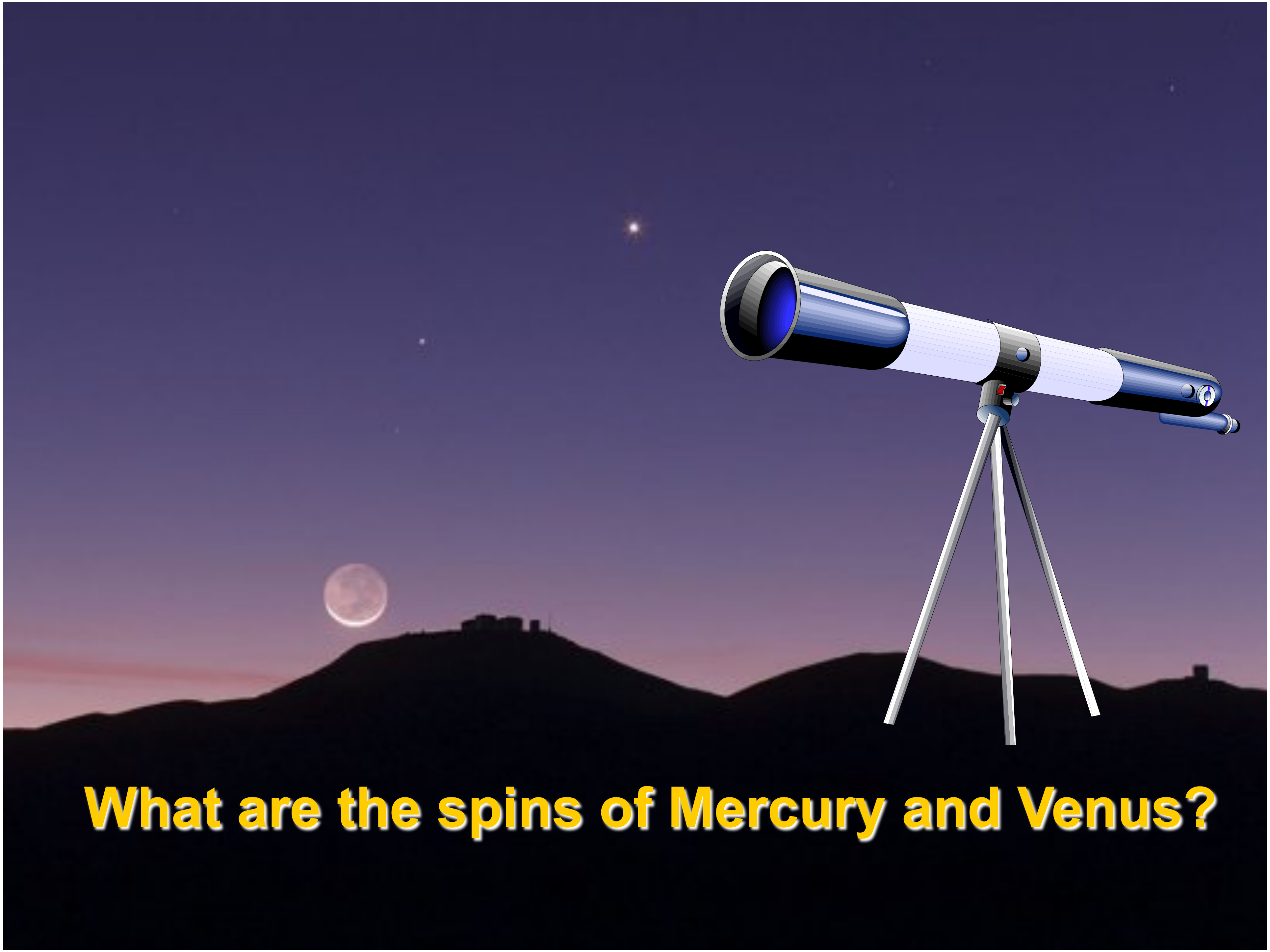
"Long-term spin evolution of Mercury and Venus"

Alexandre C. M. Correia

(Univ. Aveiro / IMCCE)

International Workshop in Astronomy and Dynamics,

29 avril 2015

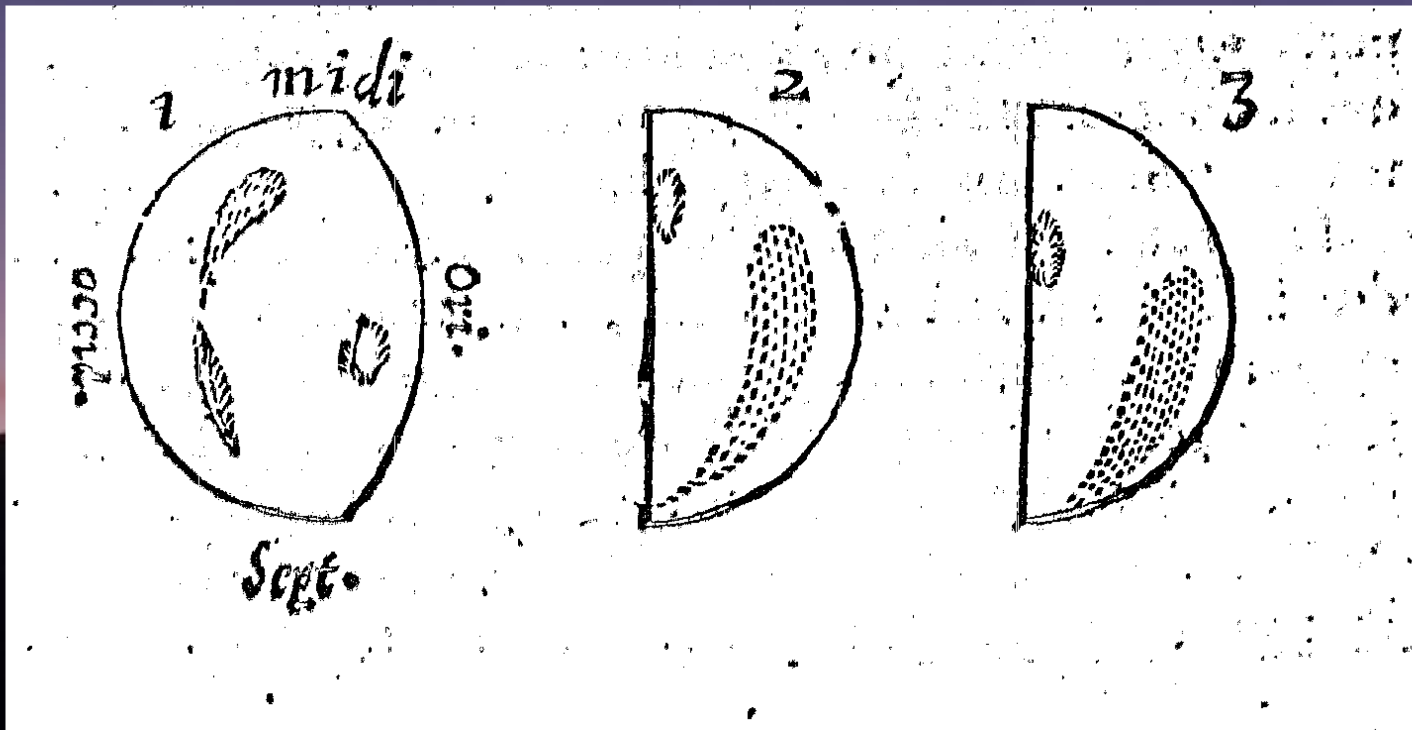

What are the spins of Mercury and Venus?

Venus:

- Jean-Dominique Cassini (1625-1712)

  1667: less than 24^h (~ $23^h 45^m$)

"Mais jusqu'au 28 jour d'Avril [Jacques' birthday], je ne pus remarquer aucune partie luisante semblable à celle que j'avais déjà vue, mais ce jour là, un quart d'heure avant le lever du Soleil, je commençais à revoir sur le disque de cette Planète, dont la moitié ou environ paraissait pour lors éclairée, une partie luisante située auprès de la section"



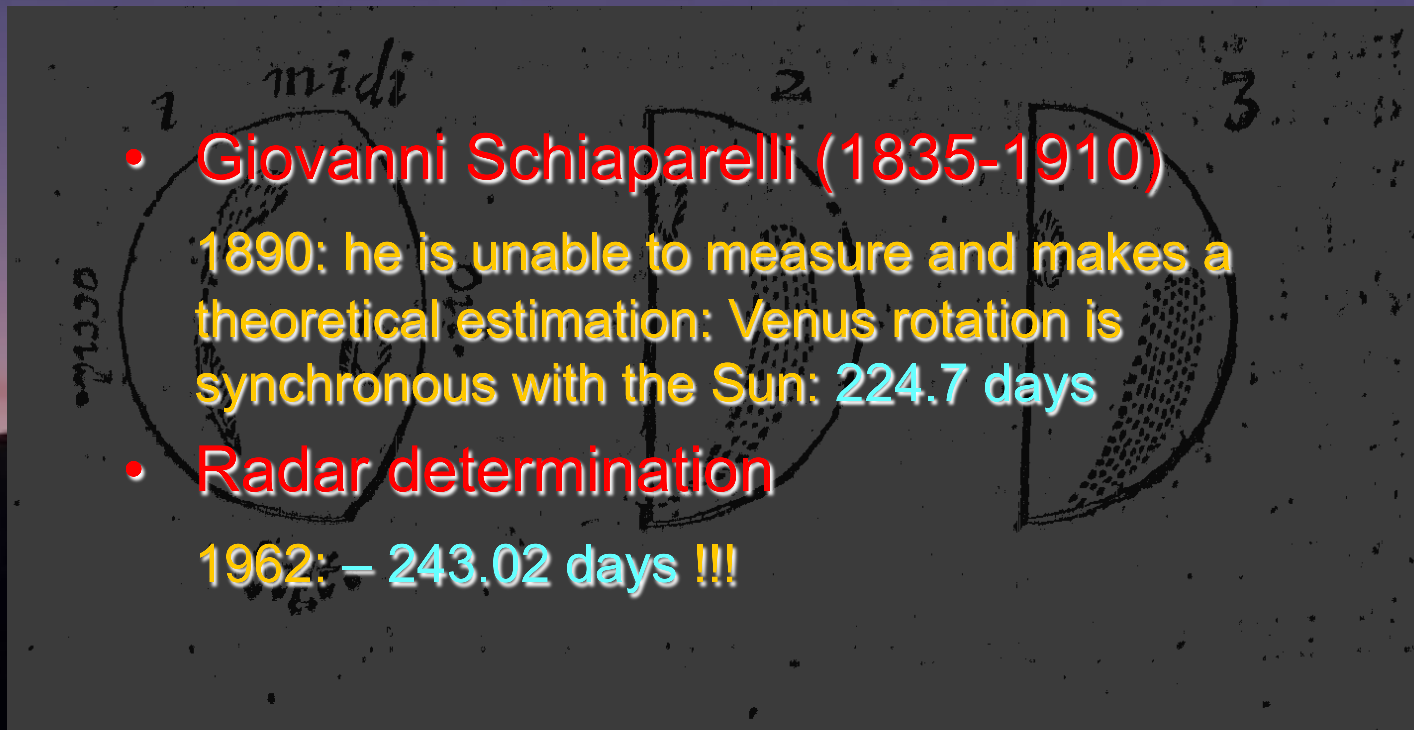
Venus:

- Jean-Dominique Cassini (1625-1712)

  1667: less than 24^h (~ 23^h45^m)

- Francesco de Vico (1805-1848)

  1841: $23^h21^m21{,}934^s$!!!



