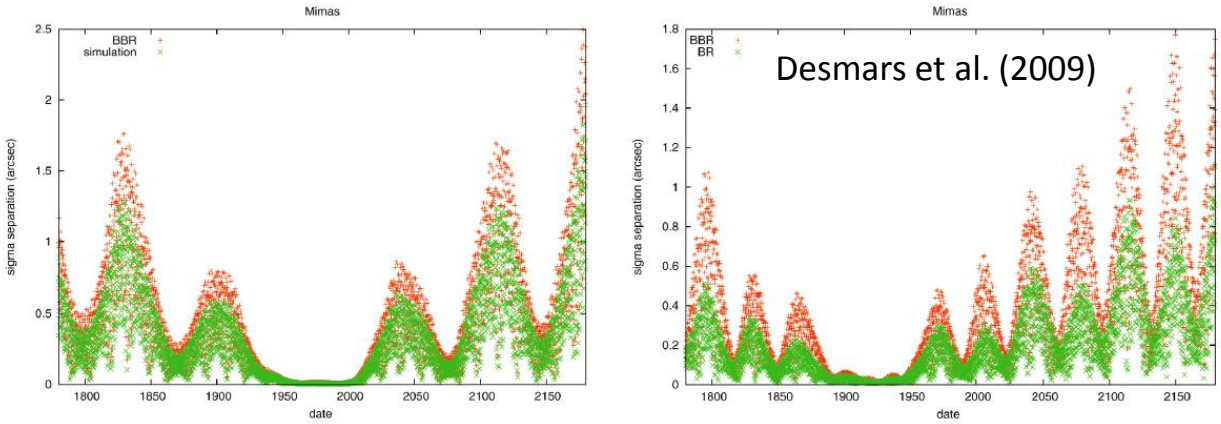
The need of long time series of observations for the natural planetary satellites

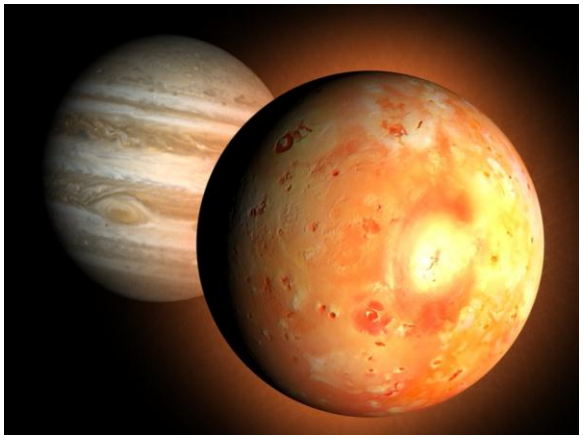
Valéry Lainey
(IMCCE)

Why shall we consider « old » ground observations at the time of space mission?

1- Because ephemerides are precise over a longer time span when a large time span of observations was used → talk of J.E.Arlot



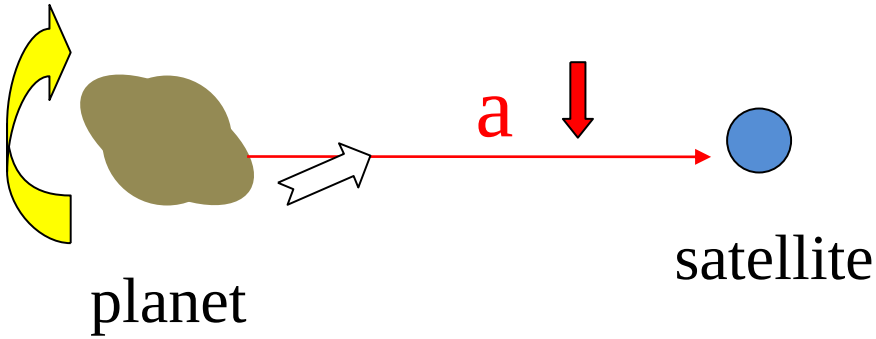
2- Because monitoring the long term evolution of moon orbits is sometimes the only way to assess physical parameters and internal state



Example of the Mars system

The terrible fate of Phobos

Why Phobos is doomed…



Question: how much time will that take place?

Example of the Mars system

Former works:

Sinclair, 1972

Shor, 1975

Sinclair, 1989

Jacobson et al. 1989

Chapront-Touzé, 1990

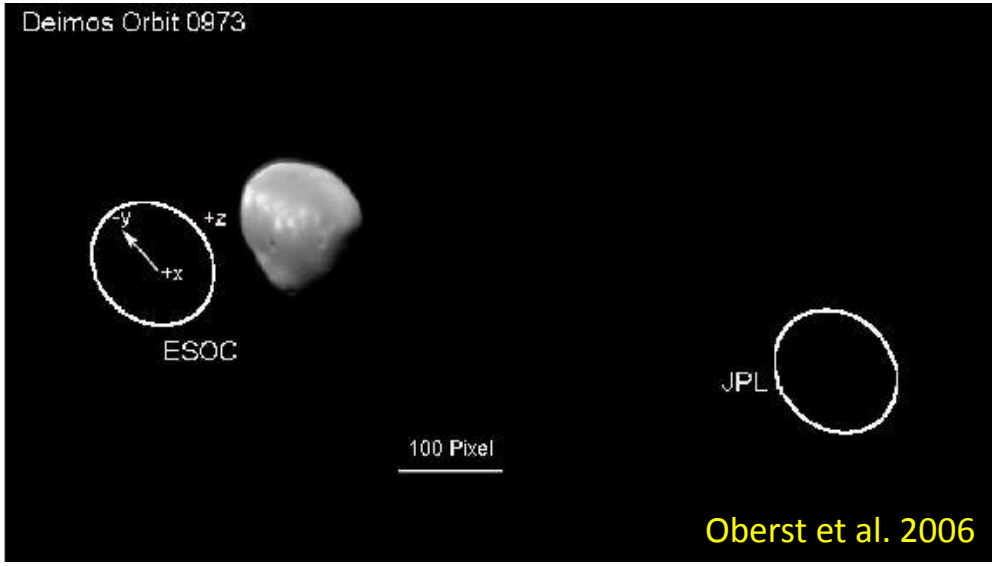
Morley, 1990

Emelianov et al. 1993

(All these models were analytic)

