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Yarkovsky and YORP effects in motion of asteroids

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Outline

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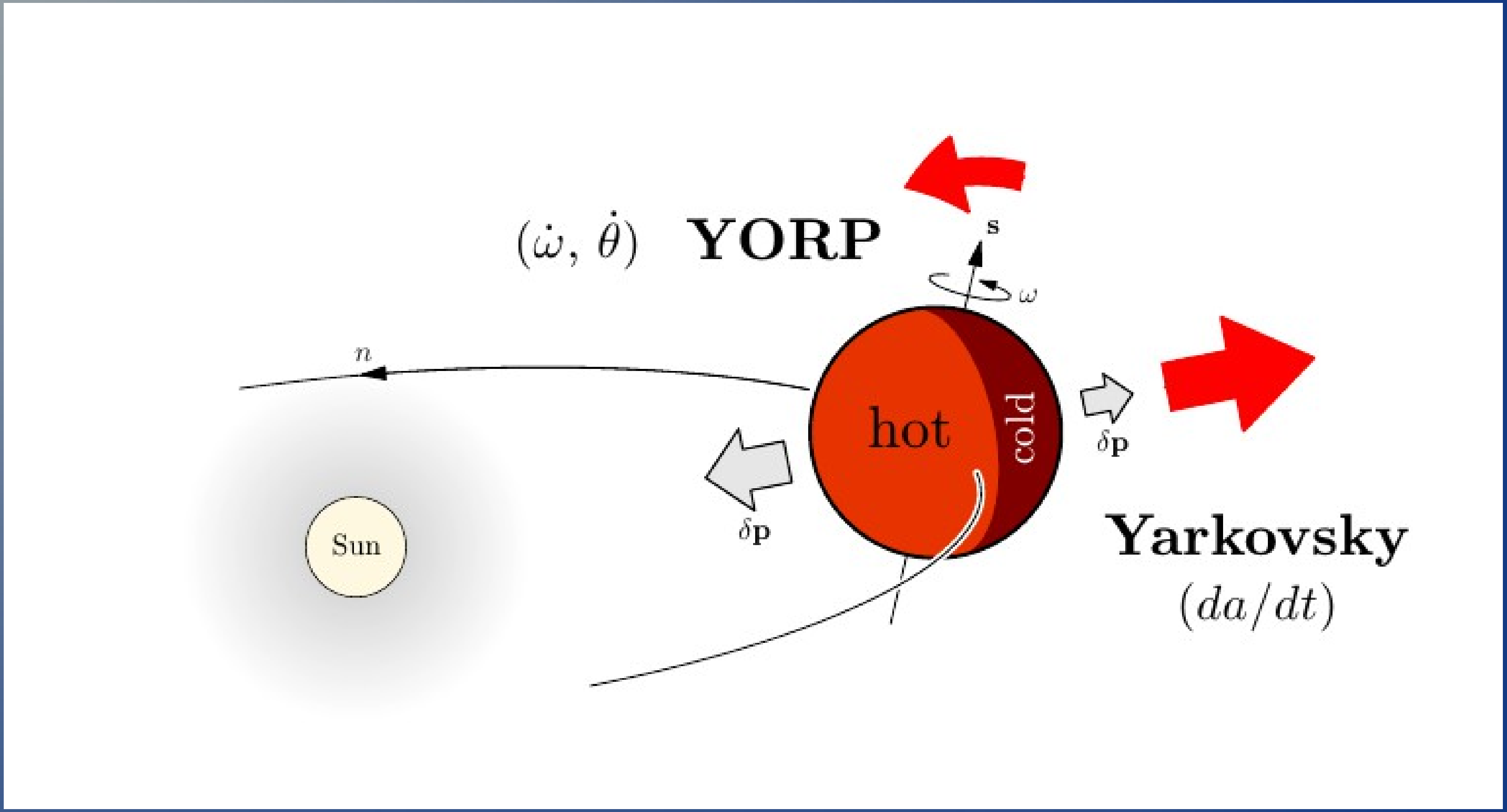
Principle forces affecting motion of asteroids (meteoroids) of sizes 10cm-10km

acceleration	radial	transversal
gravity	$GM_{\odot}=1$, $GM_{pl}\approx 10^{-3}$, $GM_{ast}<10^{-9}$	
Yarkovsky/YORP effects	10^{-7} — 10^{-11}	10^{-8} — 10^{-12}
radiation pressure	10^{-6} — 10^{-11}	
Poynting-Robertson drag		10^{-10} — 10^{-15}
solar wind, Lorentz force, plasma drag	$< 10^{-15}$	

Brož et al. (2005)

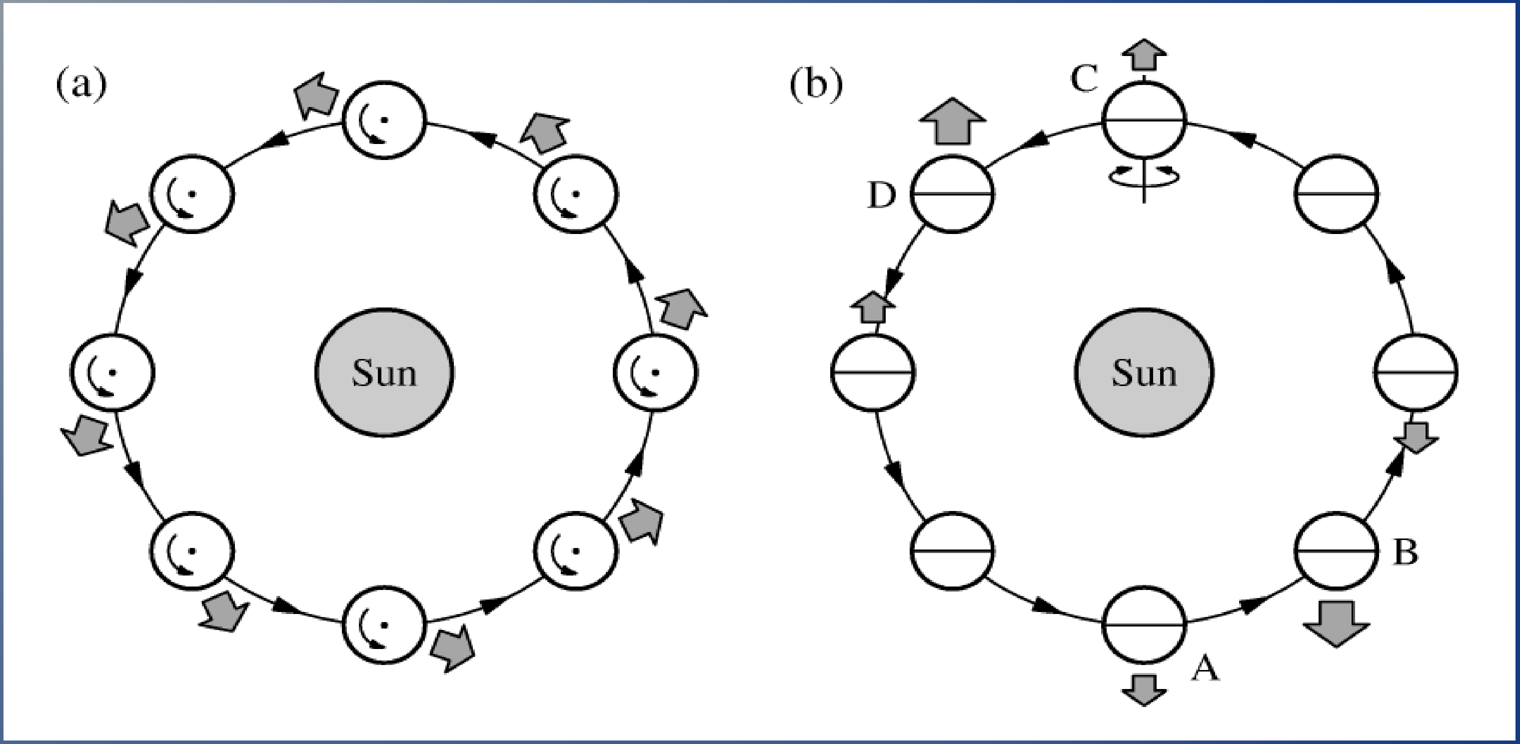
Yarkovsky/YORP effects and radiation pressure are comparable to each other for this class of objects.

