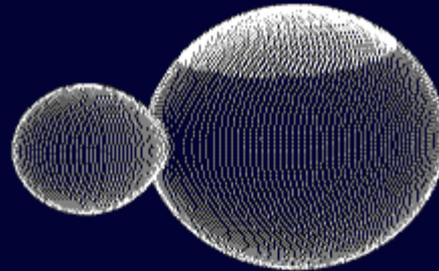


# Starspot Trek

## The Motion Picture



**Bartłomiej Debski**

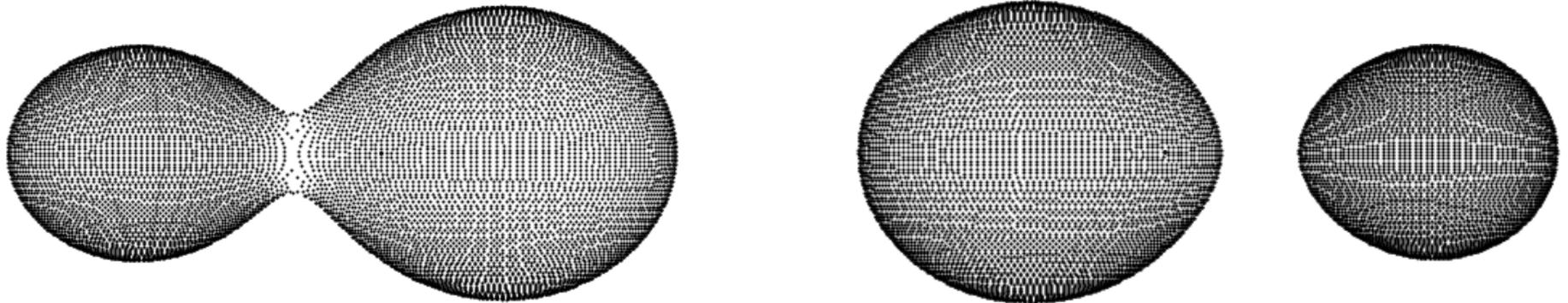
Astronomical Observatory, Jagiellonian University, Poland

Universe of Binaries, Binaries in the Universe  
10.09.2019  
Telc, Czech Republik

Under the Polish NSC grant no. 2016/23/N/ST9/01218

# Starspot migration, or how to spot a spot

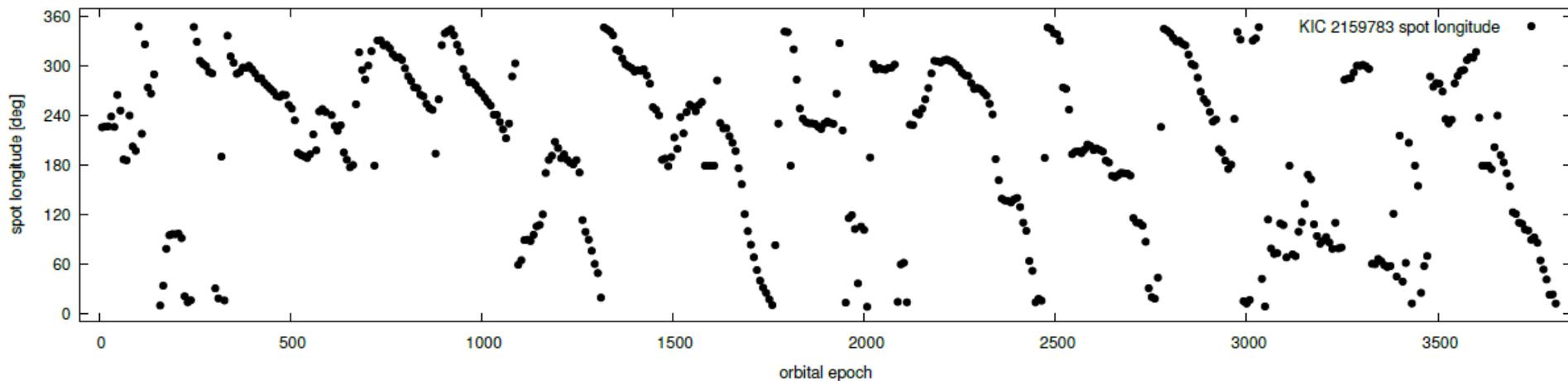
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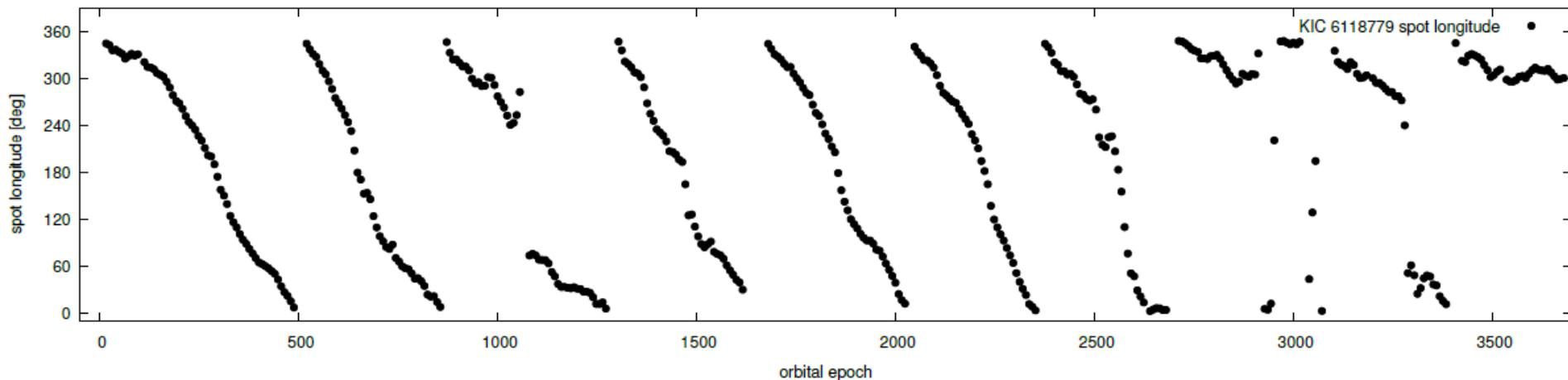
# Numerical modeling of the spot migration

The search for the spot location one epoch after another

KIC 2159783



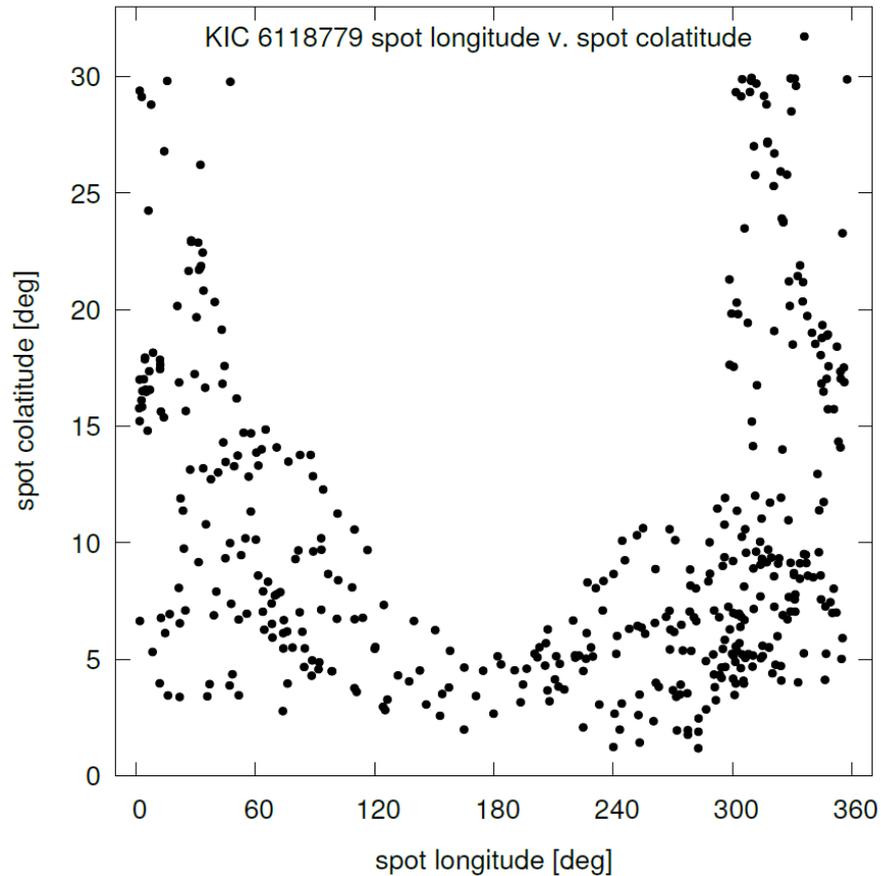
KIC 6118779



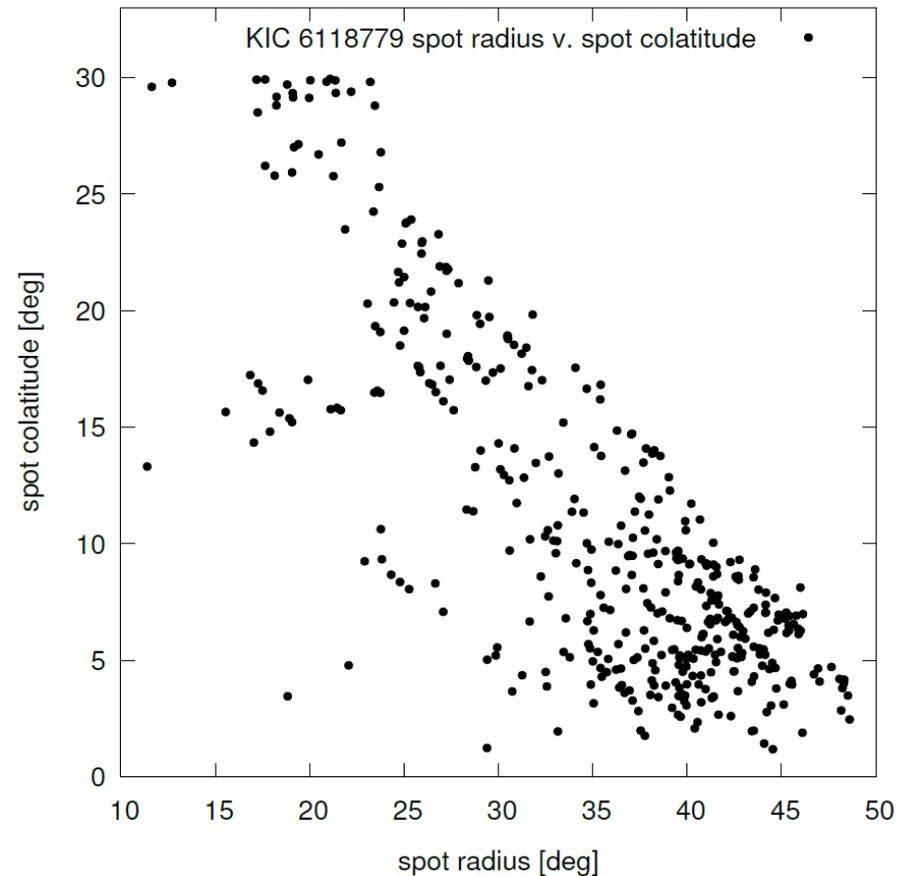
# Numerical modeling of the spot migration

