Analyzing propeller gaps in Cassini NAC images

H. Hoffmann, M. Seiler, M. Seiß, and F. Spahn
University of Potsdam, Institute of Physics and Astronomy, Potsdam, Germany
E-mail: hohoff@uni-potsdam.de

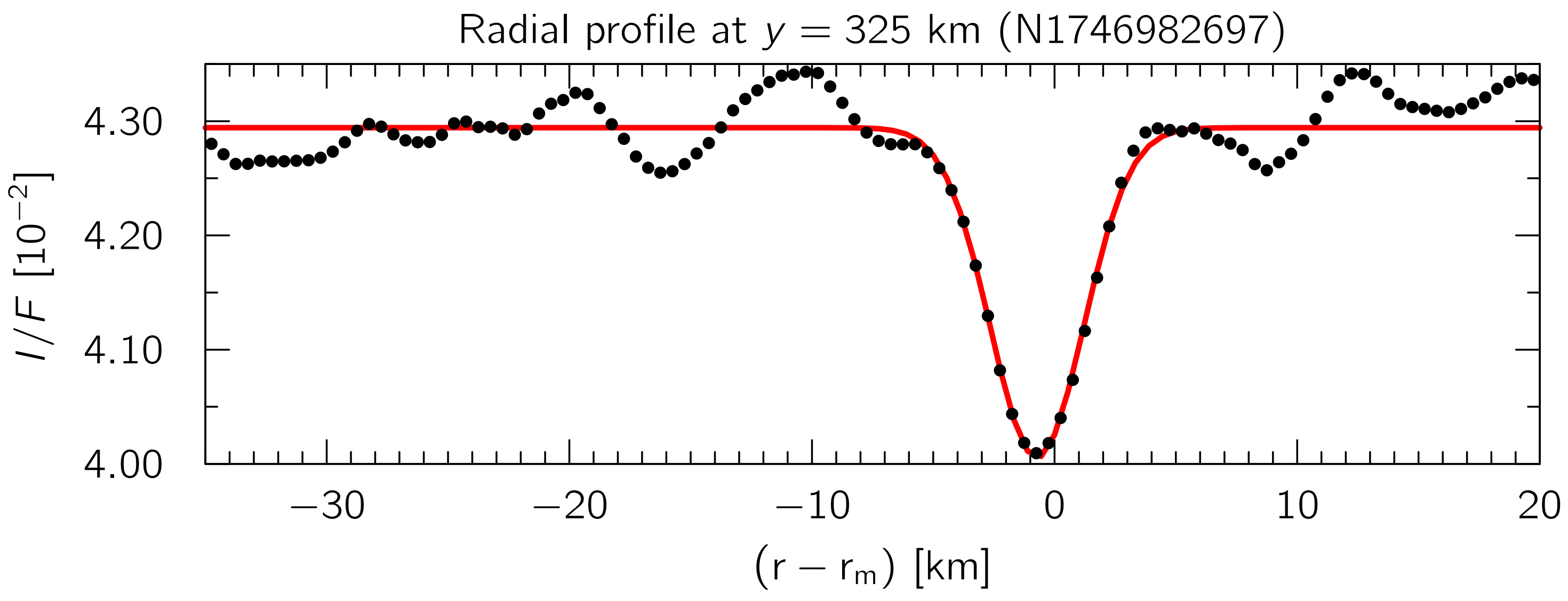
Introduction

Among the great discoveries of the Cassini mission are the propeller-shaped structures created by small moonlets embedded in Saturn's dense rings. These moonlets are not massive enough to counteract the viscous ring diffusion to open and maintain circumferential gaps, distinguishing them from ring-moons like Pan and Daphnis.

Partial gaps are one of the defining features of propeller structures. Until recently only the largest known propeller named Blériot was known to show well-formed partial gaps in images taken by the Narrow Angle Camera onboard the Cassini spacecraft. Since then, partial gaps were also resolved for the propellers Earhart and Santos-Dumont in high resolution images taken during Cassini's Ring Grazing Orbits.

