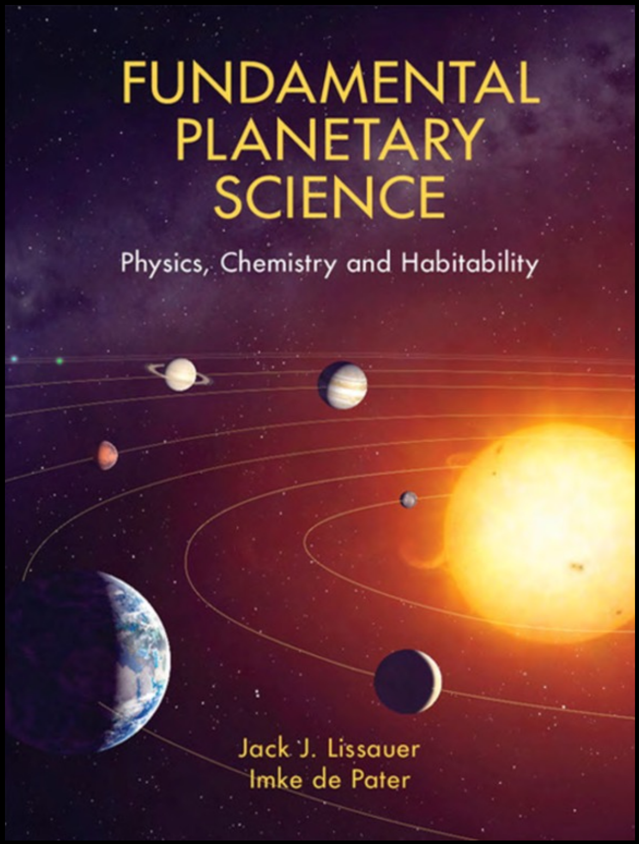
2026.03.09

Introduction to Planetary Sciences

Textbook

Fundamental Planetary Science: Physics, Chemistry and Habitability

By Lissauer J.J., Pater I.d, Cambridge University Press (2019)



Instructor

- Ruobing Dong / rbdong@pku.edu.cn
- Office: KIAA 313
- Office hours: by appointment

Ruobing Dong's Group   Home   Group   Rese

Introduction to Planetary Sc

Lecture Notes

Textbook errata
Lecture 2025.03.02

As

Assig

Assig

Assig

Assig

Ch

thi

• All t
• 2.5 /
/ 4.6.2

三北大课程(PKU Courses)

课程作业

课程作业

创建内容

评估

工具

合作伙伴内容

assignment 1

已启用:
统计跟踪

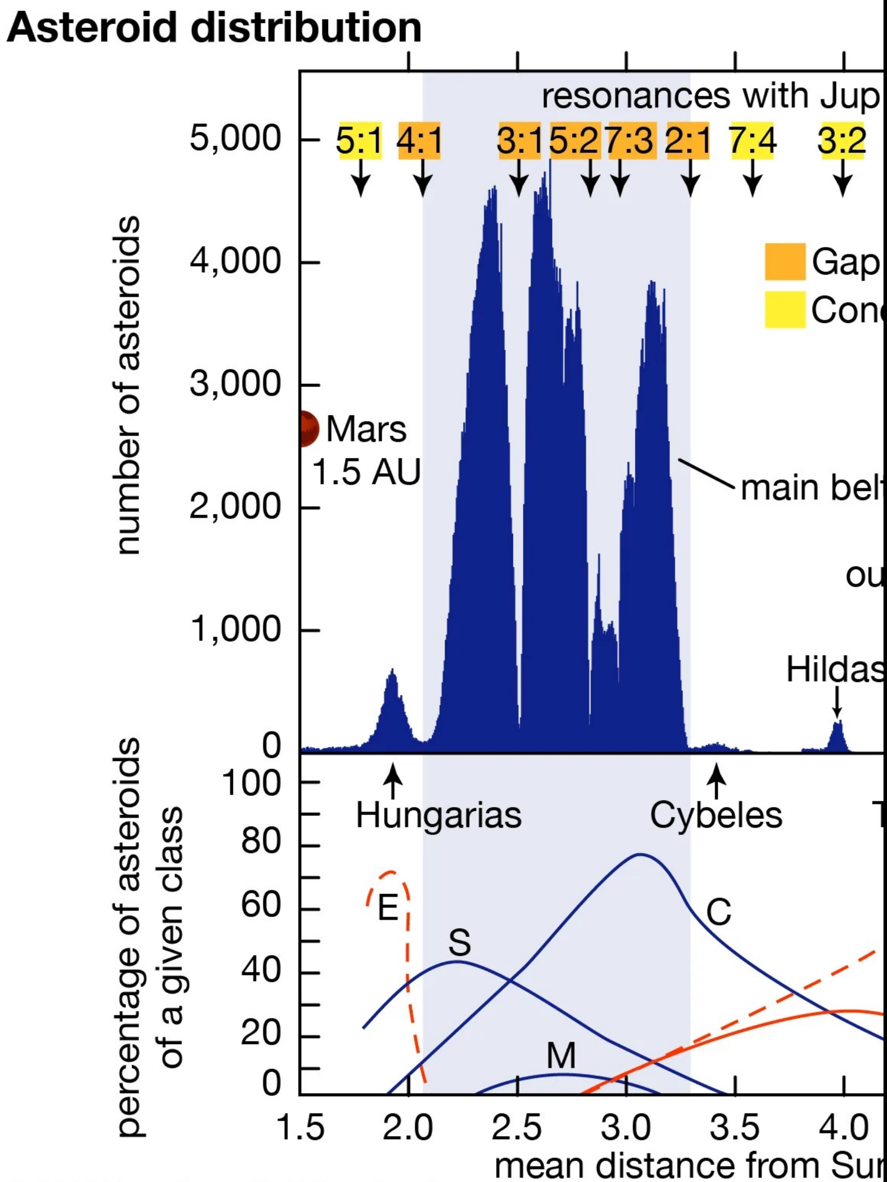
已附加文件:
ASTR255_assignment1.pdf (105.782 KB)