Example of the Mars system

Since the 90s the Martian moon ephemerides had drifted…



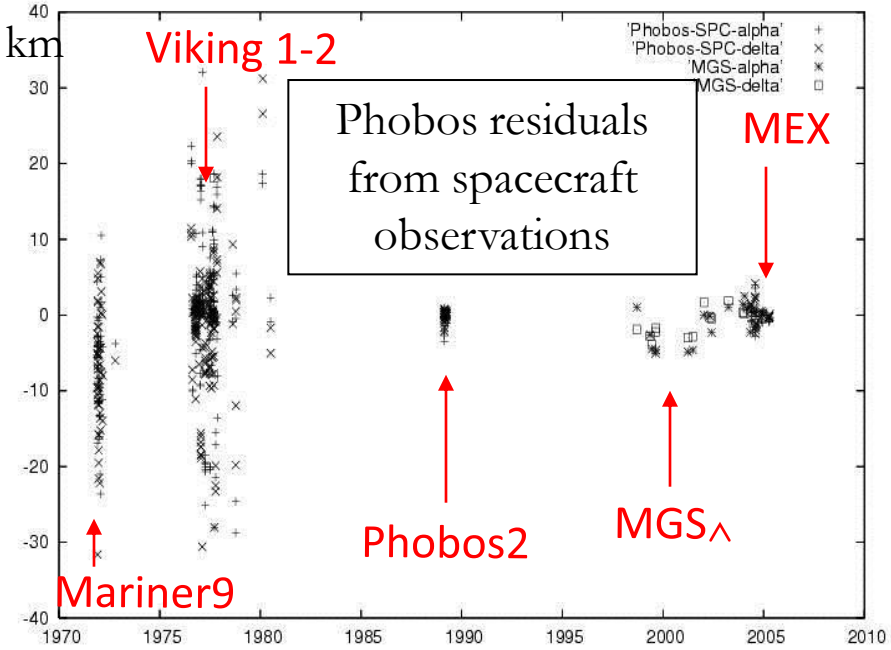
New ephemerides have been developed at JPL and IMCCE/ROB these last years to garantee a good accuracy of martian moon position in the context of MEX and MRO.

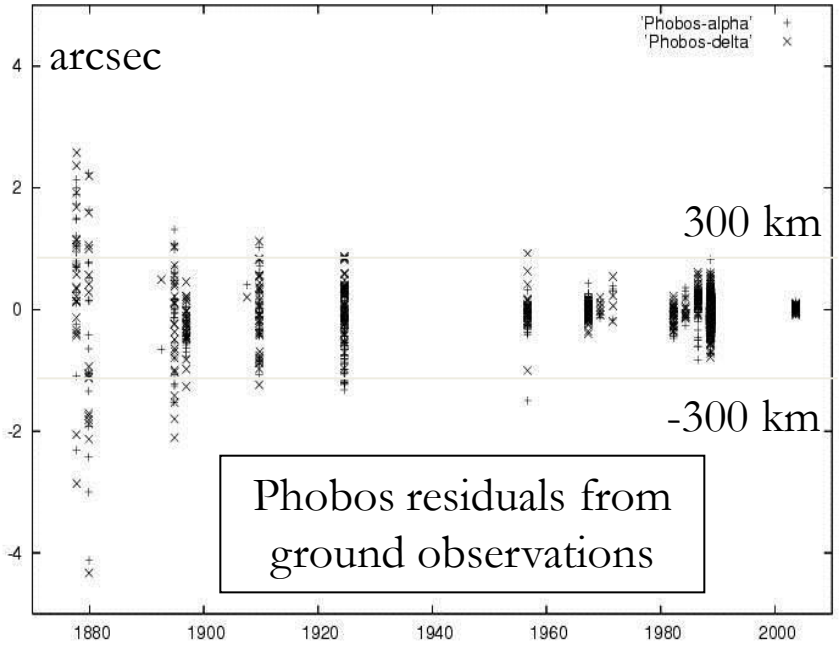
(both ephemerides are based on numerical integration)

See Lainey et al. (2007); Jacobson (2010)

Example of the Mars system

Astrometric post-fit residuals for Phobos after fit of initial state vectors, Mars **dissipation factor Q** and Phobos' oblate parameters c_{20}, c_{22}.





Lainey et al. (2007)

These ephemerides have been used by HRSC instrument (Mars Express/DLR) for the close Phobos flyby in 2008.