## The ties between the modeled spot parameters

### Spot longitude v. spot colatitude

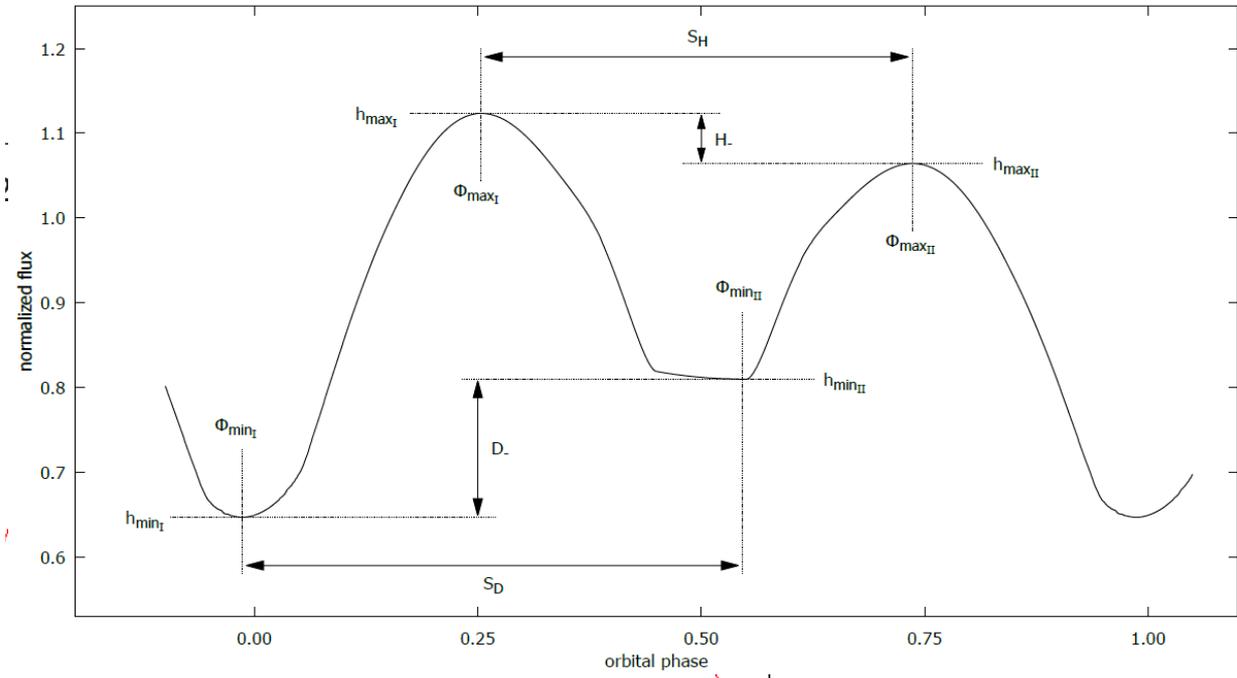
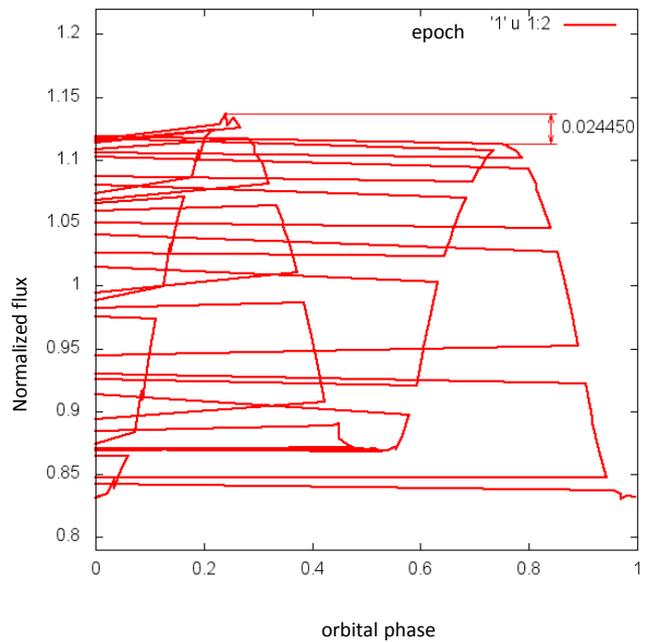
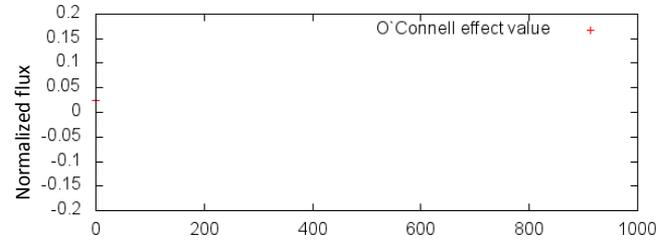


### Spot radius v. spot colatitude



# The intrinsic variability of the light curve

Let's use the time domain of the light curve evolution



First Order light curve parameters

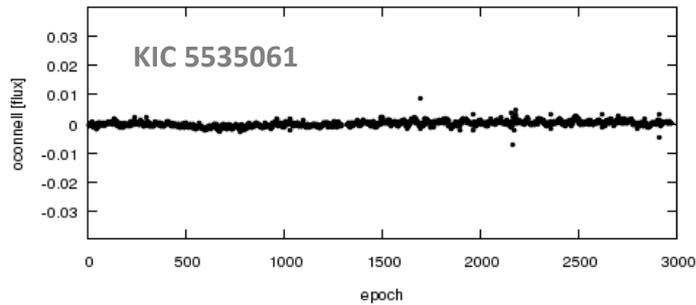
- $h_{maxI}$  and  $h_{maxII}$  - the flux level at the primary and secondary maximum
- $h_{minI}$  and  $h_{minII}$  - the flux level at the primary and secondary minimum
- $\phi_{maxI}$  and  $\phi_{maxII}$  - the position of the primary and secondary maximum, expressed in the orbital phase ( $\phi$ )
- $\phi_{minI}$  and  $\phi_{minII}$  - the position of the primary and secondary minimum, expressed in the orbital phase

0.2

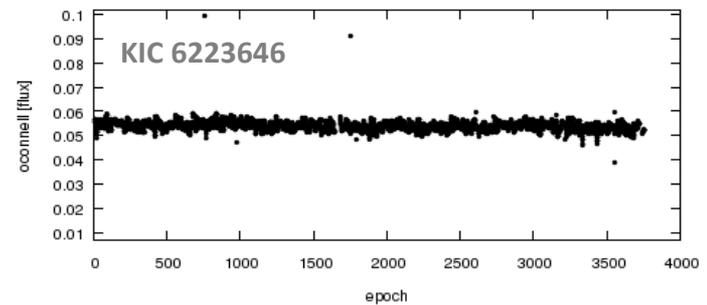
# Light curve evolution examples:

## the phenomenological classification of the O'Connell Effect

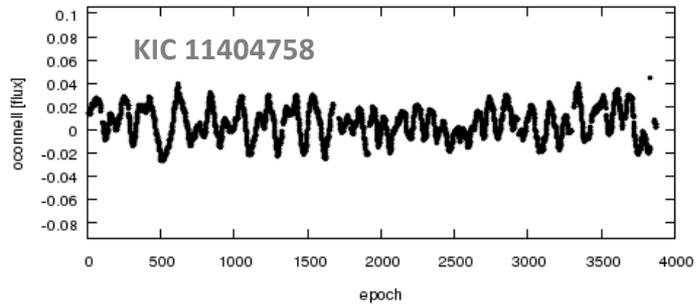
No O'Connell Effect



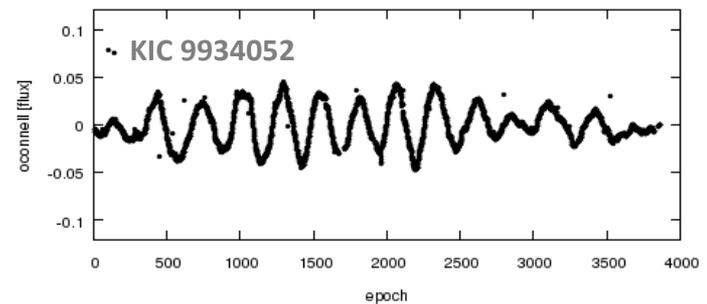
Stable, non-changing O'Connell Effect



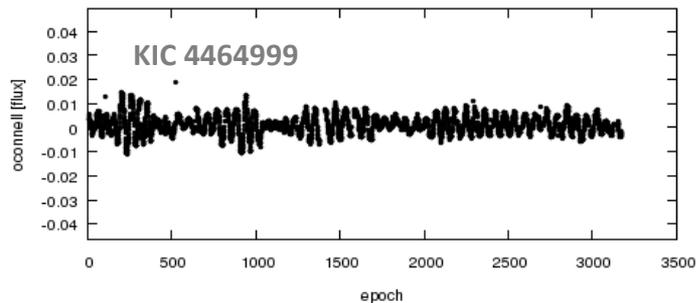
Signal of transition between spots



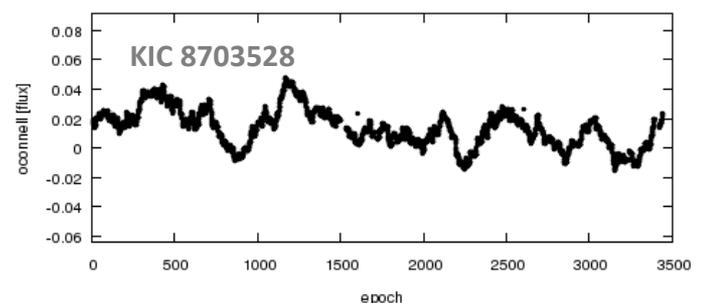
Regular variations



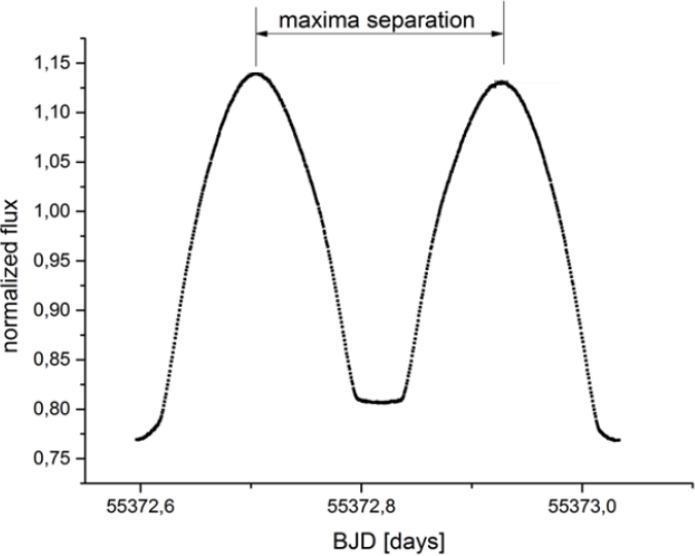
Cycles of activity



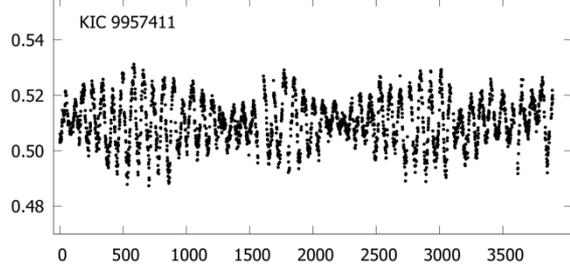
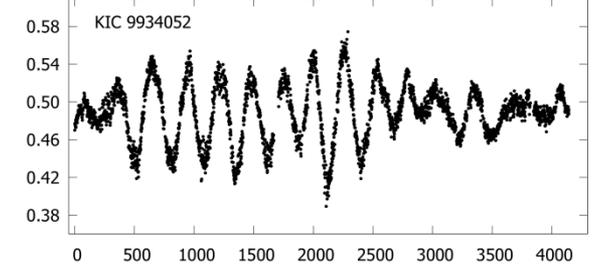
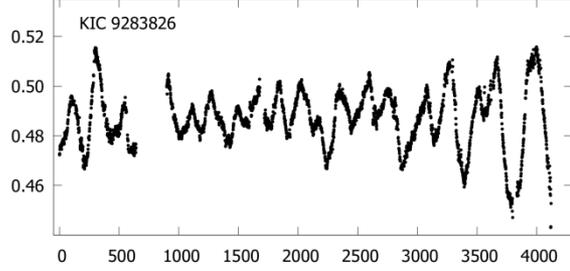
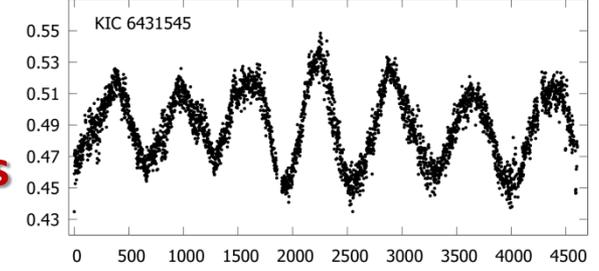
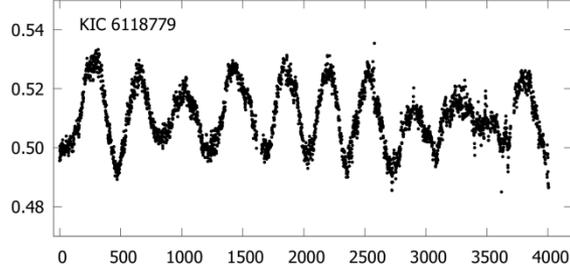
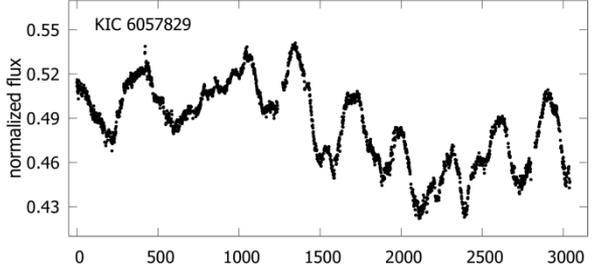
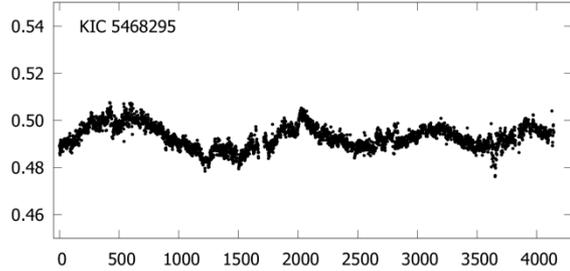
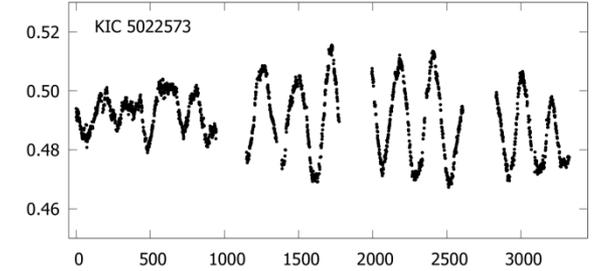
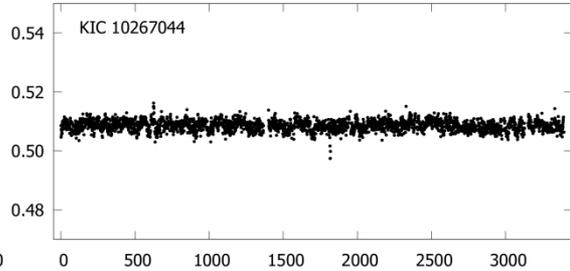
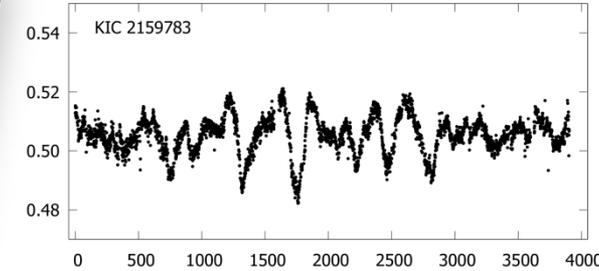
Random variations



# Light curve evolution examples: the phenomenological classification of the maxima separation



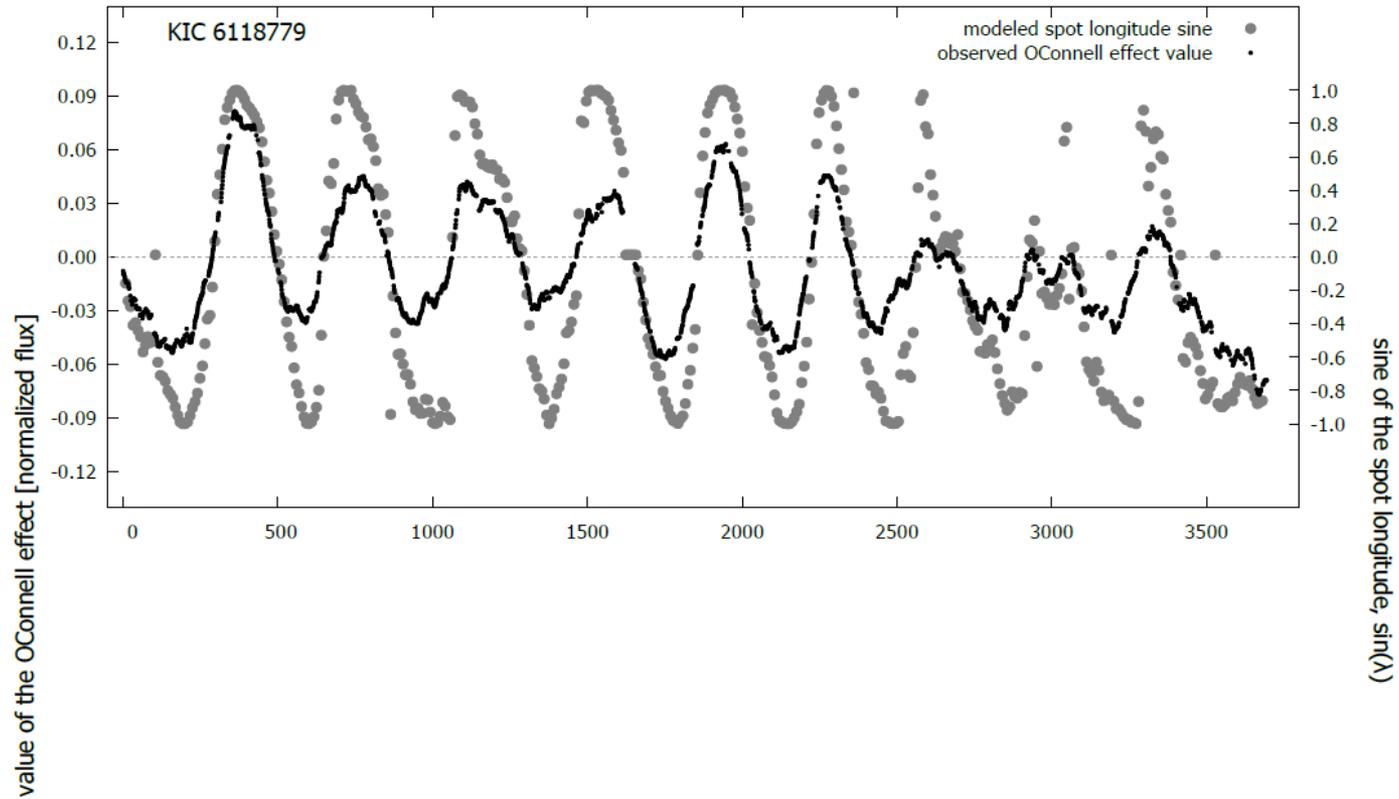
**Light Curve Morphology Analysis  
has been applied to more than  
1200 Kepler binaries**



orbital epoch

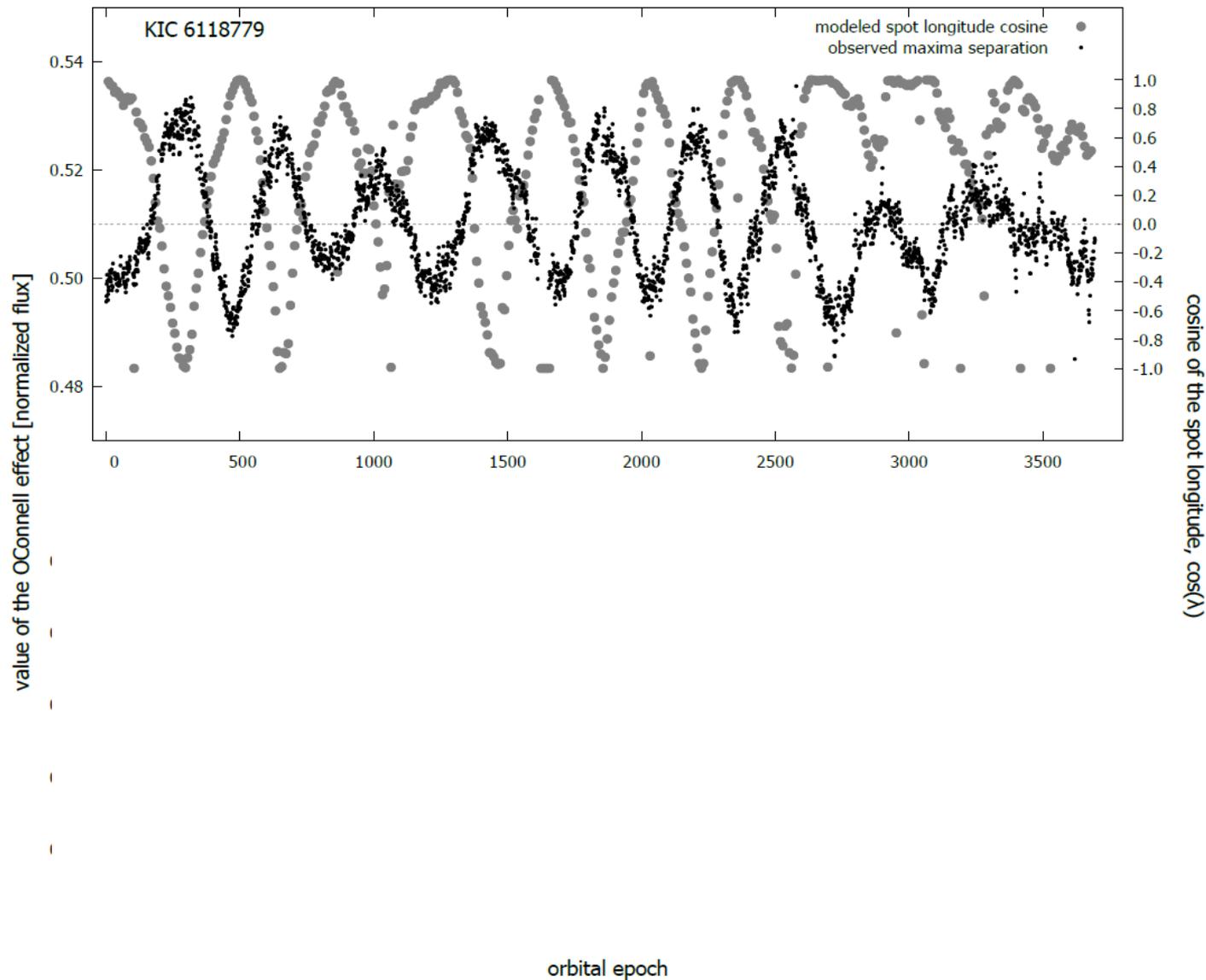
# Tracing the spot longitude:

## O'Connell effect evolution v. spot longitude sine



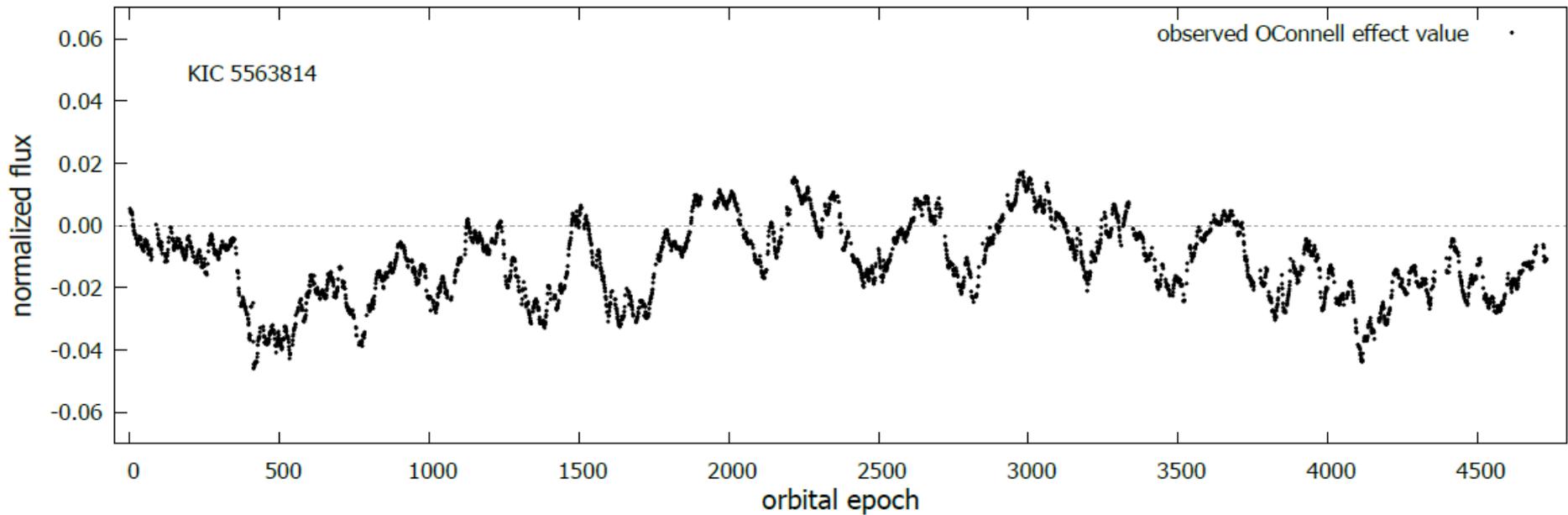
# Tracing the spot longitude:

## Maxima separation evolution v. spot longitude cosine



# Tracing the spot longitude:

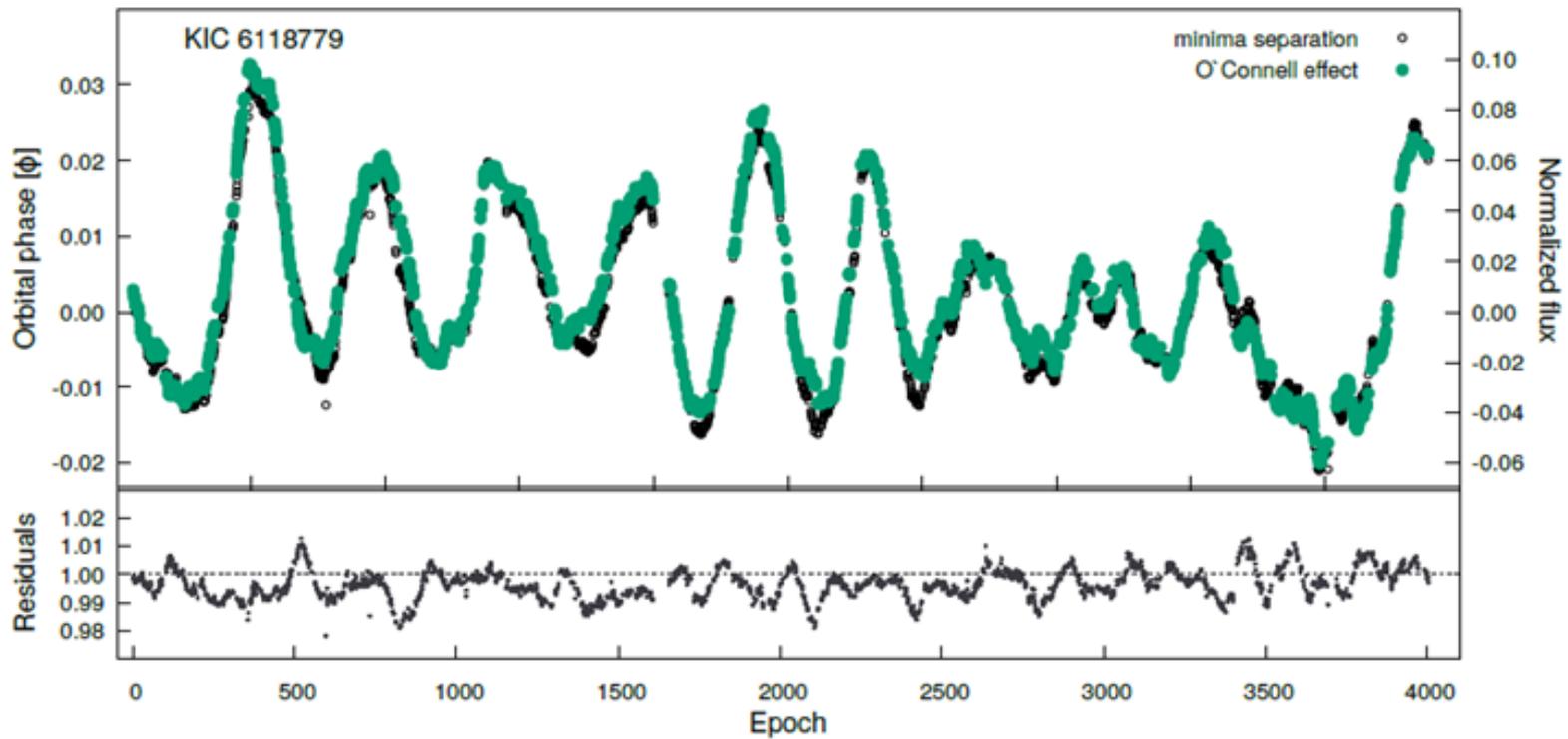
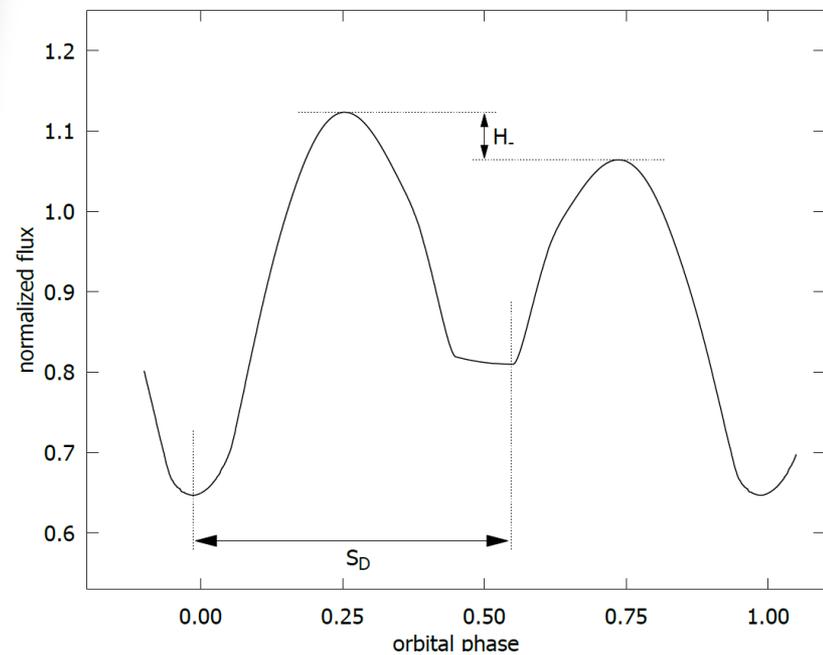
To boldly trace a spot where no numerical modeling has gone before



# Search for the spot colatitude

## Part I

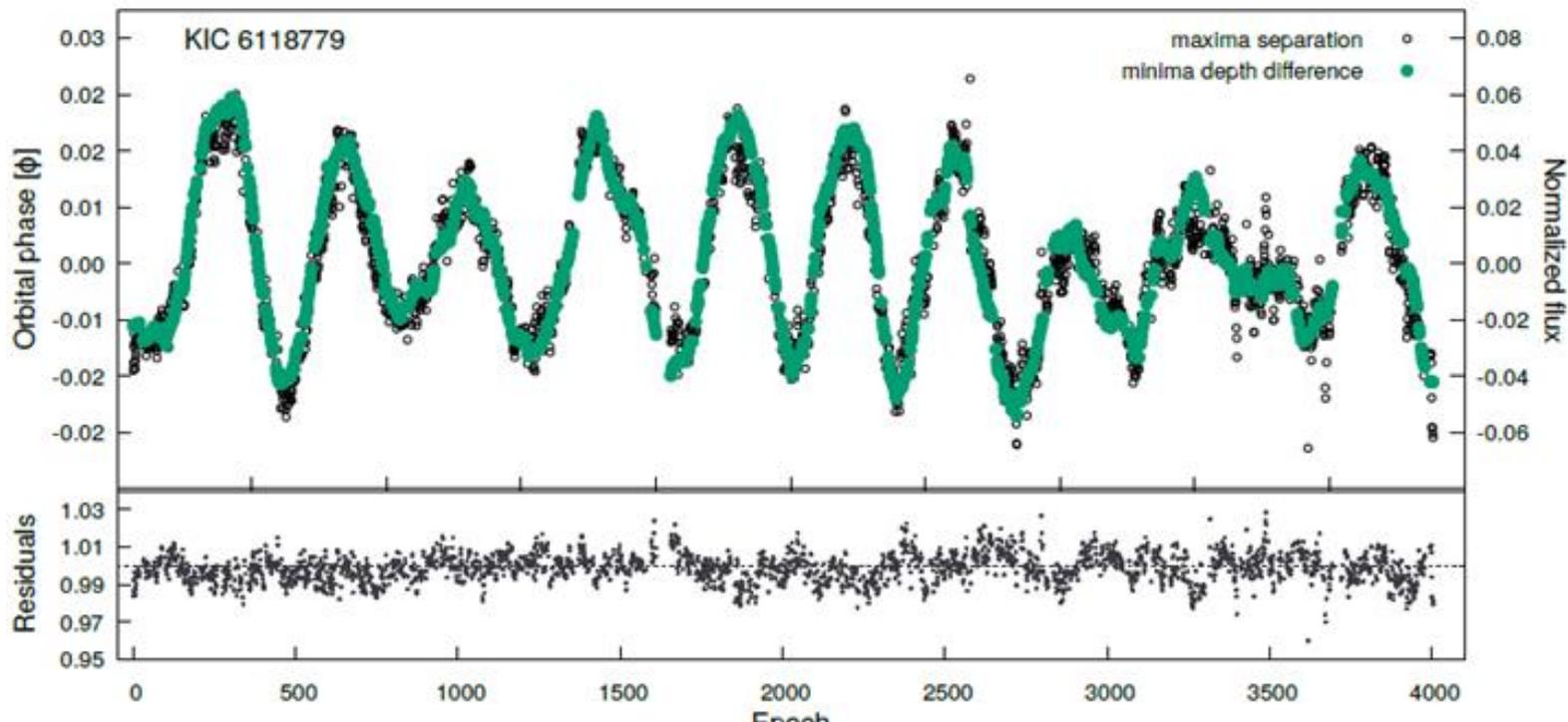
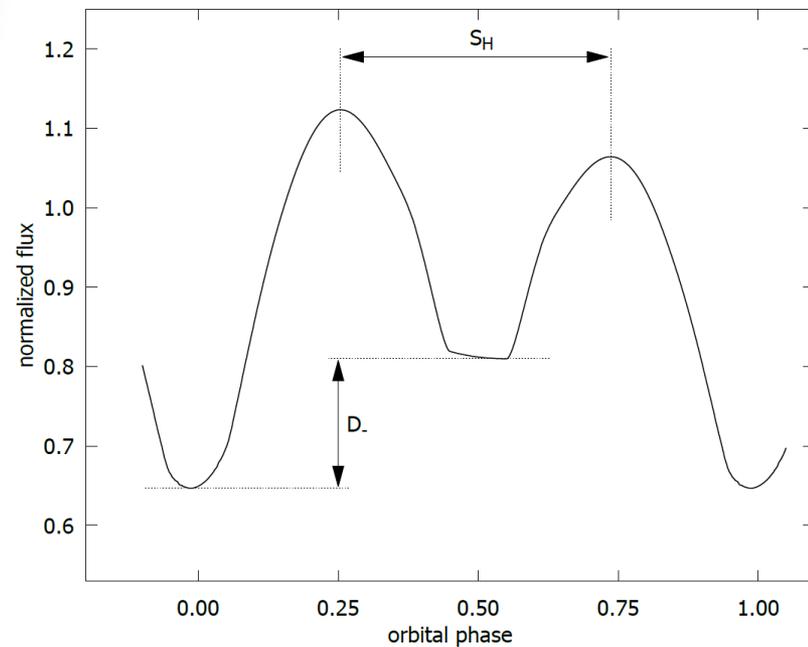
Correlation between  
the **O'Connell effect evolution**  
and  
the minima separation evolution



