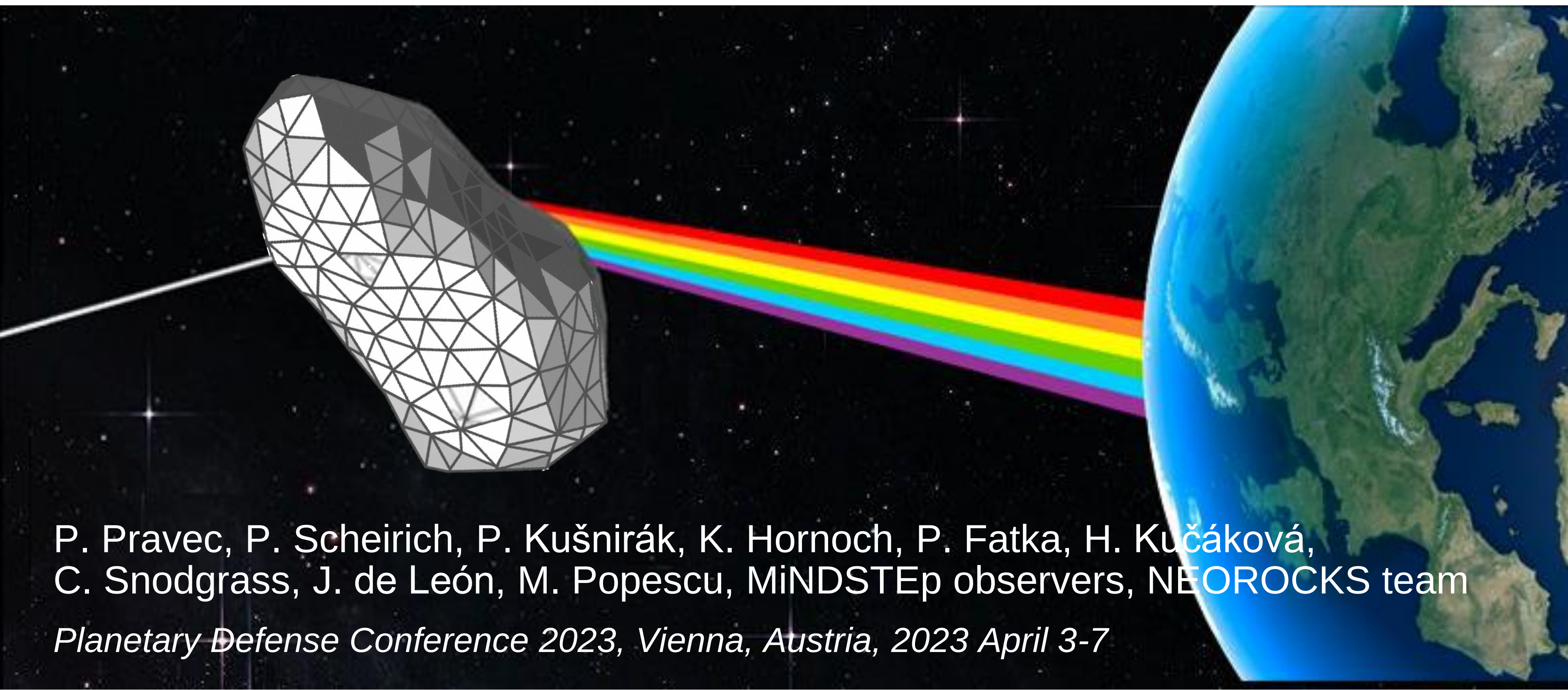
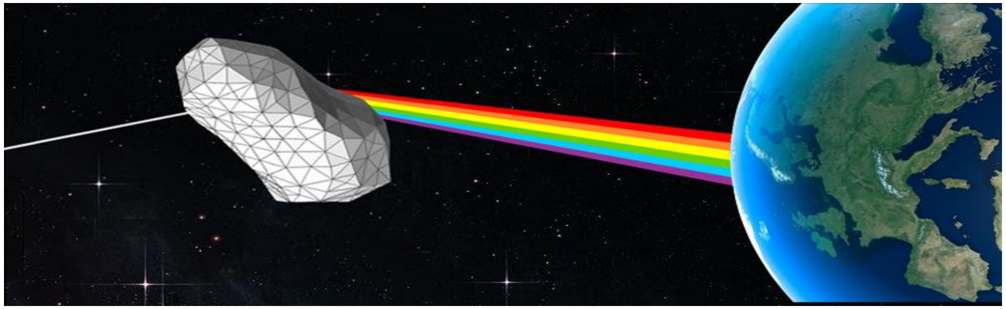
Binary systems among near-Earth asteroids observed within the NEOROCKS project



P. Pravec, P. Scheirich, P. Kušnirák, K. Hornoch, P. Fatka, H. Kučáková,
C. Snodgrass, J. de León, M. Popescu, MiNDSTEp observers, NEOROCKS team

Planetary Defense Conference 2023, Vienna, Austria, 2023 April 3-7

NEOROCKS - The NEO Rapid Observation, Characterization and Key Simulations



PROGRAMME:

Horizon 2020 - Work Programme 2018-2020
Leadership in Enabling and Industrial Technologies – Space

