483rd WE-Heraeus Seminar

Extrasolar Planets:
Towards Comparative Planetology beyond the Solar System

Tides on Earth, in the Solar System and Beyond…..

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Abteilung Planetenforschung
Köln

Planetary Research


"Nasty Girl"
BAYMIST TOO

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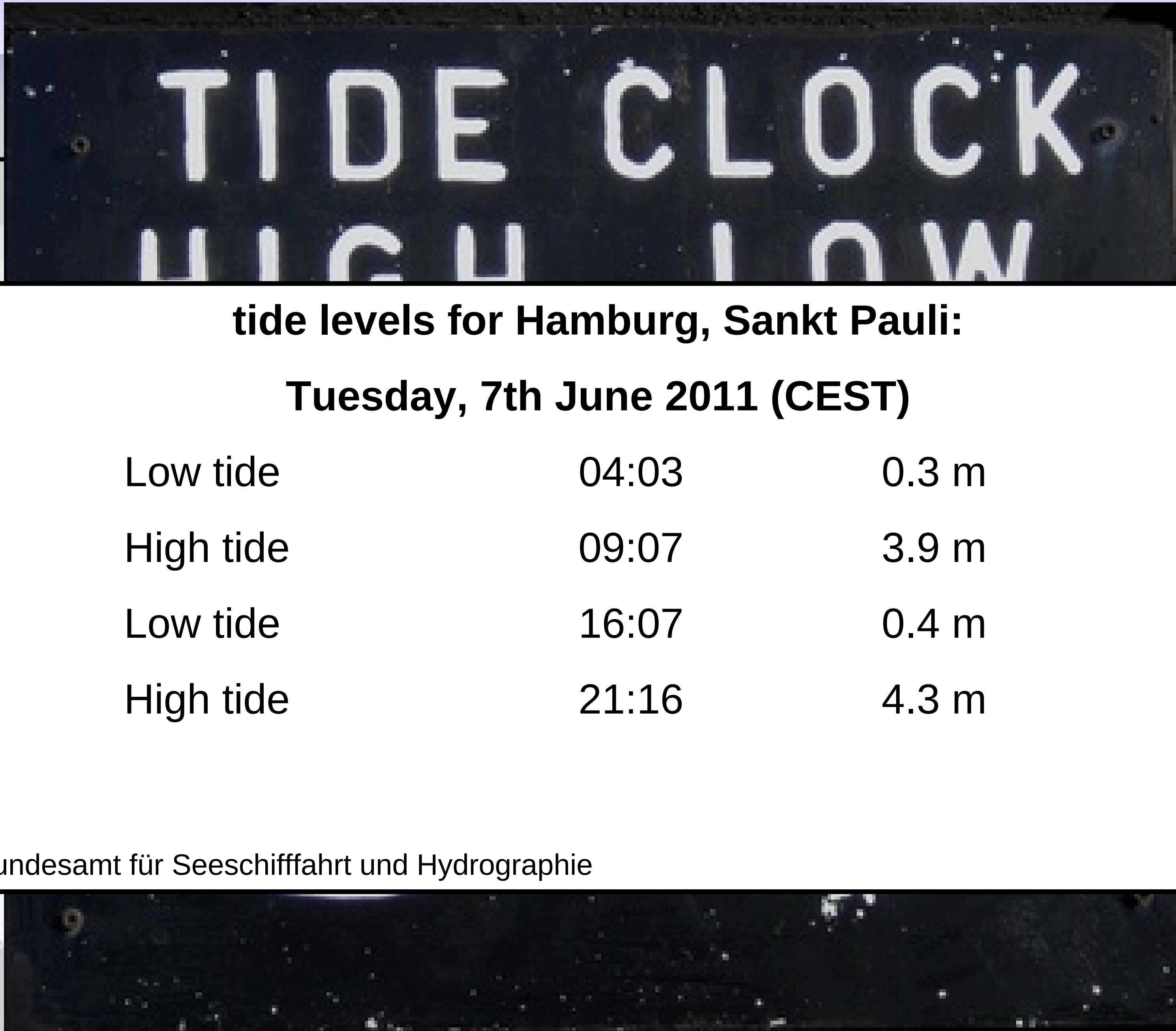
TIDE CLOCK
HIGH LOW



tide levels for Hamburg, Sankt Pauli:

Tuesday, 7th June 2011 (CEST)

Low tide	04:03	0.3 m
High tide	09:07	3.9 m
Low tide	16:07	0.4 m
High tide	21:16	4.3 m

Bundesamt für Seeschifffahrt und Hydrographie

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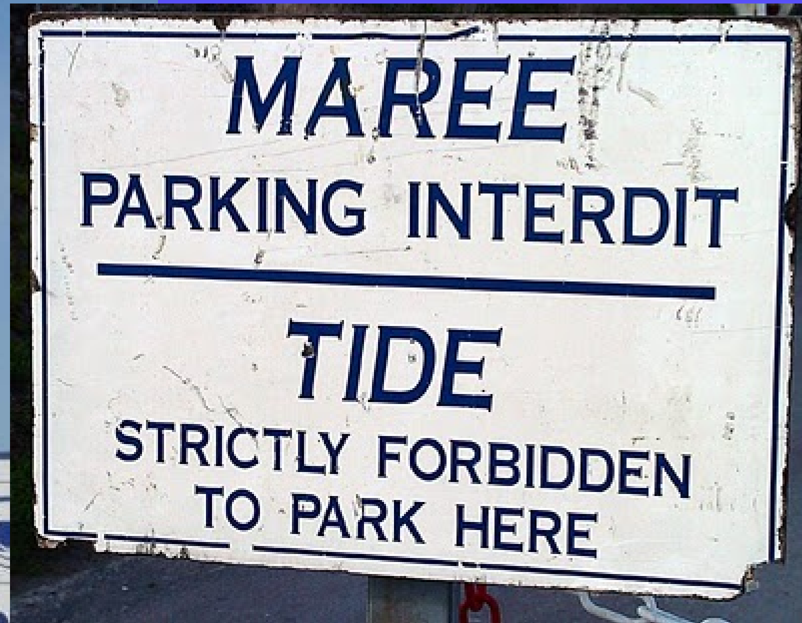
Mont St. Michel, Bretagne



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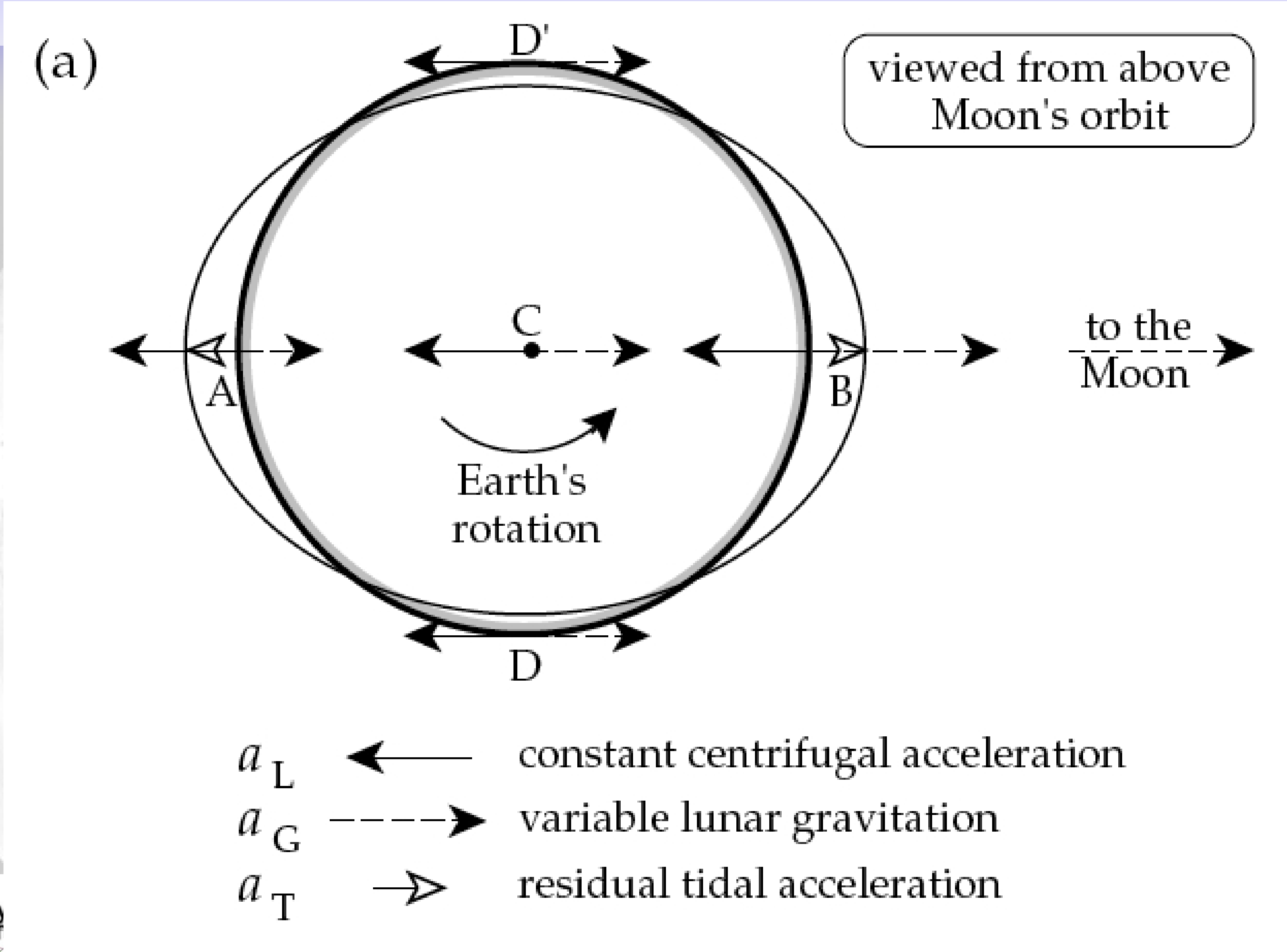
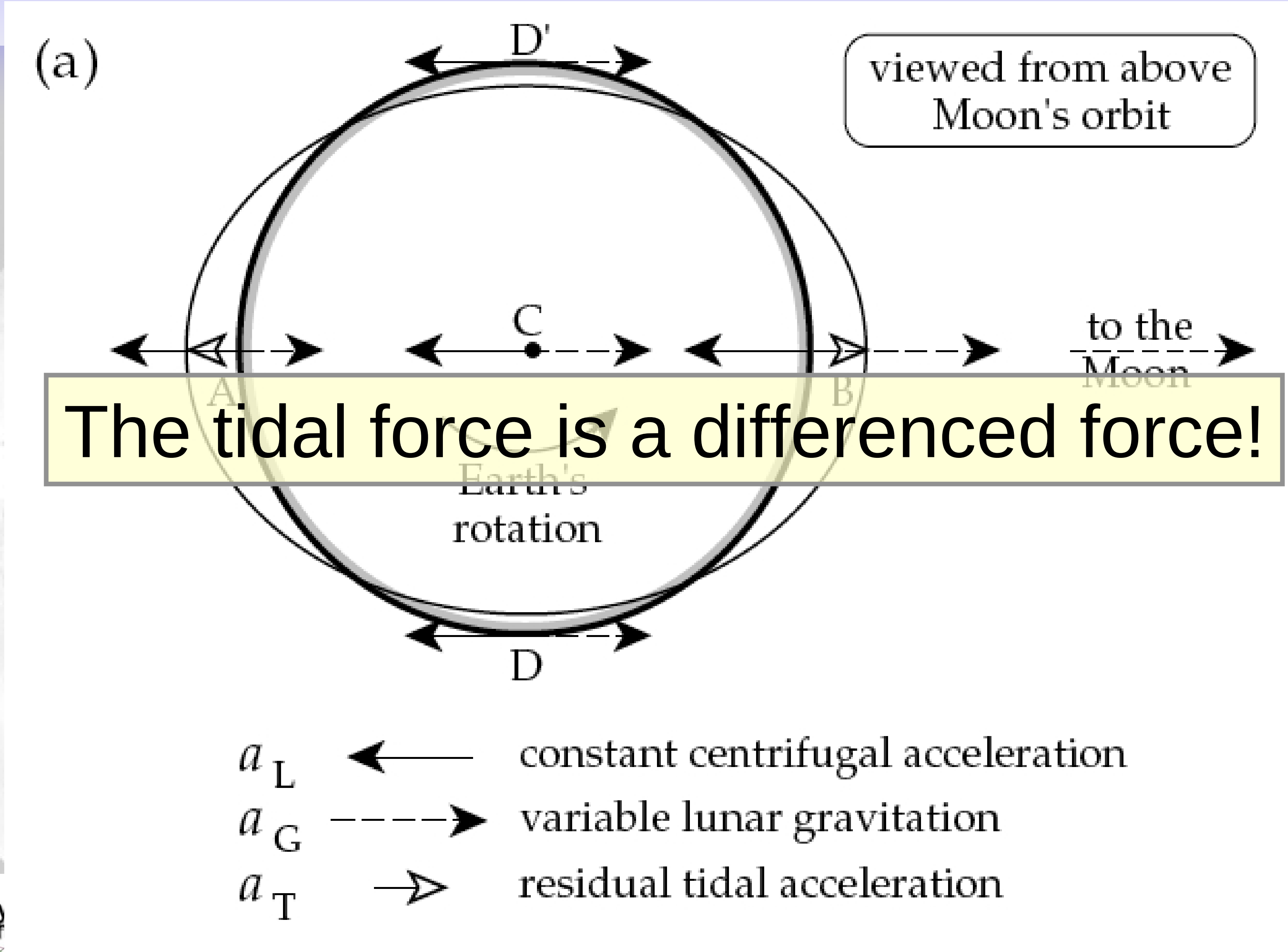

(a)
viewed from above
Moon's orbit
D'
C
A
B
to the
Moon
Earth's
rotation
D
a_L constant centrifugal acceleration
a_G variable lunar gravitation
a_T residual tidal acceleration



The tidal force is a differenced force!