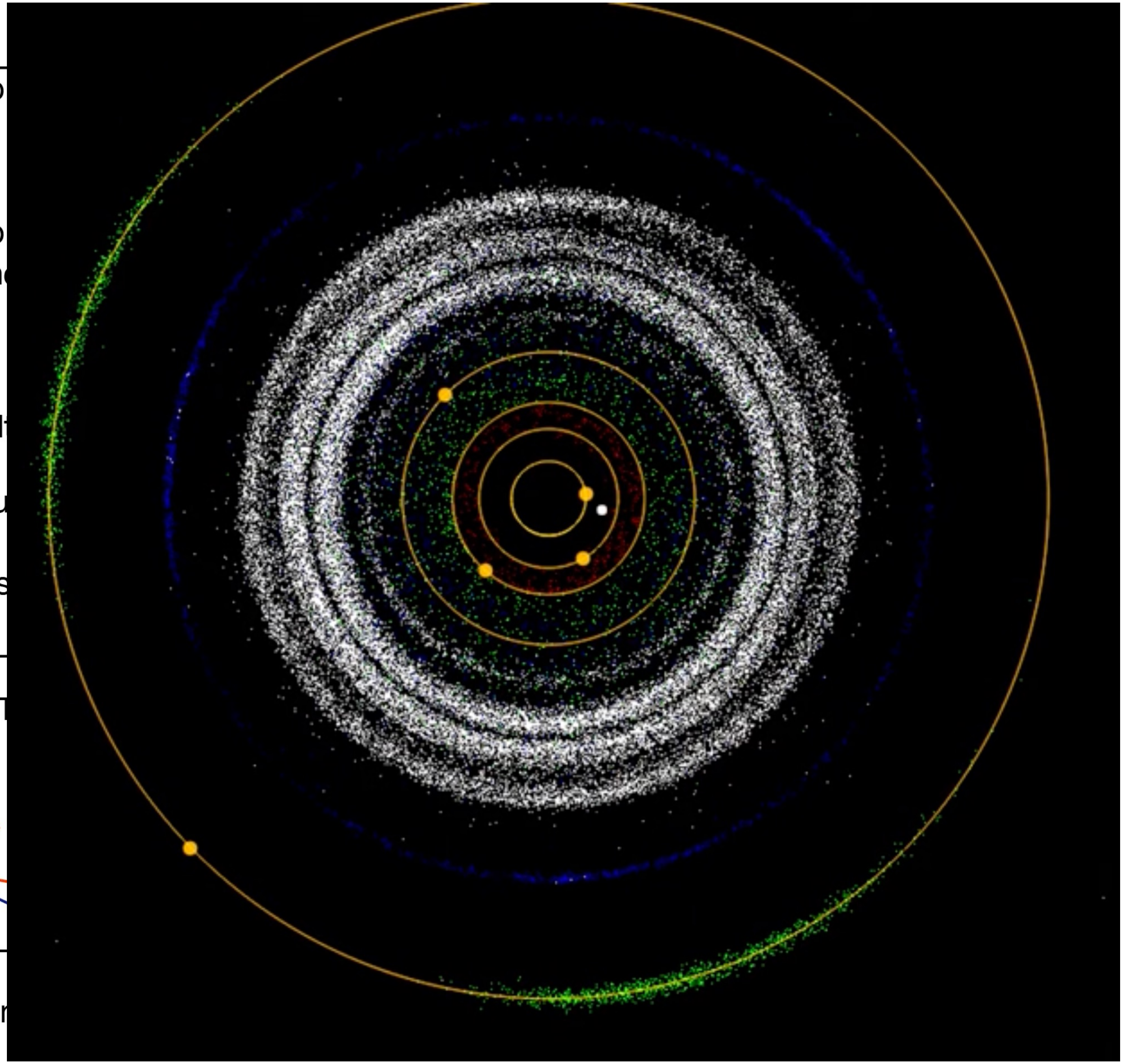
Due date: 11:59 pm, Mar 20, 2026

Late submissions will not be accepted.

If you encounter any issues and are unable to submit your assignment on time, please inform the instructor before the deadline. No excuses will be accepted after the due date.

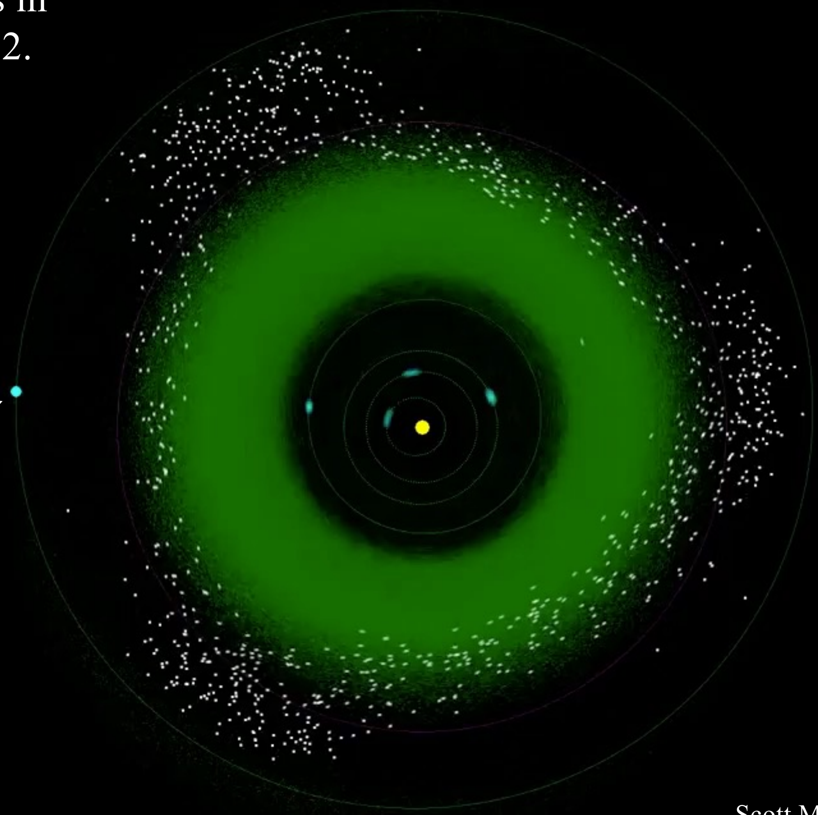
[redacted]


Asteroid distribution
resonances with Jup
5:1
4:1
3:1
5:2
7:3
2:1
7:4
3:2
Gap
Con
number of asteroids
5,000
4,000
3,000
2,000
1,000
0
Mars
1.5 AU
main bel
ou
Hildas
Hungarias
Cybeles
percentage of asteroids
of a given class
100
80
60
40
20
0
E
S
C
M
1.5
2.0
2.5
3.0
3.5
4.0
mean distance from Su