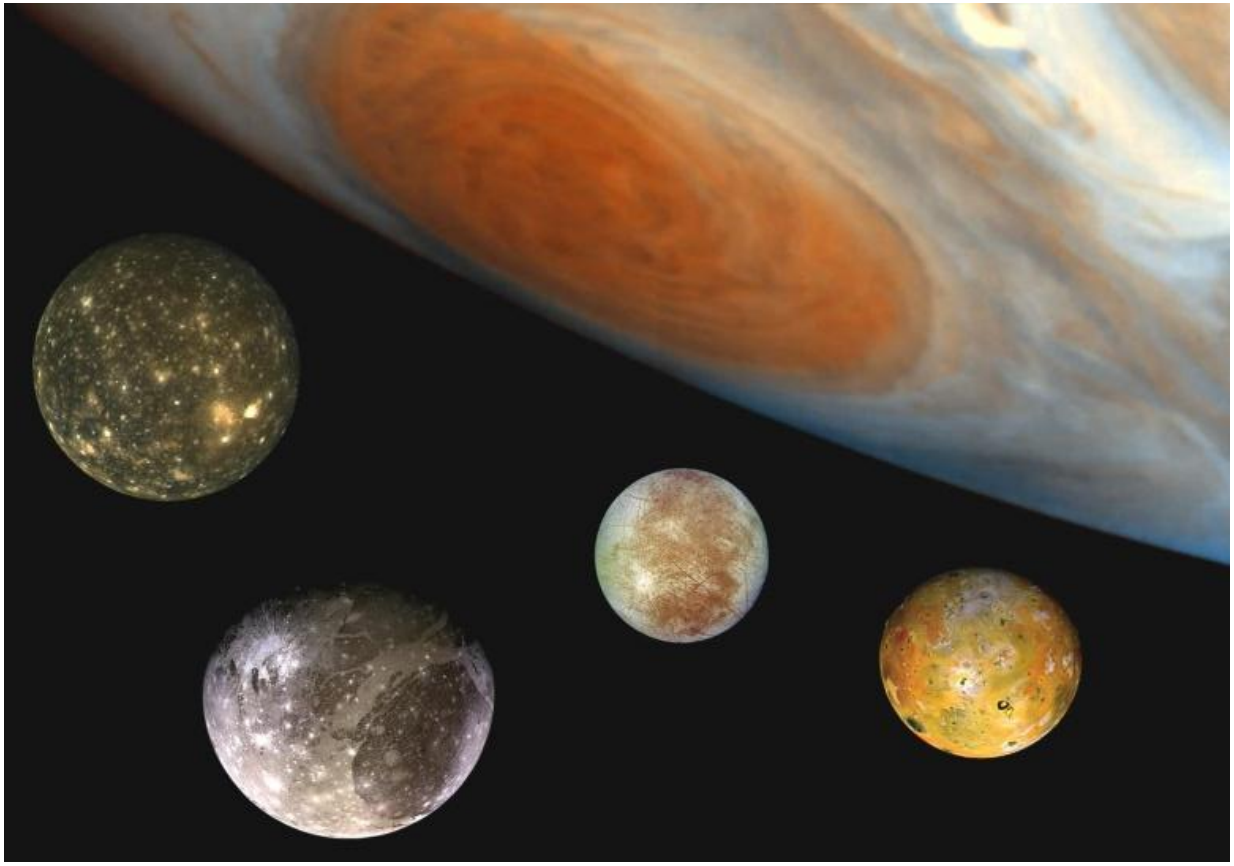
Example of the Mars system

Estimation of Phobos tidal acceleration over time (Jacobson 2010):

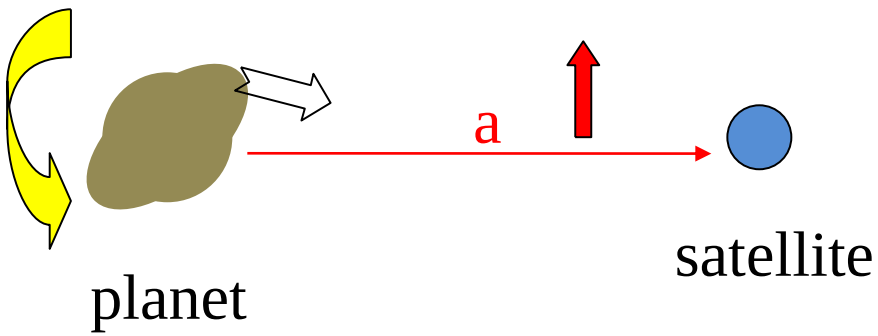
Reference	$s \times 10^{-3}$ (deg yr^{-2})	κ_2	Q	γ (deg)
Sharpless (1945)	1.882 ± 0.171			
Shor (1975)	1.427 ± 0.147			
Sinclair (1978)	1.326 ± 0.118			
Jacobson et al. (1989)	1.249 ± 0.018			
Chapront-Touzé (1990)	1.270 ± 0.008			
Emelyanov et al. (1993)	1.290 ± 0.010			
Bills et al. (2005)	1.367 ± 0.006	0.163	85.6 ± 0.4	$0.^{\circ}3346 \pm 0.^{\circ}0014$
Rainey & Aharonson (2006)	1.334 ± 0.006	0.153	78.6 ± 0.8	$0.^{\circ}3645 \pm 0.^{\circ}0039$
Lainey et al. (2007)	1.270 ± 0.015	0.152	79.9 ± 0.7	$0.^{\circ}3585 \pm 0.^{\circ}0031$
Current (**Jacobson 2010**)	1.270 ± 0.003	0.152	82.8 ± 0.2	$0.^{\circ}3458 \pm 0.^{\circ}0009$

Pretty good agreement since decades!