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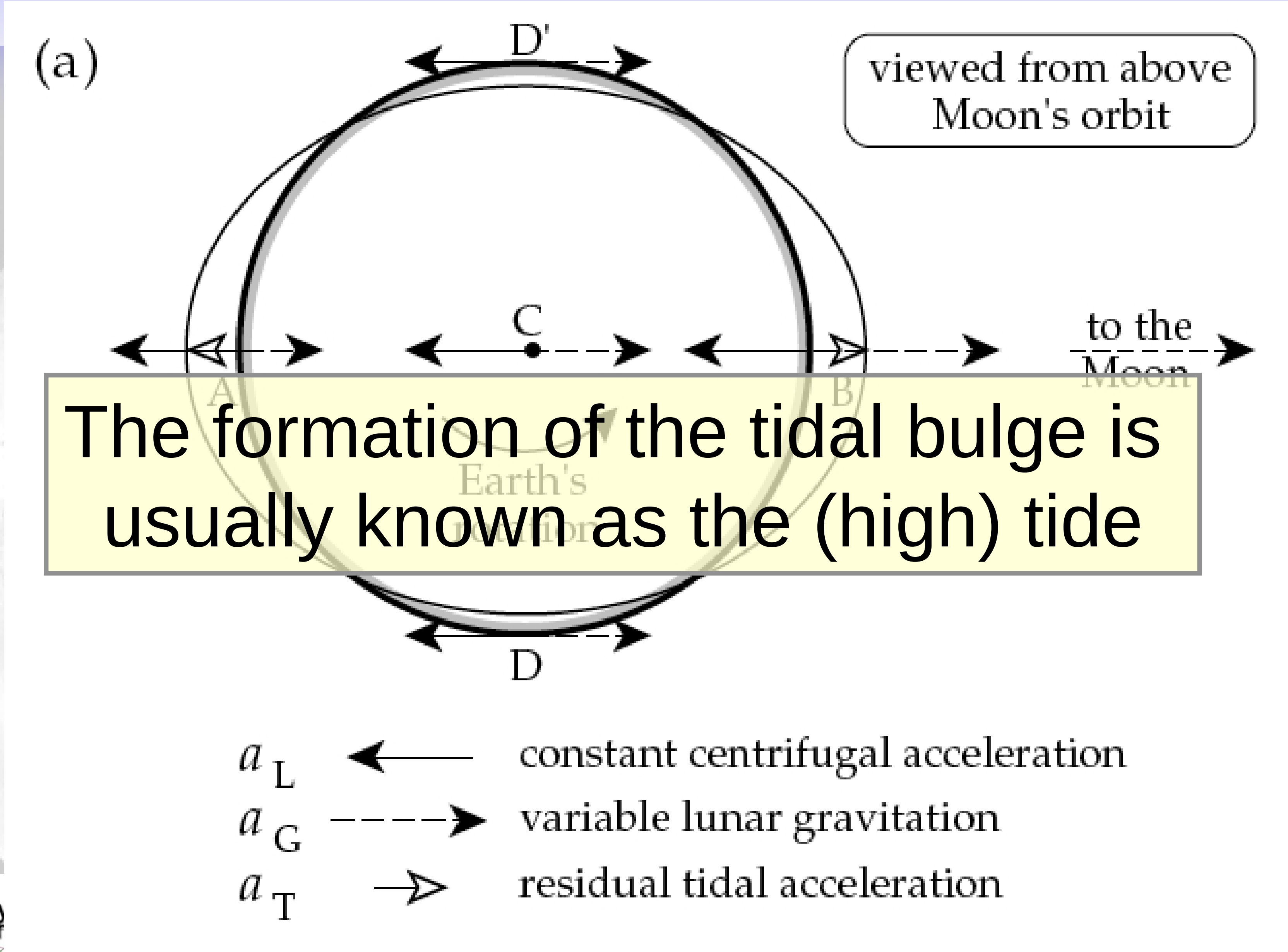
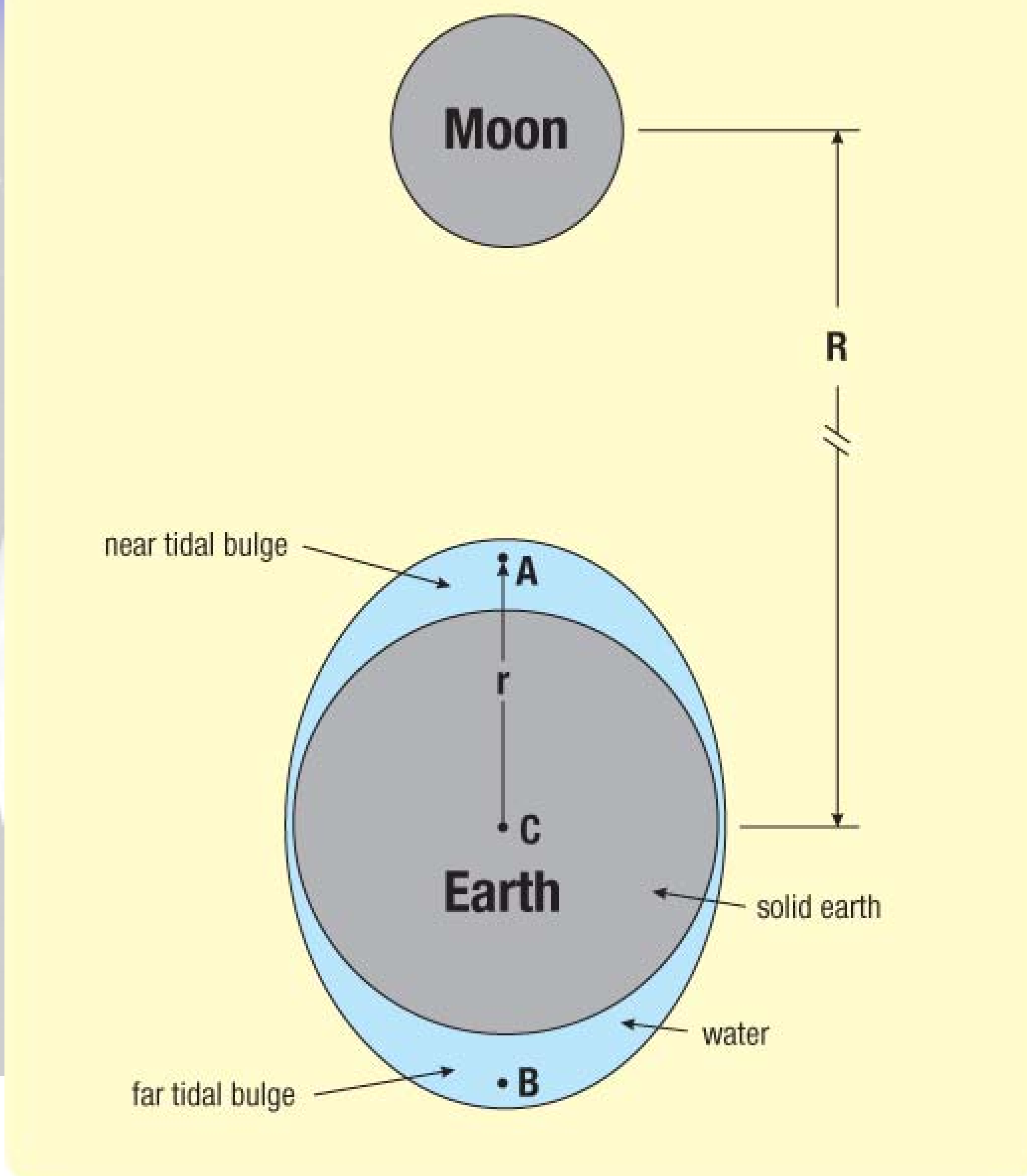