Illustration of Yarkovsky\YORP effects



The basic principle of the Yarkovsky\YORP thermal effect is the absorption of solar radiation by a body and its anisotropic thermal reemission. The appeared force causes objects to undergo semimajor axis drift and spin up/down as a function of their spin, orbit, and material properties, etc.

Diurnal and seasonal components of Yarkovsky effect



Brož et al. (2005)

The diurnal (a) and seasonal (b) Yarkovsky effects are presented. The broad arrows illustrate the Yarkovsky force appeared in these limiting cases.

Calculation of the Yarkovsky\YORP effects

- A rough estimate of the mean equilibrium temperature

$$\pi R^2 (1 - A) \frac{L_\odot}{4\pi r^2} = 4\pi R^2 \epsilon \sigma T_{\rm eq}^4 \,,$$

- Exact calculation of temperature requires solution of heat diffusion equation in the volume of the body

$$\nabla \cdot (K \nabla T) = \rho C \frac{\partial T}{\partial t} \,,$$

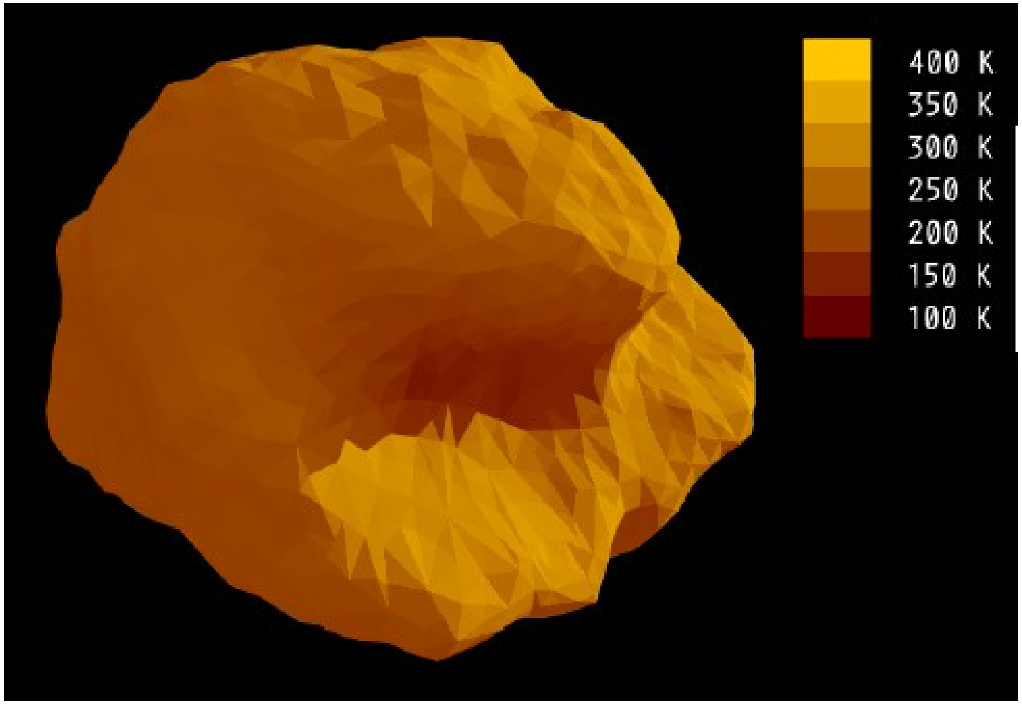
with a boundary condition on surface

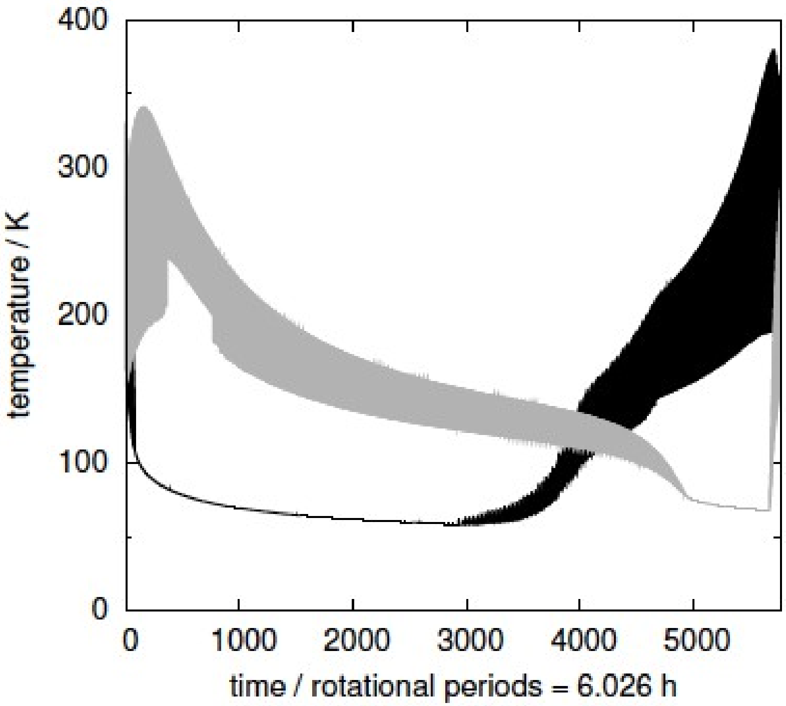
$$\left(K \frac{\partial T}{\partial r} \right)_{\rm surface} + \epsilon \sigma T^4 = (1 - A)\, \mathcal{E}(t) \cdot \mathbf{n}_\perp(\mathbf{r}) \,,$$

- The elementary force due to the reemission of photons is

$$\mathrm{d}\mathbf{F}_{\rm Y} = -\frac{2}{3} \frac{\epsilon \sigma T^4}{c} \mathrm{d}S \mathbf{n}_\perp$$

