Changes in Apophis rotation and surface gravity during its 2029 Earth flyby

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Context

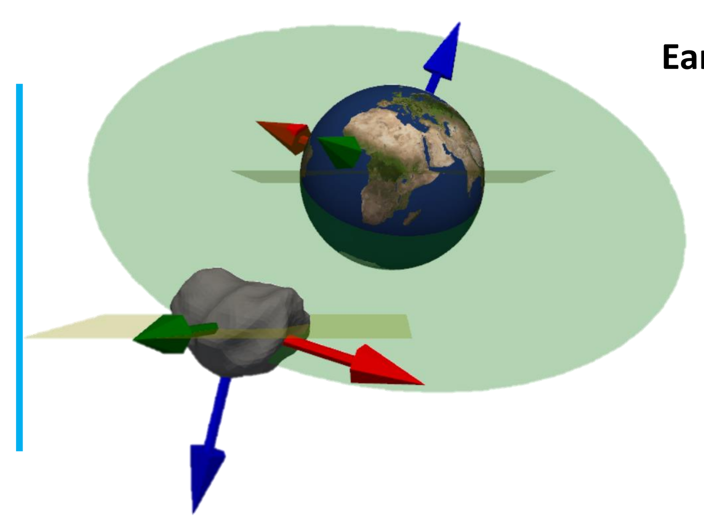
- Discovered in 2004, Apophis (99942) is a NEO with regular and extremely close Earth encounters
- On April 13, 2029, the asteroid will perform a close **flyby** of the Earth (±32,000km from the surface)
- This flyby is a unique opportunity to further investigate Apophis and learn more about asteroids in general

=> We use the F2BP code GUBAS to study the effects of this close approach on the **rotations** and the **surface gravity** of Apophis.

Simulation tool

- **GUBAS** is a Full-Two-Body-Problem (F2BP) code whish is been developed at the Un. Of Colorado Boulder (see *Davis et al (2020))*.
- It computes the dynamics of the system through gravitational interactions between mass elements.
- It uses inertia integrals to propagate the **coupled dynamics and rotations** of binary systems.
- GUBAS accepts shape models inputs.

Initial conditions and assumptions



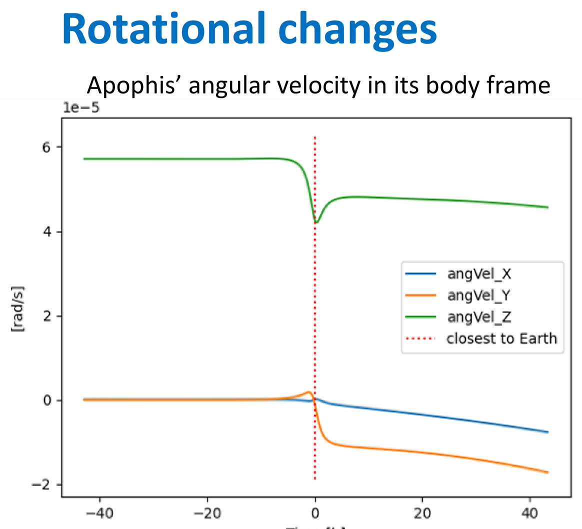
Earth
- Orientation from spice kernels
- Ellipsoid shape model
- Density = 5.5 g/cm³

Assumptions
- The simulations are propagated from when Apophis enters the Earth's sphere of influence
- Apophis spin axis, angular momentum and z axis are set parallel, **no tumbling**
- Only Earth and Apophis considered (no Moon)
- All bodies are assumed **rigid**