The formation of the tidal bulge is usually known as the (high) tide

Revolution without rotation



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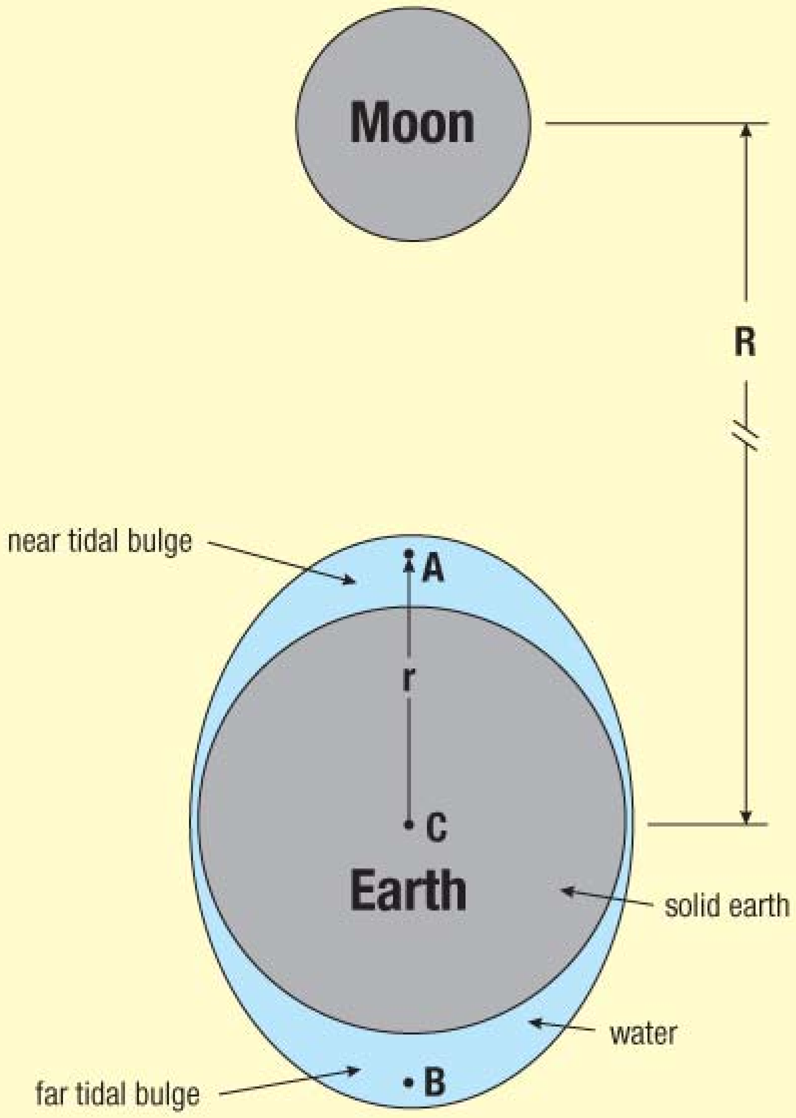
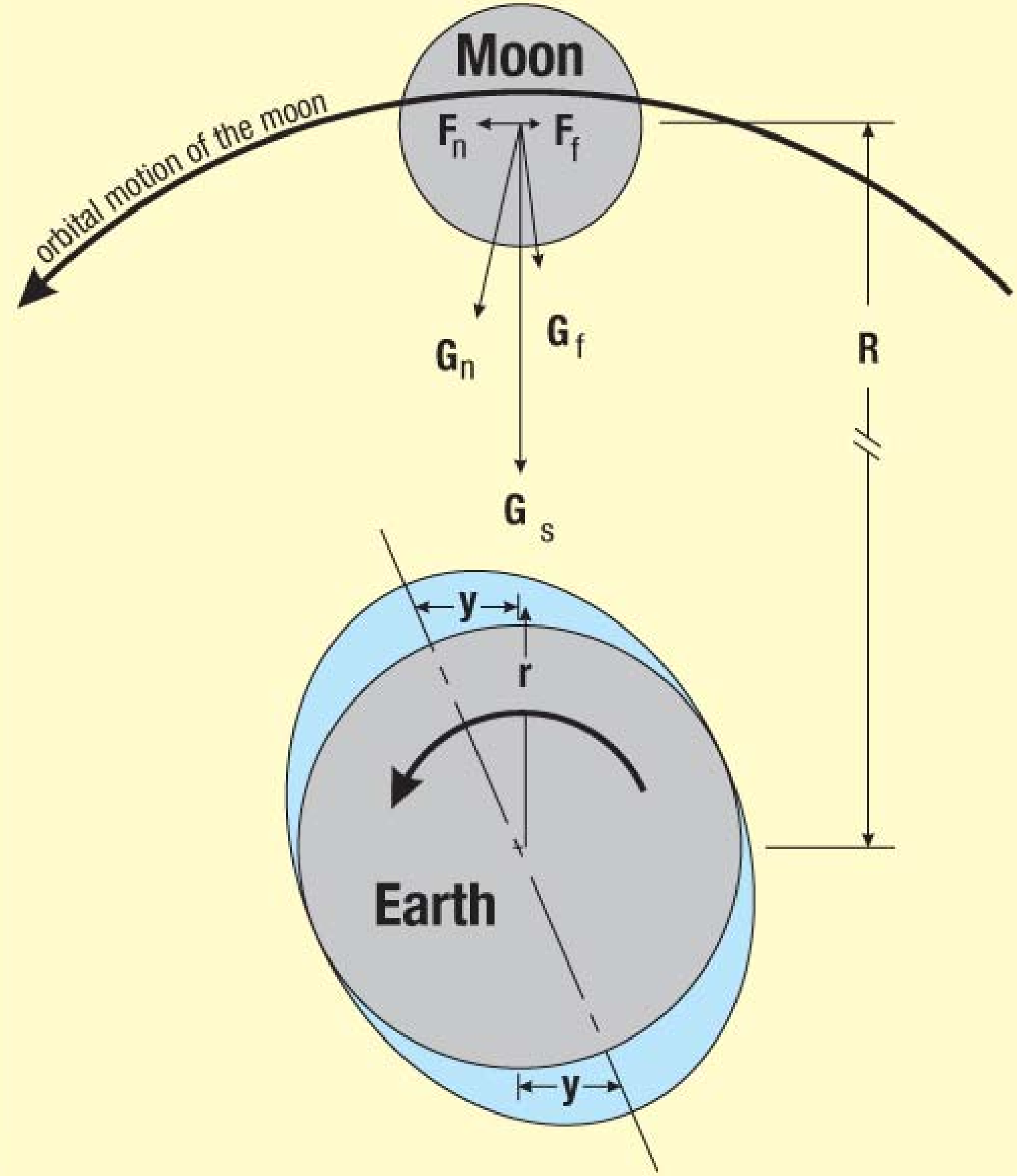
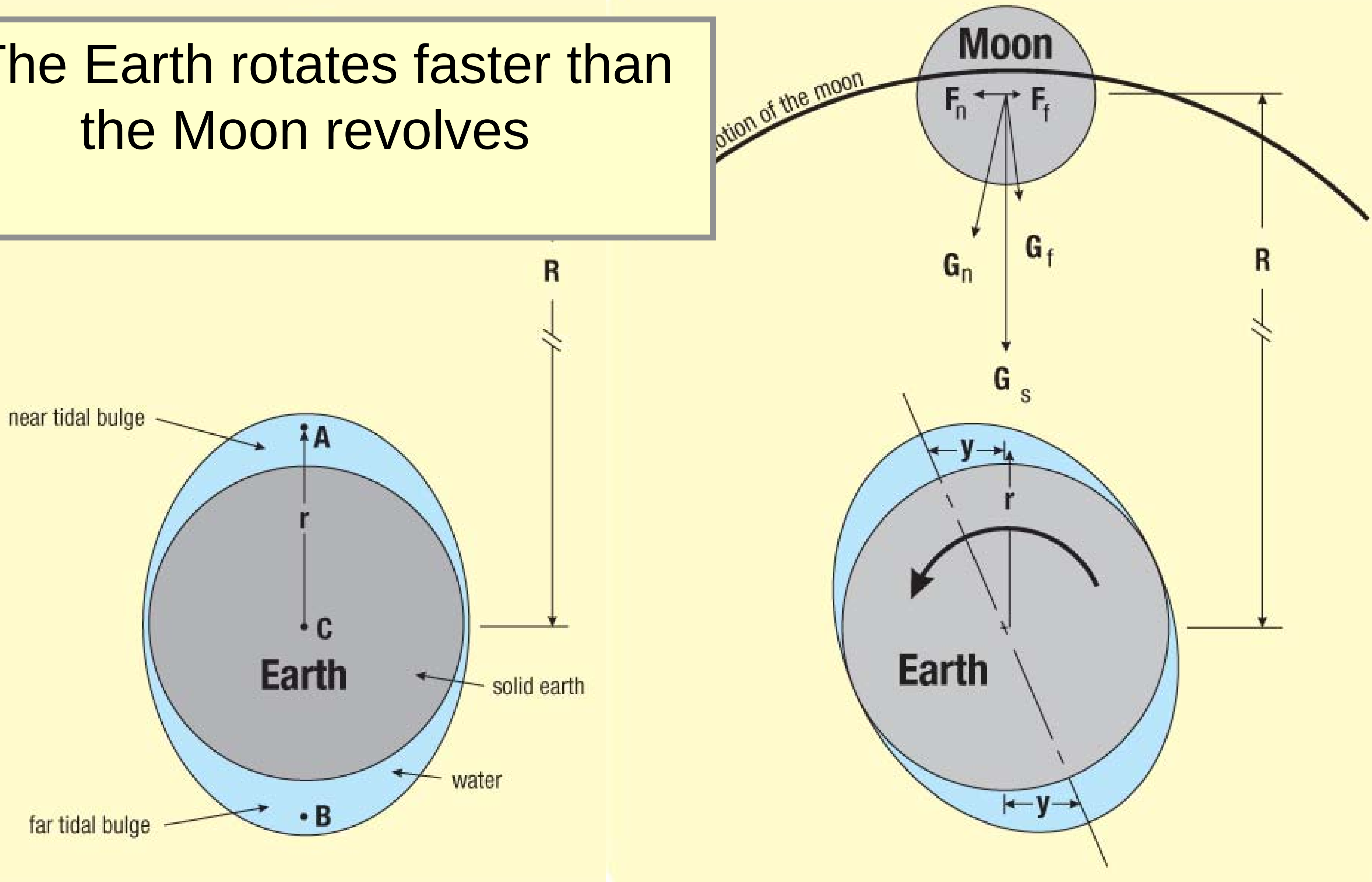


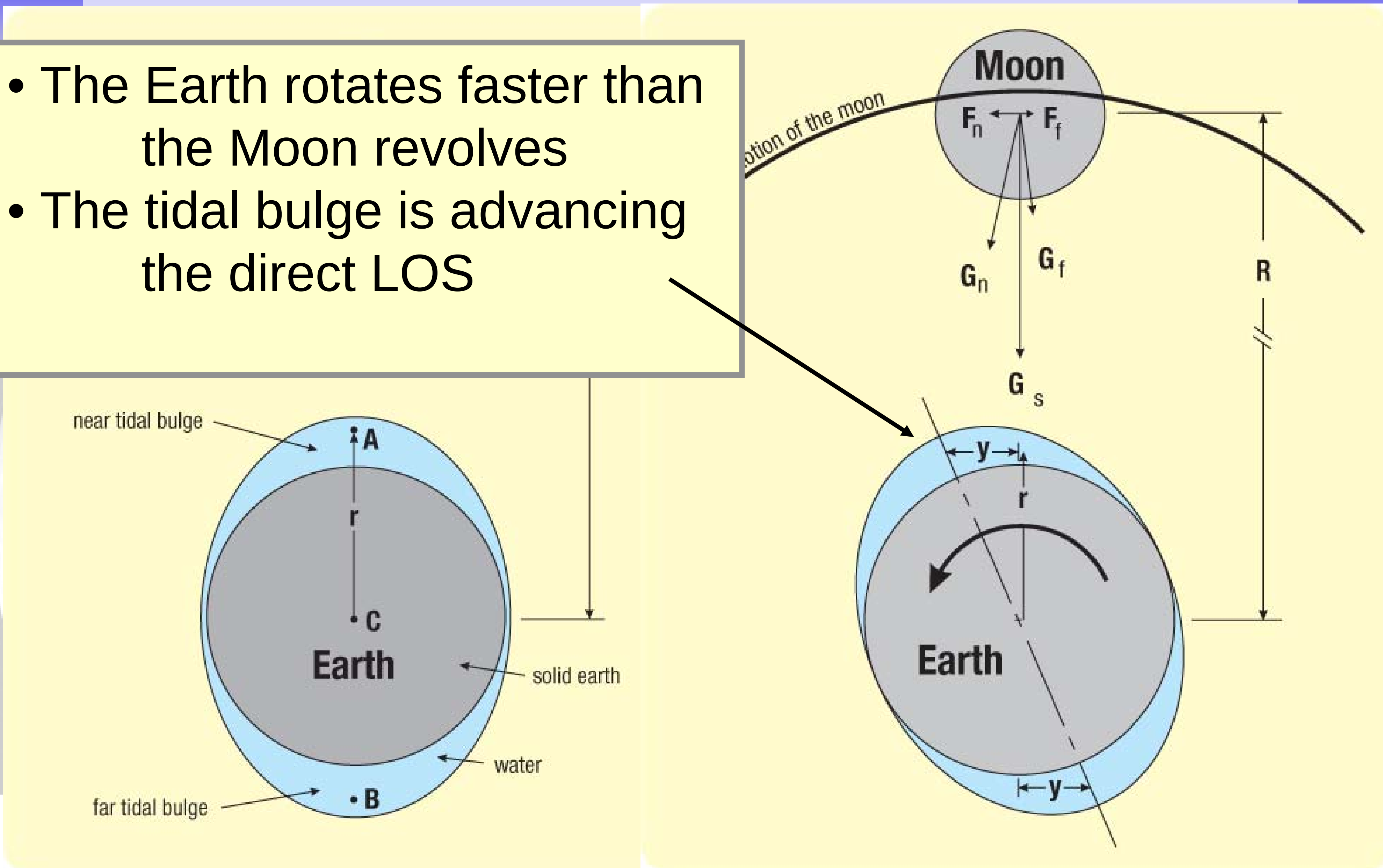
But the Earth rotates!



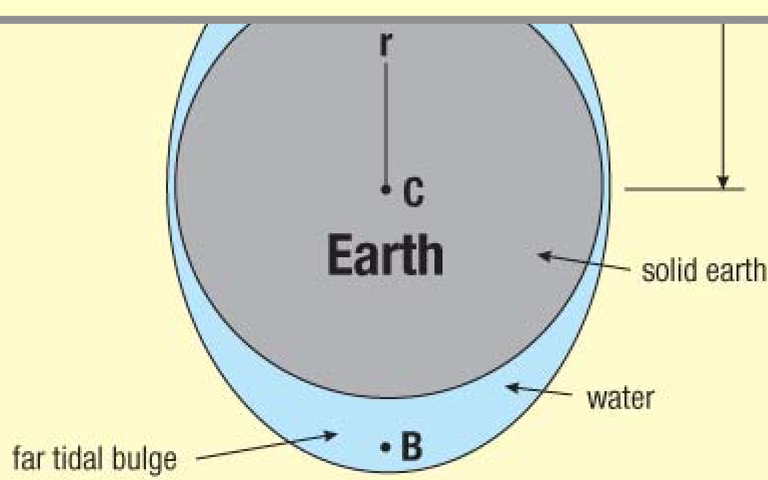
• The Earth rotates faster than the Moon revolves

