The Interior Structure of Uranus: Promise and Limitations of Precision Gravity.

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Introduction: We study the constraining power of a high-precision measurement of the gravity field for Uranus[1], as could be delivered by a low-periapse orbiter, like the Cassini Grand Finale. Our study is practical, assessing the possible deliverables and limitations of such a mission with respect to the structure of the planet. Our study is also academic, assessing in a general way the relative importance of the low-order gravity, high-order gravity, rotation rate, and moment of inertia (MOI) in constraining planetary structure. We attempt to explore all possible interior density structures of a planet that are consistent with hypothetical gravity data via MCMC sampling of parameterized density profiles. This framework is agnostic regarding layering (or lack thereof) and physical equations of state.

General Findings: When the gravity field is poorly known, as it is today, uncertainties in the rotation rate on the order of 10 minutes are unimportant, as they are interchangeable with uncertainties in the gravity coefficients. By the same token, when the gravity field is precisely determined, the rotation rate must be known to comparable precision. When gravity and rotation are well known, the MOI becomes well constrained, limiting the usefulness of independent MOI determinations unless they are extraordinarily precise.

Uranus Findings: For Uranus, density profiles can be well constrained. However, the nonuniqueness of the relative roles of H/He, the "ices," and rock in the deep interior will persist to some degree with high-precision gravity data. Nevertheless, the locations and magnitudes of any large-scale composition gradient regions can likely be identified (Fig 1), especially in density-pressure space (Fig 2) offering a crucially better picture of the interior of Uranus.

An orbiter mission to better characterize the gravity field and rotation of the planet would be of very high value. Even if high-order gravity (J_8, J_{10}, J_{12}) cannot be reliably separated into hydrostatic and dynamic parts, the interior barotrope (density versus pressure profile) could be tightly constrained. This would allow for direct comparisons of profiles of composition versus depth from formation and evolution models, opening a new era in our understanding of the planet.

Acknowledgments: We would like to acknowledge the support of NSF grant AST 1908615 and NASA grant 80NSSC19K1286. Resources supporting this work were provided by the *lux* supercomputer at UC Santa Cruz, funded by NSF MRI grant AST 1828315.

References: [1] Movshovitz, N. and Fortney, J. J. (2022) *PSJ, 3,* 4.

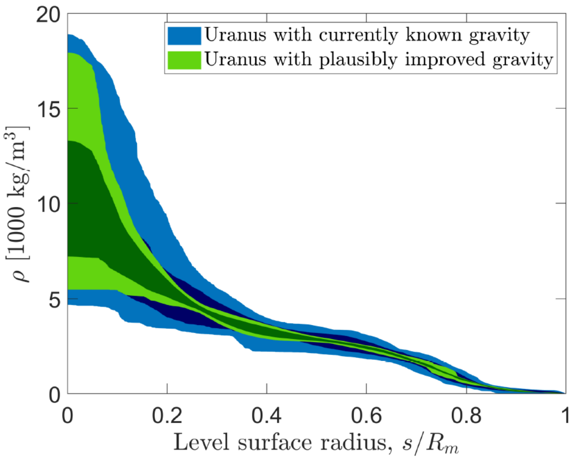

Fig 1: Envelope view of Uranus based on tens of thousands of model runs with a parameterized interior density profile. Green shaded areas are samples obtained with improved gravity constraints showing the 1-sigma (dark green) and 2-sigma (light green) sample range. Behind are samples obtained with the gravity field as currently known (blue), for comparison.

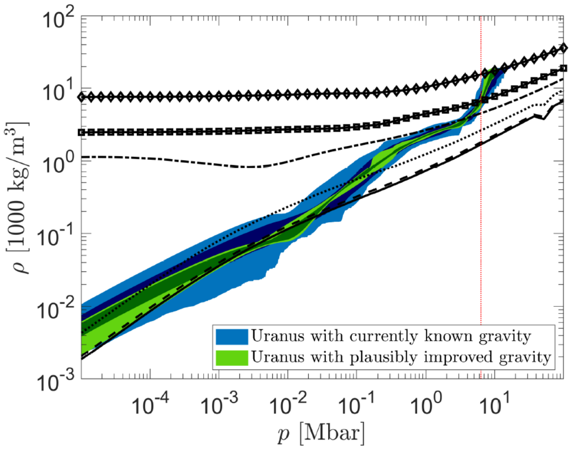

Fig 2: Barotrope view of Uranus. Colors and shading are the same as above. Overlain are isentropes for hypothetical homogeneous compositions extending from a common T_{10}bar = 150 K "surface." Diamonds: iron, squares: serpentine rock, dash-dot: water, dotted: 100x solar mix, dashed: 10x solar mix, solid: 1x solar mix. Red line shows the minimum sample-obtained value for the central pressure.