Radial gap profiles

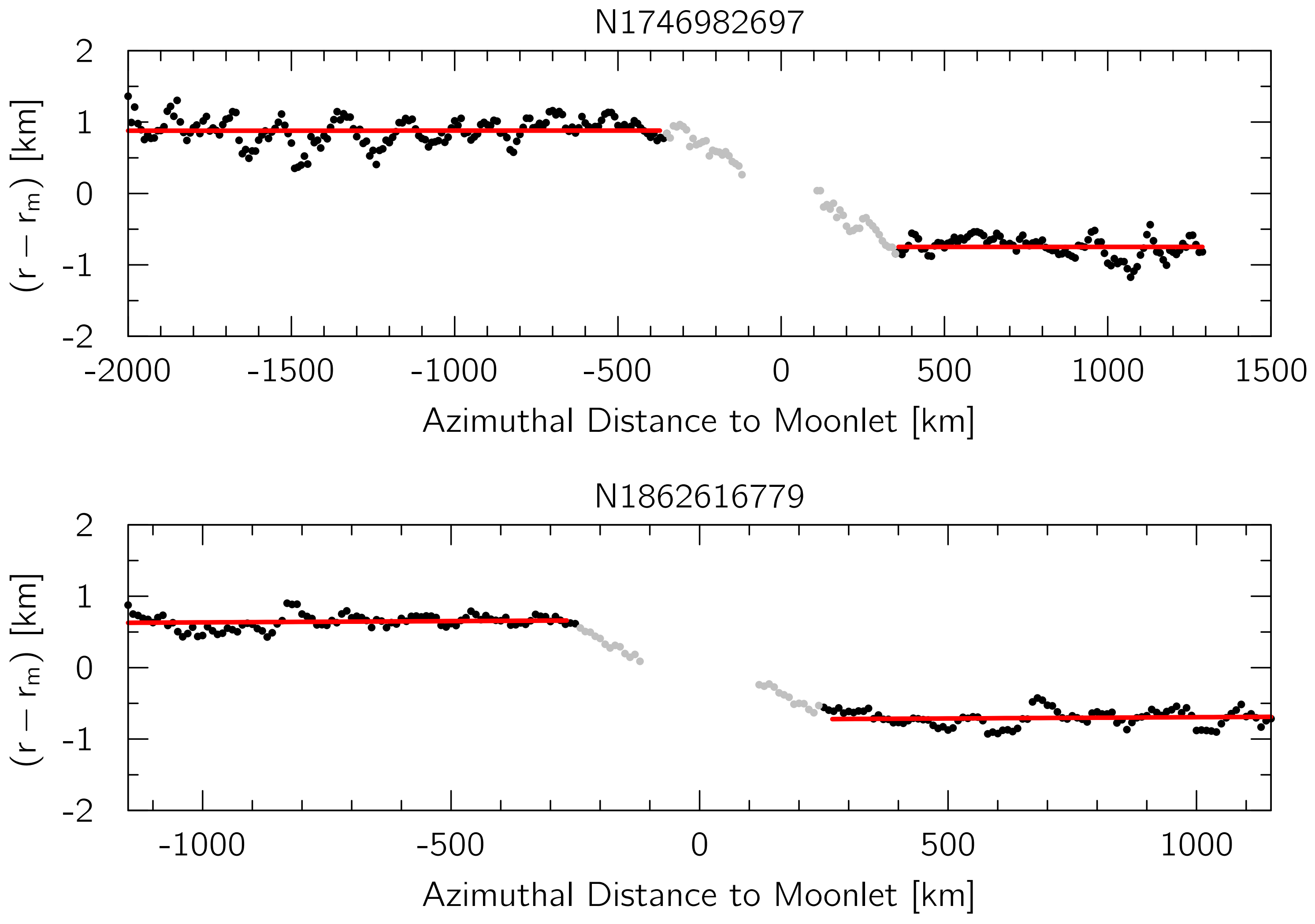
We analyze images of the sunlit side of Saturn's outer A ring which show the propellers Blériot and Santos-Dumont with clearly visible gaps. To determine radial gap profiles at different azimuthal locations, we radially bin the ring and azimuthally average pixel I/F values to reduce noise.



We fit several functions to parts of the radial gap profile to estimate the radial position of the gap minimum, the gap width and the I/F value of the gap minimum. The radial gap profile shown above, for example, is nicely modeled by a Gaussian fit function.