Objects in 3:2 Resonance with Jupiter

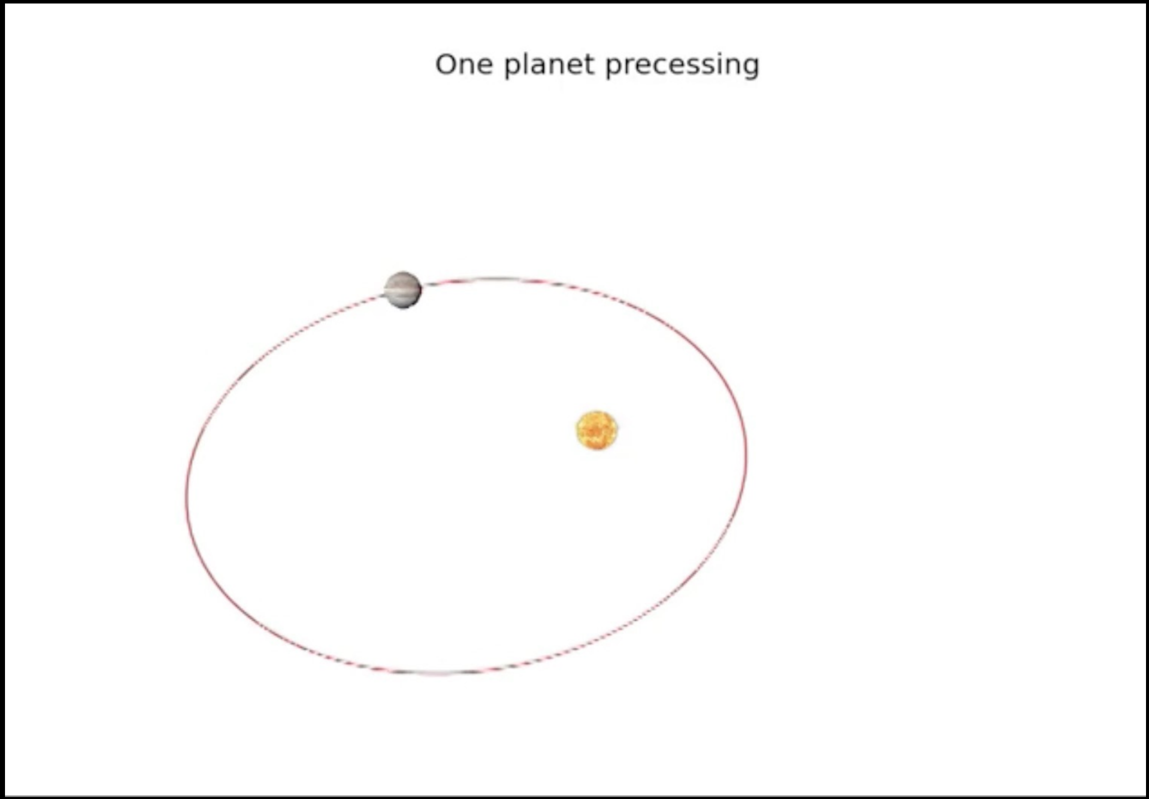
Objects in this group complete 3 orbits in the time that Jupiter takes to complete 2.