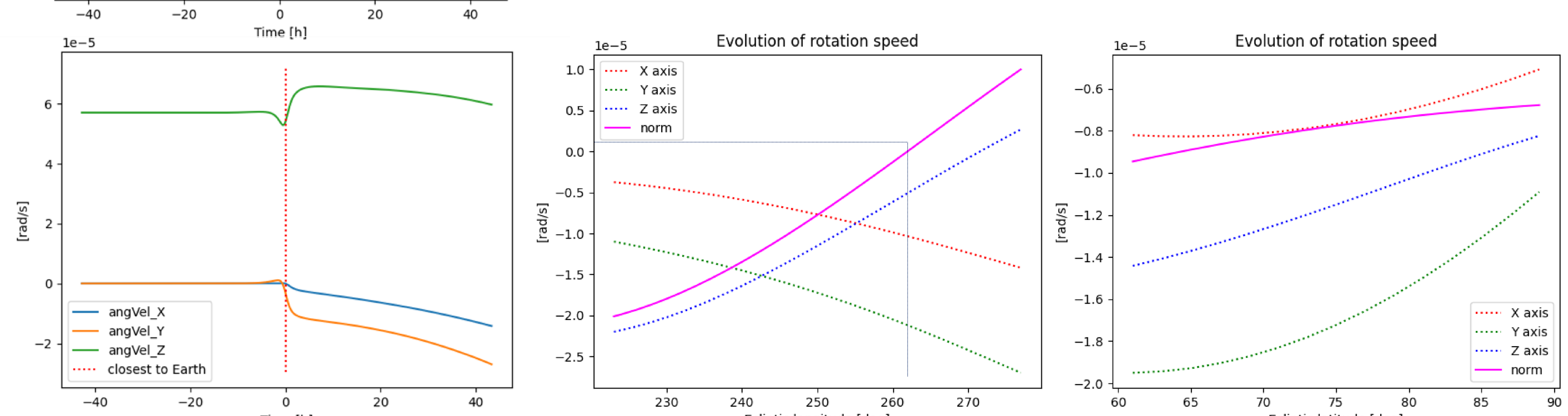
Apophis
- Relative position and speed from spice kernels
- Orientation and rotation speed from *Pravec et al 2014*
  - Ang. mom. ecliptic longitude = 250° ± 27° (1 σ)
  - Ang. mom. ecliptic latitude = -75° ±14° (1 σ)
  - Spin period = 30.56h
- Polyhedron shape model from *Brozovic et al 2018*
- Density = 2.6 g/cm³

Case	Ecliptic latitude	Ecliptic longitude
1 = nominal	-75°	250°
2	-75°	277°
3	-75°	223°
4	-89°	250°
5	-61°	250°

Rotational changes

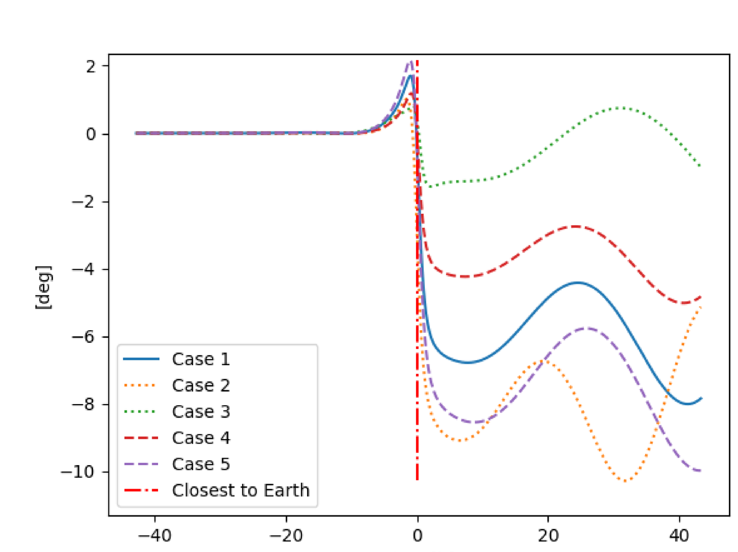


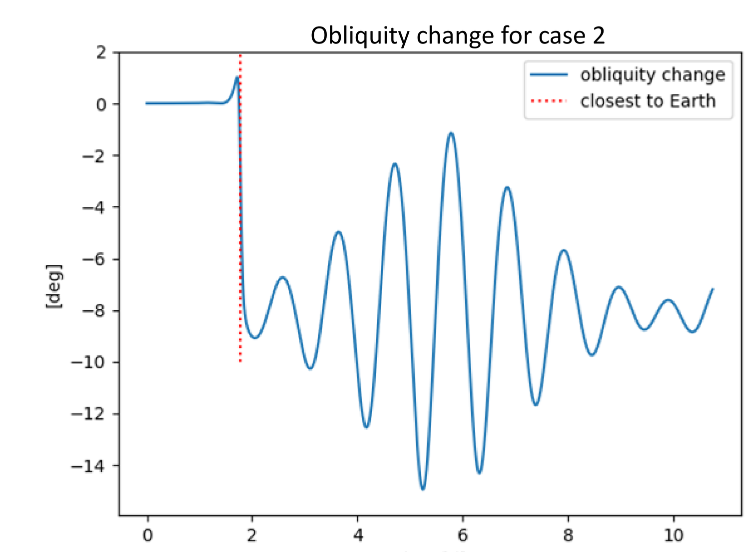
- Depending on the case studied, we can expect up to a **35% change** in the rotation speed of Apophis after the flyby.
- The speed around the z-axis is the most affected one where the changes about the y-axis are much less impacted
- The rotational speed of Apophis either **increases or decreases** depending on the initial ecliptic longitude. For a latitude of -75°, the longitude threshold is about 262°. The influence of the latitude is quite limited with all rotational speeds decreasing.