Distribution and evolution of temperature with time for (6489) Golevka asteroid

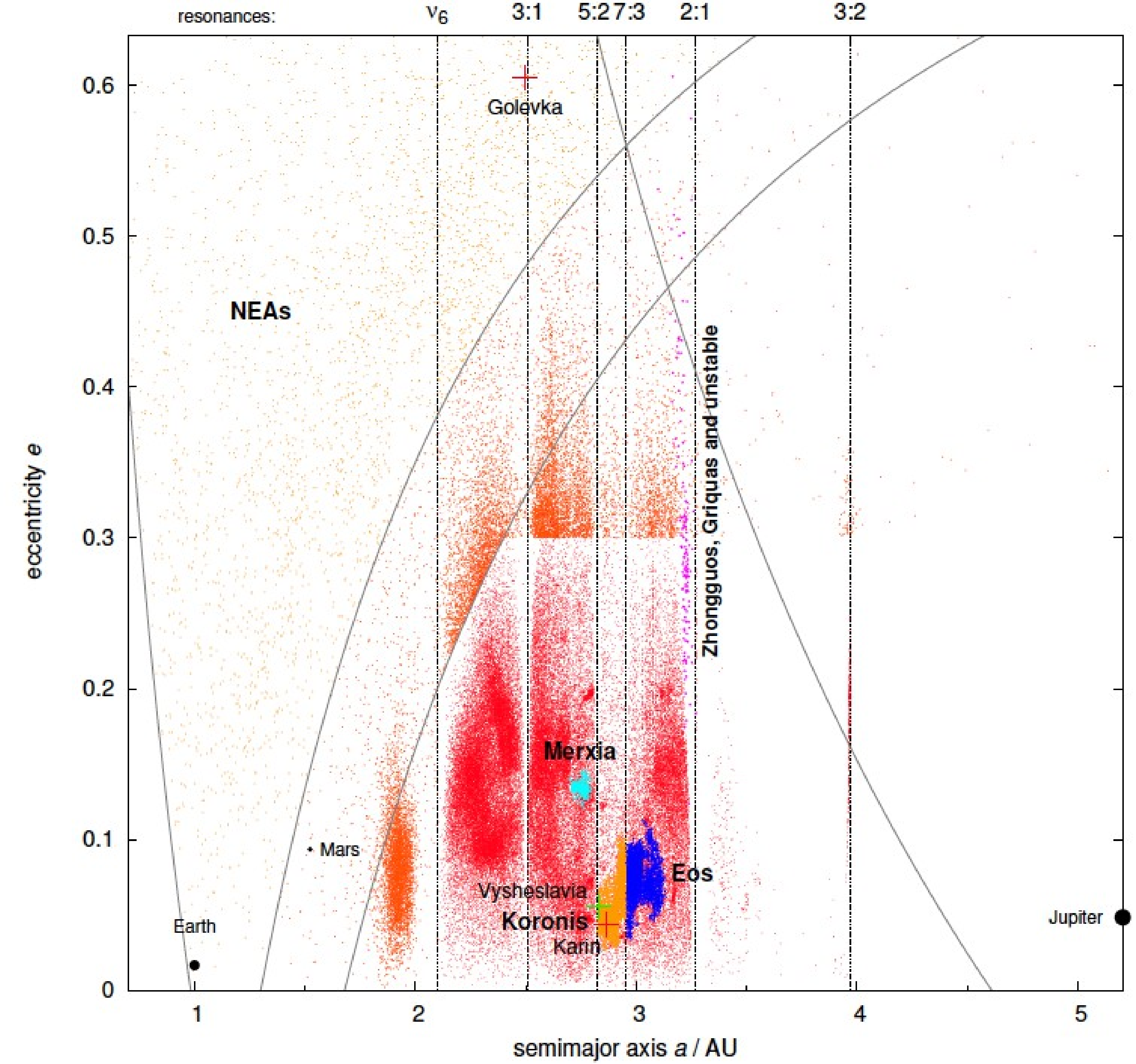




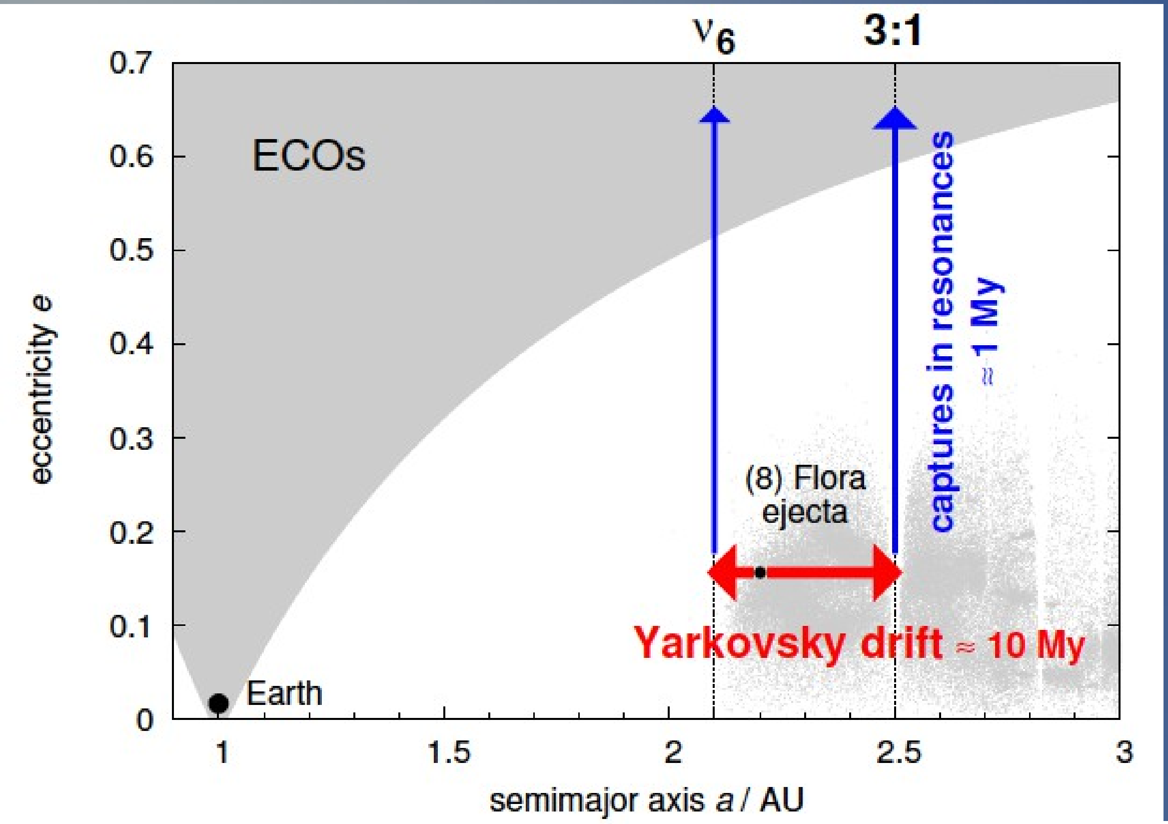
This is numerical solution of 1-d heat diffusion equation for all 4092 surface elements.

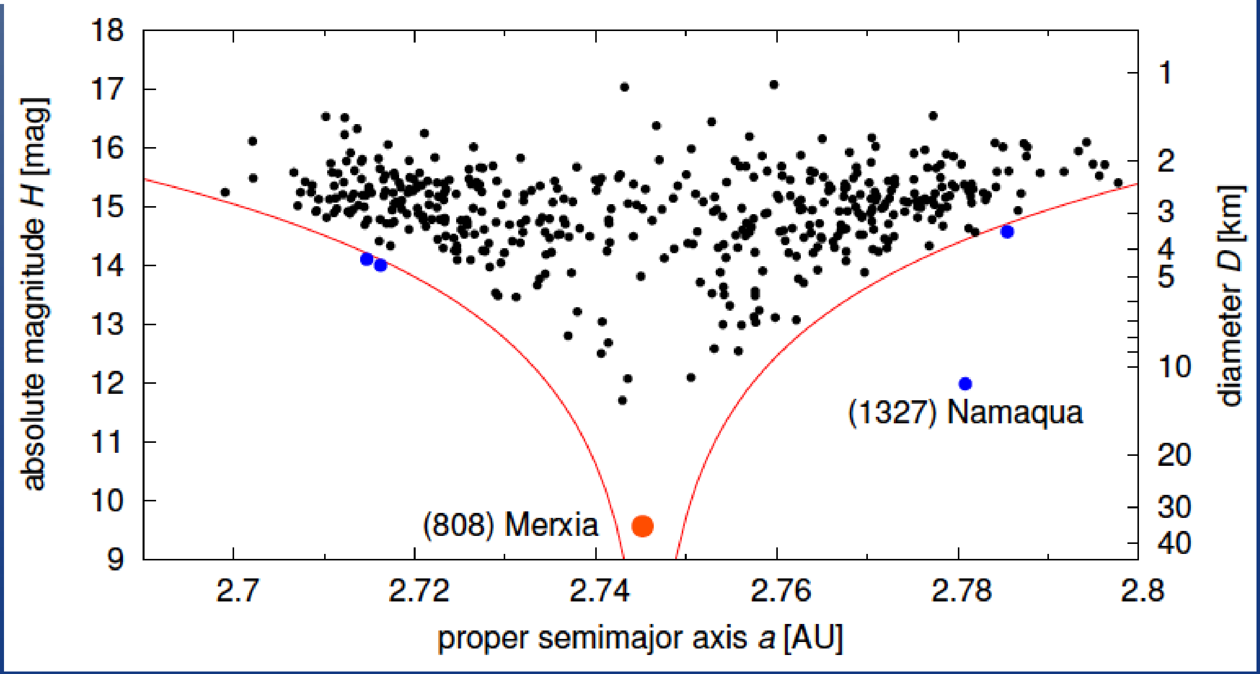
Adapted from Chesley et al. (2003).

