A new view of asteroid rotation in the era of space astronomy and the LSST

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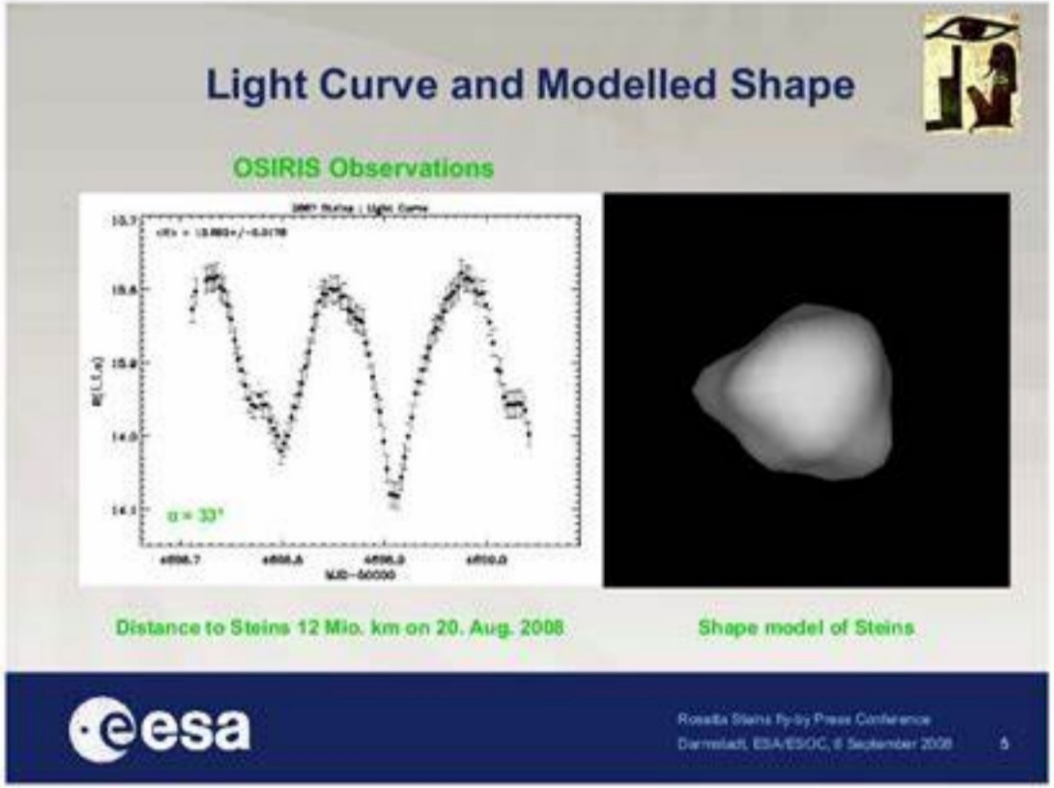
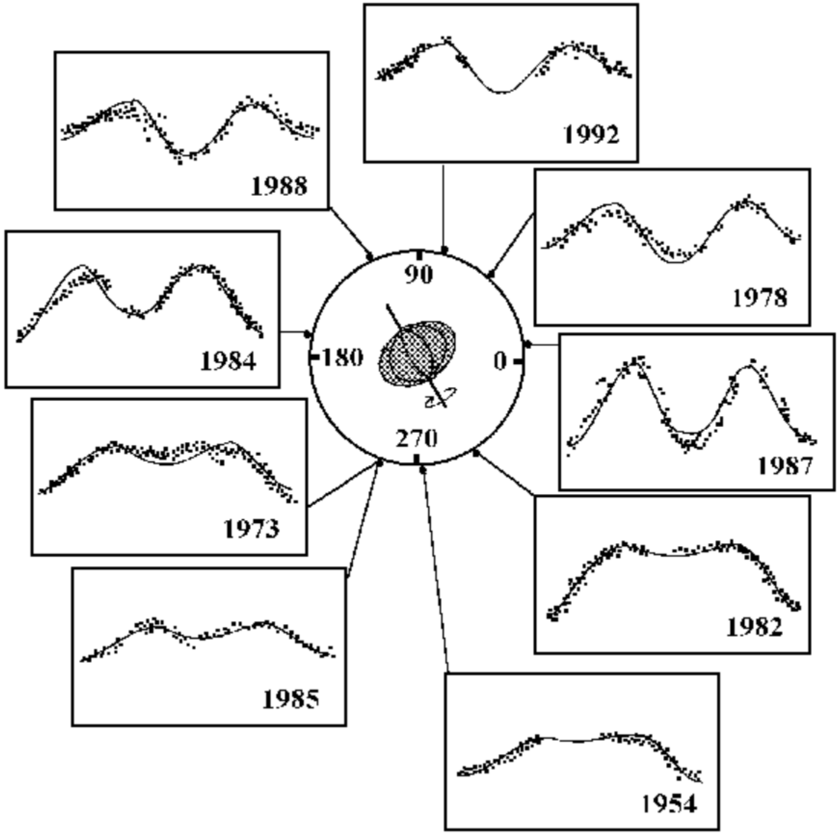
Szombathely, Hungary

Light curve modeling in old times





Light curve + Occultations

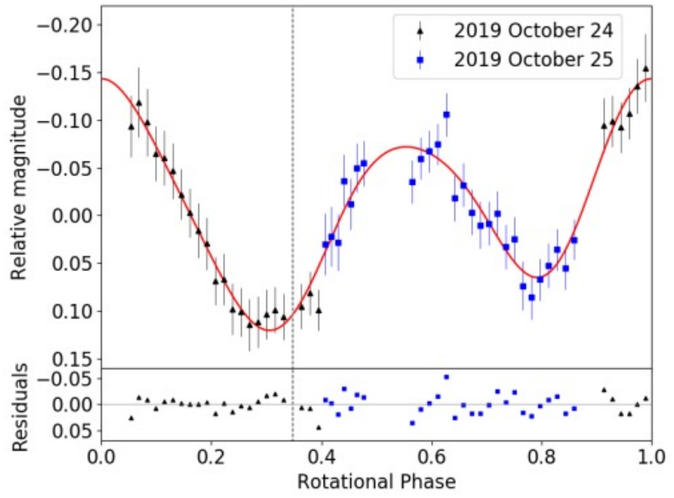
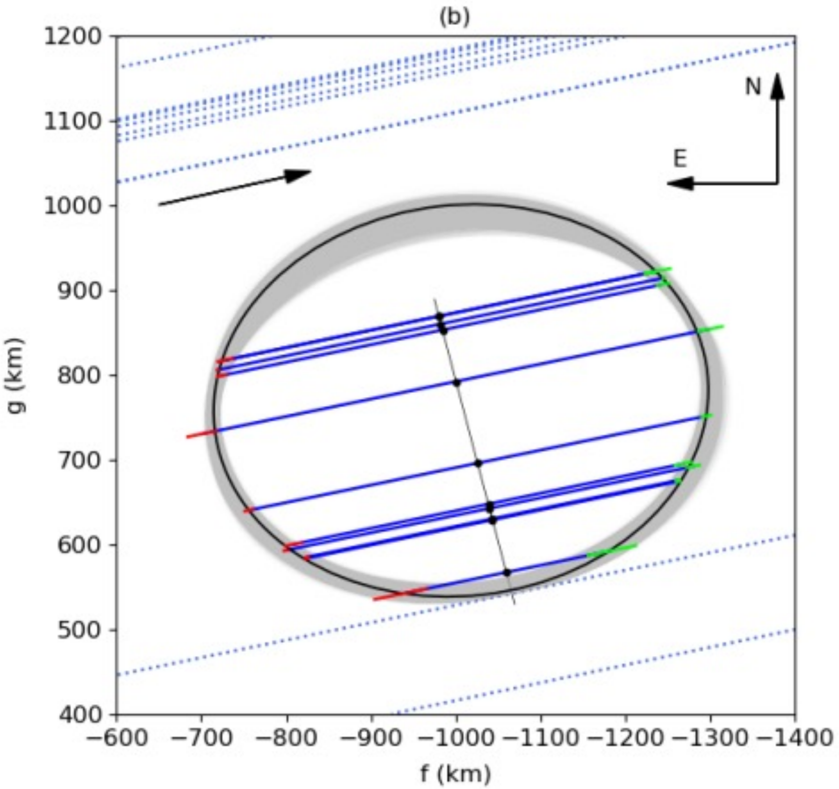
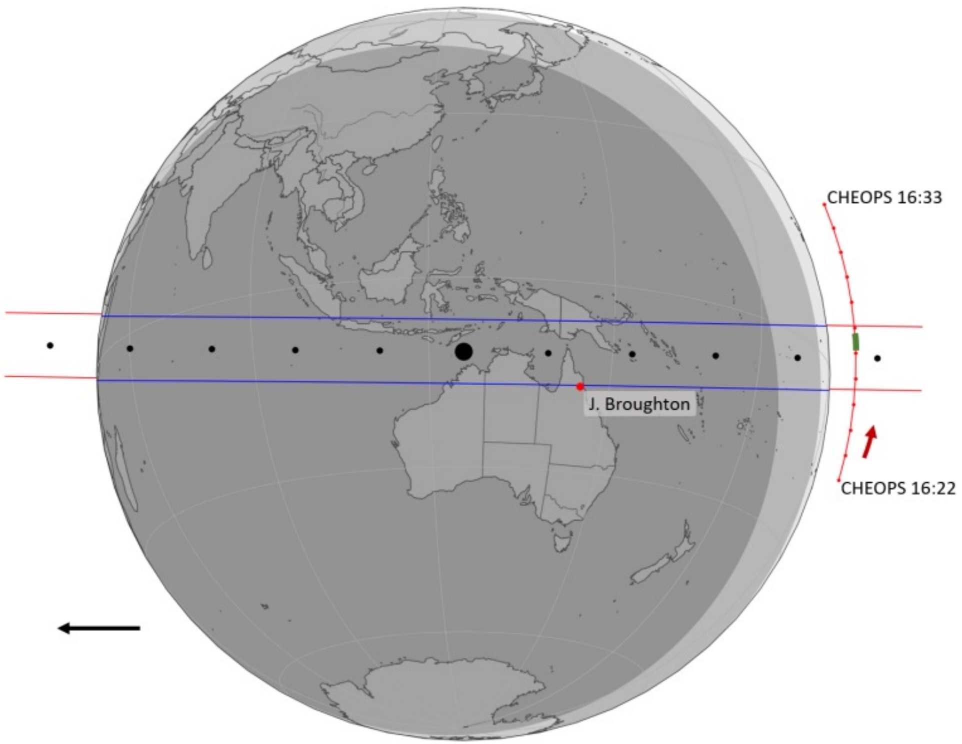