# Search for the spot colatitude

## Part II

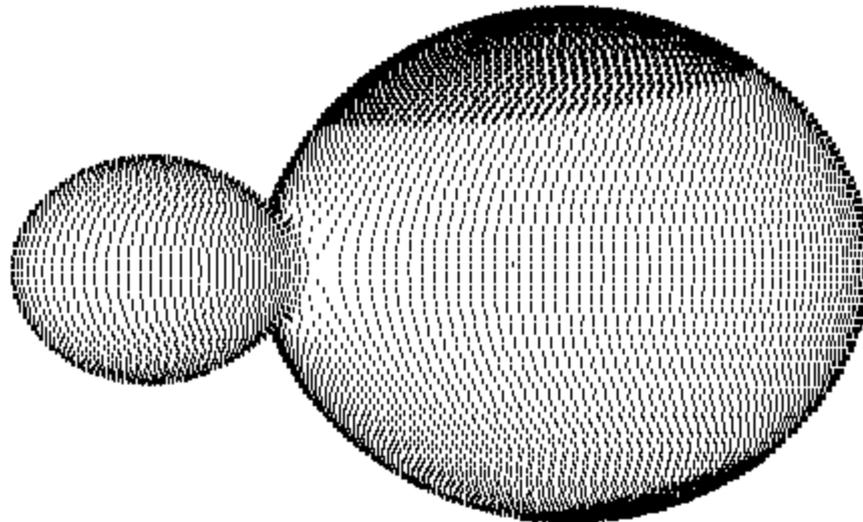
Correlation between  
the **maxima separation evolution**  
and  
the minima depth difference evolution



# Spot migration

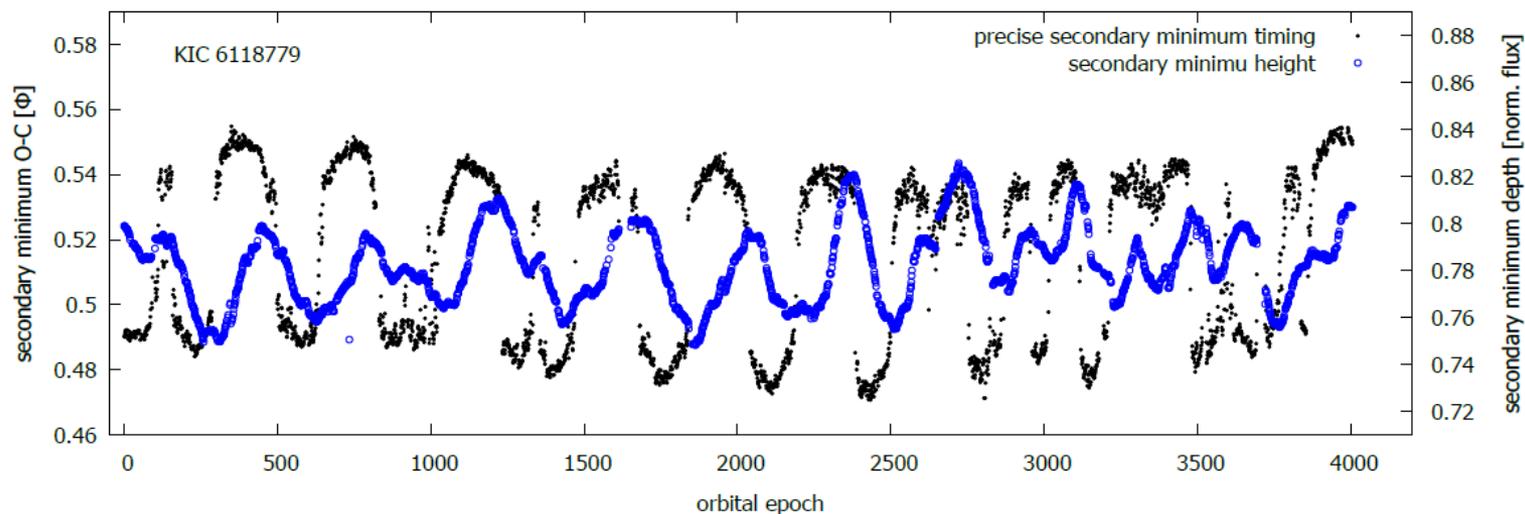
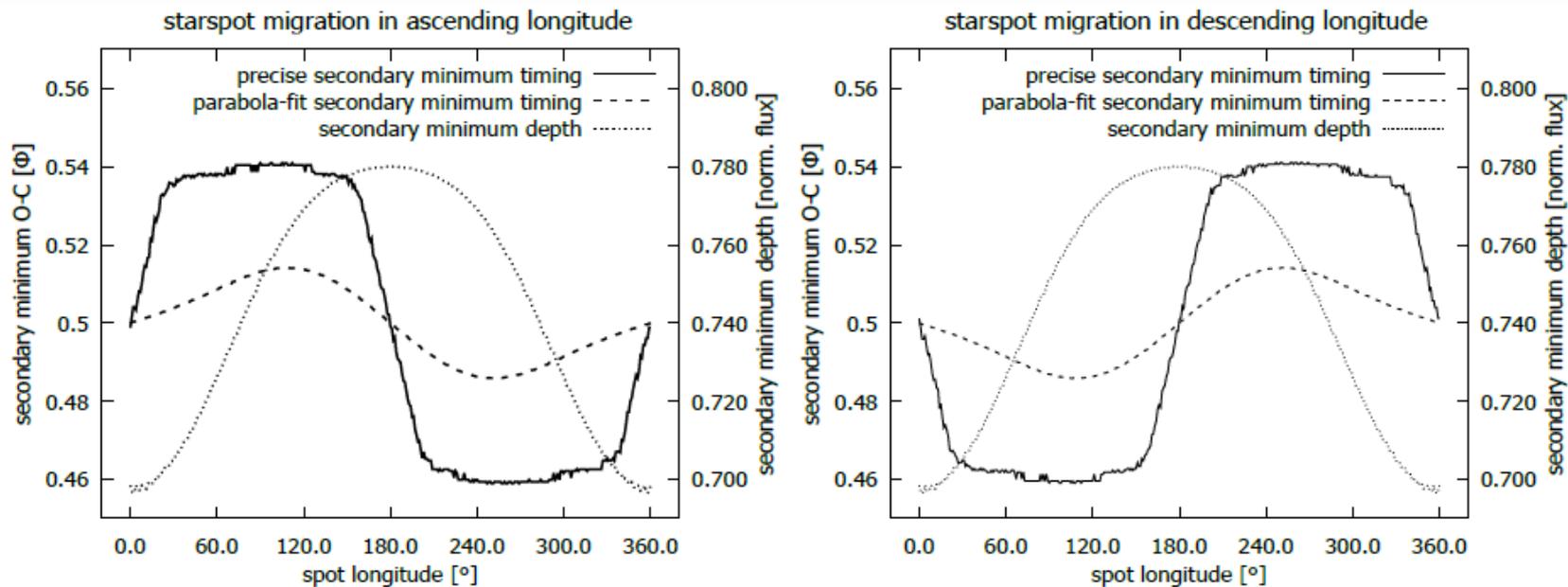
... Or a precession of the tilted polar spot

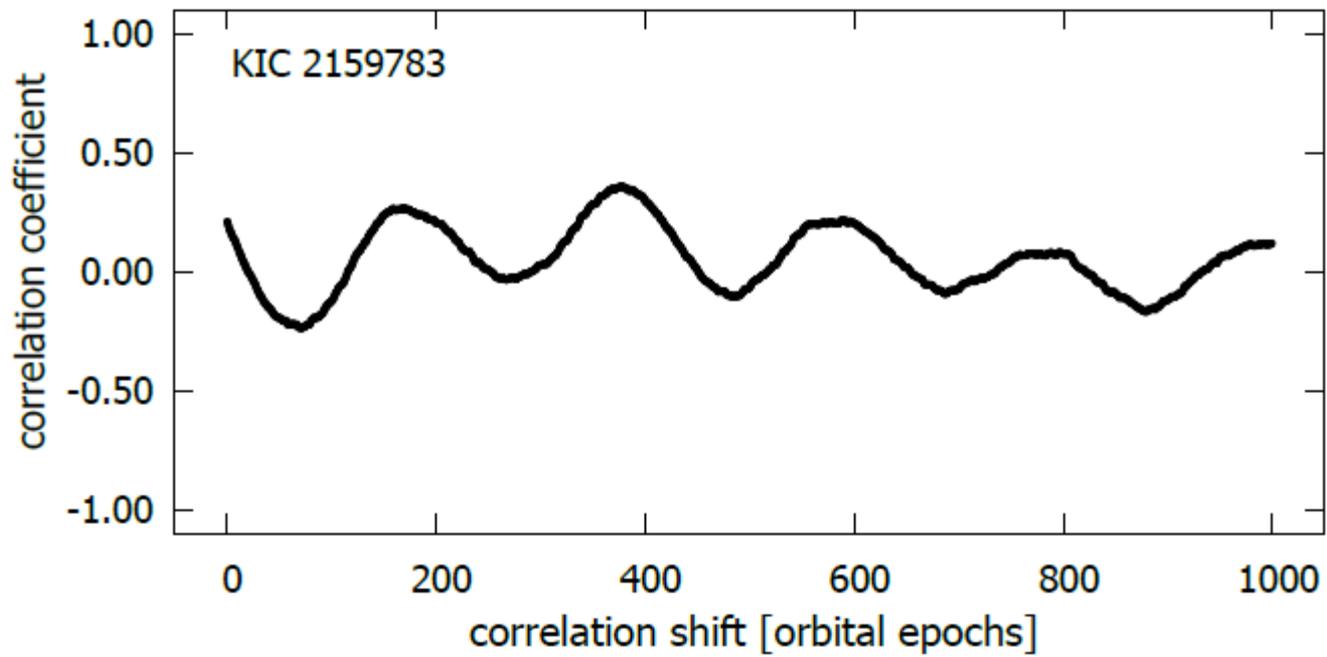
- Low colatitudes
- Large radii
- Only systems with a low inclination show single-spot modulation
- Systems with  $i \approx 90^\circ$  rarely exhibit signals attributable to just one spot



# Detecting the direction of the spot migration

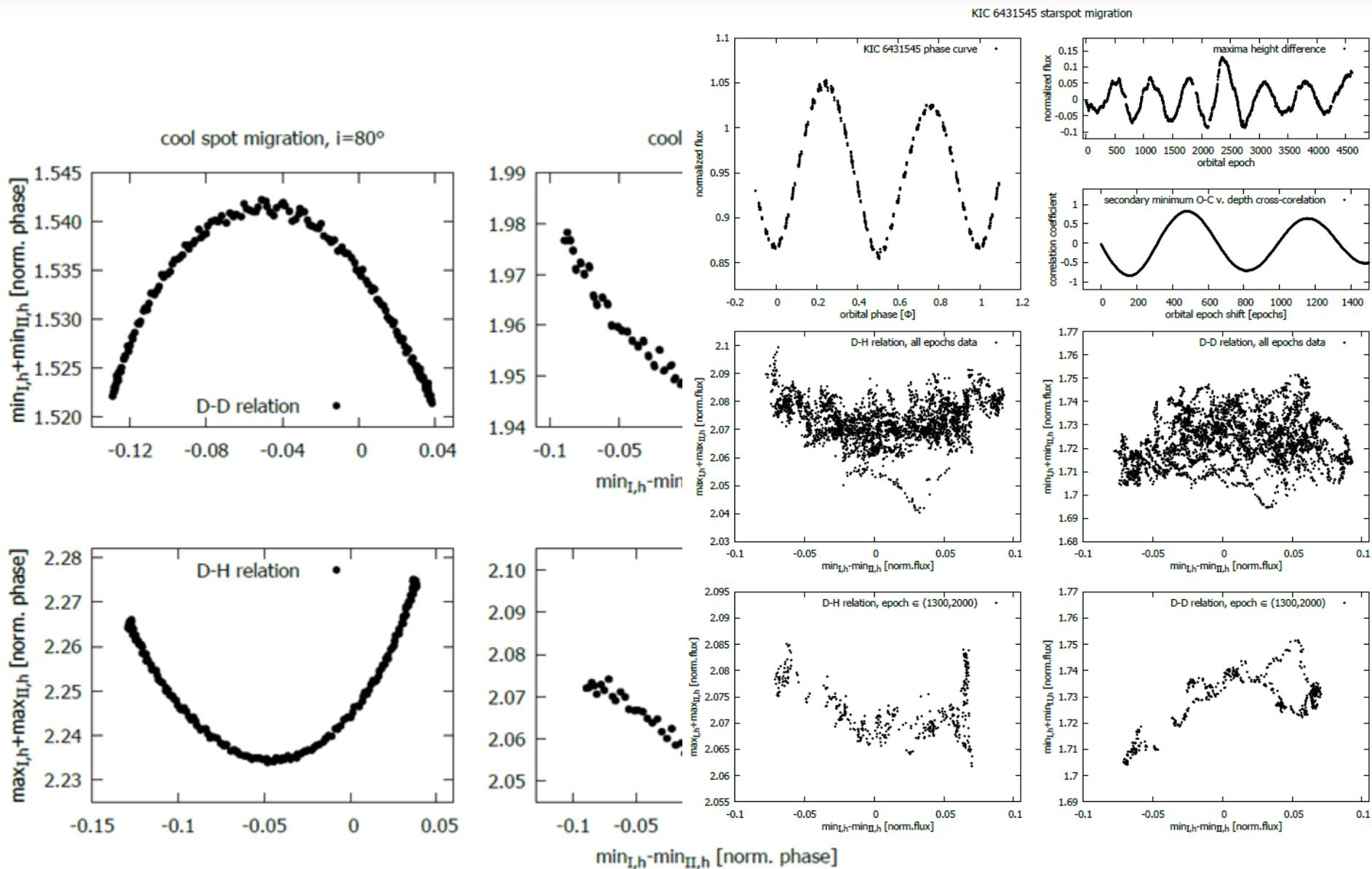
secondary minimum timing v. secondary minimum **depth variations**





