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A Common Evolutionary Pathway for Uranus and Neptune

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1. Introduction

Despite many similarities, there are significant observed differences between Uranus and Neptune: while Uranus is tilted and has a very regular set of satellites, suggesting their accretion from a disk, Neptune's two moons are on irregular orbits. In addition, Neptune seems to have an internal heat source, while Uranus is in equilibrium with solar insulation. **It is possible that the ice giants shared a common formation path** with GIs occurring shortly after their formation being responsible for their distinct properties. [4, 1].

An oblique impact with a massive impactor could not only significantly alter Uranus' spin [3], but could also eject enough material in a disk, subsequently forming its regular moons. An oblique impact is not expected to affect the planetary internal structure, so any compositional barrier that inhibits convection will remain. On the other hand, Neptune gets its interior mixed up by a head-on collision.

In this study, using Smoothed Particles Hydrodynamics (SPH), we investigate whether these differences can be explained by giant impacts (GI). For Uranus, we find that an oblique impact can tilt its spin axis and eject enough material to create a disk which forms the regular satellites. For Neptune, we investigate whether a head-on collision can mix the interior, and lead to an adiabatic temperature profile, which explains its larger flux and higher moment of inertia value. We find that massive and dense projectiles can penetrate towards the center and affect Neptune's interior.

2. Methods

The impact simulations are performed using the SPH code GASOLINE [6] with the modifications for planetary collision described in [2]: free surface treatment and the fully entropy conserving SPH algorithm. We also modify the SPH method to properly model contact discontinuities, e.g., found at the core-mantle boundary of a planet.

The planetary bodies are generated with the BALLIC method [2]. The target has a three-layer structure with a granite core, an ice mantle, and a gaseous hydrogen-helium (H-He) atmosphere. The heavy elements are modeled with the Tillotson equation of state (EOS) [5], and H-He with an ideal gas equation of state. The impactor's composition is assumed to be granite, ice or differentiated (a granite core + ice mantle). Both the impactor and target are not rotating prior to the collision.

3. Results

We explore a large parameter space (impact parameter, impactor's mass and composition, and numerical parameters, different resolutions) to identify the collisions that can reproduce Neptune and Uranus's properties. Most collisions substantially alter Uranus' rotation period and can explain its spin as can be seen in Figure 1. In Figure 2 we compare the outcome of a head-on collision and a grazing collision. Shown are the materials and internal energy. While a head-on collision affects the internal structure by depositing mass and energy in the deep interior, a gazing collision does not significantly affect the internal structure.

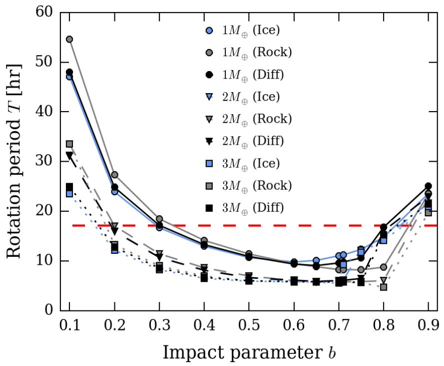

Figure 1: The post-impact rotation period of the target for different impactor's masses and compositions. Uranus' current rotation period of (17.24 h) is shown with a dashed red line. The blue and grey lines and symbols correspond to ice and rock, respectively, and black for a differentiated impactor (88% rock, 12% ice). The total mass colliding is set the Uranus' observed value, the different symbols represent different impactor masses ranging from 1 $M_\oplus$ (circle) to 3 $M_\oplus$ (squares).

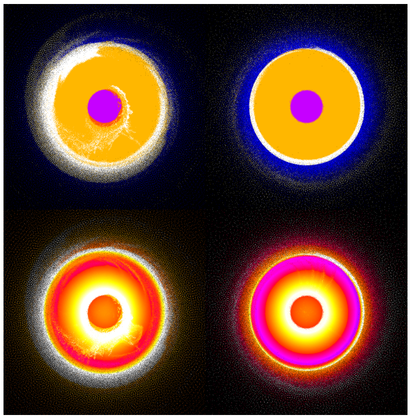

Figure 2: Slices through the planet's post impact (after 38 h) between a target of 12.5 $M_\oplus$ and a differentiated impactor of 2 $M_\oplus$. Top: (left) origin of the material for a head-on collision with b=0.2 (left), and for a grazing collision with b=0.7 (right). Bottom: internal energy for b=0.2 (left) and b=0.7 (right).

4. Conclusions

- **We show that Uranus and Nepture can have a common evolutionary path with similar giant impactors explaining the observed differences in rotation axis and internal structure.**
- We observe the formation of an extended disk around Uranus providing enough material for the formation of its regular satellites.
- The disk's composition depends on the impactor's composition and impact parameter. Grazing collisions with rocky/differentiated impactors deposit a substantial amount of rock in orbit.
- Head-on collisions with differentiated/rocky impactors for Neptune result in accretion of more mass, and substantially affect the planet's interior.

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