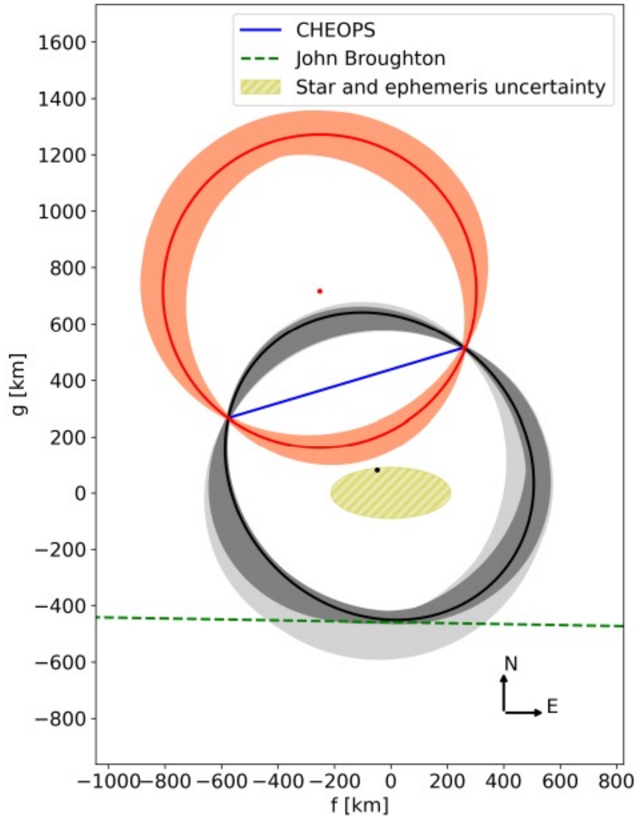
Fig. 4: On top, rotational light curve of 2003 VS_2 from data collected in 2019 October 24 (black triangles) and 25 (blue squares). The data were folded using the rotation period of 7.41753 h (Santos-Sanz et al. 2017). The fourth-order Fourier fit is shown in a solid red line. The vertical black-dashed line indicates the rotational phase of 2003 VS_2 at the time of the stellar occultation. The plot has been arbitrarily shifted to make the minimum of the fit (maximum brightness) correspond to rotational phase 0. On the bottom, differences between the observational data and the fit. Julian dates are not corrected from light travel time.



Vara-Lubiano et al.

Quaorar with CHEOPS





Morgado et al.
2022

The new view of asteroid light curves

- **Synodical period becomes more and more fuzzy**
  - With increasing period
  - With decreasing cadence

- **Unexplained long-term photometric variations**
  - beyond the “canonical” phase+geometry effects

- **Rotaional light curves are even not periodic!**
  - Tiny variations
  - Tumbliers with multiple periods
  - Completely aperiodic “monster” light curves without any recurrent pattern

Good old times

Trojans with SDSS

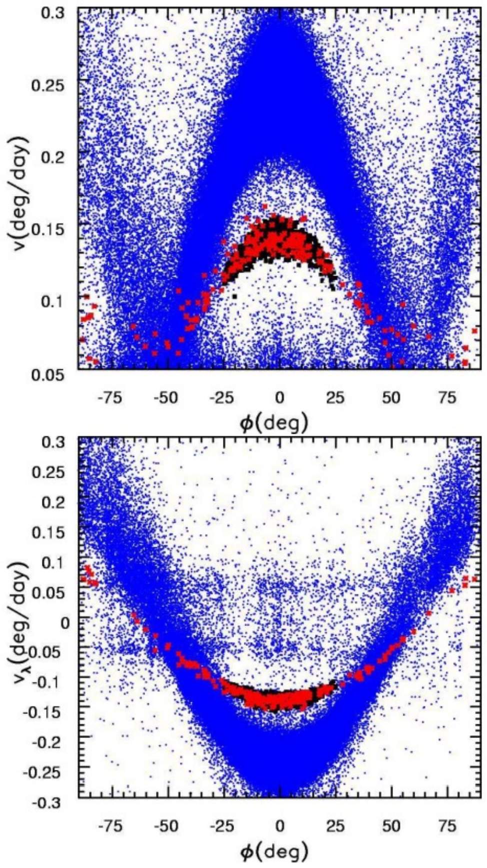
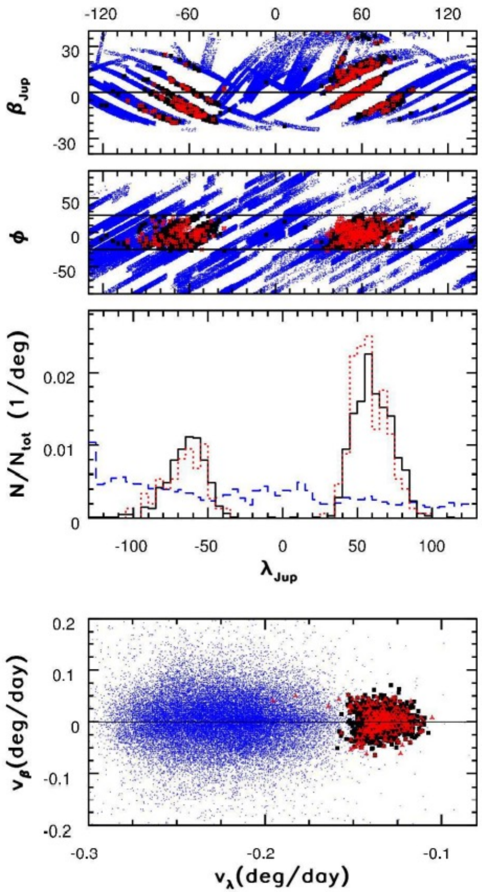
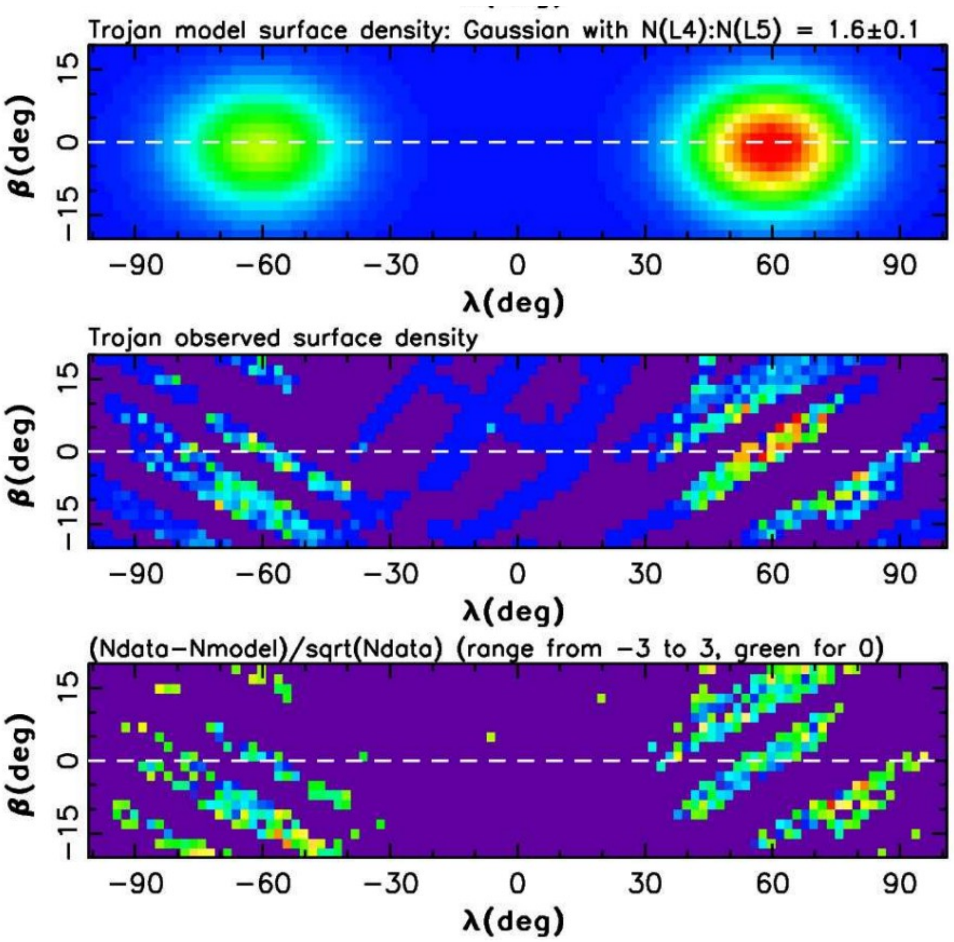


