Modelovanje evolucije asteroida: teorija naspram posmatranja

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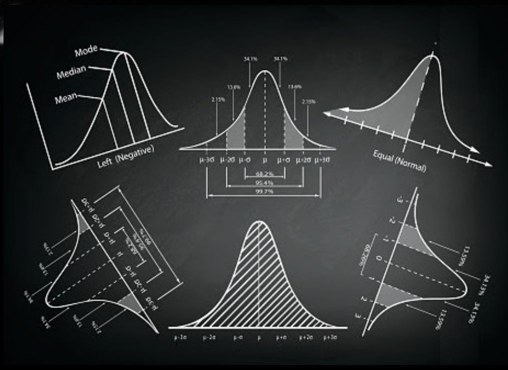

Seminar Katedre za astronomiju, 10. maj2022.

Modelling asteroid evolution: theory *vs* observations

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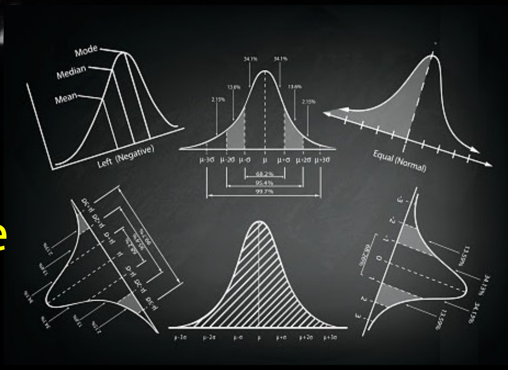
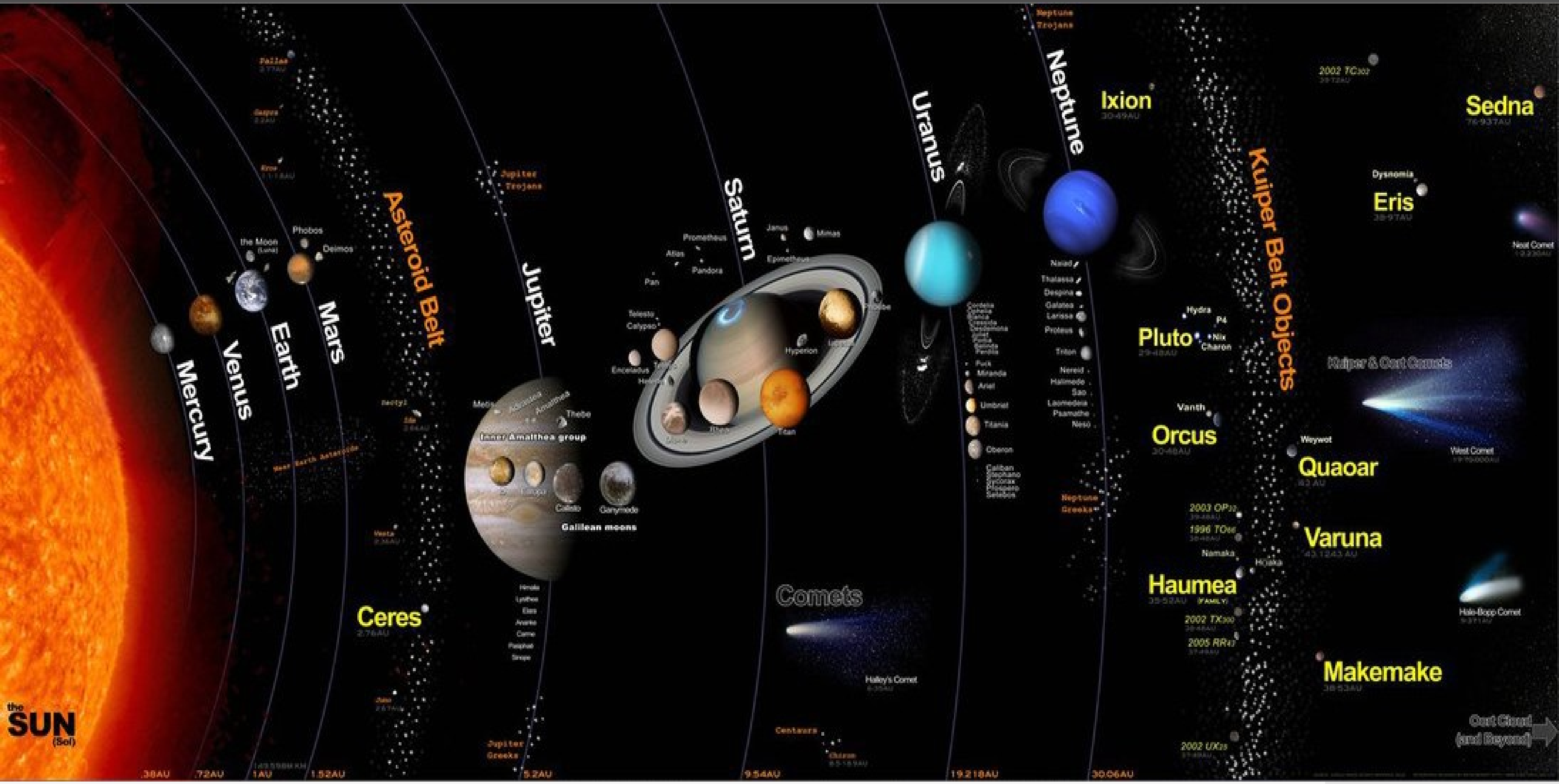
Seminar of the Department of Astronomy - 10 May 2022



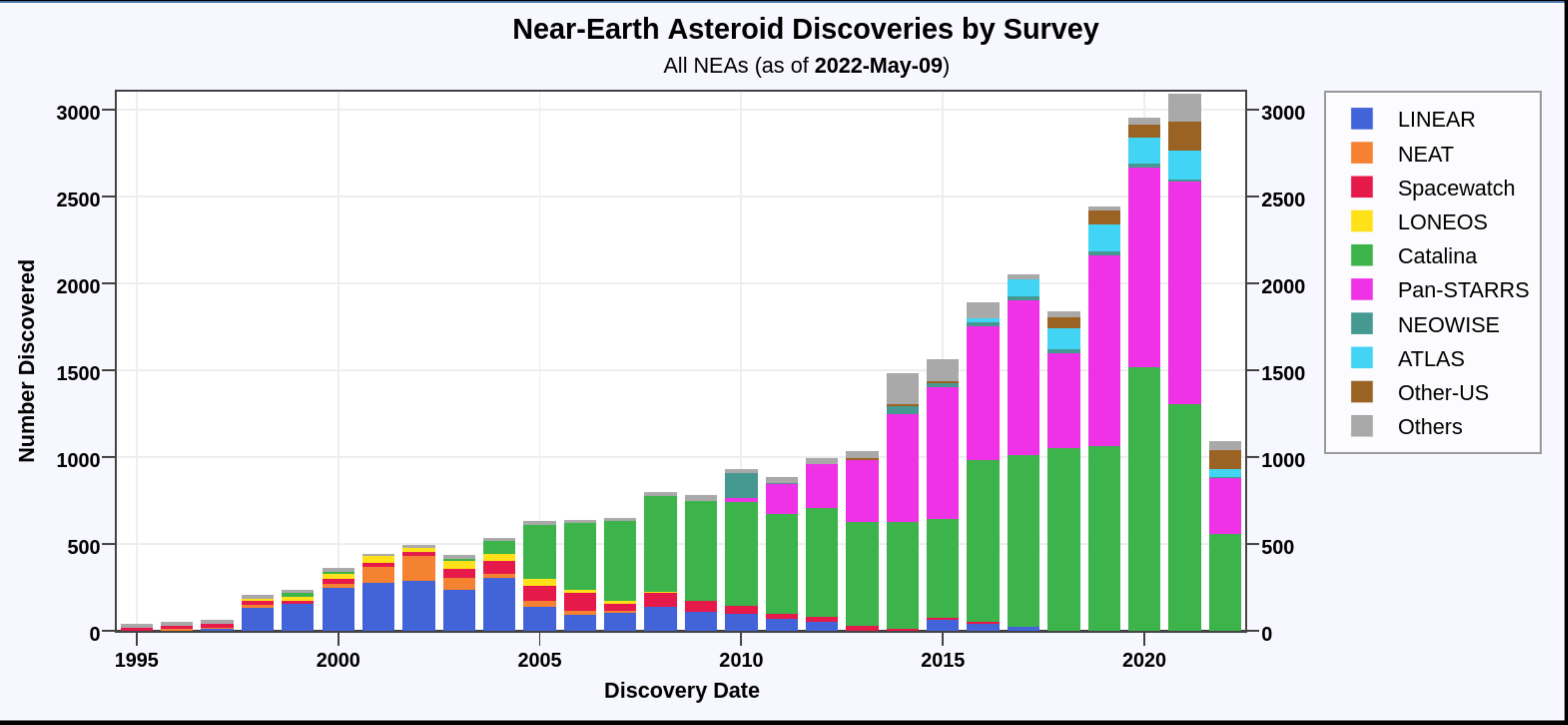
Solar System structure



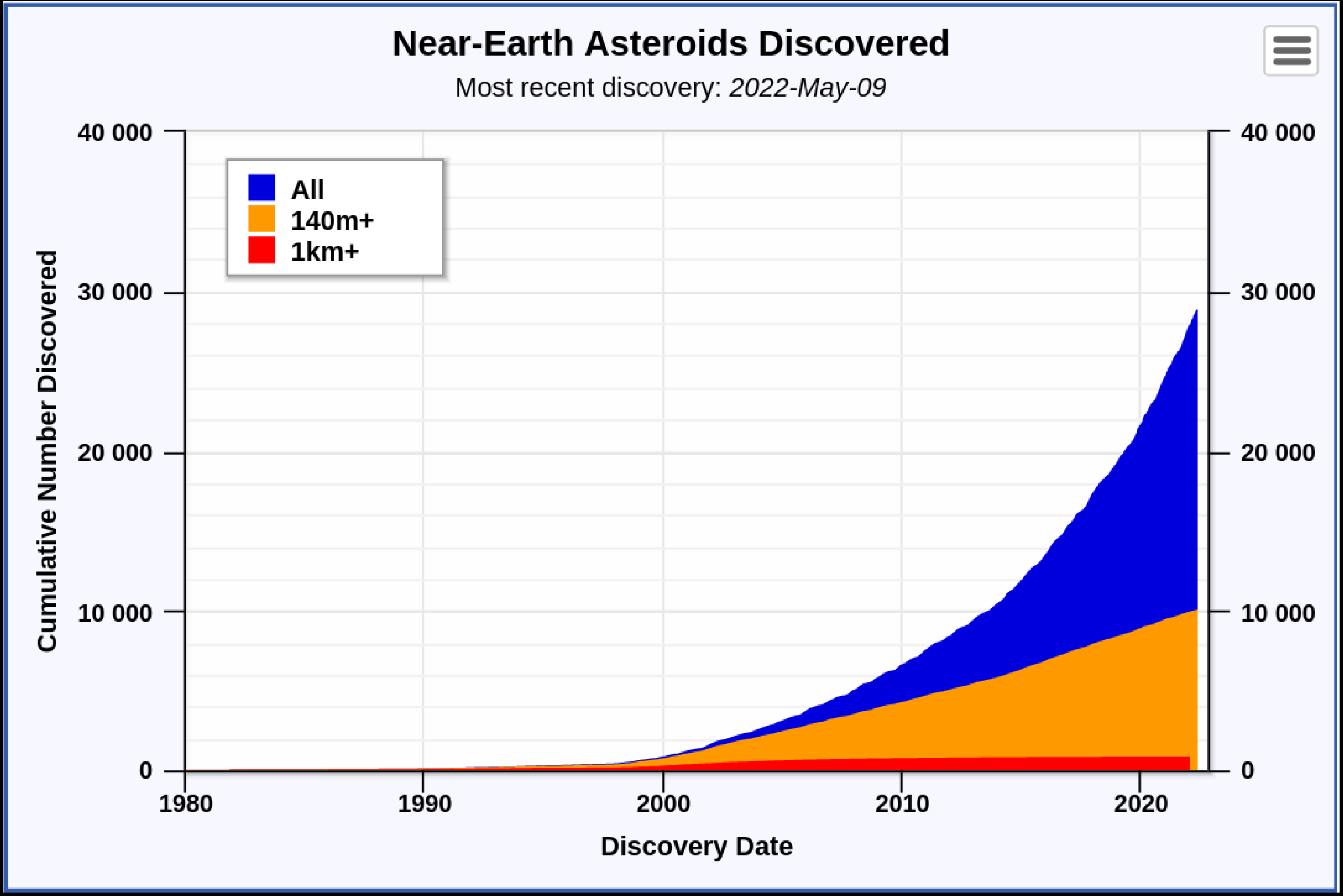
Why do we care about near-Earth asteroids?