Participant organisation name	Country
Istituto Nazionale di Astrofisica (coordinator)	Italy
Agenzia Spaziale Italiana	Italy
University of Padova	Italy
LESIA-Observatoire de Paris	France
Observatoire de la Cote d'Azur	France
University of Edinburgh	UK
Astron. Inst. of Czech Academy of Sciences	Czech Rep.
Instituto de Astrofisica de Canarias	Spain
SpaceDyS s.r.l.	Italy
DEIMOS Space s.l.u.	Spain
DEIMOS Space s.r.l.	Romania
DEIMOS Castilla La Mancha	Spain
NeoSpace sp z.o.o	Poland
Resolvo Srl	Italy

AMBITIONS:

Ambition 1: Networking large aperture telescopes

Ambition 2: Advancing NEO physical properties modelling and simulations

Ambition 3: Improving the orbit determination process

Ambition 4: Addressing the imminent impactors monitoring

Ambition 5: Establishing a NEO physical properties data centre

Ambition 6: Fostering international cooperation for follow-up

Ambition 7: Raise the public awareness on NEO and impact hazard

TIMELINE:

Start: 1st January 2020
KOM: 20th January 2020
End: June 2023

NEO ROCKS
Near Earth Object Rapid Observation, Characterization and Key Simulations

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 870403

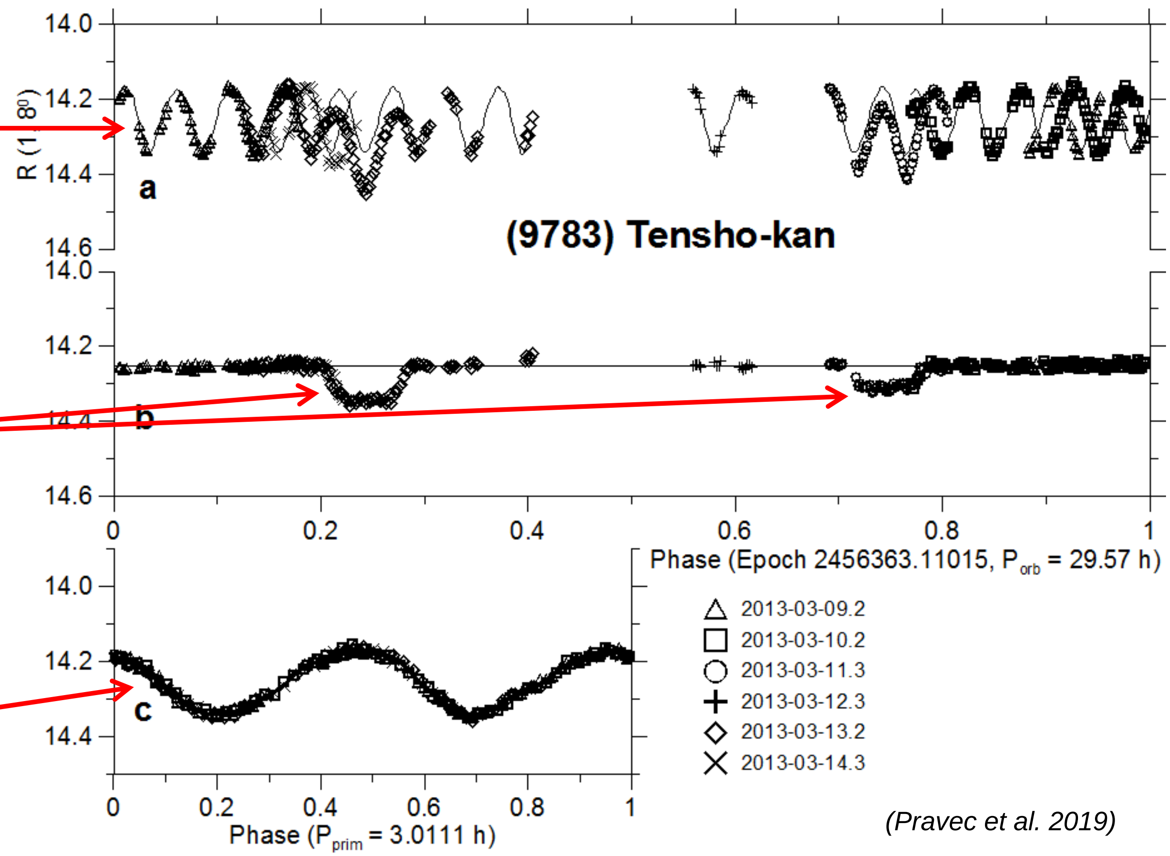
Binary asteroid detection (from lc obs.)