Distribution of asteroids wrt *a*, *e*

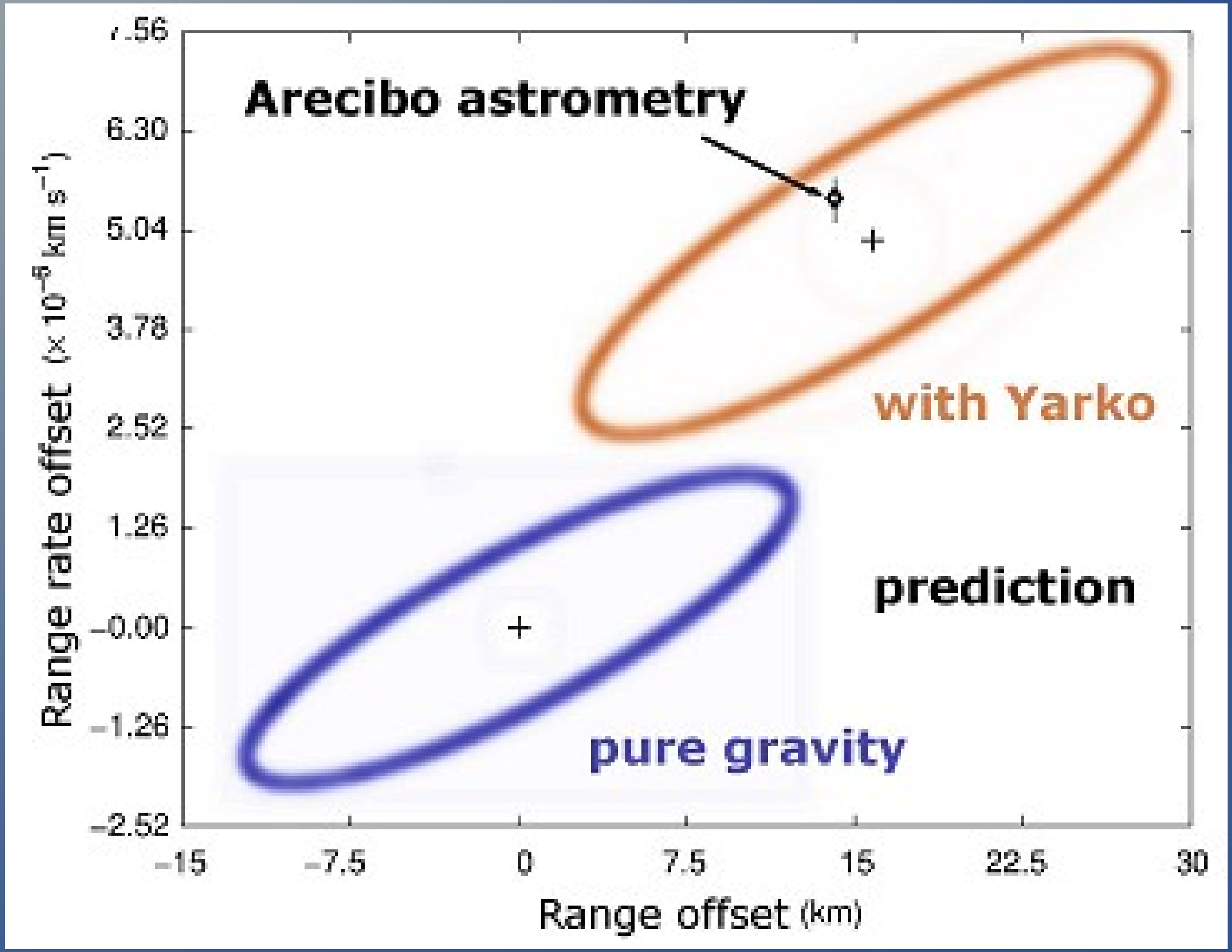


Evolution of small asteroids (meteoroids) due to the Yarkovsky effect



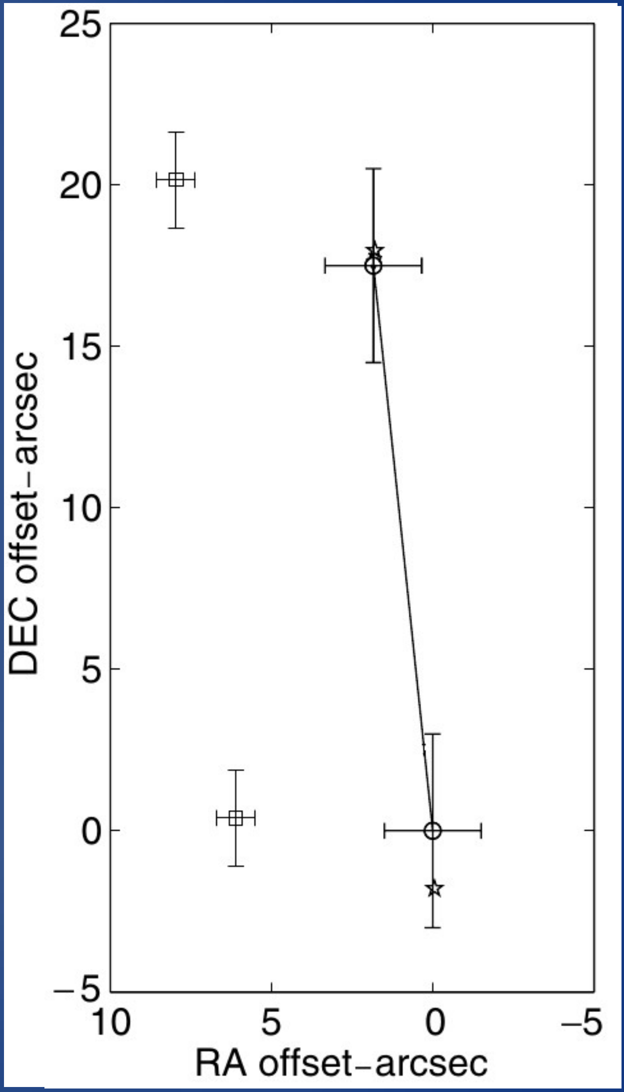


The astrometric method for detecting Yarkovsky effect



(6489) Golevka

The *(O-C)* difference in the distance from the purely gravitational and the Yarkovsky models is 15 km.



(152563) 1992 BF

Predicted positions of purely gravitational model are approximately 6 arcsec east of the observed trail.

