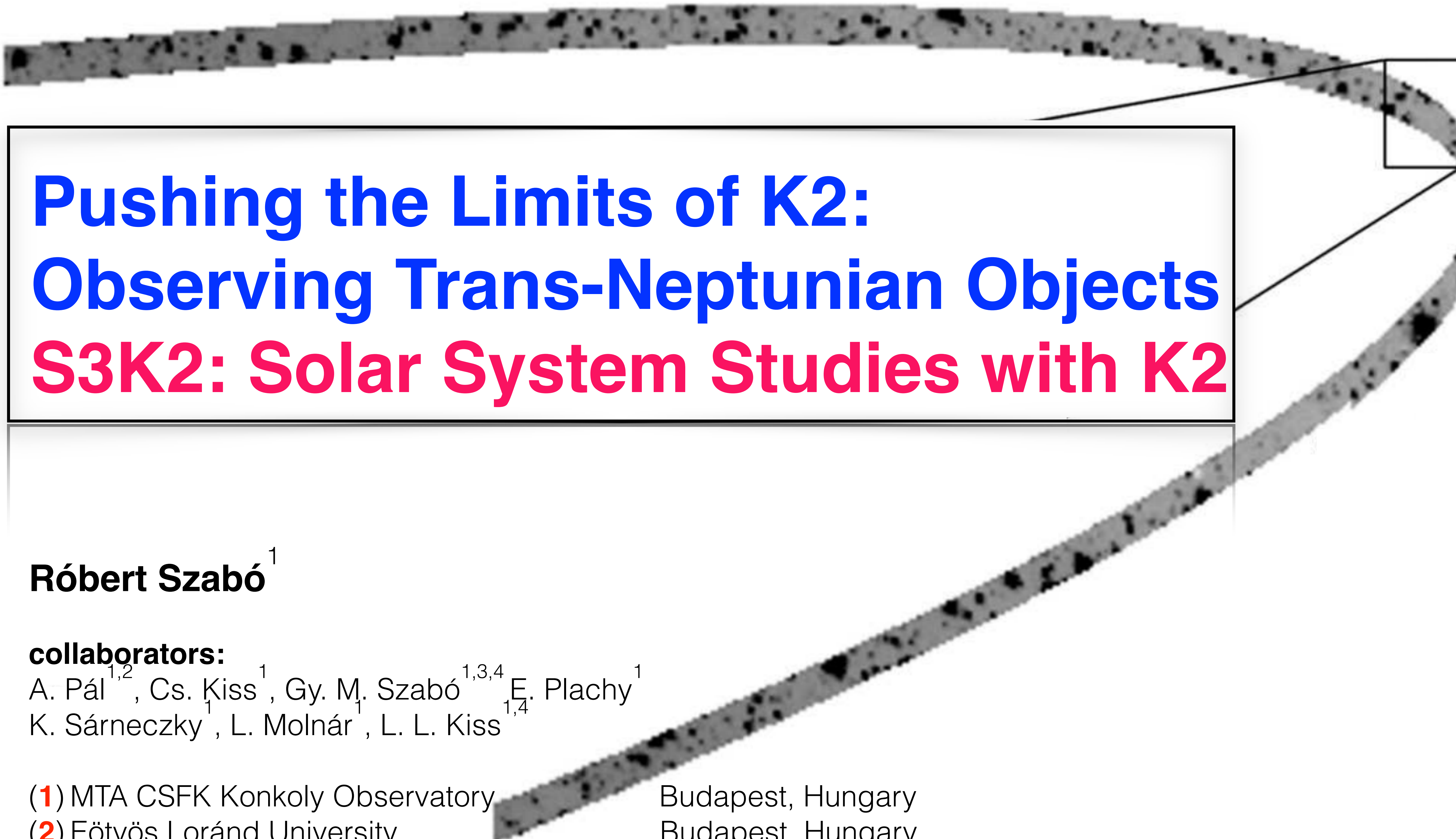

Pushing the Limits of K2: Observing Trans-Neptunian Objects

S3K2: Solar System Studies with K2

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(**4**) Gothard - Lendület Research Team, Szombathely, Hungary

Goals and methods

- Group of Hungarian senior and young astronomers, experts in **Kepler/K2 photometry**, variable stars, exoplanets, **infrared photometry**, **comets/asteroids**

WHO

- **Solar System** studies with Kepler/K2
- pushing the limits:
  detection of faint and moving objects
  Trans-Neptunian objects + Main-Belt Asteroids + moons
- study rotation rate, surface variegations, companions

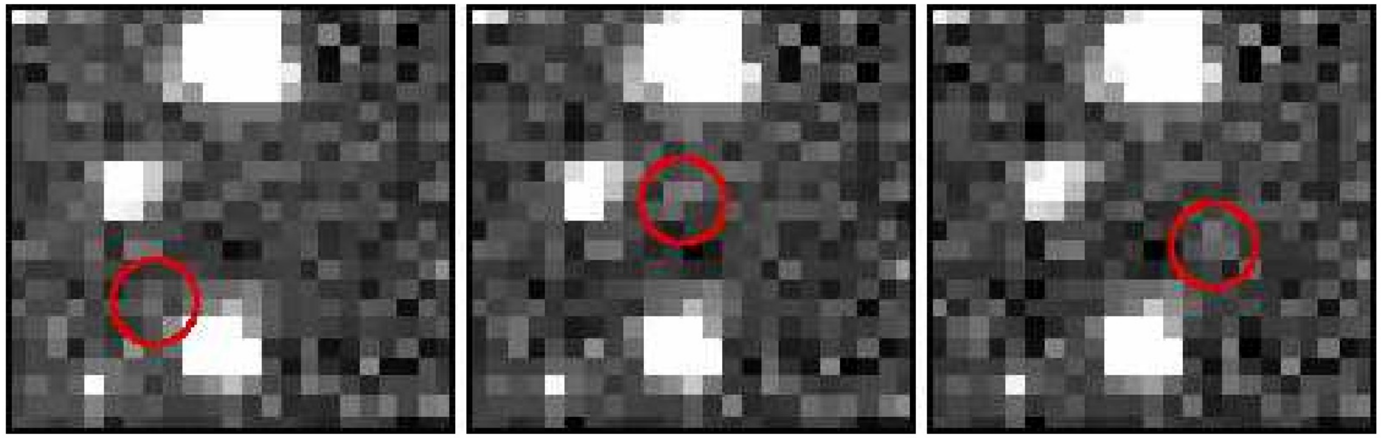
WHAT

- **boomerang-shaped pixel masks** around the stationary point (TNOs)
- large, contiguous **supermasks** (open clusters, etc.)
- astrometry + optical photometry:
  fitsh package (Pál 2012, **http://fitsh.szofi.net**)
- **infrared**: Herschel "TNOs are Cool!" key program
- **thermophysical modeling**
  thermal flux + abs. magnitude + rotation —>
  diameter + geom. albedo
- White Paper Kiss Cs. et al. 2013

HOW

TNO 2002 GV_{31} in C1

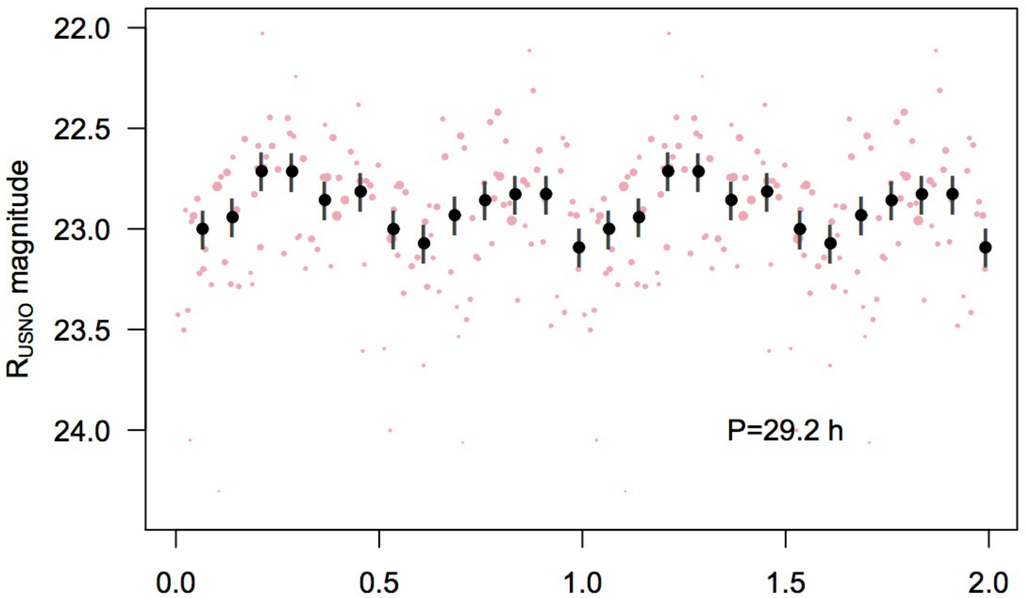
- classical Kuiper-belt object
- 40 - 48 AU P_{orb} =295yr
- R= **22.5 - 23.0** mag
- Herschel: no detection
- d<180 km



1-day co-added images

- K2: averaged 5 measurements: resulting in **129** data points
- **16** days around the stationary point

- **Detection!**
- First light curve information
- P_{rot} = **29.2 ± 1.1 h**
- long rotation period
  most TNOs have P_{rot} < 1 day



