



HAL
open science

Latest astrometric results for the Saturnian system

Valery Lainey, Nicolas Rambaux, Gabriel Tobie, Nick Cooper, Qingfeng Zhang, Benoit Noyelles, Kevin Baillié

► **To cite this version:**

Valery Lainey, Nicolas Rambaux, Gabriel Tobie, Nick Cooper, Qingfeng Zhang, et al.. Latest astrometric results for the Saturnian system. Europlanet Science Congress 2024, Sep 2024, Berlin, Germany. 10.5194/epsc2024-189 . hal-04699902

HAL Id: hal-04699902

<https://hal.science/hal-04699902v1>

Submitted on 15 Oct 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Latest astrometric results for the Saturnian system

Authors: Valéry Lainey¹, Nicolas Rambaux¹, Gabriel Tobie², Nick Cooper³, Qingfeng Zhang⁴, Benoit Noyelles⁵ and Kevin Baillié¹

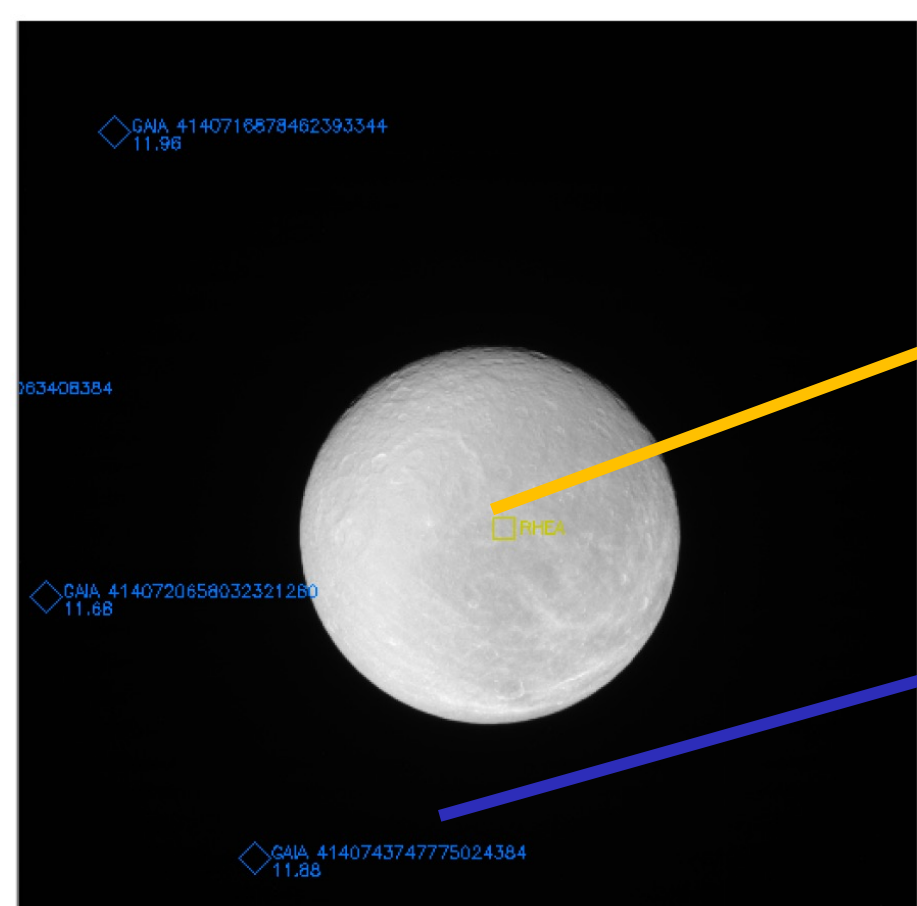
1- IMCCE, Observatoire de Paris, PSL Research University, Sorbonne Université, CNRS, Université Lille, Paris, France. 2- LPG, UMR-CNRS 6112, Nantes Université, Nantes, France. 3- Department of Physics and Astronomy, Queen Mary University of London, London, UK. 4- Department of Computer Science, Jinan University, Guangzhou, P. R. China. 5- Institut UTINAM, CNRS UMR 6213, Université de Franche-Comté, OSU THETA, BP 1615, Besançon, France