Astrometric evidences of the Yarkovsky effect

The drift of semimajor axis caused by the Yarkovsky effect can be considered next (Bottke et al. (2002):

$$da/dt \equiv f(D, P, \kappa, p_b, p_s, c, \xi, r)$$

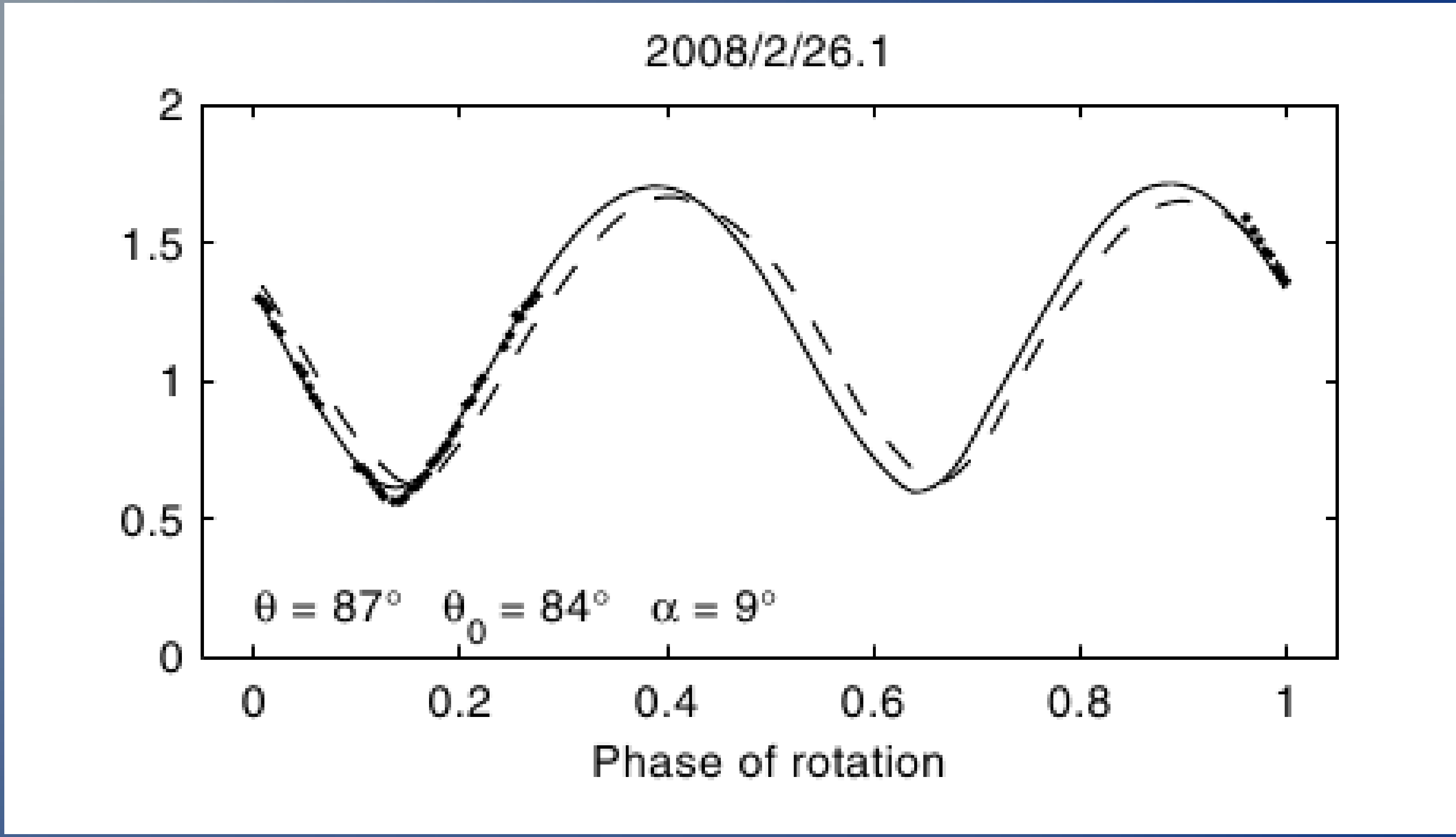
D – diameter of the asteroid;
P – rotation period;
κ – thermal conductivity;
p_b – bulk density;
p_s – surface density;
c – specific heat capacity;
ξ – obliquity of the spin vector;
r – distance from Sun.

The main consequence of the Yarkovsky effect is quadratic drift of the asteroid mean anomaly with time:

$$\Delta M = -\frac{3}{4}\frac{n}{a} da/dt \, \Delta t^2$$

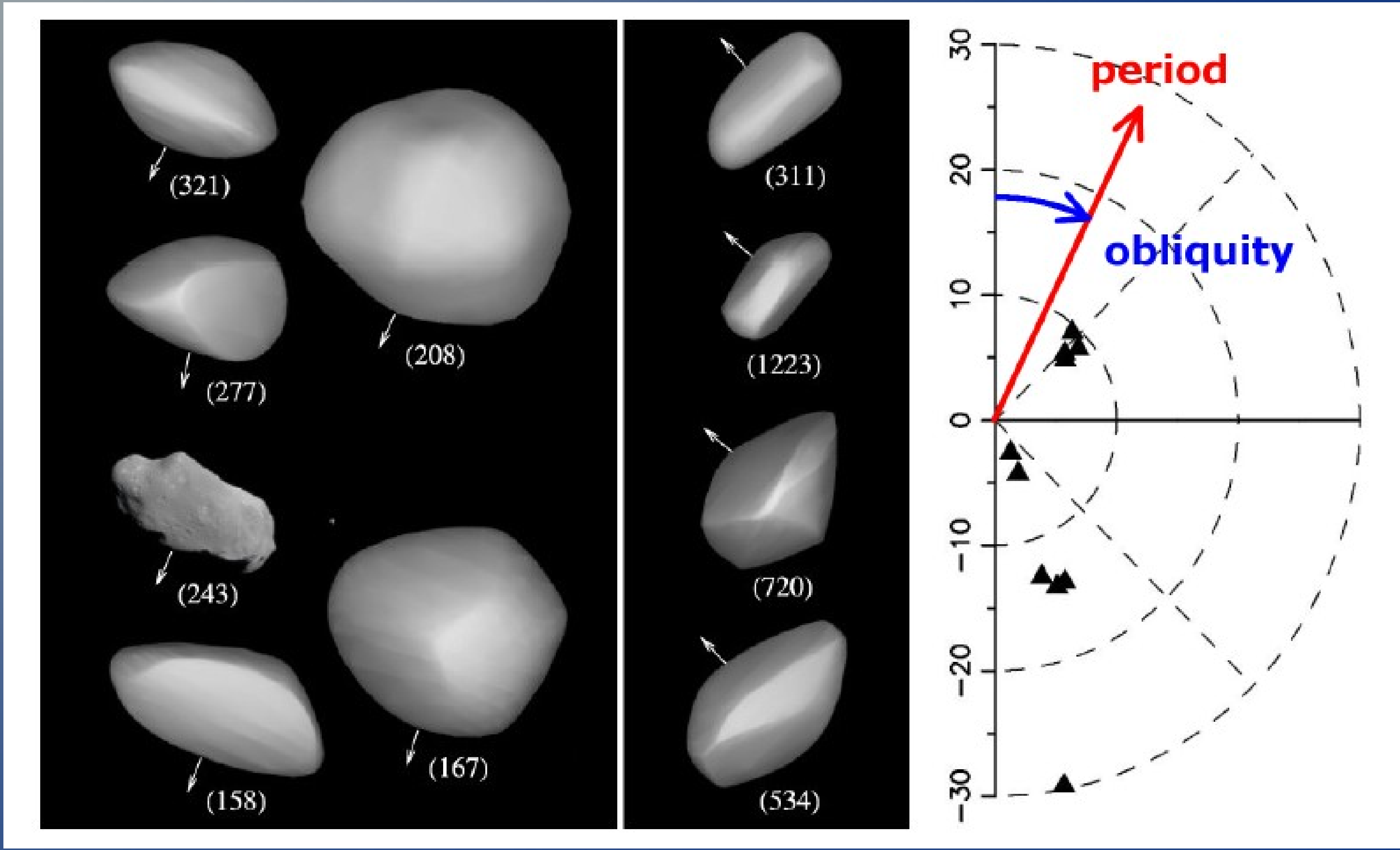
M – mean anomaly;
n – mean motion.