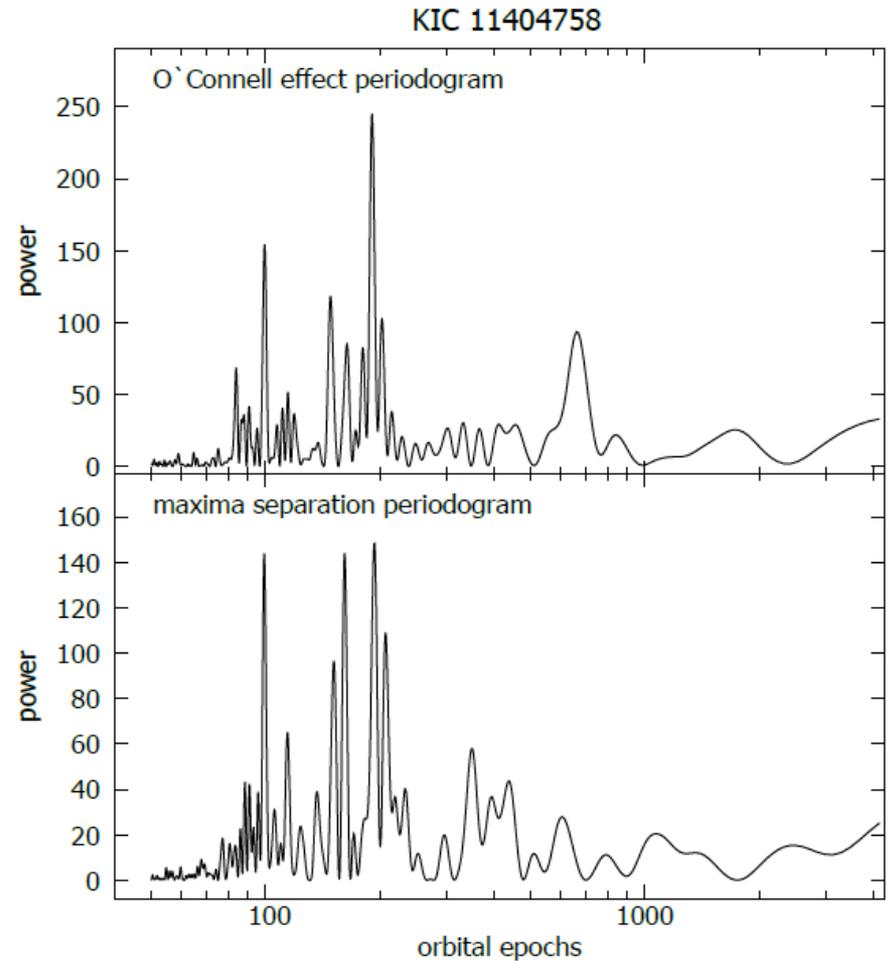
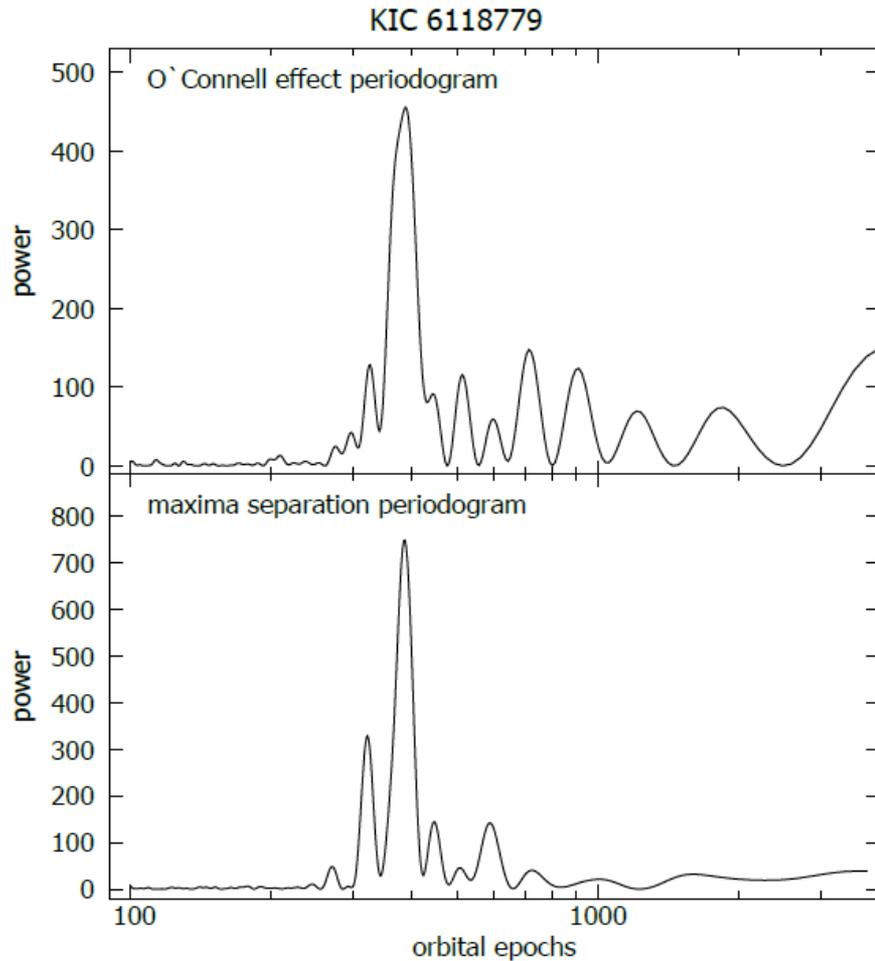
# Breaking the symmetry: hot spot or a cool spot?

Asymmetry in the minima/maxima height sums and differences relations



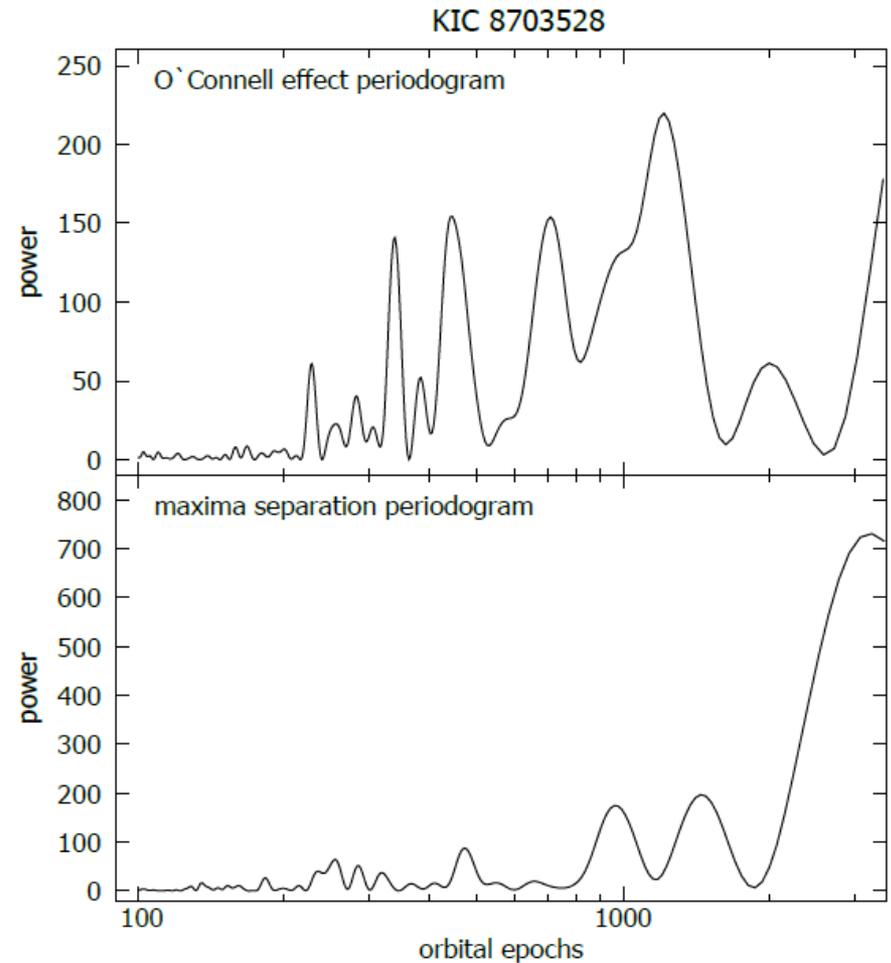
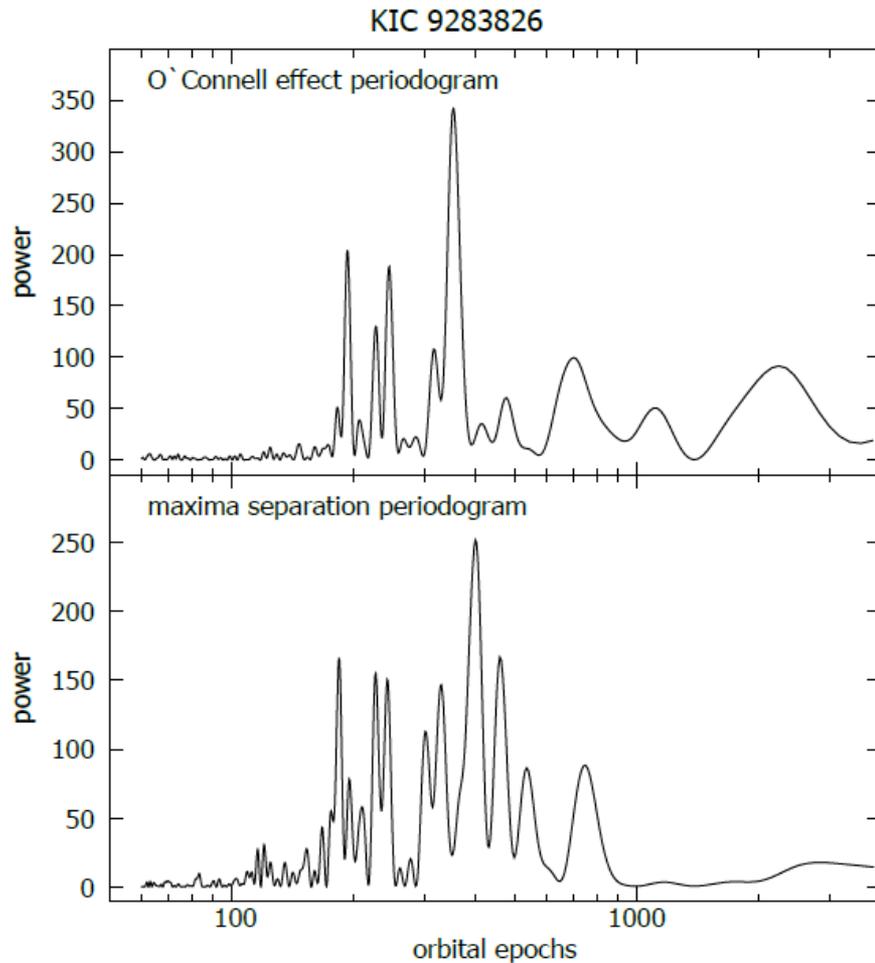
# Search for the migration timescale