Abstract: During the thirteen years spent in orbit around Saturn before its final plunge, the Cassini probe provided more than ten thousand astrometric observations of moons. Such a large amount of precise data has allowed us to search for extremely small signals in the orbital motion of the Saturnian satellites. These signals can be linked to key physical mechanisms at play in the system, opening the doors to a new vision of the Saturn system. Using more than a century of ground-based astrometric observations, and benefiting from Cassini imaging data, we have studied the orbital motion of all of Saturn's inner and main moons, including those recently discovered by the Cassini probe. We show how astrometry has allowed us to characterize the strong tidal effects acting among the Saturnian system, while assessing the interior characteristics of several moons and their primary, including the discovery of Mimas' ocean. Updated results are presented.

EPSC2024-189

What is astrometry?

Astrometry is the discipline that aims at determining the position of celestial objects with the highest accuracy.



Position of the moon we are looking for...

Known position of stars

We can use the position of the background stars to calibrate the image and determine the position of the moon's center of figure, as seen from Cassini. The IDL code, called Caviar (Cooper et al. 2018), we have been using for years when analyzing ISS data is available as open source software on IMCCE website:

<https://www.imcce.fr/recherche/equipes/pegase/caviar>

Here, we benefited from the ISS / Cassini images (Porco et al. 2004). Former ground and space based measurements were included, too.

Typical ISS measurement accuracy: few km!

Note: Saturn is more than 1.5 billion km away, and Saturn's moons, as well as the orbiter itself, are moving at several to few tens of km per second...

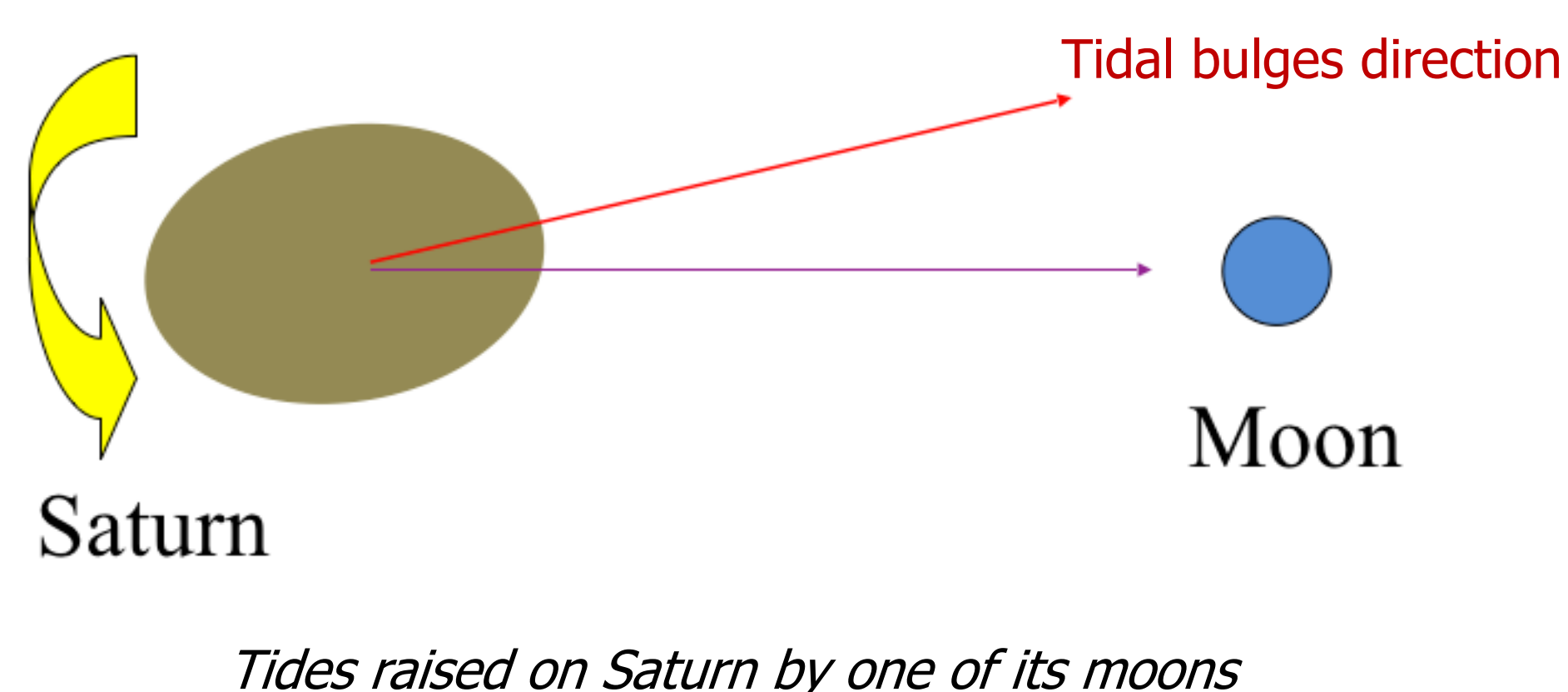
Why do we care even though Cassini is not there anymore?