Full lightcurve
(consists of 3 components)

Lightcurve decomposition:

Mutual events
eclipses/occultations
(the orbital lc component)

Primary rotational lc



(Pravec et al. 2019)

The two rotational lightcurve components are represented with two Fourier series (Pr+00, Pr+06, Pr+22):

$$F(t) = F_1(t) + F_2(t),$$

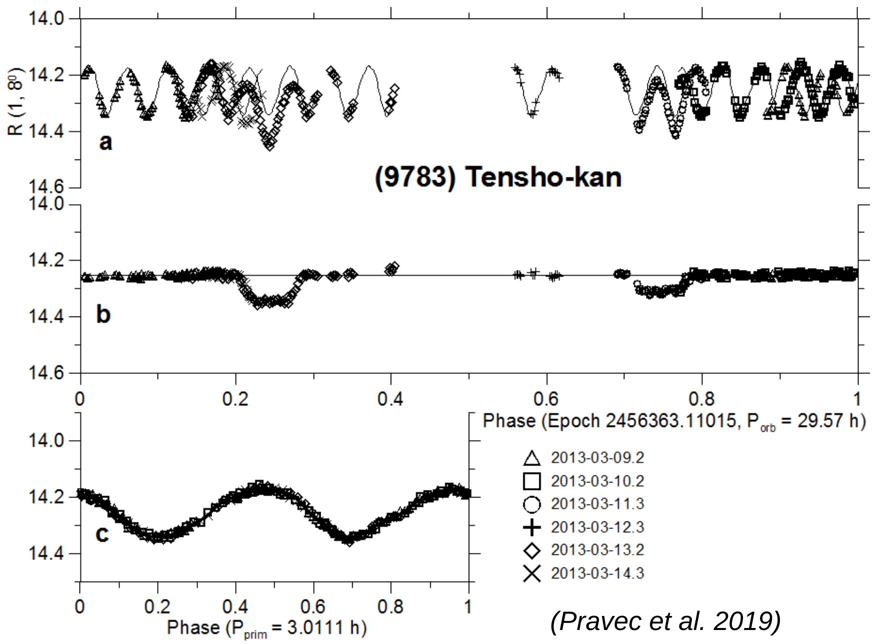
$$F_1(t) = C_1 + \sum_{k=1}^{m_1} \left[C_{1k} \cos \frac{2\pi k}{P_1}(t - t_0) + S_{1k} \sin \frac{2\pi k}{P_1}(t - t_0) \right],$$

$$F_2(t) = C_2 + \sum_{k=1}^{m_2} \left[C_{2k} \cos \frac{2\pi k}{P_2}(t - t_0) + S_{2k} \sin \frac{2\pi k}{P_2}(t - t_0) \right],$$

Binary vs tumbling asteroid lightcurve

How do we distinguish between a binary and a tumbler?

Binary (with asynchronous primary):



(Pravec et al. 2019)

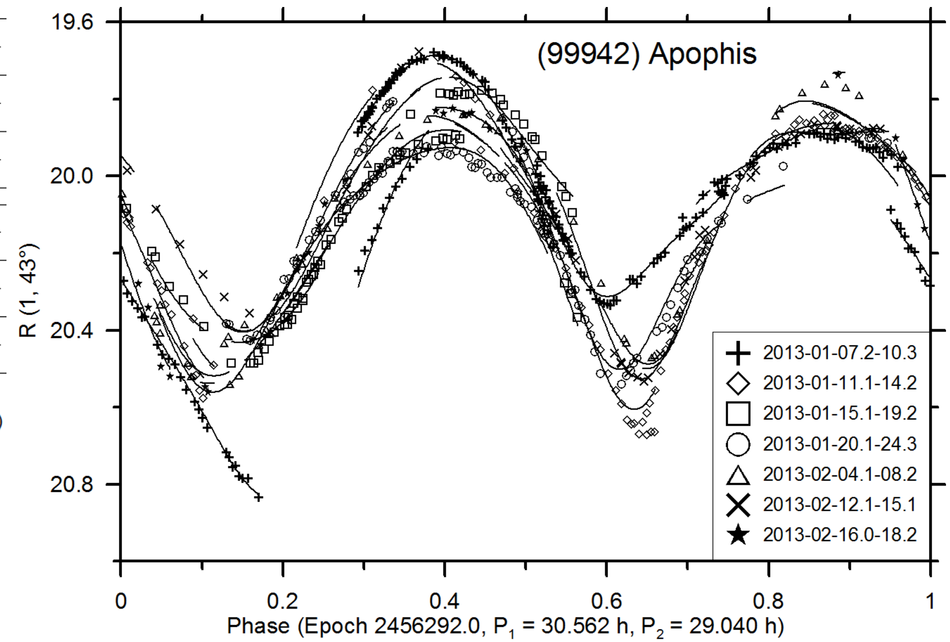
$$F(t) = F_1(t) + F_2(t),$$

$$F_1(t) = C_1 + \sum_{k=1}^{m_1}\left[C_{1k}\cos\frac{2\pi k}{P_1}(t-t_0) + S_{1k}\sin\frac{2\pi k}{P_1}(t-t_0)\right],$$

$$F_2(t) = C_2 + \sum_{k=1}^{m_2}\left[C_{2k}\cos\frac{2\pi k}{P_2}(t-t_0) + S_{2k}\sin\frac{2\pi k}{P_2}(t-t_0)\right],$$

Tumbler:

(Pravec et al. 2014)



$$F(\psi,\phi) = C_0 + \sum_{j=1}^{\infty}[C_{j0}\cos j\psi + S_{j0}\sin j\psi] + \sum_{k=1}^{\infty}\sum_{j=-\infty}^{\infty}[C_{jk}\cos(j\psi + k\phi) + S_{jk}\sin(j\psi + k\phi)],$$

where

$$C_0 = a_{00}, \quad C_{j0} = a_{j0}, \quad S_{j0} = b_{j0},$$

$$C_{0k} = a_{0k}, \quad S_{0k} = c_{0k},$$

$$C_{\pm j,k} = \frac{a_{jk} \pm d_{jk}}{2}, \quad S_{\pm j,k} = \frac{c_{jk} \pm b_{jk}}{2},$$

for $j, k > 0$.