Variations of the O'Connell effect and/or maxima separation are not best tracers



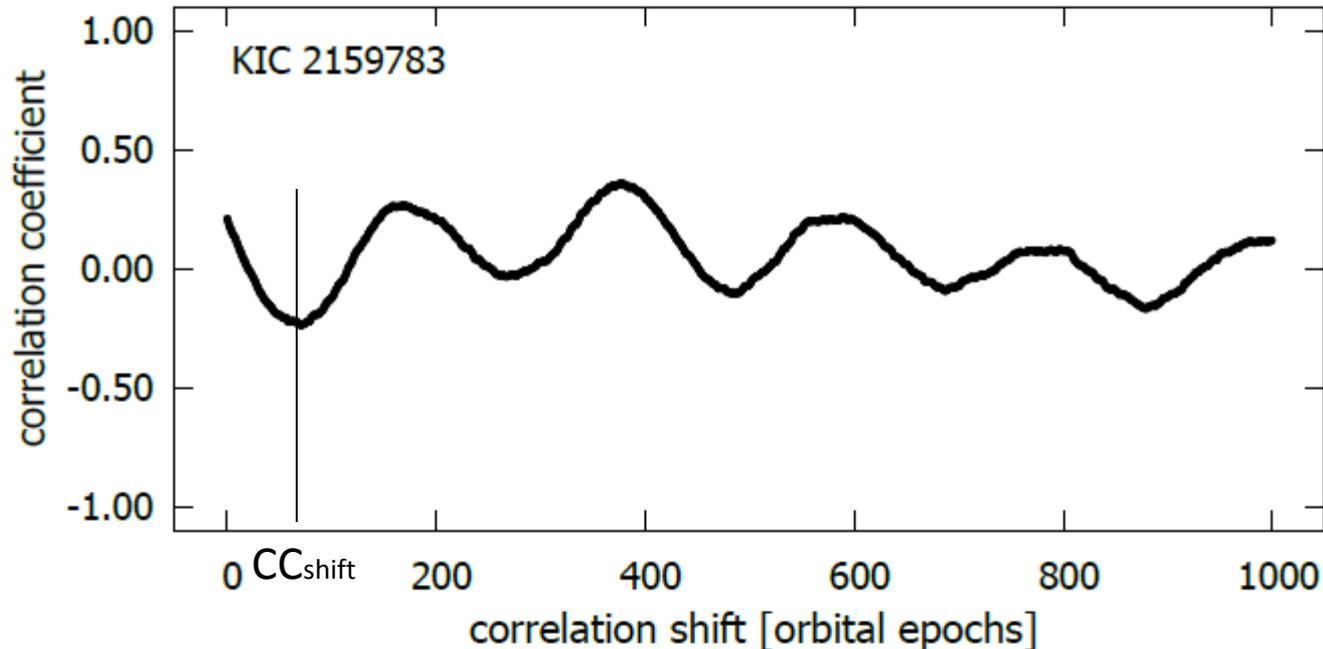
# Search for the migration timescale

Variations of the O'Connell effect and/or maxima separation are not best tracers



# Search for the migration timescale

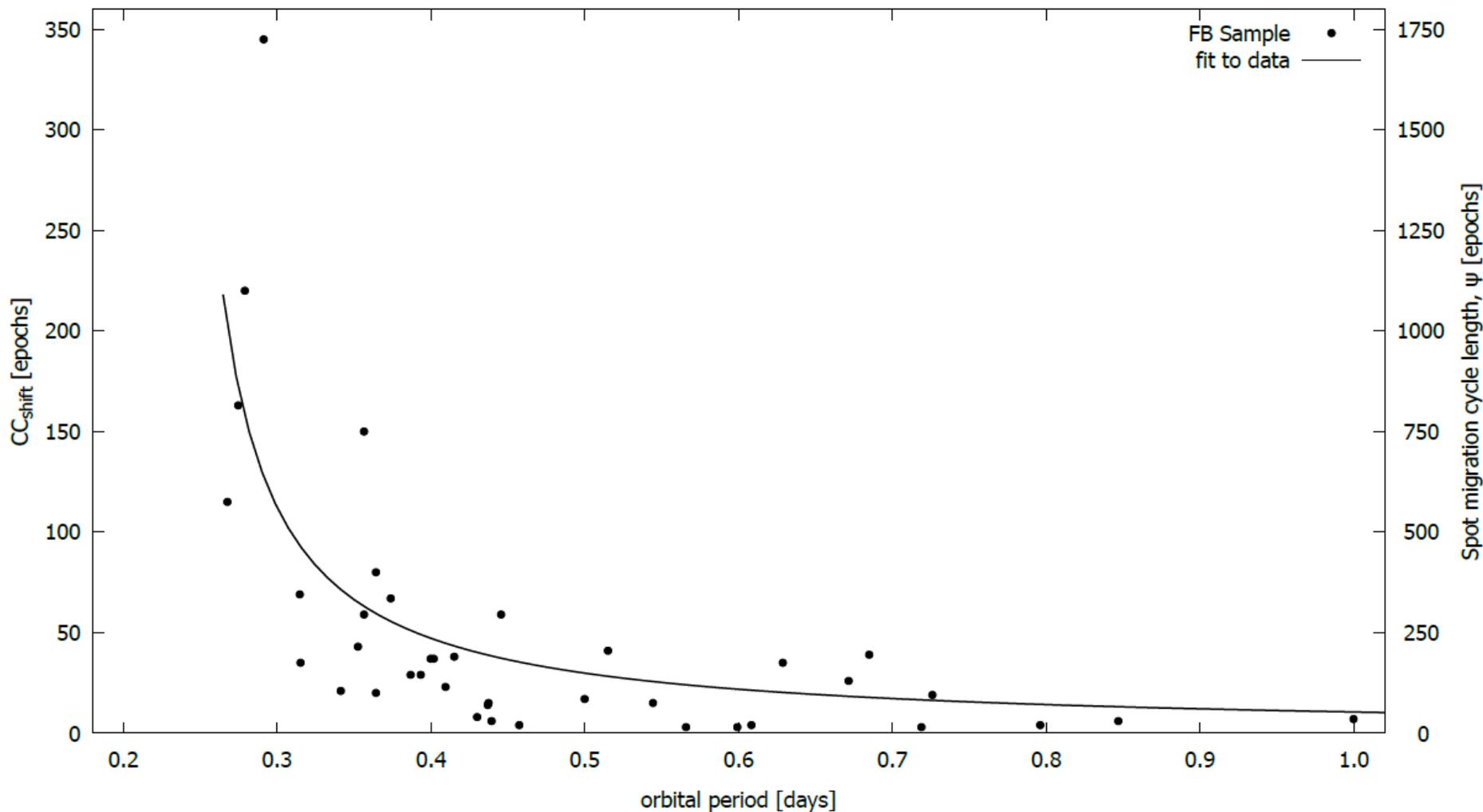
Cross-correlation shift between the secondary minimum timing and its depth



Spot migration period timescale  $P_{\text{spot}} \approx 5 * \text{CC}_{\text{shift}}$

(for contact binaries with  $i > 75^\circ$  and polar spots)

# Migration timescale in the sample of totally eclipsing contact binaries



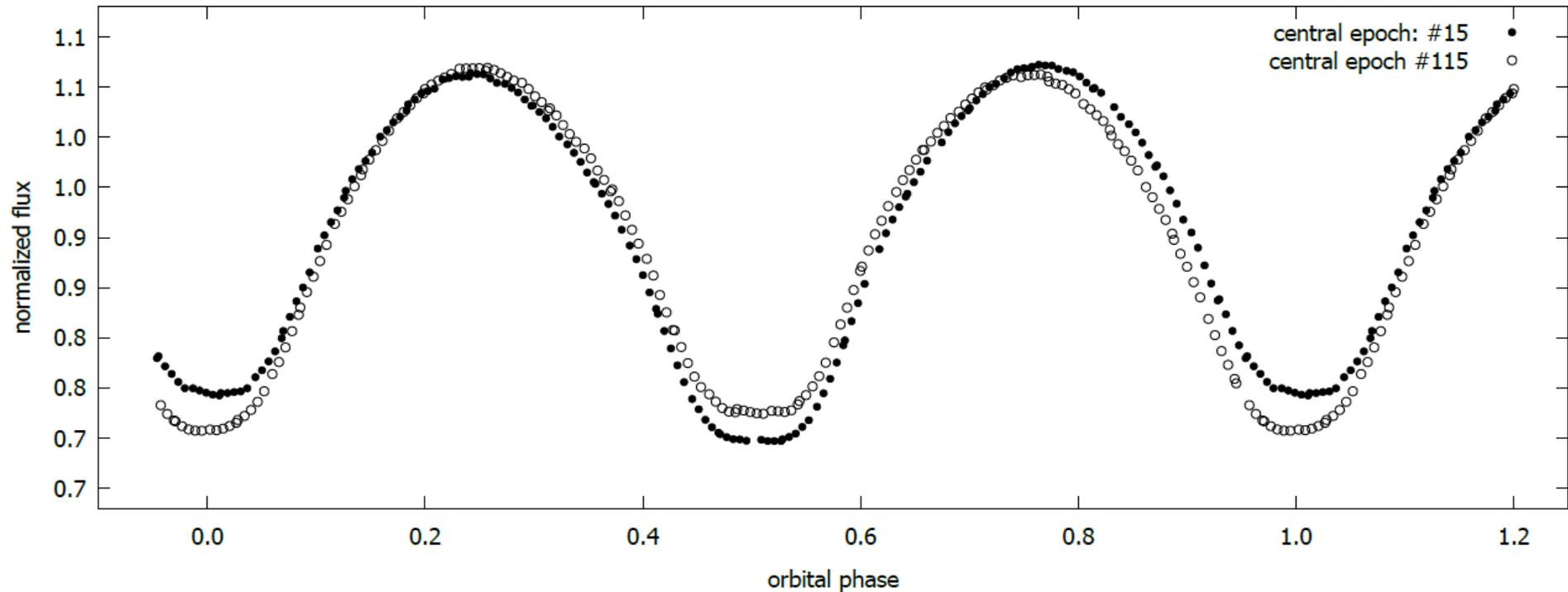
# Neverending story needs **a summary**

Intrinsic light curve variability & second order light curve parameters as tracers of the spot migration

1. Spot longitude reconstruction: O'Connell effect evolution (and maxima separation evolution)
2. Spot latitude and size: correlations between the second order light curve parameters
3. Relative temperature of the migrating spot: sign of the secondary light curve parameters relations
4. Spot migration direction: cross-correlation of the secondary minimum height and timing
5. Spot migration timescales: shift of the first extremum in the above cross-correlation