Cassini mission was an immense success for planetary sciences. But, we have found some signatures in the orbits that we do not fully understand. This suggests that we are still missing a part of the physics at play... Hopefully, analyzing these signals may help answering the still extremely debated question: what is the age of the main moons and how did they form?

Saturn's moons carry a lot of physical information including:

- Interior mass distribution → formation process
- Tidal dissipation → long term evolution of the orbits

Example:



Like an ice-skater is spinning faster when his or her arms are folded in, the Saturn's spin and the moons radial distance are linked. While friction arises inside Saturn associated with tidal deformation, its spin is decreasing and the moon's orbit is expanding.

Our method

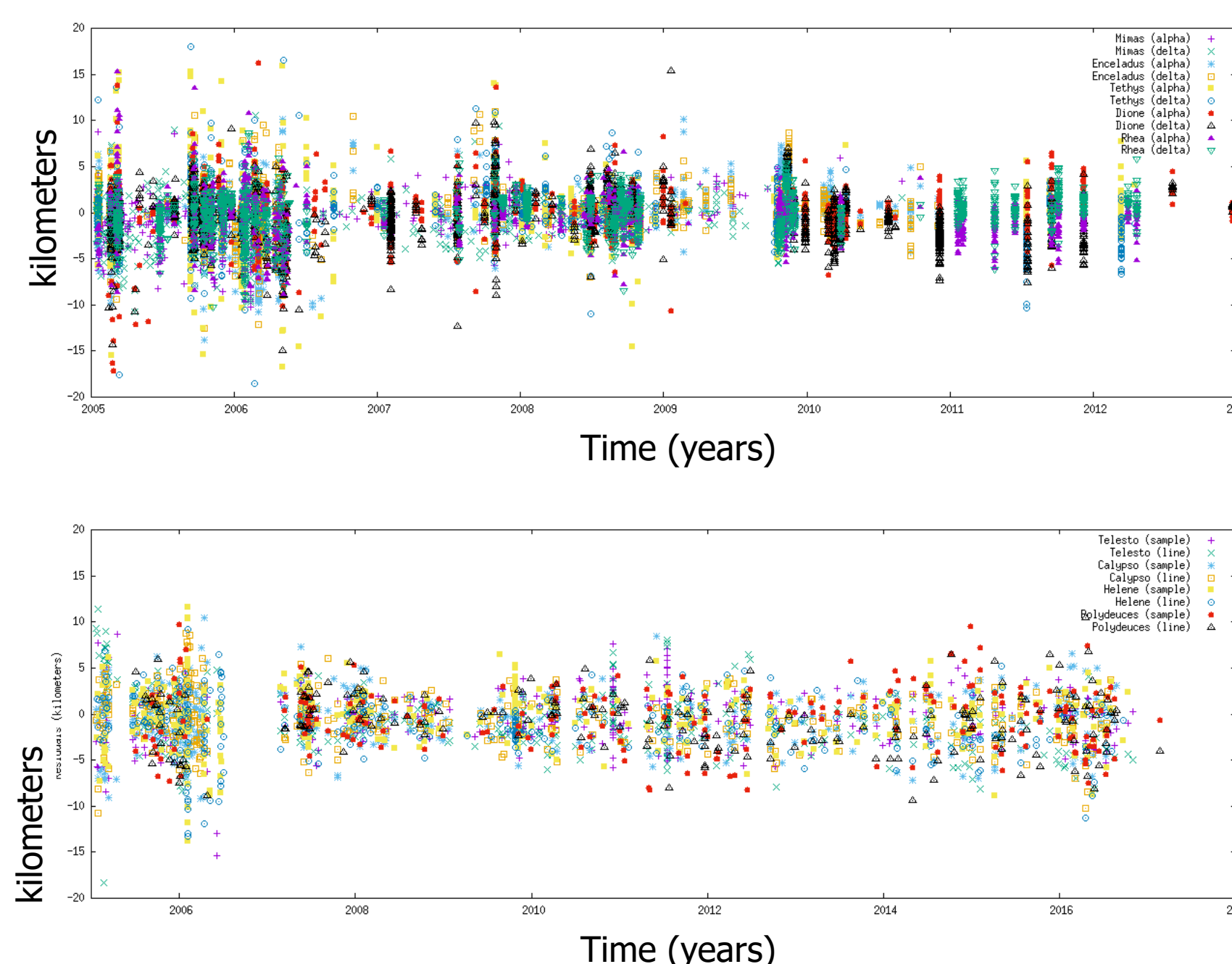
We developed a numerical code called NOE that predicts the position of the moons at any time. Then by comparison with the observations, we can correct the value of the physical parameters considered in our model. The precision on the estimated physical quantity is directly related to the precision of the astrometric measurements.