Figure 5. Analogous to Figure 4, except that all ~204,000 ob-





Trojans with SDSS

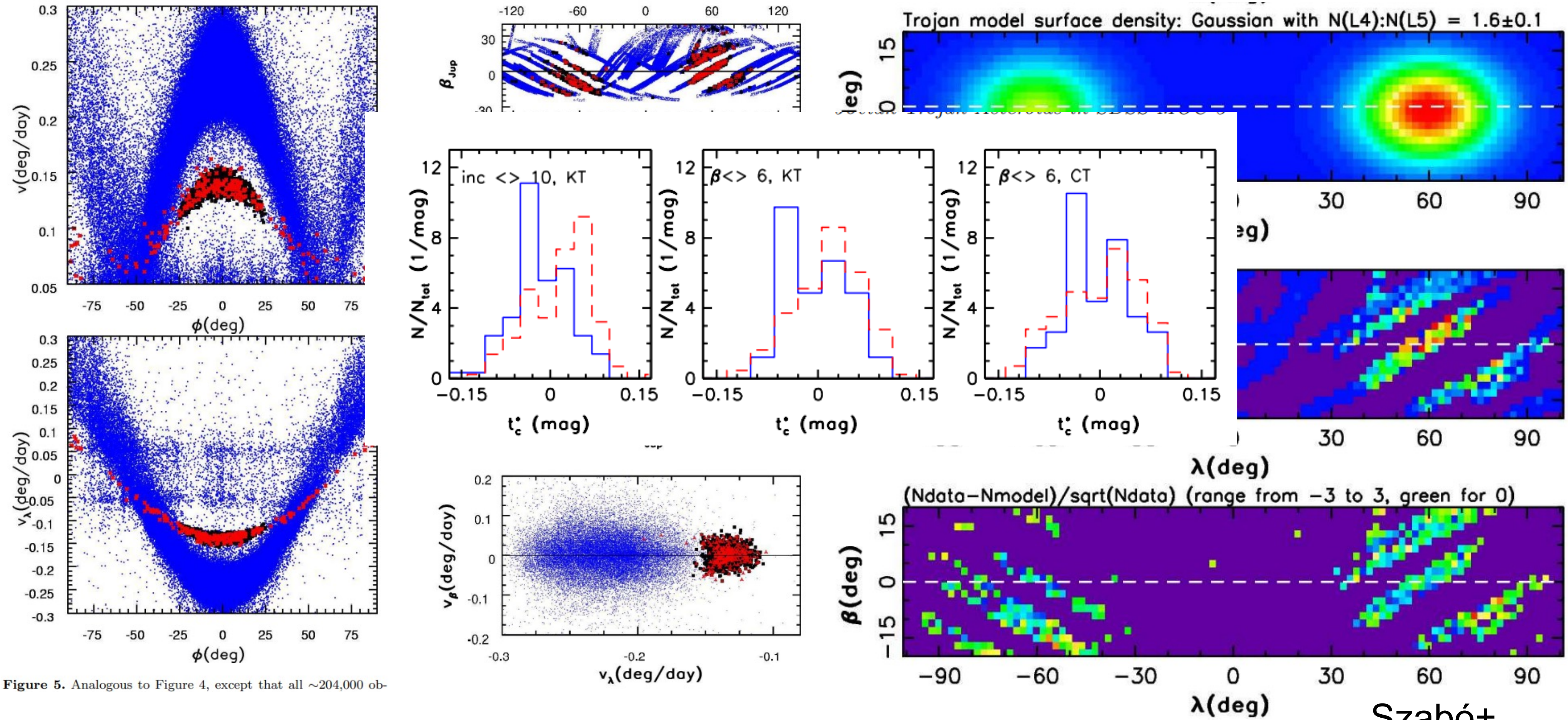


Figure 5. Analogous to Figure 4, except that all ~204,000 ob-

Szabó+

K2 and TESS as Solar System observatories

- LSST
- 10 years span
- High precision
- Multiband
- Sparse sampling

- TESS
- Max. 2x13 days span
- Stroboscopic sampling (0.5 h)
- Magnitude limit

- Kepler
- 2-8 days span
- Stroboscopic sampling
- Better magnitude limit

K2 and TESS as Solar System observatories

K2

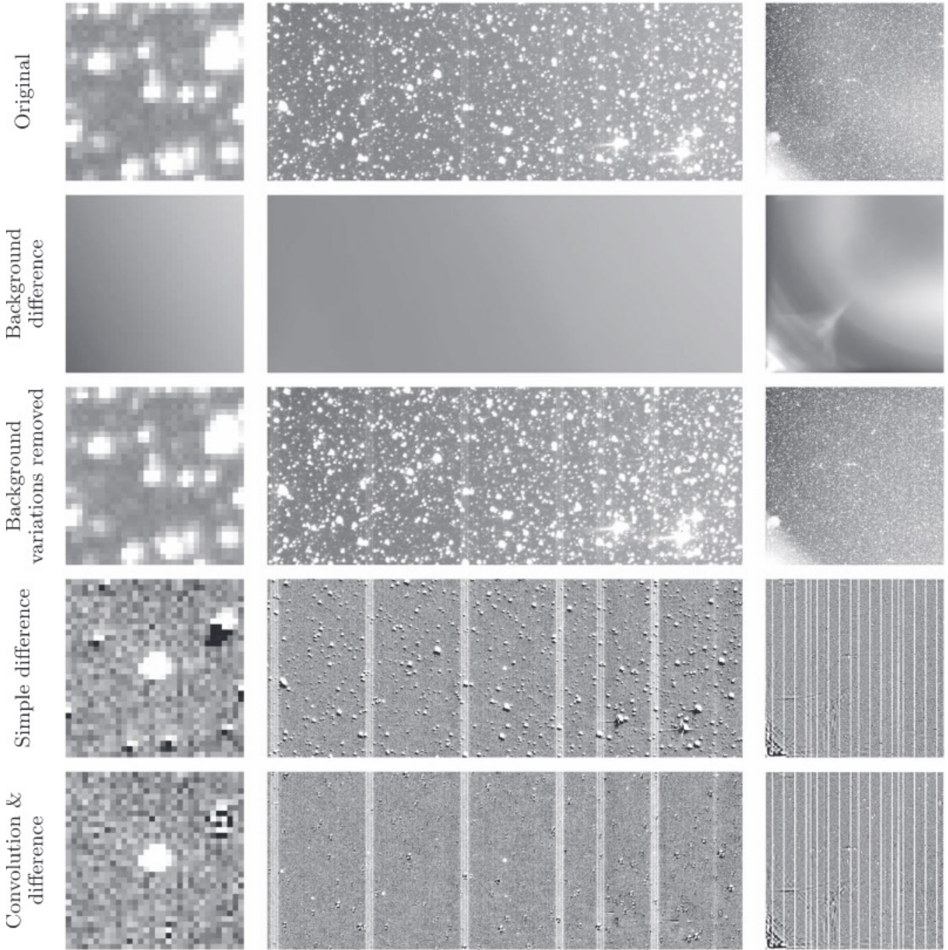
- Main Belt: 1638
  - M35: 924
  - Uranus: 608
  - Nereid: 96
- Hilda: 125
- Trojan: 110

TESS

- 9912
  - Mostly MB (Pál+2020, Szabó+ 2022)
  - S1-S13
- 10,000s to come soon

Deriving rotation parameters from pixels

- Image processing
- Light curve extraction
- Period analysis
- Light curve shape?
  - ALL with visual supervision
- Compiling the catalogs



Pál+ 2020

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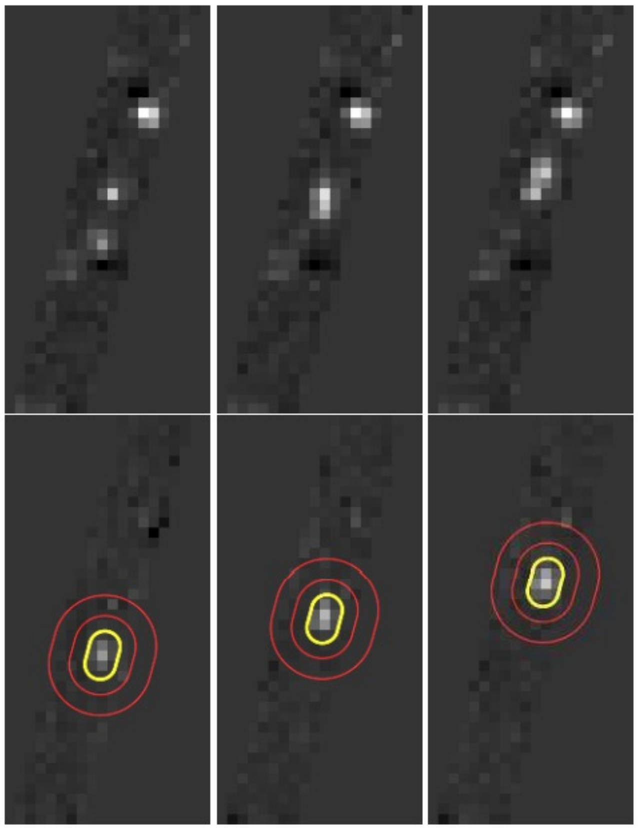

Szabó+
2017

Tasks for LSST

- **Finding faint asteroids**
  - Catalogs, ephemeris, coordinates
  - Assign likelihood to the possible sources
- Photometry of faint asteroids
- With the same algorithms as the TESS asteroid locator?

Deriving rotation parameters from pixels

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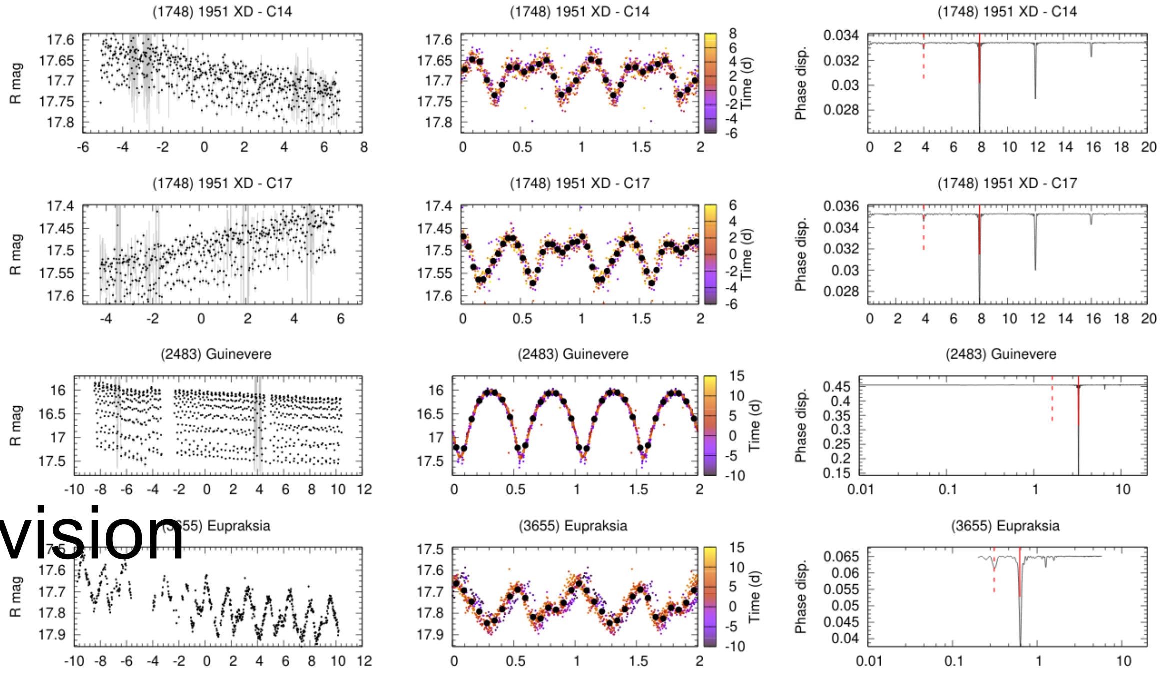
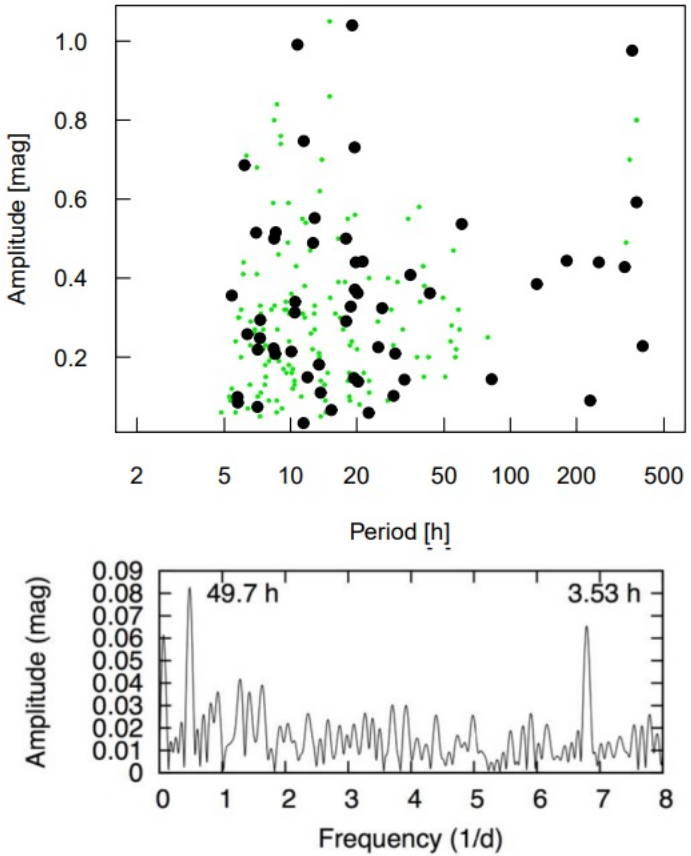