Binary's lightcurve contains only additive terms with ω_1 and ω_2, plus superimposed mutual events repeating with P_{orb}, while a tumbler's lightcurve contains also terms with $(n_1 \omega_1 \pm n_2 \omega_2)$, where $n_1, n_2 \geq 0$.

In other words, it is a decomposable (binary) vs non-decomposable (tumbler) lc.

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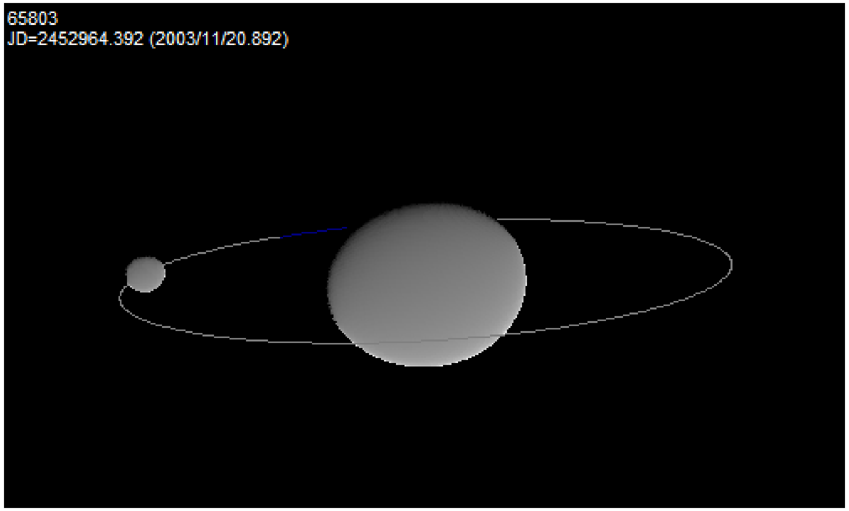
ıtion and Key Simulations

Binary lightcurve modeling

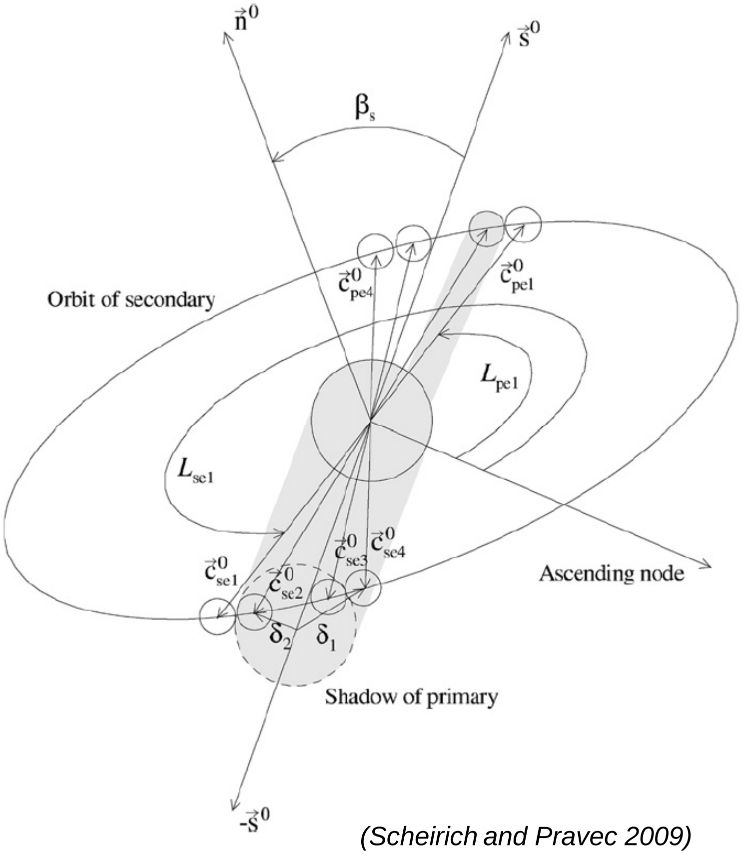
Modeling of observed mutual events (their timings and shapes) between system's components:

Derived or constrained parameters:
D_2/D_1 .... ratio of effective diameters
P_{orb}, L_{orb}, B_{orb}, a_{orb}/D_1, e_{orb}, M_{orb} …. mutual orbit
ρ_1 …. primary bulk density
ΔM_d …. secular orbit drift rate (BYORP+tides)

With extensive data (covering a sufficient range of system's viewing geometries), a unique solution for all the parameters is obtained.



(Scheirich and Pravec 2022)



(Scheirich and Pravec 2009)

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Near Earth Object Rapid Observation, Characterization and Key Simulations

Binary NEOs observed within NEOROCKS

Within the NEOROCKS project, we observed lightcurves of 100+ NEOs. Among them, we found 9 binary systems (7 of them were our discoveries, see the CBET reports). We observed them with the Danish 1.54m telescope (DK154) at La Silla, the 0.65m telescope (D65) at Ondřejov, and in two cases supported by collaborating observers Licandro et al. and Jehin & Ferrais who used the 1.52m Telescopio Carlos Sánchez (TCS) and the Trappist-South 0.6m telescope, respectively.

