observed with TESS. The migration tracers can be reliably used outside the domain of contact binaries.

More plots!

Animations!

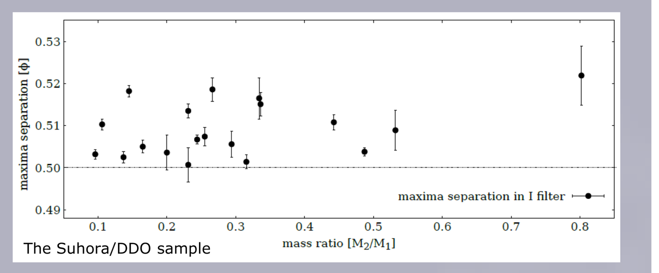
PDF!

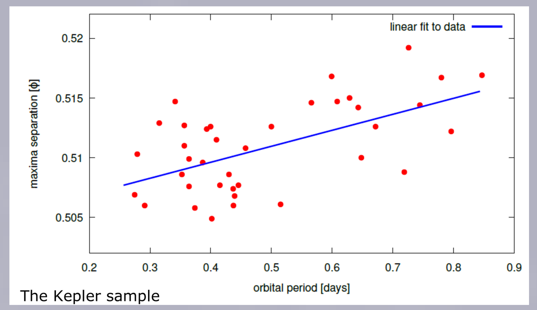
WWW!

### (2) Determination of the primary minimum

The light curves of contact binaries have minima of nearly equal depths and the components have almost the same surface temperature, even if the mass ratio of the system is as low as q = 0.1. With the means of the LCMA it is possible to determine, during which minimum the more massive star is being eclipsed, even when the system does not experience the total eclipse event.

It turns out that the separation between the brightness maxima is always larger than 0.5 of the orbital phase, if the light curve is phased so that the more massive star is at the primary minimum (phase 0.0). The exception from this rule can be produced for a time being by the presence of a starspot, but it can be oust with the mean maxima separation, taken over a long time span.



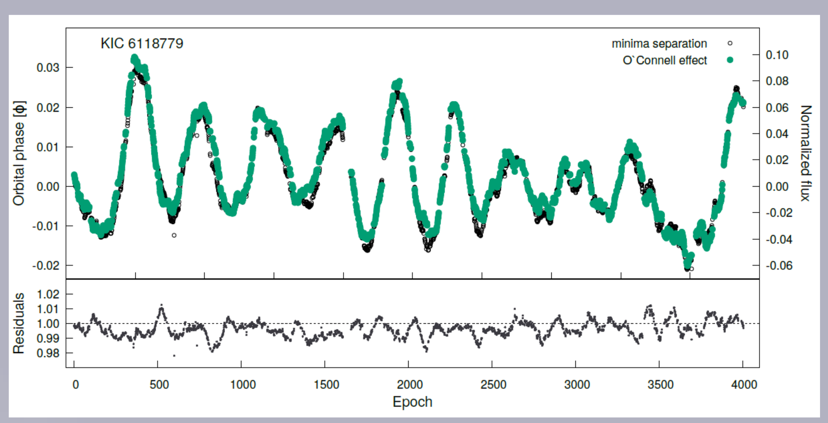



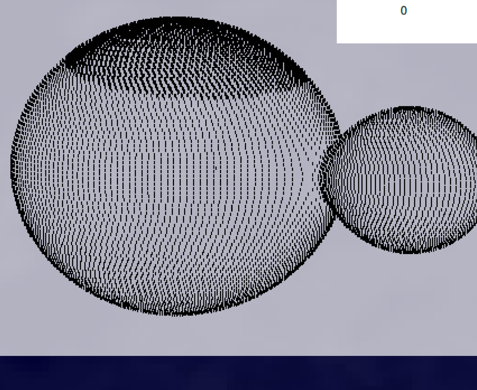

The differential analysis of the maxima separation in different photometric filters show that the components of contact binaries are of almost equal temperatures, and the secondary star is not likely to be the hotter component, even if the secondary minimum is the deeper one.

