Can The Spin Rates of Irregular Satellites Provide Constraints To Their Formation Histories?

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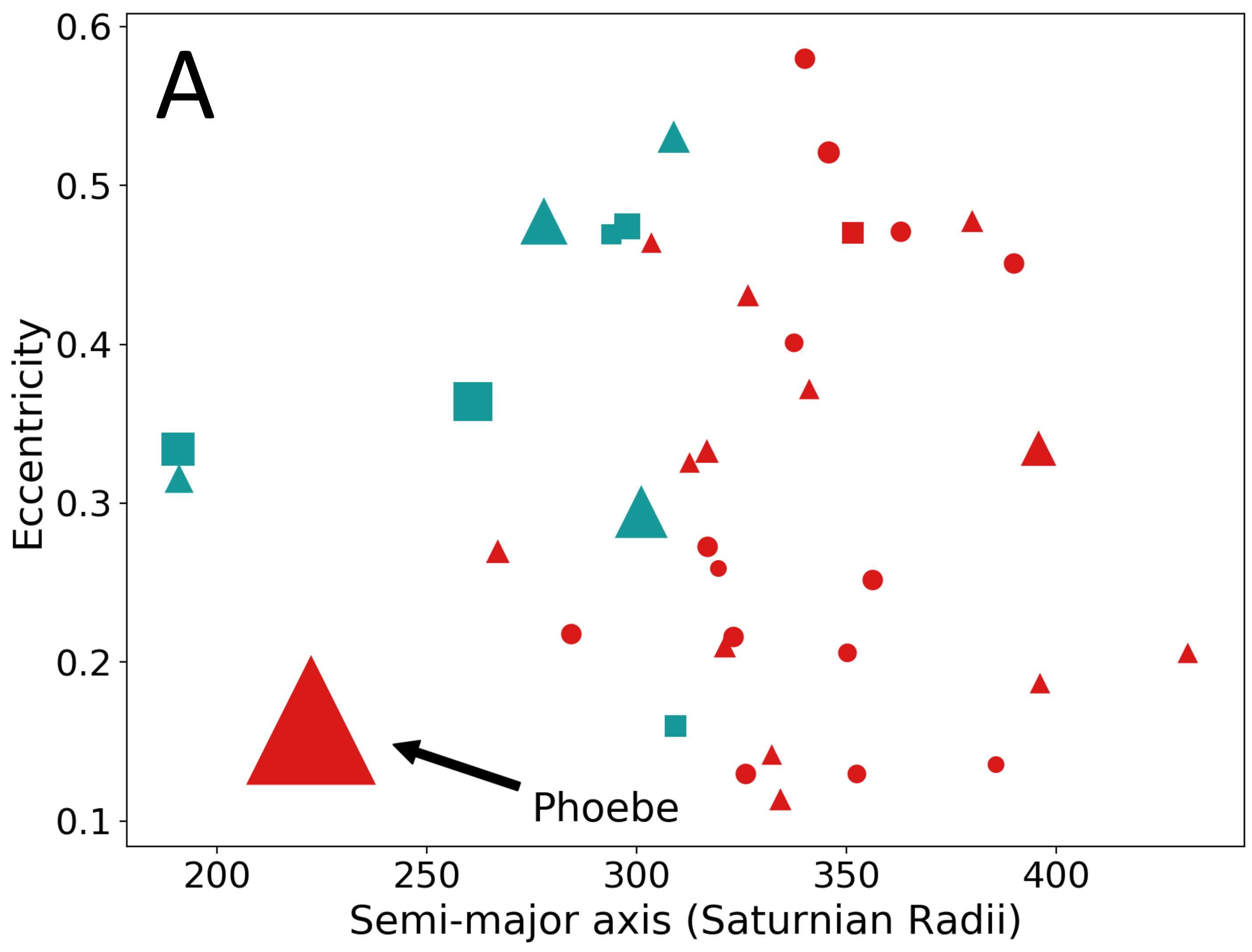
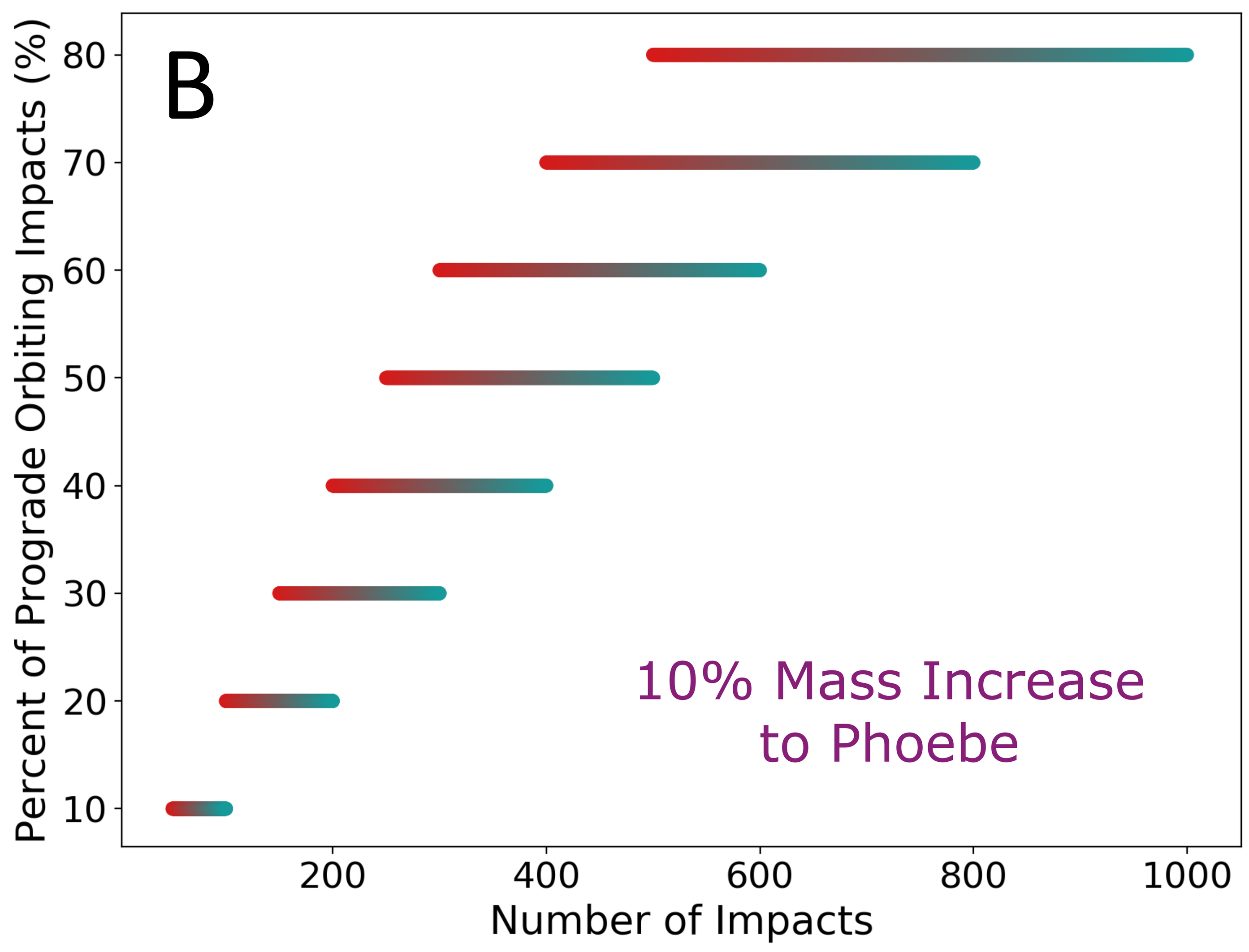
Abstract