- Giovanni Schiaparelli (1835-1910)

  1890: he is unable to measure and makes a theoretical estimation: Venus rotation is synchronous with the Sun: 224.7 days

- Radar determination

  1962: – 243.02 days !!!

present data

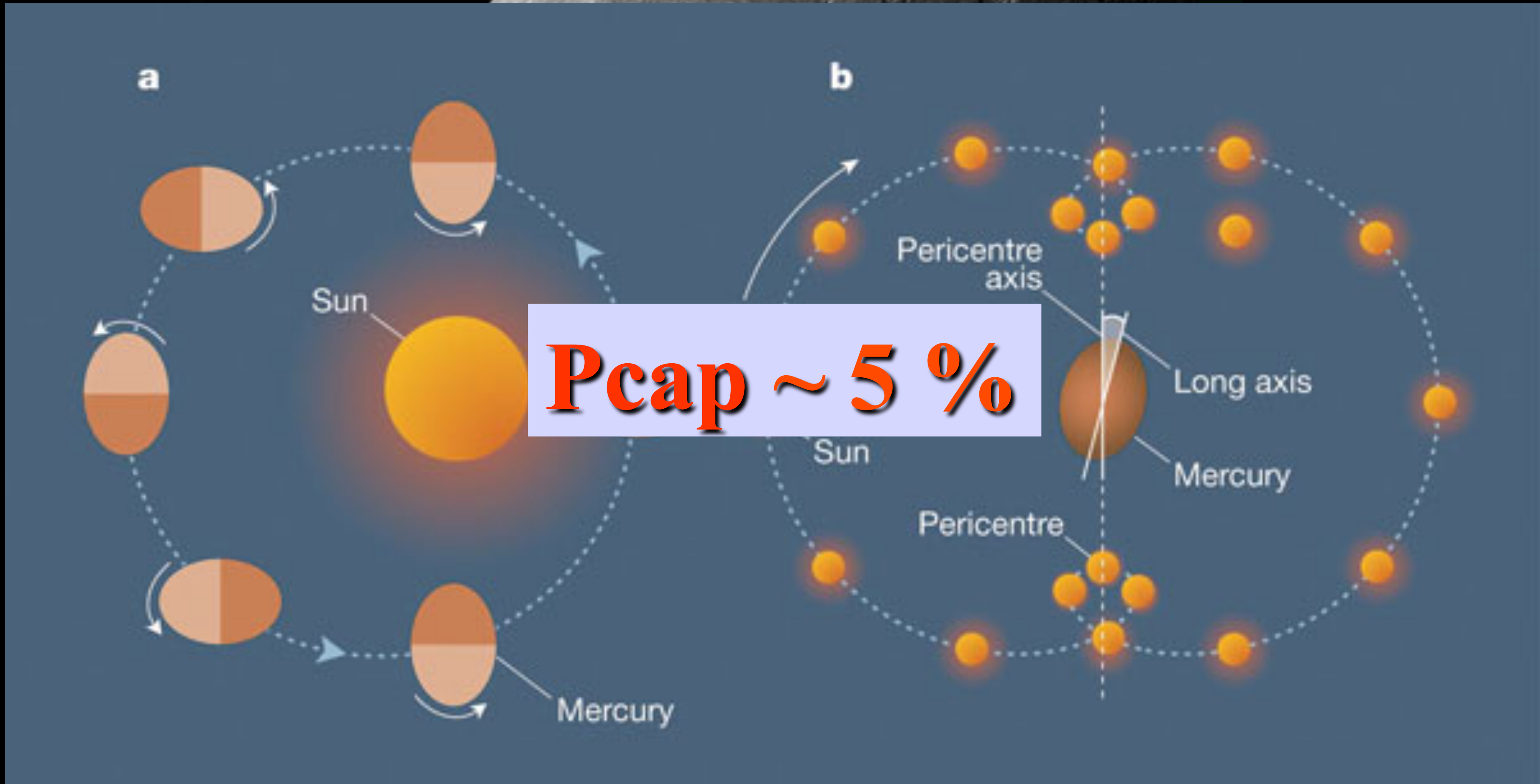
Planet	Period	Obliquity
Mercury	58 day	0,1°
Venus	−243 day	2,7°
Earth	23,93 hour	23,5°
Mars	24,62 hour	25,2°
Jupiter	9,92 hour	3,1°
Saturn	10,66 hour	26,7°
Uranus	−17,24 hour	82,1°
Neptun	16,11 hour	29,6°