Flyby influence on Apophis obliquity

- The flyby of Apophis around the Earth has a major influence on Apophis obliquity.
- **2 trends** can be extracted (consistent with *Souchay et al. (2014)*)
  - For higher initial ecliptic latitudes, the change in the obliquity is bigger. We observe an offset between the obliquity before and after the flyby, a new equilibrium is reached.
  - For increasing initial longitudes, this offset decreases. Furthermore, we observe that the initial longitude clearly influences the period of the obliquity oscillations after the flyby.

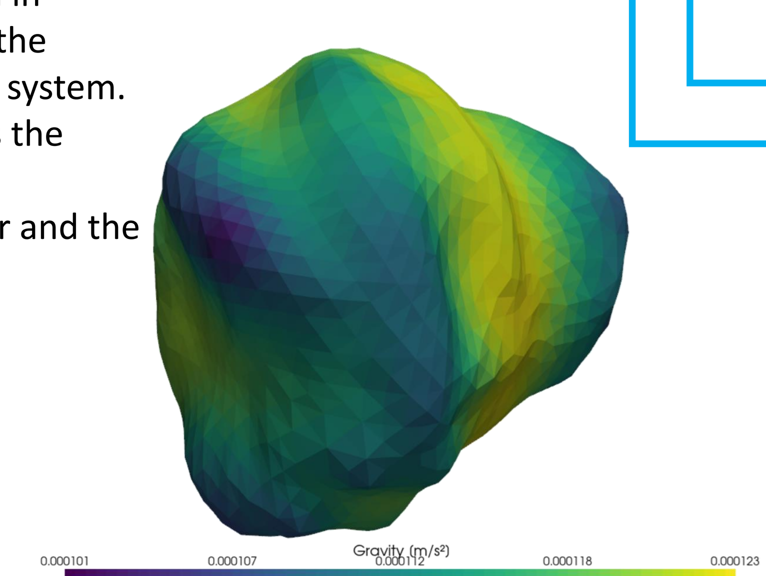




Local gravity vector and surface slopes computation

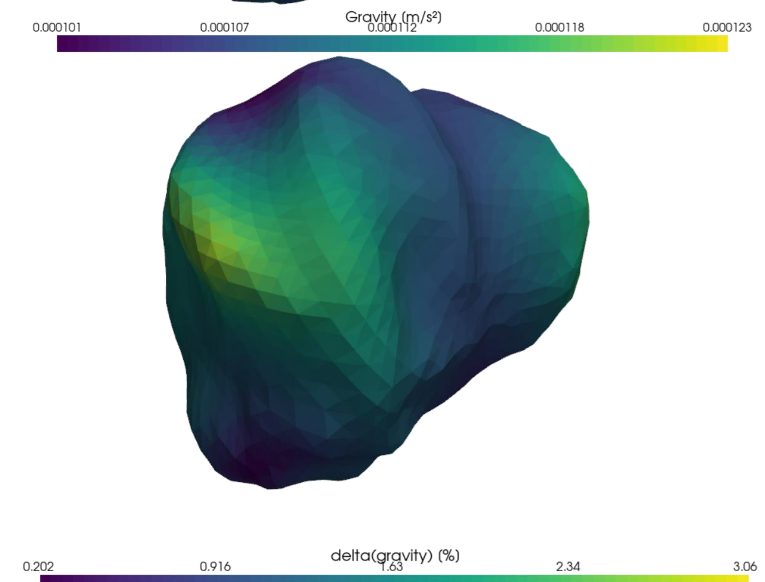
- To assess the gravity at the surface of the shape model, we use an in-house code combining the contributions of the **self-gravity** using the polyhedron method and the contributions of the **dynamics** of the system.
- The Coriolis acceleration is not considered in our computations as the body is rigid and no moving particle is on the surface.
- The surface slopes (θ) are the projection of the local gravity vector and the local normal of the facet.