White Paper Kiss Cs. et al., GO1064 Szabó

Pál et al. ApJ, 804, L45, 2015

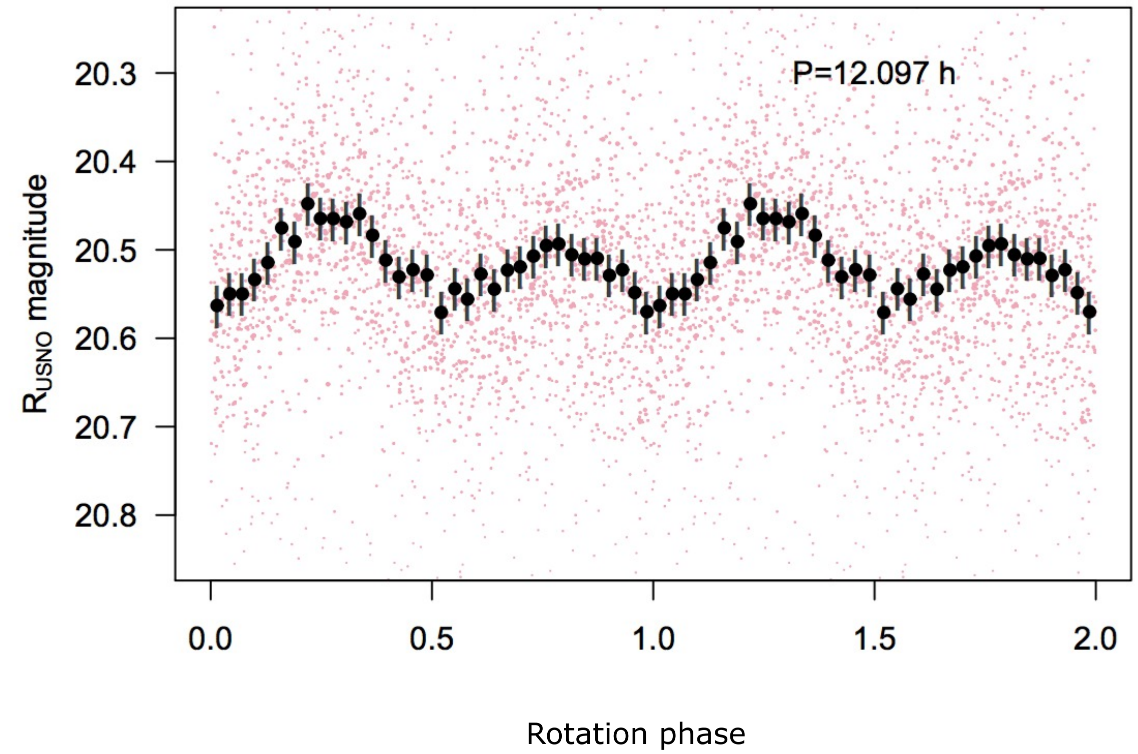
(278361) 2007 JJ_{43} in C2

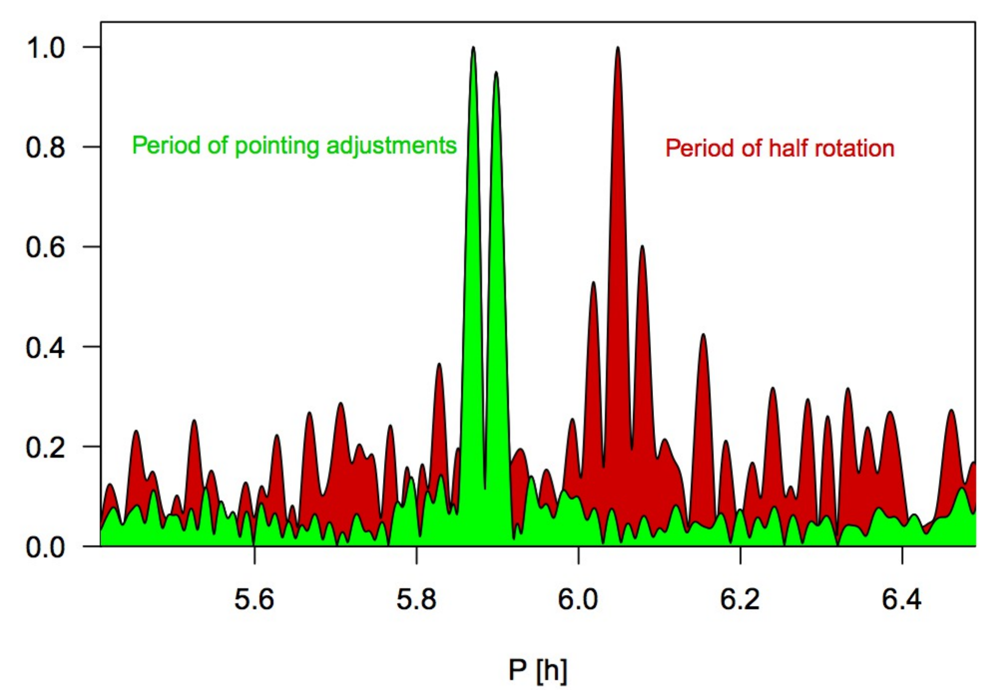
- outer Kuiper-belt object
- 40-56 AU e=0.159 i=12.0°
- likely in 2:1 resonance with Neptune
- d = 670 ±150 km

- asymmetric phased light curve
- P_{rot} = **12.097 h**
- rot. period clearly separated from the pointing adjustments

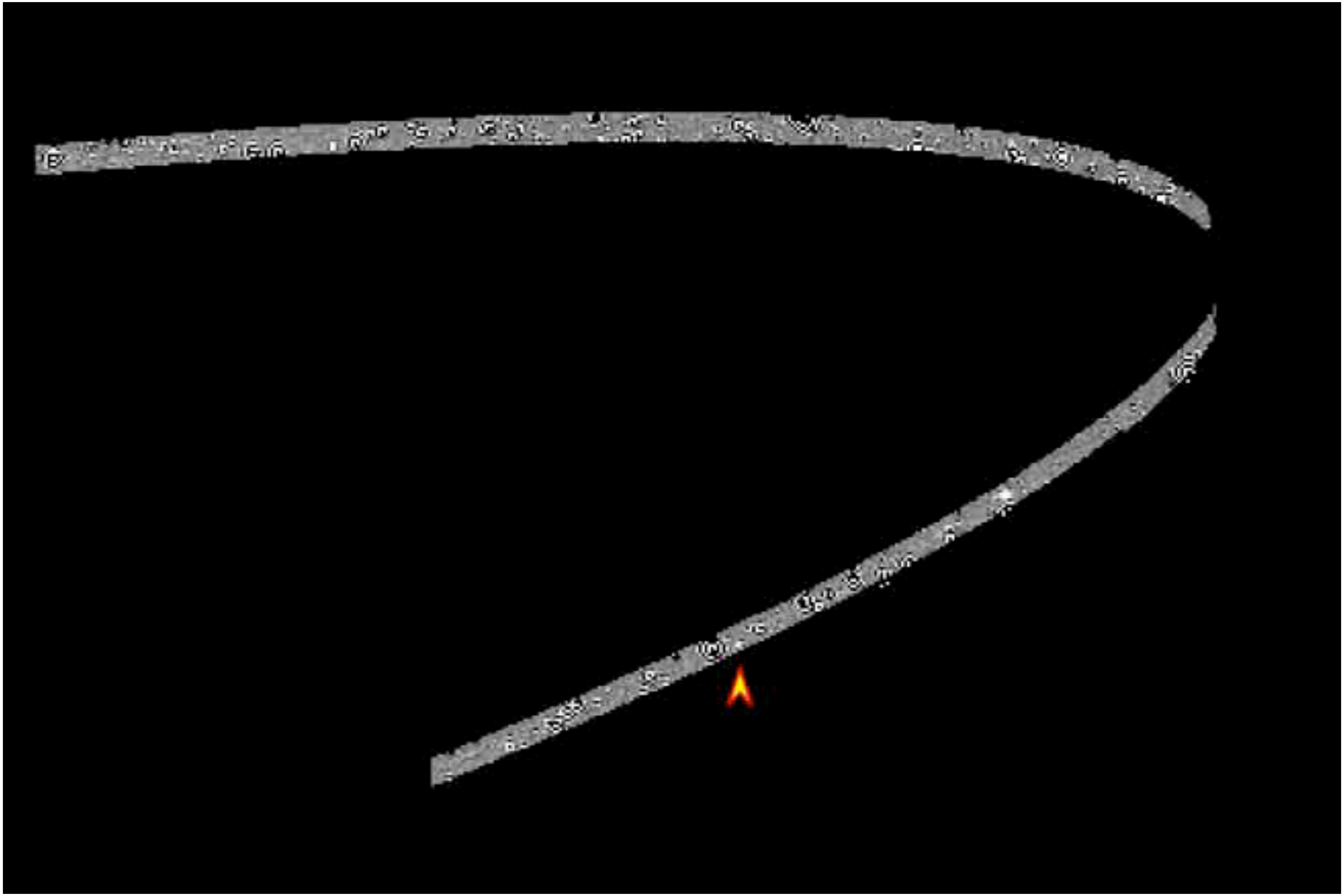
- Benecchi & Sheppard (2013) rot. period confirmed
- uneven surface structures / shape