Irregular satellites are believed to have been captured from the circumstellar disk during planetary formation, and were once probably the most collisionally active population in the Solar System [1]. The resulting orbital architectures at Jupiter and Saturn, especially the similarities between their largest irregular moons Himalia and Phoebe, may provide clues to the origin of the systems. The Cassini spacecraft observed photometric light-curves for 25 of Saturn's irregular satellites, and their spin-rates have been catalogued among other physical properties [2]. On average the prograde orbiting satellites spin slower ($1.8\ d^{-1}$) than their retrograde counterparts ($2.7\ d^{-1}$) (figure A). Since many small collisions yield slowly spinning bodies [3], it is possible that the prograde orbiting moons were struck by more impactors. We are investigating whether the spin-rate distribution can significantly constrain their collisional histories. If Phoebe and Himalia share similar histories [4][5], then the satellites' spin-rates may indicate that Jupiter and Saturn captured different populations of prograde and retrograde orbiting satellites.



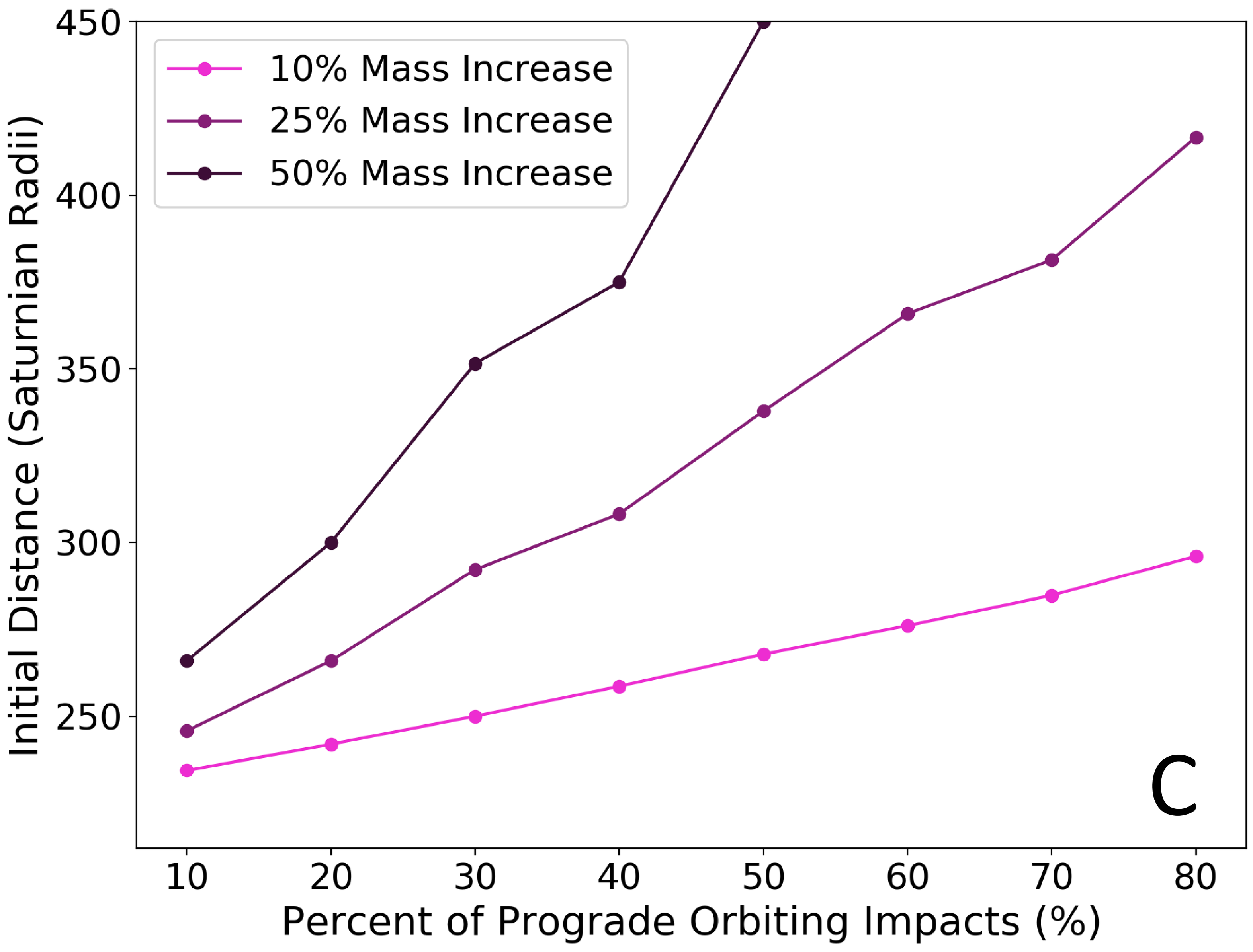
(left) Blue are the prograde orbiting moons, and red are the retrograde moons. Triangles indicate faster than average spin rates and squares indicate slower spins. The sizes of the markers represent the relative sizes of the satellites.