Radial separation of the partial propeller gaps

Propeller simulations show that the radial separation Δr of the two partial gaps is about 4 Hill radii [1, 2].



The two plots show the radial position of the gap minimum at different azimuthal locations (black and grey points) for Blériot. The red lines illustrate fits of the function

$$f(y) = \begin{cases} \alpha y + b + \Delta r & y < 0 \\ \alpha y + b & y > 0 \end{cases}$$

to the data yielding Δr. The following table lists results for the analyzed images of Blériot:

Image	Radial separation Δr [km]	Hill radius [m]
N1544842586	1.47	370
N1586641169/1255	1.95	510
N1731354160	1.78	445
N1731354280	1.65	410
N1746982697	1.63	410
N1862616735	1.39	350
N1862616779	1.40	350

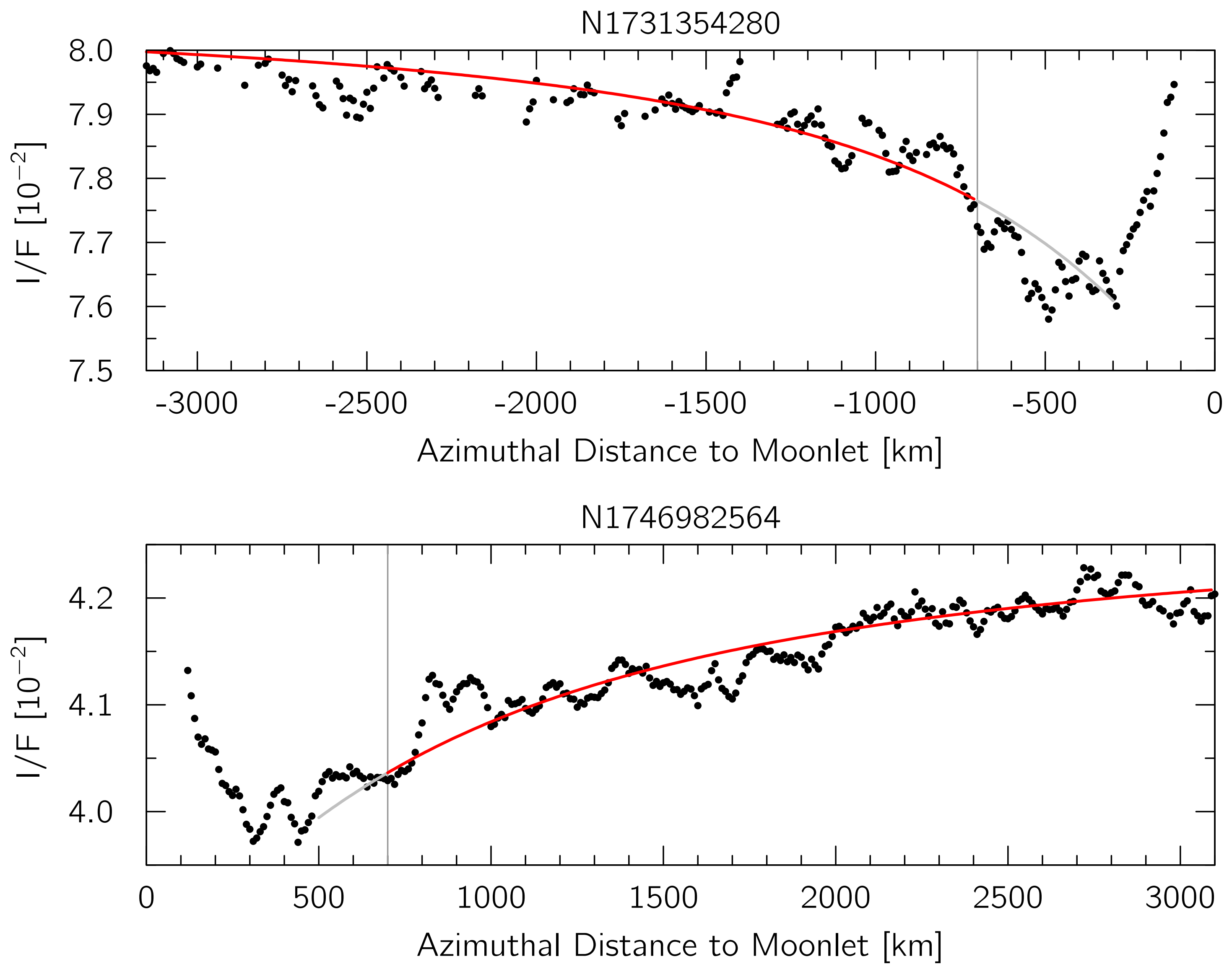
This leads to a Hill radius estimate for Blériot of $R_{\mathrm{Hill}} = (400 \pm 100)\,\mathrm{m}$, which is smaller than the estimate of $R_{\mathrm{Hill}} = (600 \pm 100)\,\mathrm{m}$ from [3]. A similar analysis of three high-resolution images of Santos-Dumont gives a Hill radius estimate for Santos-Dumont of $R_{\mathrm{Hill}} = (230 \pm 40)\,\mathrm{m}$.