Molnár+ 2018

Deriving rotation parameters from pixels

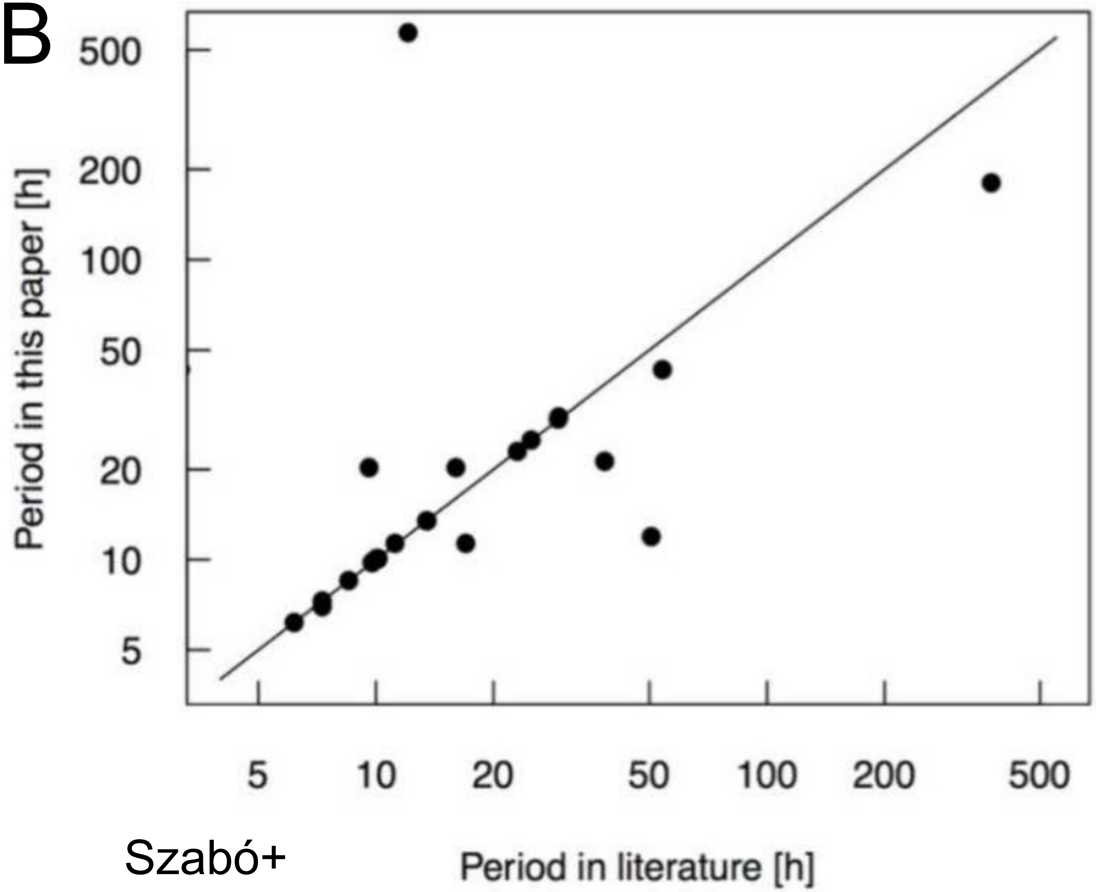


(65227) 2002 ES40

Szabó+ 2017

Reliability of periods

- Cross-check with LCDB
- TESS and K2
- Space light curves
  - Uninterrupted
  - Stable calibration



Szabó+
2017

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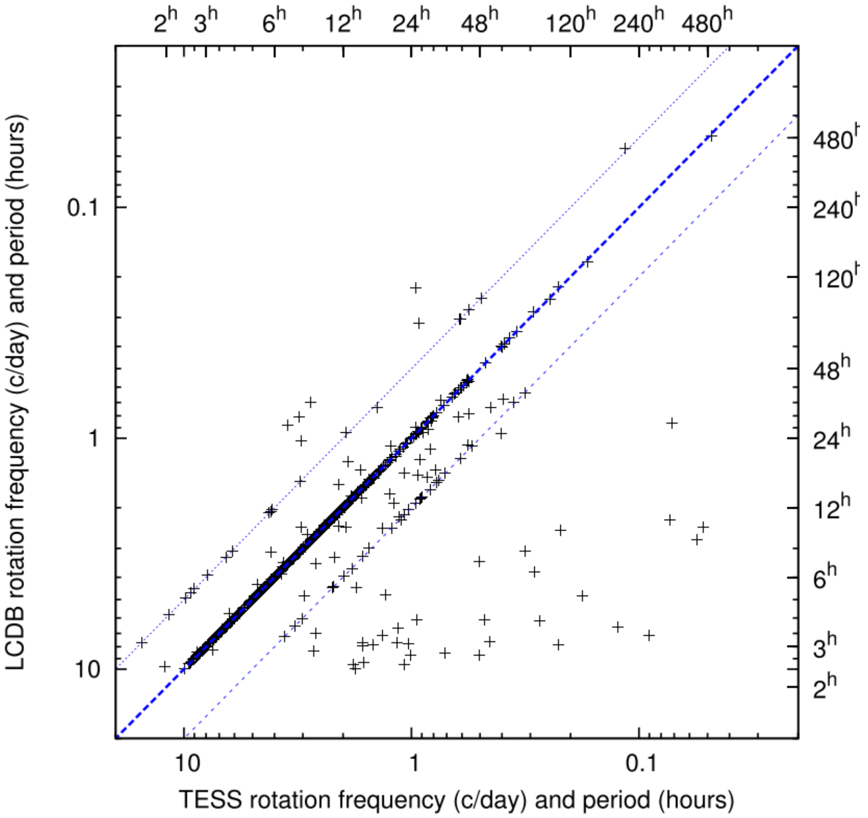
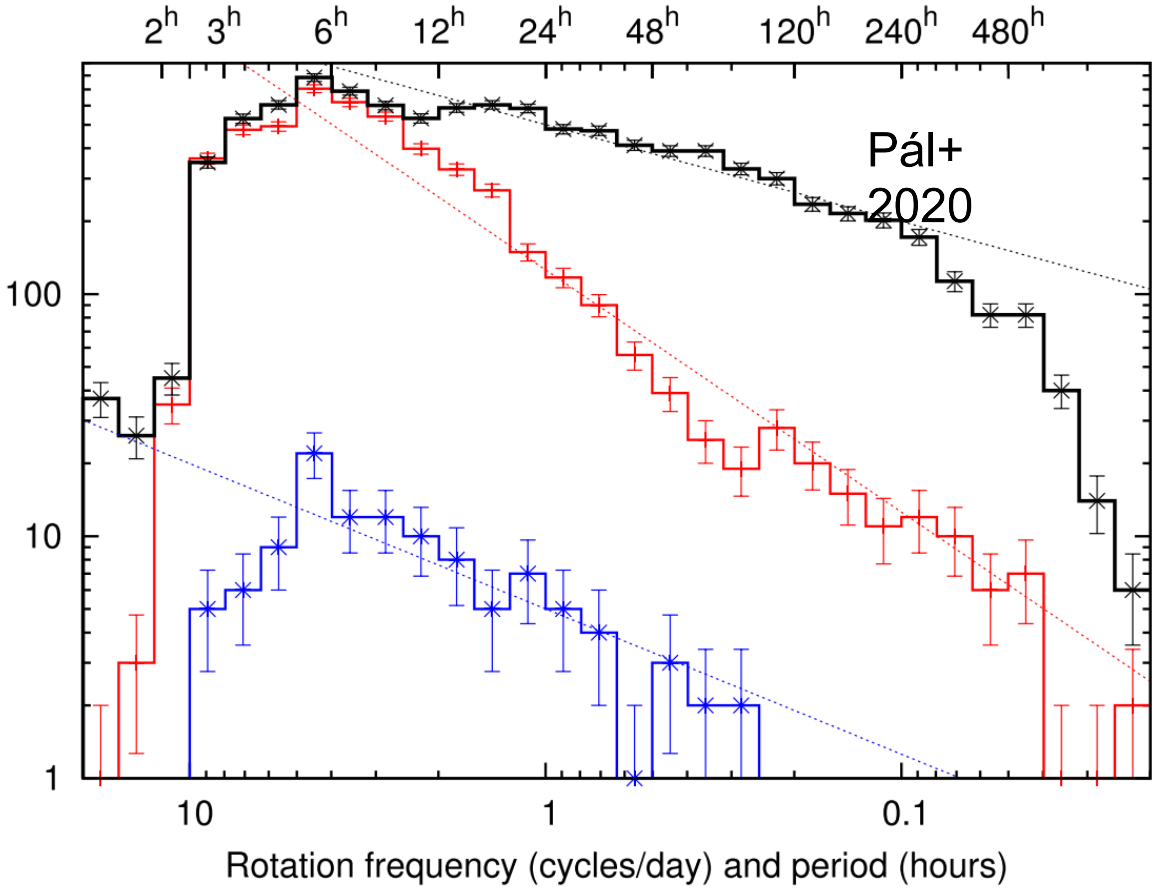


Pál+
2020

The New View

- MUCH more slow rotators
  - 12–600 h range
  - A **factor of 10** around 80 h
- TESS: 30 min sampling?
  - New results coming soon
- K2: confirms the slope!