GO2066 Schwamb,GO3053 Szabó
Pál et al. ApJ, 804, L45, 2015



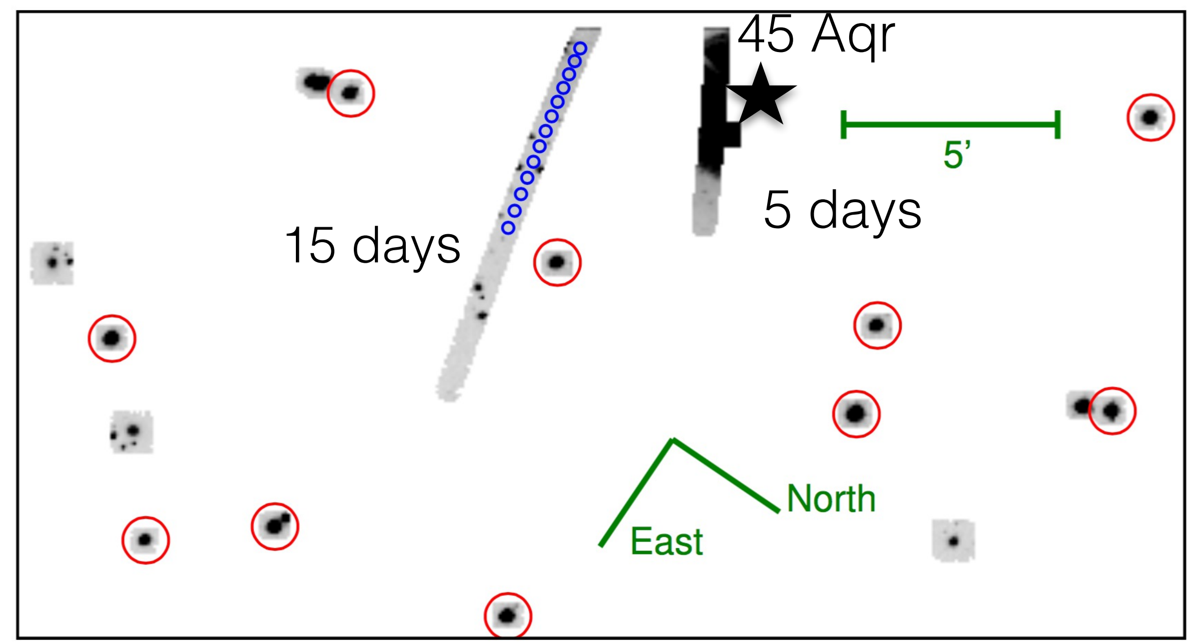


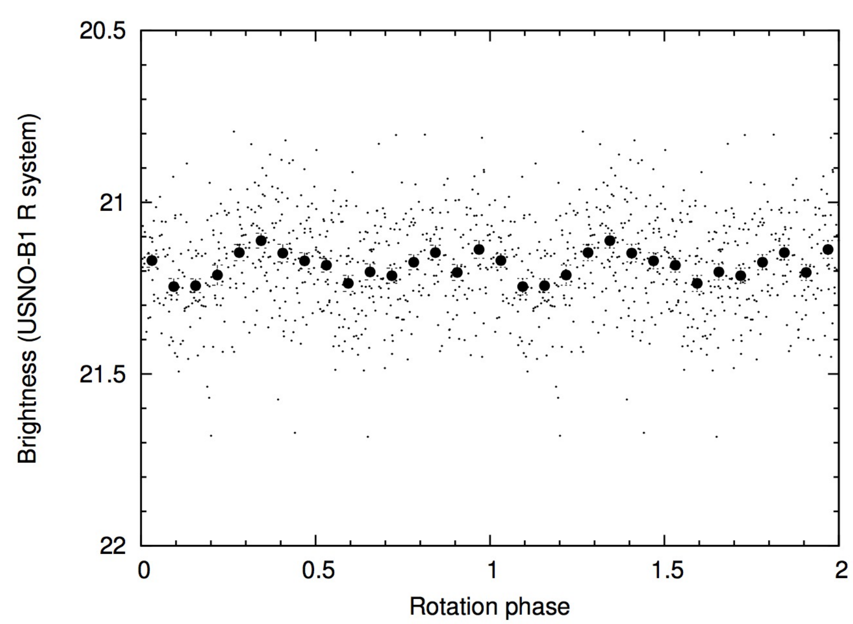
2007JJ$_{43}$

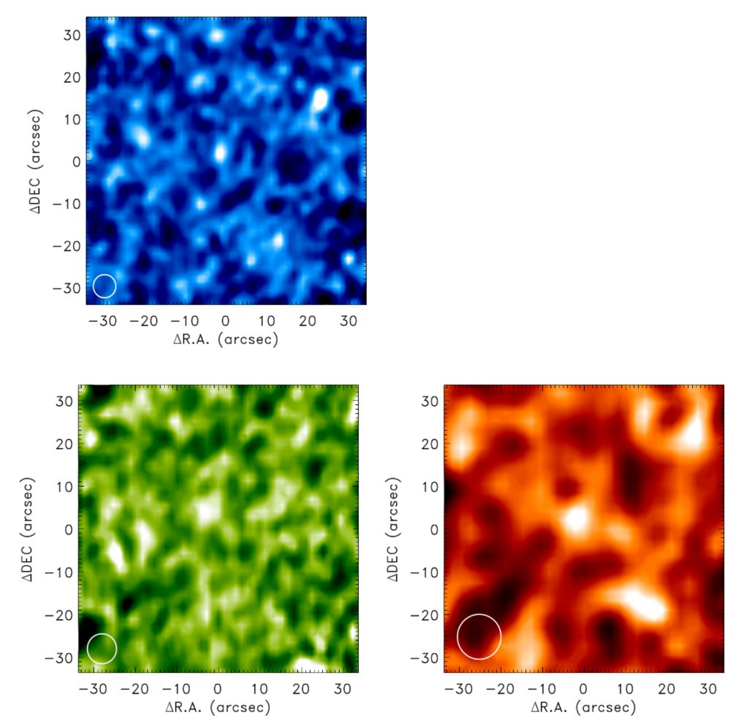


(225088) 2007 OR_{10} in C3

- second most distant TNO
  87 AU, 33-108 AU
- scattered disk object
- **first optical rotational variation** detected with K2
- P_{rot} = **44.81 h greatly** affects heat distribution
- Herschel 60-210μm —>
  alb. $p_V=0.089^{+0.031}_{-0.009}$
  size d=**1535** $^{+75}_{-225}$ km







- larger, darker
  3rd largest dwarf planet!
- volatiles (CH_4, CO, N_2) may be retained

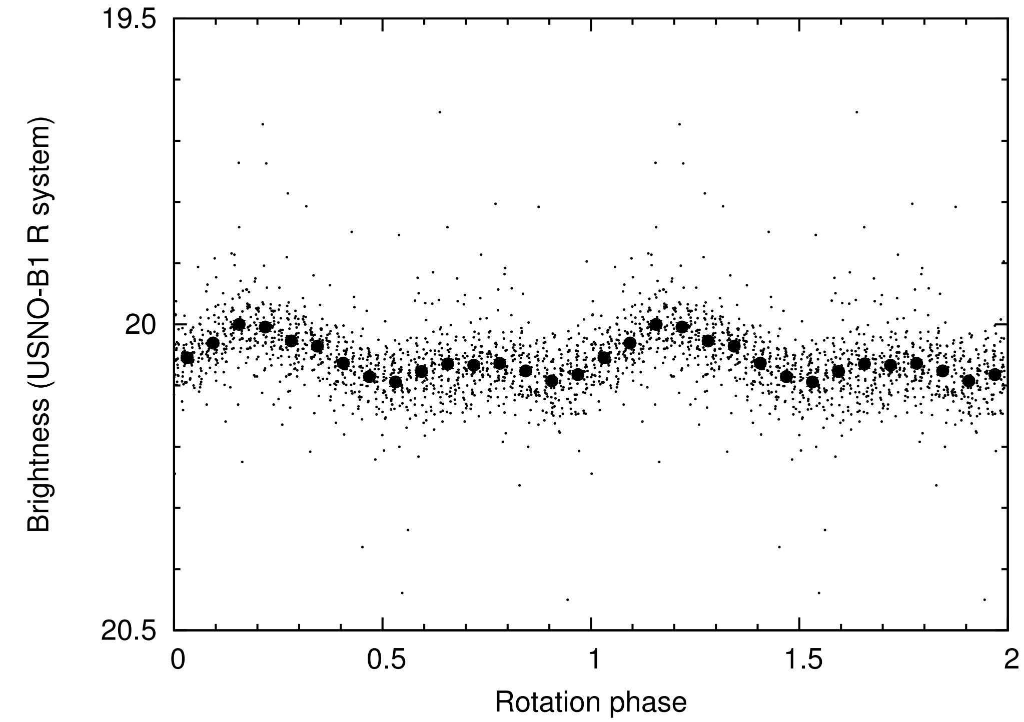
GO3053 Szabó R. et al.
Pál et al. AJ, submitted

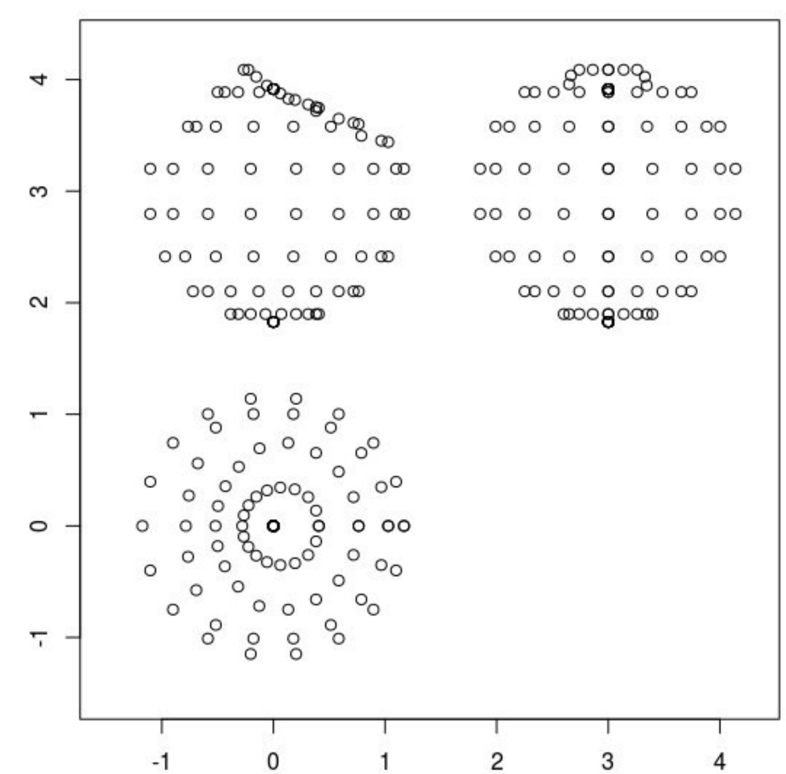
(250112) 2002 KY_{14} in C4

- observed for **29** days
- **20th** magnitude
- distance between 8.6-16.5 AU
- d=**47±4 km** Duffard et al. 2014

- P_{rot} = **8.502 h**
- double-peaked maxima
- asymmetric light curve
  needs a planar cut in the shape
- **first centaur with a 3D shape model**