Tidal effect

$P_{orb} = P_{rot}$
pependicular axis
circular orbits

Case of the Moon and
remaining satellites of
the Solar System

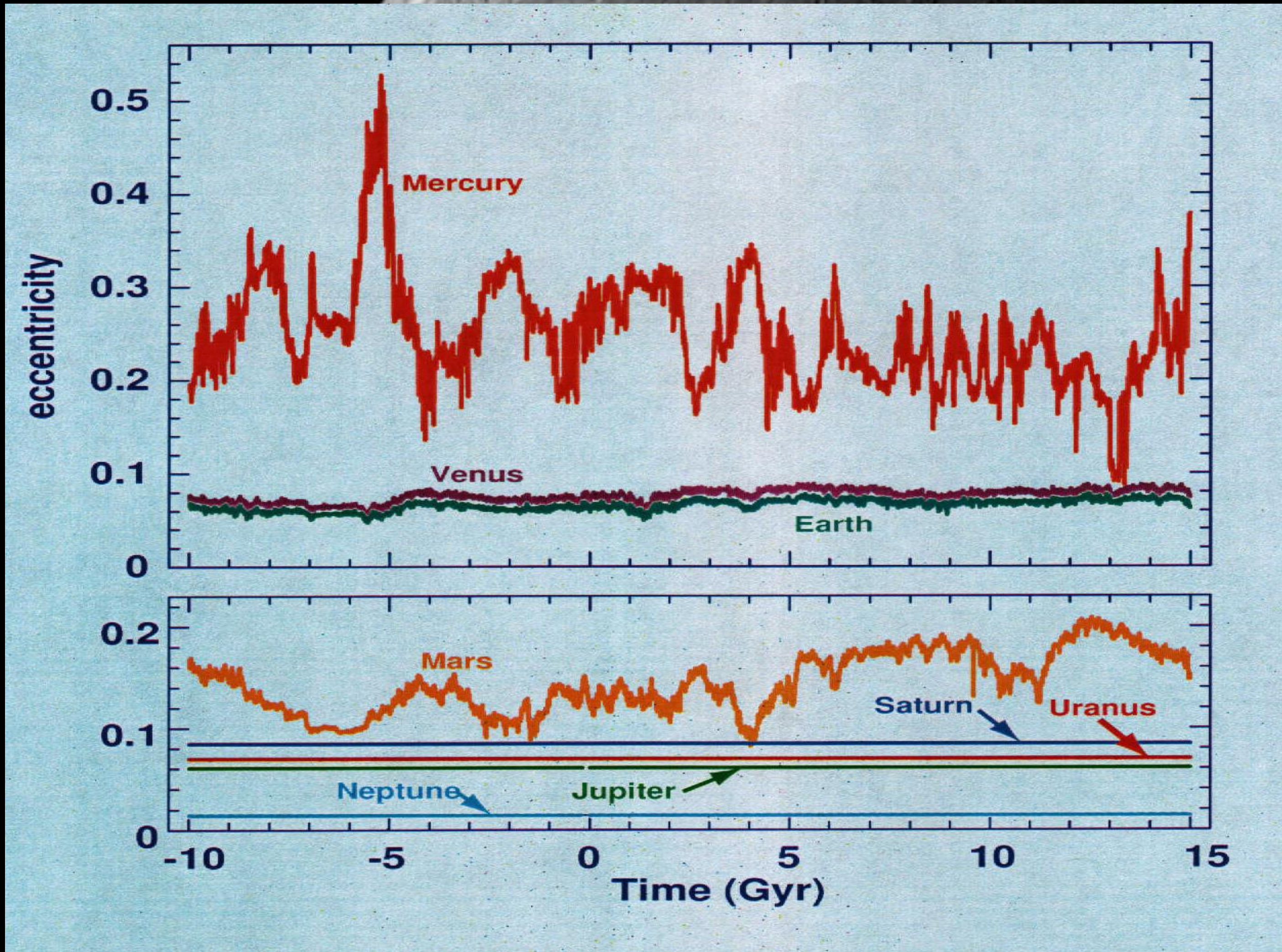
Mercury:
3/2 spin-orbit resonance



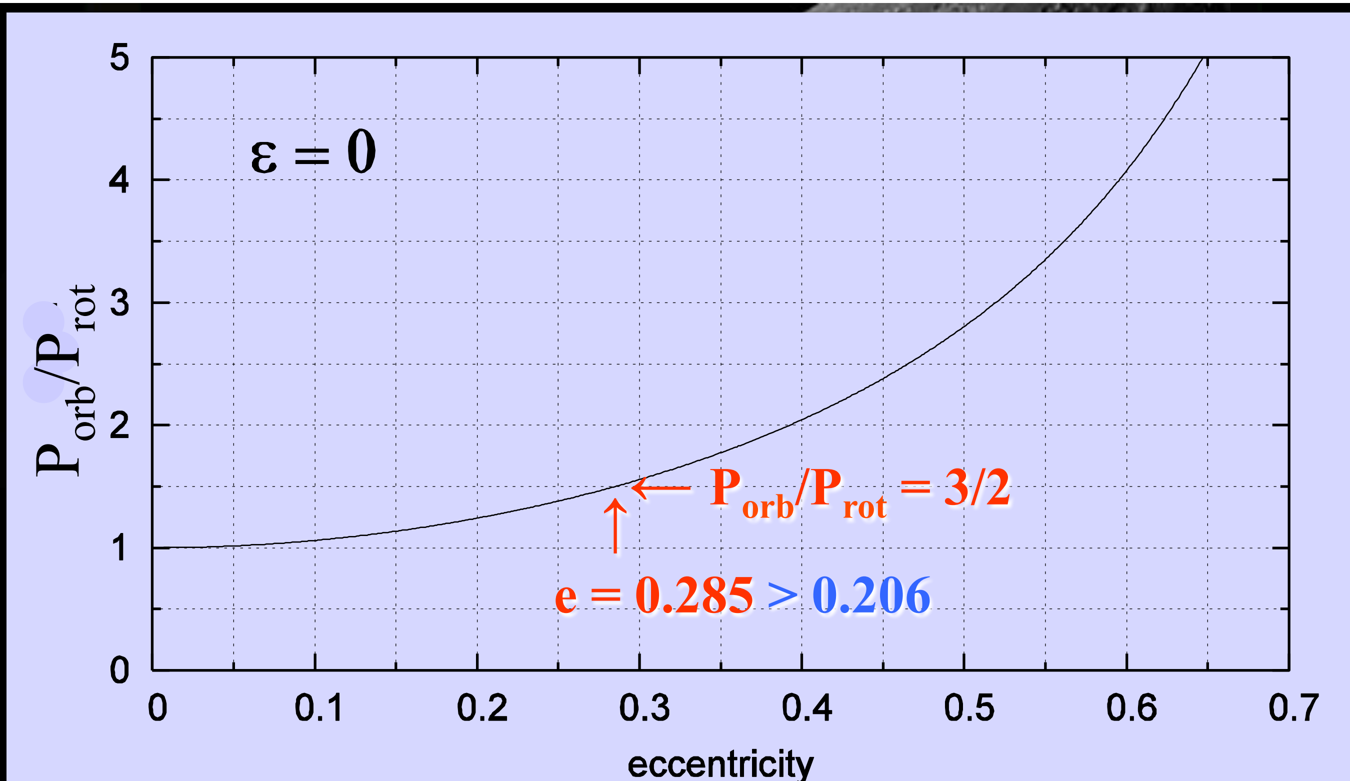
Pcap ~ 5 %

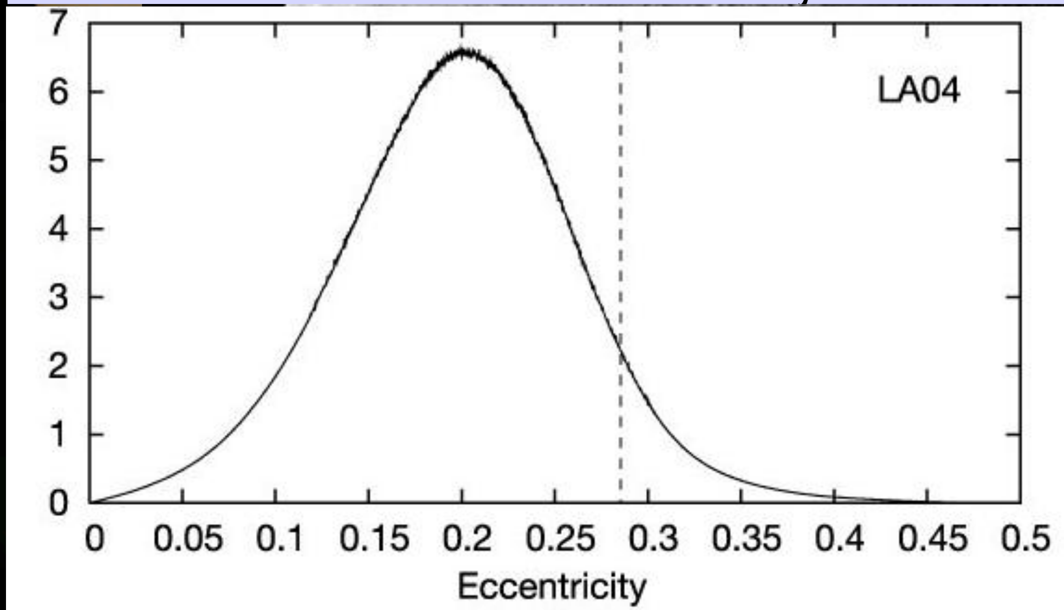
Colombo, 1965,
Goldreich & Peale, 1966

planetary perturbations

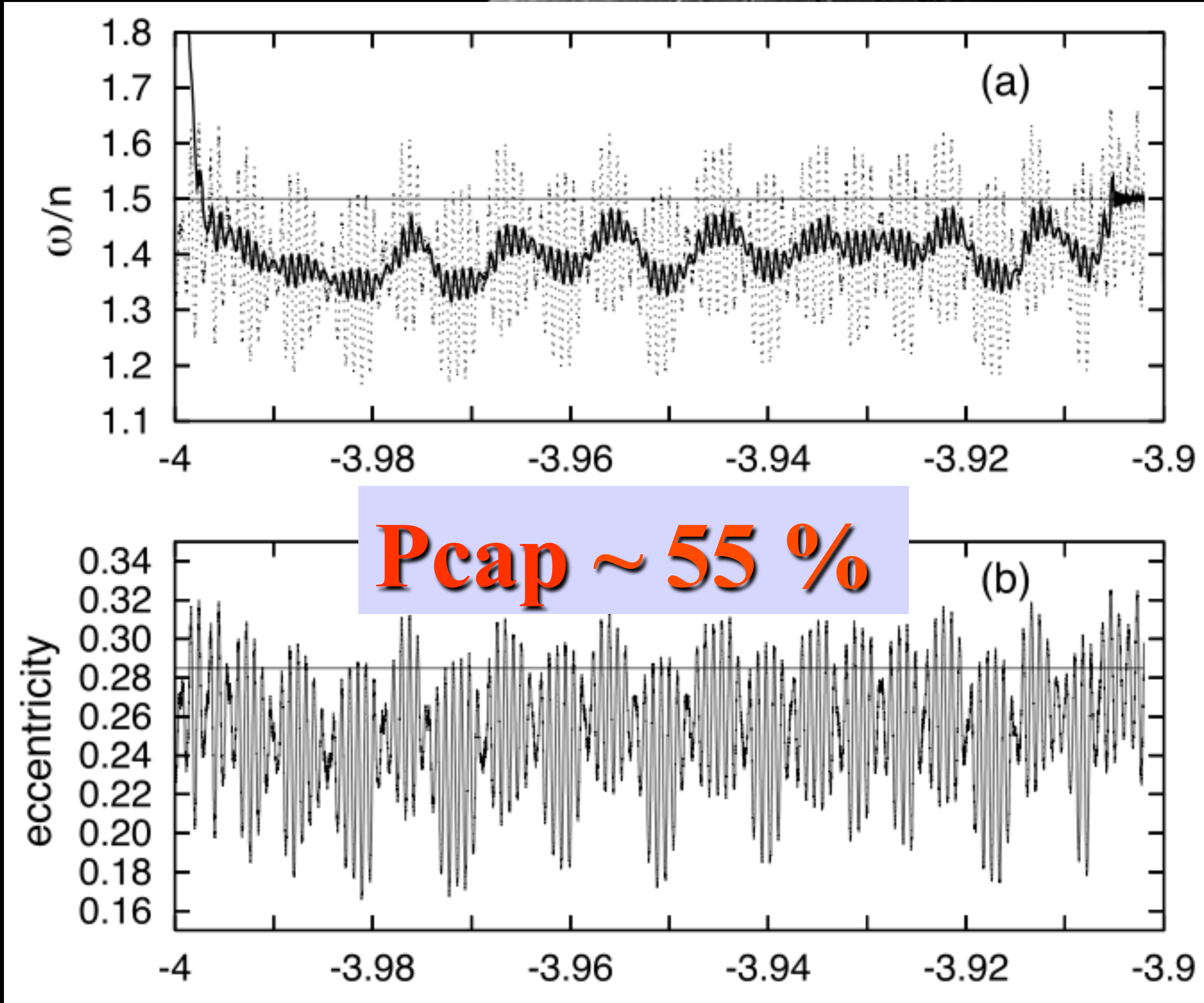


Laskar, 1994

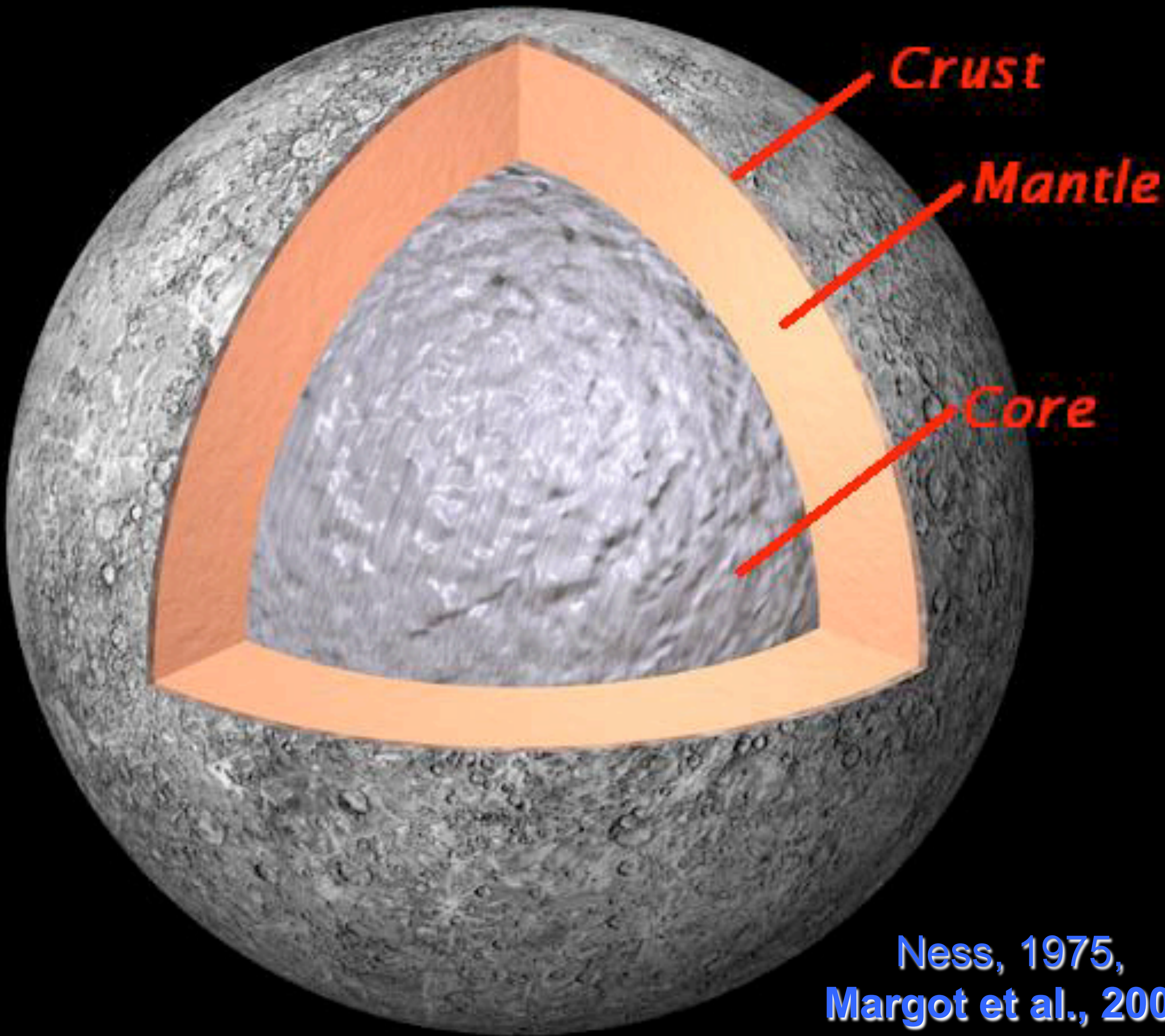




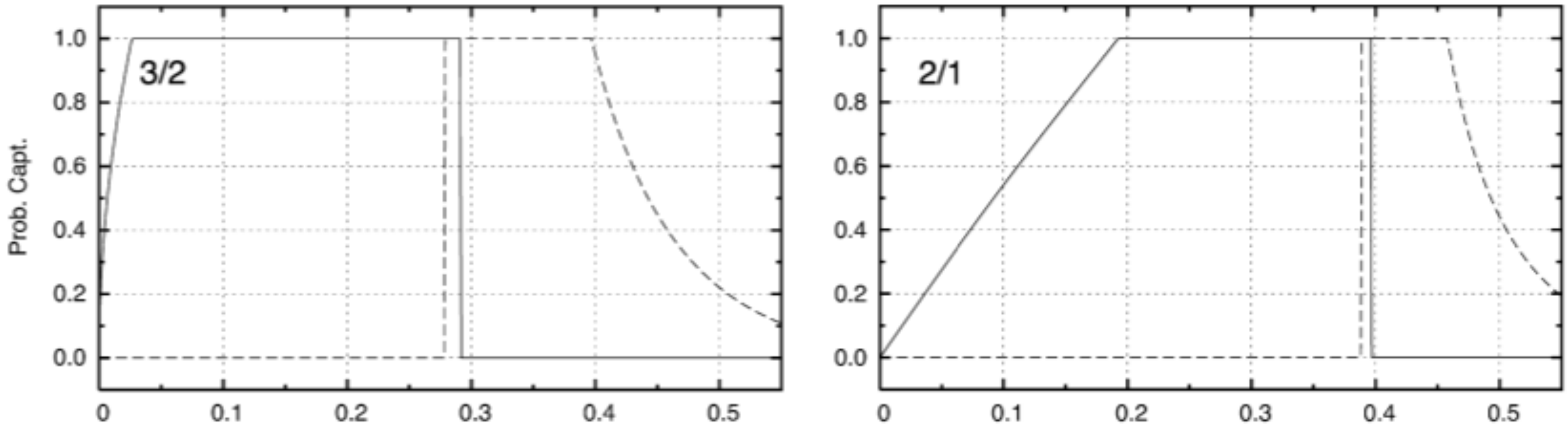
Correia & Laskar,
Nature, 2004



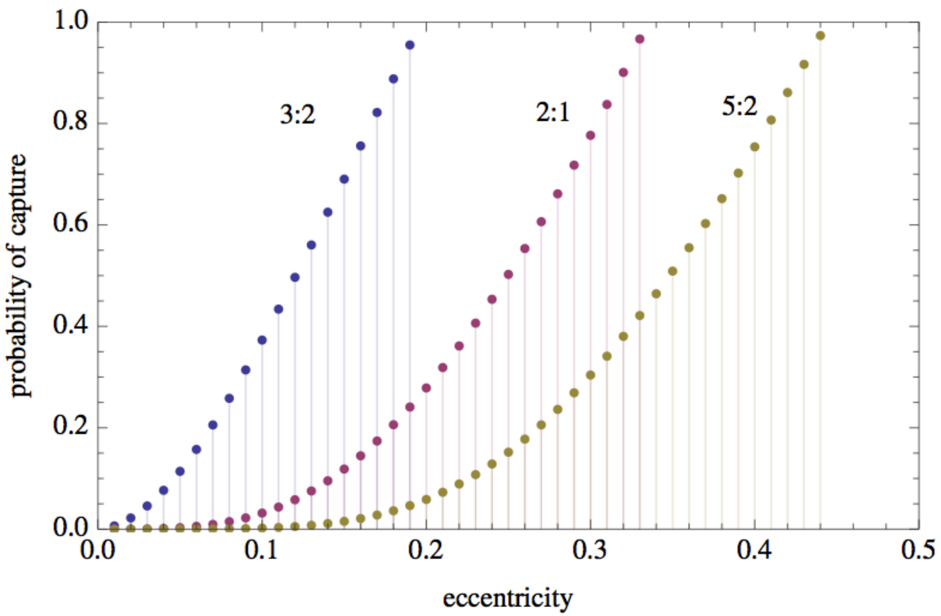
Correia & Laskar, *Nature*, (2004)