- Science, Planetary Defense, Exploration, and maybe Exploitation

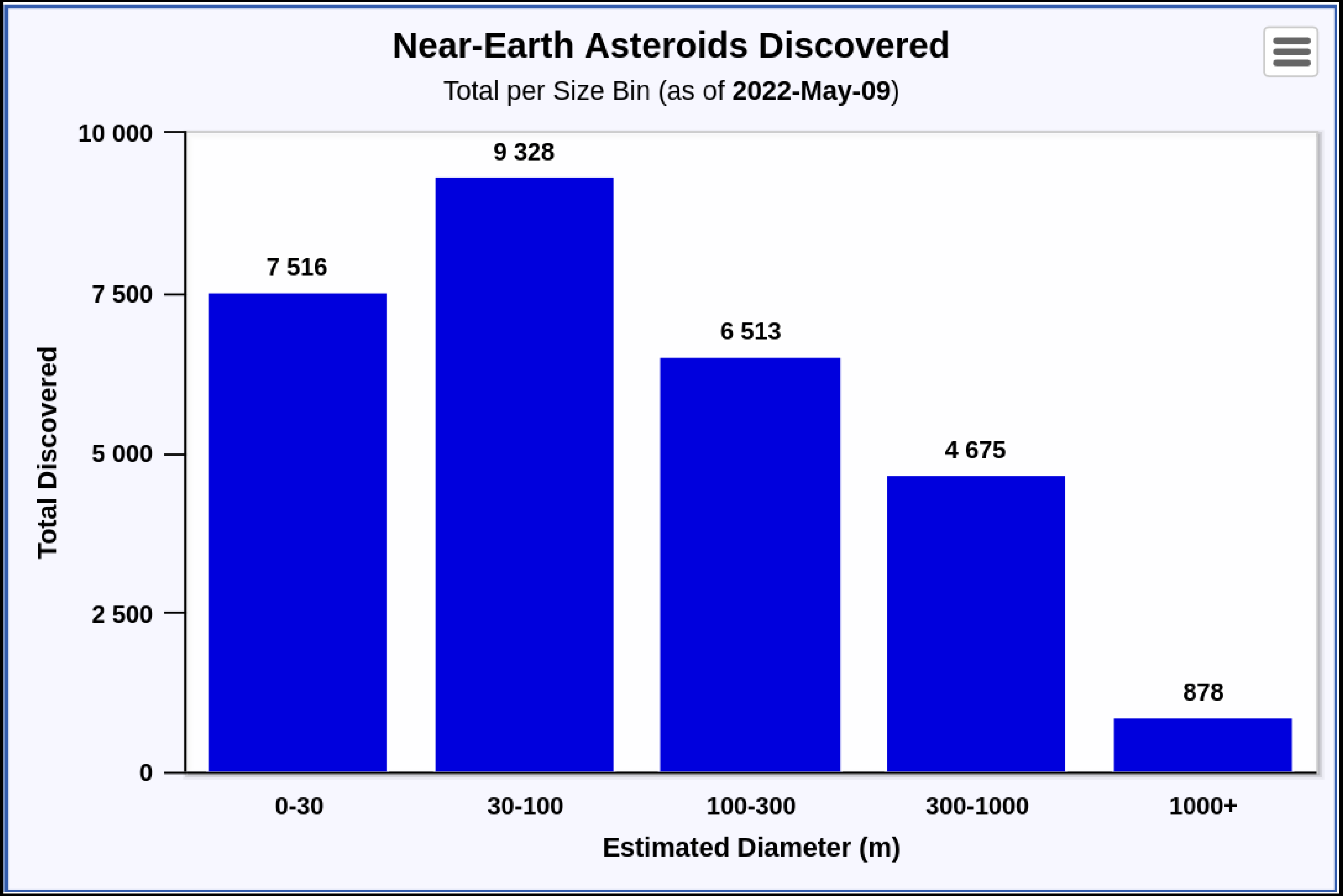
Discovery of Near Earth Asteroids



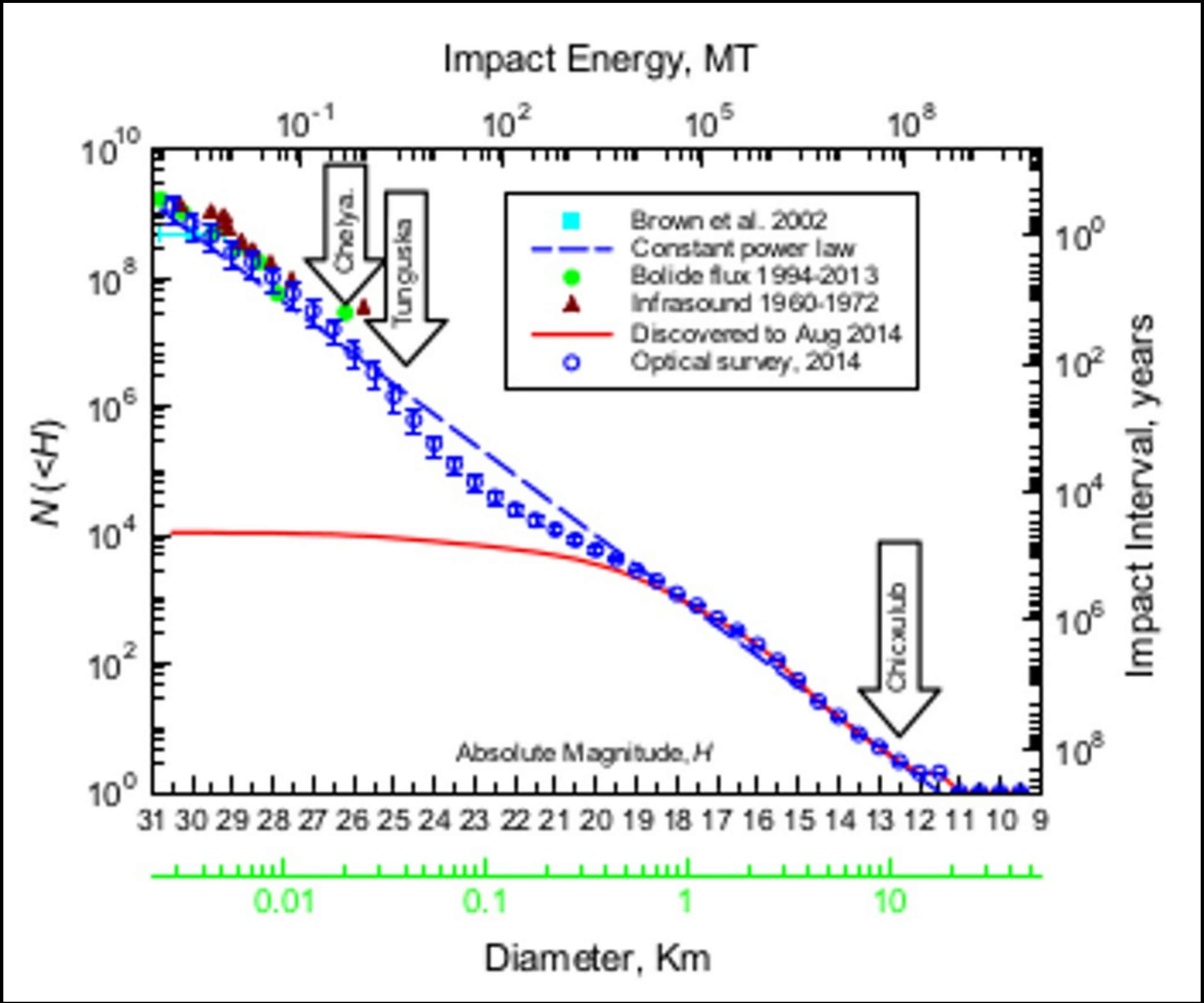
Discovery of Near Earth Asteroids



Discovery of Near Earth Asteroids



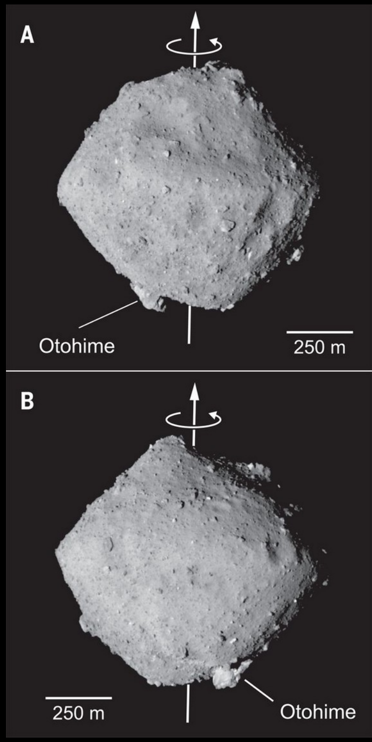
Near Earth Asteroids:
how many of them are there?