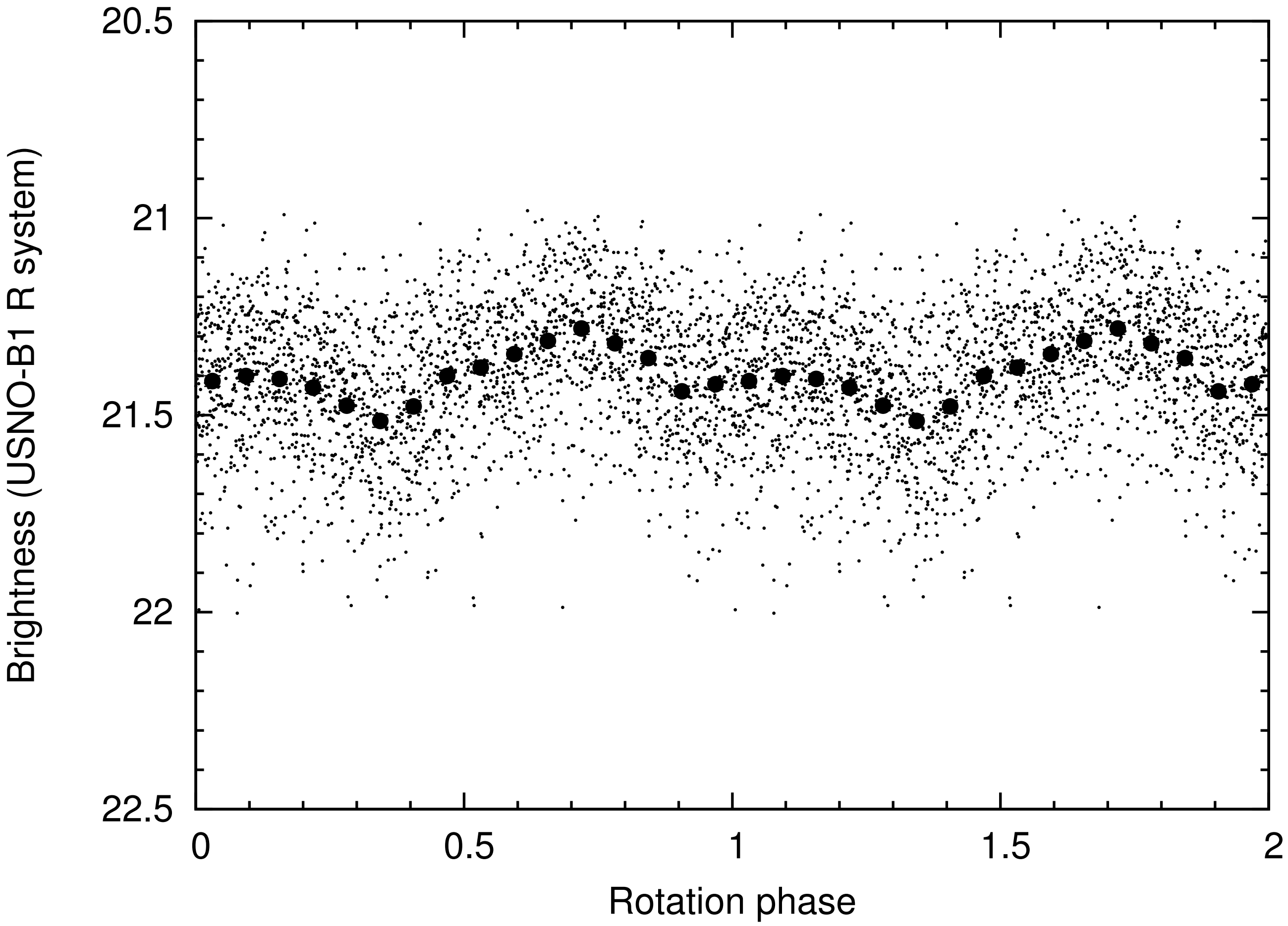
GO04110 Schwamb
Szabó Gy. M. et al. in prep.





(126154) 2001 YH_{140} in C5

- observed for **77** days
- **21.3** magnitude
- distance between 36-48 AU
- 3:5 resonance with Neptune
  d= 300-390 km
- P_{rot} = **27.38 ± 0.14 h**
- double-peaked maxima
  at >15 sigma confidence level
- Good agreement with
  Sheppard 2007 AJ, **134**, 787
  (P_{rot} = **13.25 ± 0.2 h**)



GO05110 Schwamb

work in progress !

Nereid, moon of Neptune in C3

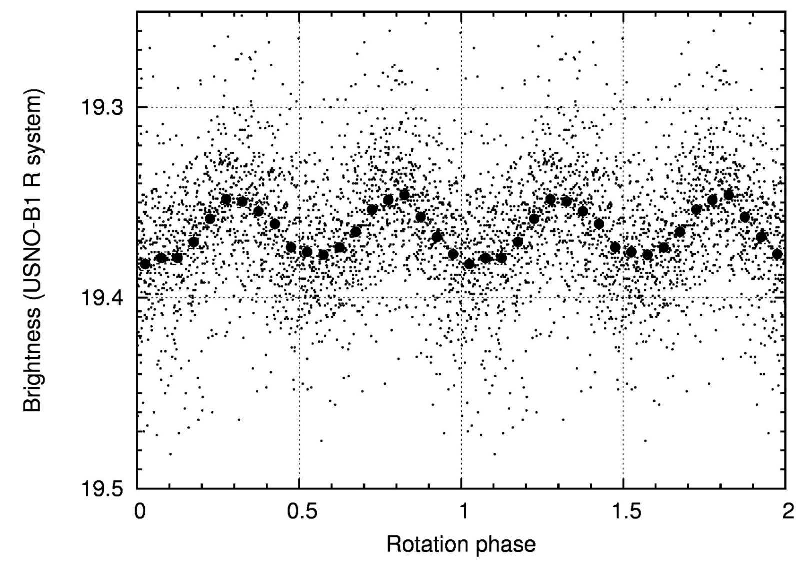
- large, irregular satellite
- captured TNO?
- very eccentric and irregular orbit
- shape, orientation, rotation?
- small / large amplitude phases

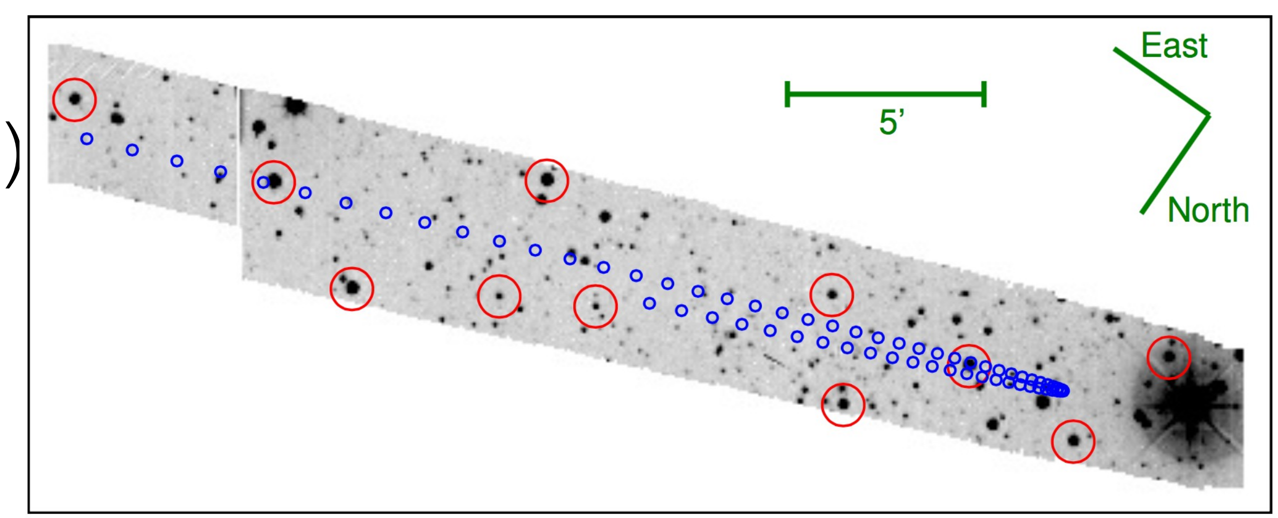
- P_{rot} = **11.504 ± 0.017 h**
- max. a:c axis ratio: **1.3 : 1.0**
  cannot be in forced precession state
- low amplitude state
- Herschel + Spitzer observations
- **high surface roughness** (cratered)
- d = **345 ± 15 km**