$$\vec{a}_{tot} = \underbrace{\vec{g}_{Apophis}}_{\text{Selfgravity}} + \overbrace{\vec{a}_{Earth}}^{\text{Earth tidal acceleration}} - \underbrace{\cancel{2\vec{\Omega}\times\vec{v}}}_{\text{Coriolis acceleration}} + \overbrace{\vec{\Omega}\times\vec{\Omega}\times\vec{r}}^{\text{Centrifugal acceleration}} - \underbrace{\frac{d\vec{\Omega}}{dt}\times\vec{r}}_{\text{Euler acceleration}}$$



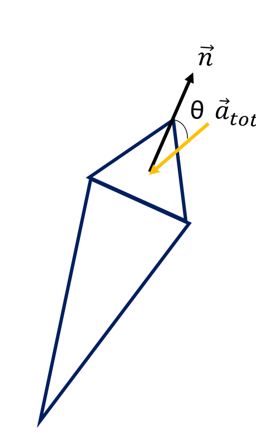
Gravity Results

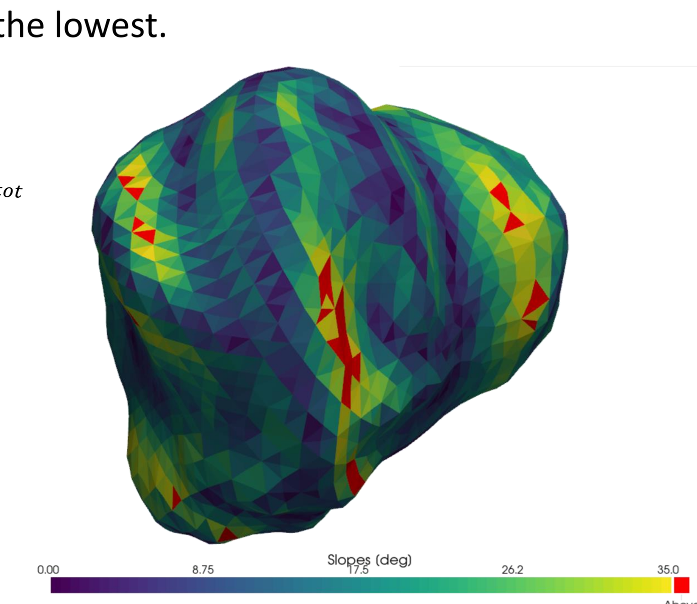
- As expected the local gravity is **lower** at the extremes of Apophis where the centrifugal contributions is the strongest.
- Due to the flyby the gravity felt on the surface will change and these changes are more likely to affect the low gravity zones. There, changes of about **3%** can be expected.
- However, most of the surface will only feel a change in local accelerations of about **2%**.

