The distribution of small near-Earth objects and the role of the Yarkovsky effect

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Summary

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   - General trend
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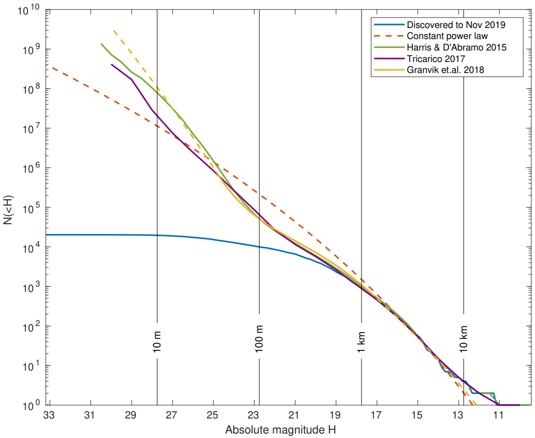
Introduction



- More than **20.000** NEOs have been discovered so far.
- The NEO catalogue is full for

$$H < 17.5$$

- ∼94% of objects with D > 1 km have been discovered so far.
- Models predict:
  - about **50k** objects with D > 100 m;
  - about **100M** objects with D > 10 m.

Granvik model

Granvik et. al. 2018, Icarus 312

- It provides a 4 dimensional orbital distribution of NEOs: (a, e, i, H)
- It is valid for $17 < H < 25$
- It is based on the transport mechanism of objects from the Main Belt to the Near Earth region

Basic modeling equation:

$$\boxed{n(a,e,i,H)} = \boxed{\epsilon(a,e,i,H)} \sum_s \boxed{N(H;P_s)} \boxed{R_s(a,e,i)}$$

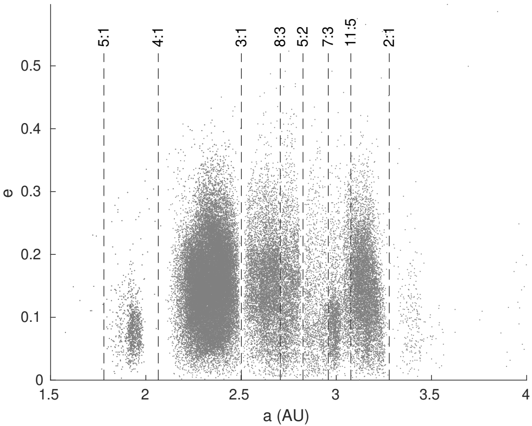
Observed population — **Observational bias** — **True population** — **Orbital distribution**

Transport routes

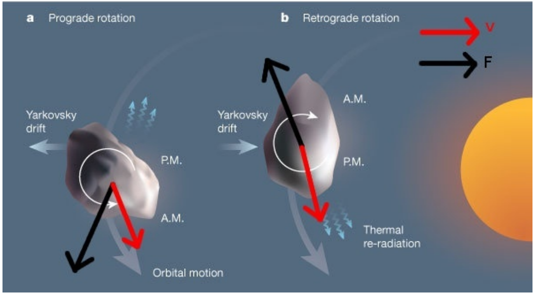
Objects move from the main belt region to the near-Earth region by means of dynamical effects:

- **Jupiter mean-motion resonances** (e.g. 3:1, 4:1, 2:1, etc)
- **Secular resonances** (e.g. the ν_6 secular resonance)

They cause changes in **eccentricity** and **inclination**.



The Yarkovsky effect



- The Yarkovsky effect changes the **semimajor axis** a
- The drift is **size dependant**:

$$\frac{da}{dt} \propto \frac{1}{D}$$

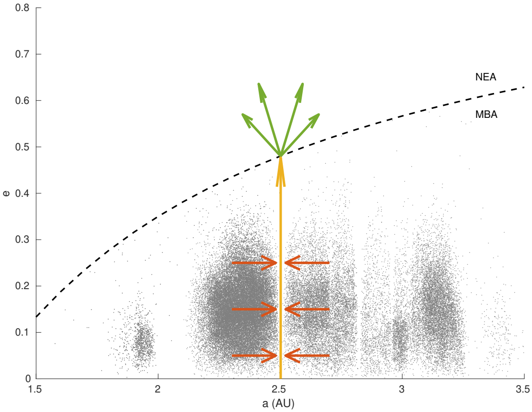
- The total drift strongly depends on the **physical and thermal characteristics** (i.e. density, surface composition)