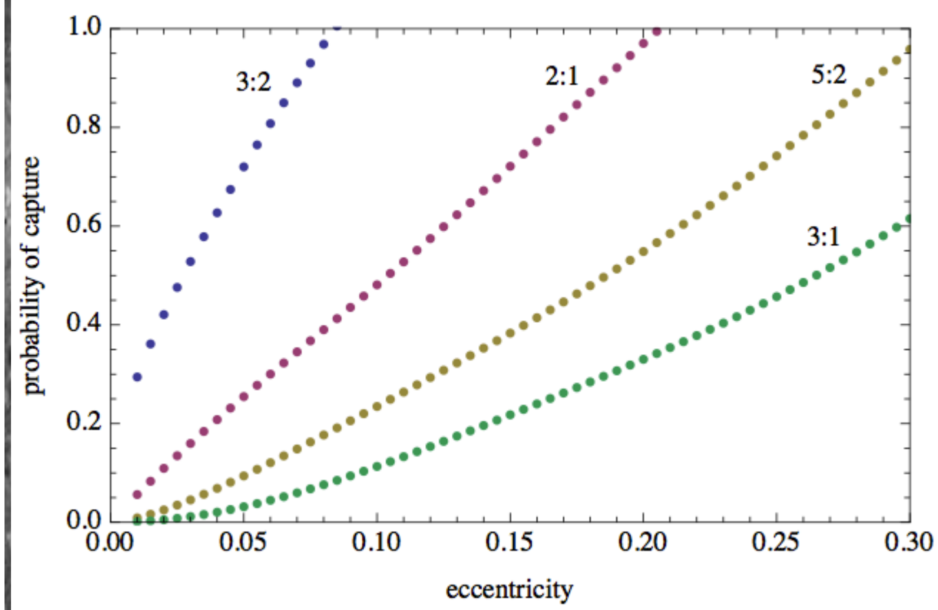
Ness, 1975,
Margot et al., 2007



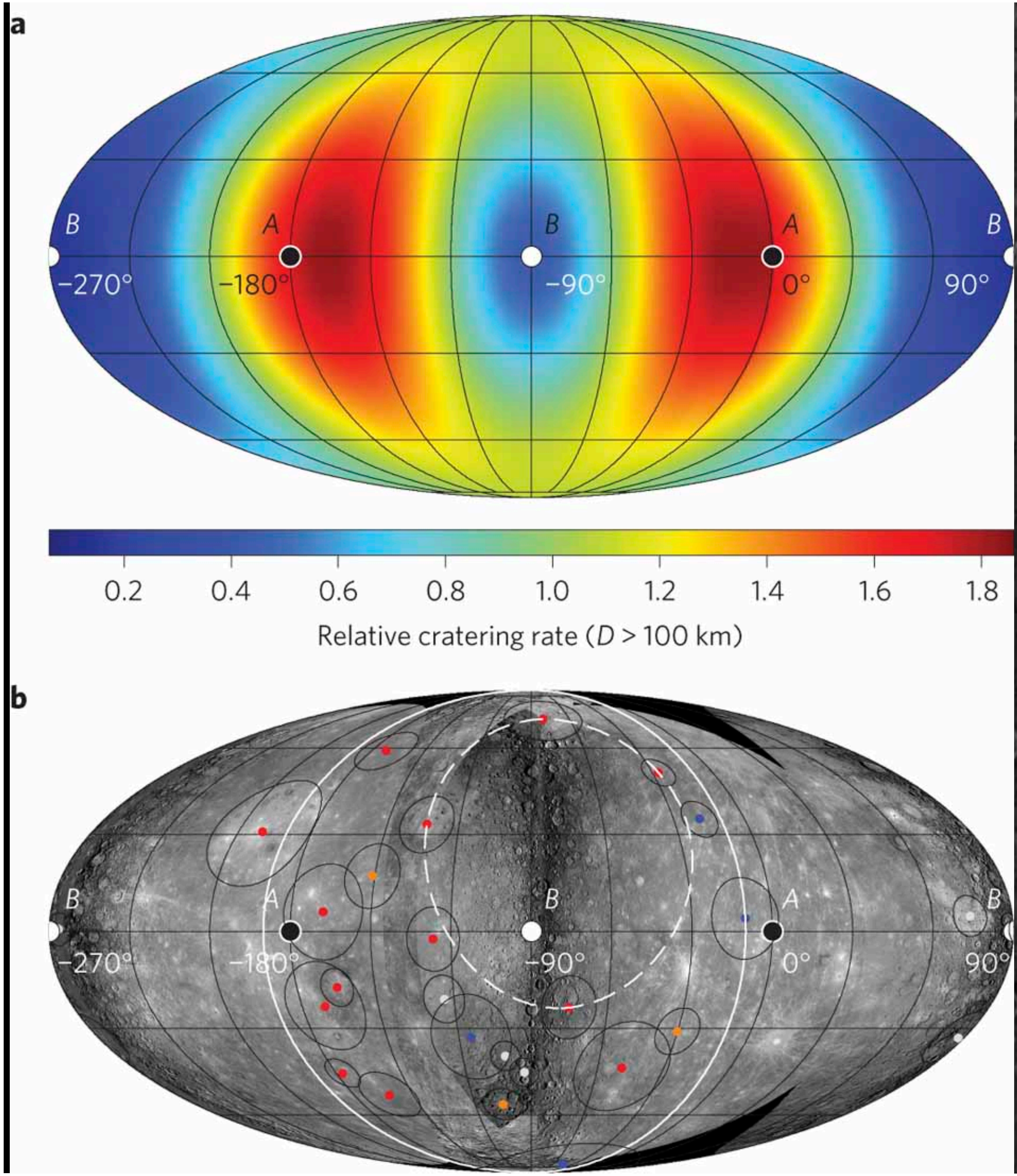
Correia & Laskar, 2009



Makarov, 2012



Noyelles et al., 2014



Was Mercury synchro-nous?

Wieczoreck,Correia, Laskar, Rambaux, ***Nature Geo*, 2012**

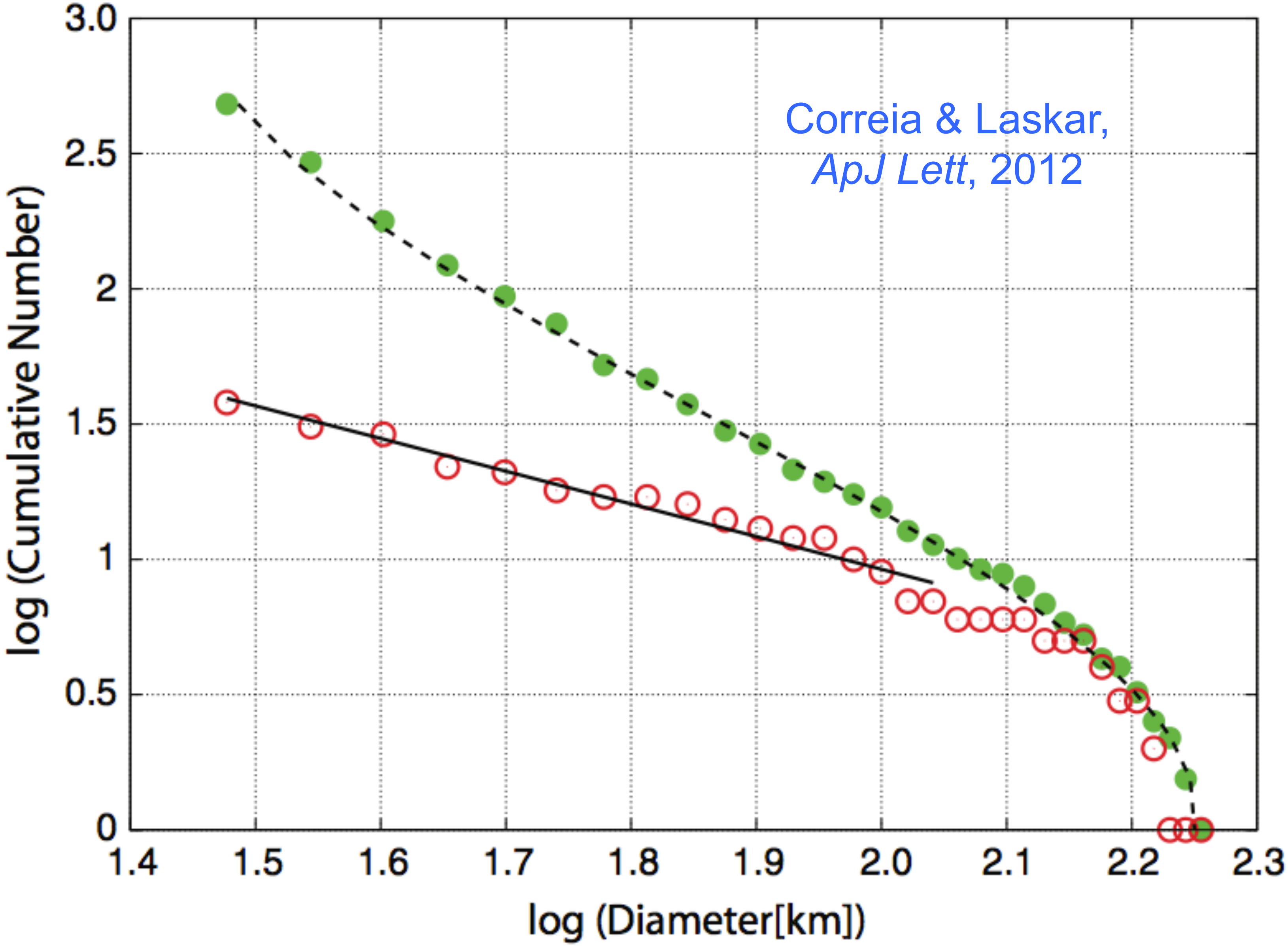
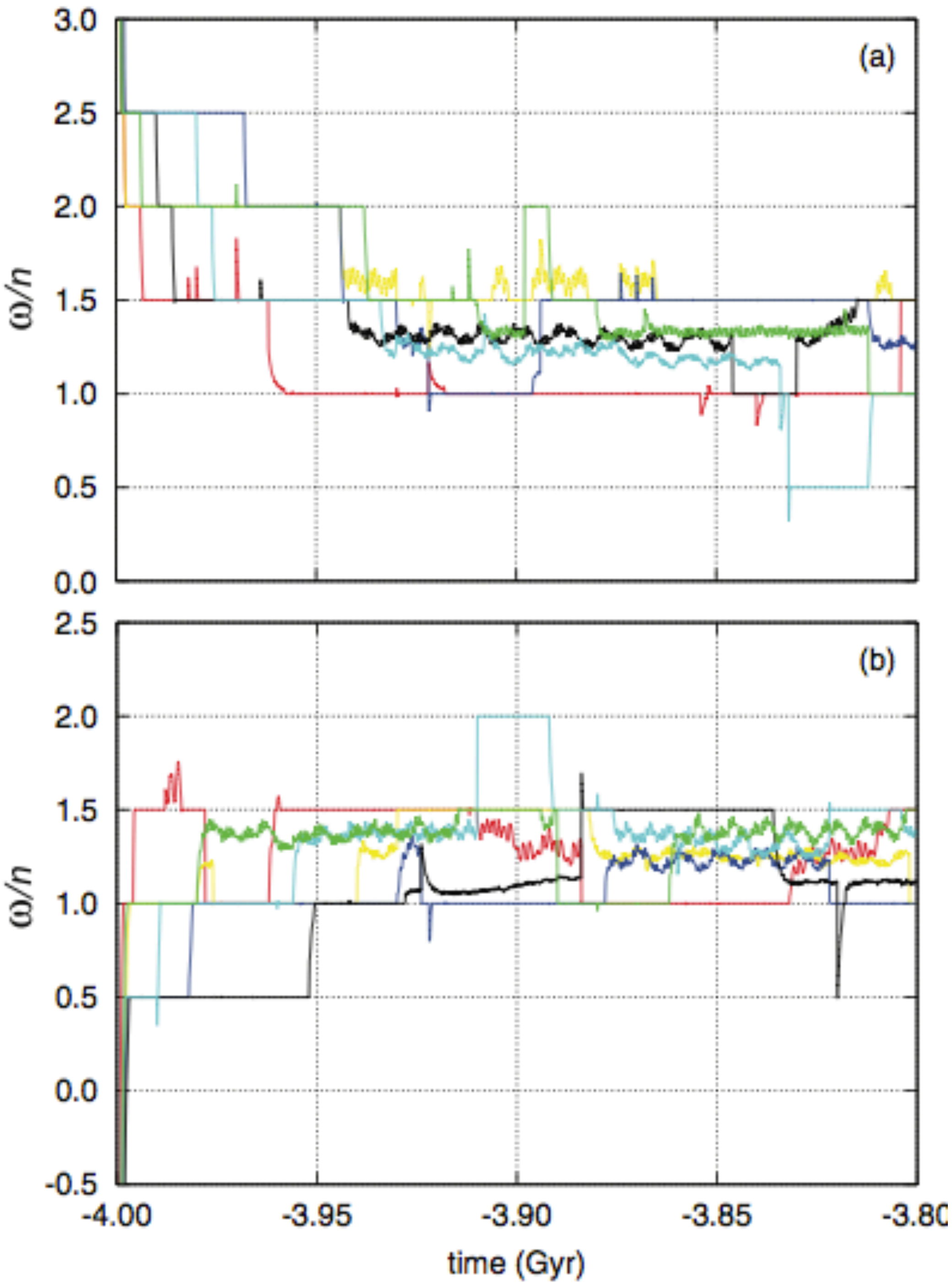
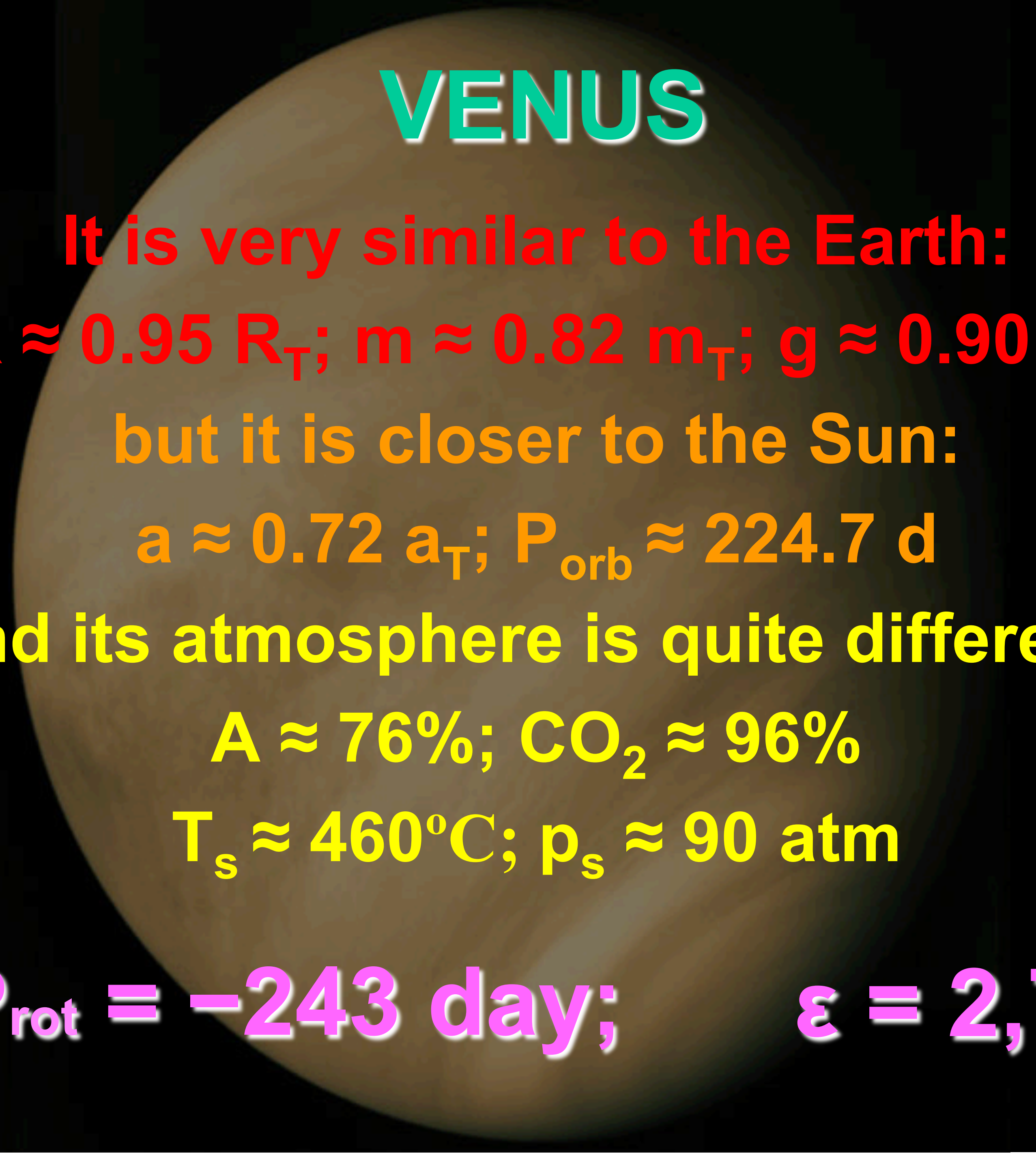


Figure 1. Cumulative number of impacts observed on Mercury's surface (IMD, red), and normalized size distribution in the asteroid-belt (ABD, green). The diameter of the bodies is binned in classes of 5 km.