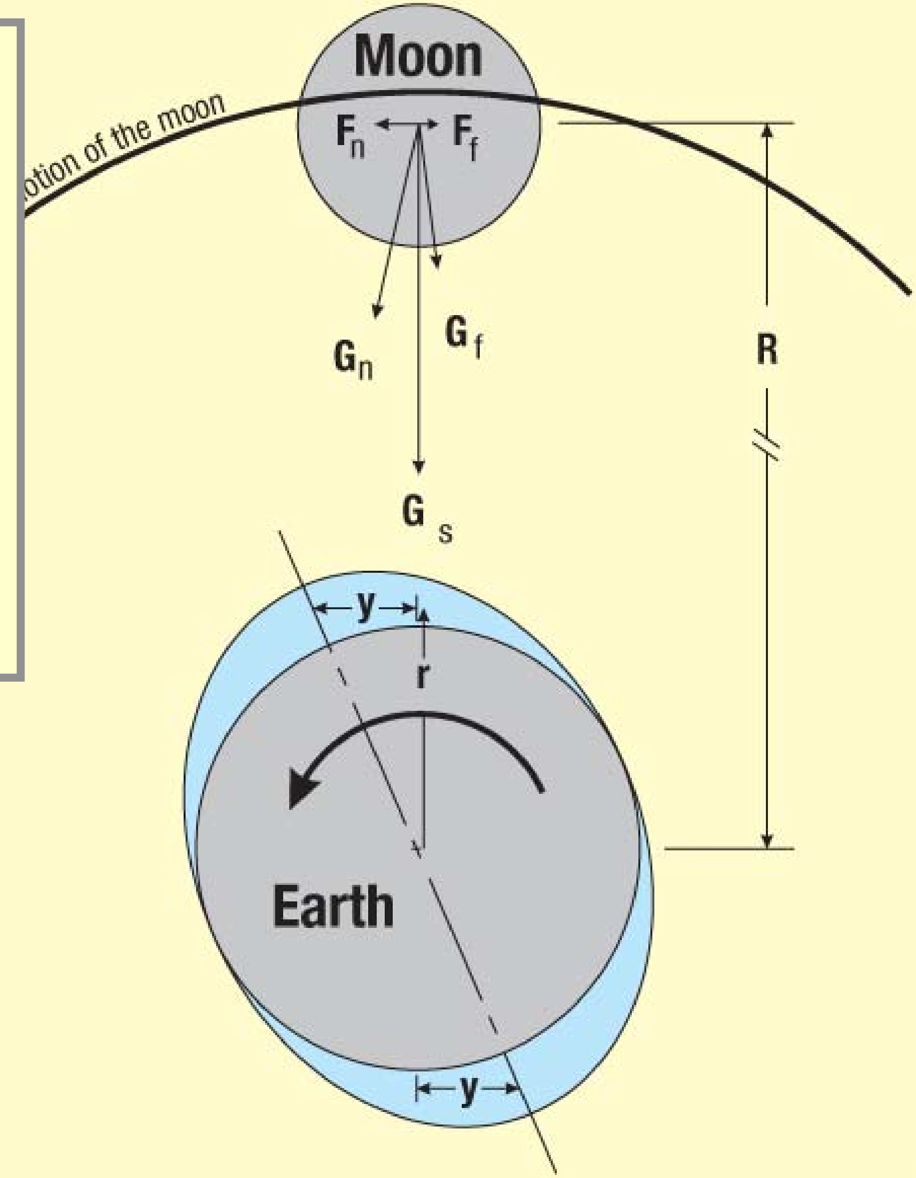


- The Earth rotates faster than the Moon revolves
- The tidal bulge is advancing the direct LOS



- The Earth rotates faster than the Moon revolves
- The tidal bulge is advancing the direct LOS
- Torques try to pull the tidal bulge back into LOS





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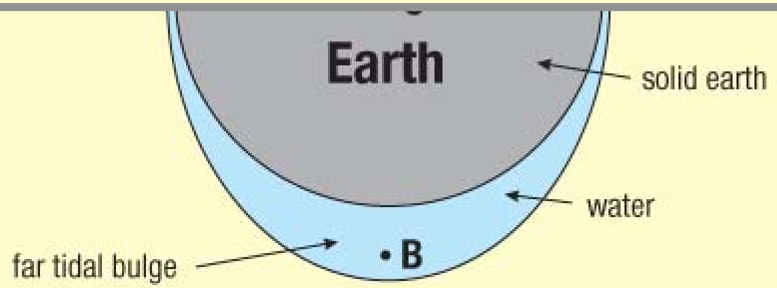
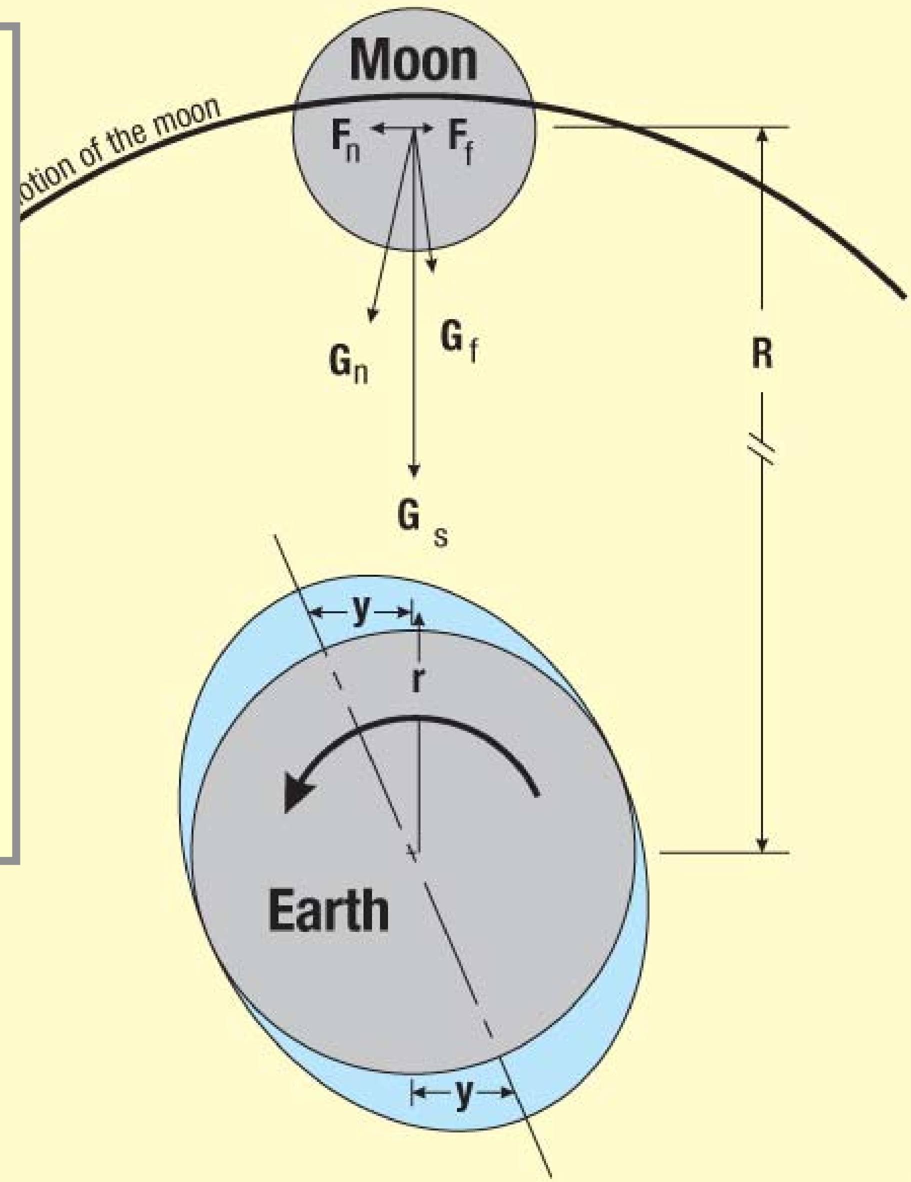
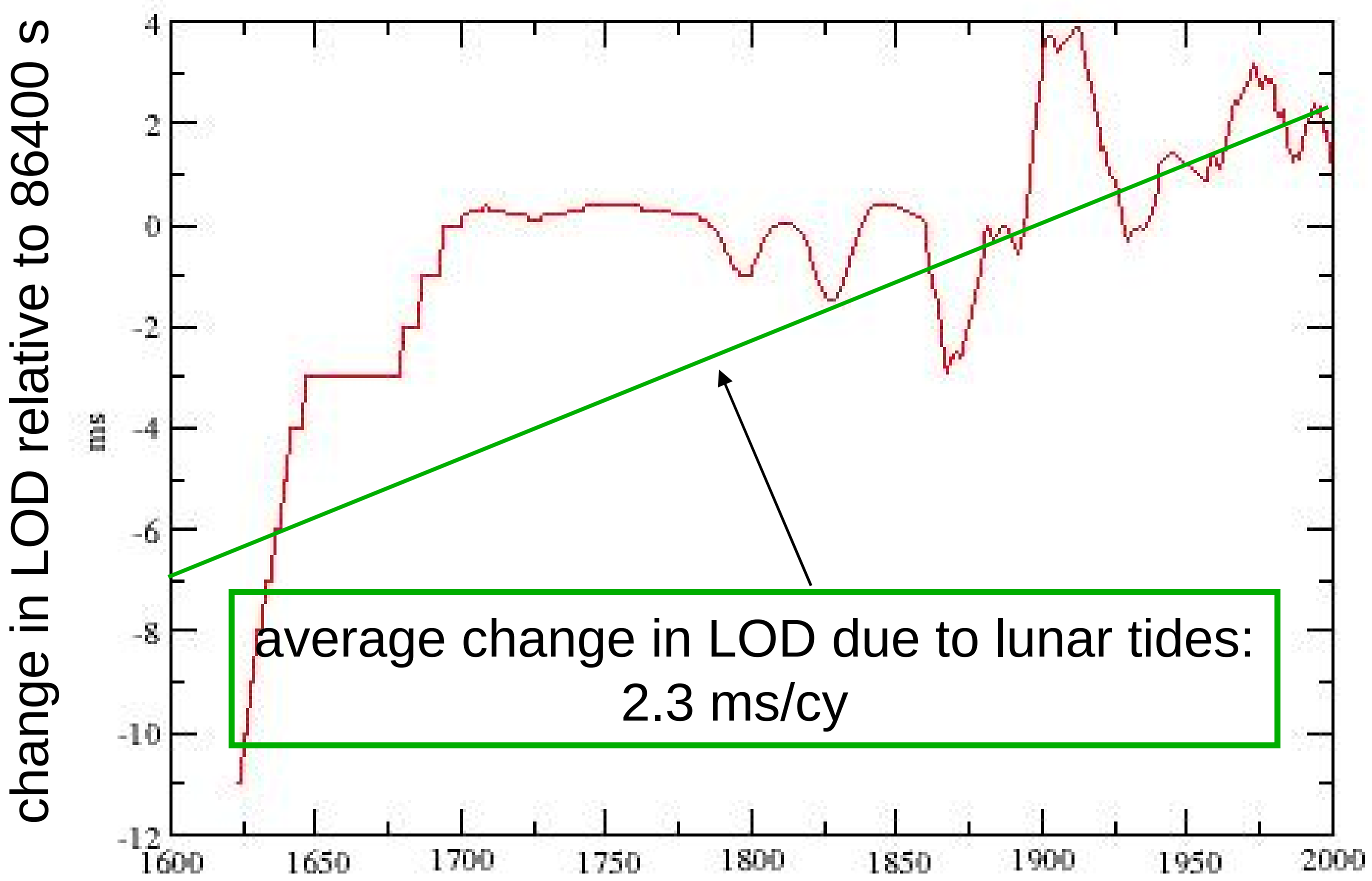
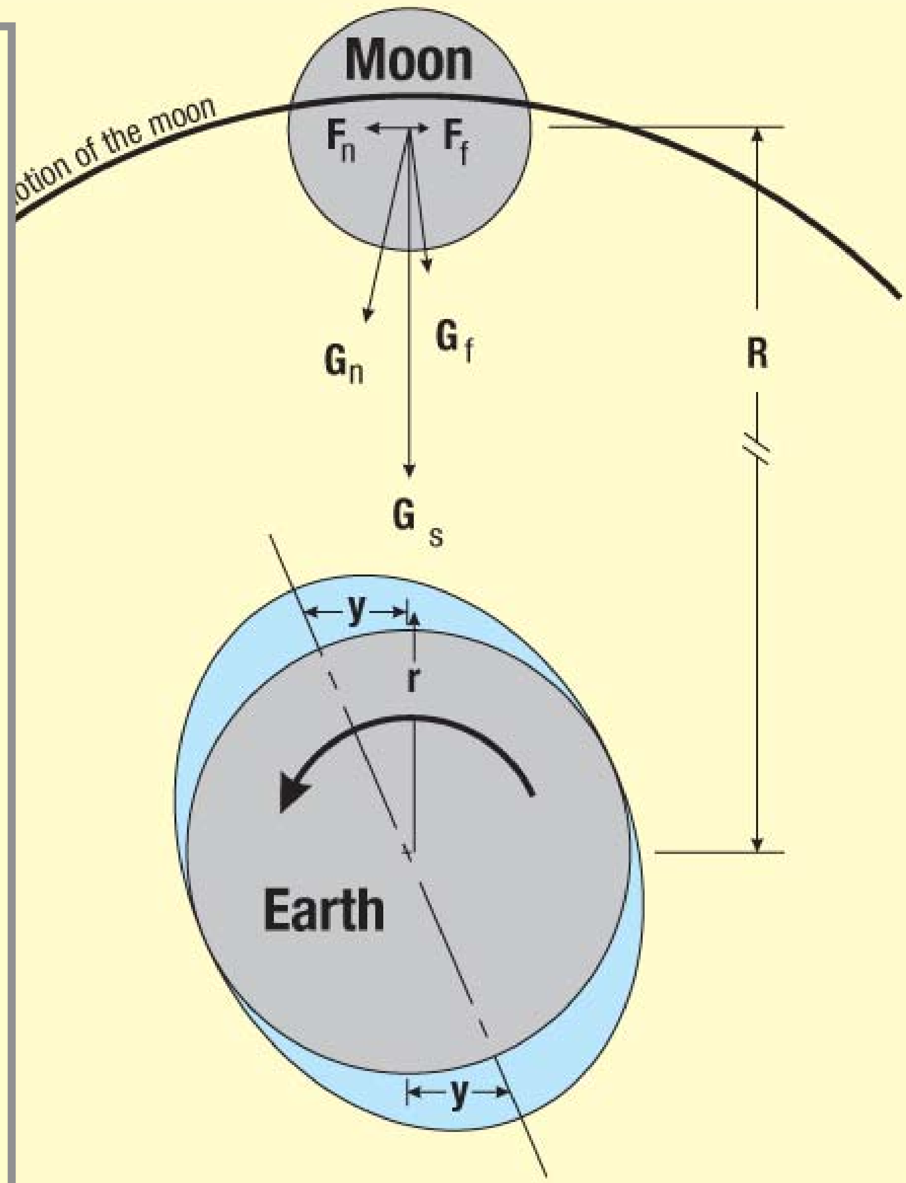
- Consequence is a slow down of Earth rotation (tidal friction)