Example of transportation

Step 1: Yarkovsky drift

Step 2: 3:1 Jupiter MMR

Step 3: Possible close encounters



Modeling the population of small NEOs

Motivations

YE is not included in the NEO region by Granvik et. al 2018

The YE has been detected on many NEOs:

- 87 objects in *Del Vigna et. al.*, 2018
- 176 objects in the NASA JPL SBDB
- 247 objects in *Greenberg et. al.*, 2020

The YE could be large for very small asteroids.

Aims

- Understand how the basic components of the migration model are affected, depending on the magnitude of the drift
- Understand how fast should be the drift to affect the results
- Understand the typical drifts for small objects, **from 1 meter up to 100 meters in diameter**, and if they can reach the critical values

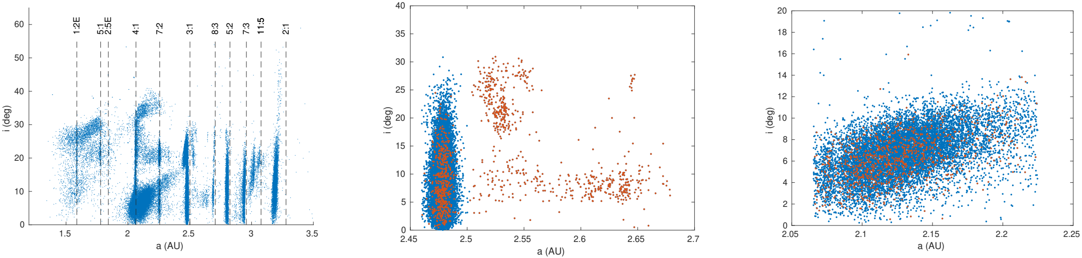
Numerical simulations: initial conditions

Initial conditions taken from **Granvik et. al. 2018** (left panel).

Two selected sets of NEOs:

a) 1000 objects entering through the 3:1 Jupiter MMR (central panel).

b) 1000 objects entering through the ν_6 secular resonance (right panel).



Numerical simulations: computational details

Dynamical model:

- attraction of the Sun and the 8 planets;
- constant Yarkovsky drift, as acceleration along the velocity.

Numerical integration:

- `mercury` integrator by J. Chambers;
- hybrid symplectic/Burlisch-Stoer algorithm;
- variable timestep, 12 h maximum;
- 10 My integration time.

Output:

- osculating elements recorded every 250 yr;
- average time spent in the NEO region

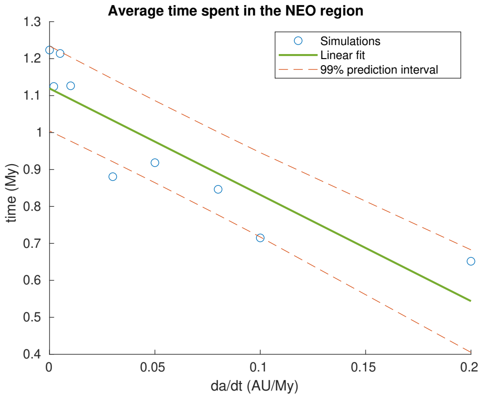
$$\langle L \rangle_{\mathsf{NEO}};$$

- orbital distributions

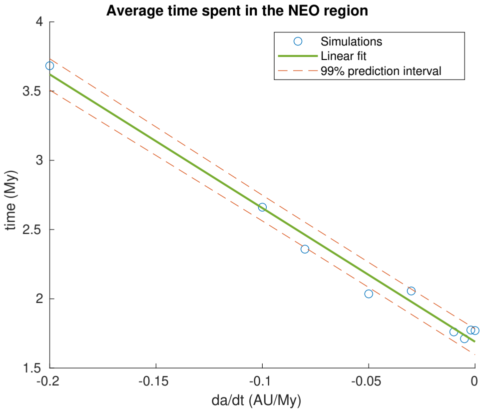
$$R_{3:1}(a, e, i), \quad R_{\nu_6}(a, e, i).$$

