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Press release

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Why is the Solar System so stable?

The long-term orbital stability of the inner planets in our Solar System is still an open problem: the orbits of Mercury, Venus, Earth, and Mars are highly stable over the lifetime of the Solar System, even though they are strongly chaotic. In a study published on May 3rd 2023 in the *Physical Review X* journal, researchers from the Observatoire de Paris – PSL and CNRS explain this stability in terms of near-symmetries and quasi-conserved quantities.

The long-term motion of the planets in the Solar System is a long-standing problem that dates back to Newton's formulation of the universal law of gravitation. Jacques Laskar, CNRS senior researcher at Observatoire de Paris – PSL in the Institut de mécanique céleste et de calcul des éphémérides (CNRS, Observatoire de Paris - PSL, CNRS, Sorbonne Université, Université de Lille) discovered in 1989 that the planet motion is chaotic on a timescale of 5 million years and becomes unpredictable beyond 60 million years.

In 2008, Jacques Laskar showed that the probability of a collision between the inner planets (Mercury, Venus, Earth and Mars) is only 1% over the next 5 billion years, a timescale comparable to the age of the Solar System.

Two years ago, Federico Mogavero, post-doctoral fellow at the Observatoire de Paris - PSL within the IMCCE and Jacques Laskar showed that the typical time to wait for a catastrophic event is in fact much longer than the age of the universe!

So what makes the inner planets of the Solar System so stable?

The researchers at the Observatoire de Paris – PSL and CNRS, in IMCCE, propose a framework that justifies this remarkable stability. They show that the long-term motion of the inner planets is described by a hierarchy of timescales ranging from 5 to 500 million years.

Three symmetries characterise the strongest planetary interactions responsible for the orbital chaos. These symmetries are broken by weak resonances, leading to the existence of quasi-conserved quantities that represent the slowest variables of the dynamics. A principal component analysis of the numerical simulations confirms these results.

The stability of the inner planets over the lifetime of the Solar System naturally emerges from the constraints that the quasi-conserved quantities exert on the chaotic variations of the orbits.

Reference

"*Timescales of Chaos in the Inner Solar System: Lyapunov Spectrum and Quasi-integrals of Motion*" by Federico Mogavero, Nam H. Hoang et Jacques Laskar is published in *Physical Review X* on 3rd May.