Our N-body code takes into account:

- Mutual perturbations of Saturn and its twenty closest moons
- Extended gravity fields of all objects
- Solar and planetary perturbations
- Precession and nutations of Saturn's pole
- Tidal effects inside Saturn and Enceladus
- Physical libration of the inner moons
- General relativity

"Residuals"

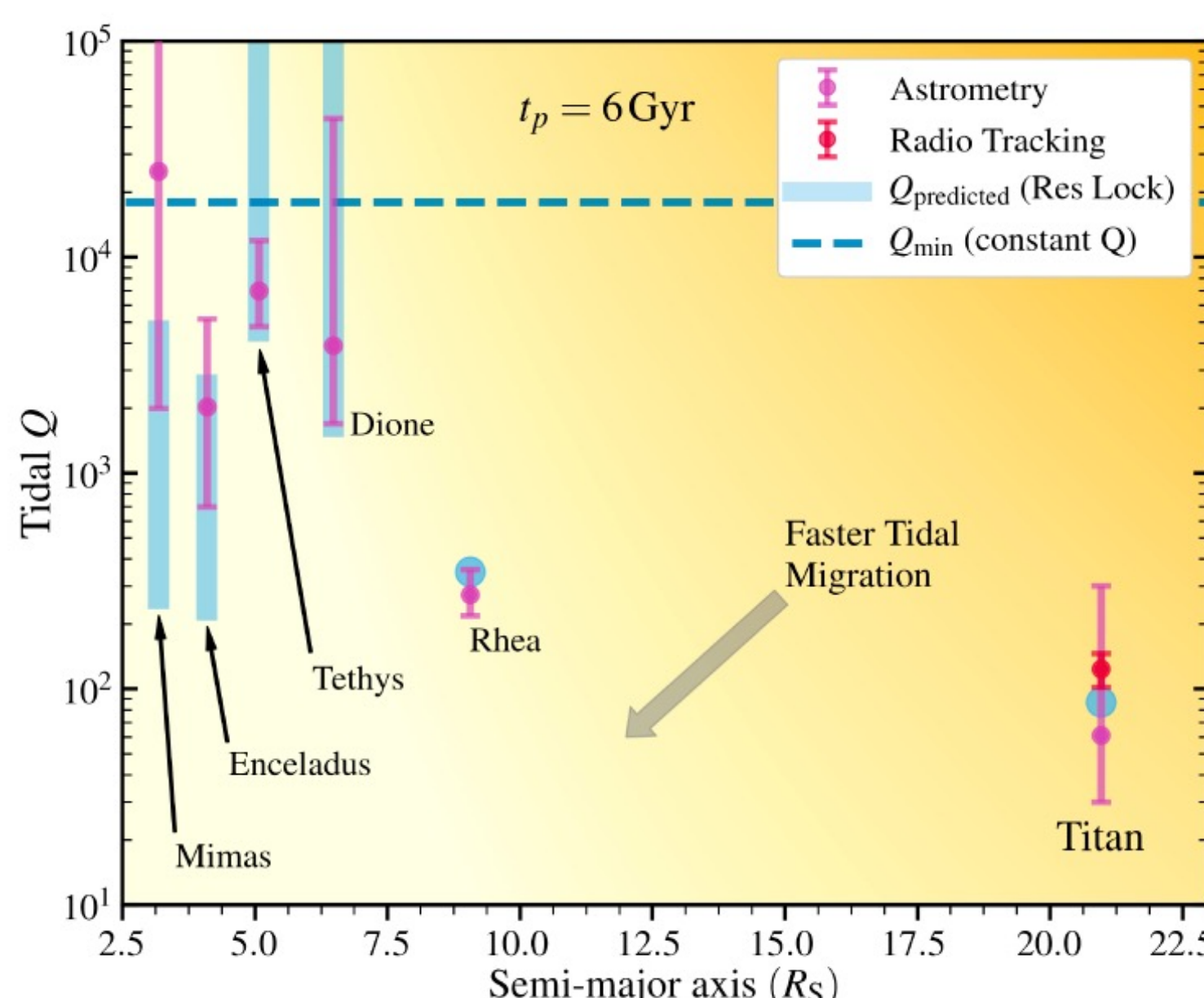
Typical differences between our model and the Cassini-ISS observations:



What we have found...

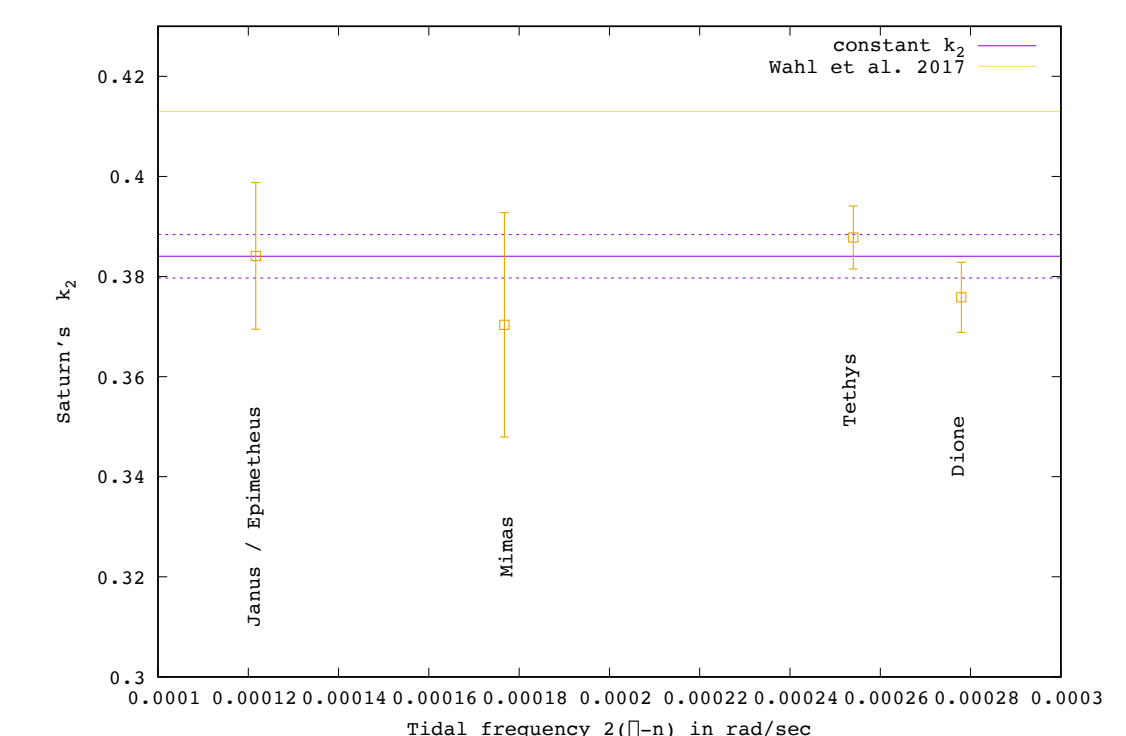
We found that the inner moons of Saturn are close to homogeneity by measuring the feedback of their physical libration on their orbit (Rambaux et al. 2022; Lainey et al. 2023).