Table 2
Critical Eccentricity and Minimal Impactor Diameter to Destabilize Each Spin–Orbit Resonance

p	$e_{\text{crit.}}$	D (km) $e = 0.1$	D (km) $e = 0.2$
5/1	0.211334	–	–
9/2	0.174269	–	14.9
4/1	0.135506	–	17.9
7/2	0.095959	12.2	21.4
3/1	0.057675	16.3	25.5
5/2	0.024877	21.5	30.0
2/1	0.004602	27.9	34.8
3/2	0.000026	35.4	39.3
1/1	–	40.6	41.6
1/2	0.000180	25.7	28.8





VENUS

It is very similar to the Earth:

$R \approx 0.95\ R_T$; $m \approx 0.82\ m_T$; $g \approx 0.90\ g_T$

but it is closer to the Sun:

$a \approx 0.72\ a_T$; $P_{orb} \approx 224.7$ d

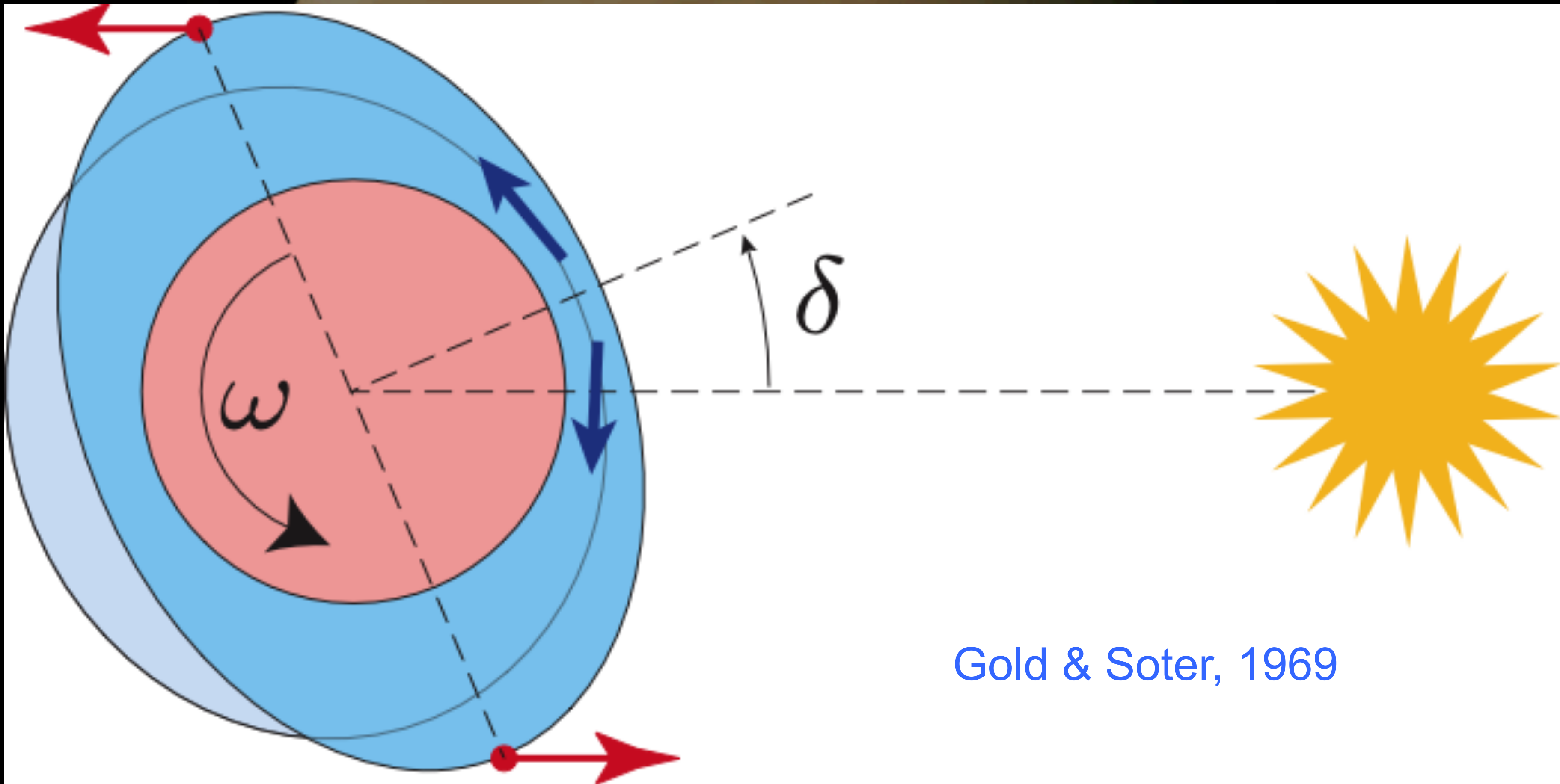
and its atmosphere is quite different:

$A \approx 76\%$; $CO_2 \approx 96\%$

$T_s \approx 460^{o}C$; $p_s \approx 90$ atm

$P_{rot} = -243$ day; $\varepsilon = 2,7°$

thermal atmospheric tides



Gold & Soter, 1969

Dissipative effects on Venus

effects that slowly modify the spin

Gravitational Tides (GT)

Due to differential gravitational attraction from the Sun

Atmospheric Tides (AT)

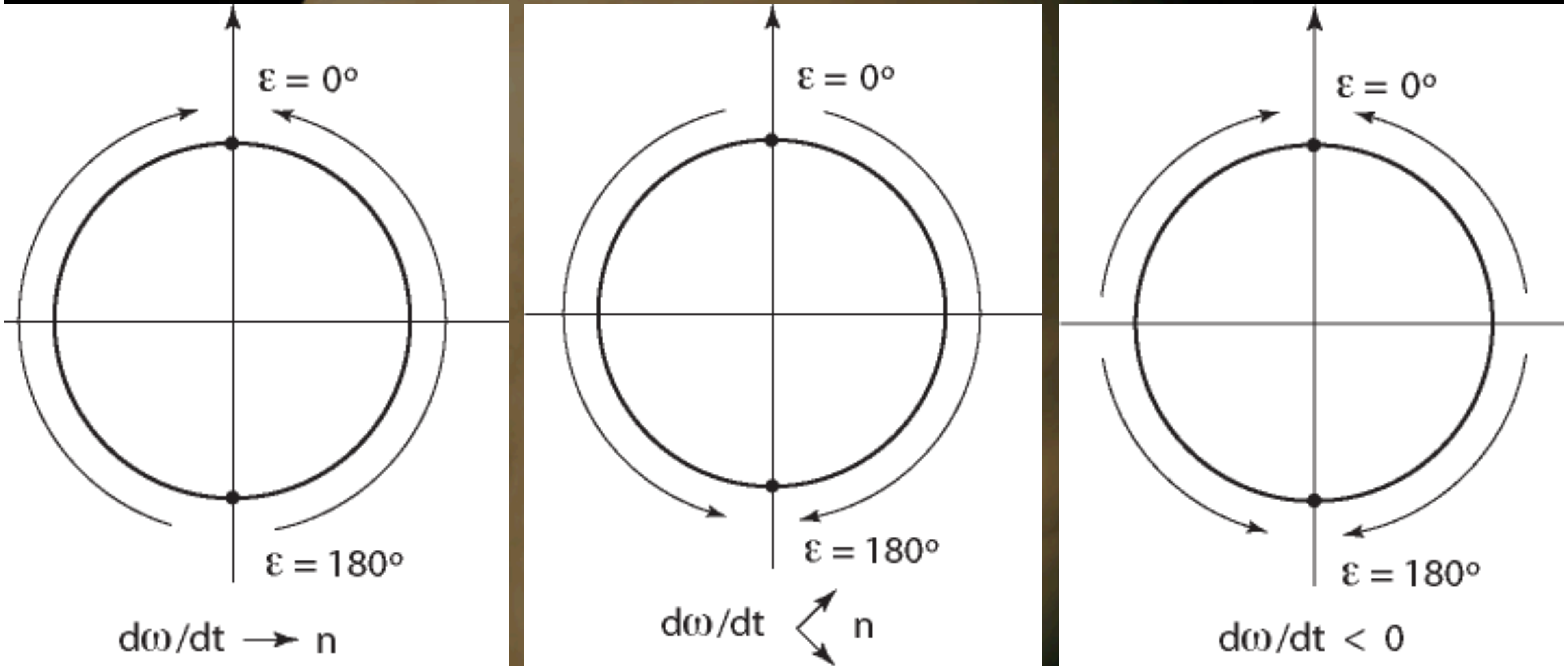
Due to differential thermal heating from the Sun

Core-Mantle Friction (CMF)

Due to differential precession rates between the core and the mantle of the planet

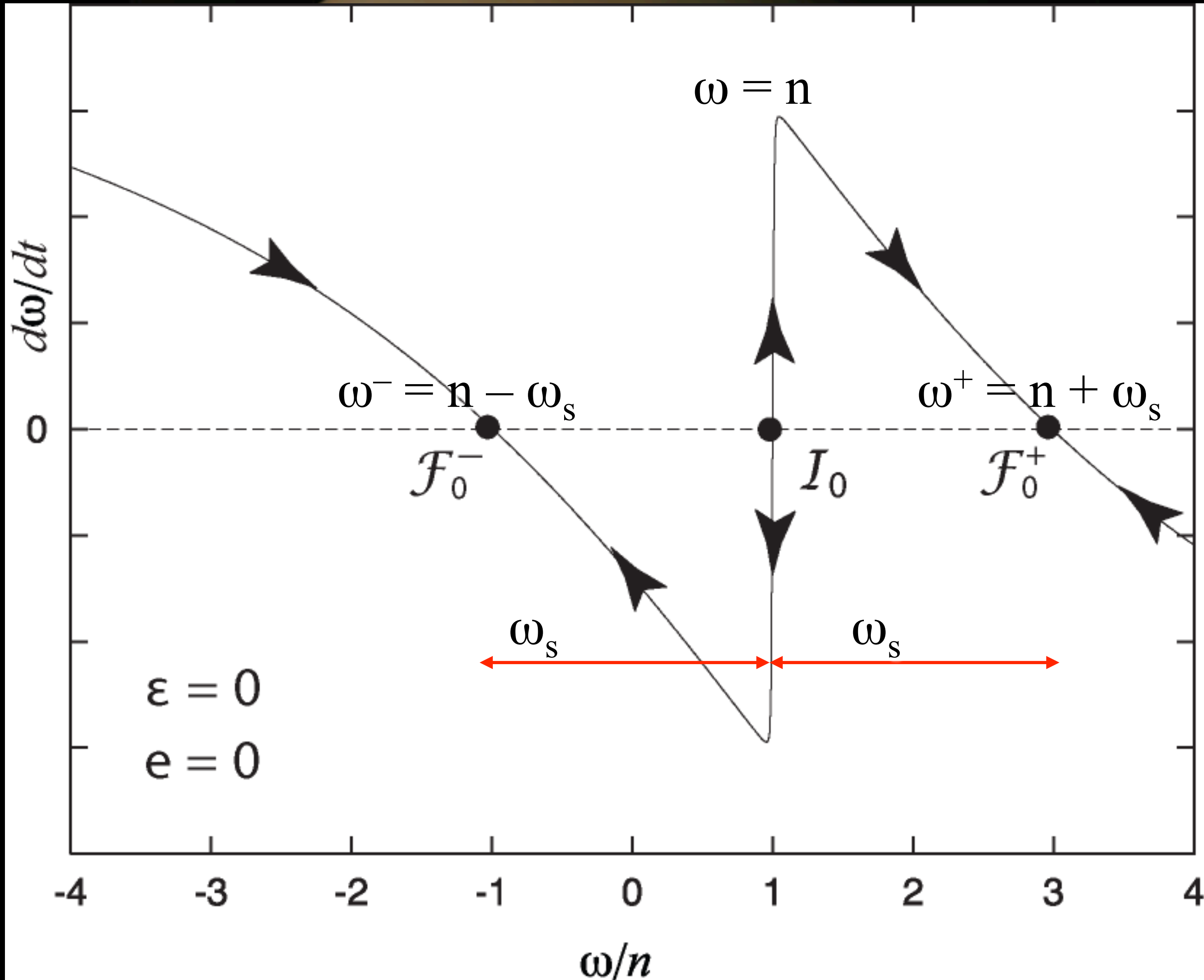
Main consequences:

The obliquity will always end at 0º or 180º



GT AT CMF

Equilibrium rotation at 0°



Correia & Laskar, 2003

The 4 final spin states of Venus

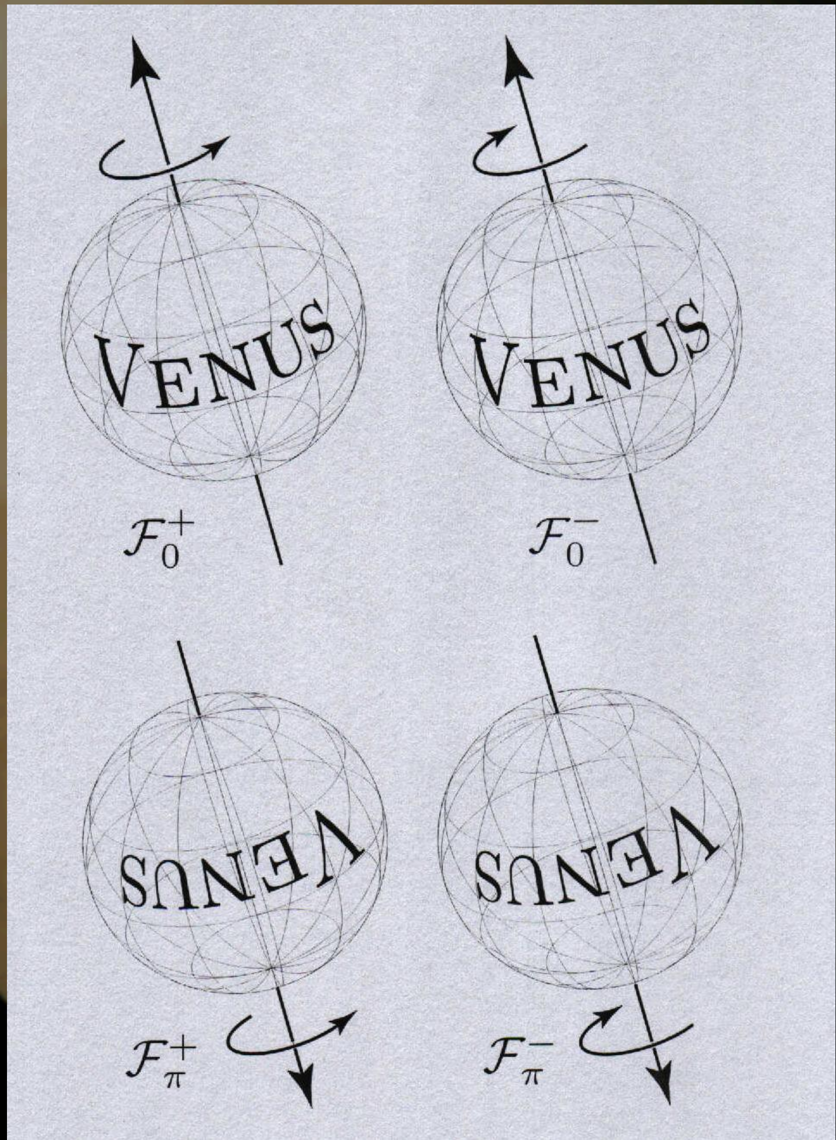
Prot = 76,8 d

ε = 0°

Direct

Prot = - 76,8 d

ε = 180°



Prot = - 243 d

ε = 0°

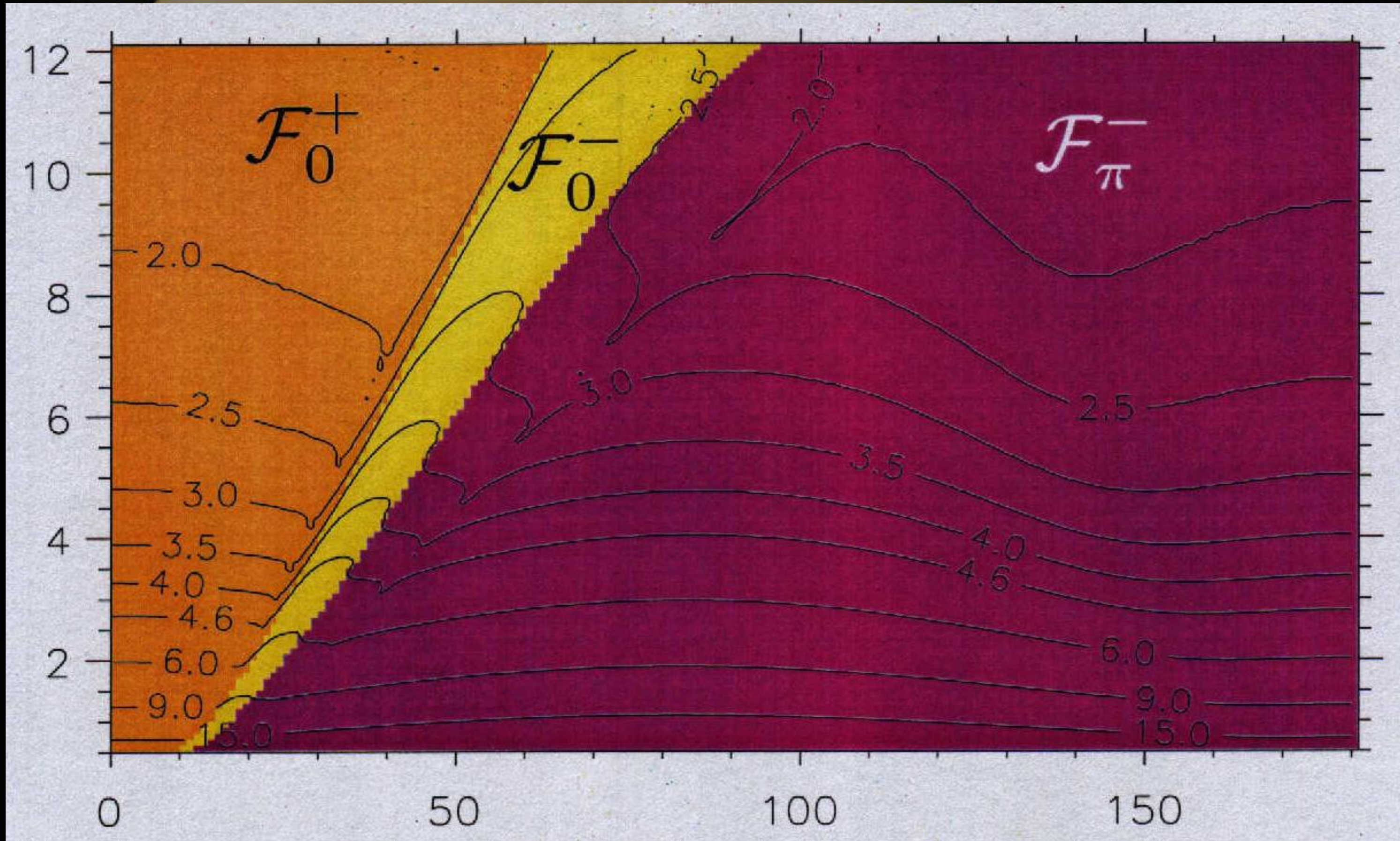
Retrograde

Prot = 243 d

ε = 180°

Correia & Laskar, *Nature*, 2001

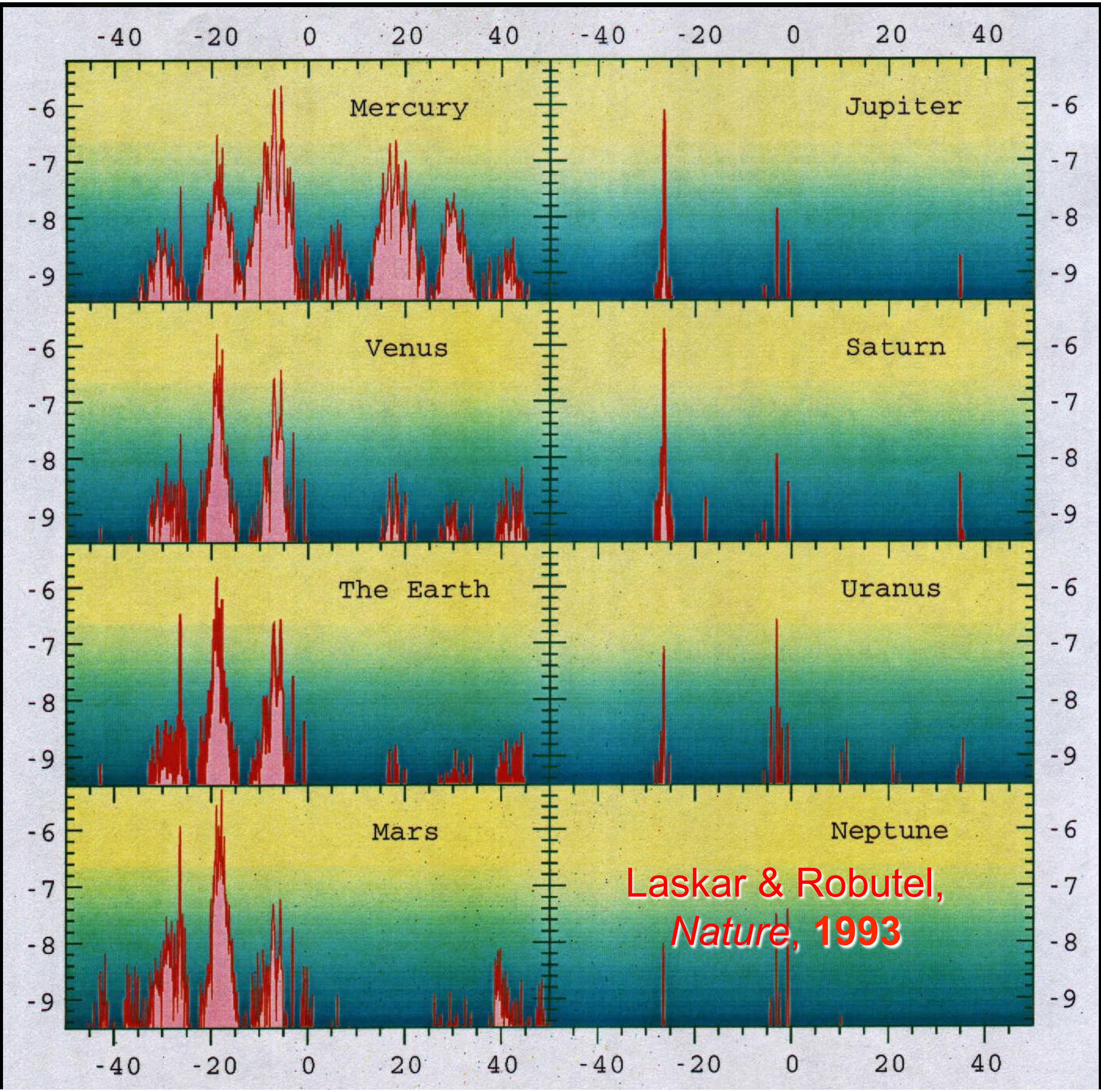
final evolution



Initial period (day)

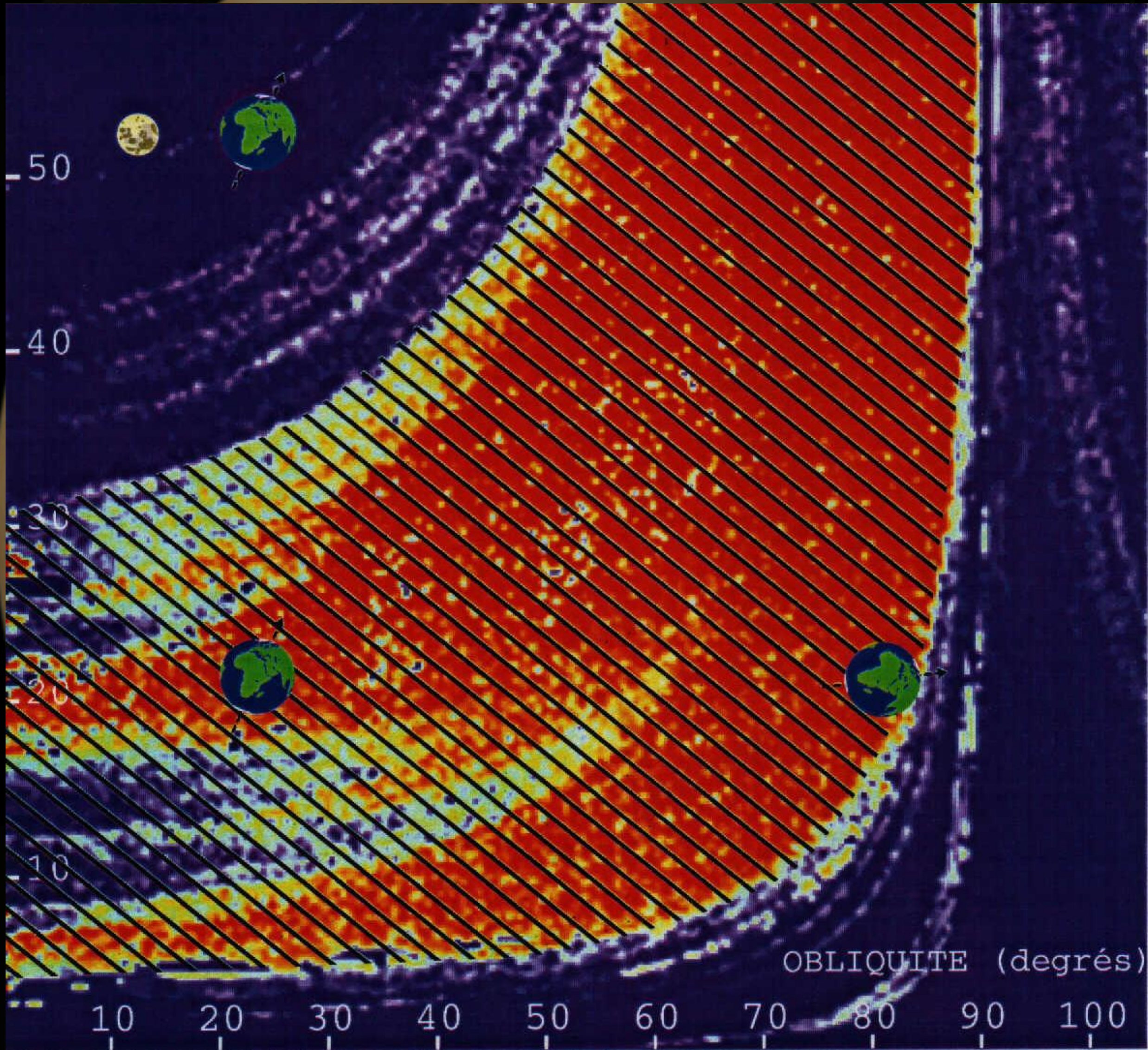
Initial obliquity (degree)

