Smashing Uranus' Moons

Vicki Toy
Astro630
October 10, 2012

Although other planetary satellite systems have been studied more thoroughly, the uranian system is unique due to its condensed and varied structure. Uranus consists of three types of satellites: 13 low-mass inner moons, 5 classical moons, and 9 distant irregular moons. Duncan and Lissauer (1997) demonstrated that the inner satellites were unstable on short timescales of $\sim 10^6$ years. While Voyager 2 discovered the majority of the inner moons in its flyby in 1986 (Smith et al., 1986), the Hubble Space Telescope observed two additional satellites, Cupid and Mab, in 2006 (Showalter and Lissauer, 2006). French and Showalter (2012) were strongly motivated to investigate if these additional inner moons altered the stability of the uranian system and they also considered a broader set of mass estimates. In order to have an unbiased comparison, they used the same simulator and integrator as Duncan and Lissauer (1997).

The stability of the system was measured in terms of crossing time, which is defined as the point when an inner satellite's apoapsis is greater than an outer satellite's periapsis. Most satellite crossings do not immediately result in collisions; however, crossings typically end in collisions due to the change in precession rates from the interaction unless there are protection mechanisms in action (Mikkola and Innanen, 1995). The simulations take into account Uranus' oblateness, but ignore effects from classical moons because this only alters the crossing time by $\sim 10^{4.4}$ years which is insignificant compared to timescales of 10^5-10^6 (French and Showalter, 2012). The largest uncertainties lie in satellite densities because there are no dynamical mass estimates for the inner satellites. Duncan and Lissauer (1997) found a power law that related the crossing time to a satellite mass multiplier. This power law holds for the wider range of mass models that French and Showalter (2012) used.

The uranian system is unstable for all 32 varying density models with timescales ranging from $10^{3.1}$ to $10^{6.2}$ for ρ=0.5-3.0 g/cm^2 (French and Showalter, 2012). Cupid and Belinda are the first satellites to cross in 30 models, with Cressida and Desdemona crossing in the other 2 models (French and Showalter, 2012). French and Showalter (2012) ran additional simulations removing each inner satellite one at a time using the same initial conditions. The Cupid-Belinda pair crossed in 8 out of the 13 situations suggesting that individually the satellites are not strongly affecting the crossing. The simulation times were extended well beyond the crossing times of Cupid-Belinda and Cressida-Desdemona to investigate the evolution of the system post-collision. The authors assumed that the colliding satellites form a combined satellite with mass-weighted orbital elements and properties. The result is that after a crossing time of $10^{7.6}$ years 6 of the satellites have formed into 2 new combined satellites.

The crossing timescales are short compared to Uranus' lifetime, making it statistically improbable that we could observe the uranian system near the end of some of its moons' lifetimes. The authors offer two suggestions: there is some unidentified phenomenon at work, which is unlikely from observations of other systems, or that the satellites are in a steady state–constantly colliding and recombining at roughly the same rate.

I will use an orbital integrator, HNBody, to probe the relationship between satellite density and stability between the most likely collision pairs, Cupid-Belinda and Cressida-Desdemona. Density is the least constrained parameter and it is possible that a certain density combination or range can stabilize the system and eliminate the necessity of a steady state satellite theory.

REFERENCES

Duncan, M.J. & J.J. Lissauer. 1997. Icar. 125: 1-12.
French, R.S. & M.R. Showalter. 2012. Icar. 220: 911-921.
Mikkola, S. & K. Innanen. 1995. MNRAS 277: 497-501.
Showalter, M.R. & J.J. Lissauer. 2006. Science 311: 973-977.
Smith, B.A. et al. 1986. Science 233: 43-64.

This preprint was prepared with the AAS LaTeX macros v5.2.