Could Ariel have been Heated by Tidal Friction?

S. J. Peale (University of California at Santa Barbara)

For significant dissipation in Ariel, one must hypothesize the past existence of an orbital resonance to force and maintain a substantial eccentricity in the orbit. The certain capture of Ariel/Umbriel into a simple eccentricity resonance at the 2/1 commensurability of orbital mean motions had they passed through singles out this strong resonance as the most likely to have had any effect on Ariel's interior. An immediately apparent problem with the occupancy of this resonance is the neccessity for an escape by an unknown mechanism. A lack of resolution of this problem may mean that tidal expansion of the satellite orbits has been insufficient for the 2/1 commensurability to have been encountered, but the striking modifications of Ariel's surface suggests that something much more dramatic has happened. A maximum dissipation occurs when Ariel's eccentricity has been forced to an equilibrium value where the ratio of orbital mean motions of the resonant pair is fixed as the orbits of the satellites continue to expand from tides raised on Uranus. The dissipation is then simply the difference between the rate of work done by the tidal torques from Uranus and the rate of orbital energy increase, where nearly all of the dissipation occurs in Ariel. With dissipation $dE/dt = 0.26nT$ (n = mean motion, T = torque), we can infer a maximum effect on Ariel's thermal history by assuming the longest possible existence of the resonance in equilibrium with the minimum average value of Q for Uranus. $Q_{min} = 4600$ ($k_2 = .104$) is now determined by Miranda starting at the "standstill" orbit. The maximum dissipation rate in Ariel would have been 7×10^{18} ergs/sec which would drop to 2.3×10^{17} ergs/sec at the last position at which the 2/1 resonance could have existed 2.6×10^9 years later—the resonance being disrupted at least 2×10^9 years ago. The absolute maximum dissipation rate would be reduced both by the time necessary to establish the resonance in the first place and by a consequently larger minimum Q. Subsolidus convection may be able to remove the heat even at the highest rate of deposition without disrupting a rigid lithosphere, but such a conclusion depends on highly uncertain parameters. The actual heating rate has undoubtedly been much less than this maximum, so even the former (unlikely?) existence of a 2/1 resonance may not be sufficient to account for Ariel's smoothed surface. Miranda could never have been trapped in any first order resonance, so its even younger surface is more a mystery.