Results for the 3:1 Jupiter MMR: lifetimes

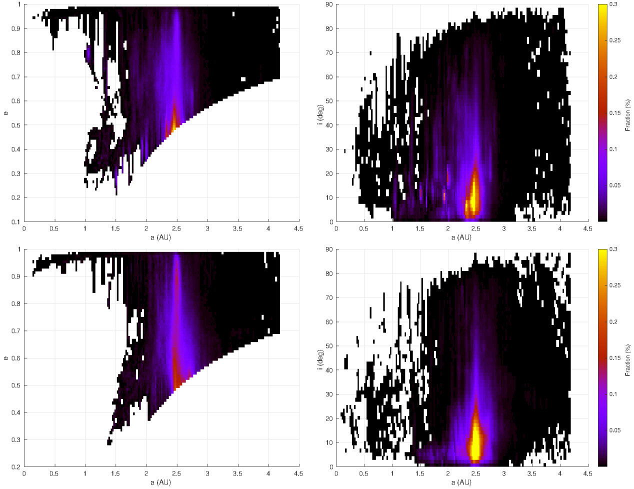
Inner part



Outer part



Results for the 3:1 Jupiter MMR: orbital distribution



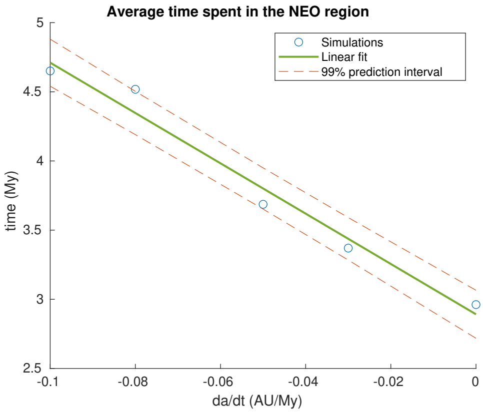
Upper row

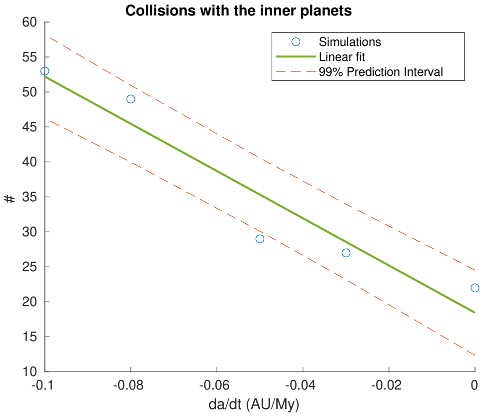
Purely gravitational model

Lower row

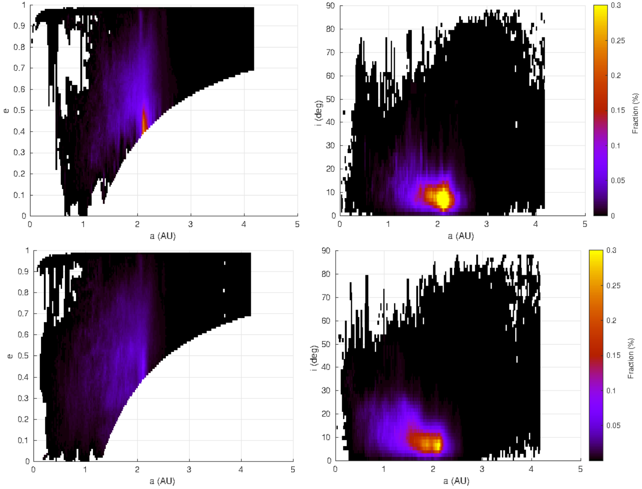
$$\frac{da}{dt} = 0.1 \text{ AU/My}$$

Results for the ν_6 resonance: lifetimes





Results for the ν_6 resonance: orbital distribution



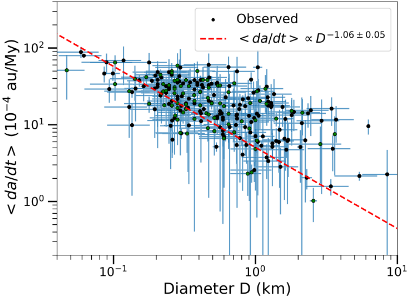
Upper row

Purely gravitational model

Lower row

$$\frac{da}{dt} = -0.08 \text{ AU/My}$$

How fast can be the drift?



Credits: Greenberg et. al. 2020, The Astronomical Journal 159:92.

Some objects with fast drifts:

Name	da/dt
2006 GY2	-0.037 AU/My
2009 BD	-0.038 AU/My
2011 MD	-0.048 AU/My
2012 LA	-0.097 AU/My
2015 TC25	-0.197 AU/My

Estimation of the surface properties[1]

Input: a NEO with a measured Yarkovsky drift and measured rotation period.

Methods:

1. Model the distributions for ρ, D, γ, P and measured drift;
2. Invert the relation

$$\boxed{\frac{da}{dt}(a_0, \rho, K, C, \gamma, P)} = \boxed{\left(\frac{da}{dt}\right)_{\mathrm{m}}}$$