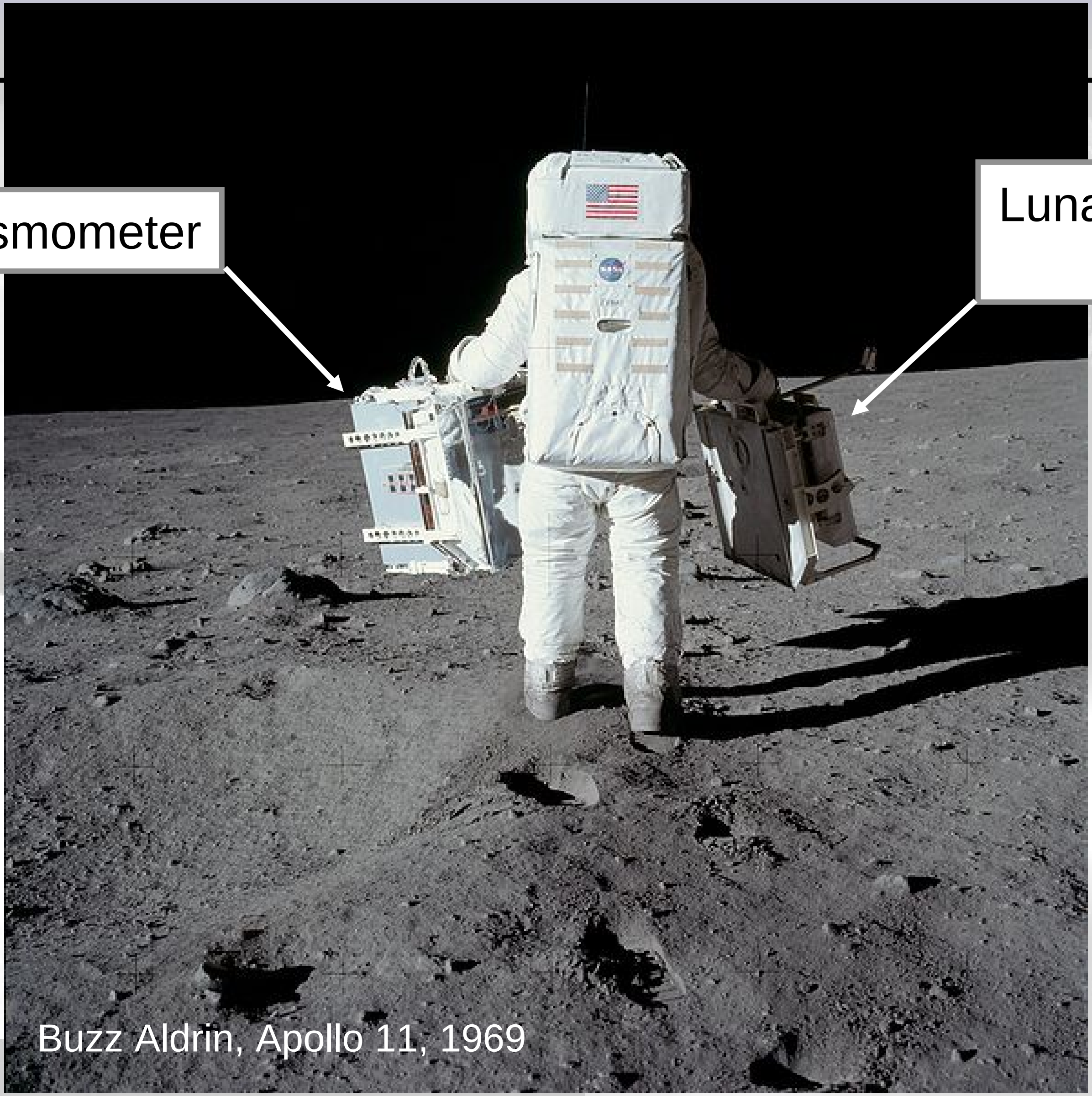



change in LOD relative to 86400 s
ms
4
2
0
-2
-4
-6
-8
-10
-12
1600
1650
1700
1750
1800
1850
1900
1950
2000
average change in LOD due to lunar tides:
2.3 ms/cy

- The Earth rotates faster than the Moon revolves
- The tidal bulge is advancing the direct LOS
- Torques try to pull the tidal bulge back into LOS
- Consequence is a slow down of Earth rotation (tidal friction)
- another consequence from conservation of angular momentum: the Moon recedes from the Earth



The first extraterrestrial applied space geophysicist



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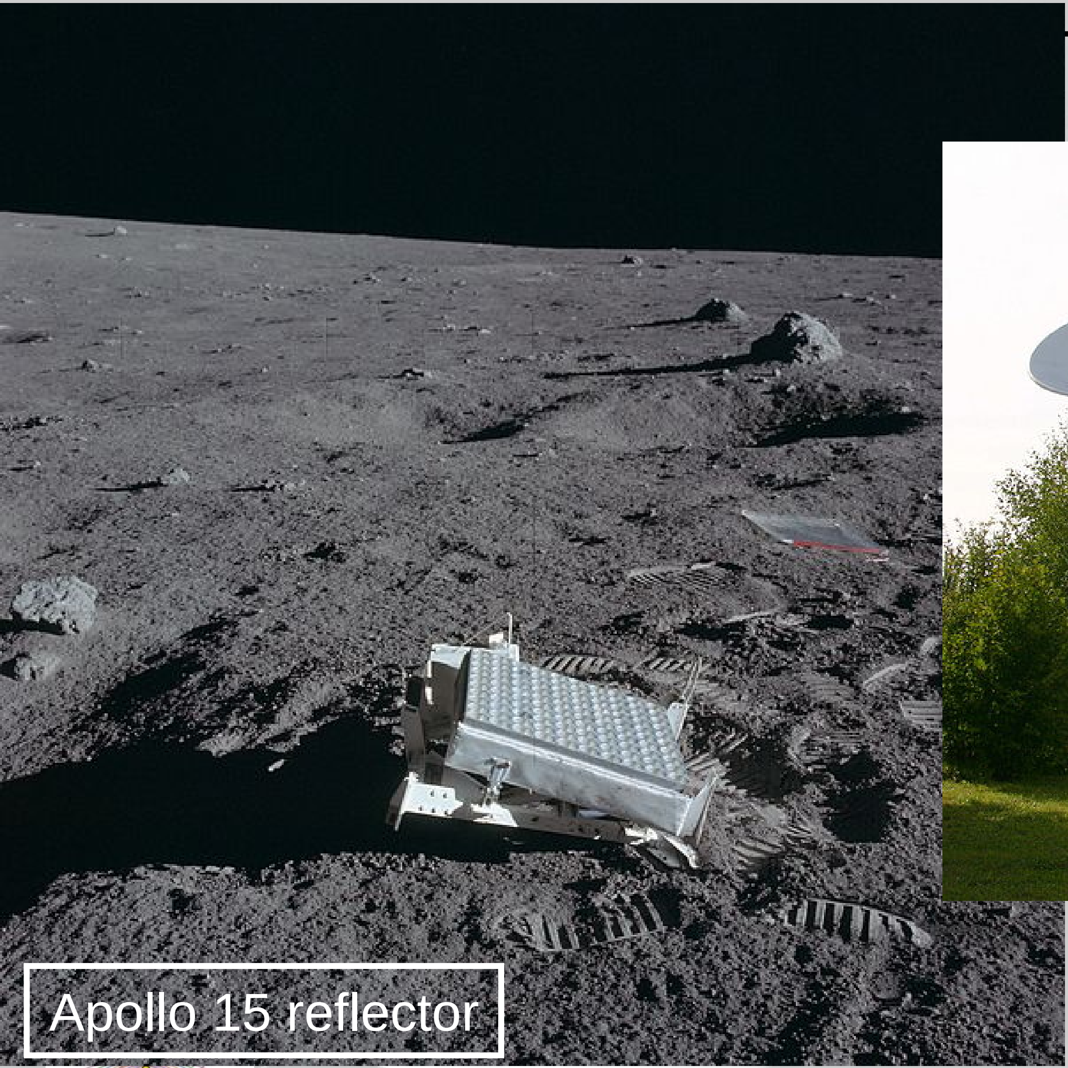
Lunar Laser Ranging



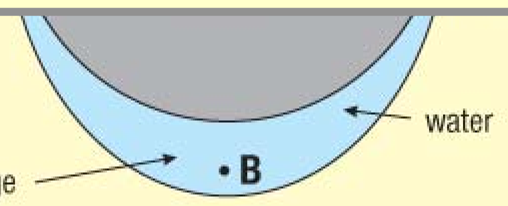
Lunar Laser Ranging

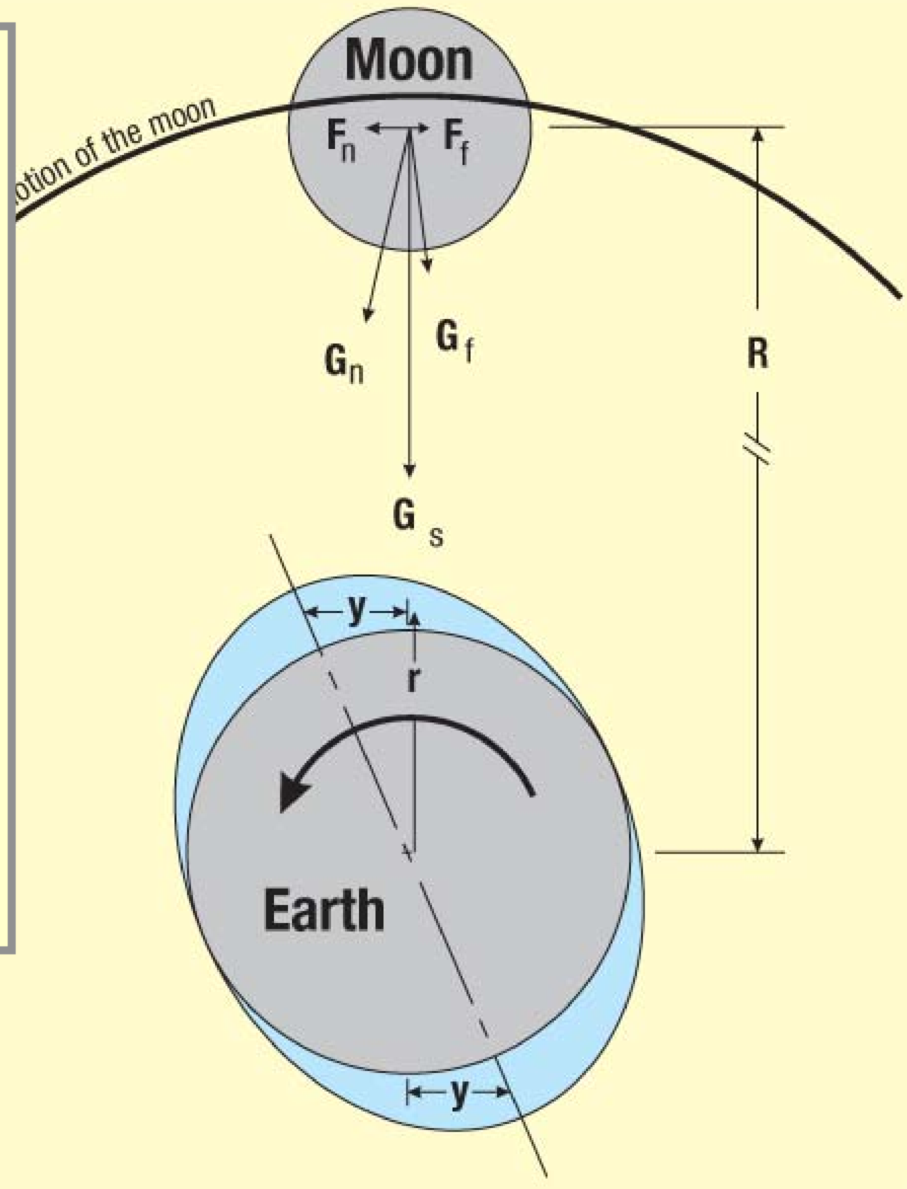
The Moon recedes from Earth by 4m/cy

Apollo 15 reflector

Wettzell Lunar Laser Station

- The Earth rotates faster than the Moon revolves
- The tidal bulge is advancing the direct LOS by 3°
- Earth rotates below the tidal bulge
- A location on the surface experiences periodically high and low tides