Azimuthal evolution of propeller gaps

The propeller gaps scale azimuthally with

$$aK = \frac{\Omega R_{\mathrm{Hill}}^3}{2(1+\beta)\nu}\,,$$

where Ω is the Kepler frequency at the radial location of the propeller moonlet and ν a viscosity parameter which describes the mass diffusion into the gap. The constant aK can be estimated with help of a quasi-analytic solution for the mass density in propeller gaps [4].



The two plots show the minimal I/F values in the propeller gaps at different azimuthal locations (black points) for the propeller Blériot. The red lines illustrate fits of the quasi-analytic solution for the mass density, where we use a single-scattering solution to relate the mass density to I/F values.

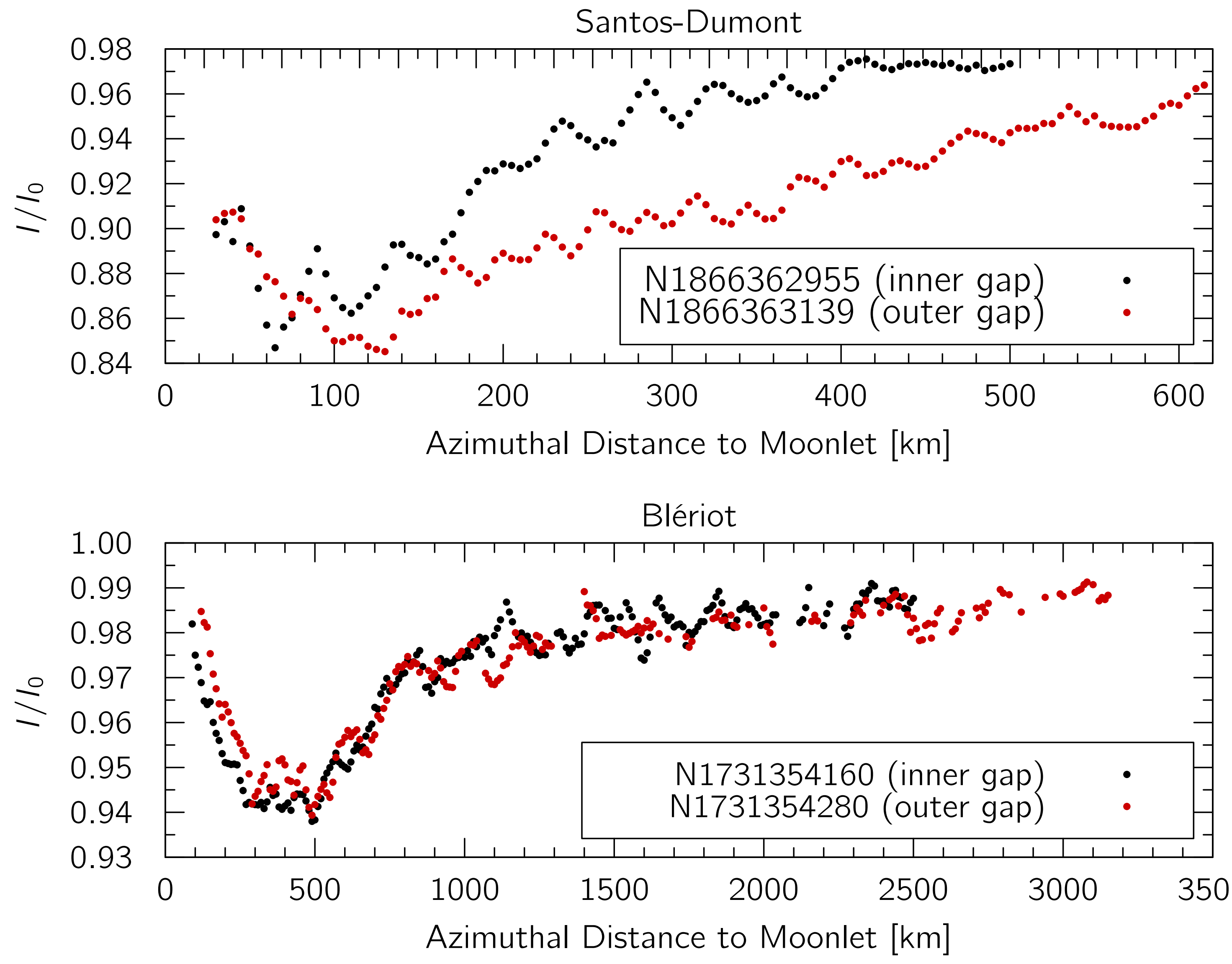
By assuming a power law dependence of the viscosity parameter ν on the mass density with a power law exponent β, the viscosity parameter can be estimated. The following table summarizes estimates for the propeller Blériot:

Image	aK [km]	$\nu_{\beta=0.67}$ [$\mathrm{cm^2\,s^{-1}}$]	$\nu_{\beta=2}$ [$\mathrm{cm^2\,s^{-1}}$]
N1731354160	216	110	61
N1731354280	224	106	59
N1746982564	275	87	48
N1746982697	276	86	48
N1862616735	198	120	67
N1862616823	222	107	60

From these values we estimate $aK = (235 \pm 60)\,\mathrm{km}$ leading to $\nu_{\beta=0.67} = (100 \pm 30)\,\mathrm{cm^2\,s^{-1}}$ and $\nu_{\beta=2} = (60 \pm 20)\,\mathrm{cm^2\,s^{-1}}$ for Blériot. These estimates are consistent with the viscosity parametrization by Daisaka et al. [5]. The viscosity value for $\beta = 2$ agrees well with the value of $64\,\mathrm{cm^2\,s^{-1}}$ estimated for the Encke gap edge [6], but is significantly smaller than the value of $(340 \pm 120)\,\mathrm{cm^2\,s^{-1}}$ estimated by matching isothermal hydrodynamic propeller simulations to UVIS scans of Blériot [3].

Asymmetric propeller gaps

High-resolution images of the propeller Santos-Dumont taken during the Ring Grazing Orbits show asymmetric gaps illustrated in the upper plot below. For comparison, the lower plot shows the azimuthal evolution of the inner and outer gap of the propeller Blériot.



Several trans-Encke propellers show longitude residuals with respect to a mean circular orbit, which are much larger than the observational errors [7, 8, 9]. Assuming this excess motion is kinematically caused by changes in the semimajor axis of the propeller moonlets, the resulting change of the moonlet's mean motion might explain the gap asymmetry seen in the upper plot above (see also Poster M11). Crucial to see a gap asymmetry is the relation between the timescale of the radial moonlet wandering and the time ring particles need to azimuthally travel through the propeller gap.

References

[1] Seiß, M., et al., Vol. 32, L11205, 2005.

[2] Lewis, M. C., and Stewart, G. R., Vol. 199, p. 387-412, 2009.

[3] Seiß, M., et al., submitted to ApJ, 2018.

[4] Sremčević, M., Spahn, F. and Duschl, W. J., MNRAS, Vol. 337, p. 1139-1152, 2002.

[5] Daisaka, H., Tanaka, H., and Ida, S., Icarus, Vol. 154, p. 296-312, 2001.

[6] Tajeddine, R., et al., ApJS, Vol. 232:28, (2017).

[7] Tiscareno, M. S., et al., ApJL, Vol. 718, p. L92-L96, 2010.

[8] Seiler, M., et al., ApJL, Vol. 840, L16, 2017.

[9] Spahn, F., et al., in: Planetary Ring Systems, Cambridge University Press, (2018).