The photometric method for detecting the YORP effect



Examples of Geographos' lightcurves were fitted with synthetic ones based on the convex shape model. The solid curve corresponds to the best model with the accelerated rotation rate while the dashed curve corresponds to the best constant-period model.

The secular changes due to the YORP effect



There is a bimodality of distribution of obliquities of asteroids within the family, e.g. for 11 members of Koronis family. Adapted from Slivan et al. (2003).

History of measurements for the Yarkovsky/YORP effects

Name of asteroid	Detection year	Yarkovsky/YORP effects	Method of detecting
(6489) Golevka	2003	$da/dt \simeq -6 \times 10^{-4}\ AU/Myr$	Astrometric observations (radar ranging)
(152563) 1992 BF	2006	$da/dt \simeq -(10.7 \pm 0.7) \times 10^{-4}\ AU/Myr$	Astrometric observations (optical observations)
(54509) 2000 PH5	2007	$d\omega/dt = (3.5 \pm 0.35) \times 10^{-6}\ rad/d^2$	Lightcurve inversion
(1862) Apollo	2007, 2008	$d\omega/dt = (5.5 \pm 1.2) \times 10^{-8}\ rad/d^2$	Lightcurve inversion
(1620) Geographos	2008	$d\omega/dt = (1.15 \pm 0.15) \times 10^{-8}\ rad/d^2$	Lightcurve inversion
(3103) Eger	2009	$d\omega/dt = (9 \pm 6) \times 10^{-9}\ rad/d^2$	Lightcurve inversion

In 2012 the Yarkovsky effect was determined for 54 near-Earth asteroids, Nugent et al. (2012).

Prospect asteroids for determination of the transversal component of acceleration (non-gravitational effects)*

Asteroid	**Diam,** km	**a,** a.e.	**e**	**mag**	**Rotation period,** hour	**Revolution period,** year	**Observation interval**
1036	41	2.66	0.54	14.8	10.31	4.34	1924-2008
1863	2.77	2.26	0.61	20.9	7.46	3.4	1948-2006
1864	3.81	1.46	0.61	18.5	8.57	1.77	1971-2008
1916	3.67	2.27	0.45	20.7	3.49	3.43	1953-2008
1917	5.9	2.15	0.5	19.6	2.69	3.15	1954-2008
2212	5.98	2.17	0.83	17.4	≈20	3.19	1974-2007
5660	2.58	1.79	0.76	20.1	17.5	2.39	1974-2008
8567	3.1	2.05	0.45	20.3	8.76	2.93	1955-2008
53789	1.23	1.37	0.27	17.9	≈43	1.6	1955-2008
87309	1.07	0.85	0.46	19.8	-	0.78	1975-2007
162004	0.81	0.89	0.66	20.3	-	0.84	1954-2008
2004FX31	1.12	1.26	0.44	20.5	-	1.42	1990-2007

* Extraction from Chernetenko et al. (2009).

Prospect asteroids for future measuring of the Yarkovskiy effect*

JPL Small-Body Database Search Engine

[Refine Search] **Results:** 22 matching objects

Constraints: numbered asteroids and a-sigma <= 1e-9 (AU)

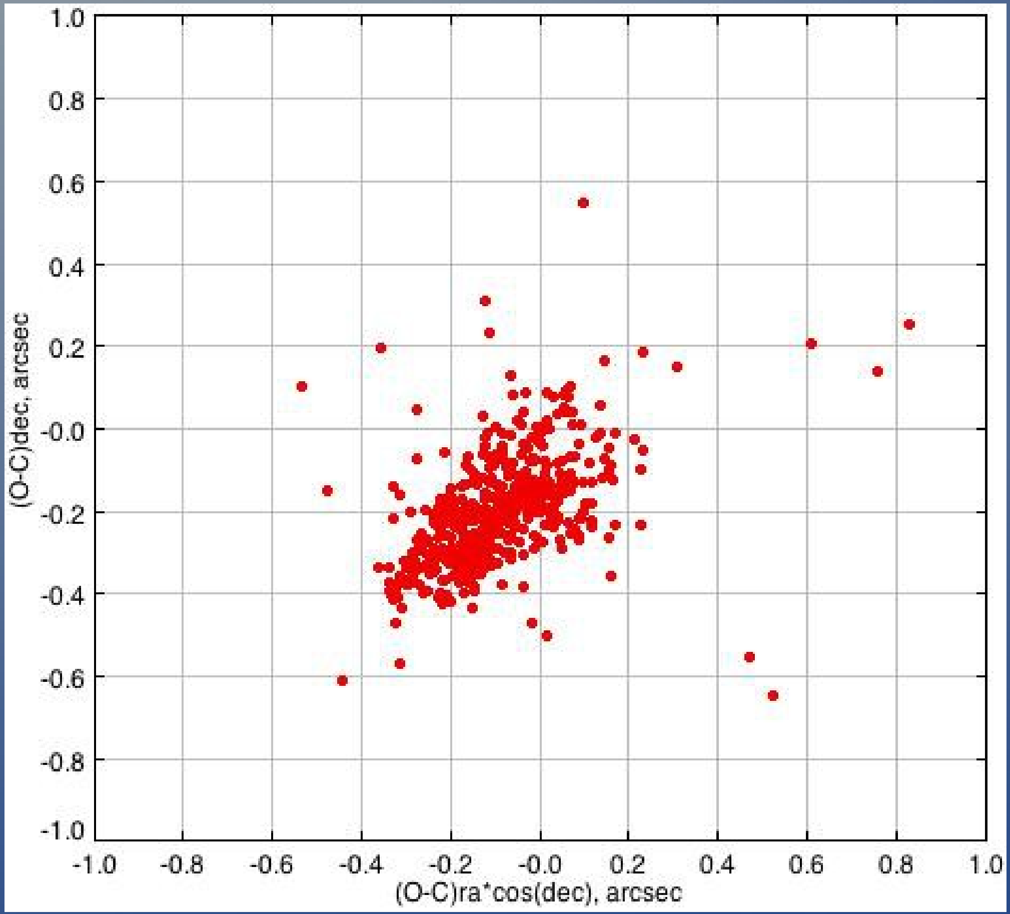
prim. desig. ?	a-sigma (AU) ?	H (mag) ?	diameter (km) ?	extent (km) ?	albedo ?	date of first obs. (UT) ?	date of last obs. (UT) ?	# obs. used (total) ?	# obs. used (del.) ?	# obs. used (dop.) ?	norm. RMS of fit (arcsec) ?
4	9.8e-10	3.2	530		0.4228	1827-12-11	2010-05-11	6635			.62524
433	3.1e-10	11.2	16.84	34.4x11.2x11.2	0.25	1963-07-15	2012-09-03	4987	1	3	.45634
1566	4.4e-10	16.9	1.0		0.51	1949-06-27	2012-06-07	784	0	11	1.0059
1580	2.8e-10	14.5	5.8		0.08	1950-05-22	2012-06-08	548	5	7	.70335
1620	4.9e-10	15.6	2.56	5.0x2.0x2.1	0.3258	1951-08-31	2012-09-30	2888	3	4	.57017
1685	3.9e-10	14.2	3.4		0.31	1948-07-17	2012-08-20	1464	5	2	.42038
1862	9.8e-10	16.2	1.5		0.25	1930-12-13	2008-02-28	838	8	9	.64108
2063	8.6e-10	17.1		1.1x1.1x2.6		1977-04-24	2012-09-14	371	6	5	.49441
2100	6.4e-10	16.1	2.3		0.13	1975-10-03	2012-08-23	1262	4	2	.53081
2340	4.5e-10	19.2	0.3			1976-10-25	2012-02-03	183			.7098
3908	1.7e-10	17.4	1.0		0.23	1980-08-06	2012-09-14	1345	15	1	.44067
4179	1.2e-10	15.3	5.4	1.70x2.03x4.26		1934-02-10	2012-10-04	4007	24	28	.37812
4769	3.0e-10	16.9	1.4			1989-08-01	2012-09-14	213	8	7	.4945
6489	1.8e-10	19.2	0.53		0.151	1995-03-07	2003-10-20	836	14	20	.7445
7341	3.4e-10	16.7				1991-09-12	2012-06-07	944	8	3	.43862
37655	6.8e-10	17.7				1994-08-01	2012-08-13	414	1	0	.45151
38071	9.1e-10	19.6				1999-04-10	2008-06-20	451	6	5	.5833
85774	4.3e-10	19.1				1989-04-30	2009-06-14	471	3	4	.47301
101955	1.2e-10	20.8				1999-09-11	2006-05-26	298	9	4	.52072
175706	9.7e-10	18.3				1996-03-24	2012-04-23	1605	6	1	.36136
185851	4.5e-10	18.2				2000-02-29	2011-01-28	823	11	2	.46199
234145	4.2e-10	21.2				2000-03-09	2010-03-13	316	4	6	.5784