A frame corotating with Jupiter's mean motion

Scott Manley
https://www.youtube.com/watch?v=yt1qPCiOq-8

Secular Resonance

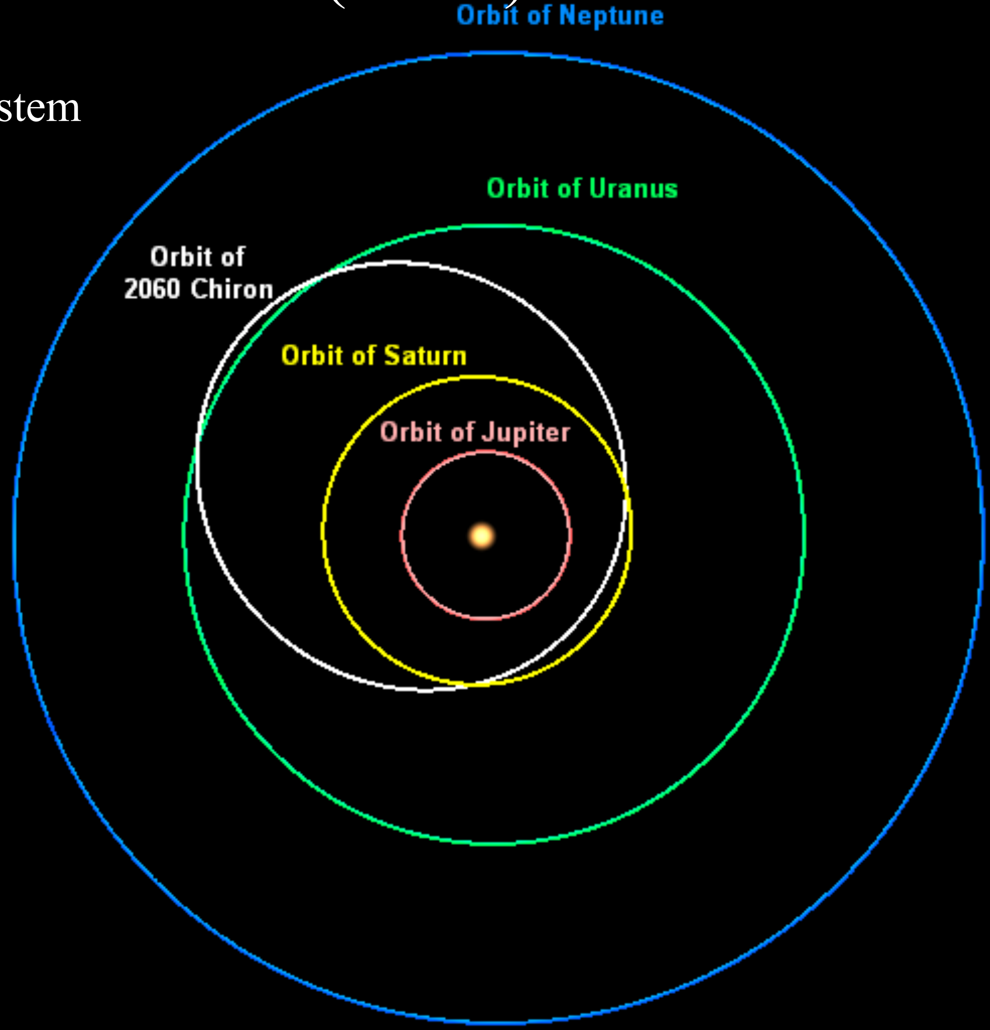


Machinefiend
https://www.youtube.com/watch?v=L3h_OIHU5pc

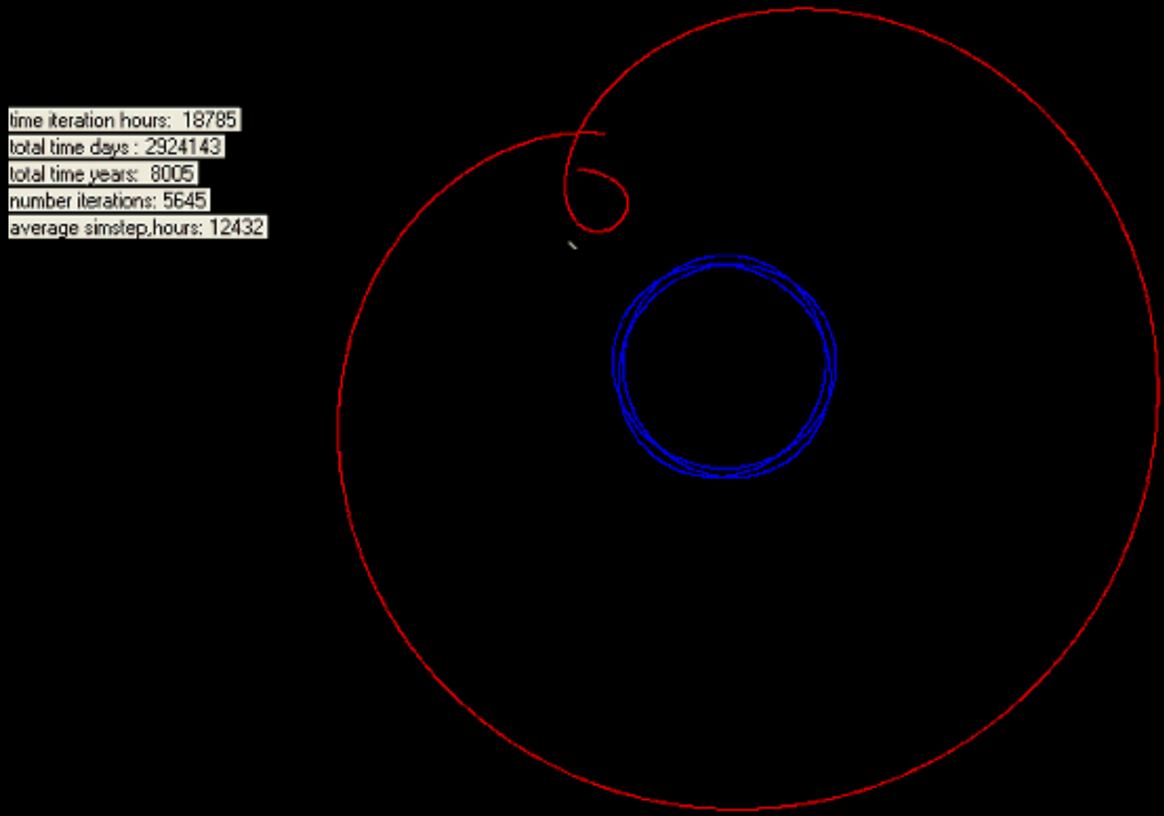
- Secular refers to the long-term motion of a system
- Resonance is when two periods or frequencies are a simple numerical ratio of small integers.
- A secular resonance occurs when the apses or nodes of two orbits precess at the same rate.

Chaotic Motion (C.2.4)

- The evolution of a chaotic system depends sensitively on the system's precise initial state
- The behavior is in effect unpredictable



Reyk
https://en.wikipedia.org/wiki/2060_Chiron



Chaotic, unstable motion of Chiron with Saturn (stationary, white dot at 10 o'clock) and Jupiter (blue)

Gravity (C.2.5)

- Moment of Inertia (C.2.5.1)

$$I \equiv \iiint \rho(\mathbf{r}) r_c^2 d\mathbf{r},$$

- Gravitational potential (C.2.5.2)

$$\Phi_g(\mathbf{r}) \equiv -\int_{\infty}^{\mathbf{r}} \frac{\mathbf{F}_g(\mathbf{r}')}{m} \cdot d\mathbf{r}'.$$

(the integral is path-independent; conservative force)

- Φ_g satisfies the Poisson equation

$$\nabla^2 \Phi_g = 4\pi\rho G.$$

- Φ_g outside a spherically symmetric body is identical to that of a point particle of the same mass.
- $\Phi_g = -Gm/r$ for spherically symmetric objects. What about non-spherically symmetric objects, such as a real planet?

C.2.5, 2.6 Optional

Ruobing Dong's Group — Home | Group | Research | Publications | Media | Teaching

Introduction to Planetary Sciences

Lecture Notes

Textbook errata

Assignments

Assignment 1 (due 23:59, March 20, 2026)

Assignment 2

Assignment 3

Assignment 4

Chapters not covered in this course:

- All the chapters marked by "*" in the book
- 2.5 / 2.6 / 2.7 / 3.1.2 / 3.1.3 / 3.1.4 / 4.5.3 / 4.5.4 / 4.6.1 / 4.6.2 / 5.4 / 5.5.2 / 5.6

Final Pre Sign Up Sheet

【Tencent Docs】 Intro to Planetary Sciences Final Pre Schedule
https://docs.qq.com/sheet/DTVZwU3JESldPem1S?tab=BB08J2

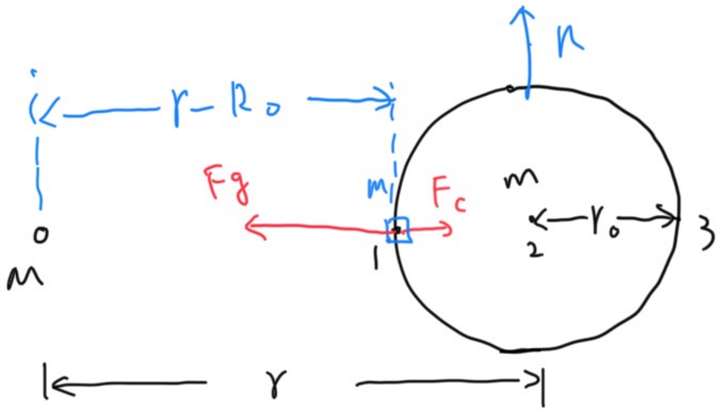
Tide (C.2.7)

Additional reading: https://en.wikipedia.org/wiki/Tide
https://en.wikipedia.org/wiki/Centrifugal_force

- There are two possible ways to hold a secondary object *m* together
  - For a small object, it could be hold together by internal strength.
  - For a large objects, it may be hold together by self-gravity

- But if neither works, the object can be pulled apart.

- This is what happened to Shoemaker–Levy 9



m is in circular orbit around M

$M >> m$, $r_0 << r$

$$\frac{GMm}{r^2} = m n^2 r \Rightarrow n^2 = \frac{GM}{r^3}$$

Now, place a small obj m_1 at 1

In a corotating system, $F_g = \frac{GMm_1}{(r-r_0)^2}$, $F_c = m_1 n^2 (r-r_0) = m_1 \frac{GM}{r^3}(r-r_0)$

$$F_g - F_c = GMm_1\left(\frac{1}{(r-r_0)^2} - \frac{r-r_0}{r^3}\right) = GMm_1 \frac{1}{r^2}\left(\left(1-\frac{r_0}{r}\right)^{-2} - \left(1-\frac{r_0}{r}\right)\right)$$

$$= \frac{GMm_1}{r^2}\left(1+\frac{2r_0}{r} - 1 + \frac{r_0}{r}\right) = \frac{3GMm_1}{r^2}\frac{r_0}{r} > 0$$

has the tendancy to be pulled away! (obj at 3 is pulled to the opposite direction)

Note that the effect is proportional to r_0, and inversely proportional to r^3. So the closer m is to M, the stronger the effect.

Shoemaker–Levy 9

NASA
https://www.youtube.com/watch?v=gbsqWozEBBw&feature=emb_logo

Three Tidal Effects in the Earth-Moon System

Tomruen
https://en.wikipedia.org/wiki/Orbit_of_the_Moon#/

- A modern-d[…] a century ago
- The same effects happens on the moon: tidal locking of the moon – why we can only see one side of the moon.