GO3115 Schaefer
Kiss Cs. et al. MNRAS, submitted

Best Voyager-2 image 1989

K2 light curve





Path of Neptune and Nereid in the K2 FoV

Nereid, moon of Neptune in C3

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GO3115 Schaefer
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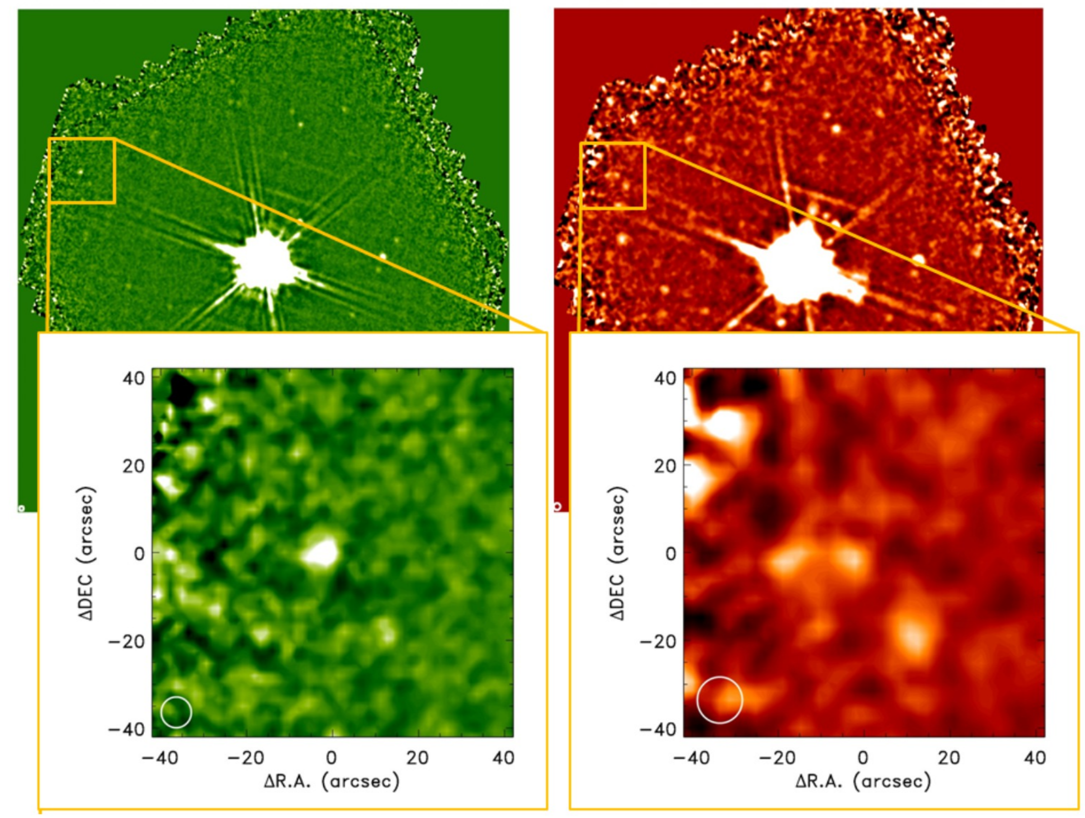

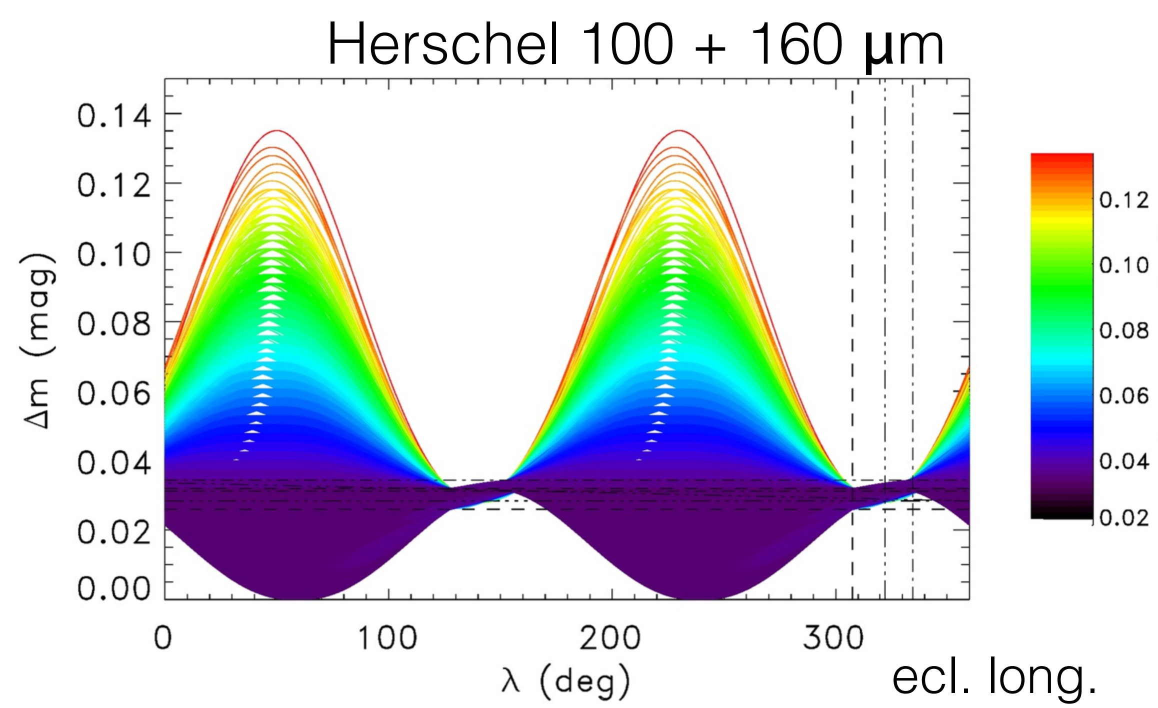

X: triaxial ellipsoid shape parameter b=1 a=(1+X)b c=(1-X)b

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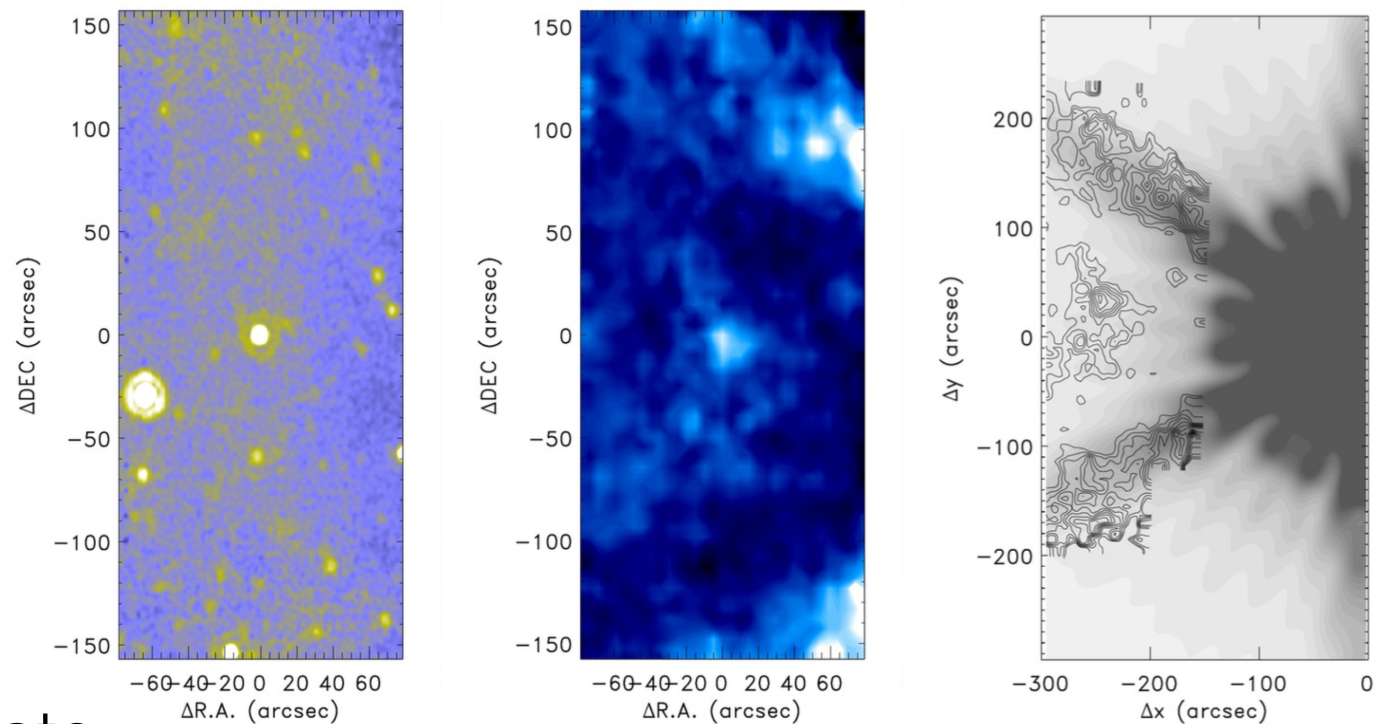
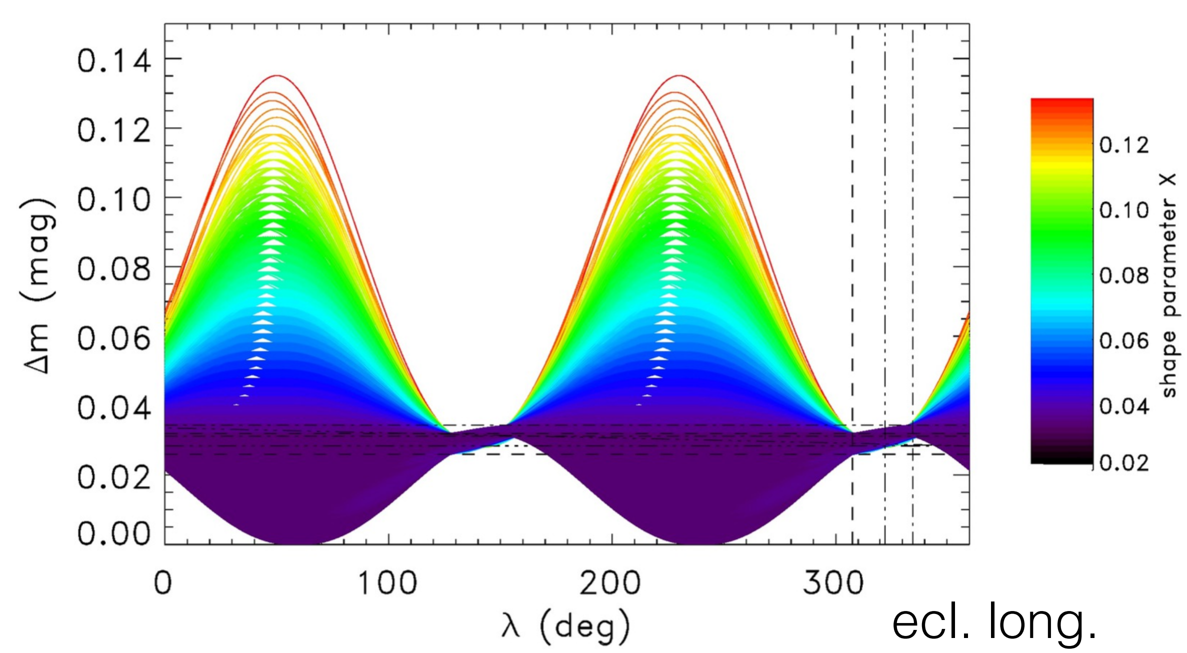
GO3115 Schaefer
Kiss Cs. et al. MNRAS, submitted