Near Earth Asteroids: what we know about their physical properties

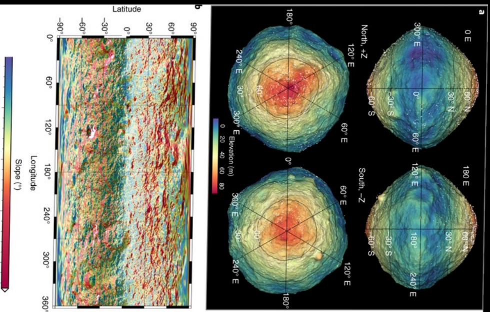
- Knowledge of the surface and internal properties of NEAs is required for assessing their hazard potential and the effectiveness of proposed mitigation strategies , as well as for the design of lander and sample return spacecraft missions

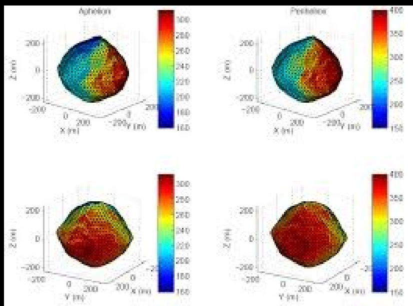
- Insights into the physical properties of asteroids are required for proper understanding of many processes, including the formation of planetesimals , bolides in planetary atmospheres, impact cratering, the evolution of the meteoroids parent bodies, and many others



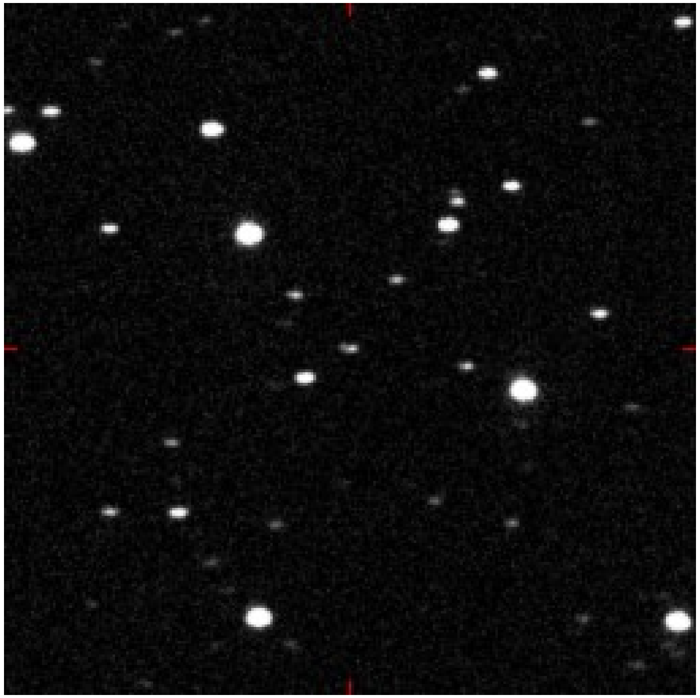
Near Earth Asteroids:
what we know about their physical properties

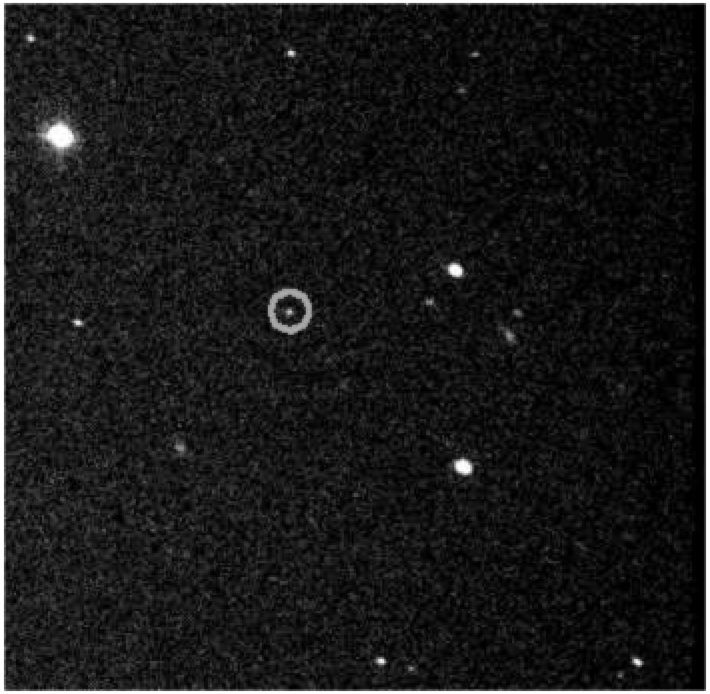
- Despite their great importance, knowledge of the physical properties of most NEAs lags far behind the current rate of their discoveries
- The asteroid surface and internal properties could often be inferred only from the space-borne observations or the space missions
- Asteroid surfaces and internal structures are very diverse, and knowledge derived from a limited number of asteroids typically could not be safely applied to a large number of objects



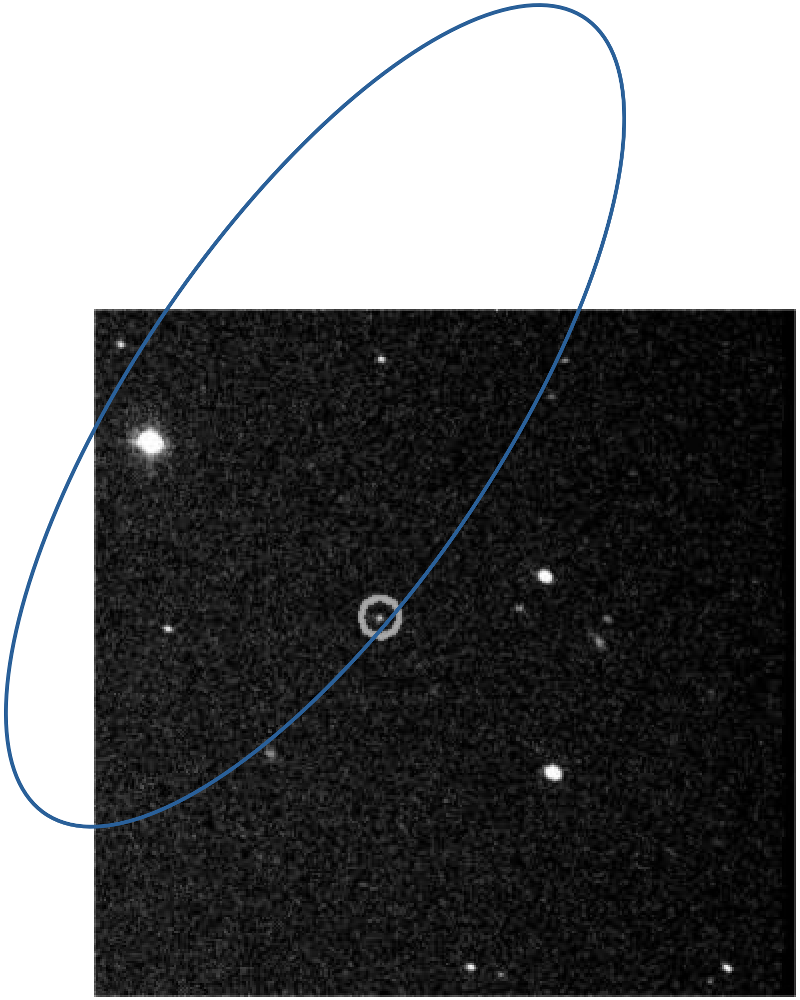


Near Earth Asteroids:
- from detection to orbital motion prediction





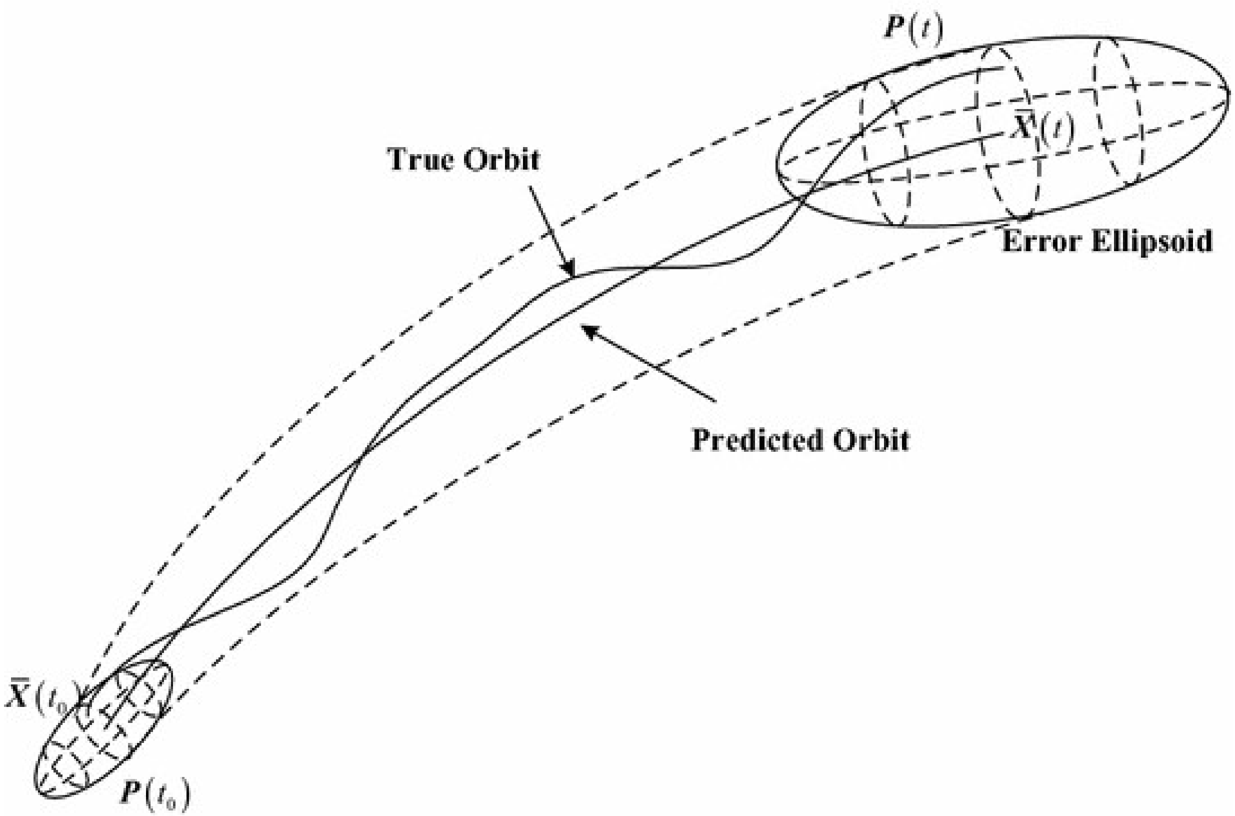
Near Earth Asteroids:
- from detection to orbital motion prediction



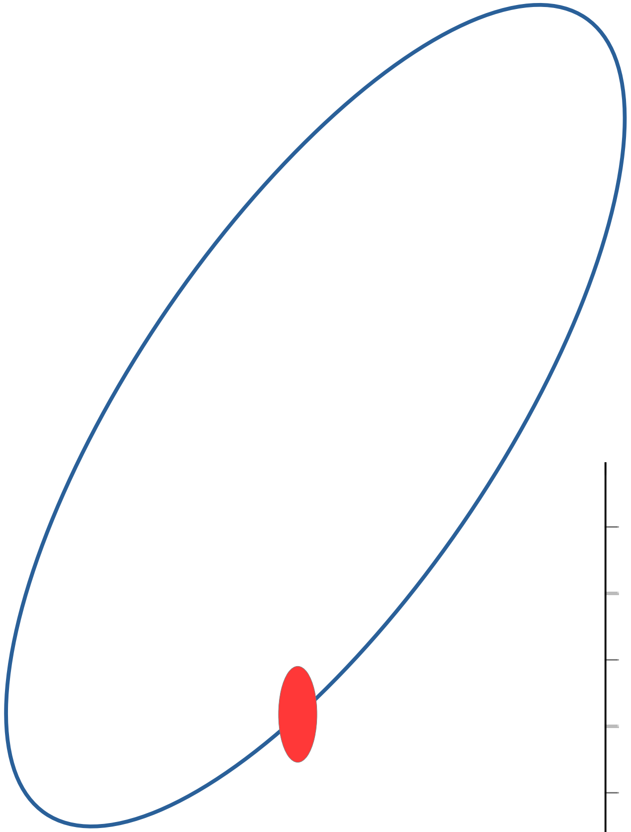
- Orbit determination from observations
- At least three position measurements
- Problems: small arc and position uncertainties
- Solutions: many observations + least square fitting