Correia & Laskar, *Nature*, 2001



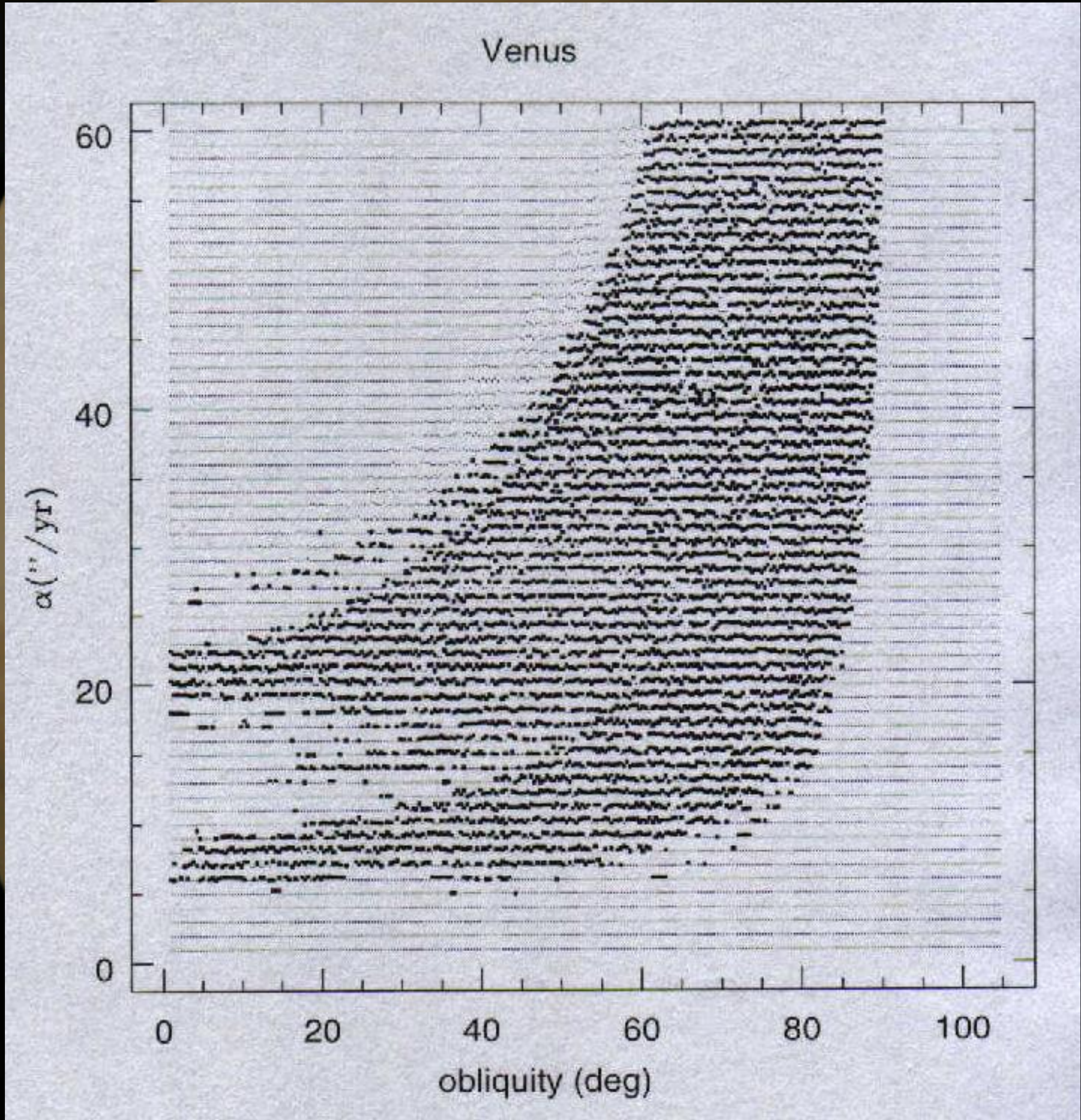
Mercury
Venus
The Earth
Mars
Jupiter
Saturn
Uranus
Neptune
-40
-20
0
20
40
-6
-7
-8
-9
Laskar & Robutel,
Nature, 1993

Earth

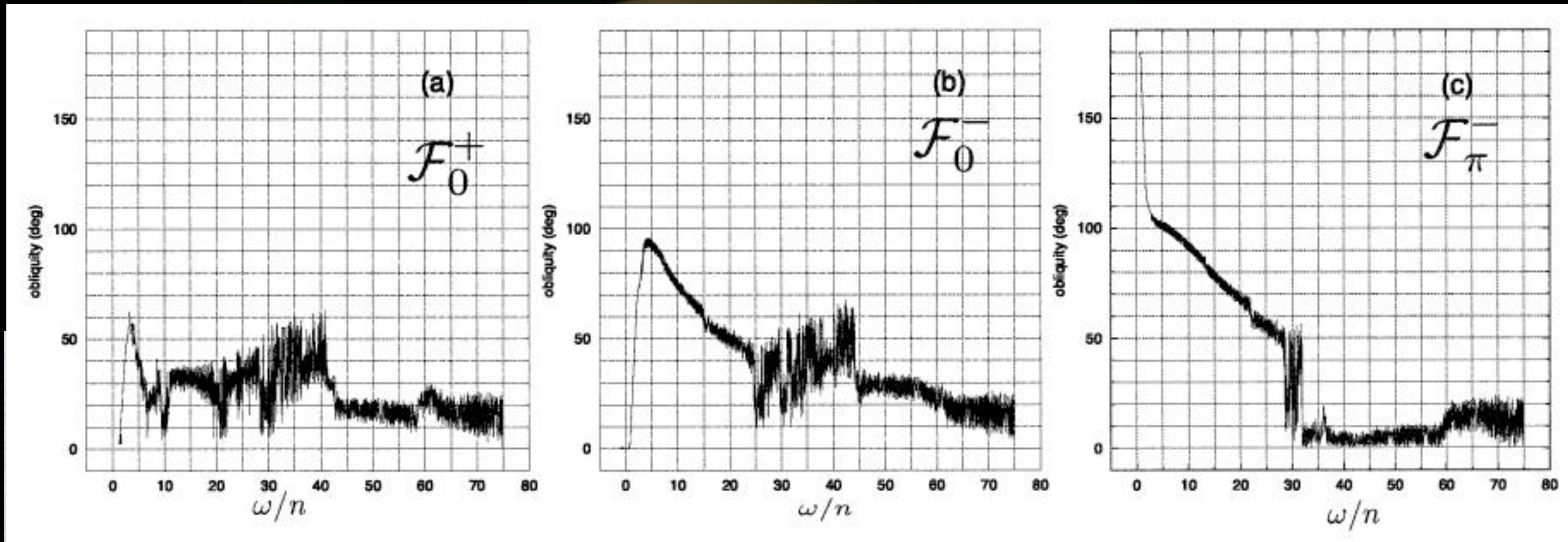


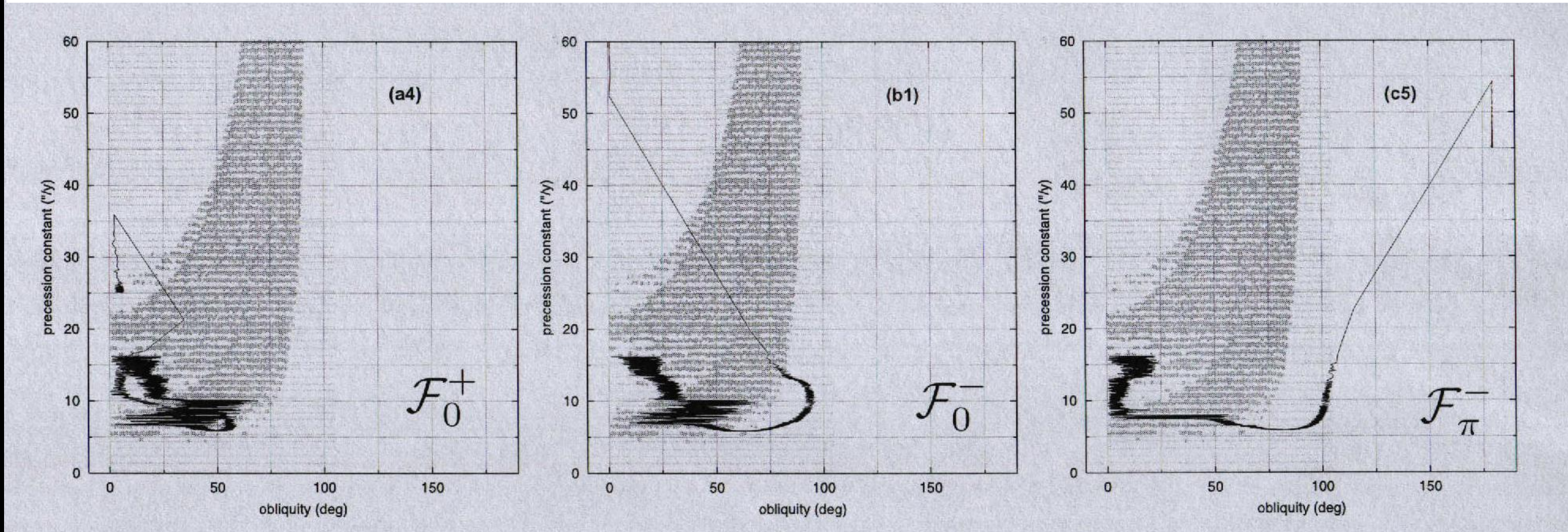
Laskar, Joutel & Robutel, *Nature*, (1993)

Venus



Laskar & Robutel, *Nature*, (1993)