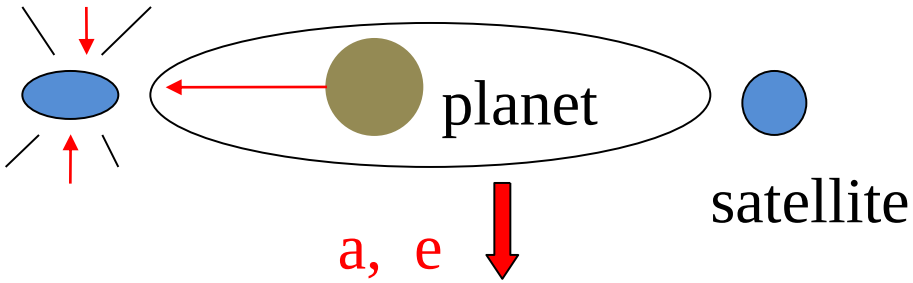
Example of the Jovian system



Competition between tidal dissipation effects

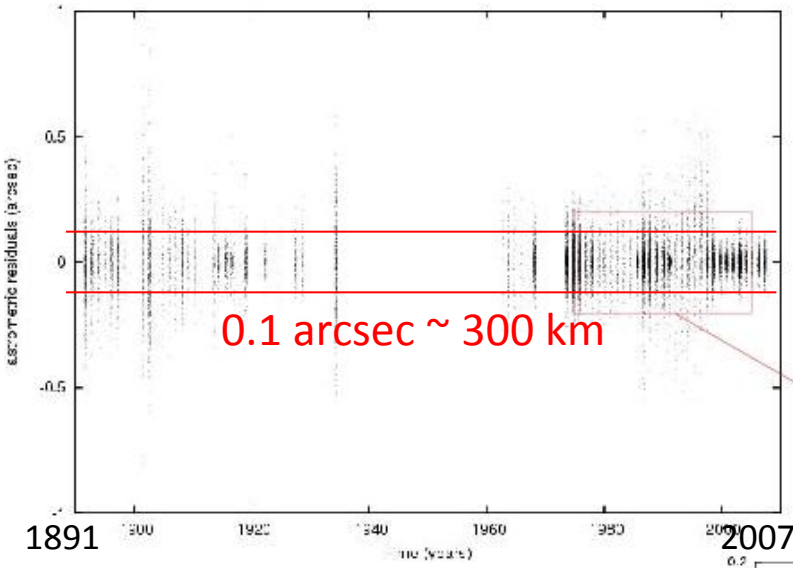


Secular deceleration on the mean motion



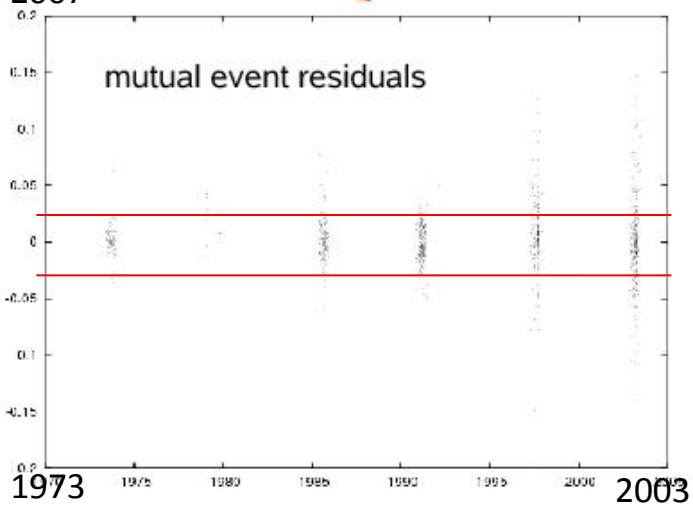
Secular acceleration on the mean motion

Example of the Jovian system



0.1 arcsec ~ 300 km

→Residuals after fitting the initial state vectors of all the Galilean moons and the ratios k_2/Q inside Io and Jupiter