A modern-day is longer by about
1.7 milliseconds than a century ago

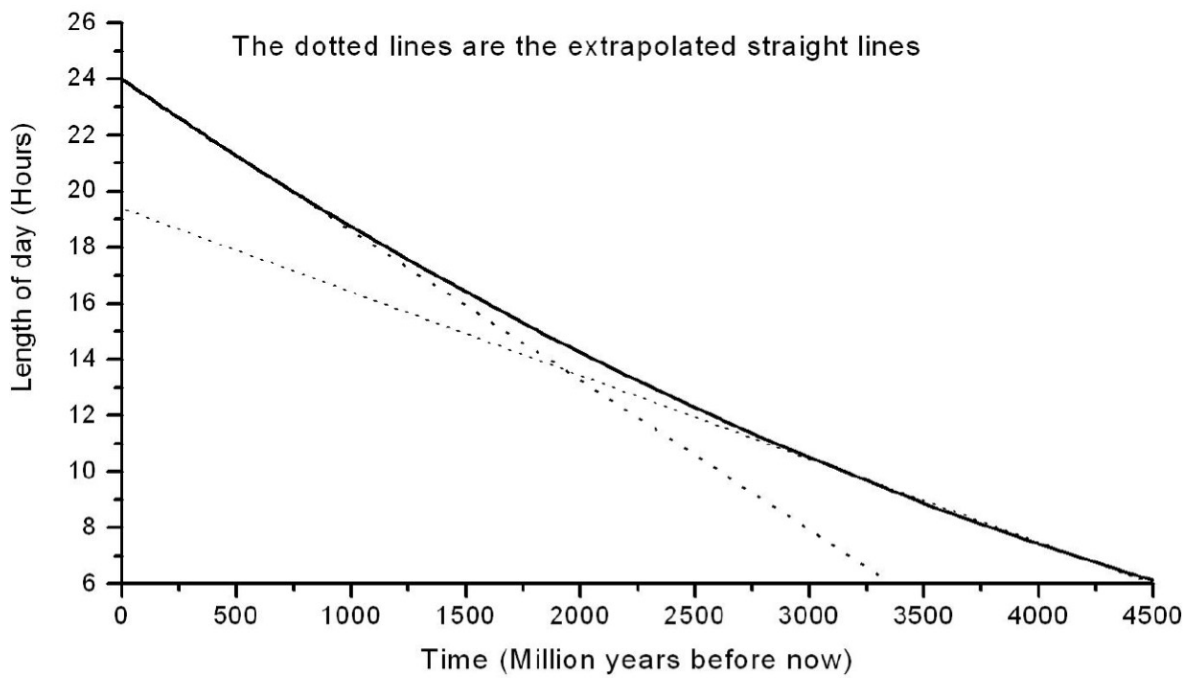
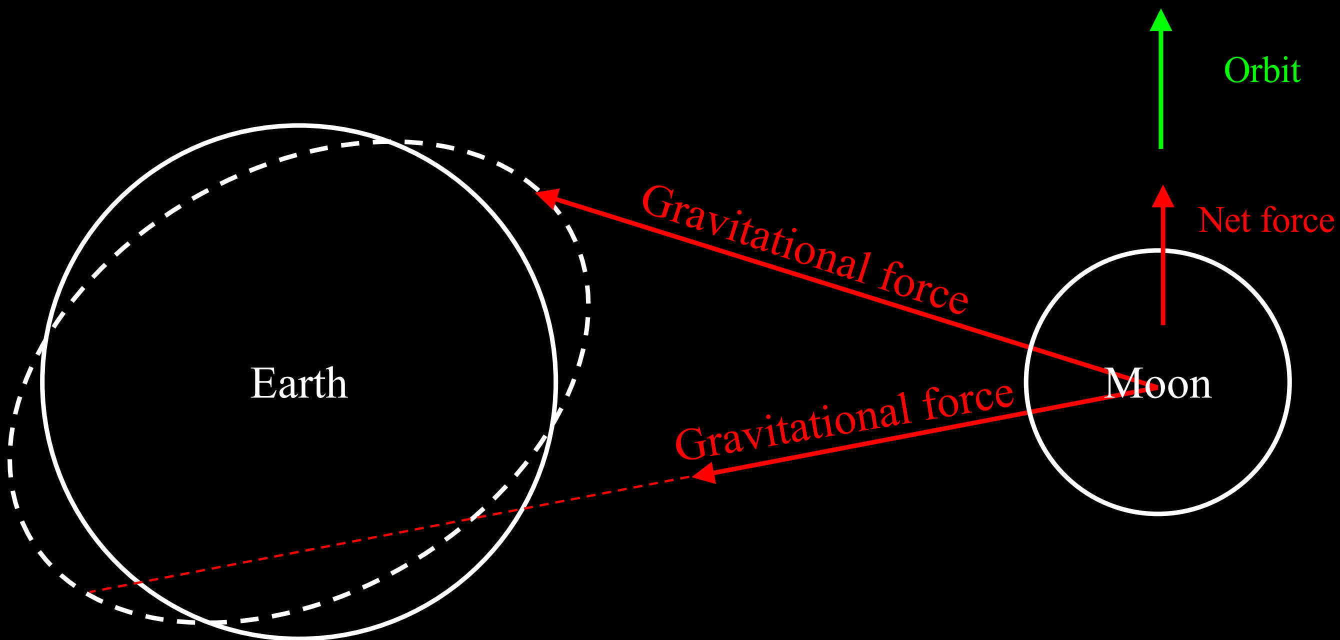


Fig. 1: The variation of length of day versus geological time.