Spitzer 24 + 70 μm



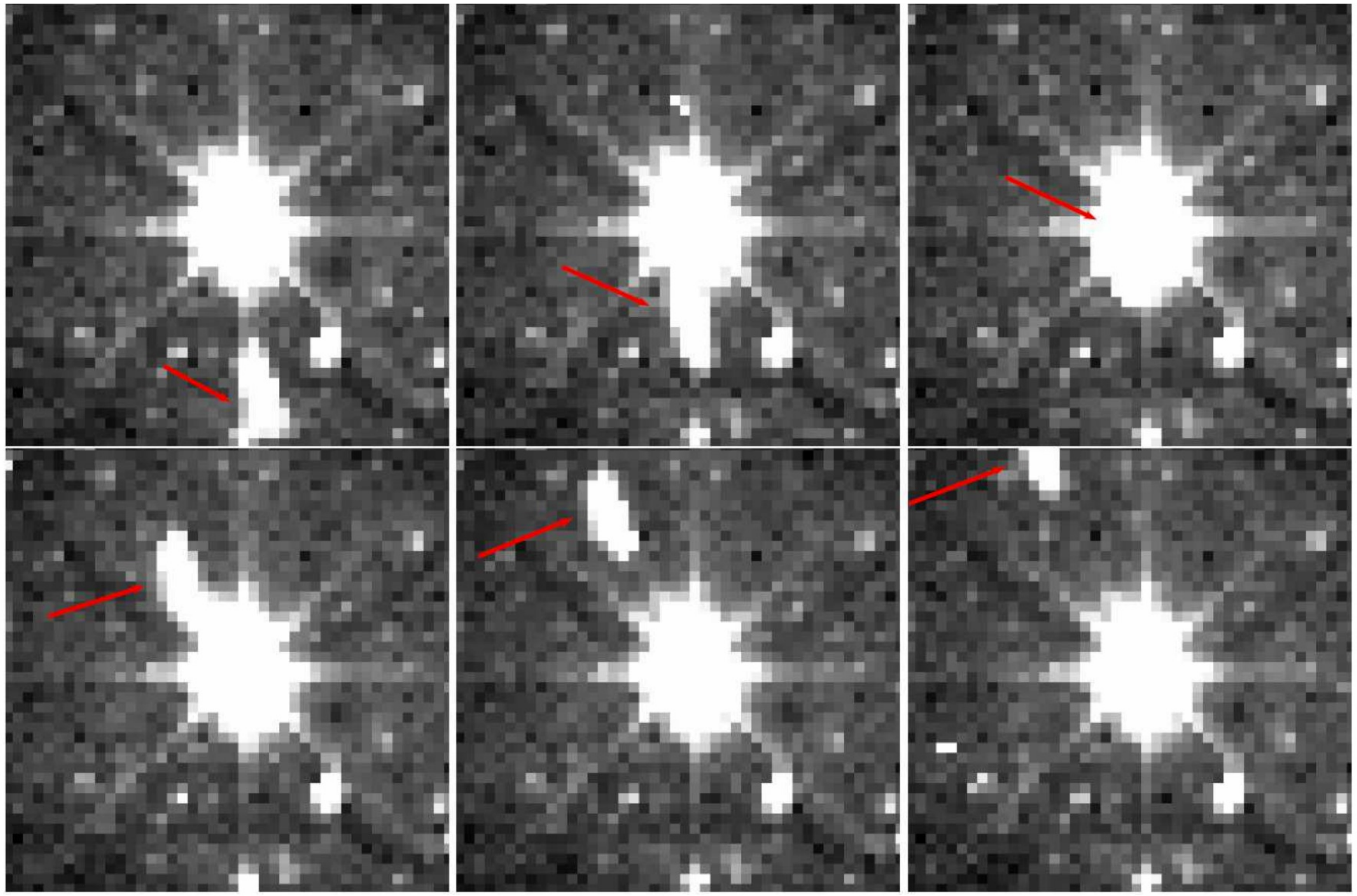
X: triaxial ellipsoid shape parameter b=1 a=(1+X)b c=(1-X)b

Main-Belt Asteroids in the K2-E2 field

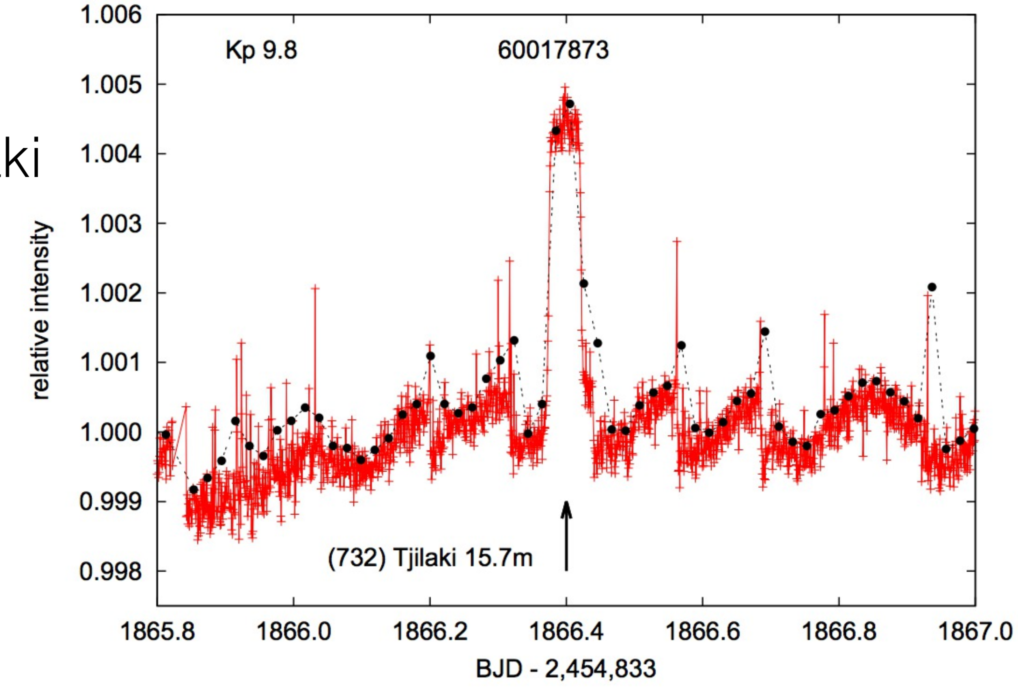
- **2096** targets **8.9** d long
- **300** subsample selected

- **What is the effect of asteroid encounters?**

- All predicted asteroids recovered down to ~21^{m}
- All found asteroids could be identified
- No new M-B asteroids



15.7 mag (732) Tjilaki
EPIC 60017873
(Kp=9.8 mag)