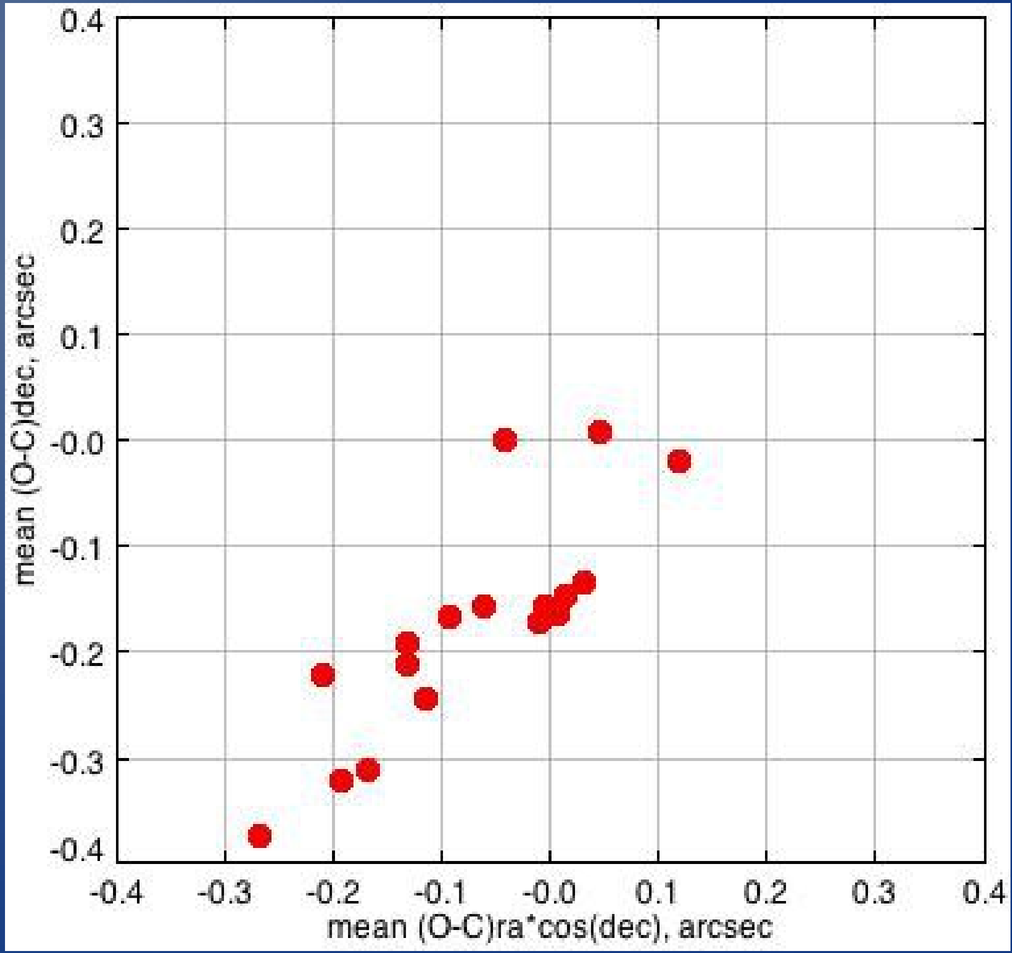
* (4) Vesta is very big in size, so it is not a suitable object; (433) Eros is also very big, size of which is located at the limit of the Yarkovskiy detectability.

Astrometric observations of (4558) Janesick asteroid at T100 telescope. Summary

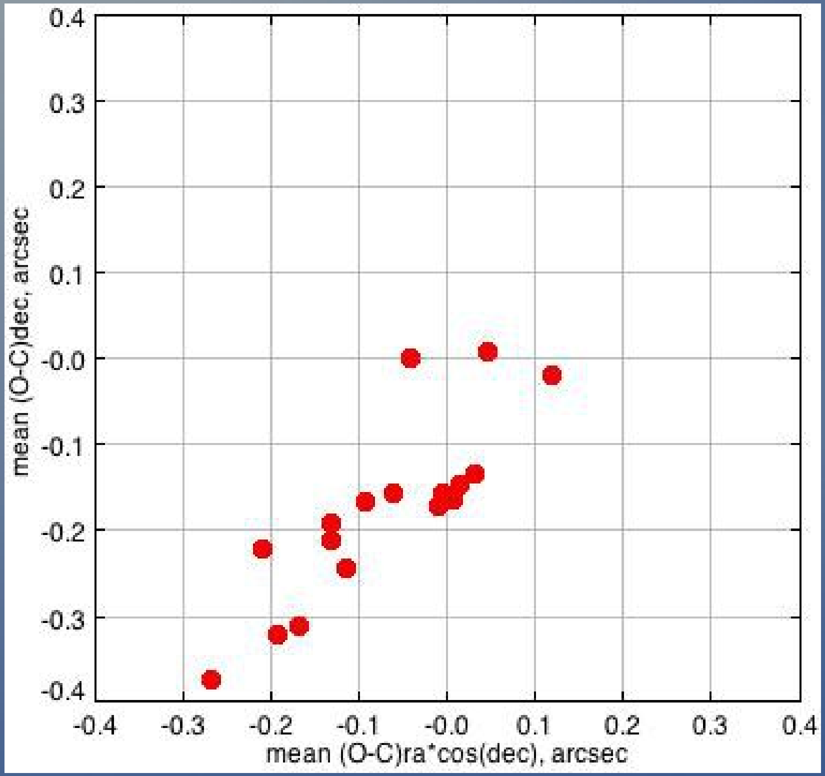
- The available 496 positions of asteroid (4558) Janesick cover the period from 27-08-2011 till 23-02-2012.
- There are 17 series of observations with mean value of 29 images per series.
- The brightness of object (V-band) was 14.3-16.3 mag. The observations were made in EVRN bands.
- Zenith distances at the mean moments of observations were from 17 to 58 deg.
- The weighted mean errors of positions were 0.12” and 0.10” in R.A. and Dec.