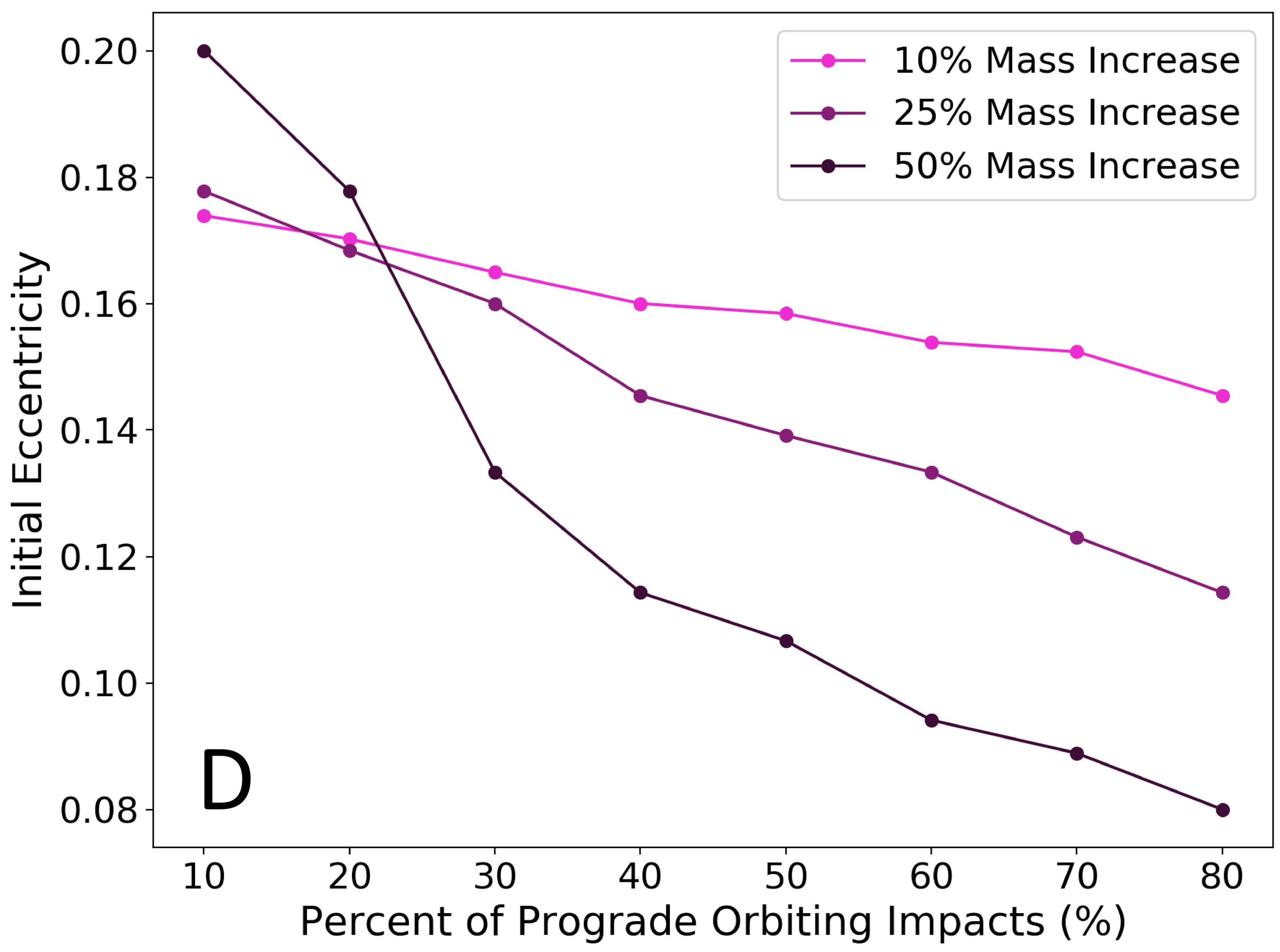
(right) The number of impacts required to generate Phoebe's spin rate for different populations of impactors. The colors are the average spin-rates for their corresponding population.



Our aim is to determine the number of impacts responsible for Phoebe's spin rate for different possible populations of impactors while also accounting for changes to Phoebe's orbit. Since Phoebe and Himalia are both located closer to their central planets than the other irregular satellites and are orbiting on relatively circular orbits, they may have been initially located farther out on more eccentric orbits. If Phoebe accreted only 10% of its mass from collisions, then it would have needed to experience mostly head-on collisions to decrease its semi-major axis significantly (figure C); however, headwinds tend to increase a body's eccentricity (figure D). Increasing the total mass imparted would increase the magnitude of the impulse imparted, and so the satellite's orbit would shrink faster. If Phoebe was initially located beyond 300 Saturnian radii, then imparting 50% of its mass from collisions would instead circularize its orbit if most of the impactors were orbiting on retrograde orbits.

If the average mass of each impactor is larger, then the satellite will tend to spin faster [3]. Shrinking the mass per impactor by increasing the number of collisions will minimize this effect (figure B). Phoebe would need to have been struck by more than 500 impactors to generate its current spin rate from an initially non-spinning state if its mass grew by 10% and most of the collisions were head-on. The results are similar if we instead increase the total mass imparted by a factor of 5 and require that most of the impactors travel on retrograde orbits; however, the total number of impactors will increase by more than an order of magnitude. Since Phoebe is speckled with over a thousand different sized craters [6][7], a few relatively giant head-on impacts among a tailwind of many smaller impactors may shrink the number of impacts further.





References:
[1] Bottke et al. 2010 [2] Denk & Mottola 2019 [3] Dones & Tremaine 1993
[4] Hamilton 2001 [5] Hamilton 2003 [6] Porco et al. 2005 [7] Sisto & Brunini 2011

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