Orbital and Photometric Analysis of the Inner Uranian Satellites from Hubble Images

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1. Introduction

We have performed astrometry and photometry of 12 inner Uranian satellites (Ophelia to Mab) using 807 images taken by the Hubble Space Telescope 2003–2013 using a variety of filters on the WFPC2/PC1, WFC3/UVIS, WFC3/IR, and ACS/HRC instruments. We derived high-quality orbit fits for each moon as well as a combined model for Perdita and Belinda, which are in a 43:44 resonance. Light curves show that Cupid has a very large hemispherical asymmetry.

2. Orbit Fits

Orbital elements are given in Table 1. Typical residuals are ~0.2 UVIS pixels (~0.008") (Fig. 1). The orbit of tiny Mab is well described by a precessing ellipse; previous reports of unusually large residuals were the result of a 0.13% plate scale error in HRC images taken with the CLEAR filter.

3. The Belinda:Perdita Resonance

Belinda and Perdita show exceedingly large residuals (Fig. 1, red) until one considers their resonance:

$$\Phi = 44\lambda_{Perdita} - 43\lambda_{Belinda} - d\varpi/dt_{Belinda}$$

A modified orbital formula including mean motion libration revealed that Φ librates at a rate of 73°/year (Fig. 2). In our current analysis the amplitude of libration is 200°, which is clearly impossible. A new fit, with the amplitude constrained to <180°, is in progress. Nevertheless, our results indicate that the moons are at the edge of resonance, suggesting that their current configuration might be temporary.

The relative amplitude of the librations indicates that Belinda and Perdita have a mass ratio of ~27. Because their volumes are highly uncertain, this ratio is generally compatible with two bodies of the same albedo and density.

4. Rotation Curves

We have performed aperture photometry on all twelve moons. After modeling and dividing out each moon's phase function, the moons all show distinct brightness variations that correlate with orbital longitude, indicating tidal lock. Most rotation curves, such as that of Portia (Fig. 3, left), show two humps as one would expect for a uniformly-colored ellipsoid with its long axis pointing toward Uranus.

However, Cupid and Puck show additional variations (Fig. 3, center and right). In each case, the trailing face is brighter than the leading face. For Puck, the trailing face is brighter by ~15%; for Cupid, the ratio is ~2.3. Such a large variation is quite unusual; it may be caused by a cloud of dust that preferentially "paints" one face of the moon, as is the case for Iapetus. This result will require further study.

Acknowledgments

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1.13 9.80

	a (km)	e	I (°)	λ (°)	ϖ (°)	Ω (°)	dϖ/dt (°/d)	dΩ/dt (°/d)
Ophelia	53,763.797	0.00948	0.09080	231.99175	270.59183	87.00642	1.143831	-1.142464
Cressida	61,766.760	0.00056	0.05023	137.70117	274.65569	207.44872	0.702843	-0.702207
Desdemona	62,658.422	0.00073	0.04673	352.89892	157.93454	122.42866	0.668376	-0.667789
Juliet	64,358.268	0.00122	0.03518	76.17466	89.97098	144.28899	0.608475	-0.607968
Portia	66,097.314	0.00051	0.01643	50.43991	6.91932	31.75335	0.554151	-0.553714
Rosalind	69,926.849	0.00090	0.04922	139.85182	239.72554	249.40149	0.454831	-0.454510
Cupid	74,392.338	0.00047	0.07028	109.06840	320.20439	59.71798	0.366093	-0.365865
Belinda	75,255.674	0.00079	0.00172	324.66202	38.78082	232.28659	0.351580	-0.351366
Perdita	76,416.764	0.00345	0.05889	67.48953	338.81201	248.66870	0.333207	-0.333011
Puck	86,004.545	0.00010	0.33114	306.44436	136.73741	235.33913	0.220192	-0.220089
Mab	97,735.966	0.00347	0.12217	153.06479	149.92208	84.63121	0.140678	-0.140627

Table 1: Orbital elements for all inner moons except Cordelia. The epoch is 2008-09-01 00:00:00 UTC.