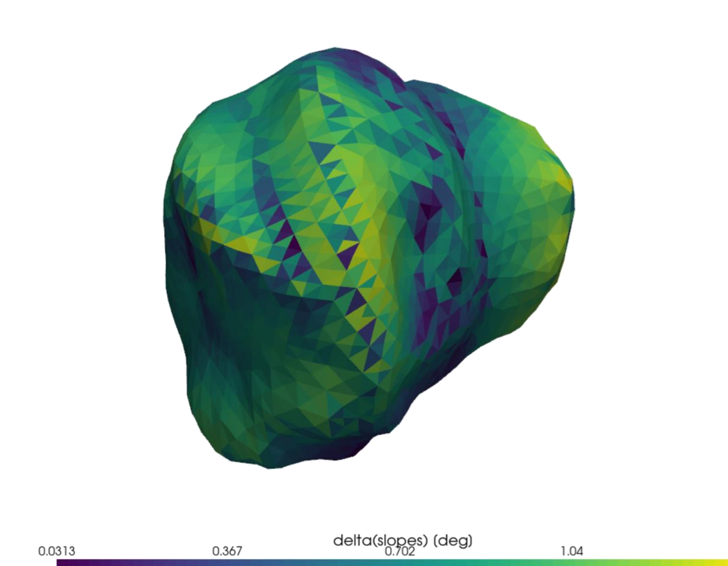


Slopes Results

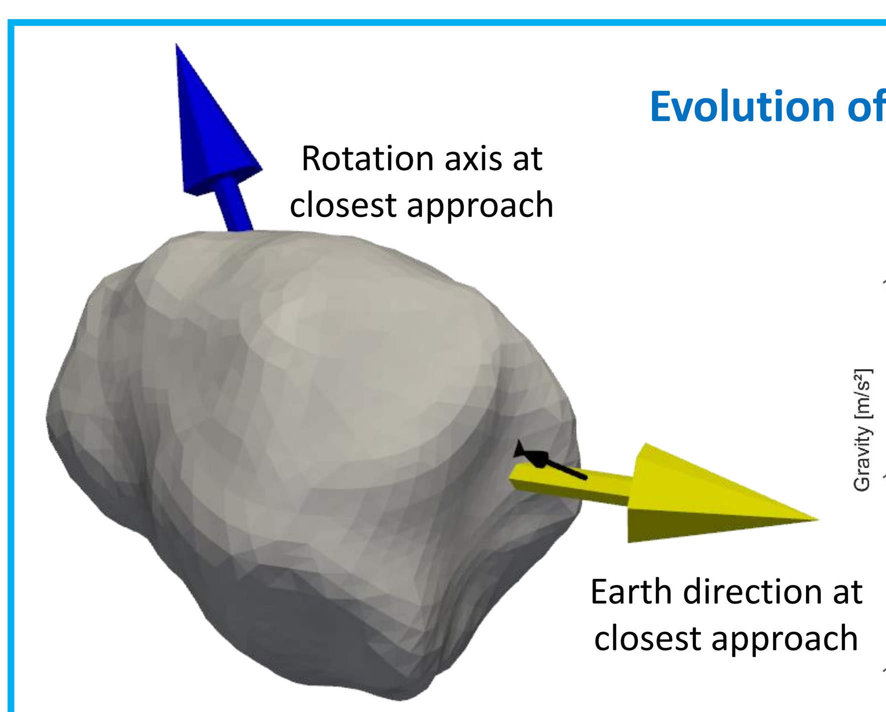
- From the initial conditions, it is already shown that for some facets, **the slope achieved the threshold value of 35°**. This is consistent with *Hirabayashi et al. (2020)*.
- This is commonly accepted as the angle above witch we might expect landslides and possible reshaping.
- This change is rather limited with a change of **maximum 1.37°**, mostly in regions where the initial gravity is the lowest.