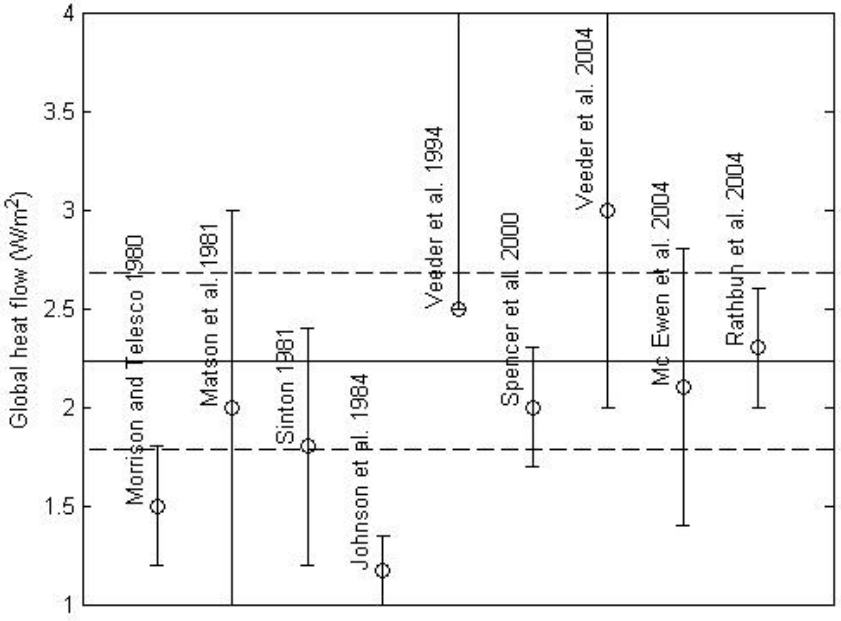
0.025 arcsec ~ 75 km

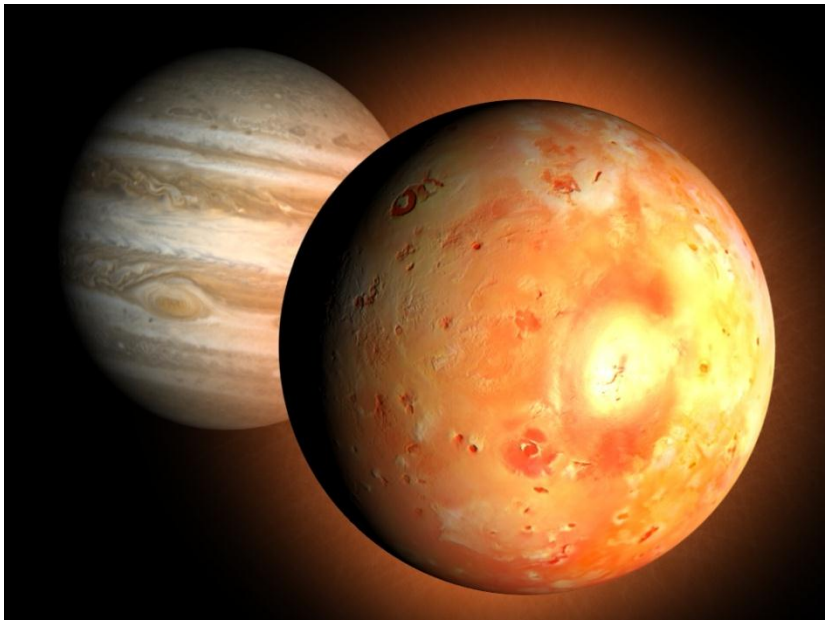
Lainey, Arlot, Karatekin, Van Hoolst (Nature, 2009)

Example of the Jovian system

Our fit of Io's dissipation provides $k_2/Q = 0.015 \pm 0.003$

One can compare our value with the ones derived from IR emission





We obtained a very good agreement and confirm the values derived from heat flux observations!

Example of the Jovian system

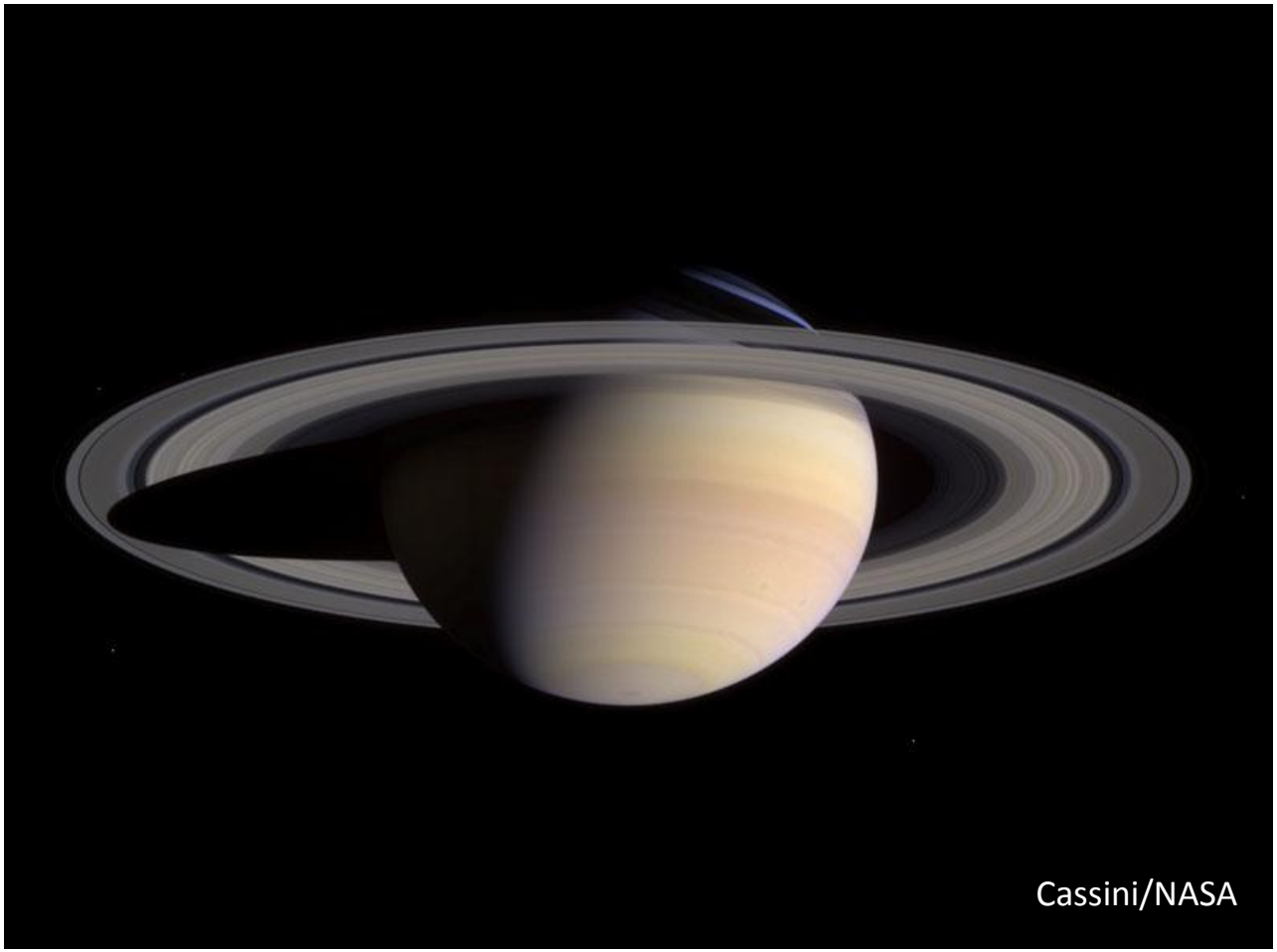
Our value of the Jovian dissipation is Q=35600 ± 6600 assuming k_2=0.379