Ocean tides are the directly visible manifestation of tidal forces

- **The Earth rotates faster than the Moon revolves**
- The tidal bulge is advancing the direct LOS
- T
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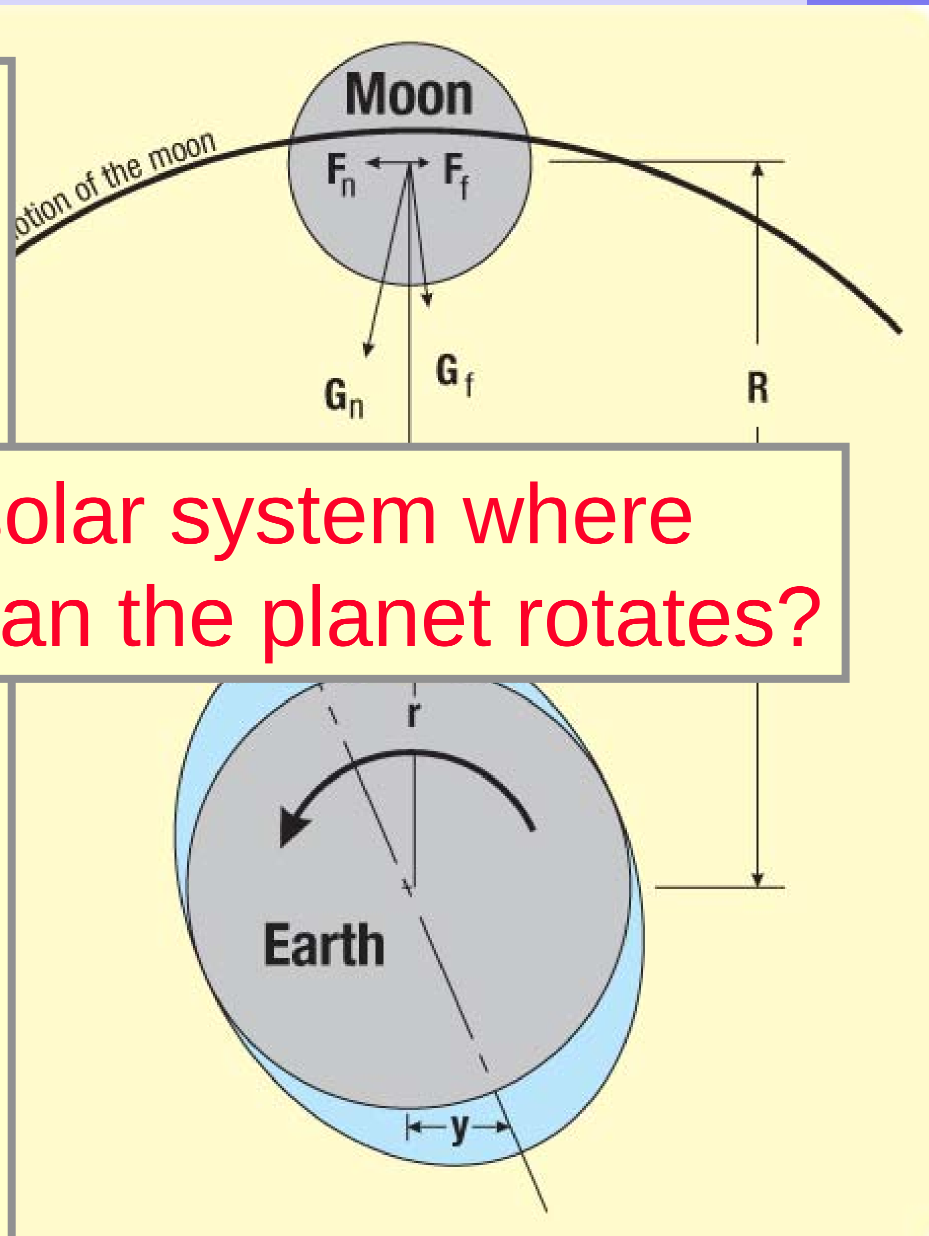
Is there a case in the solar system where a moon revolves faster than the planet rotates?



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- (…
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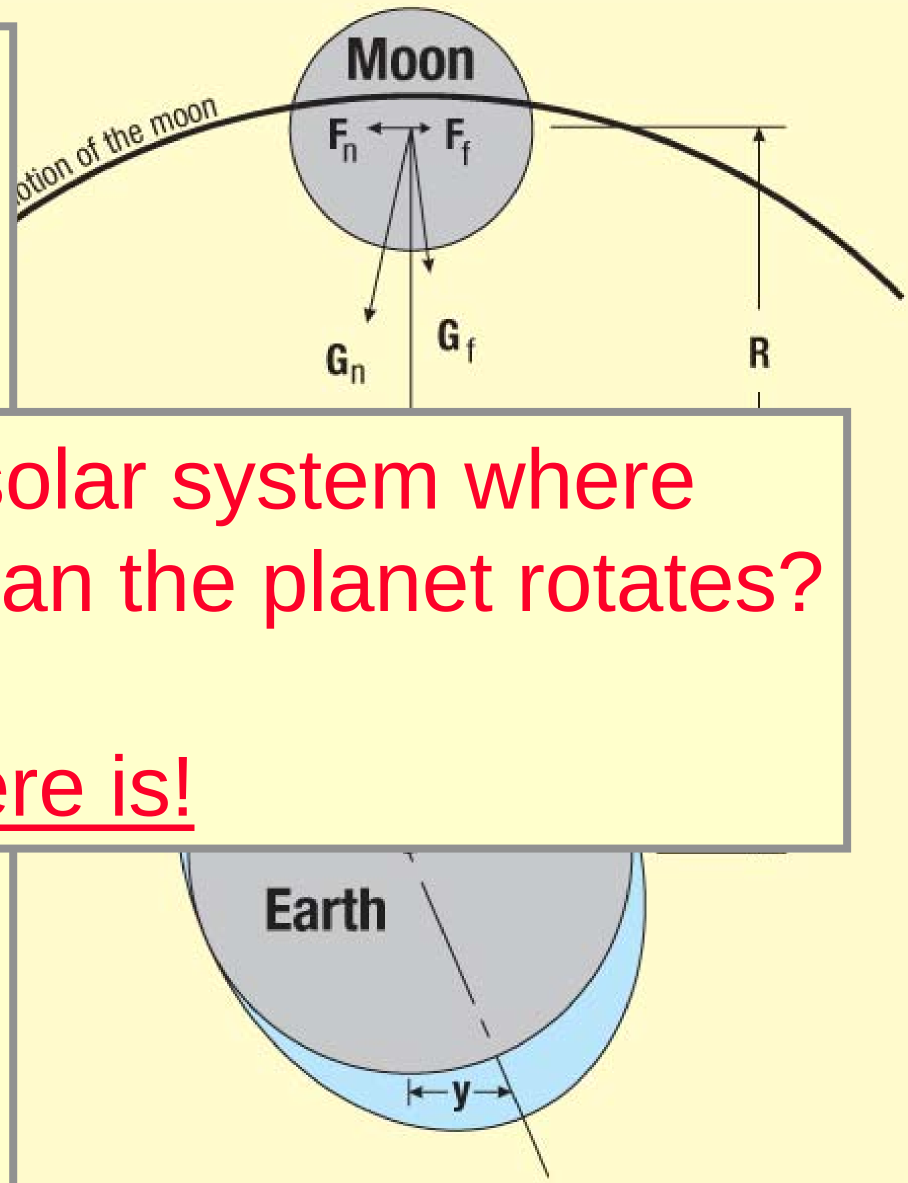
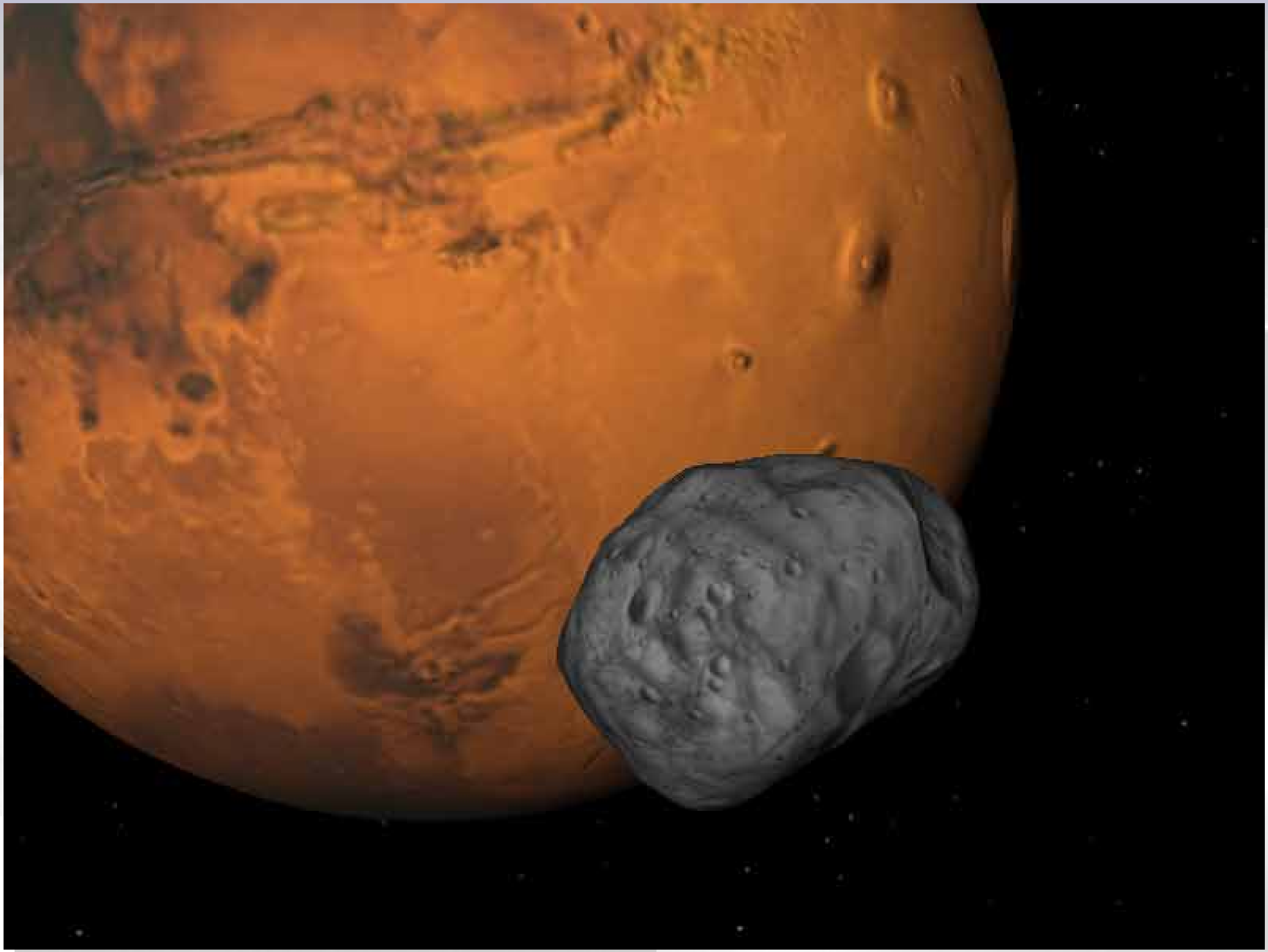


Is there a case in the solar system where a moon revolves faster than the planet rotates?