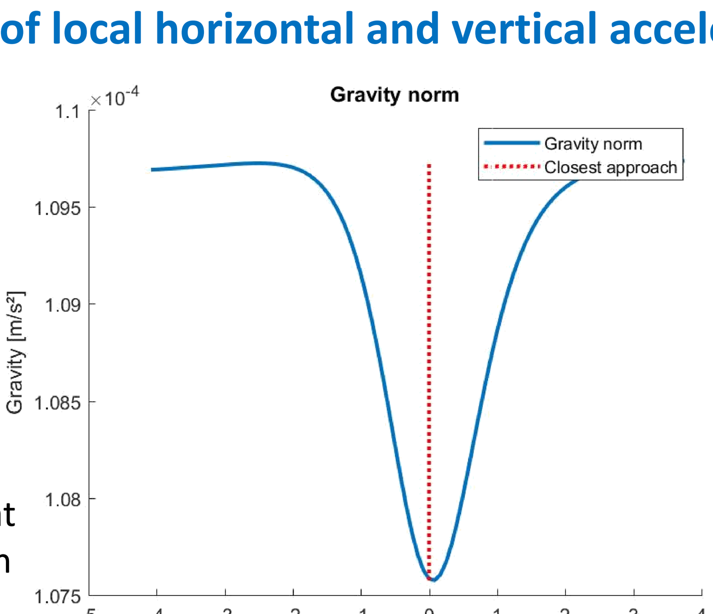


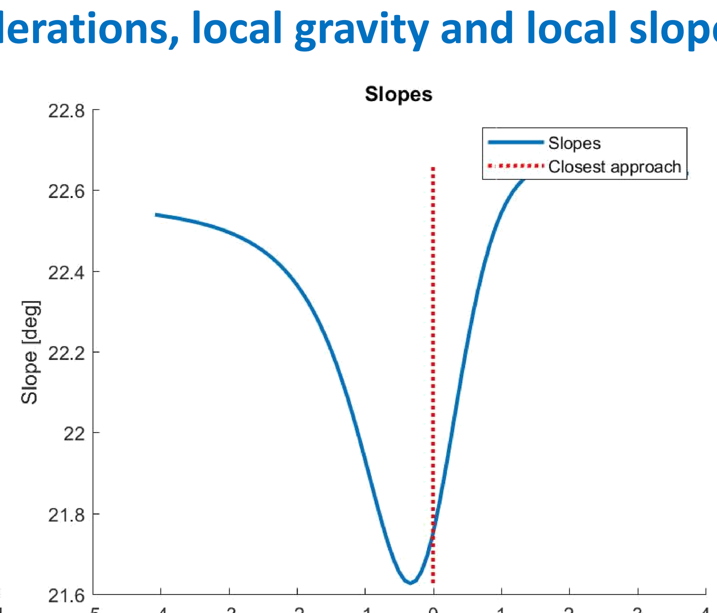


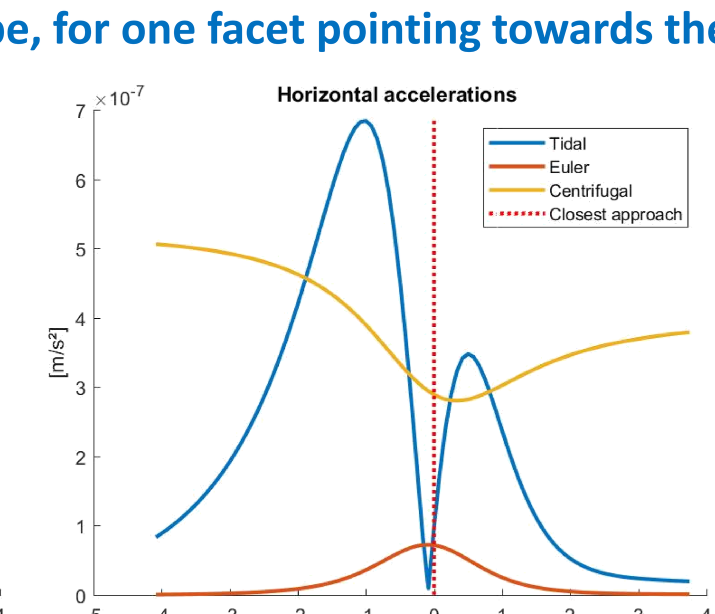


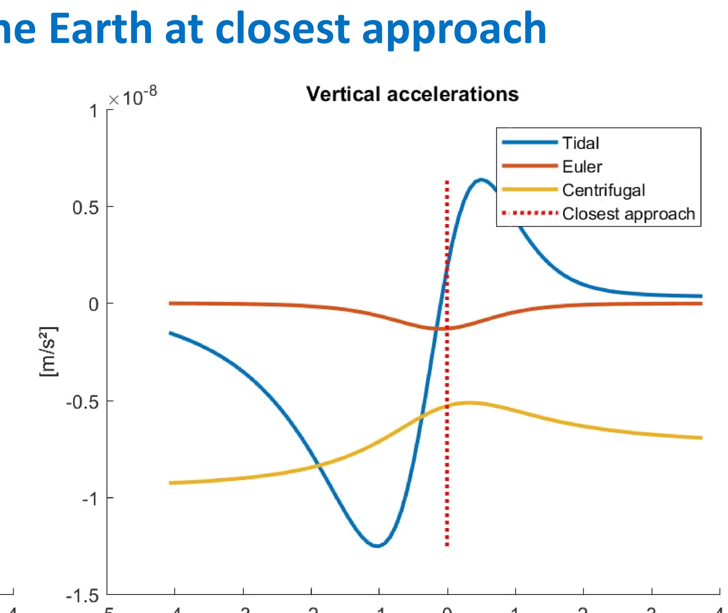
Evolution of local horizontal and vertical accelerations, local gravity and local slope, for one facet pointing towards the Earth at closest approach











Further work

- Actually, it has been measured that Apophis is in a **SAM** (short-axis-mode) rotation and that the asteroid is already **tumbling** before the flyby (*Pravec et al. (2014), Brozović et al. (2018), Benson et al. (2023)*). Our next step is to investigate how the body would behave when being already tumbling.

Acknowledgement and References

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Benson et al. (2023). Icarus, 390, 115324. Scheeres et al. (2006). Science, 314 (5803), 1280–1283. Souchay et al. (2018). Astronomy and Astrophysics, 617, 1–11. Souchay et al. (2014). Astronomy and Astrophysics, 563, 1–6. Davis et al. (2020). Icarus, 341. Pravec et al. (2014). Icarus, 233, 48–60. Brozović et al. (2018). Icarus, 300, 115–128. Hirabayashi et al. (2020). LPI Contribution, 2242