### (4) Star spots = tilted polar `caps'

The separation of the minima and the O'Connell effect evolutions are highly correlated. The same happens with the maxima separation and the minima depth difference. Such phenomenon occurs for almost all studied binaries and can be explained only with a very large spots located around the stellar pole.

Such starspots could be described as slightly tilted polar spots or `caps', with the `tilt' being small in comparison with the diameter of the starspot itself.



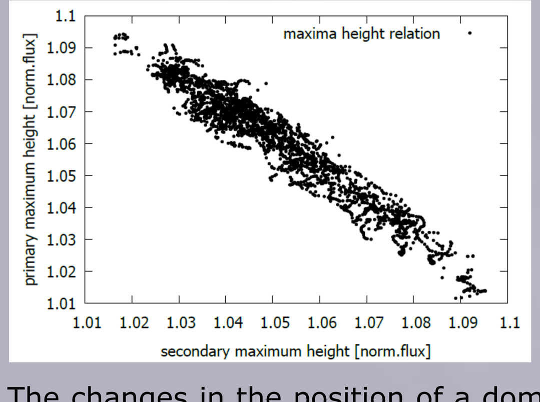



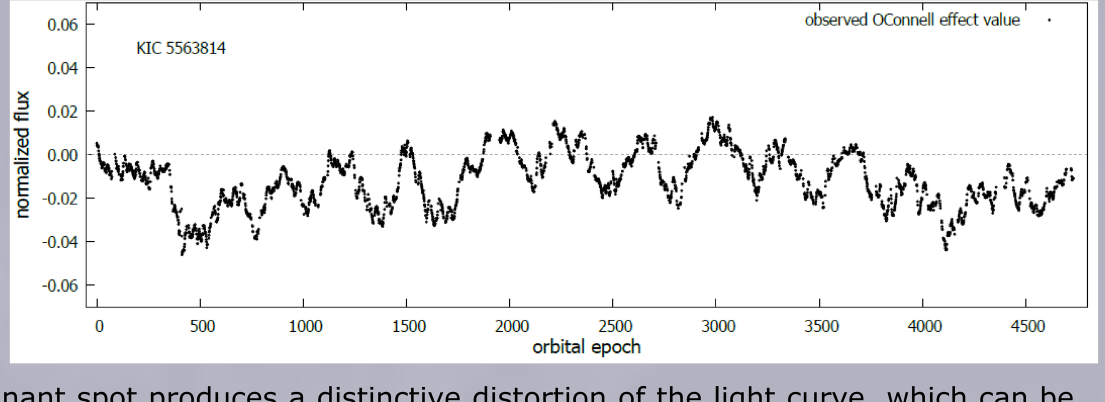
The migration of such a polar spot is effectively the same as the rotation of the spot, or the spot `precession'.

The existence of polar spots is, generally, in agreement with the models of fast rotating stars.

### (3) Detection and tracing of the starspot migration

Evolution of the O'Connell effect acts as the spot migration tracer. Checking the anticorrelation of the maxima heights is the easiest method of establishing, if the object experience the spot migration.




The changes in the position of a dominant spot produces a distinctive distortion of the light curve, which can be traced trough the evolution of the O'Connell effect and the evolution of the maxima separation. This method is more universal and reliable than the numerical modeling process.

One of the most promising methods comes from the anticorrelation between the cosine of the spot longitude with the value of the maxima separation and the anticorrelation between the sine of the spot longitude and the O'Connell effect value. Moreover, the method works as well with the two-spot migration patterns, where the means of the numerical modeling usually fail. See the evoluton of the O'Connell effect in KIC 5563814.

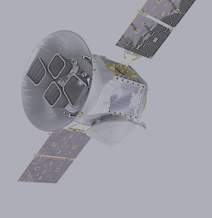

### Acknowledgements

I am grateful to the Polish National Science Centre for funding the grant 2016/23/N/ST9/01218, which made this project possible for realization

I am thankful to the Polish Ministry of Science and Higher Education for partialy funding my trip to this conference under grant 7150/E-338/M/2018.


### Selected literature


(1) Debski, Zola, Baran 2014
(2) Debski, Baran, Zola 2015
(3) Zola et al. 2017
(4) Debski 2019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