Near Earth Asteroids:
orbital motion prediction

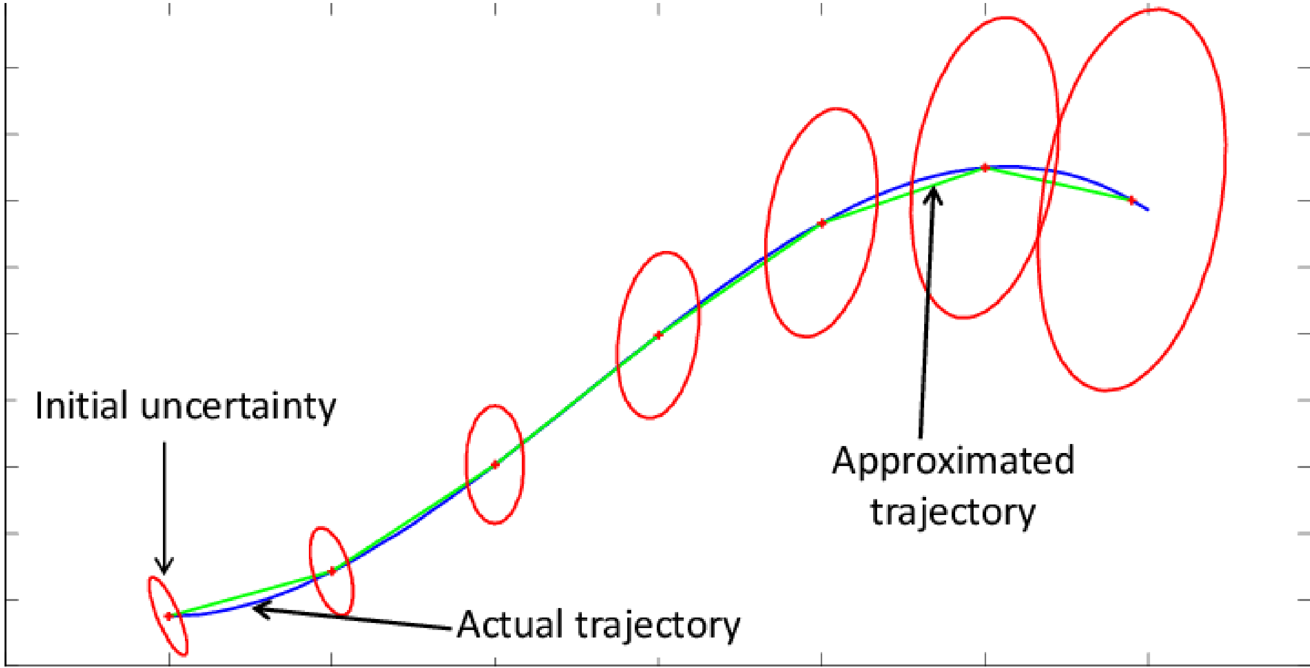
- **Solution:** large number of observations + least square method
- **Additional problem:** numerical methods have their own uncertainties



Near Earth Asteroids:
orbital motion prediction

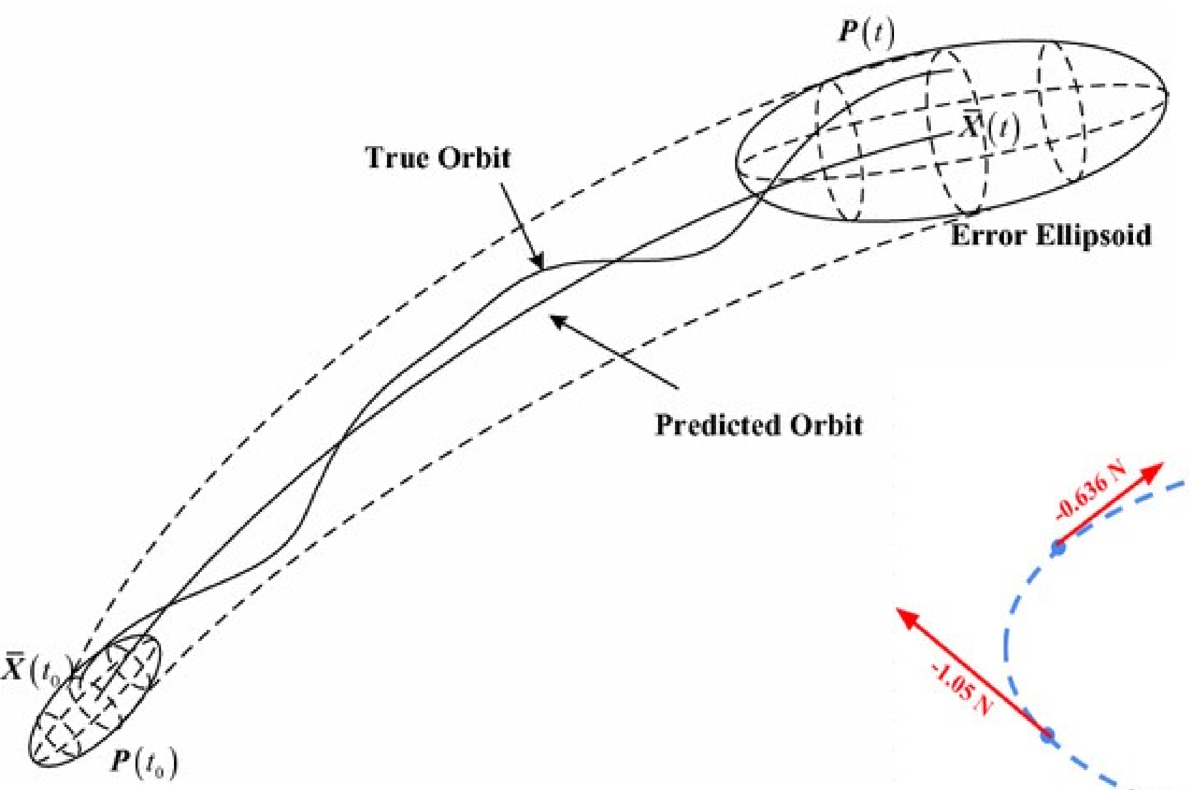


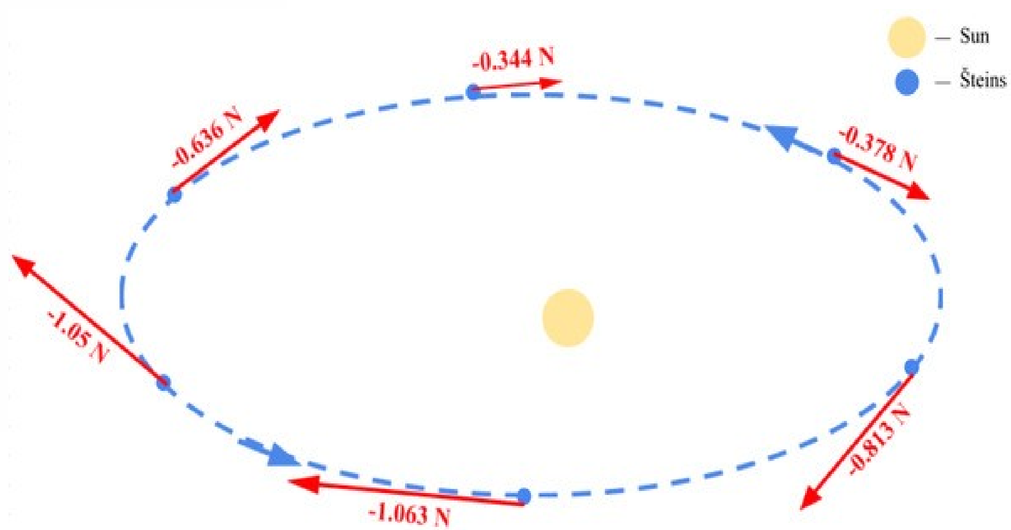
- Solution:
  large number of observations + least square method
- Additional problem: numerical methods have their own uncertainties



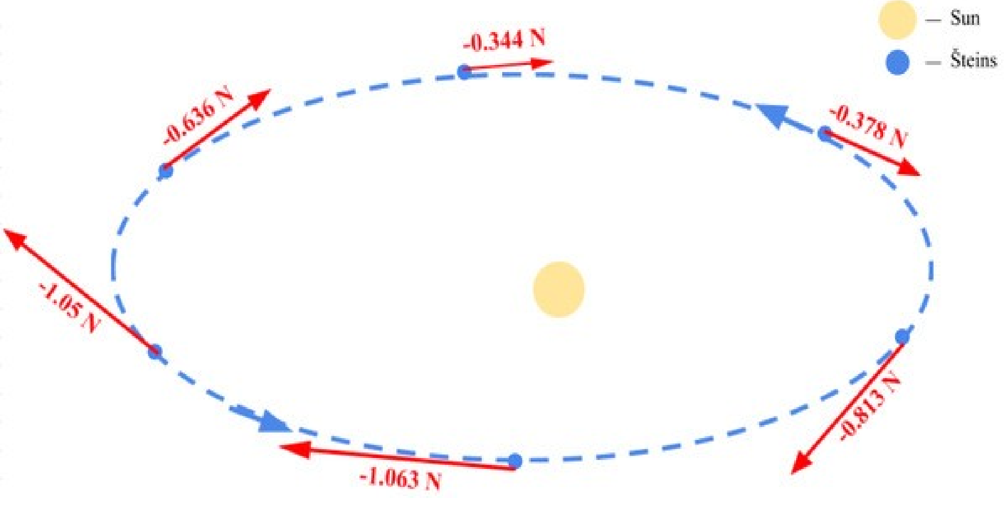
Near Earth Asteroids: orbital motion prediction

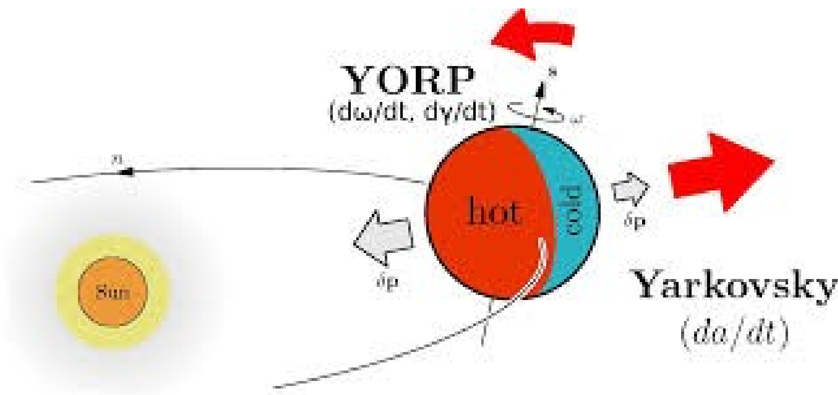
- **More problems:** trajectory is also a function of time!