<u>YES, there is!</u>

The Mars/Phobos case



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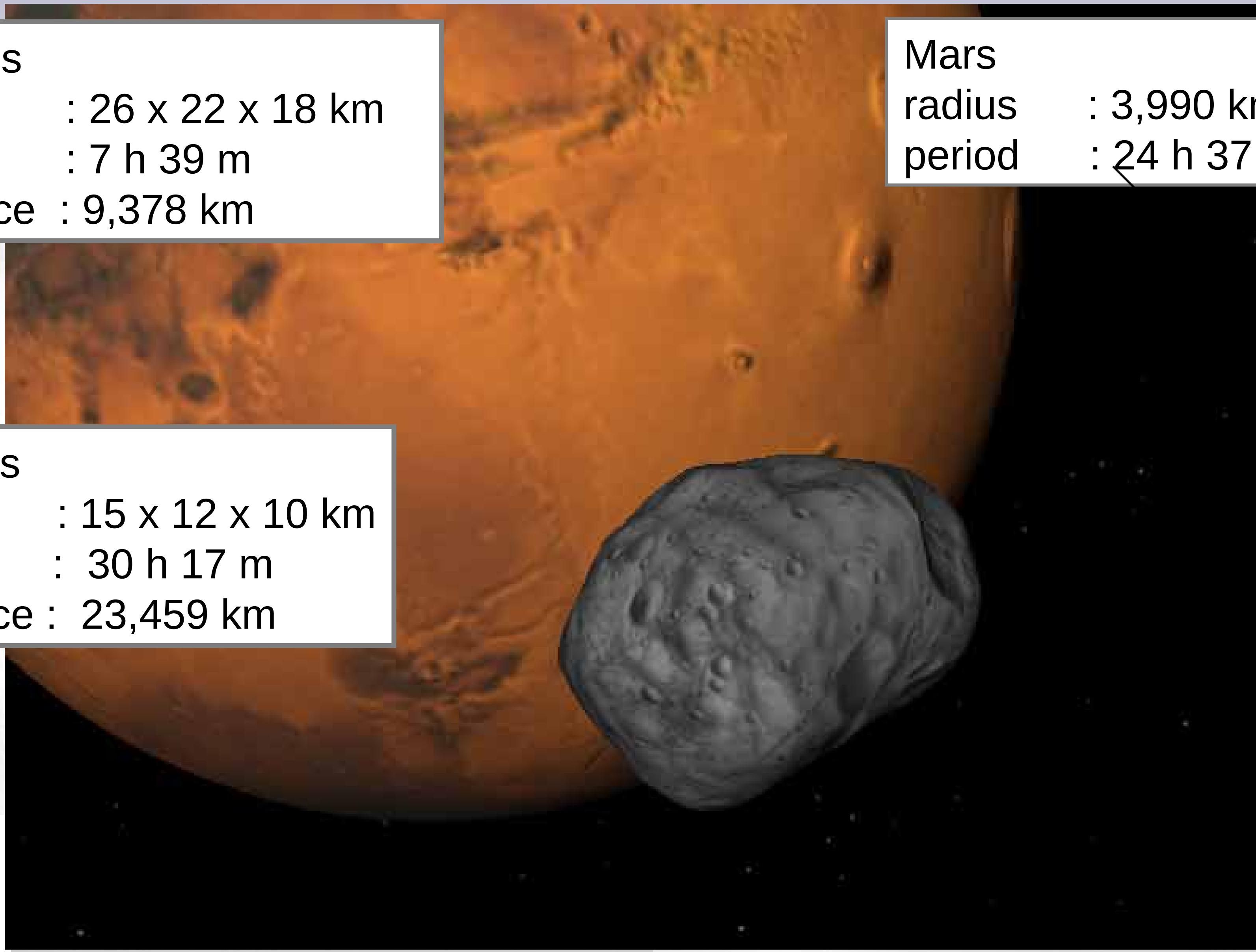
The Mars/Phobos case



Phobos
size : 26 x 22 x 18 km
period : 7 h 39 m
distance : 9,378 km

Mars
radius : 3,990 km
period : 24 h 37 m

Deimos
size : 15 x 12 x 10 km
period : 30 h 17 m
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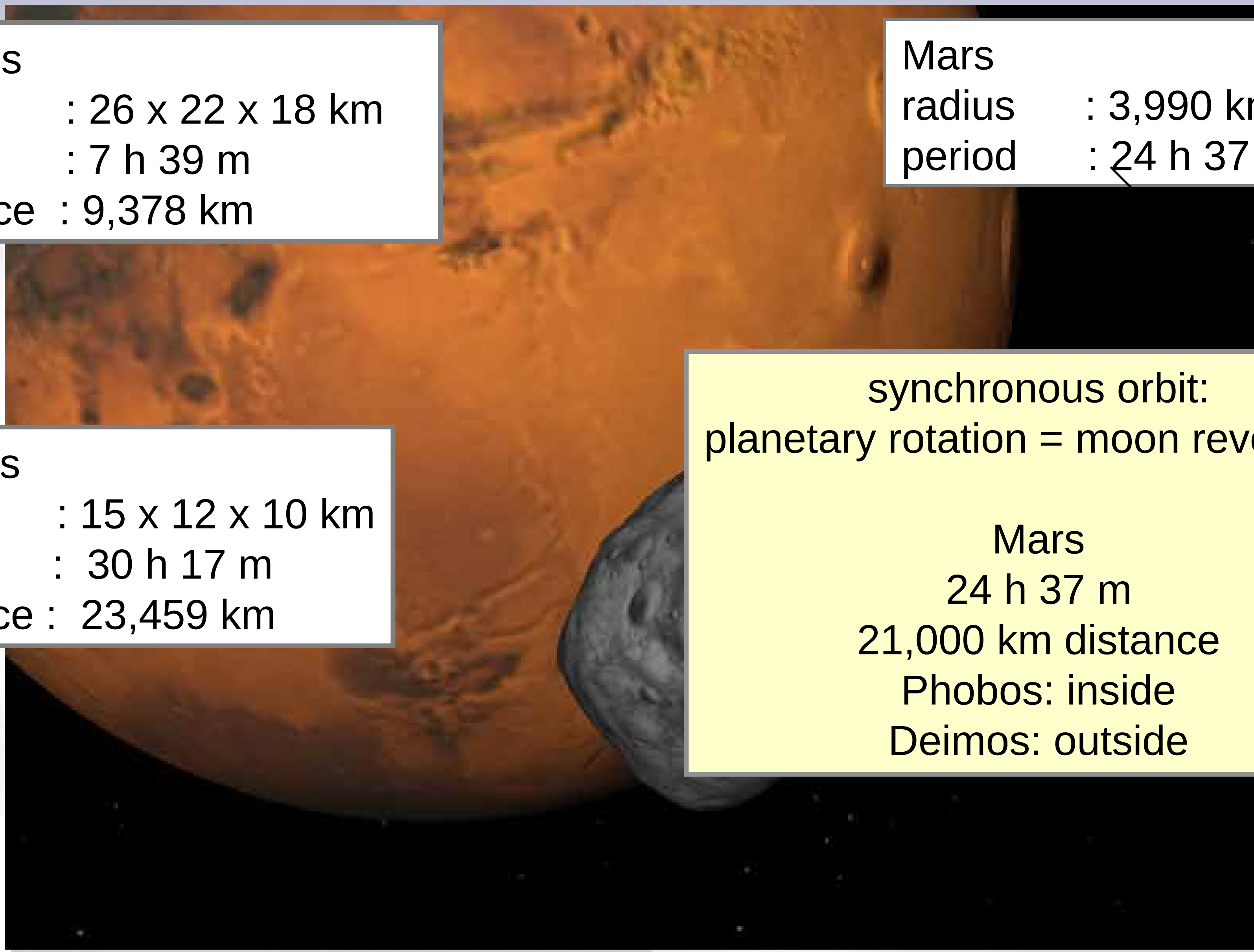

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synchronous orbit:
planetary rotation = moon revolution

Mars
24 h 37 m
21,000 km distance
Phobos: inside
Deimos: outside

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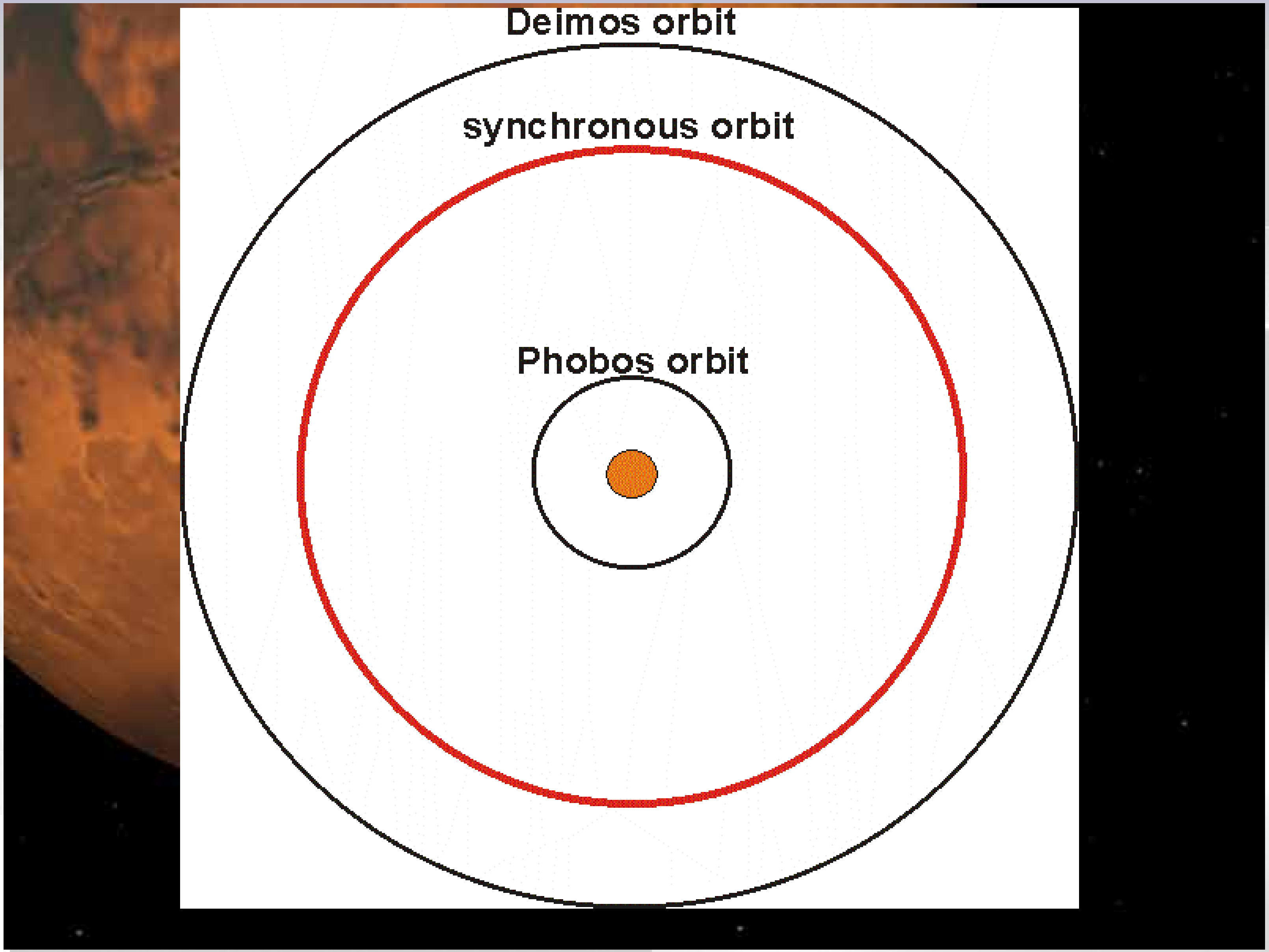
The Mars/Phobos case