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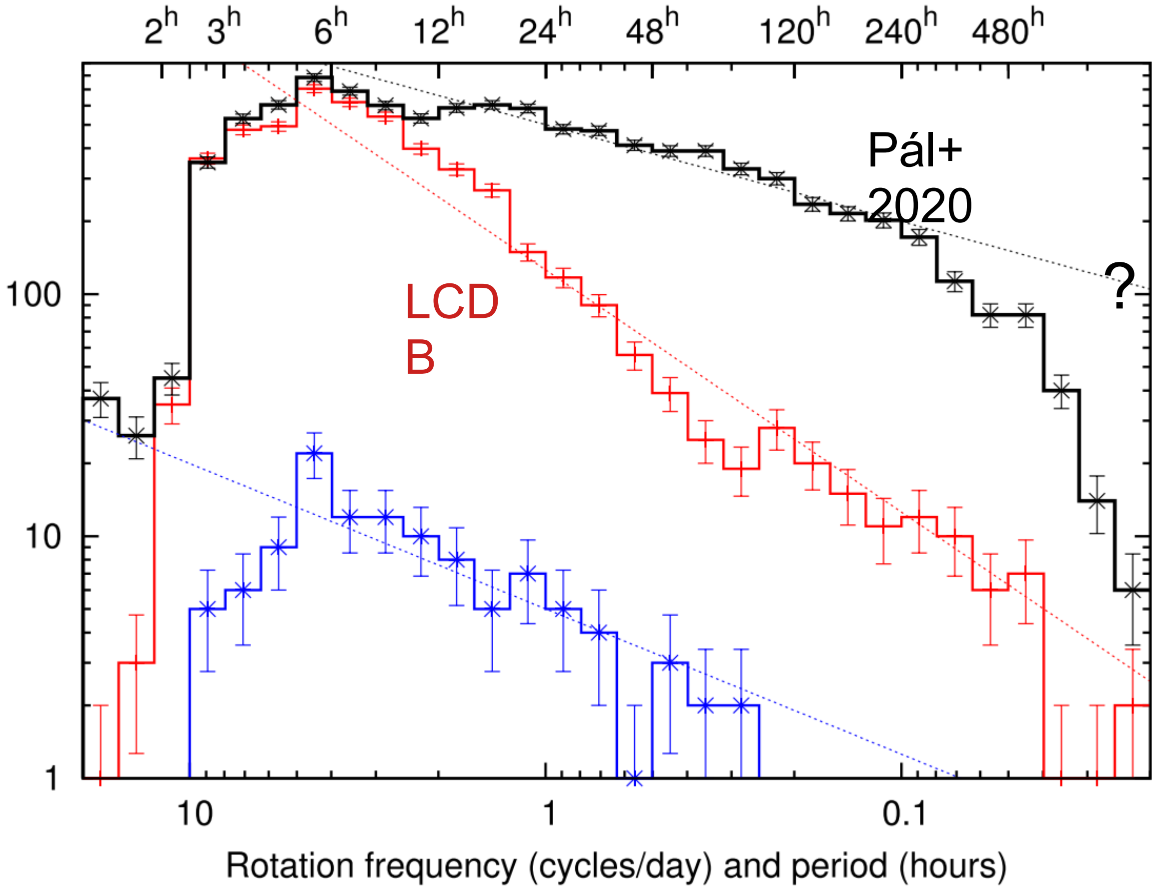
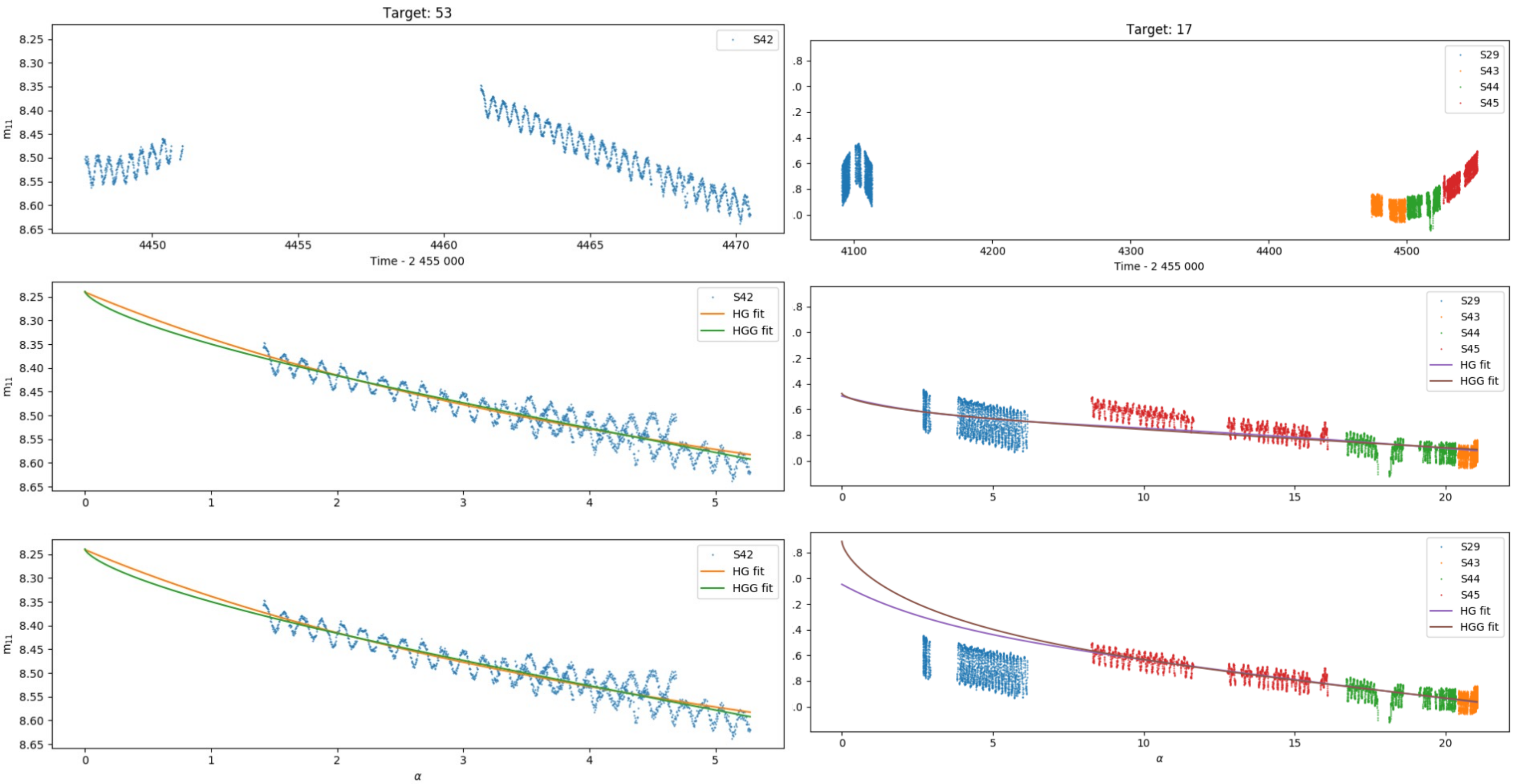




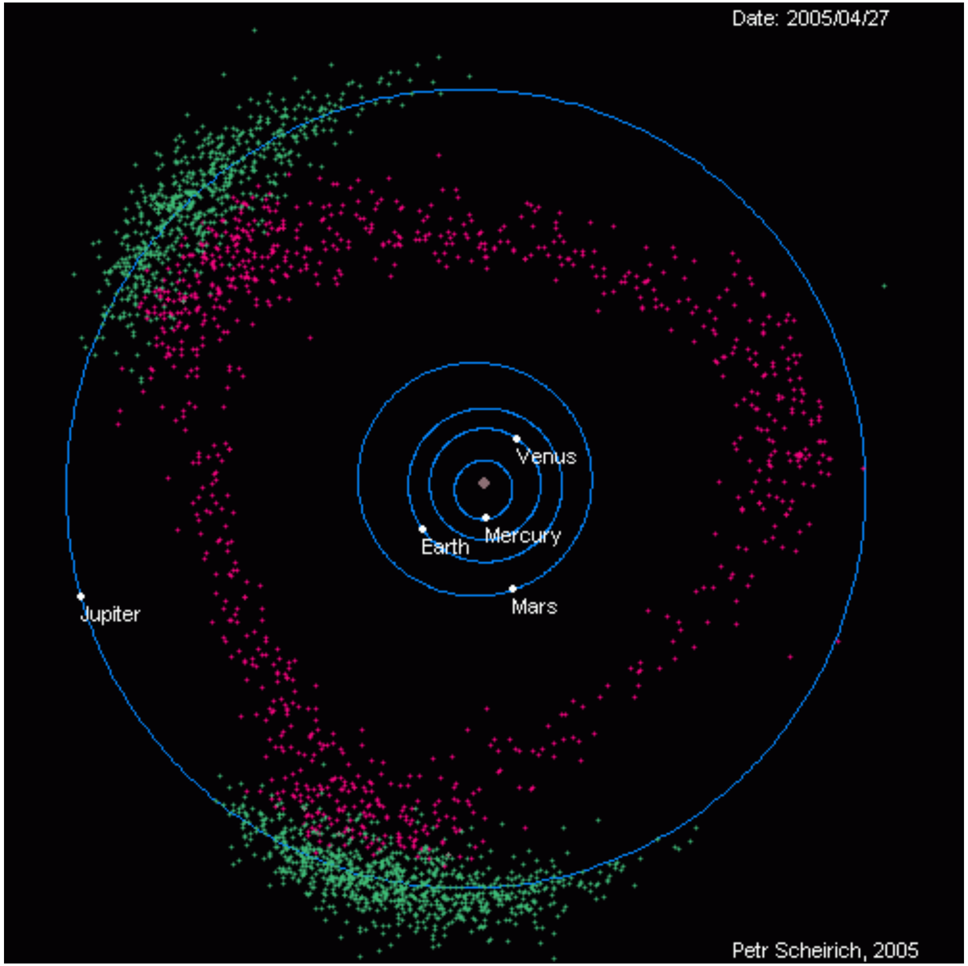
Target: 53
Target: 17
S42
S29
S43
S44
S45
HG fit
HGG fit
m11
Time - 2 455 000
α

Tasks for LSST

- How can we find the period?
  - being clear of aliases?
  - In deep details: stability issues?
  - Unique solutions?

- Very different from how we did it before

Main Belt, Trojans and Hildas



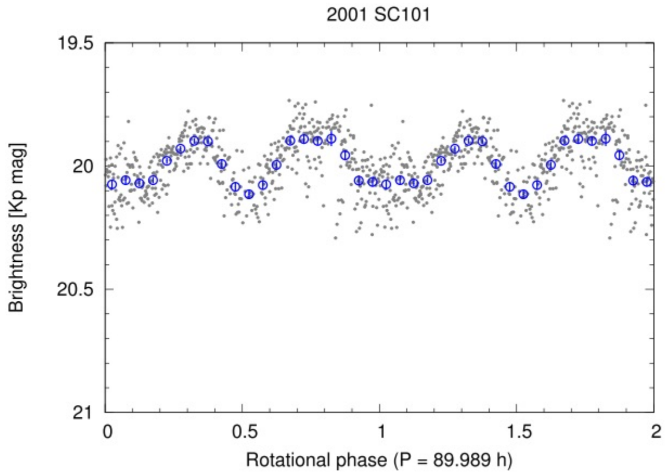
The face of the Trojans

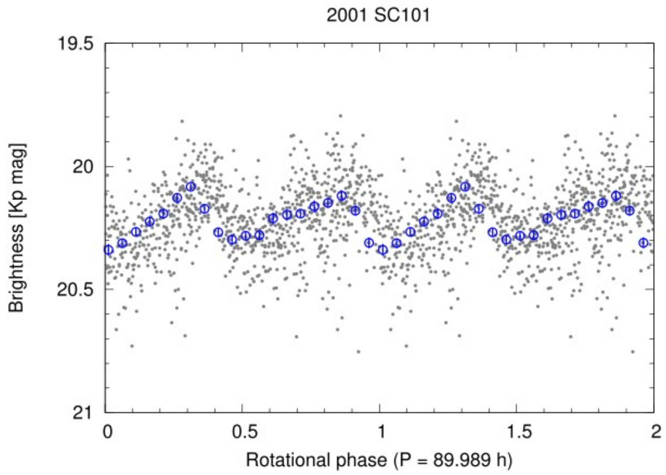
Several Trojans observed multi-epoch

Towards shape modeling

Example: 2011 SC101
89.989 hours

C16 and C18





Kalup+ 2021

Who are the Hildas?