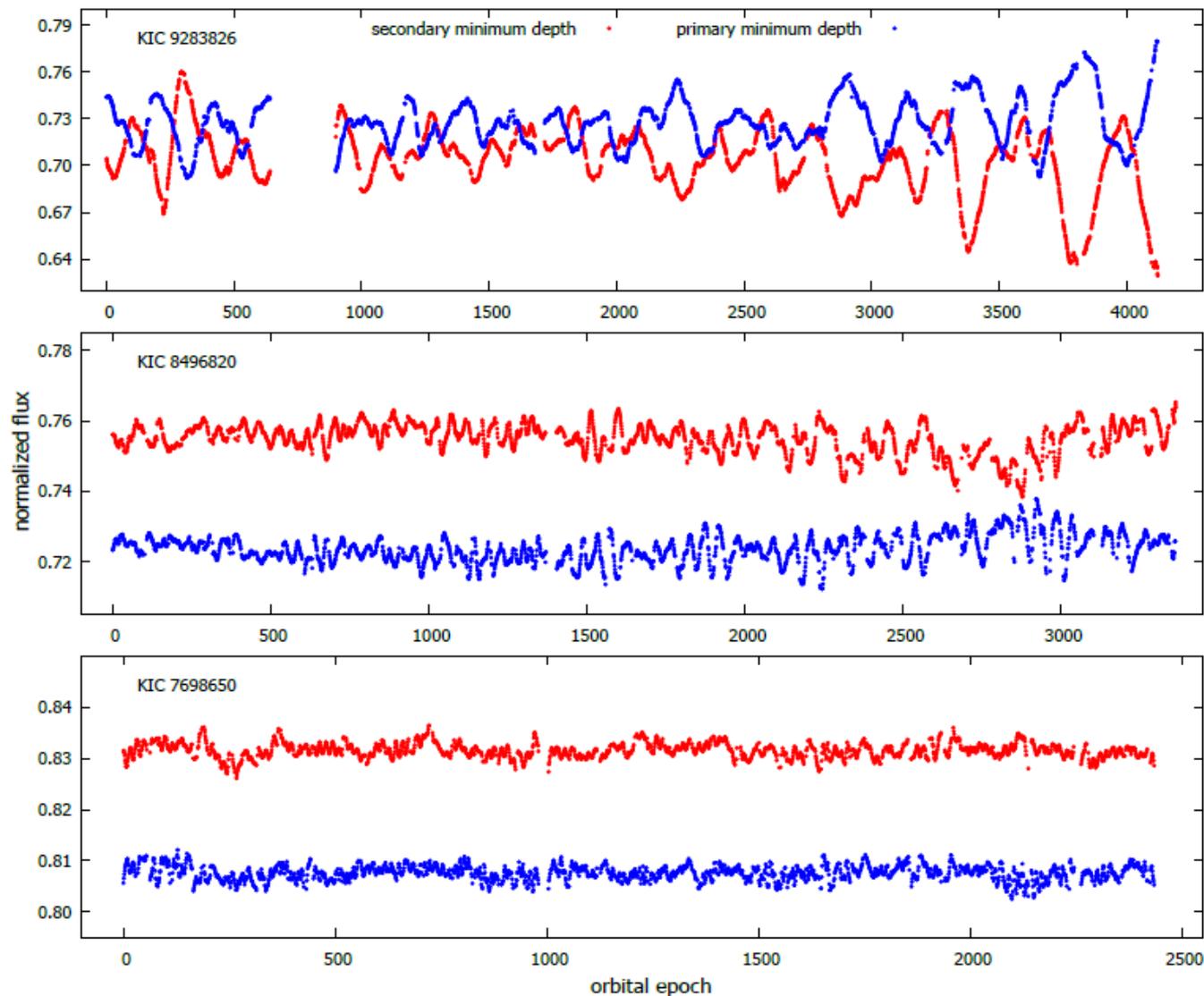
# Hints from the intrinsic light curve variability

Beware the A/W-subtypes of contact binaries



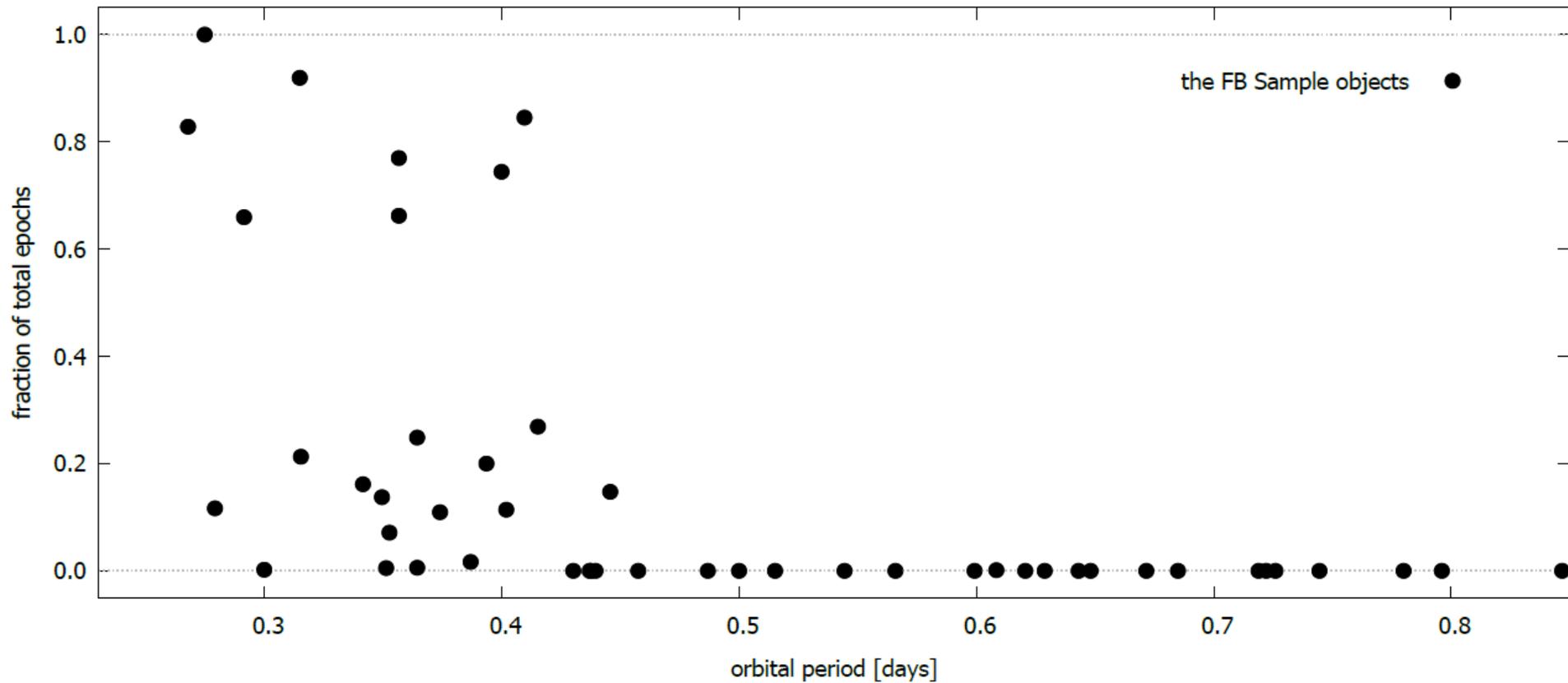
# Hints from the intrinsic light curve variability

Beware the A/W-subtypes of contact binaries



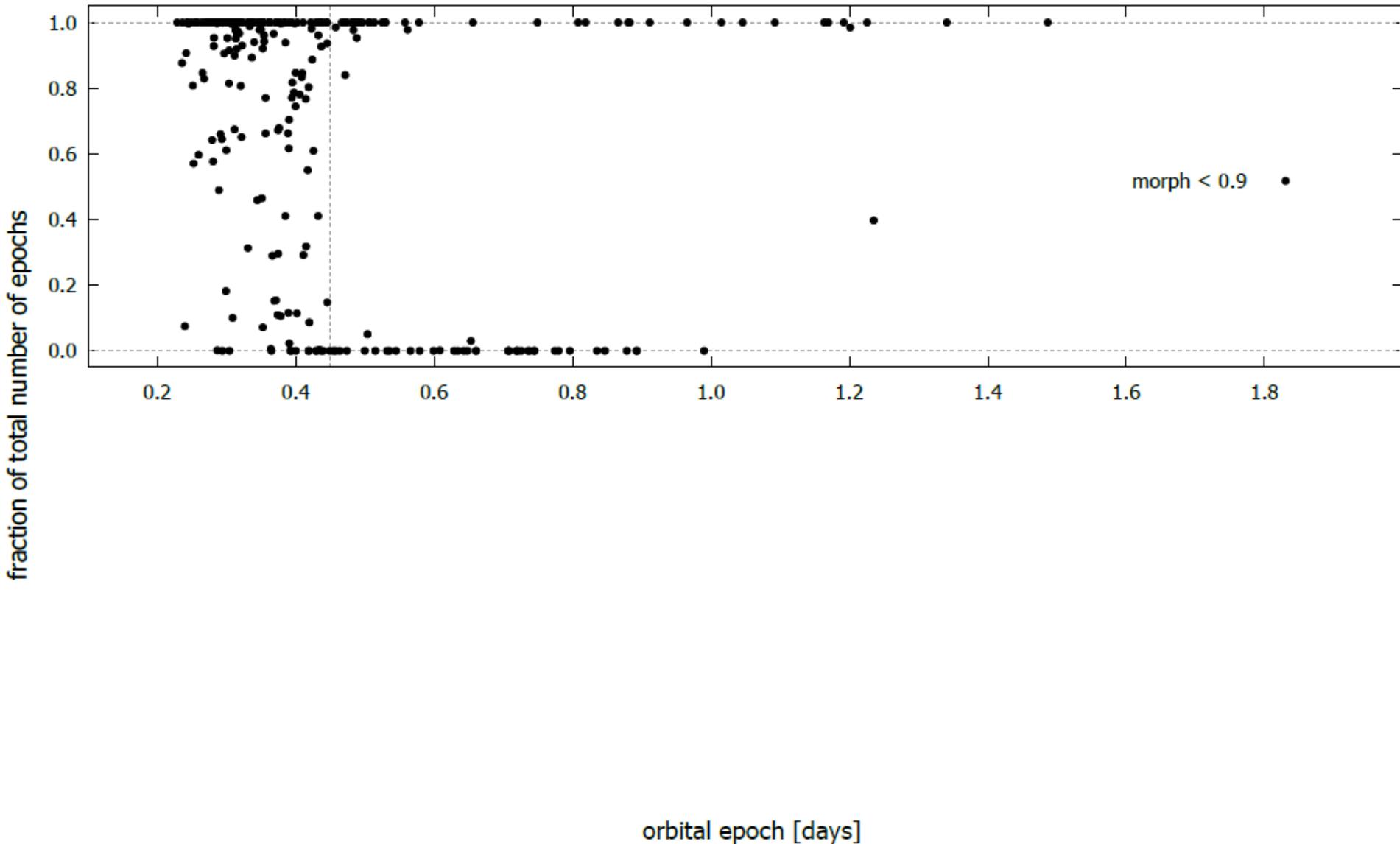
# Hints from the intrinsic light curve variability

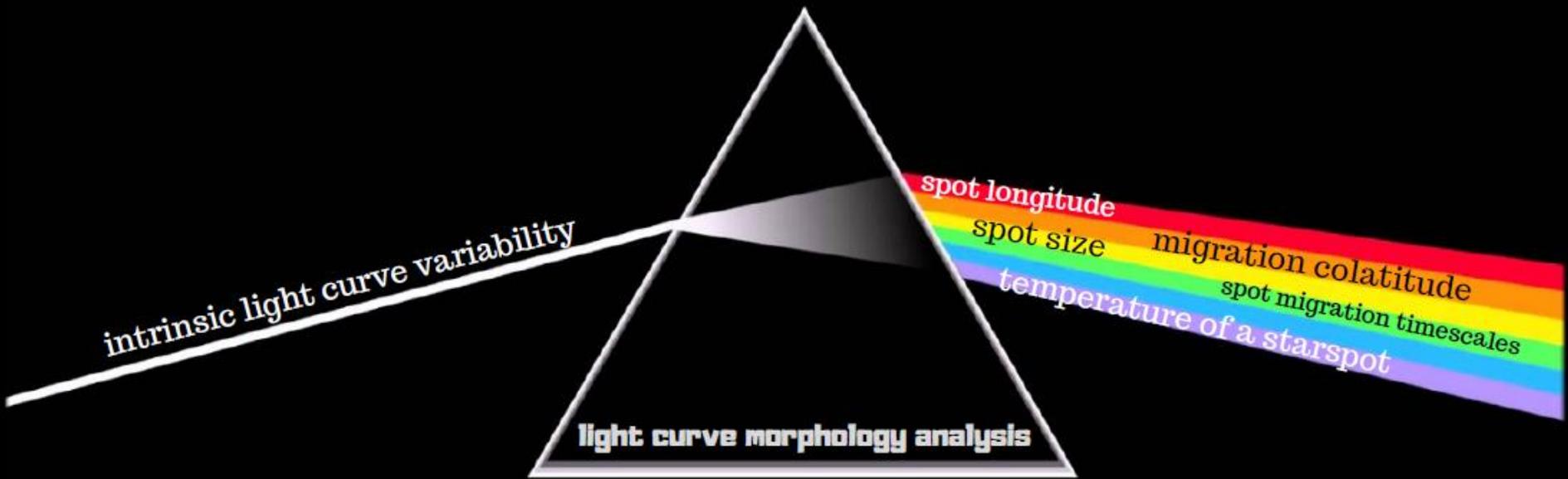
Beware the A/W-subtypes of contact binaries



# Hints from the intrinsic light curve variability

Beware the A/W-subtypes of contact binaries





**e-mail: bartlomiej.debski@uj.edu.pl**

**My webpage with more results, animations, explanations and a catalogue of 1217 objects:  
<http://bade.space>**