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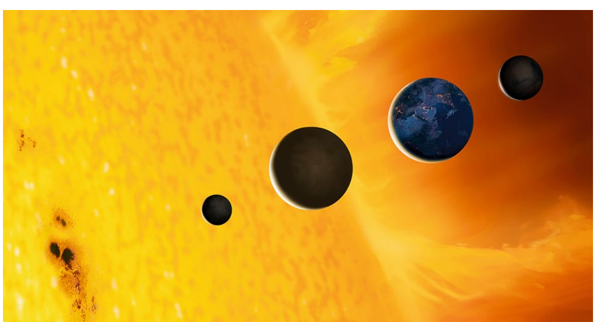
CHAOS

The path to the Solar system's destabilization

The Solar system is chaotic: beyond a few tens of millions of years, it is impossible to predict the motion of the planets based on their known positions and momenta today. Outside that timeframe, trajectories can only be studied probabilistically, using supercomputers to simulate many possible paths. Such simulations show that over the Sun's remaining lifetime, 5 billion years, around 1% of possible trajectories of the planets involve Mercury's orbit becoming so eccentric it could collide with Venus or the Sun. Now, writing in *Physical Review Letters*, Eric Woillez and Freddy Bouchet show that Mercury's destabilization can be described by a computationally much simpler approach that uses a path known as an instanton.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Instantons are classical solutions to the equations of motion of a system with given initial and final conditions, which minimize the action. They are used in gauge field theory or statistical mechanics, in which fluctuations make many trajectories possible, but the most probable are those closest to the instanton. For instance, tunnelling of a quantum mechanical particle in a double-well potential can be treated as a classical process in imaginary time; the classical solution is an instanton, which approximates the full path integral treatment of the quantum system. Instantons have been studied for decades, and in many situations a rigorous mathematical treatment exists. However, this is not the case for chaotic systems such as the Solar system, and it is not obvious that an instanton-based phenomenology would be applicable. Woillez and Bouchet show that, at least for a simplified model of the dynamics, the problem can be transformed into a diffusion problem that can be predicted using instantons. In other words, for a given destabilization time, the system's path fluctuates around the instanton that connects present-day conditions to those at a future destabilization event. Because the result comes from a simplified model, it can only qualitatively describe the Solar system, but suggests that studies of more realistic models should look for similar results.

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ORIGINAL ARTICLE Woillez, E. & Bouchet, F. Instantons for the destabilization of the inner Solar System. *Phys. Rev. Lett.* **125**, 021101 (2020).