- Lack of very fast rotators

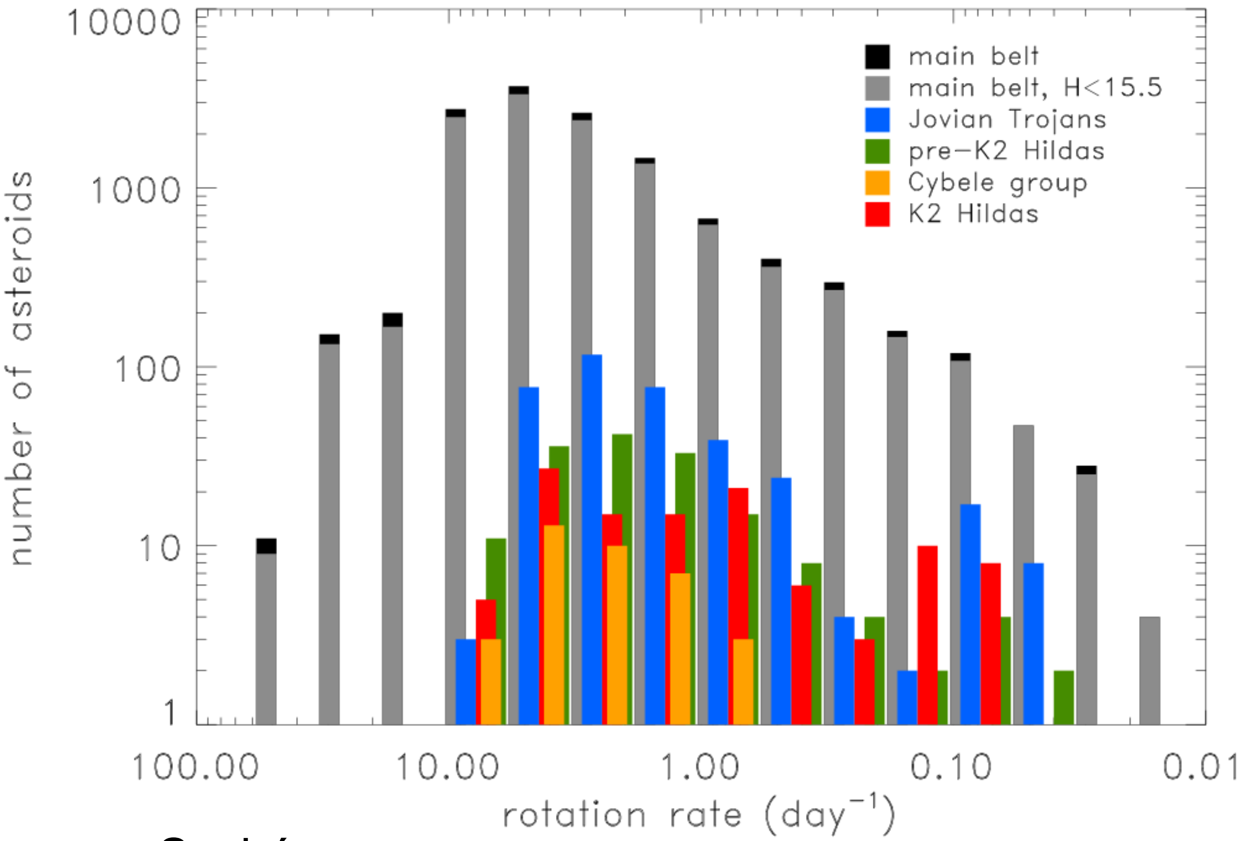
- Lower cutoff of critical density
In Hildas than in MB

- Huge number of very slow rotators
(17%, the highest value in the
Solar System)

- A large fraction of binary Hildas
(20-25%, Nesvorny et al. 2020,
Szabó et al. 2020)

- Hildas differ from Main Bels a lot

- Hildas and Trojans are undiscernable
for rotation statistics!



Szabó+

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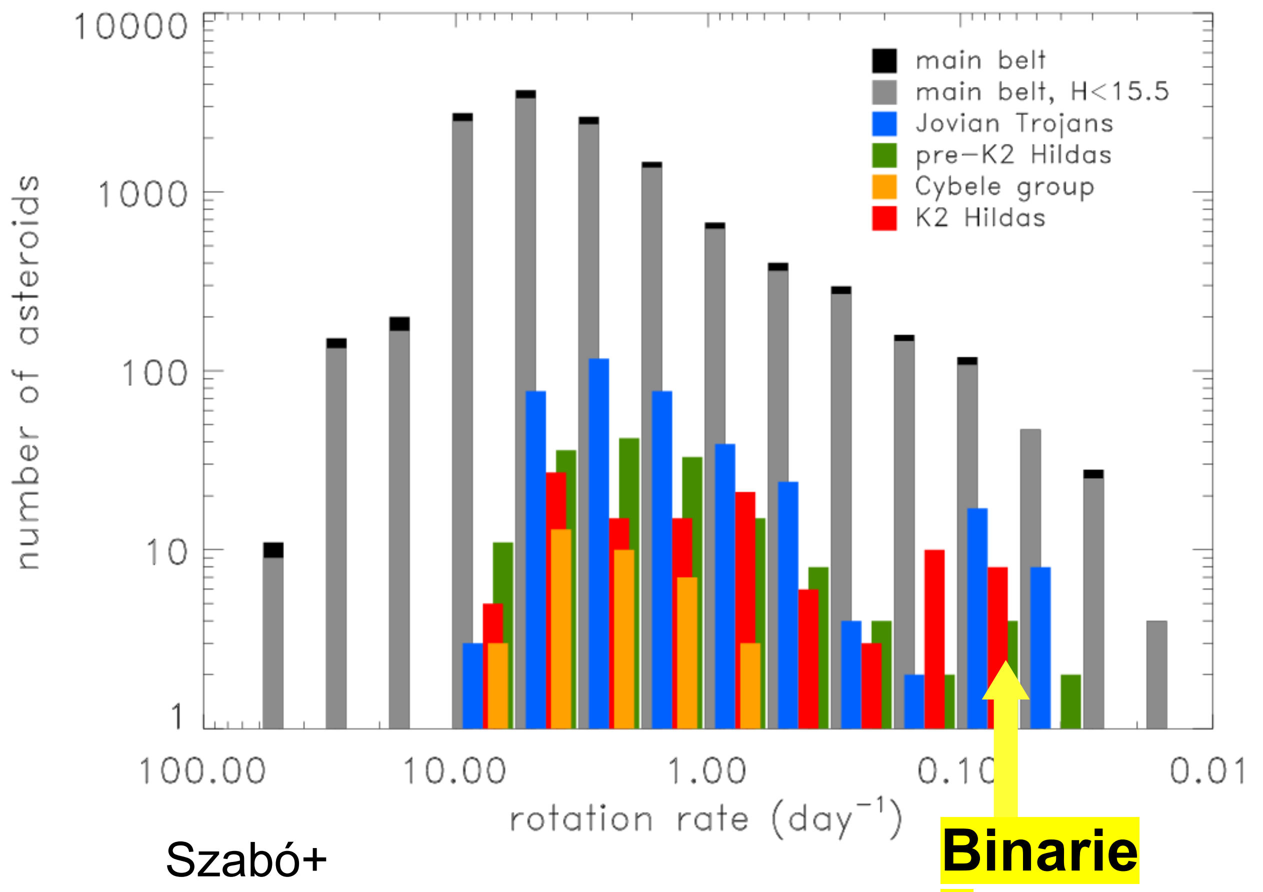


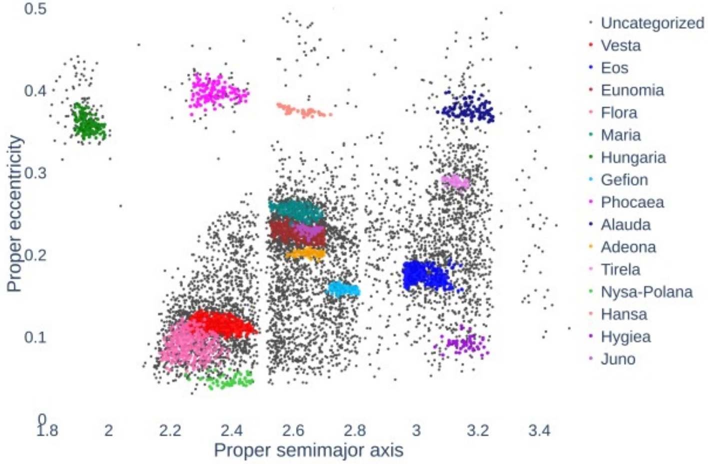
Szabó+

Asteroid rotation in MB families

TESS S1-S13

16 families with Statistical significance

Ages from literature (mostly dynamical)



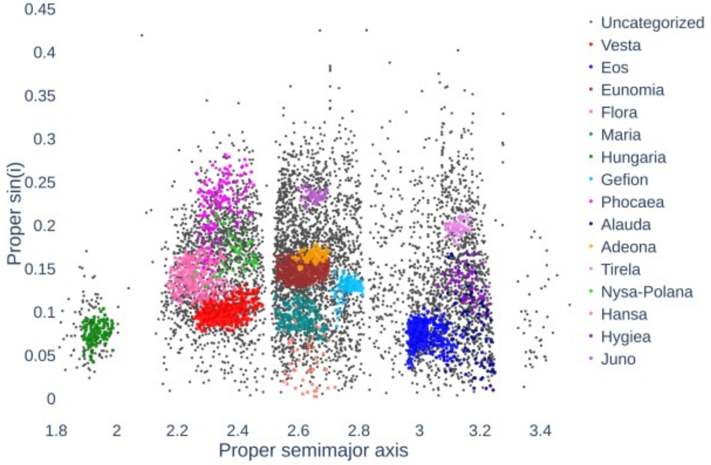


Table 1. Asteroid families examined in this paper. All ages are taken from Brož (2013), and references are given if there have been other investigations on the family age. Notes: [1] considered as old; [2] from cratering statistics.

Family	No.	age (Myr)	Further references
Adeona	92	800 ± 100	
Alauda	98	<3500	Margot & Rojo (2007)[1]
Gefion	130	480 ± 50	
Eos	479	1300± 200	
Eucharis	58	< 3500	
Eunomia	450	1400 ± 200	Milani et al. (2014)
Flora	331	1000 ± 500	
Hansa	51	<1600	
Hungaria	139	500 ± 200	
Hygiea	51	3200^{+380}_{-120}	Carruba et al. (2014)
Juno	51	<700	
Maria	184	3000± 1000	
Nysa-Polana	54	~2000	Walsh et al. (2013)
Phocaea	120	1200 ± 120	Carruba (2009)
Tirela	68	<1000	
Vesta	503	1000 ± 250	

rotators. Cibulková et al. (2018) also present a possible bimodal shape distribution in the case of the Phocaea family.