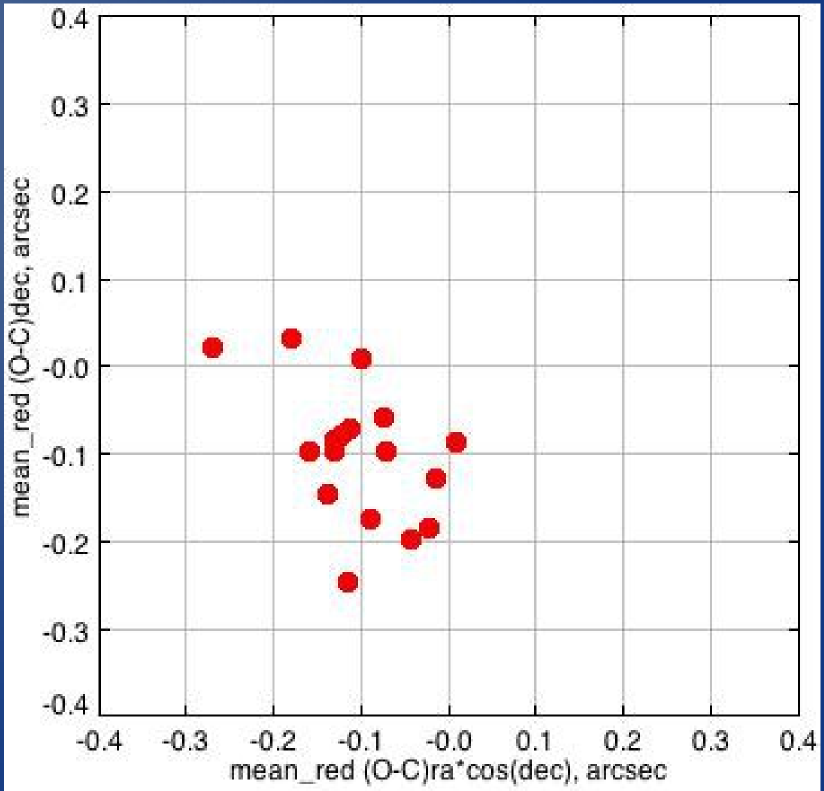
Distributions of (O-C)





Problem with time moments? Critical!



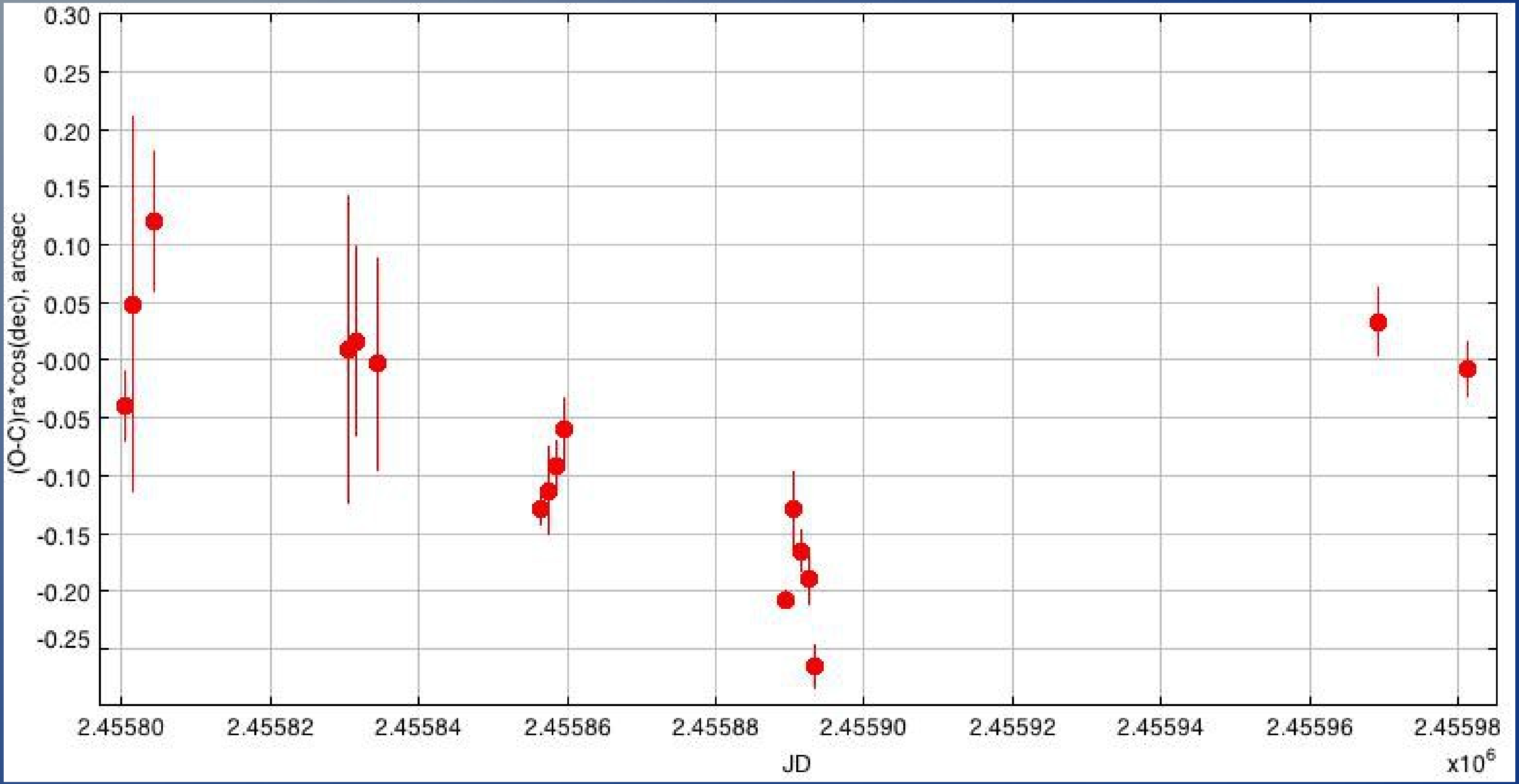


$$(O-C)_{\alpha} * \cos\delta = v_{\alpha} * \cos\delta * \Delta t + \epsilon_{\alpha}$$

$$(O-C)_{\delta} = v_{\delta} * \Delta t + \epsilon_{\delta}$$

$$Found\ \Delta t = 10.7\mathrm{s}$$

(O-C)ra*cos(dec) wrt time



Recommendations for improving astrometry at T100:

Instrumental:

- Check the GPS and time moments written in the images. The precision of time moments is better to have 0.1s (critical for making astrometry).
- The siderale rate of the telescope should be checked against time. In two subsequent series there was found different correction 0.06..-0.03 pixels/second = 0.02..-0.01arcsec/s.
- Astrometric observations should be made in the definite filter, preferably V or R to reduce correction due to color refraction.

Software:

- There is a need in modeling of the field of view distortion for removing systematical errors (0.2 arcsec).

Conclusions

The Yarkovsky effect, as one of non-gravitational effects, is now an inevitable ingredient of dynamical models for small asteroids and meteoroids. The measured effect of the Yarkovsky acceleration is a secular drift of the semimajor axis of the orbit of the order of $\sim 10^{-4}$AU/Myr = 10^{-10} AU/yr.

At present, the Yarkovsky effect is measured for about 50 asteroids in 2012. However, these measurements are constrained with the available astrometric observations and some guesses on the surface and bulk properties. So, there is a lot of work to do.

The astrometric precision and accuracy are important for measuring such small effects. The best astrometric precision gained at the best observational conditions (site + telescope) in the world is 0.1 pixel without using image reconstruction, which for T100 telescope corresponds to 0.03 arcsec. At present the weighted error of a single observation is 0.12 arcsec.