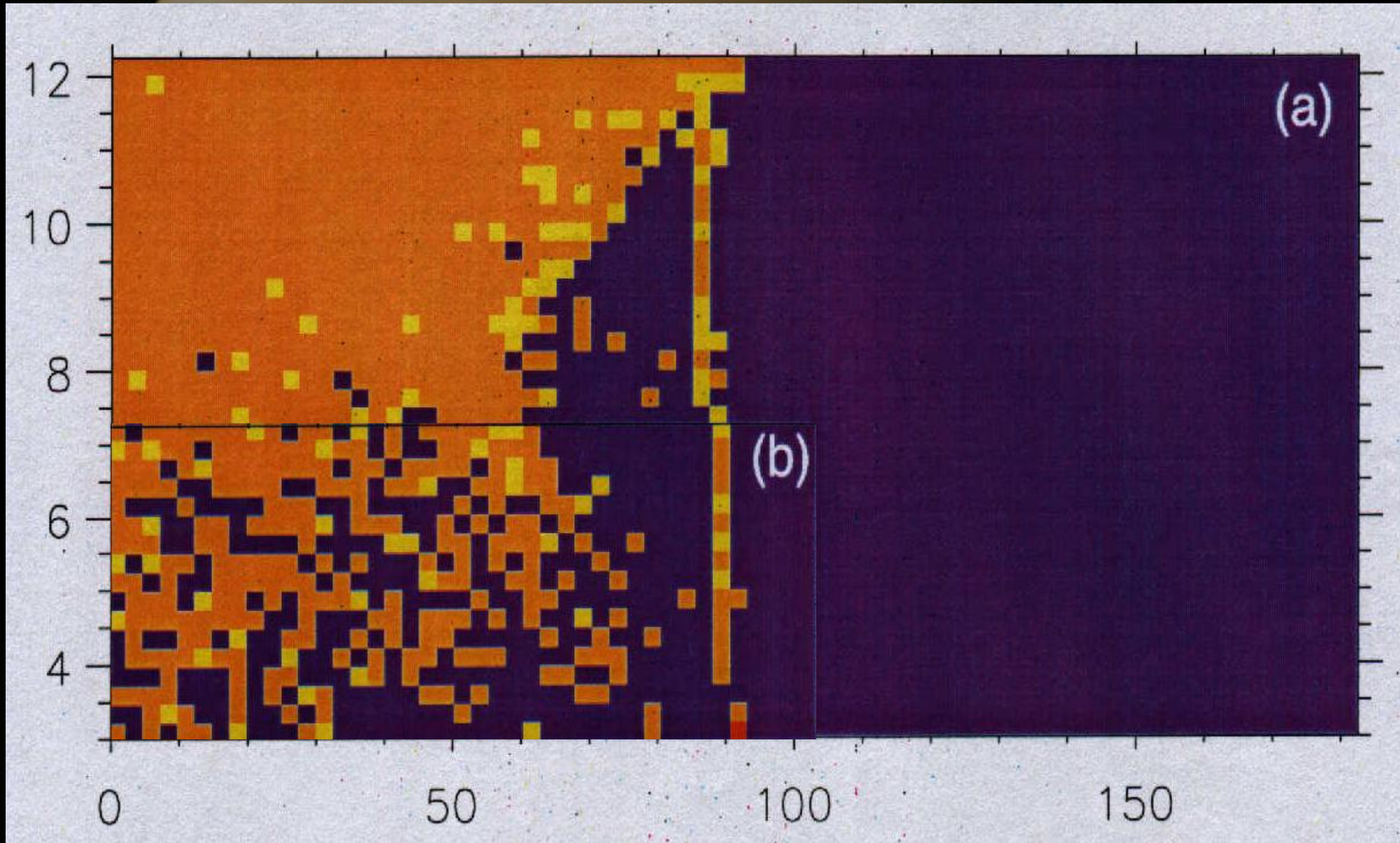




α_0=16.2"/an ($\mathcal{P}_0$=3jours) ; ε_0=1°

Correia & Laskar, *Icarus*, 2003

final evolution

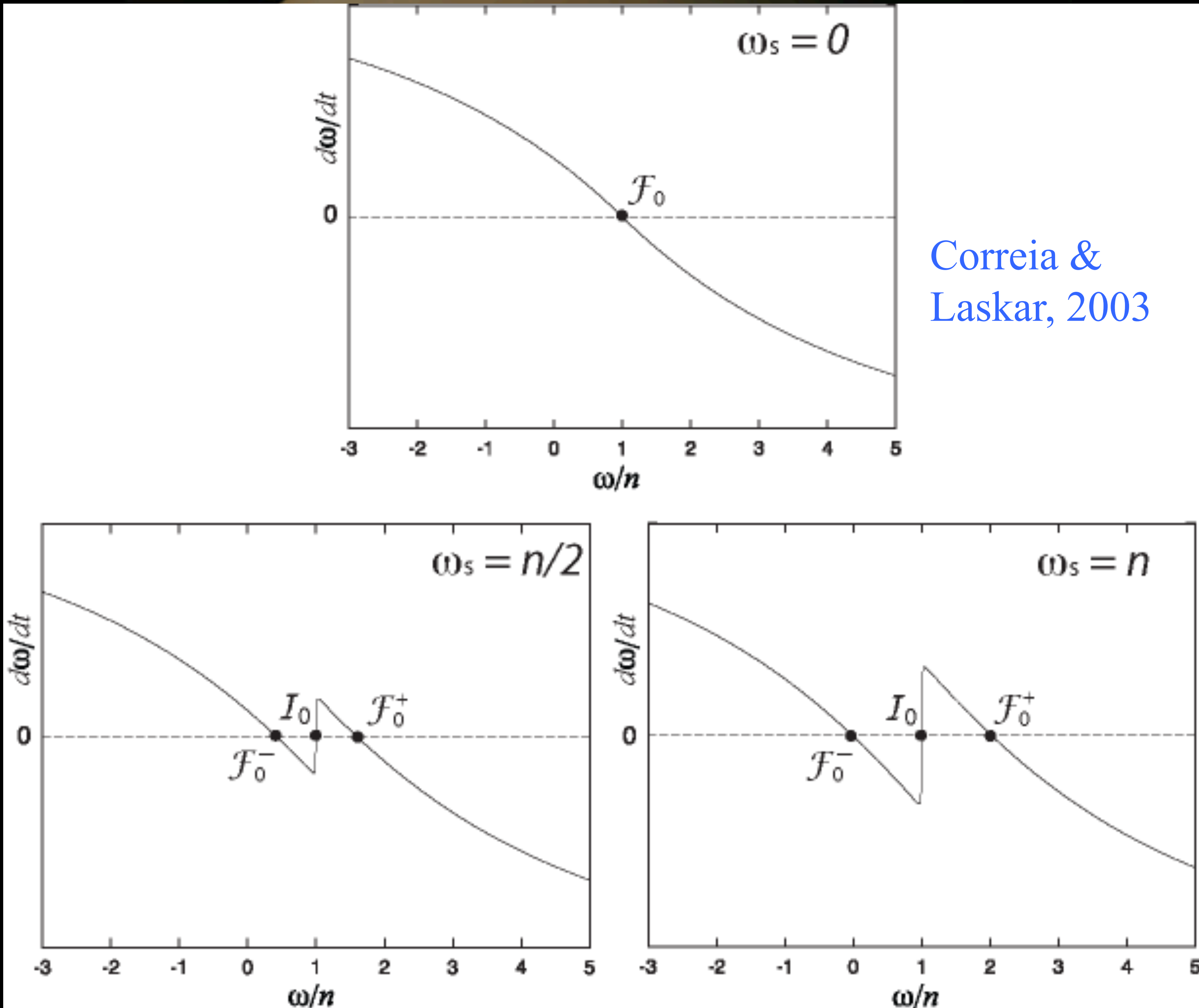


Initial period (day)

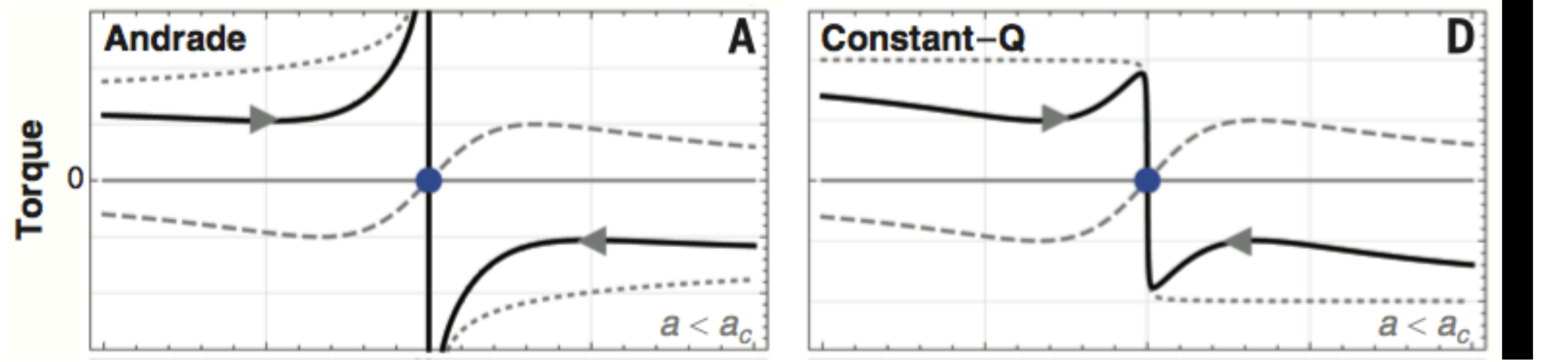
Initial obliquity (degree)

Correia & Laskar, *Nature*, 2001

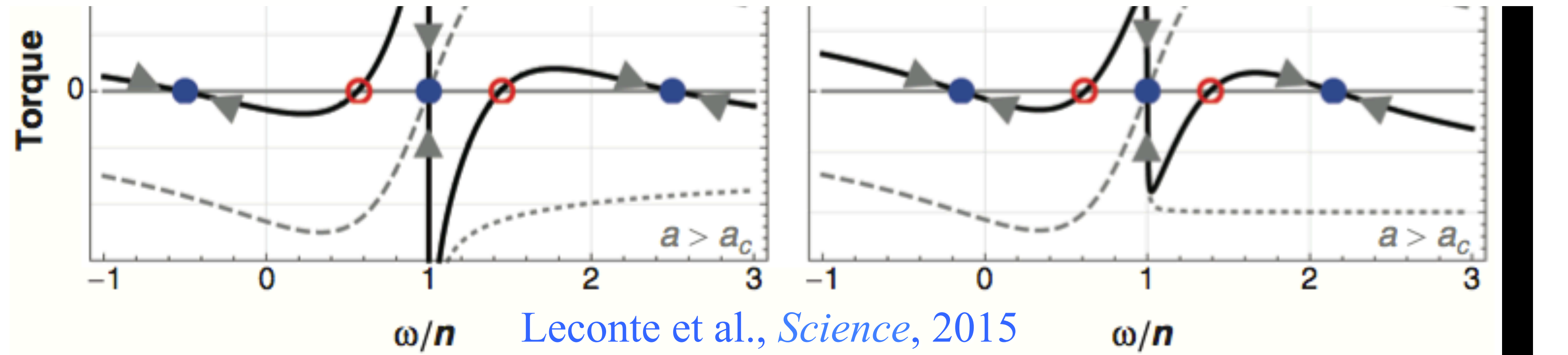
Different tidal strengths



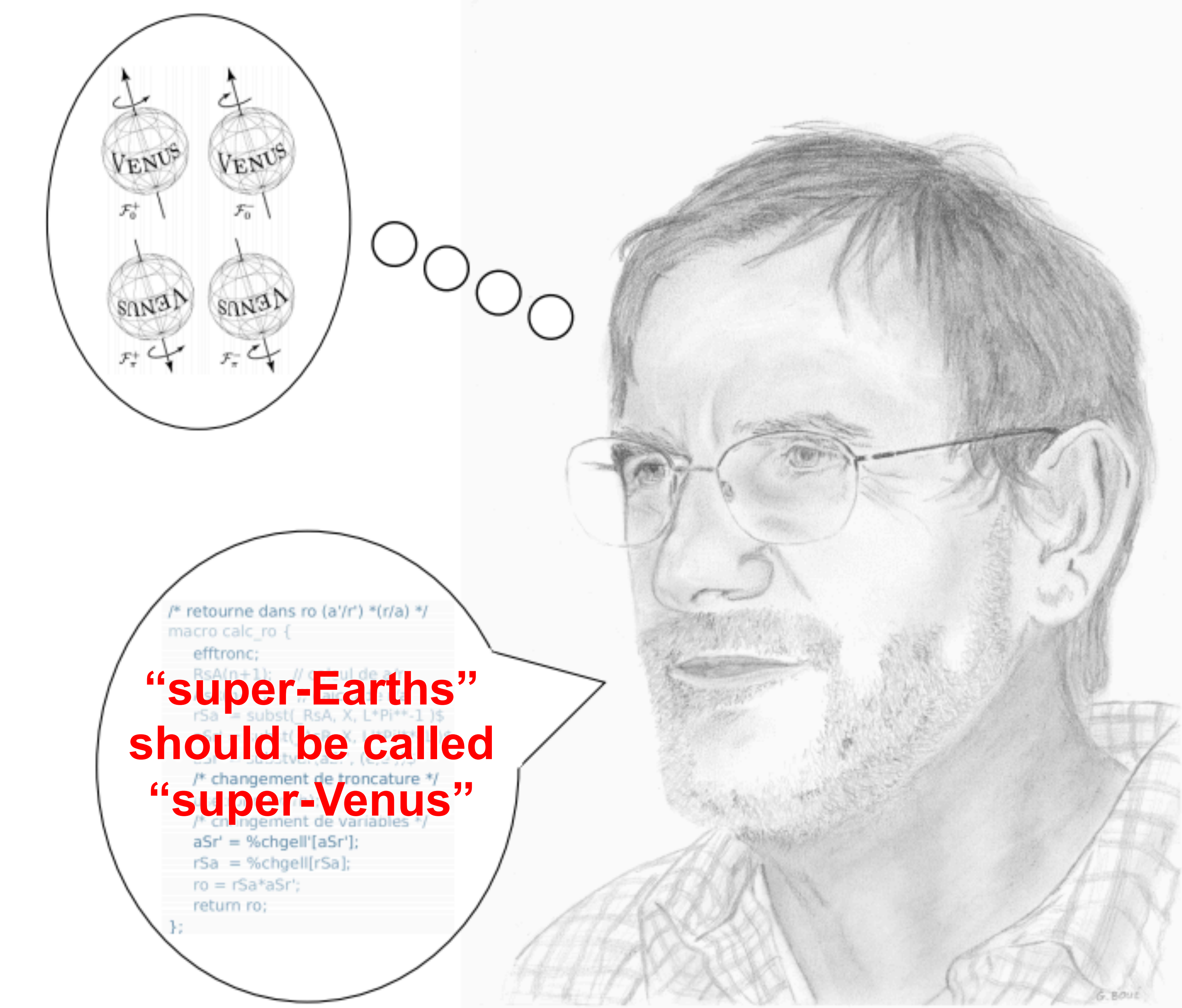
Correia & Laskar, 2003



Sets of simulations	Model output				
	$F(W.m^{-2})$	p_s (bar)	q_0 (Pa)	ω_0 (s^{-1})	$2\pi/\omega_0$ (days)
Venus	2610	92	201	3.77×10^{-7}	193
Inner habitable zone	1366	1	1180	2.30×10^{-6}	32
		10	4050	1.46×10^{-6}	50
Outer habitable zone (N_2)	450	1	890	1.18×10^{-6}	62
		10	2960	7.17×10^{-7}	101
Outer habitable zone (CO_2)	450	10	2590	9.7×10^{-7}	70



Leconte et al., *Science*, 2015


VENUS
VENUS
VENUS
VENUS
/* retourne dans ro (a'/r') *(r/a) */
macro calc_ro {
efftronc;
/* changement de troncature */
aSr' = %chgell'[aSr'];
rSa = %chgell[rSa];
ro = rSa*aSr';
return ro;
};
“super-Earths” should be called “super-Venus”