The estimation from (Goldreich and Soter (1966), Gavrilov and Zharkov (1977))

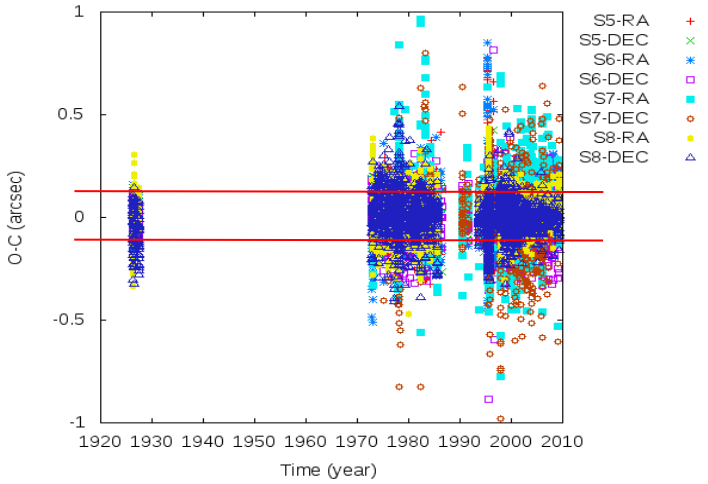
$$2.5\ 10^4 < Q_{jupiter} < 2.5\ 10^5$$

Our estimation gets a much smaller error bar AND it is derived from observations

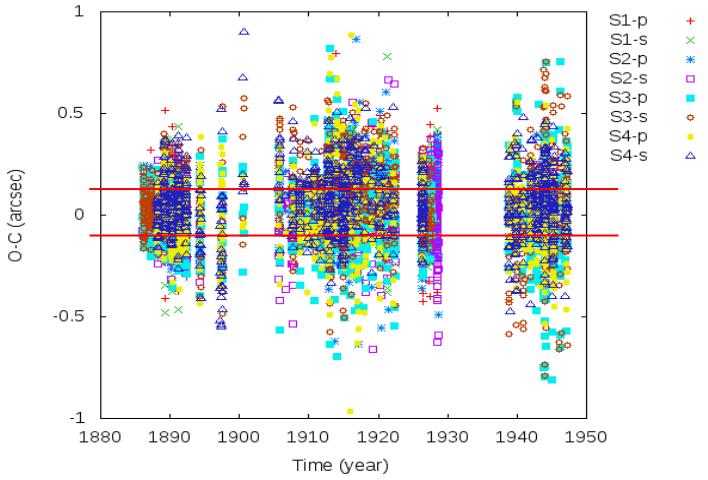
Example of the Saturnian system



Example of the Saturnian system



0.1 arcsec ~ 600 km



→Residuals after fitting the initial state vectors of all the eight main Saturn moons, the ratio k_2/Q inside Saturn and a constant drift da/dt.

Observation subset:	ν_x	σ_x	ν_y	σ_y	N_x, N_y
All Observations:					
S1	0.0140	0.1027	0.0131	0.1152	1285, 1298
S2	-0.0032	0.0988	0.0048	0.1069	2640, 2643
S3	0.0157	0.1130	-0.0003	0.1152	4702, 4700
S4	0.0150	0.1045	0.0023	0.1096	3775, 3776
S5	0.0113	0.1088	0.0030	0.1151	4471, 4489
S6	0.0238	0.0937	-0.0049	0.1084	2842, 2836
S7	0.0017	0.3275	0.1068	0.4838	138, 113
S8	0.0179	0.0766	0.0076	0.1246	1098, 1101

Observation subset:	$\nu_{\alpha\cos(\delta)}$	$\sigma_{\alpha\cos(\delta)}$	ν_δ	σ_δ	N_α, N_δ
All observations					
S1	-0.0057	0.0952	-0.0108	0.0725	371, 371
S2	0.0019	0.1040	0.0028	0.1101	822, 822
S3	-0.0199	0.1267	0.0122	0.1067	1972, 1972
S4	0.0020	0.1066	0.0113	0.1067	2271, 2271
S5	0.0047	0.0899	-0.0023	0.0863	2977, 2977
S6	0.0121	0.1060	-0.0171	0.1070	3271, 3271
S7	0.1098	0.2984	0.0036	0.2166	973, 973
S8	0.0140	0.1143	-0.0052	0.1155	2008, 2008

