PHYSICAL CHARACTERISTICS AND POSSIBLE ACCRETIONARY ORIGINS FOR SATURN'S SMALL SATELLITES.

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Introduction Cassini imaging observations have yielded sizes and shapes of Saturn's small (</~ 100 km radius) satellites from standard techniques [1]. For most of these satellites, masses (and thence densities) have been determined either from orbital integrations, when the satellite measurably perturbs another [2], or from the moon's effect on the rings [3]. Sizes, shapes and densities together can yield clues to the internal structure and origins of these bodies. We examine here the possibility that, rather than being monolithic collisional shards covered with a thin, dusty regolith, these satellites have formed by accretion from a disk of smaller-sized material to their present size.

Results: We begin by comparing the observed satellite properties with those expected for `rubble piles' that have formed by accretion. The physical characteristics of the ring-region moons Pan, Atlas, Prometheus, Pandora, Janus and Epimetheus are given in Table 1; we include Tethys' Trojans Calypso and Telesto also, though their masses are unavailable. We find that the observed long axes of Pan, Atlas, and Prometheus are, within the errors, identical to the Roche zone long axis for a body of the given mass at the satellites' orbit; Pandora, Janus and Epimetheus are progressively smaller. (The Roche zone is the region beyond which the sum of the tidal and gravitational forces point away from the moonlet. Material will no longer accrete beyond this point. Roche zone dimensions are given in Table 1) All the bodies in Table 1 have vertical to horizontal dimensions equivalent to those of the Roche zone, with the exception of Atlas, Prometheus and Calypso, which are flatter. Nonetheless, these similarities alone suggest that all these bodies may be rubble piles formed by accretion.

We have examined accretion into a `rubble pile' using a ring-patch code which realistically simulates the behavior of ring particles in orbit around Saturn, inclusive of collisional and self-gravitational effects. In this patch, we embedded a solid 25-meter radius core of internal density $\rho = 0.9$ g cm^{-3}. We chose particle disk characteristics believed to be representative of Saturn's A ring.

The core accreted particles until it became a moon with an effective bulk density of 0.4 g cm^{-3}. The moon's growth stopped when its bulk density dropped to the critical density: ie, the value where it exactly fills its Roche zone. The simulated moon had axes close to the effective Roche zone axes.

The real satellites have surprising low densities: ~0.4–0.6 g cm^{-3}, near the critical densities. These observations suggest formation not unlike the accretionary growth observed in our simulations, i.e., growth by the accretion of material around a small monolithic "core". Of course, the details of accretion – eg, whether or not material will preferentially accrete onto the equator of the body, making it flatter – will also affect the shape. Nevertheless, if this interpretation is correct, we can now add an additional factor to the dynamic and accretionary history of a moon. like Pan, which opens and maintains a gap in Saturn's rings. For example, if the required mass to open a gap is reached before the Roche zone is filled, accretion may continue provided there is still material in the gap to accrete. For Pan in the Encke gap, this is the case. These conditions place restrictions on the size of the original "core". The discrepancy between the Roche zone size and the sizes of the more distant moons may imply that these moons ran out of material before reaching maximum size and/or formed at a distance closer to Saturn.

References: [1] Thomas, P. C. 1993. *Icarus* **105**, 326-344. [2] Spitale et al, *Astron. J.* Submitted. [3] Porco, C. et al. 2005. *Science* **307**, 1226-1236.

Table 1 Small Satellites

Satellite	a	b	c	R_m	a_R	$b_R = c_R$	a/a_R	GM, km^3 s^{-2} x10^{-3}	ρ, g cm^{-3}	
Pan	17.6	17.3	11.5	14.8±2.0	19.1	12.7	0.92	0.33±0.05	0.36±0.16	
Atlas	22.8	19.0	9.6	15.3±1.2	21.6	14.4	1.05	0.44±0.04	0.44±0.11	
Prometheus	59.5	43.7	30.4	43.1±2.0	62.9	41.9	0.95	10.45±0.13	0.47±0.07	
Pandora	51.5	39.8	32.0	40.3±2.2	61	40.7	0.84	9.05±0.15	0.49±0.082	
Janus	96.6	86.6	68.6	89.4±3.0	157.4	105	0.61	127.58±0.33	0.64±0.064	
Epimetheus	67.4	54.2	52.3	56.7±3.1	102.7	68.4	0.66	35.4±0.09	0.69±0.11	
Telesto	14.6	11.1	10.2	11.8±1.0	--	--	--	--	--	
Calypso	15.1	11.4	7.0	10.7±1.0	--	--	--	--	--	

a, b, c, Rm, and Roche zone dimensions a_R, b_R, c_R in km.; densities determined from masses, GM, reported in [2, 3].