Arbab et al. 2009

The Earth-Moon System



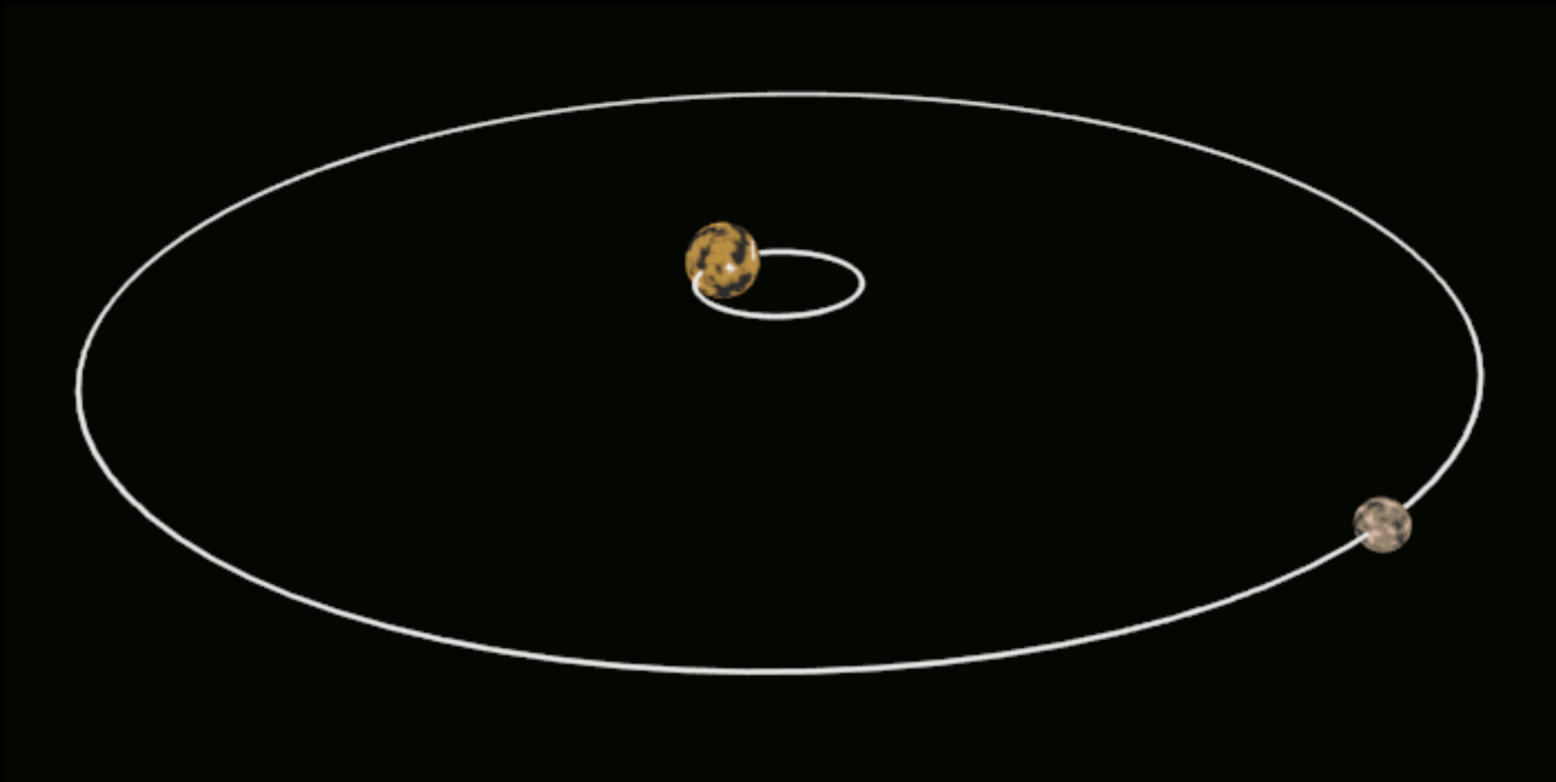
- A modern-day is longer by about 1.7 milliseconds than a century ago
- Tidal locking of the moon – why we can only see one side of the moon.
- Moon is moving away by 38 mm per year.

Moon is moving away by 38 mm per year.

It turns out that this increase in the moon's orbital energy moves it away from Earth at a rate of about 3.8 cm per year. We know this because we can fire a pulse of laser light at the corner cubic laser reflectors left on the moon by the Apollo missions and time its return. 3.8cm per year is not very much perhaps, but over millions of years, it certainly adds up. This means there will come a point in time where the moon is too far away from Earth to fully cover the sun from any point in its orbit. The best estimates we have suggest that in about 650 million years, there will be no point in the moon's orbit around the Earth where it will be able to cover the entire sun, so, no more total solar eclipses.

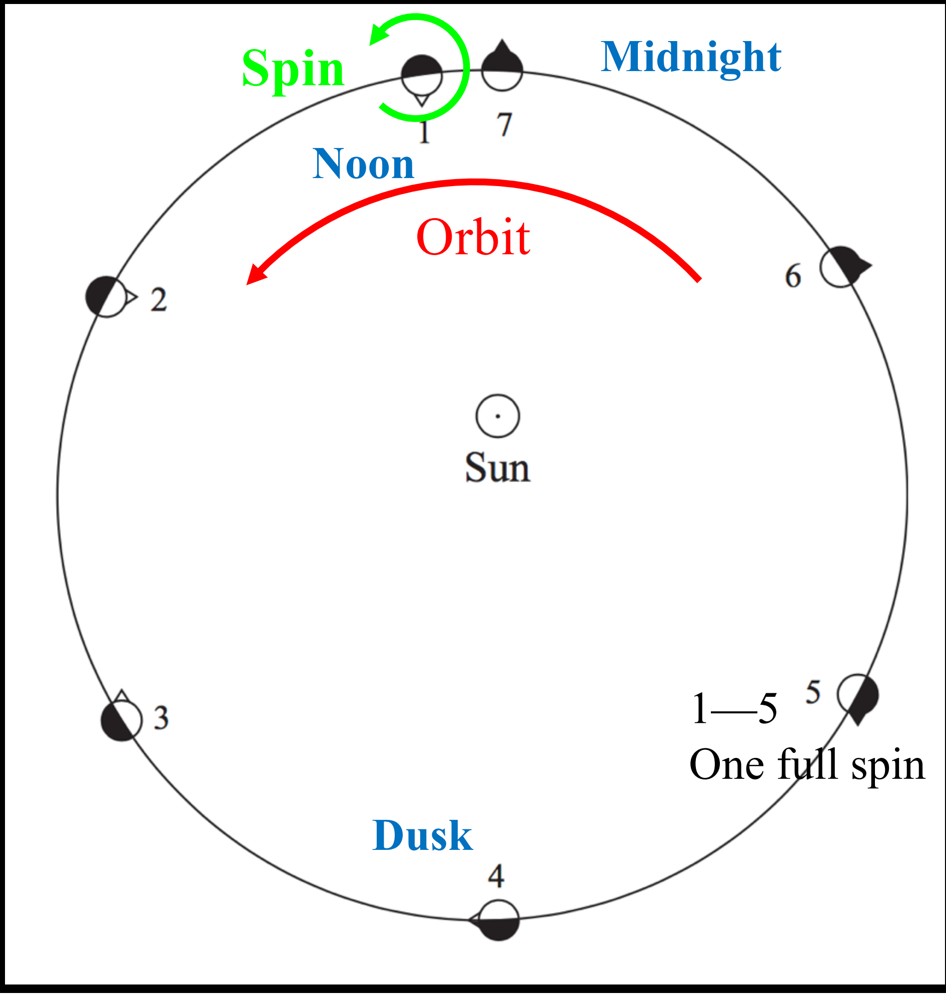
https://web.archive.org/web/20170822023627/https://eclipse2017.nasa.gov/what's-very-last-solar-eclipse

Pluto and Charon Tidal Lock



Stephanie Hoover
https://en.wikipedia.org/wiki/Tidal_locking

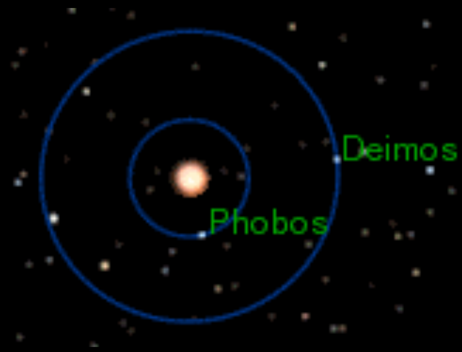
Mercury’s 3:2 Spin-Orbit Resonance



Mecury’s day lasts twice as long as its solar year.