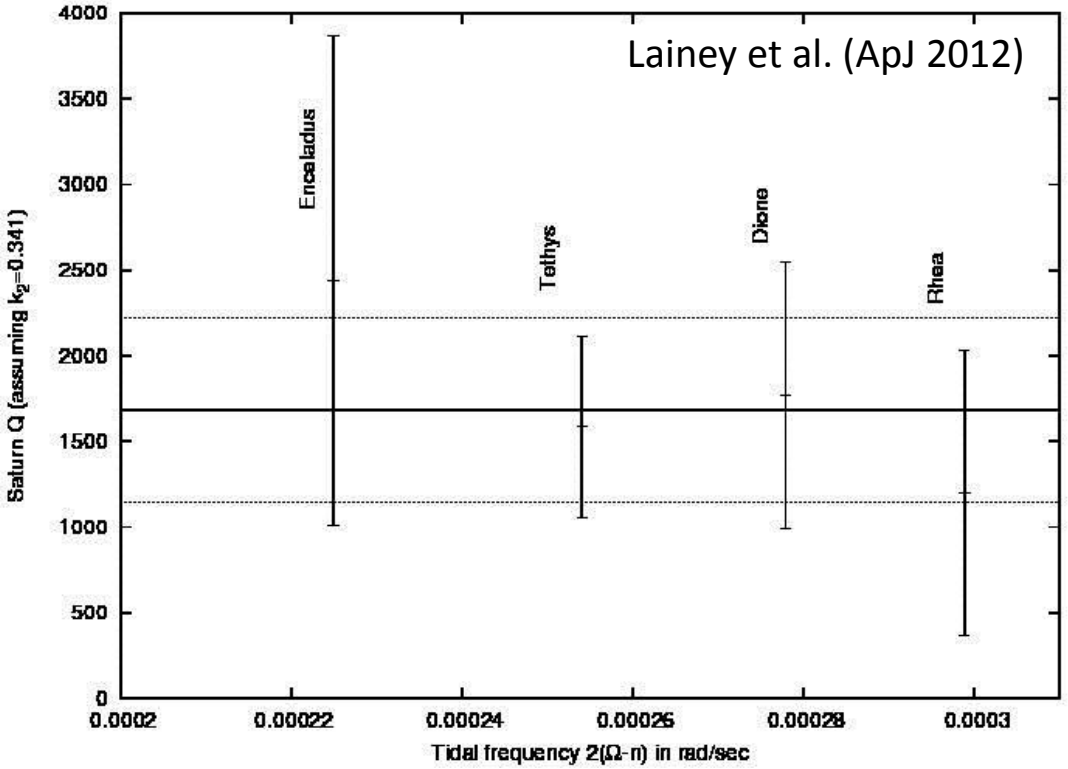
Lainey et al. (*ApJ, 2012*)

$k_2/Q = (2.3 \pm 0.7) \times 10^{-4}$;

$da/dt = -(15.3 \pm 4.0) \times 10^{-15}$ au/day.

Example of the Saturnian system

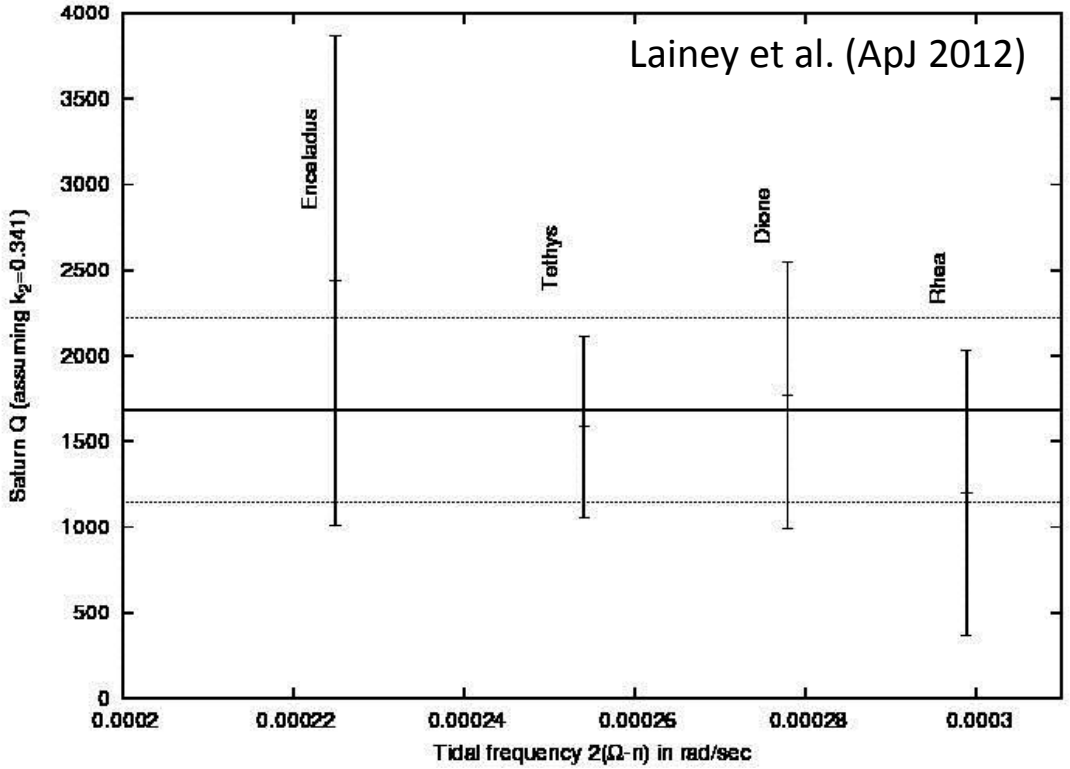
What if we release as free parameters one k_2/Q ratio per tide raising satellite…?



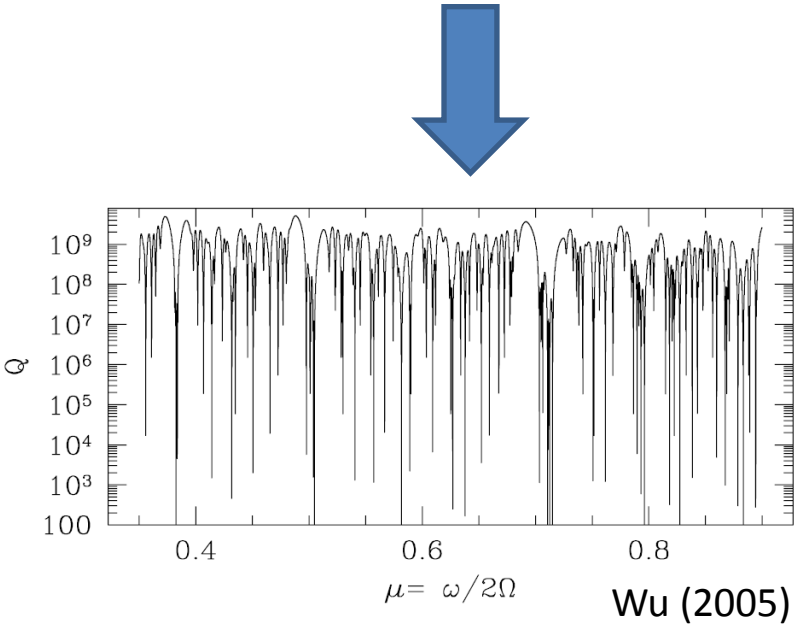
Tidal dissipation seems to be a smooth function of tidal frequency.