Perturbations of the motion:
gravitational + non-gravitational



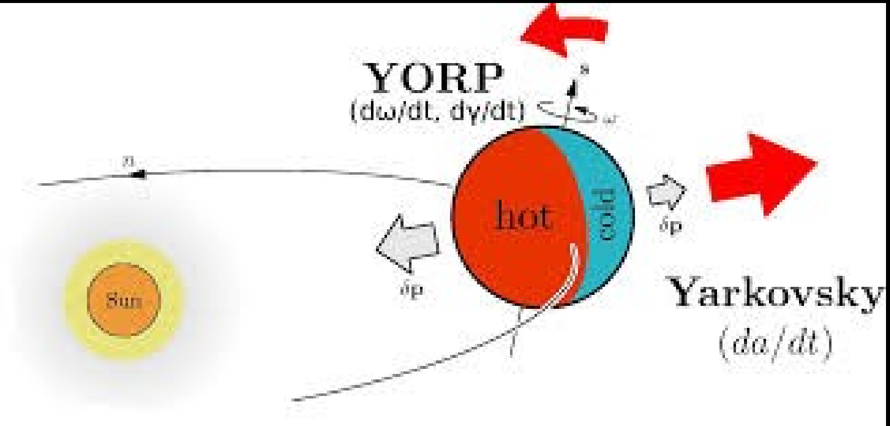


Non-gravitation effects on the motion

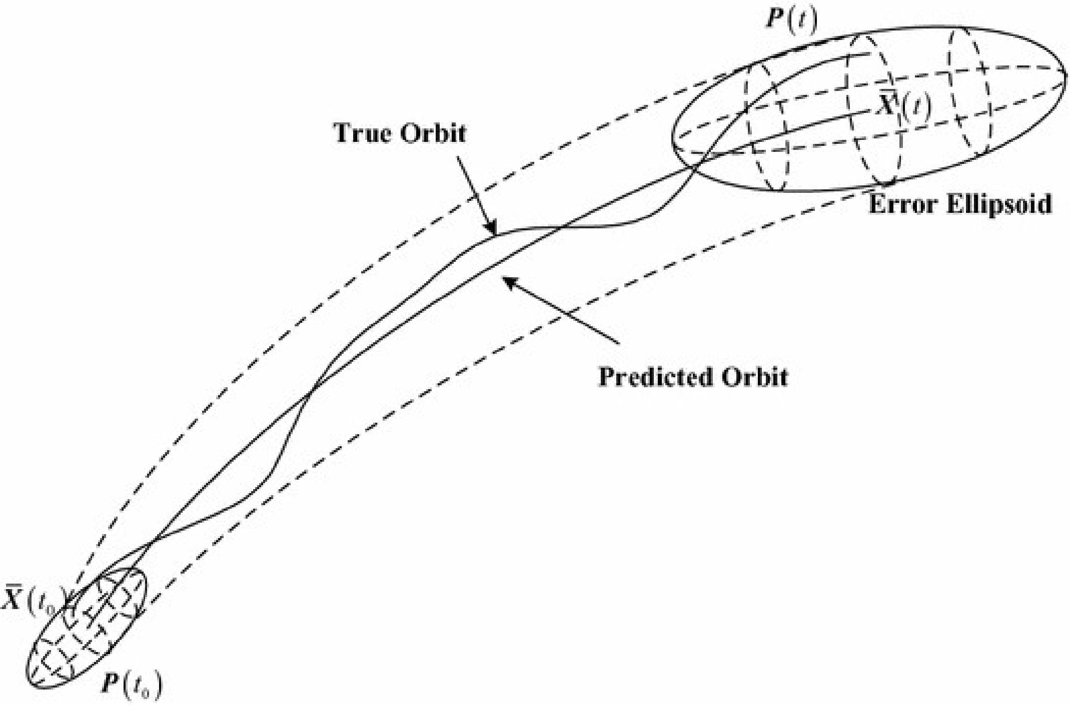
Depends on many non-orbital parameters, such as:

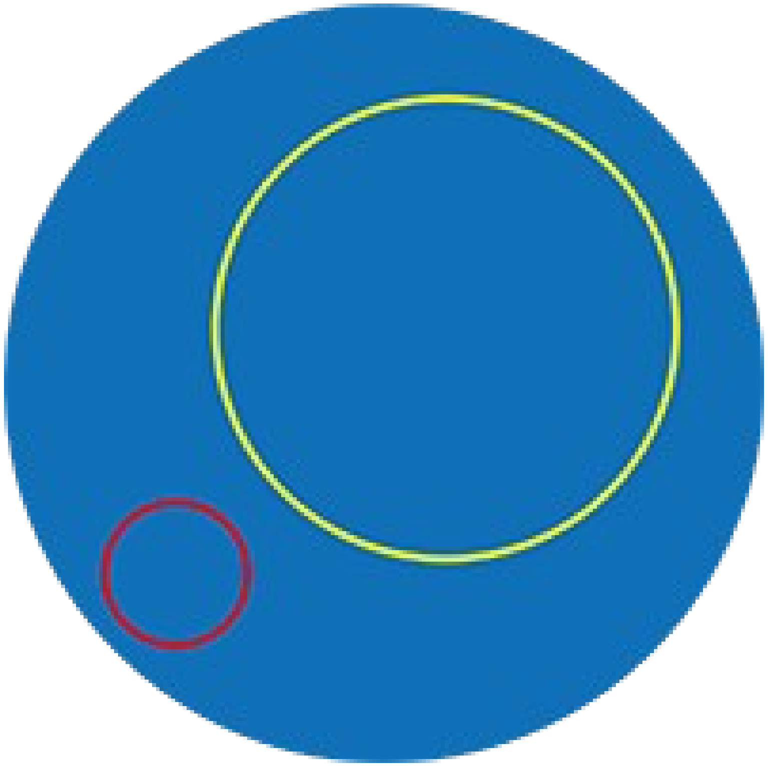
- size,
- density,
- shape,
- rotation state (obliquity and period of rotation),
- surface thermal characteristics

Problem: in most cases we do not know values of these parameters, and in many cases we even do not know how to model their distribution



Near Earth Asteroids:
orbital motion prediction



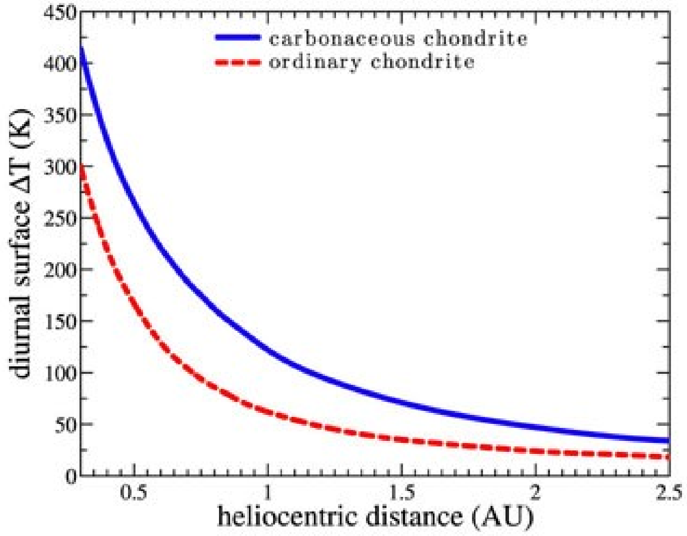


Demystifying near-Earth Asteroids project

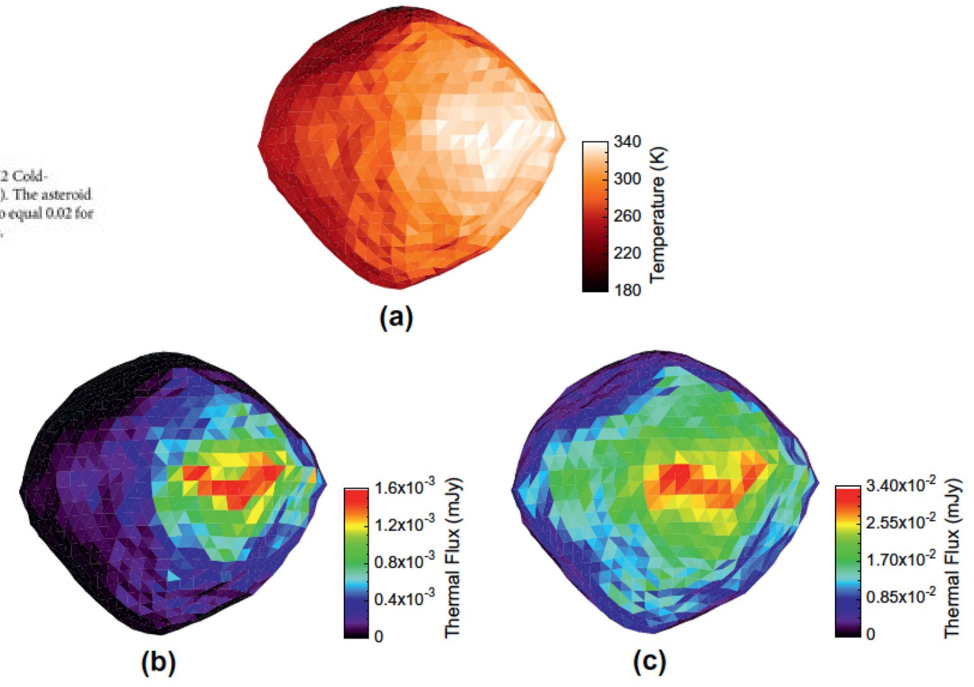
D-NEAs
Demystifying Near-Earth Asteroids

- Demystifying near-Earth Asteroids (D-NEAs) 2022-2024: Planetary Society Step Grant
- Objective #1: Modeling surface thermal properties from the ground-based data
- Objective #2: Asteroid densities from the combined dat

Demystifying near-Earth Asteroids project



Extended Data Figure 2 | Diurnal surface temperature excursions on asteroids as a function of the distance to the Sun. Temperatures are calculated at the equator of a spherical asteroid by means of an asteroid thermophysical model[illegible] (Methods), assuming the thermal properties (Extended Data Table 1) of a carbonaceous chondrite (the CM2 Cold-Bokkevel) and that of an ordinary chondrite (the H5 Cronstad). The asteroid rotation period is set to 6 h. The bolometric albedo is assumed to equal 0.02 for the carbonaceous chondrite and 0.1 for the ordinary chondrite.