More importantly, we have quantified (Lainey et al. 2021) the orbital expansion of six main moons of Saturn!



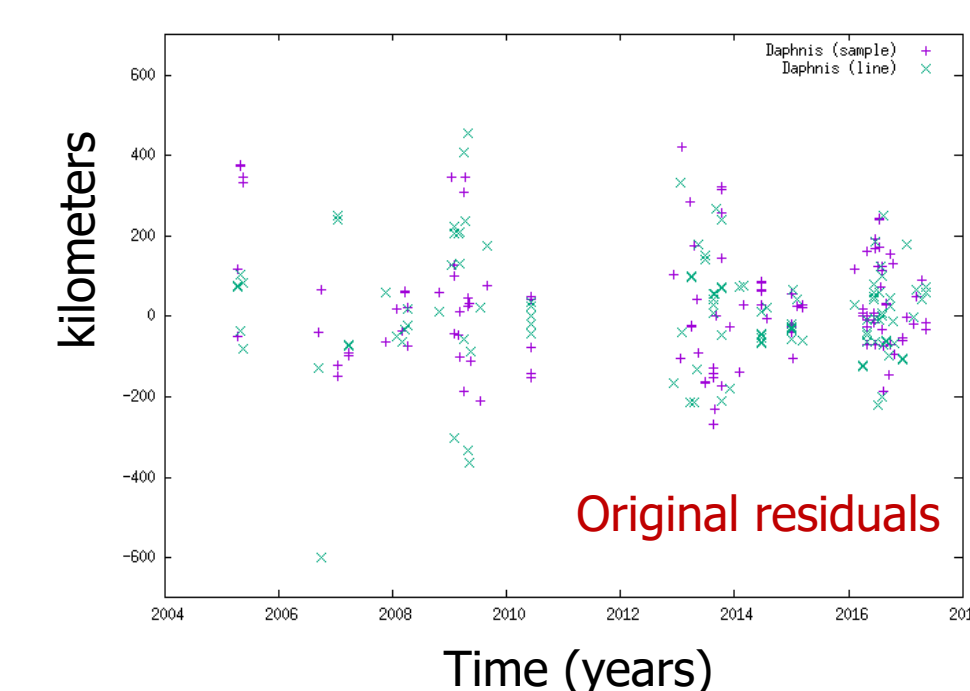
Unlike commonly believed, we have found that the moon's orbital expansion is barely decreasing with distance. A very non intuitive thing caused by the excitation of inertial waves inside the atmosphere of Saturn.

Moreover, we have succeeded in fitting the Saturnian Love number k_2 at four different tidal frequencies, showing that it is barely frequency dependent (Lainey et al. in prep.).



What was not expected...

Daphnis is a very small moon evolving at the outer edge of the Saturn's rings. Sounds boring? For a mysterious reason its ephemeris has been almost unpredictable within several hundreds of kilometers!



The origin of this dynamical behavior is still not fully understood.

Mimas: A new hope

In Tajeddine et al. (2014), Mimas was found to possess a global ocean under its icy crust or a very elongated silicate core. Both scenarios would imply very different formation and evolution. Unfortunately, it's hard to drill a hole inside Mimas...



Using the feedback of Mimas' rotation on its orbit, Lainey et al. (2024) could rule out the elongated core scenario.

Your take away

We found that tidal effects in Saturn may rely on a different physical mechanism than previously thought

Formation and orbital evolution of the main moons have to be reconsidered in light of our results

There remains quite a few dynamical features appearing in the Cassini-ISS data that have not been fully quantified, yet.

Astrometry is like a chocolate box: "you never know what you're gonna get!"

References

- Cooper et al., *A&A*, 610 (2018)
- Lainey et al., *Nat. Ast.*, 4 (2020)
- Lainey et al., *A&A*, 670 (2023)
- Lainey et al., *A&A*, 684 (2024)
- Lainey et al., *Nature* 626 (2024)
- Porco et al., *SSR*, 115 (2004)
- Rambaux et al., *A&A*, 667 (2022)
- Tajeddine et al., *Science* 346 (2014)