**PHOEBE AND SATURN'S CAPTURED OUTER MOONS.** T. Denk[1], S. Mottola[2], W.F. Bottke[3], and D.P. Hamilton[4], [1]Freie Universität Berlin, Germany (Tilmann.Denk@gmx.de), [2]DLR (German Aerospace Center), Berlin, Germany, [3]SwRI, Boulder, CO, [4]University of Maryland, College Park, MD.

**Introduction:** The giant planets of our solar system are known to host far more than 100 outer moons which orbit at distances of many million kilometers on eccentric and inclined paths. Similarly to Jupiter Trojans, Centaurs, or Kuiper belt objects, the "irregulars" constitute another distinct group of small objects residing in the outer solar system.

Around Saturn, 38 irregular satellites have been discovered so far (compared to 24 regular moons), 29 of which on retrograde orbits. Their sizes lie between 4 km and 40 km (with the exception of Phoebe: 213 km), the apparent magnitudes as seen from Earth are ≳ 20 mag (Phoebe: 16.4 mag). Their distances to Saturn range from $7.6 \cdot 10^6$ to $33 \cdot 10^6$ km, the orbit excentricities from 0.11 to 0.54, and the inclinations from 34° to 47° (prograde moons) and from 145° to almost 180° (retrograde moons; these ranges correspond to inclination supplemental angles $i'$ between ~0° and 35°, with $i' = 90° - |90°-i|$). While orbital parameters and in parts sizes, albedos, and colors of these objects were measured from ground-based observations, most other fundamental physical parameters remained unknown.

*Tab. 1:* 24 rotational periods of irregular moons from Cassini ISS data, in hours. Left column: moons in orbits with $i' < 27°$; right: $i' > 27°$. *Italic*: prograde moons. Less reliable periods are marked with '*'.

| | | | |
|---|---|---|---|
| Hati | 5.42 | *Siarnaq* | *10.188* |
| Mundilfari | 6.74 | Narvi | 10.21 |
| Loge | 6.94* | *Tarvos* | *10.69* |
| Skoll | 7.26 | Skathi | 11.45 |
| Kari | 7.70 | Hyrrokkin | 12.76 |
| Suttungr | 7.82* | *Ijiraq* | *13.03* |
| Bergelmir | 8.13 | *Albiorix* | *13.32* |
| Phoebe | 9.27 | Bestla | 14.624 |
| Ymir | 11.922 | *Bebhionn* | *16.4* |
| Greip | 12.79* | *Paaliaq* | *18.75* |
| Thrymr | 35 or >45* | *Kiviuq* | *22* |
| | | *Erriapus* | *28.0* |
| | | *Tarqeq* | *60-90** |

**Cassini imaging observation campaign:** Particularly during the second half of the Cassini mission at Saturn, a campaign to study the outer moons was performed with the goal of investigating basic physical properties through disk-integrated photometric lightcurves with the ISS camera [1]. Doing such a research from a spacecraft offers *numerous* advantages like a large phase angle range, long continuous observation times, almost no straylight and weather issues, and many more. As of summer 2016, 25 outer Saturnian moons have been investigated with the ISS.

**Rotational periods:** *Tab. 1* shows results for 24 moons. For 19 satellites, rotation periods were measured to an accuracy better than 1%. For 5 objects, the results are less reliable and require improvement. The shortest period (5.4 h) is not even close to the spin barrier observed for asteroids (2.3 h). Minimum ratios of the equatorial axes $(a/b)_{min}$ of the bodies have also been determined. For at least 5 objects, $(a/b)_{min} > 1.4$.

**Patterns:** Two general trends from lower to higher phase angles are observed: an increase in the number of lightcurve extrema, and an increase in the lightcurve amplitudes. While the amount of "2max/2min" lightcurves is ~85% for low-phase (≲ 45°) observations, the number of "3max/3min" lightcurves increases to ~50% for mid-phase (~45° to ~90°) and even to ~2/3 for high phase angle (≳ 90°) observations. Also, most low-phase observations show amplitudes ≲ 0.5 mag, while most lightcurves taken at mid- and high phase exhibit amplitudes ≳ 0.5 mag.

An unexpected correlation between orbit inclination supplemental angles and rotational periods was found. All 13 known objects with $i' \gtrsim 27°$ have rotational periods > 10 h, while most measured moons with a lower $i'$ have shorter periods < 8.2 h (see *Tab. 1*).

**Pole directions and shapes:** Pole directions and convex shape models were calculated for three objects so far. Two of them show 3max/3min lightcurves even at low phase, and their shapes show triangular equatorial sections. Some objects have been found to be very elongated, which suggests a contact binary nature.

**Phoebe:** The by far largest outer moon of Saturn has been observed from Earth, Voyager 2, and Cassini. During the targeted flyby on 11 June 2004, Cassini came as close as 2070 km to Phoebe, and images with a resolution down to 13 m/pxl were obtained [2]. Several physical and photometric parameters, surface composition, and the crater-size distribution could be determined. Albedo, topographic, and cartographic maps were also compiled from these data.

**Phoebe dust ring:** A very faint dust ring, discovered in 2009, extends from $\sim 6 \cdot 10^6$ to $\sim 16 \cdot 10^6$ km from Saturn [3]. It is very likely produced by Phoebe and other retrograde irregular moons, and plays an important role in shaping the global asymmetry of the thermally driven albedo dichotomy on Iapetus [4].

**Origin:** The origin of the irregular satellites is still debated. In the Nice model, comet capture via three body interactions, followed by intense collisional evolution among the irregulars, is a viable option [5].

**References:** [1] Denk T. (2013) Participating Scientist prop., NASA Prop. No. 13-CDAPS13_2-0049. [2] Porco, C.C. *et al.* (2005) *Science* **307**, 1237-1242. [3] Hamilton, D.P. *et al.* (2015) *Nature* **522**, 185-187. [4] Spencer, J., Denk, T. (2010) *Science* **327**, 432-435. [5] Bottke, W.F. *et al.* (2010) *AJ* **139**, 994-1014.