Yarkovsky effect in the orbital motion

Methods: model vs. observed Yarkovsky drift

$$\left(\frac{\mathrm{da}}{\mathrm{dt}}\right)(\mathrm{a}, \mathrm{D}, \rho, \mathrm{K}, \mathrm{C}, \gamma, \mathrm{P}, \alpha, \varepsilon) = \left(\frac{\mathrm{da}}{\mathrm{dt}}\right)_{\mathrm{m}}$$

Parameters:

- **a** semimajor axis
- **D** diameter
- ρ density
- **K** thermal conductivity
- **C** heat capacity
- γ obliquity
- **P** rotation period

Method:

- Assume distributions for all the parameters but K
- Solve for K the model vs. observed equation
- Use a Monte Carlo method for statistical analysis

Basic Yarkovsky model

Analytical Yarkovsky model from Vokrouhlicky (1998, 1999):

1. Spherical homogeneous body
2. Linearized BC in heat diffusion equation
3. Circular orbit

$$\frac{\mathrm{d}a}{\mathrm{d}t} = \kappa_1 \cos\gamma + \kappa_2 \sin^2\gamma$$

where k_1 and k_2 are **analytic** functions

Special case: super-fast rotators

It is supposed that

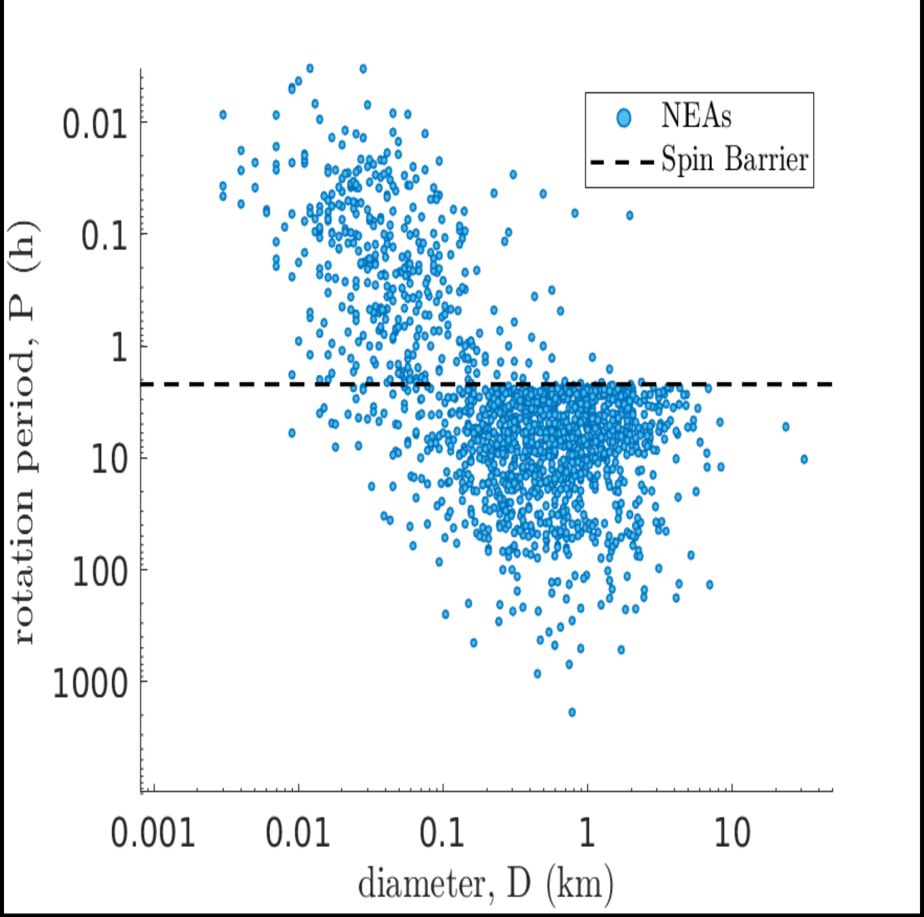
Small and fast rotating asteroids are monolithic blocks

Monolithic rocky objects have high thermal inertia

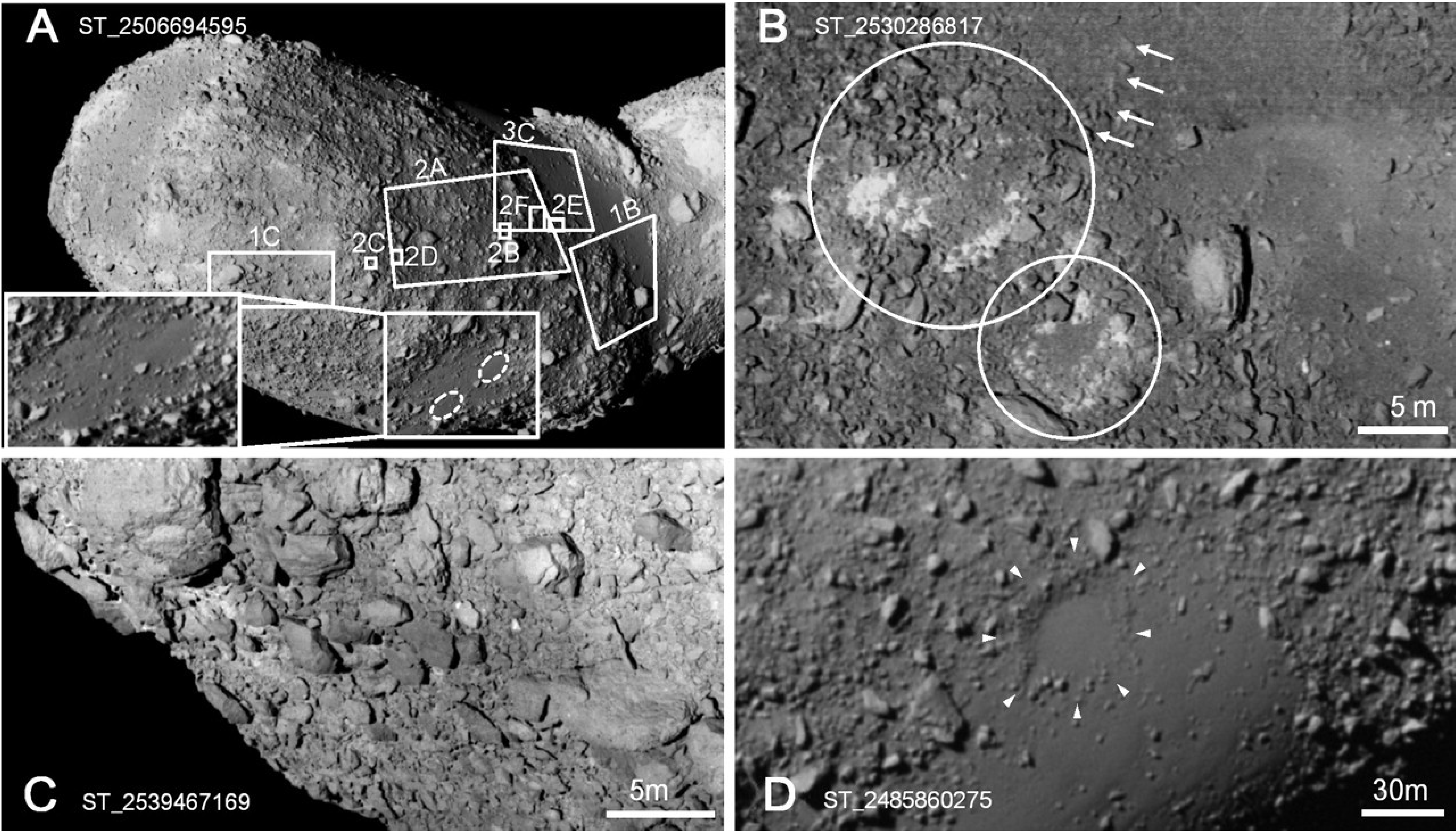
High thermal inertia prevent a fast Yarkovsky drift to be achieved.

However

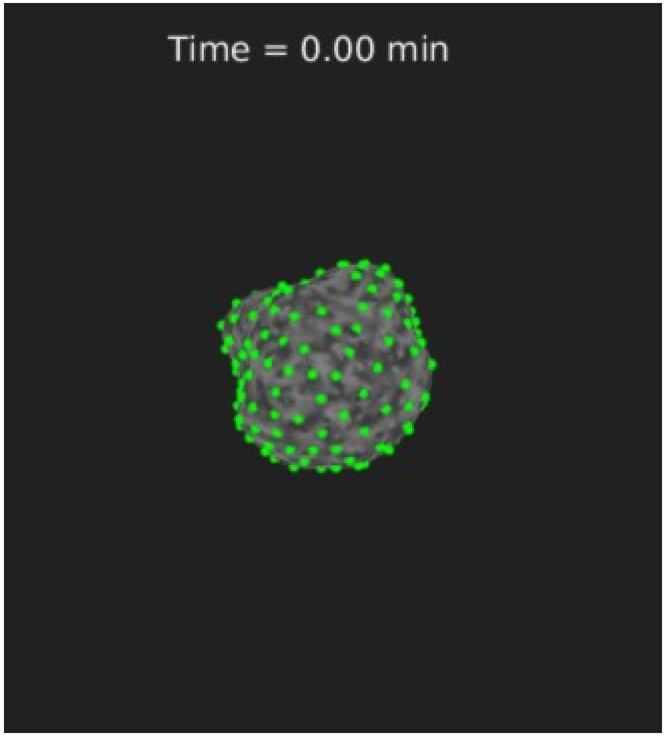
Del Vigna et al. 2018 and **Greenberg et al. 2020** found small objects with fast Yarkovsky drifts



Asteroid Regolith



Thermal inertia and fast rotators



Thermal inertia and fast rotators

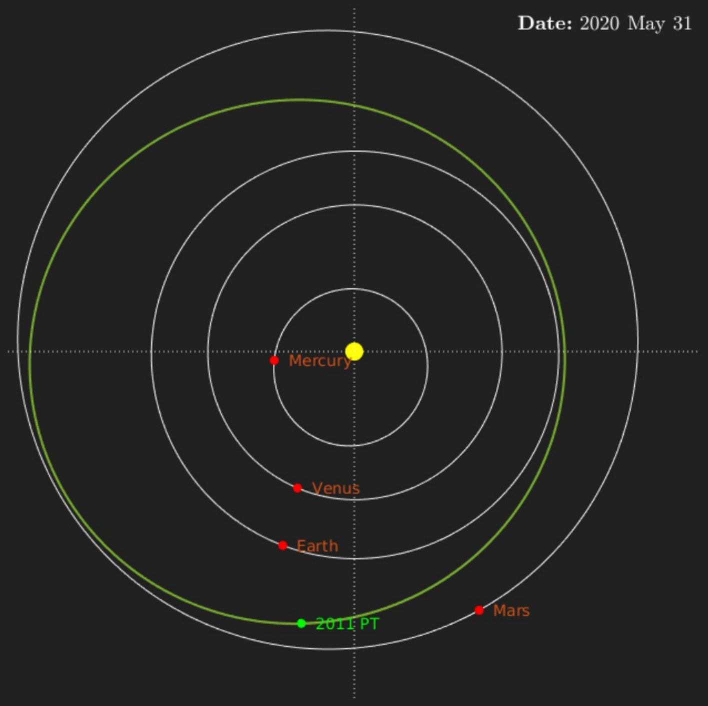
Case study: (499998) 2011 PT

Characteristics:

- $H \sim 24$ mag $\Rightarrow$ **D $\sim$ 35 m**
- $P \sim 11$ min
- **Yarkovsky effect** detected by
  - Del Vigna et al. 2018
  - Greenberg et al. 2020
  - JPL SBDB

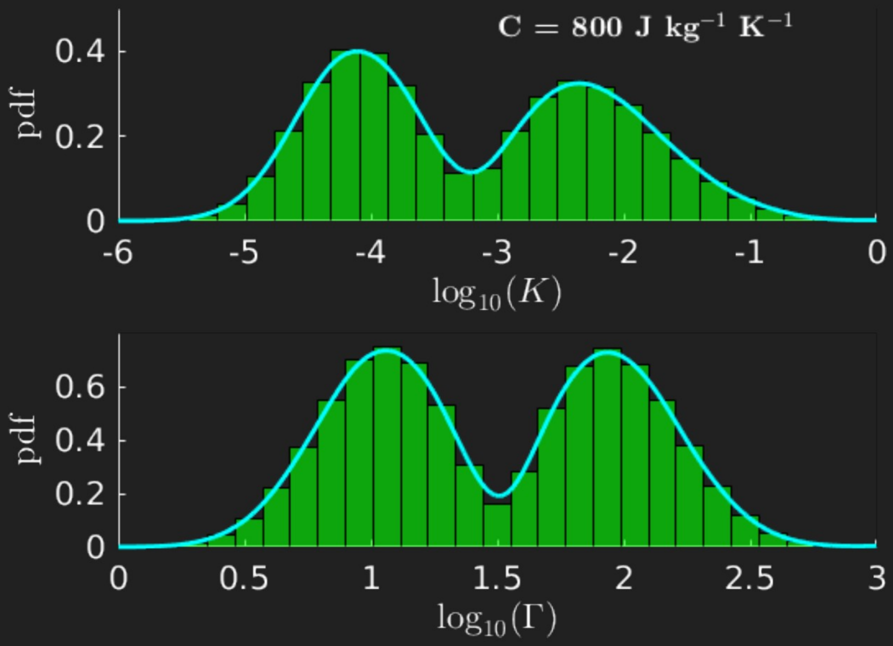
Goal:

- Constrain the **thermal conductivity** (**thermal inertia**)



First results

Results of the Monte Carlo simulations Fenucci et al. (2021)



- The distributions are always **bimodal**
- **First peak** in K at around

$$\sim \mathbf{7 \cdot 10^{-5}} \text{ W m}^{-1} \text{ K}^{-1}$$

- **Second peak** in K at around

$$\sim \mathbf{5 \cdot 10^{-3}} \text{ W m}^{-1} \text{ K}^{-1}$$

- $P(K < 0.1 \text{ W m}^{-1} \text{ K}^{-1}) > 0.95$

Improved model

Semi-analytical Yarko model and thermal inertia variation

Semi-analytical Yarkovsky model

Assuming 1. and 2. the instantaneous drift is (Vokrouhlicky et al. 2017)

$$\frac{\mathrm{d}a}{\mathrm{d}t} = \frac{2}{n^2 a}\mathrm{f}_Y \cdot \mathbf{v}$$

Total drift:

$$\left(\frac{\mathrm{d}a}{\mathrm{d}t}\right)_{\mathrm{tot}} = \int_0^T \frac{\mathrm{d}a}{\mathrm{d}t}\,\mathrm{d}t$$

TI variation (Rozitis et al 2018)