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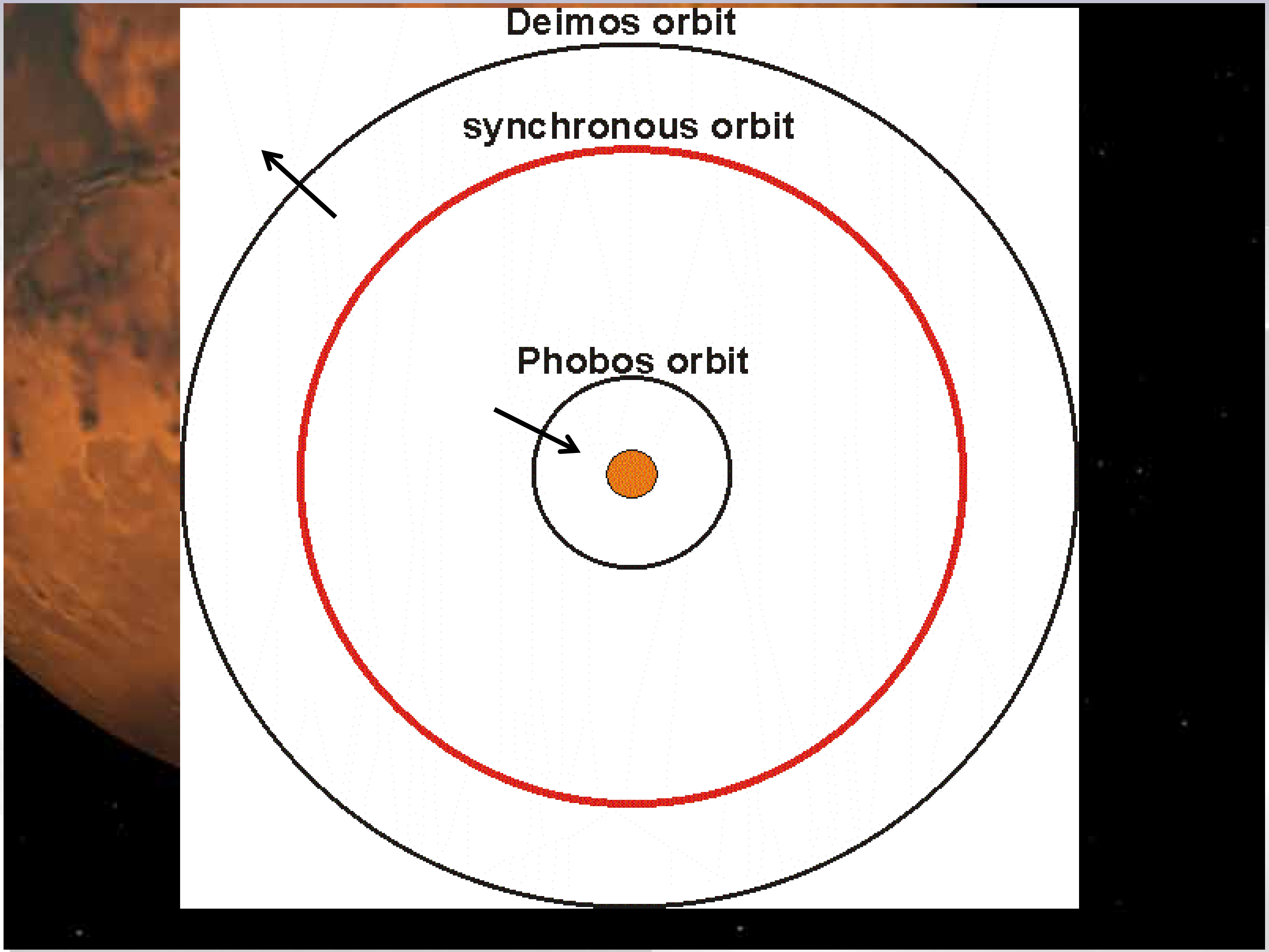
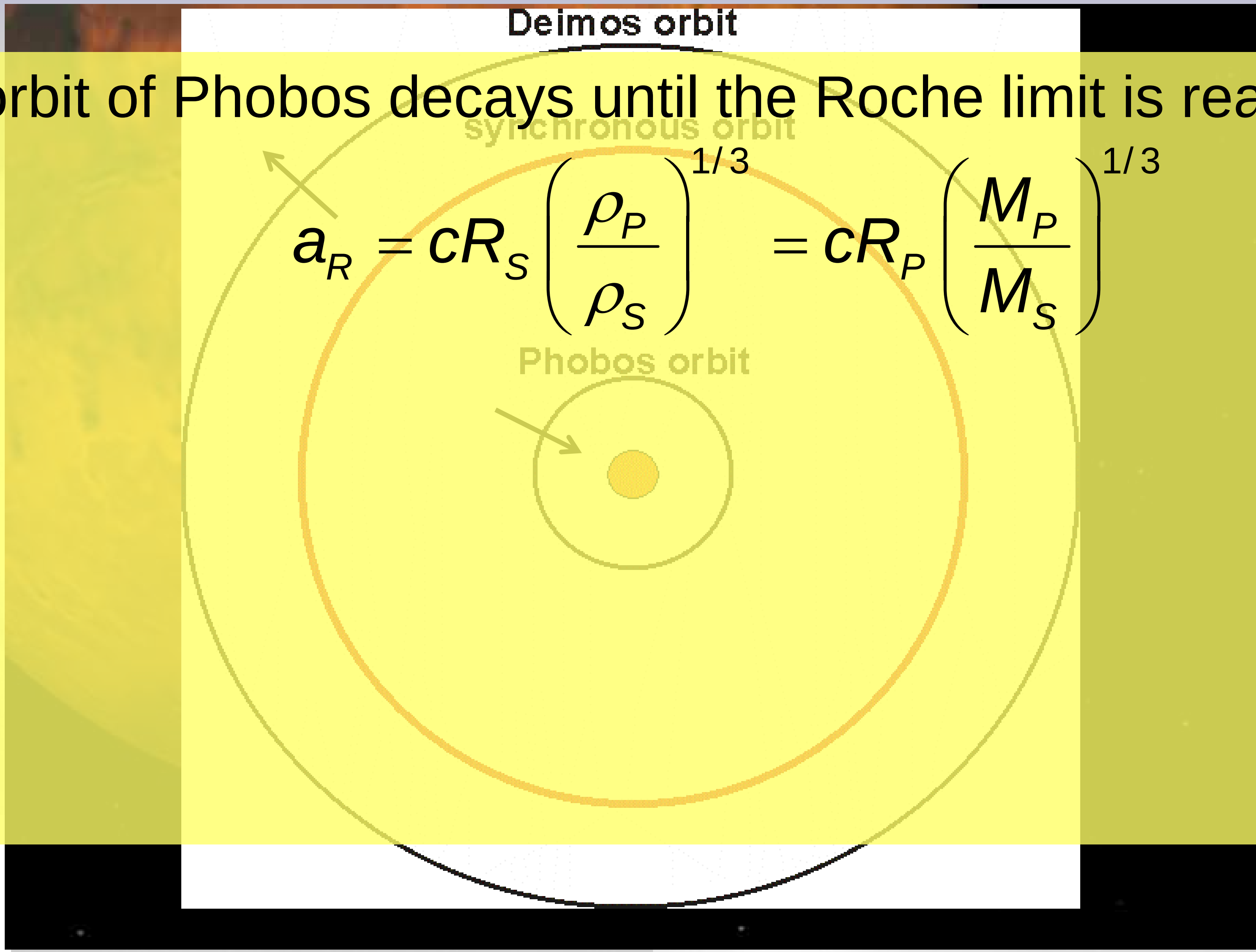


The Mars/Phobos case

The orbit of Phobos decays until the Roche limit is reached.

$$a_R = cR_S\left(\frac{\rho_P}{\rho_S}\right)^{1/3} = cR_P\left(\frac{M_P}{M_S}\right)^{1/3}$$



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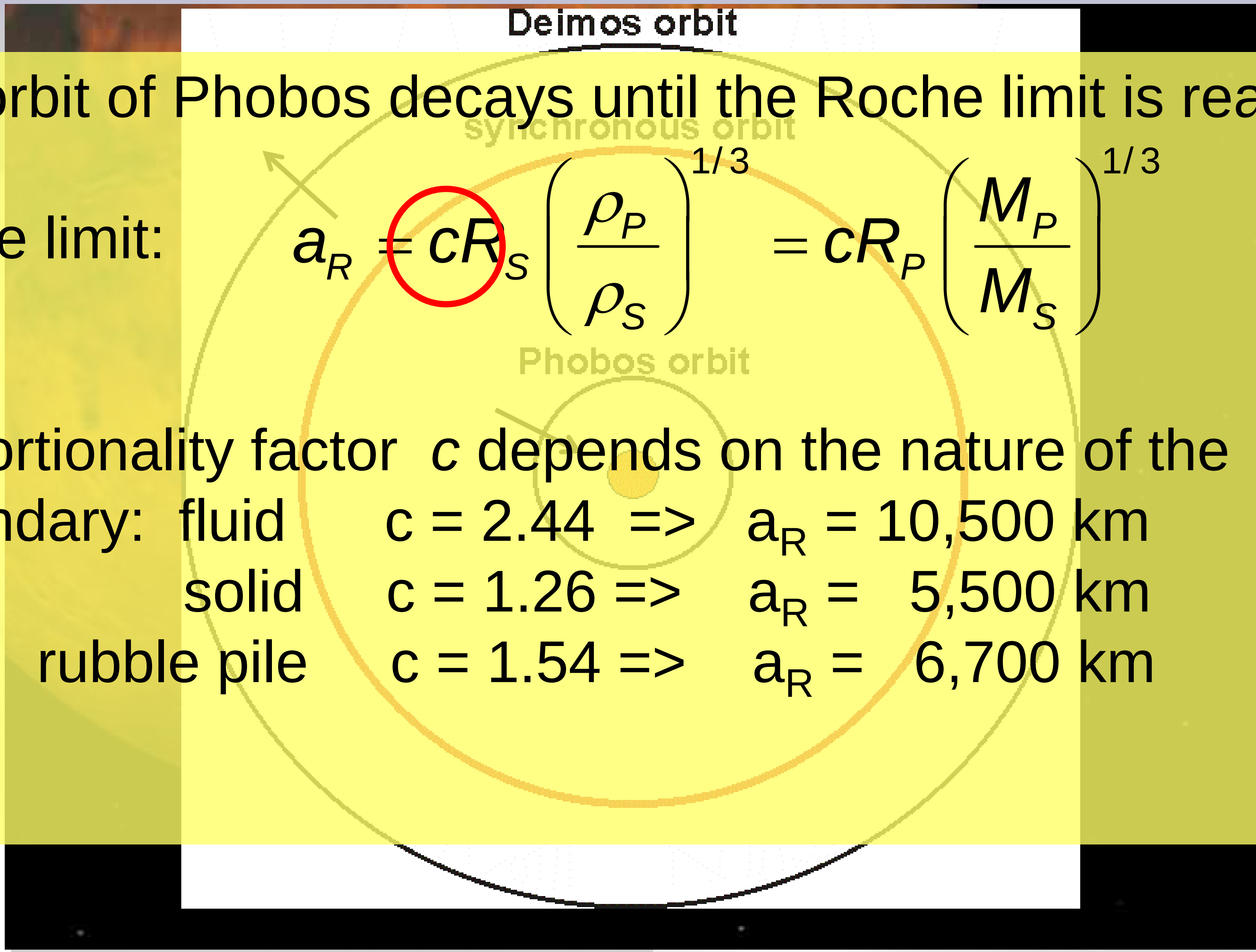

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Proportionality factor *c* depends on the nature of the secondary:

fluid	$c = 2.44$ =>	a_R =	10,500 km
solid	$c = 1.26$ =>	a_R =	5,500 km
rubble pile	$c = 1.54$ =>	a_R =	6,700 km

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rubble pile	$c = 1.54$ =>	a_R = 6,700 km

Phobos is highly porous => „rubble pile“ (Andert et al., 2010)

When will Phobos reach the Roche limit?

$$\tau_{Roche} = \frac{\frac{2}{13}\left(a^{13/2} - a_R^{13/2}\right)}{3\frac{k_{2,Mars}}{Q_{Mars}}\frac{M_{Ph}}{M_{Mars}}R_{Mars}^5\sqrt{GM_{Mars}}}$$

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Other tidal phenomena in the solar system

- forcing Mercury in a 3/2 resonance
- forcing all moons in the solar system into synchronous rotation
- deforming the Jupiter moon Io periodically => tidal heating => volcanic activity
- and the non-plus-ultra:

Other tidal phenomena in the solar system

- forcing Mercury in a 3/2 resonance
- forcing all moons in the solar system into synchronous rotation
- deforming the Jupiter moon Io periodically => tidal heating => volcanic activity
- and the non-plus-ultra: synchronizing the Pluto system

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Tides in extrasolar systems

- studying tides in extrasolar planetary systems requires the knowledge of mass and size of the planet and the star
- feasible with transiting planets combined with radial velocity observations and spectroscopy

- orbital decay => survivability
- stellar spin-up
- spin-orbit coupling => synchronization of rotation and revolution
- circularization => e -> 0

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The tidal potential or the Doodson constant

two tidal potentials:

a)The primary acting on the secondary

b) The secondary acting on the primary

$$D_{ps} = \frac{GM_p}{a^3} R_s^2 \qquad D_{sp} = \frac{GM_s}{a^3} R_p^2$$

The tidal potential or the Doodson constant

two tidal potentials:
a) The primary acting on the secondary
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$$D_{ps} = \frac{GM_p}{a^3} R_s^2 \qquad D_{sp} = \frac{GM_s}{a^3} R_p^2$$

Earth/Moon system:

Earth on Moon
$D_{ps} = 20.9\ m^2/s^2$

Moon on Earth
$D_{sp} = 3.5\ m^2/s^2$

Sun on Earth
$D_{sp} = 1.6\ m^2/s^2$

When will the planet reach the stellar Roche limit?

$$\tau_{Roche} = \frac{\frac{2}{13}\left(a^{13/2} - a_R^{13/2}\right)}{3\frac{k_{2,star}}{Q_{star}}\frac{M_P}{M_{star}}R_{star}^5\sqrt{GM_{star}}}$$

When will the planet reach the stellar Roche limit?

$$\tau_{Roche} = \frac{\frac{2}{13}\left(a^{13/2} - a_R^{13/2}\right)}{3\frac{k_{2,star}}{Q_{star}}\frac{M_P}{M_{star}}R_{star}^5\sqrt{GM_{star}}}$$

stellar property factor

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When will the planet reach the stellar Roche limit?

$$\tau_{Roche} = \frac{\frac{2}{13}\left(a^{13/2} - a_R^{\;13/2}\right)}{3\frac{k_{2,star}}{Q_{star}}\frac{M_P}{M_{star}}R_{star}^5\sqrt{GM_{star}}}$$

- tidal forces affect the evolution of extrasolar planetary systems
  - if $a < 0.1$ AU
  - if M_p is large
  - may force orbits towards e -> 0
  - may lead to the loss of companions
  - may force massive companions into double-synchronous rotation
    - but the companion is not safe….
  - may spin-up stellar rotation (look for old fast rotating stars)

…book your next boat tour when the tide is in!

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