K2 Two-Wheel Concept Engineering Test

Szabó R. et al. AJ, 149, 112, 2015

Main-Belt Asteroids in the K2-E2 field

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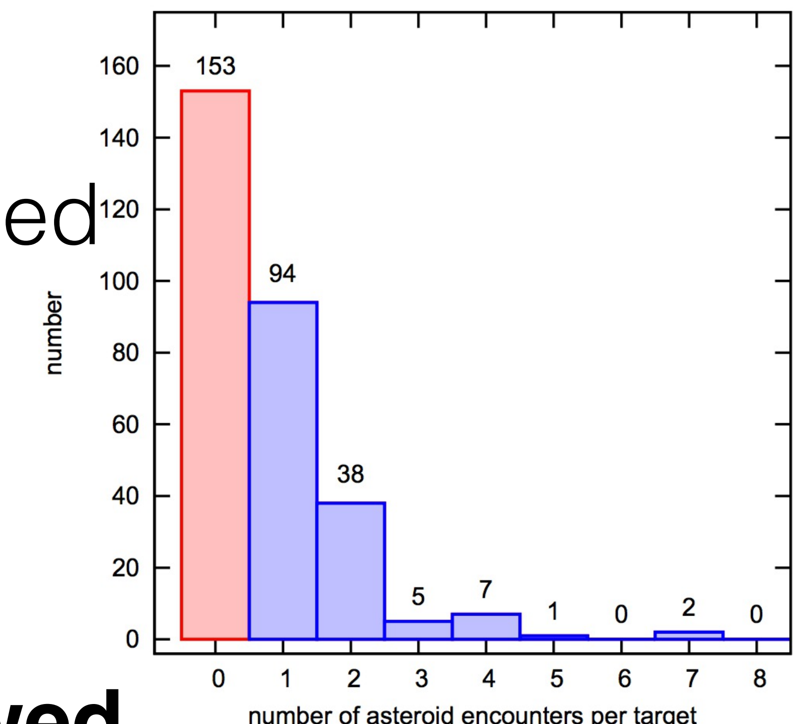
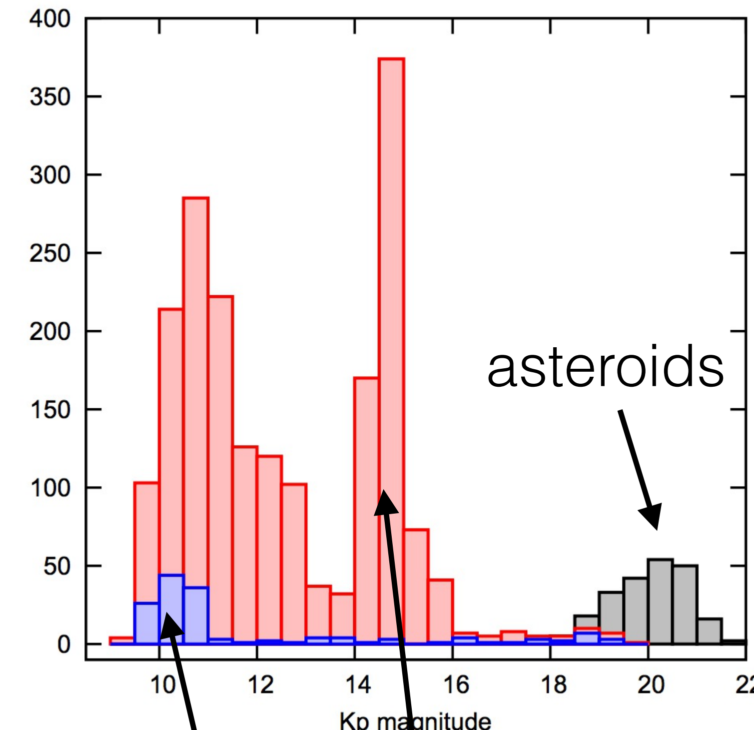
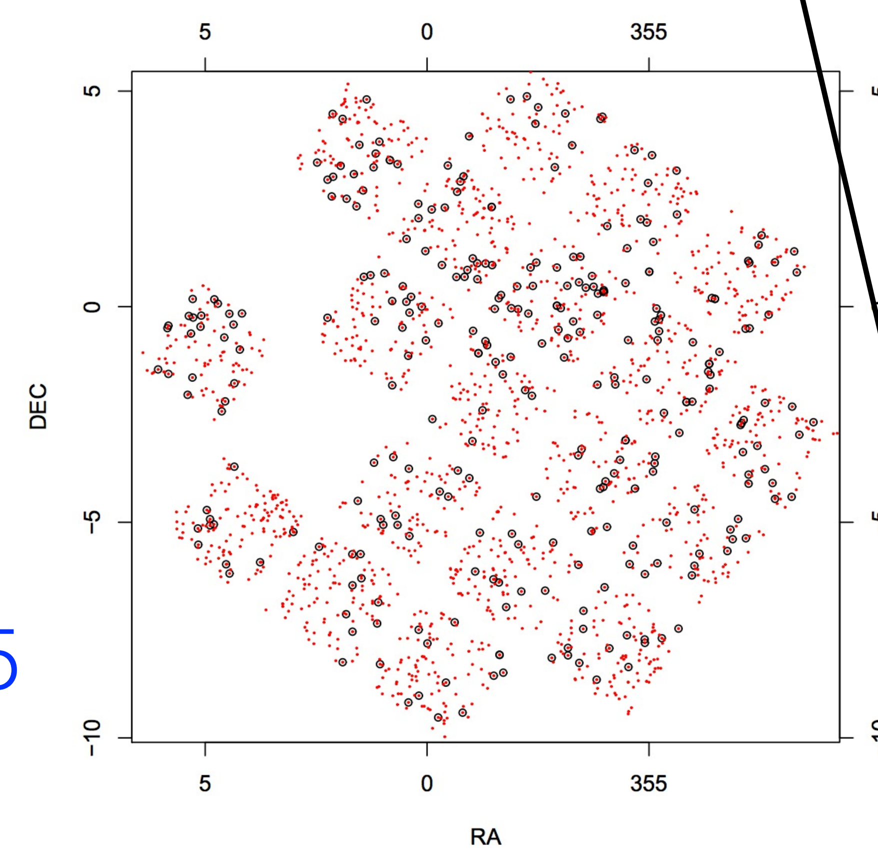




- **What is the effect of asteroid encounters?**

- **half of our targets showed asteroid encounter!**
- **many targets had several encounters**



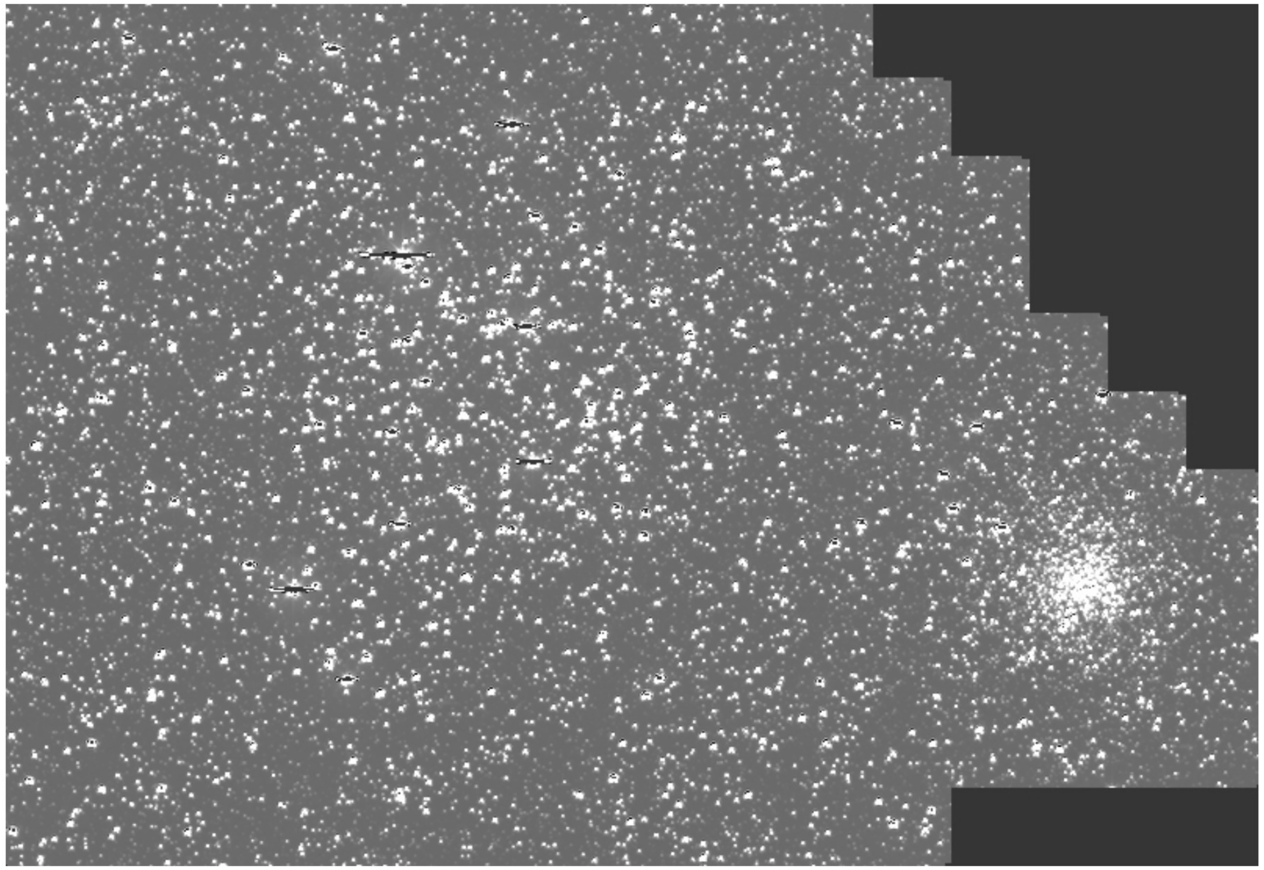
red dots:
all K2E2 targets

black circles:
random sample

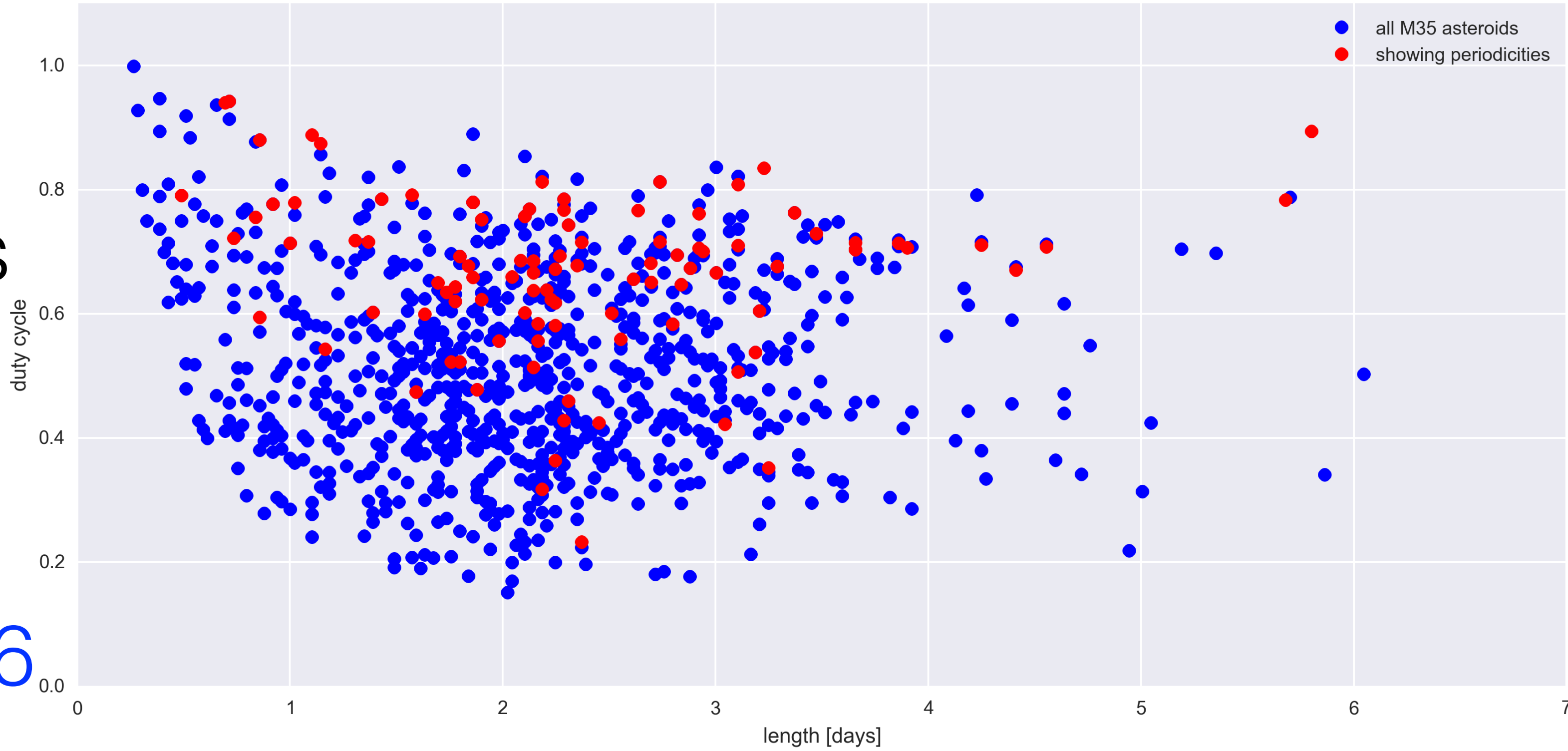
K2 Two-Wheel Concept
Engineering Test
Szabó R. et al. AJ, 149, 112, 2015