Example of the Saturnian system

What if we release as free parameters one k_2/Q ratio per tide raising satellite…?



Comparison with recent hydrodynamical code

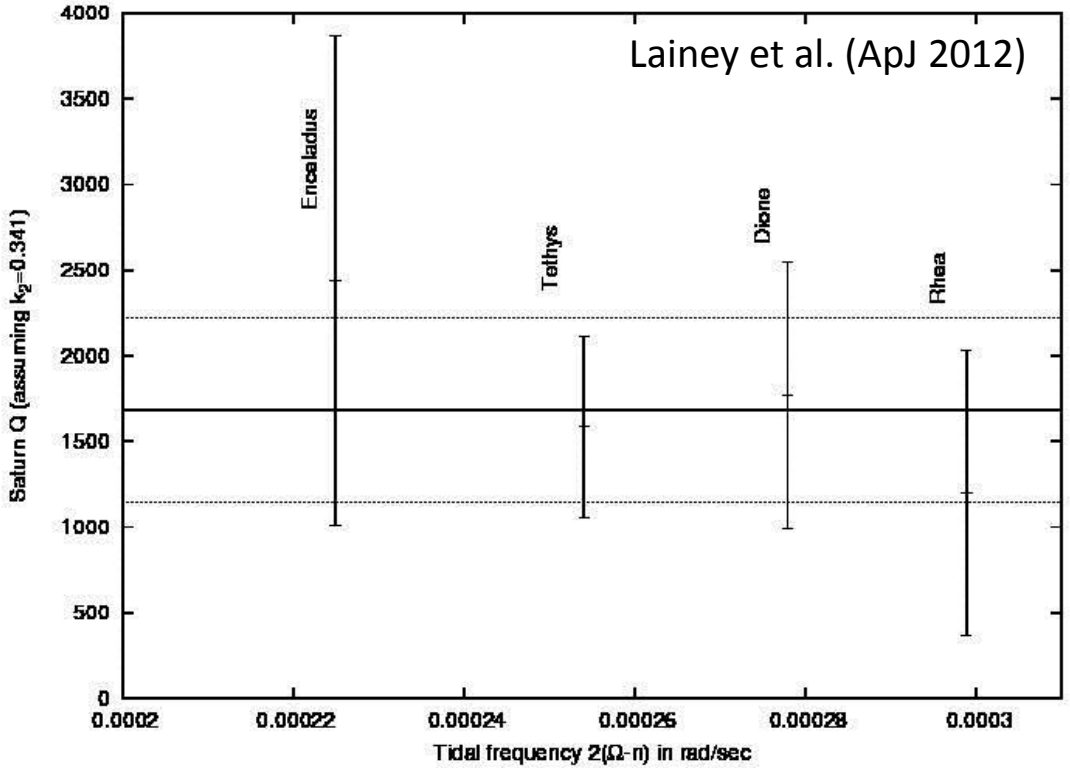


Wu (2005)

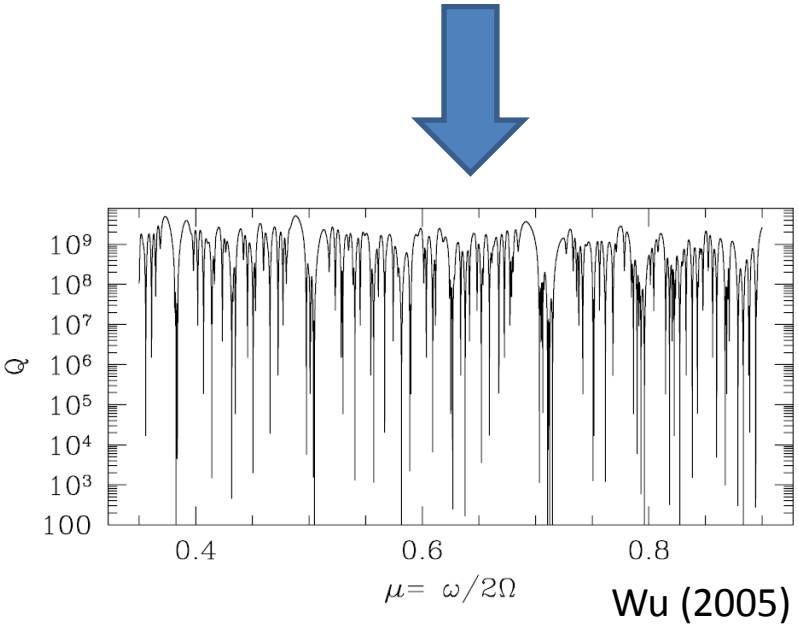
Tidal dissipation seems to be a smooth function of tidal frequency.

Example of the Saturnian system

What if we release as free parameters one k_2/Q ratio per tide raising satellite…?



Comparison with recent hydrodynamical code



Wu (2005)

Tidal dissipation seems to be a smooth function of tidal frequency.

Hence, such strong dissipation **cannot** come from the atmosphere.

→Strong tidal dissipation may arise in the icy core!!

I had a dream…

Let’s make the dream come true