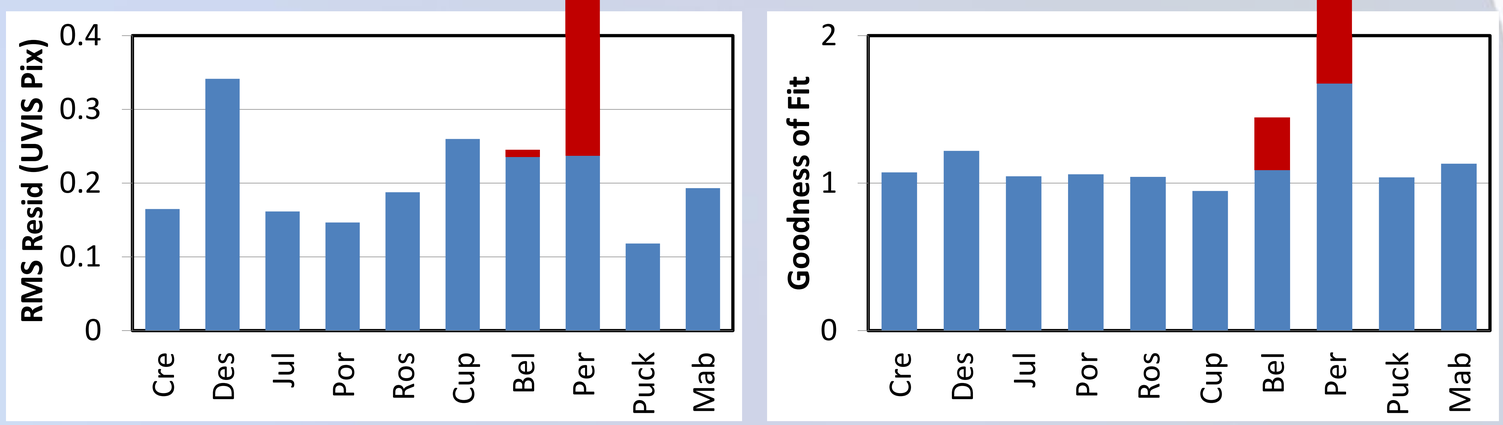

Figure 1: [Left] RMS residuals for orbit fits in units of WFC3/UVIS pixels (0.04"). [Right] Goodness of fit in units of estimated standard deviation. For Belinda and Perdita, the blue portion is the residual after libration is taken into account; the red extension is the residual without libration.

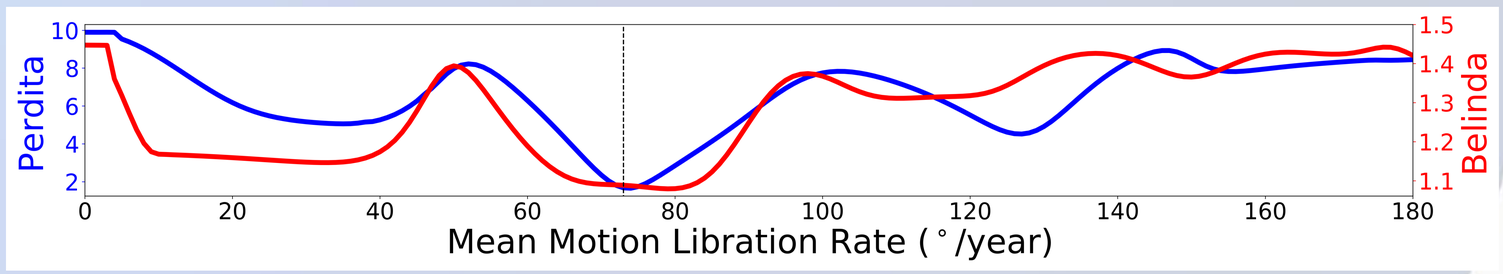

Figure 2: Goodness of fit for Belinda and Perdita for various libration rates. The lowest goodness of fit for Perdita occurs at 73°/day and coincides with the broader minimum for Belinda.

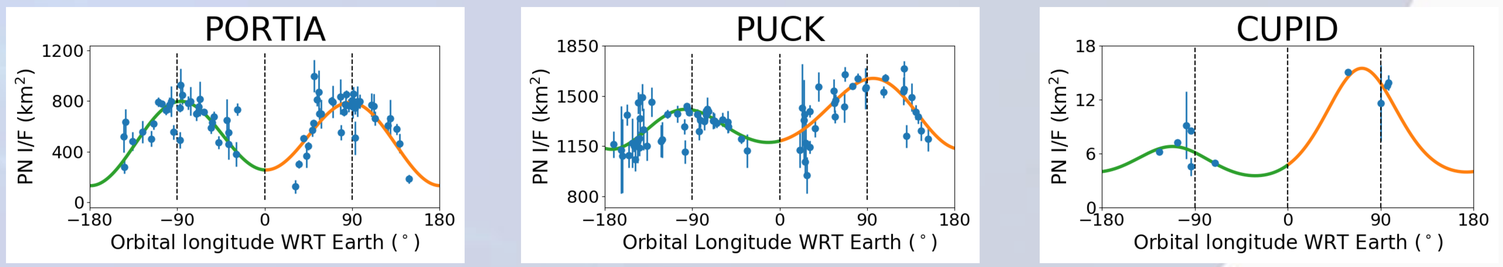

Figure 3: Light curves for three moons. Longitude is measured with respect to the Earth observer, with negative numbers representing the leading face. Portia and most moons show synchronous rotation and uniform albedo. Puck is ~15% brighter on its trailing face, whereas Cupid, mysteriously, is 2.3 times as bright on its trailing face.