$$\Gamma = \Gamma_0 r^{-\alpha}$$

where Γ_0 is the **TI at 1 au**

Assuming constant ρ and *C*, *K* varies as

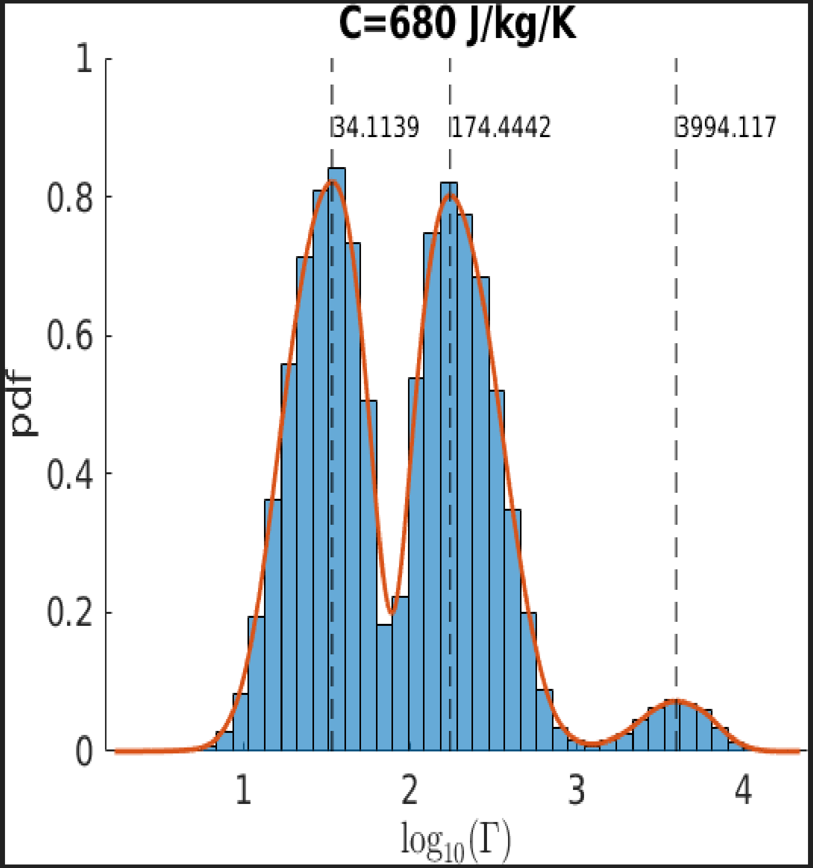
$$K = K_0 r^{-2\alpha}$$

where K_0 is the **conductivity at 1 au**

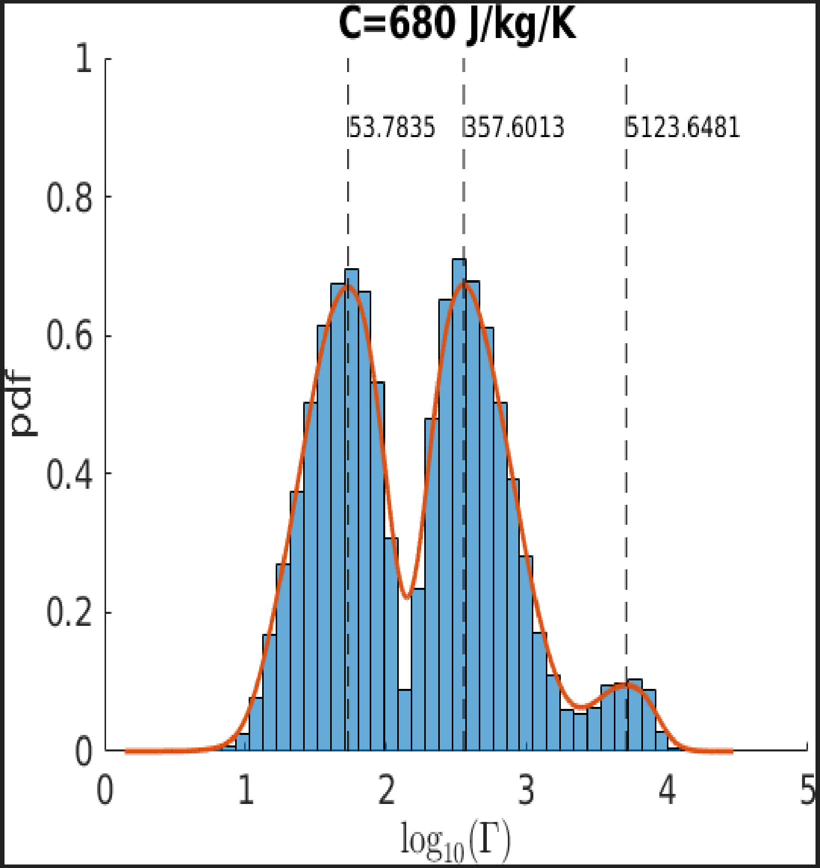
Comparison between models: 1950 DA

1950DA: km-sized NEO, e ~ 0.5, q ~ 0.83 au, Q ~ 2.56 au

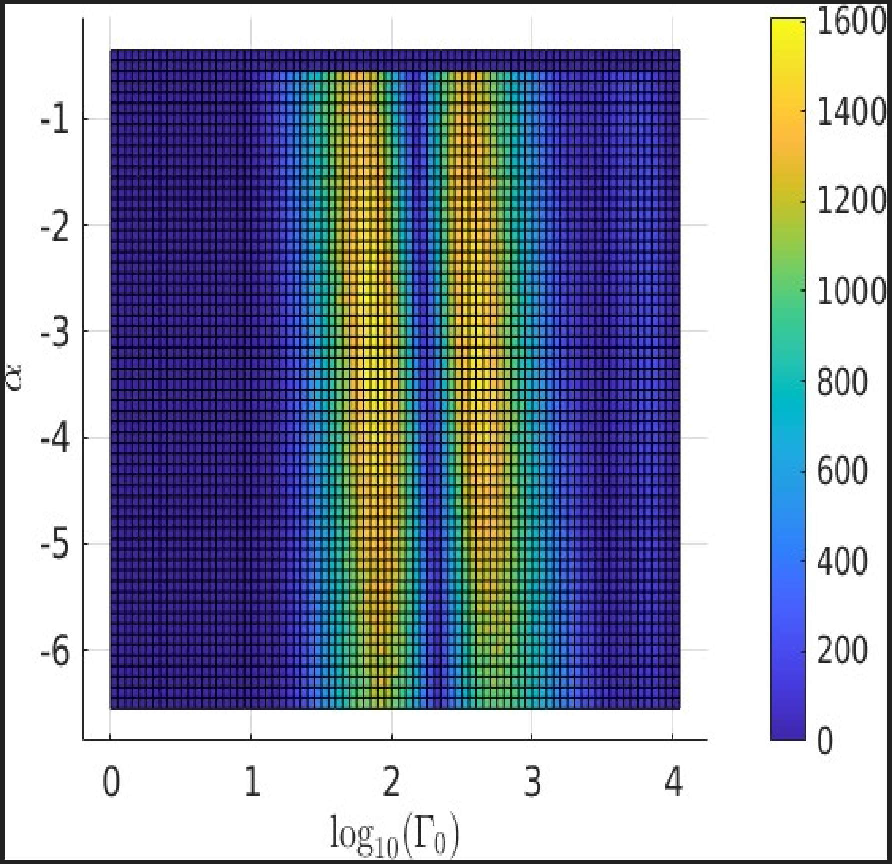
Circular model

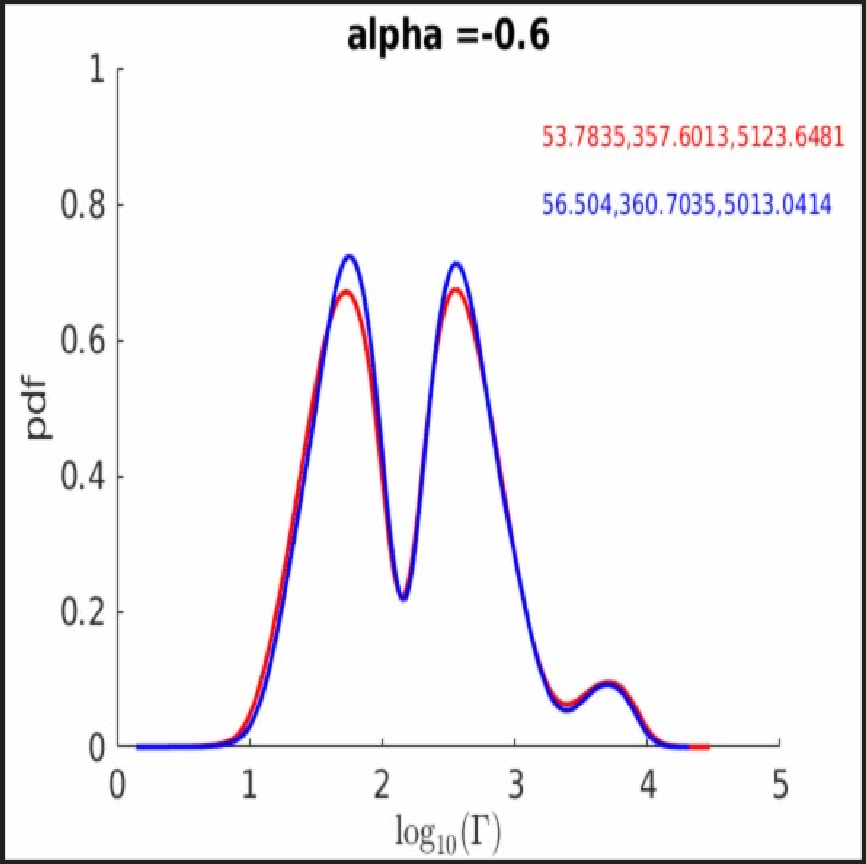


Eccentric model

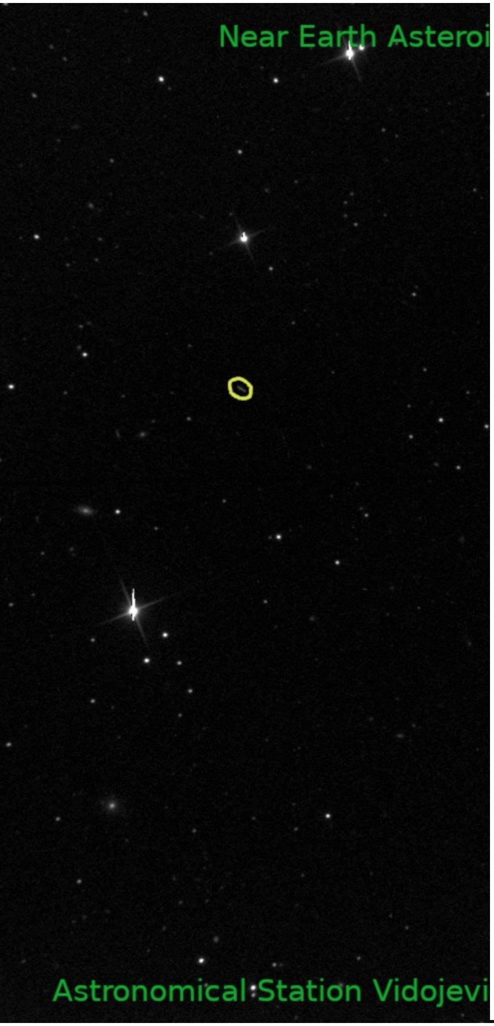


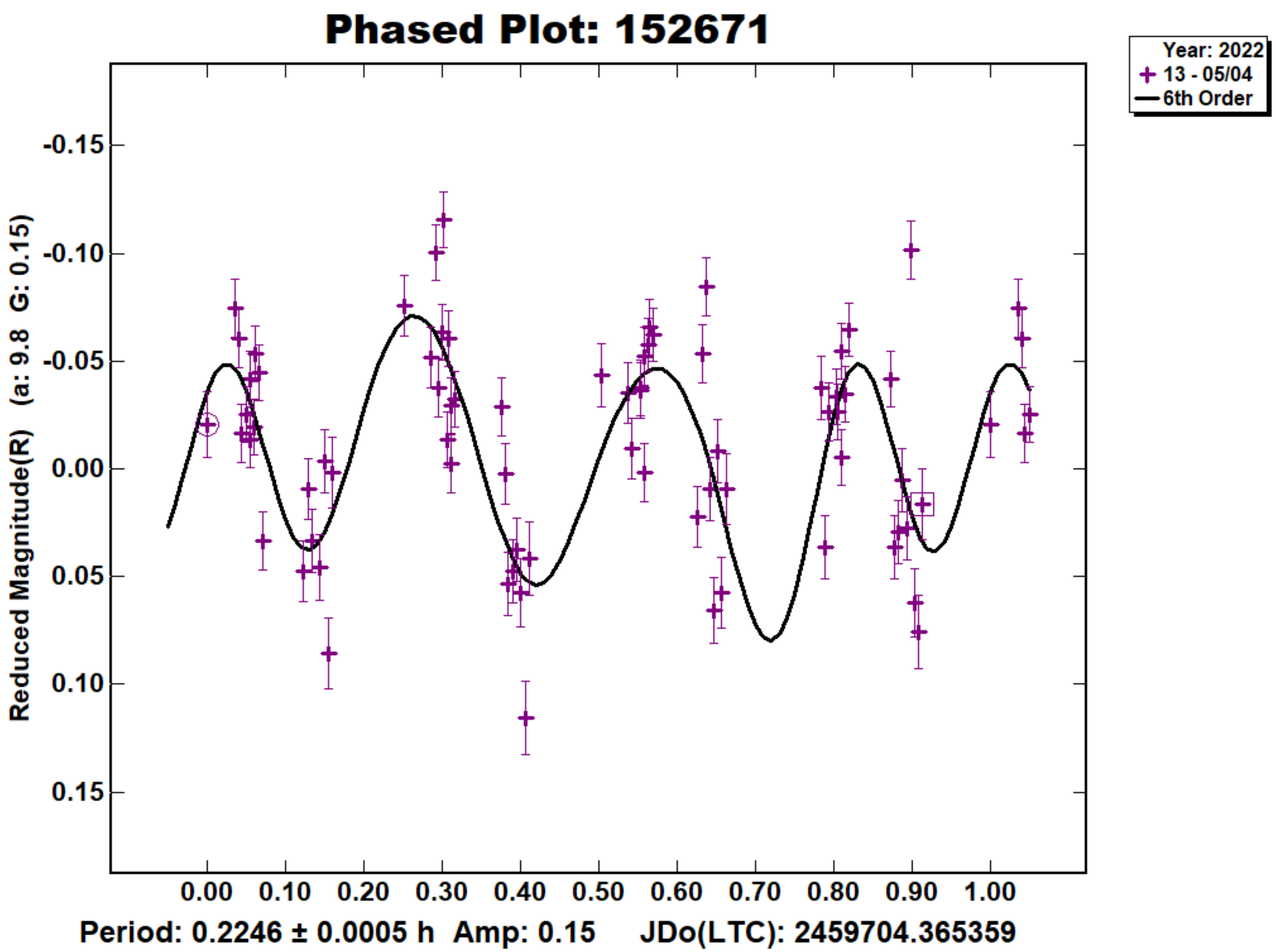
Comparison between models: 1950 DA

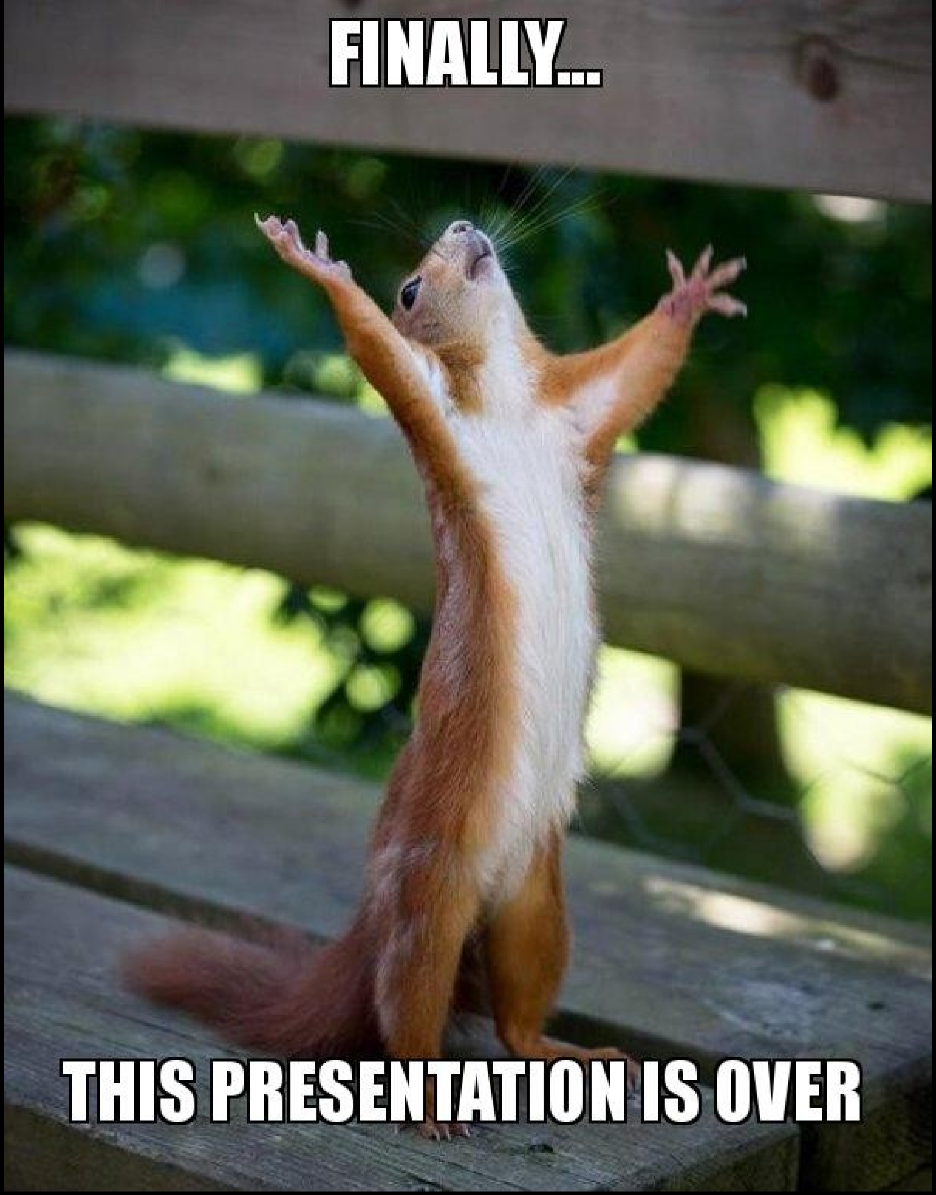




Recent observations from AS Vidojevica







Any questions?