K2[5] Main-Belt Asteroids in the M35 field - C0

- **924** asteroids crossed the field
- **865** had >12 data points
- **32** showed periodicities
- we used 35-day, continuous fine-point measurements



- Goal: light curves —> **shape reconstruction**
- P_{rot} = **2.54 - 56.01** h, median: **7.0** h
- coverage: **0.26 - 6.05** days median: **2.0** days



M35 superstamp

Szabó R. et al. in prep. 2016

K2[5] Main-Belt Asteroids in the M35 field - C0

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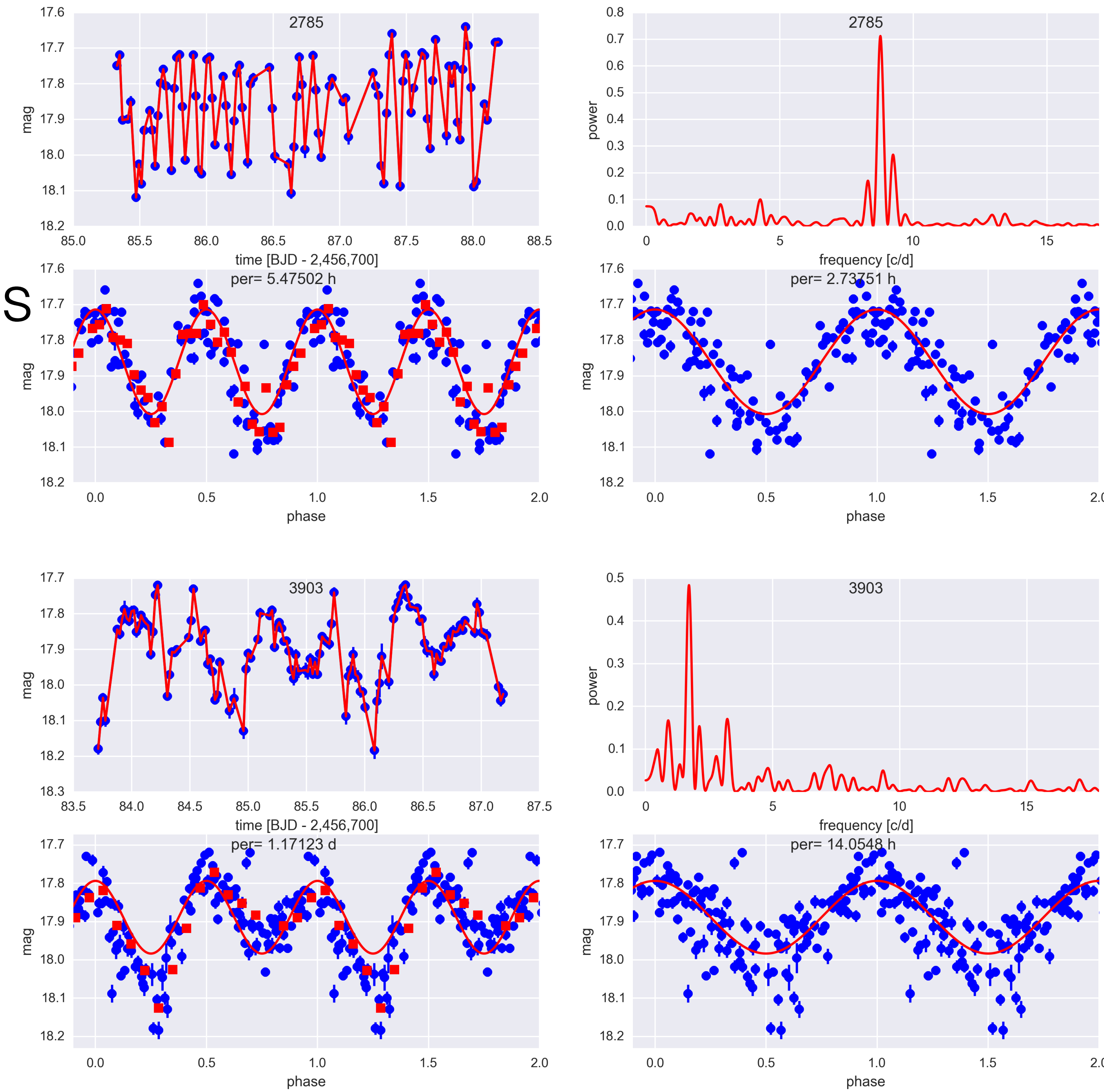

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M35 superstamp

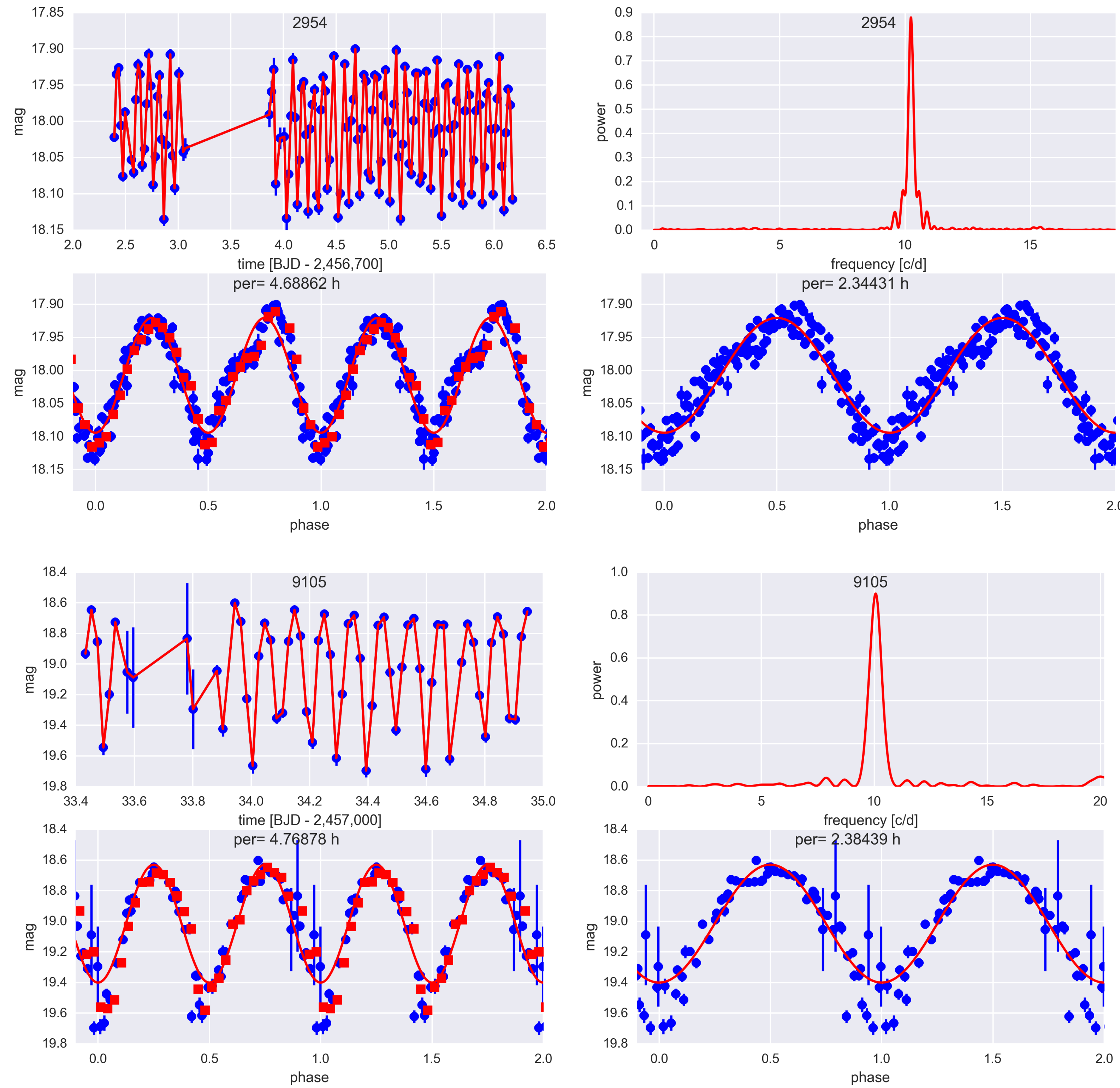
Szabó R. et al. in prep. 2016

Main-Belt Asteroids in the Nereid field - C3

- **96** asteroids crossed the Nereid field
- **14** showed periodicities

- Goal: light curves —> **shape reconstruction**
- P_{rot} = **2.78 - 14.63** h, median: **4.74** h
- coverage: **0.05 - 14.63** d median: **1.25** days

Neptune field
Szabó R. et al. in prep. 2016



Conclusions

- K2 provides a **unique way** to study Solar System objects
- **Long, uninterrupted, precise** photometry is unbeatable
- K2 can routinely observe in the **20-22.5 mag** range
- Covering the TNOs' path close to the stationary point only (where the movement is slowest) requires a **modest number of pixels**
- A few bright (20-22 mag) TNOs available per campaign
- **Main-Belt asteroids** and **moons** are also cool!


Thank you