DOI : https://doi.org/10.1103/PhysRevX.13.021018

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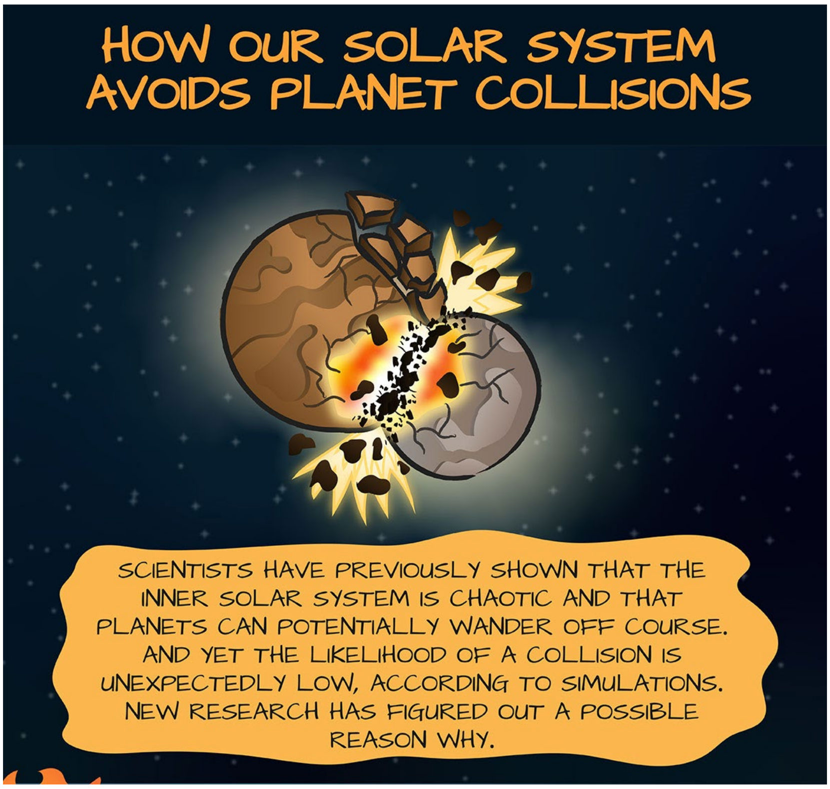
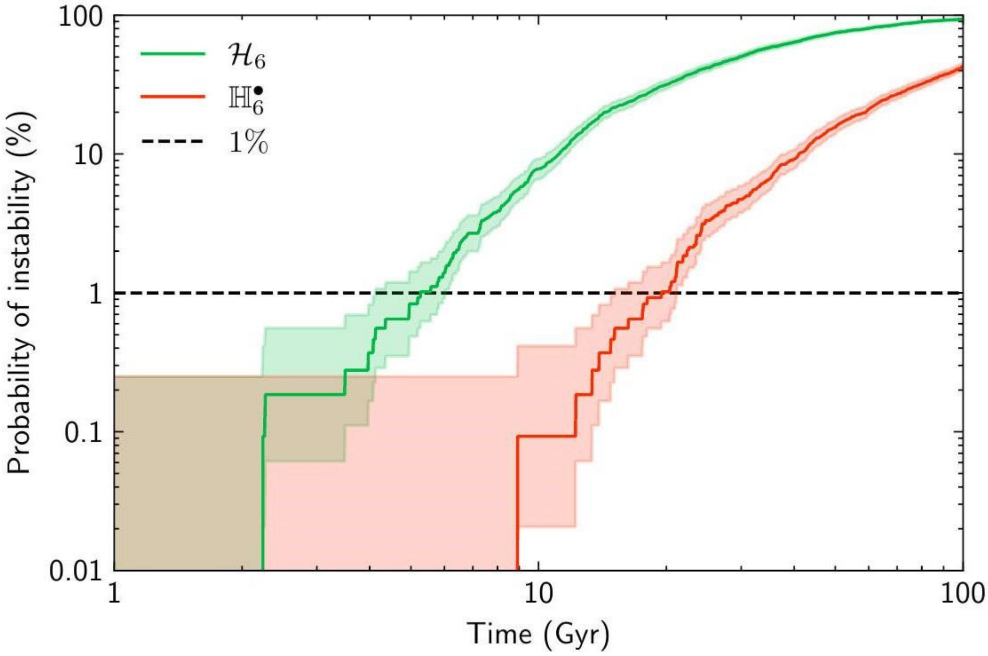
For more information

- **Research news:** "The Final Piece in the Solar System-Stability Puzzle? ", by Katherine Wright, Deputy Editor of Physics Magazine, May 3, 2023, Physics 16, 72.
https://physics.aps.org/articles/v16/72
- **Viewpoint:** "*Tackling the Puzzle of Our Solar System's Stability*", by Daniel Tamayo, Department of Physics, Harvey Mudd College, Claremont, California, May 3, 2023, Physics 16, 57.
https://physics.aps.org/articles/v16/57
- **Special Feature:** "How Our Solar System Avoids Planet Collisions", comic strip, by Laura Canil and Michael Schirber, May 3, 2023, Physics 16, 73.
https://physics.aps.org/articles/v16/73



Credit: Laura Canil and Michael Schirber

Image



Caption: Probability of an orbital instability (e.g., a planetary collision) for the inner planets over time. The green curve represents the nominal statistics of the Solar System (note that most of the possible evolutions of the inner planets are unstable over 100 billions of years.). The red curve corresponds to a simplified dynamical model in which the quasi-conserved quantities change even more slowly than in the real system. As a result the dynamical instability takes more time to develop.

Credit: Federico Mogavero, Nam H. Hoang and Jacques Laskar, Observatoire de Paris - PSL