(31346) 1998 PB1 – Observed (binary nature discovered) with DK154 in April-June 2021 *(CBET 4978)*

(85628) 1998 KV2 – Observed with D65 in April 2020 and March-April 2022

(143649) 2003 QQ47 – Observed (binary nature discovered) with DK154 in Aug.-Sept. 2021 *(CBET 5037)*

(326732) 2003 HB6 – Observed (binary nature discovered) with D65 and Trappist in Aug.-Sept. 2021 *(CBET 5039)*

(350751) 2002 AW – Observed (binary nature discovered) with DK154 and TCS in February-March 2022 *(CBET 5110)*

(539940) 2017 HW1 – Observed with D65 in April 2020

(612098) 1999 RM45 – Observed (binary nature discovered) with DK154 in February 2021 *(CBET 4931)*

2013 PY6 – Observed (binary nature discovered) with DK154 and D65 in October-December 2020 *(CBET 4891)*

2020 AZ2 – Observed (binary nature discovered) with DK154 in February-March 2020 *(CBET 4728)*

Spectral or color observations were taken for 8 of the 9 binaries with the 1.52m TCS, the 2.54m INT, the 10.4m GTC, or obtained from Binzel et al. (2019), Simion et al. (2021) and Mahlke et al. (2022) → taxonomy (and an albedo constraint, allowing to derive their sizes with good accuracy)

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Parameters of the 9 binary NEOs

Binary	D_1 (km)	D_2/D_1	P_{orb} (h)	P_1 (h)	P_2 (h)	a_1/b_1	Taxon.
(31346)	0.91	≥ 0.38	55.39	2.7358		1.11	Q
(85628)	0.97	0.29	21.173	2.8229	21.17	1.09	Q
(143639)	0.79	0.33	13.065	2.6446	13.07	1.03	Q
(326732)	1.9	0.23	22.92	3.4630	22.9	1.07	D/X
(350751)	0.34	0.21	25.10	4.647		1.07	B
(539940)	0.90	≥ 0.28	26.2	2.633	26	1.09	
(612098)	0.29	0.45	16.45	3.0703	16.46	1.06	Sq
2013 PY6	0.50	0.24	27.31	3.6244		1.08	Xc
2020 AZ2	0.14	≥ 0.53	22.03	2.3582	22.03	1.05	Q/S

The parameters of the 9 binary NEOs are mostly in line with NEO binaries observed in the past, but there are a few interesting exceptions/outliers/end members.

Primary sizes: 2020 AZ2 is the smallest binary asteroid we have observed so far!
Size ratios: The secondary of 2020 AZ2 is one of the largest (in relative terms) observed so far (for binaries with asynchronous primaries).
Orbit periods: (31346) is a relatively wide binary, but not really an outlier (we observed similar cases before).
Primary periods: The primaries of (326732), (350751) and 2013 PY6 are relatively slow rotators; low bulk densities?
Secondary periods: Most of the secondaries are synchronous.
Primary elongations: All the primaries are nearly spheroidal.
Taxonomic classifications: (326732), (350751) and 2013 PY6 are D/X, B, Xc, which are unusual classes (among NEAs).
Apparent correlation between slower primary rotations and primitive (?) taxonomy (low bulk density?). We plan to investigate it on a larger sample.

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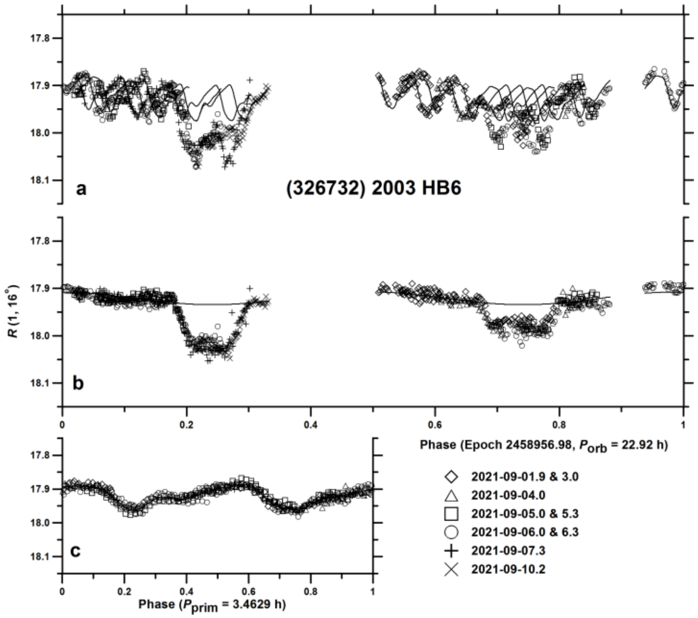
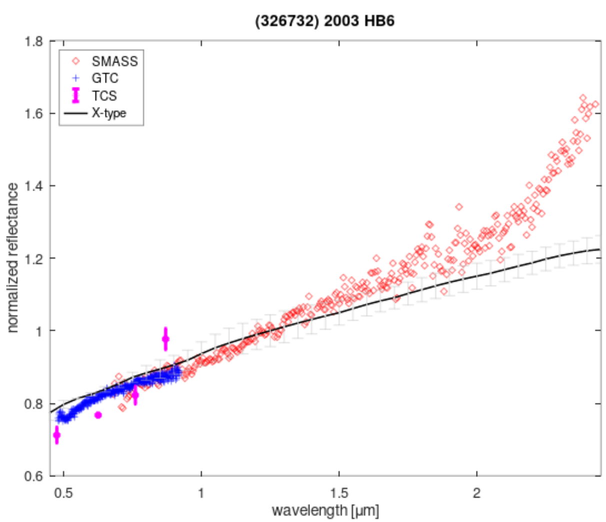
(326732) 2003 HB6