In the first year of the *Transiting Exoplanet Survey Satellite* (TESS; Ricker et al. 2015) mission, nearly ten thousand asteroid light curves were extracted with unambiguous determination of rotation characteristics (Pál et al. 2020). This data set enabled us to derive some fundamental physical properties for these objects and also to compare the distribution of rotation periods and amplitudes in different asteroid families.

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Asteroid rotation in MB families

SDSS MOC hypothesis:
Old families have more rounded members

Asteroids are reshaped by impact shaking?
(Szabó+ Kiss 2006)

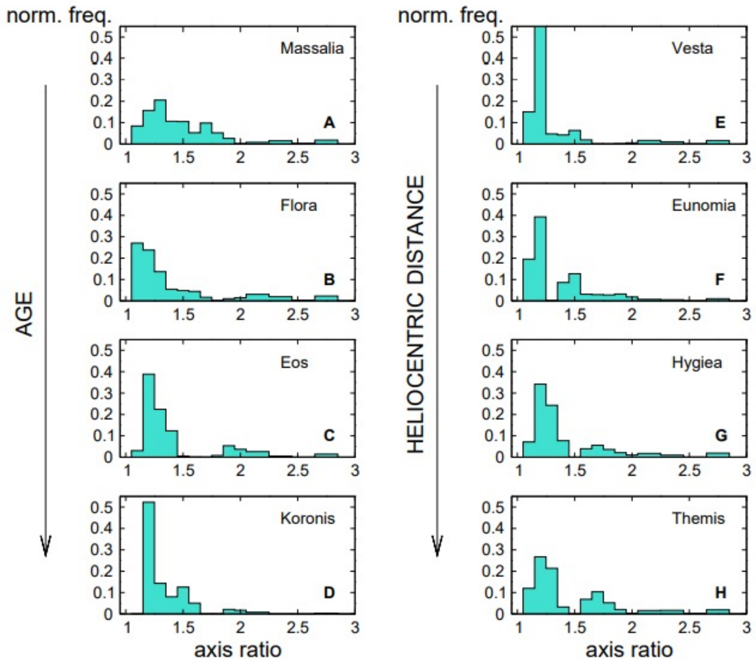


Fig. 4. The evolution of shape distribution in asteroid families. A-D: (Massalia to Koronis) families of 150 to 2500 million years show the dependence on age: the more elongated members of young families erode in time toward rough spheroids, whose relative frequency increases up to 50%. E-H: (Vesta to Themis) old families at increasing heliocentric distances – the farther the family, the more elongated its members. Note the distinct peaks of the distributions.

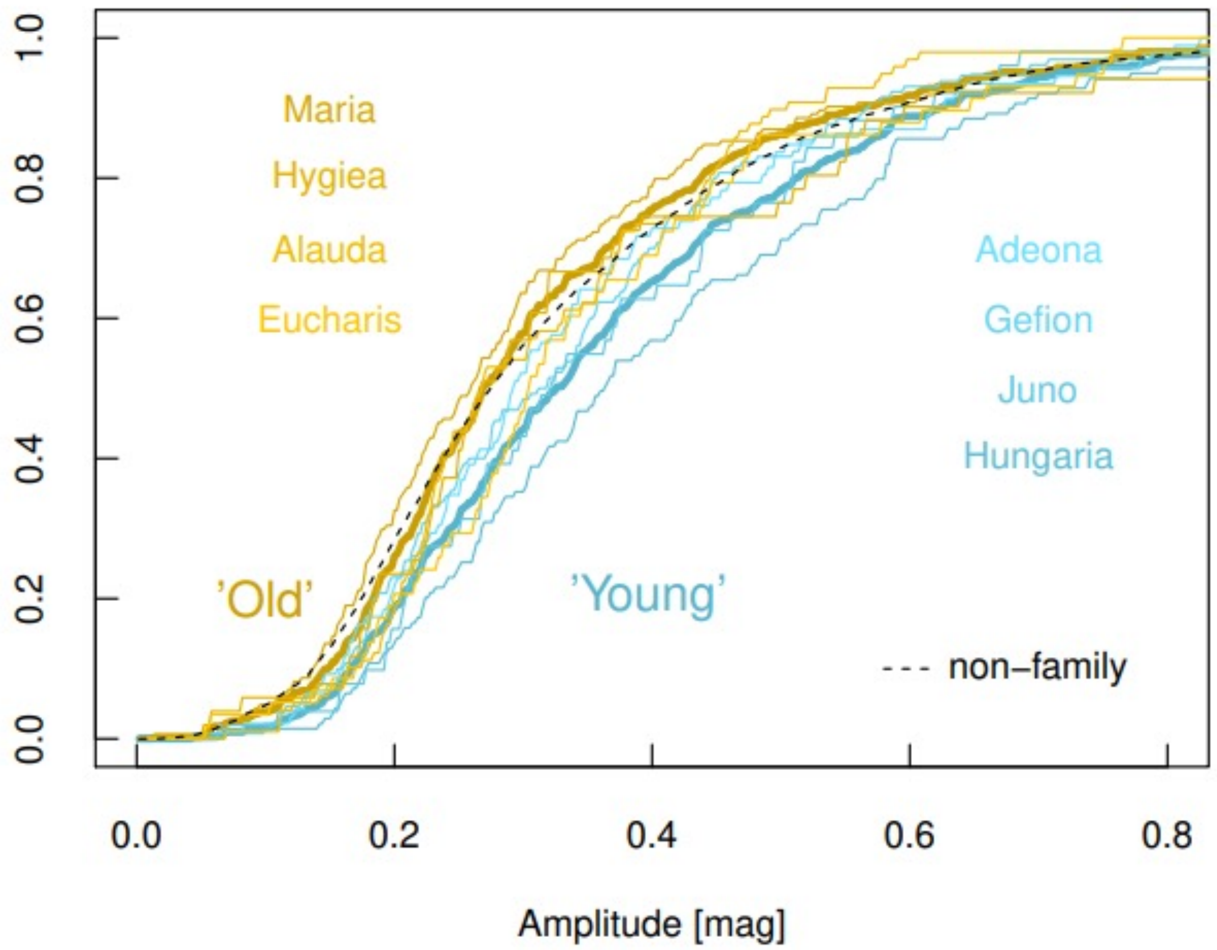
Asteroid rotation in MB families

TESS S1-S13

16 families with
Statistical significance

Ages from literature
(mostly dynamical)

- Mean amplitude decreases with age

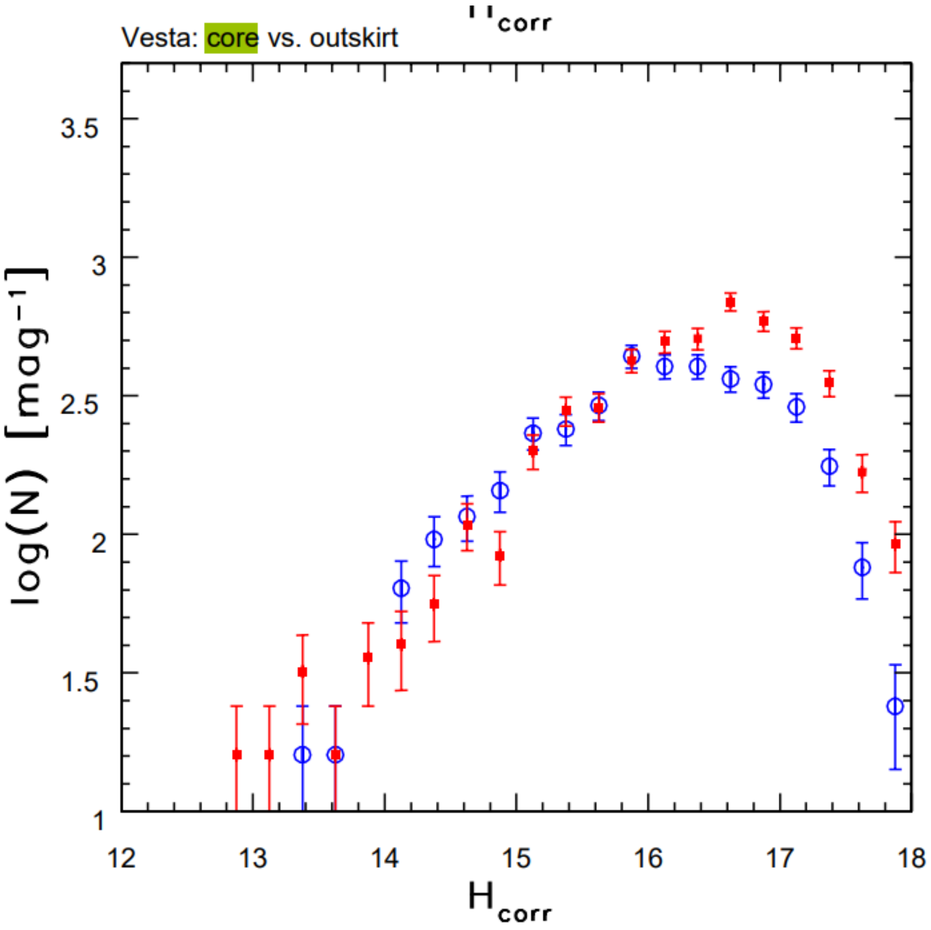


Szabó+ 2022

Family structure in the Main Belt

Cores and outskirts are known to have asteroids with different size distribution
power laws

(Parker et al. 2008)