Theoretical model of YE — **Measured YE**

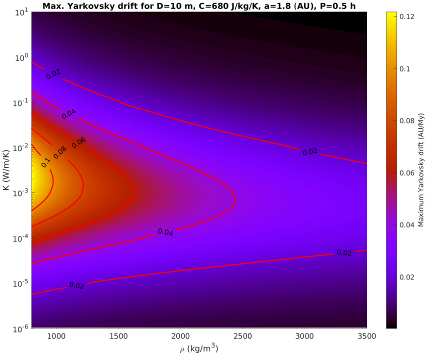
and solve for K;

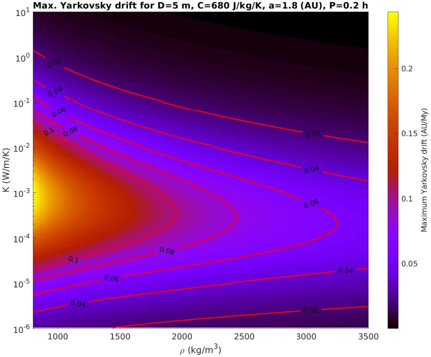
3. Perform a MC simulation.

Output: probability density function for K.

[1] Fenucci, Novaković & Vokrouhlický, 2020 (in preparation)

How fast can be the drift?





Note: eccentricity increases significantly the magnitude of the drift[2].

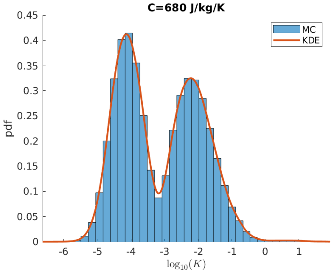
[2] Spitale & Greenberg 2001

Thermal properties of fast rotators

(499998) 2011 PT

Diameter: ∼45 meters

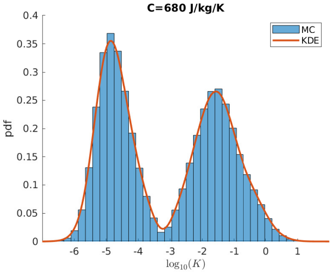
Rotation period: ∼11 minutes



2012 TC4

Diameter: ∼10 meters

Rotation period: ∼12 minutes



Conclusions and future works

Conclusions:

- The YE causes significant statistical changes in the lifetimes
- The YE causes significant changes in the orbital distributions
- Fast drifts can be actually reached

Future works:

- Introduce a variable YE in the NEO region
- Understand better the typical drifts for different sizes, asteroid compositions, and different source region
- Simulate the migration of small bodies from the main belt to the NEO region

That's all folks!