A sample of our lightcurve data:





Observed (binary nature discovered) with D65, Trappist and DK154 during August-November 2021 *(CBET 5039).*

Relatively large binary NEO: D_1 = 1.9 ± 0.2 km

Secondary of a fairly typical size (D_2/D_1 = 0.23 ± 0.02) and synchronous with moderate equatorial elongation (a_2/b_2 ~ 1.4), on a close orbit (P_{orb} = 22.92 ± 0.05 h).

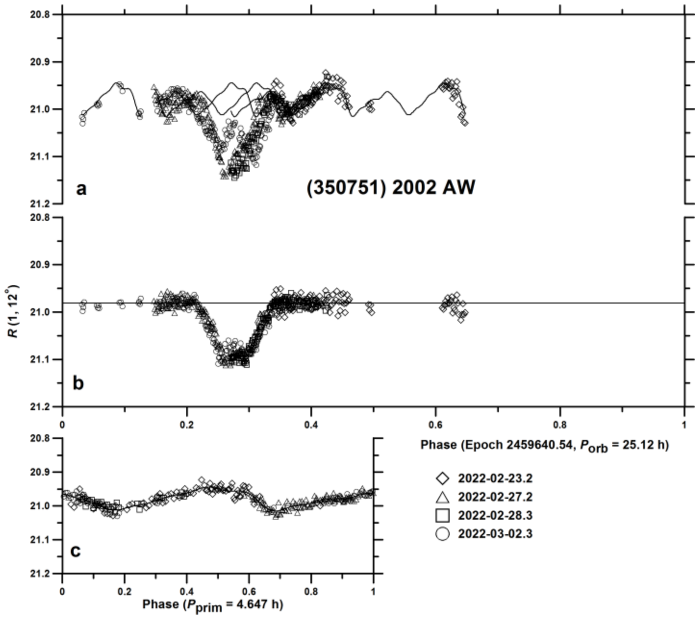
Primary is nearly spheroidal (a_1/b_1 = 1.07), but it has a relatively slow rotation: P_1 = 3.4630 ± 0.0008 h.

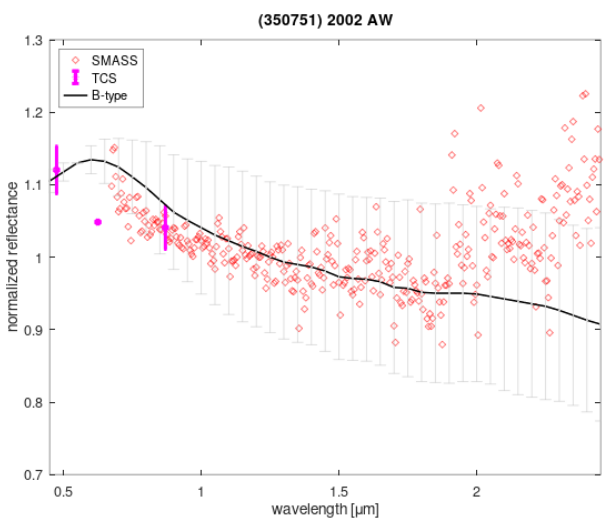
Spectral and color observations (SMASS, GTC, TCS; Binzel+2019, Simion+2021, Mahlke+2022) suggest a low-albedo X or D type.

Does it have a lower bulk density than average NEO?

(350751) 2002 AW

A sample of our lightcurve data:





Observed (binary nature discovered) with DK154 and TCS during February-March 2022 *(CBET 5110).*

Relatively small binary NEO: D_1 = 0.34 ± 0.05 km

Secondary of a fairly typical size (D_2/D_1 = 0.21 ± 0.02), on a close orbit (P_{orb} = 25.10 ± 0.02 h). The orbit is moderately eccentric: e = 0.120 ± 0.013.

Primary is nearly spheroidal (a_1/b_1 = 1.07), but it has an unusually slow rotation: P_1 = 4.647 ± 0.002 h.

Spectral and color observations (SMASS and TCS) classify it as a B type.

Does it have a lower bulk density than average NEO?