Asteroid rotation in MB families

TESS S1-S13

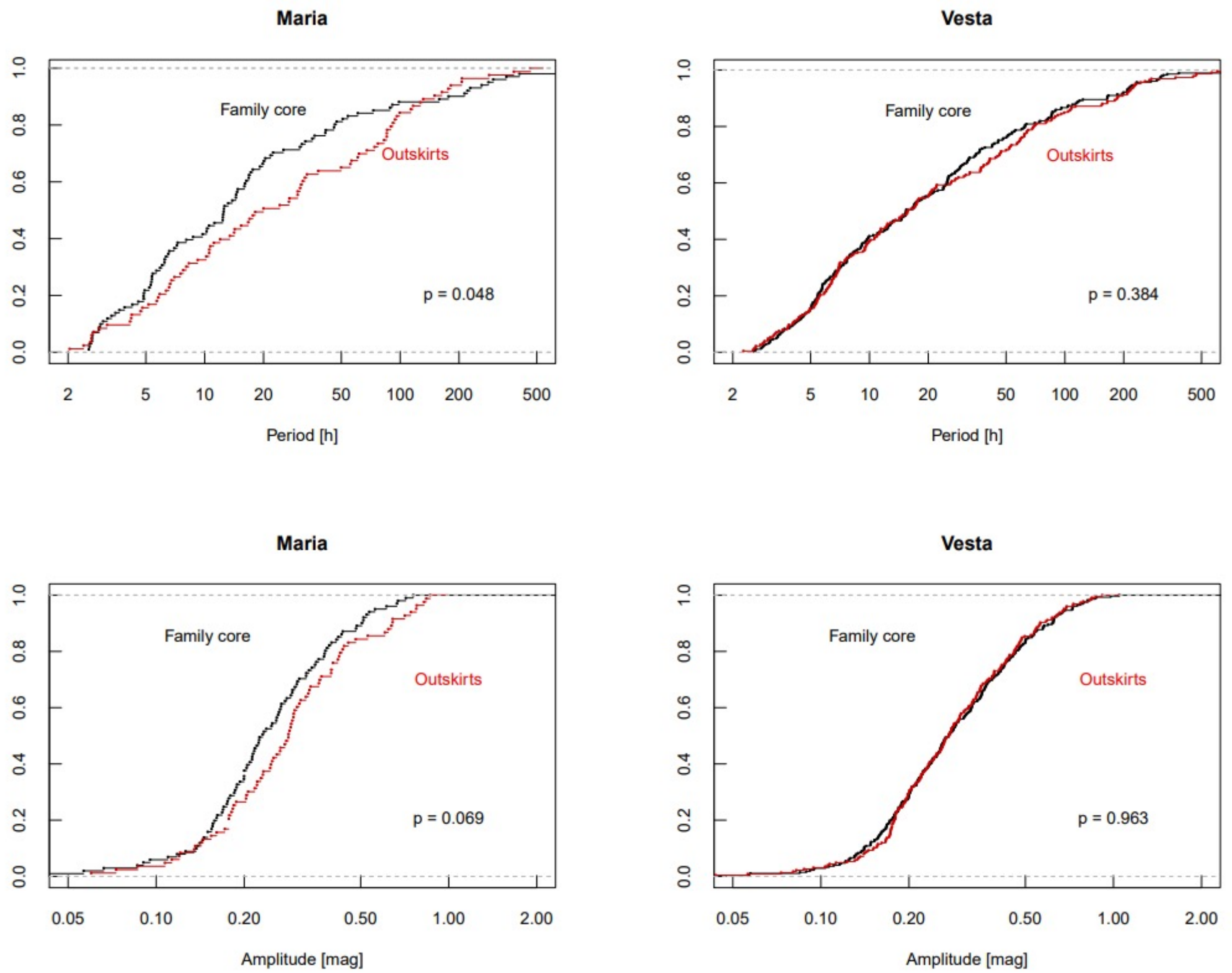
16 families with
Statistical significance

Ages from literature
(mostly dynamical)

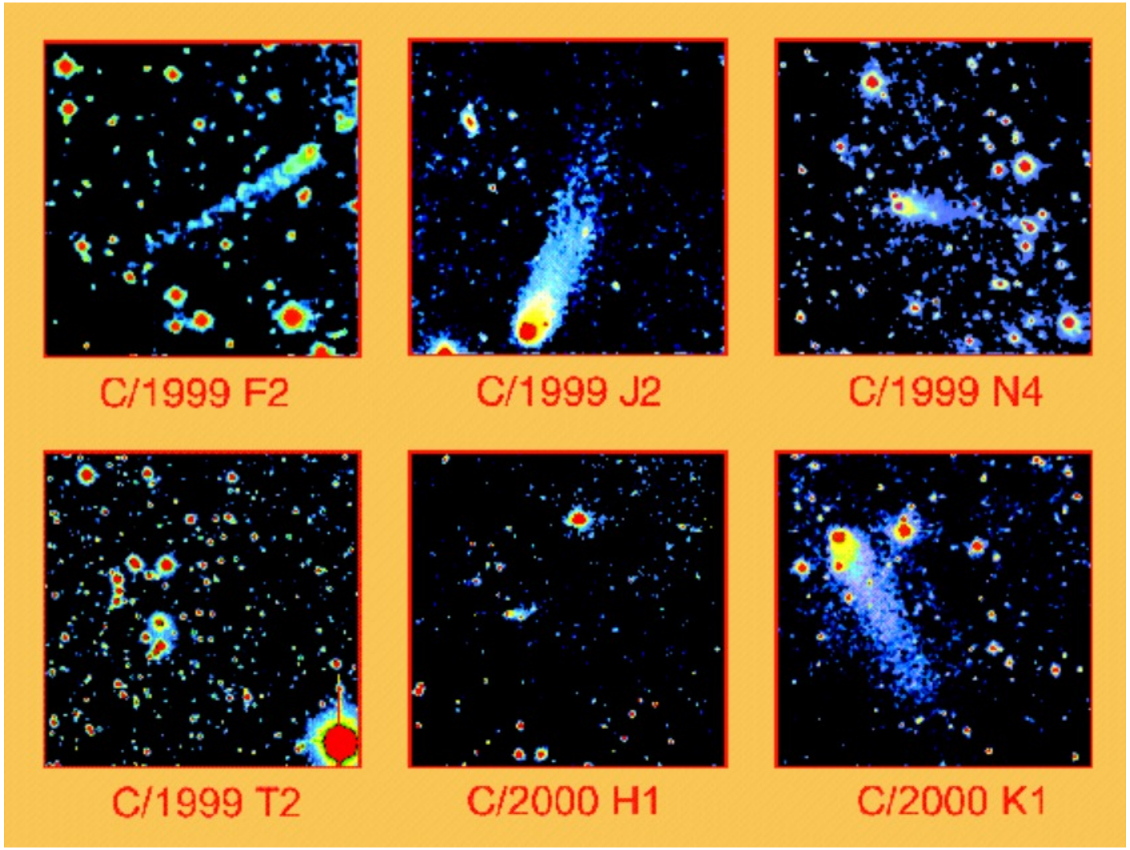
- **Mean amplitude decreases with age**
(also Szabó+Kiss 2006)

- Some families have **internal structure**

Szabó+



Comets with LSST



LP comets
Active beyond Jupiter's orbit

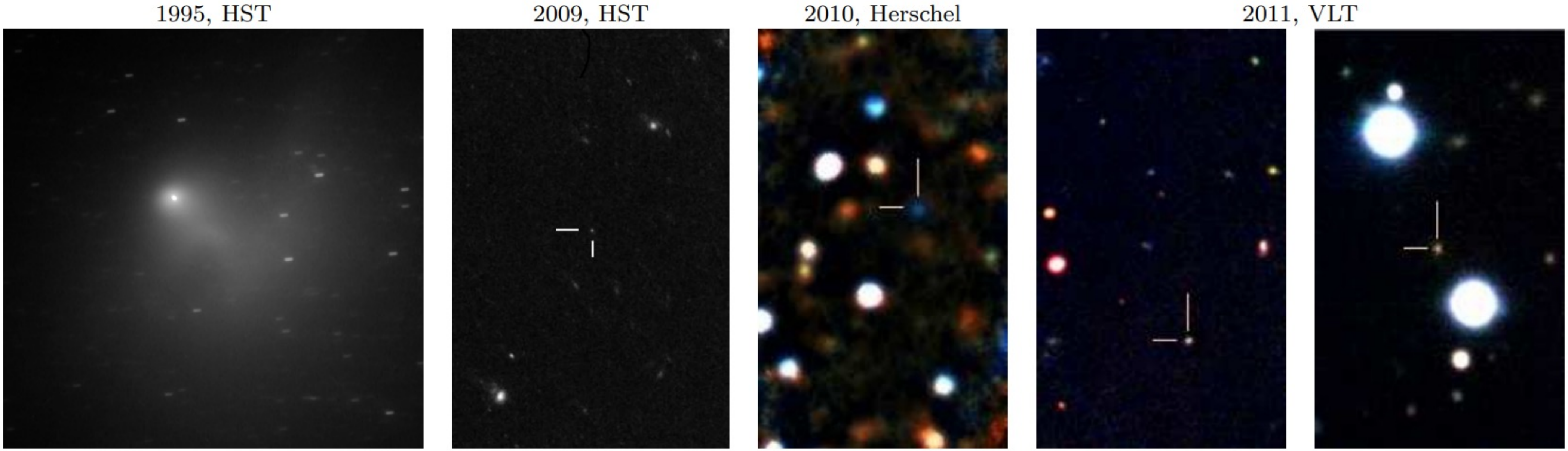
A&A cover page image
Volume 374 / No 2 (August I 2001)
Szabó et al.

A generalized coma model for LSST

$$I(r,\alpha) = \frac{C(\alpha)}{\gamma + r^{\beta(r,\alpha)}}.$$

$$\beta(r,\alpha) = \beta_0 + r\beta_1 \sin(\alpha - \beta_2).$$

(Szabó et al. 2011)



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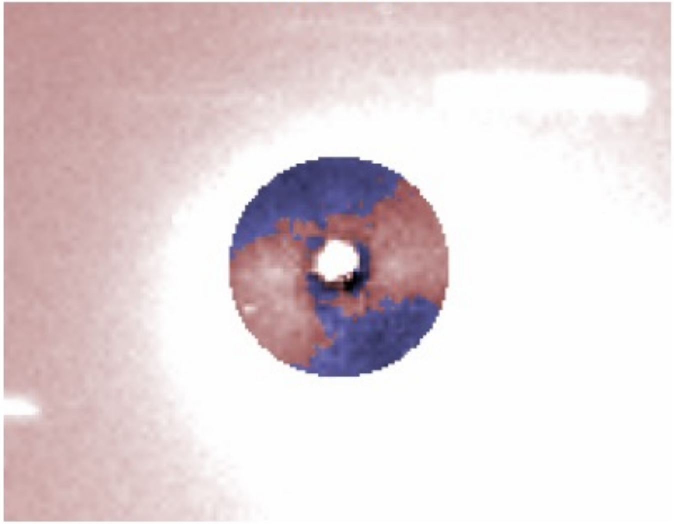
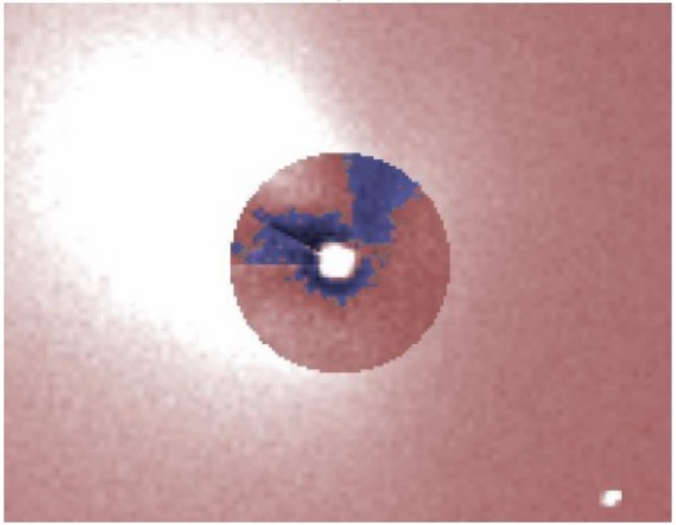
23 Oct 1995



20 May 1996



1995, HST