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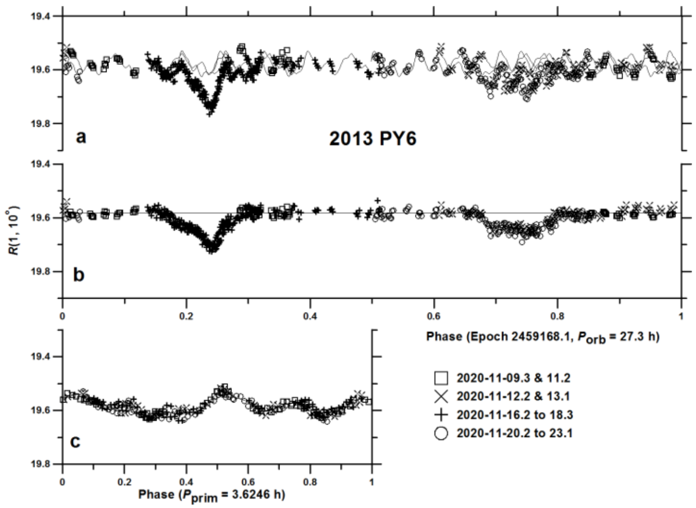
2013 PY6

A sample of our lightcurve data:



Observed (binary nature discovered) with DK154 and D65 during October-December 2020 *(CBET 4891).*

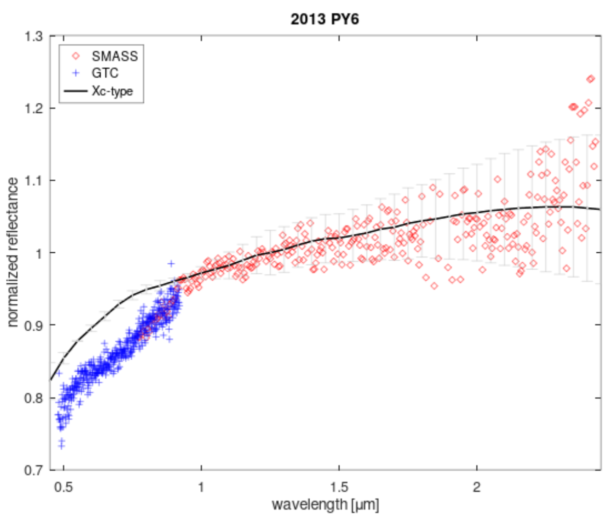
Medium size binary NEO: $D_1 = 0.50 \pm 0.15$ km

Secondary of a fairly typical size ($D_2/D_1 = 0.24 \pm 0.02$), on a close orbit ($P_{orb} = 27.31 \pm 0.08$ h).

Primary is nearly spheroidal ($a_1/b_1 = 1.08$), but it has a relatively slow rotation: $P_1 = 3.6244 \pm 0.0010$ h.

Spectral observations (SMASS and GTC) classify it as an Xc type.

Does it have a lower bulk density than average NEO?



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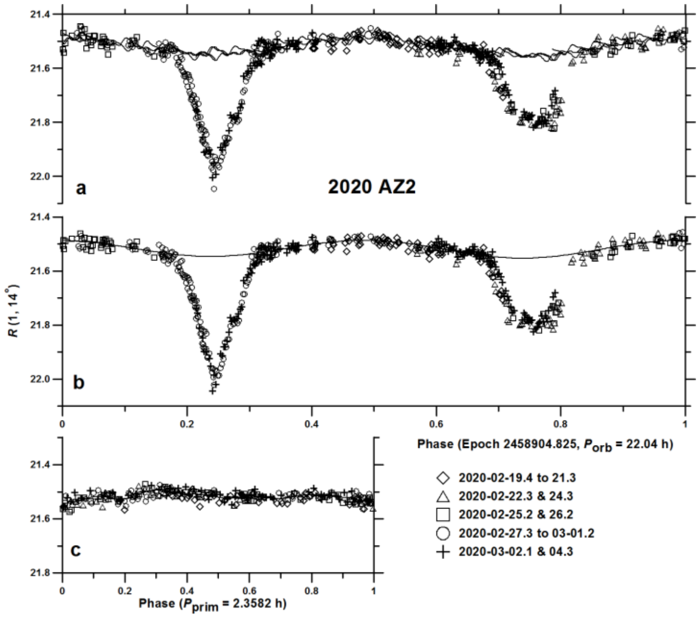
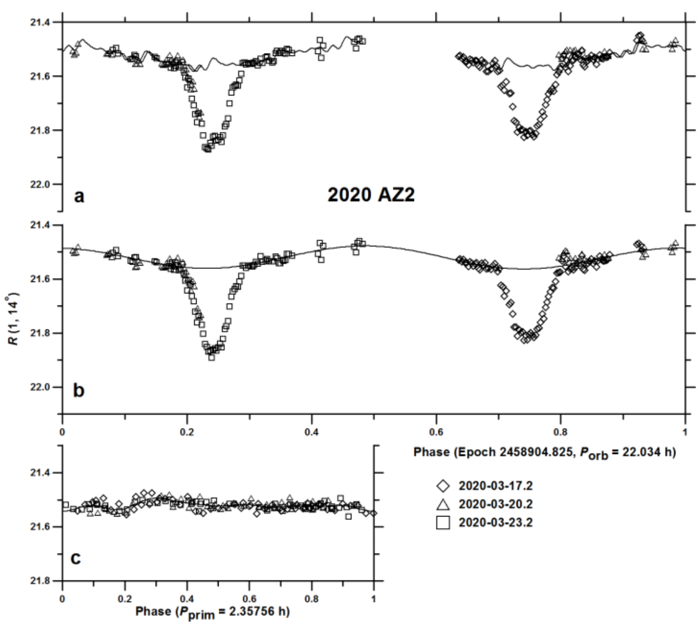
2020 AZ2





Observed (binary nature discovered) with DK154 during February-March 2020 *(CBET 4728).*

Extremely small binary NEO: D_1 = 0.14 ± 0.02 km. (Derived from the measured mean H = 21.32 ± 0.05 and assumed p_V = 0.22 ± 0.05 for its Q/S classification.) It's the smallest binary asteroid we have observed so far!

Unusually large secondary (in relative terms): $D_2/D_1 \geq 0.53$, it is synchronous with a moderate equatorial elongation (a_2/b_2 = 1.20 ± 0.05), on a close orbit (P_{orb} = 22.03 ± 0.04 h).

Primary is nearly spheroidal (a_1/b_1 = 1.05) and it rotates fast (P_1 = 2.3582 ± 0.0004 h), as typical for binary NEOs.

Color observations (TCS) suggest a Q/S class.

Is it one of the smallest "rubble pile" asteroids (with low cohesion)?

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Conclusions

Lightcurve, spectral and color observations of 100+ near-Earth objects taken within the NEOROCKS project revealed 9 of them to be binary systems and allowed us to characterize them.

5 of the 8 binaries with determined taxonomy are Q, S or Sq types (typical for NEOs), but 3 are D/X, B and Xc types (primitive material?), which are relatively rare in the NEO population.

The primitive taxonomy appears to correlate with slower primary rotations. We speculate that it is because of their lower bulk densities than average among NEOs. Assuming that the mechanical formation process of binaries with primitive taxonomy is similar to non-primitive (Q/S/Sq) type binaries, the ratio between the mean P_1 of these two groups (3.91 and 2.71 h, respectively) suggests that primitive type binaries have the mean bulk density about half [= $(3.91/2.71)^{-2}$] of that of non-primitive types. We plan to study this correlation on a larger sample of binary NEOs in the near future.

The extremely small binary NEO 2020 AZ2 may be one of the smallest asteroids with a “rubble pile” (low cohesion) structure.

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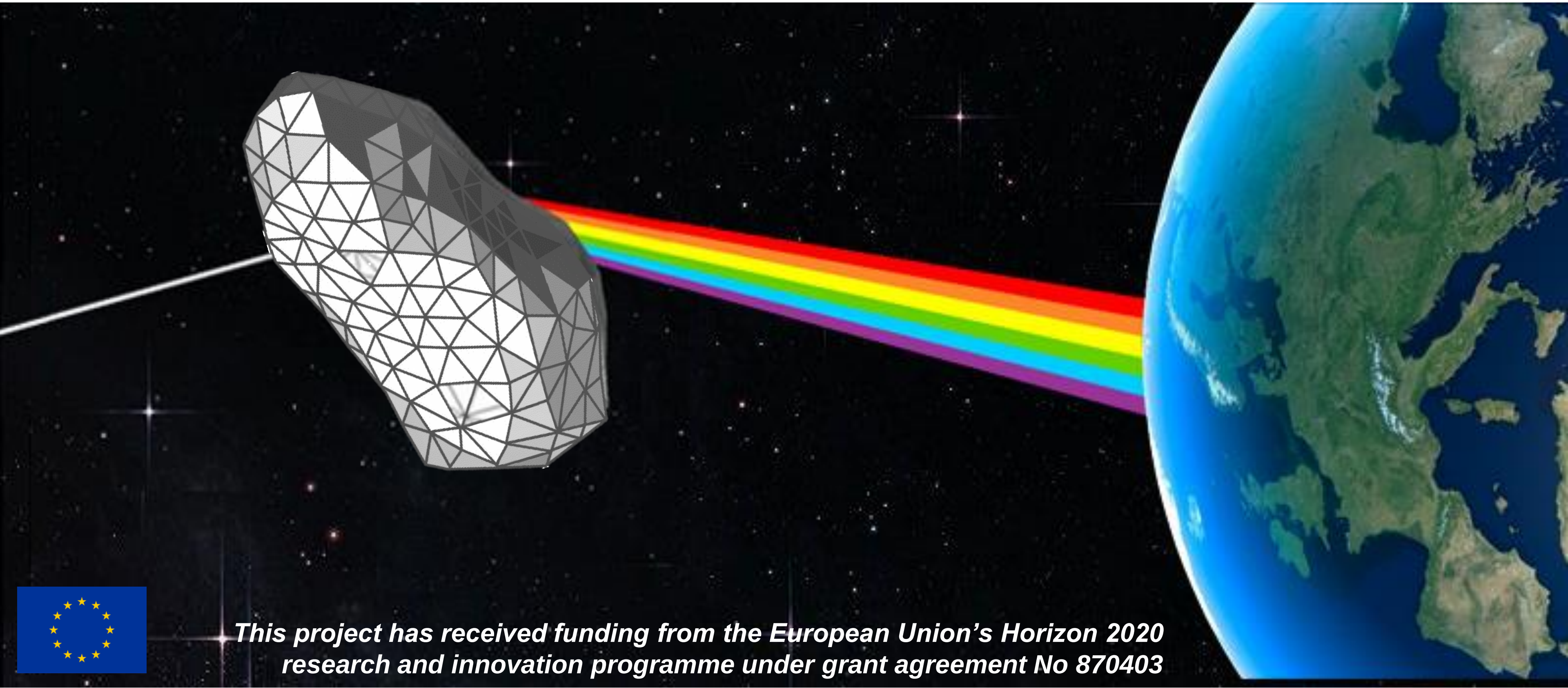
THANK YOU!



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