Tidal Effects in the Mars-Phobos System

- *a*: 2.76 Mars radii
- Phobos *P*: ~7.5 hours
- Mars spin *P*: 24.6 hours

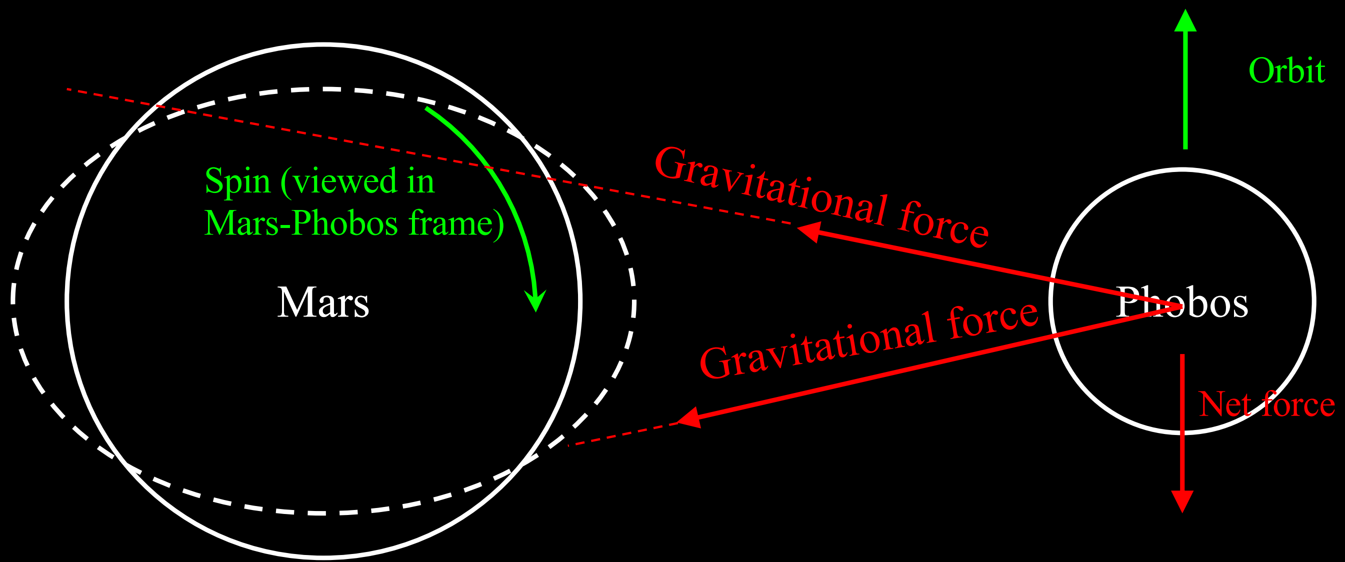


By JiFish https://commons.wikimedia.org/w/index.php?curid=515828

Tidal Effects in the Earth-Moon System

- *a*: 60 Earth radii
- Moon *P*: 29.5 days
- Earth spin *P*: 1 day

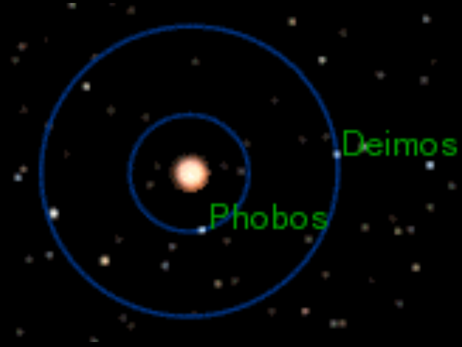
Tidal Effects in the Mars-Phobos System



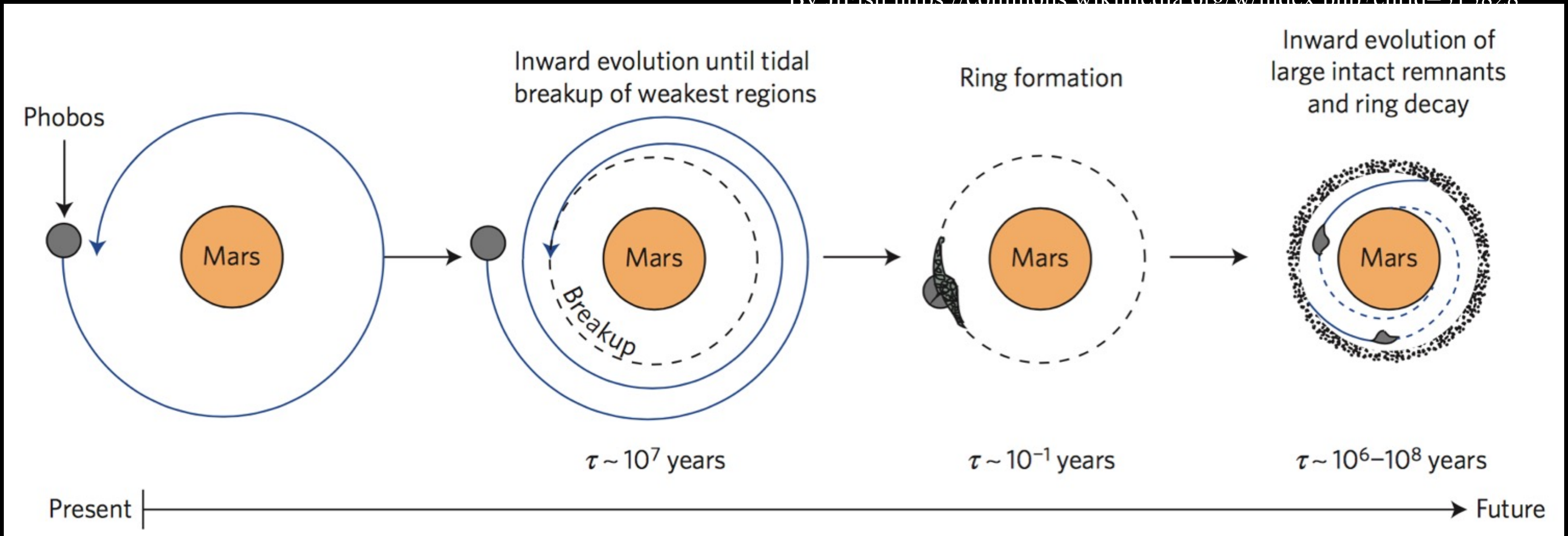
- Phobos orbit is decaying

Tidal Effects in the Mars-Phobos System

- *a*: 2.76 Mars radii
- Phobos *P*: ~7.5 hours
- Mars spin *P*: 24.6 hours

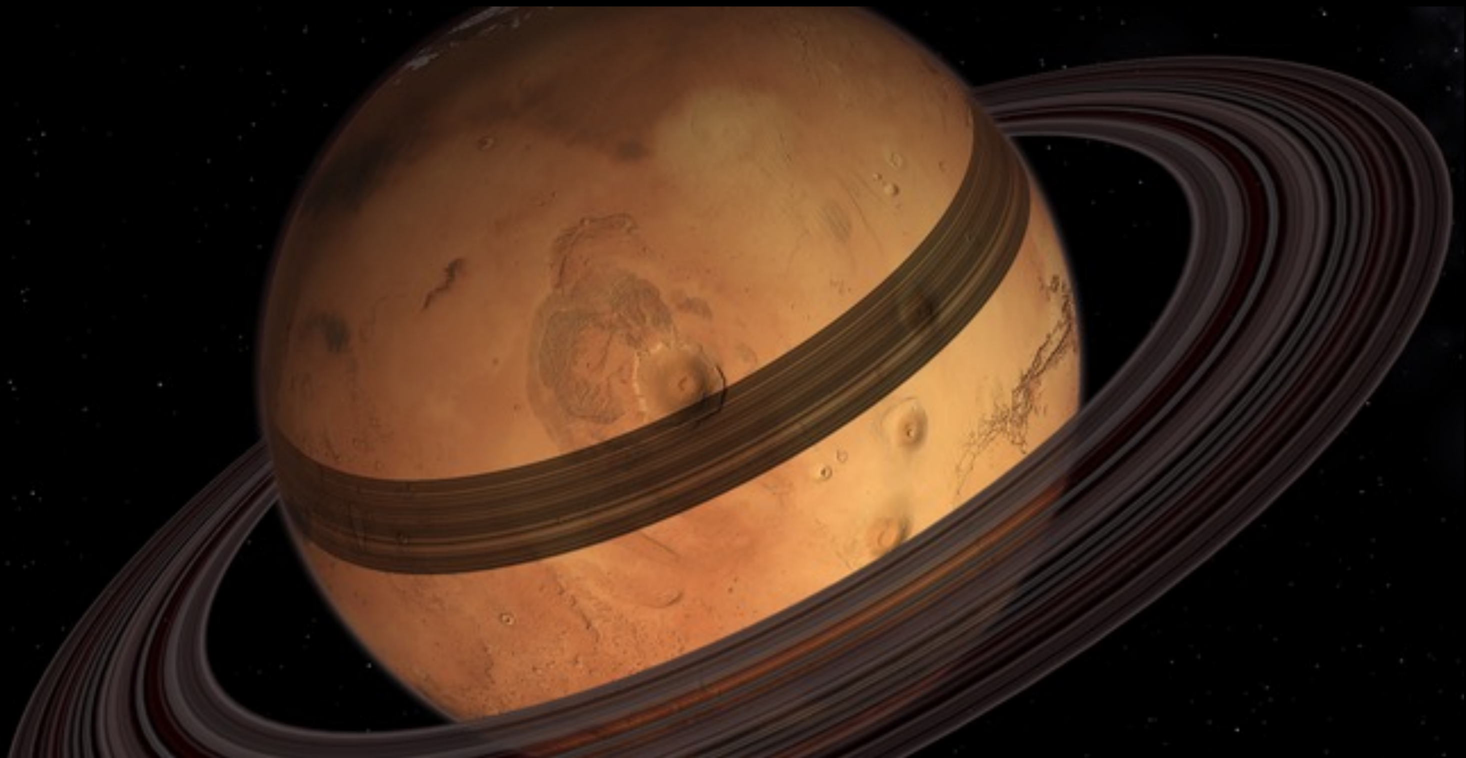


By JiFish https://commons.wikimedia.org/w/index.php?curid=515828



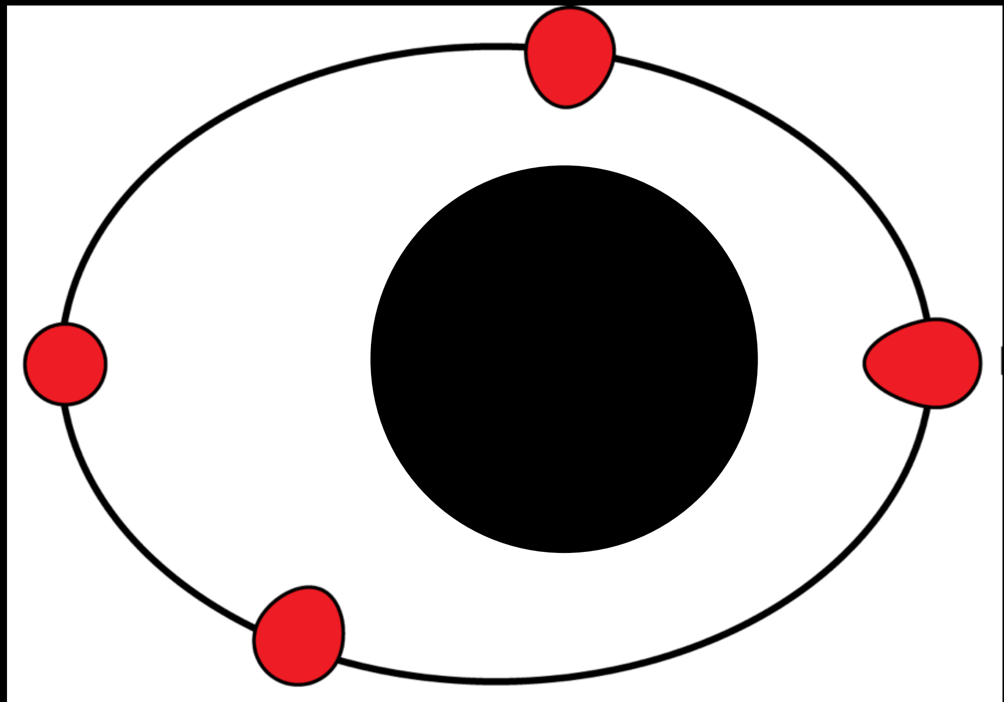
Black & Mittal 2015

In ~10 million years, Mars will Have a Ring!



Black & Mittal 2015

Tidal Heating



Lsuanli
https://en.wikipedia.org/wiki/Tidal_heating_of_Io

Tidal Heating

https://www.nasa.gov/press-release/nasa-missions-provide-new-insights-into-ocean-worlds-in-our-solar-system/

Questions?

Dissipative Forces and the Orbits of Small Bodies (C.2.8)

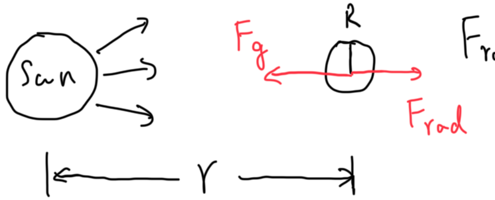
- Radiation pressure
- Poynting-Robertson drag
- Yarkovsky effect

Orbits about a Mass-Losing Star (C.2.9)

Radiation pressure (2.59)

Momentum received per second = F

$p = \frac{E}{c}$ for a photon $\qquad E = I \cdot A$



$$F_{rad} = \frac{L_\odot}{4\pi r^2} \pi R^2 Q_{pr} \frac{1}{c}$$

Energy received per second

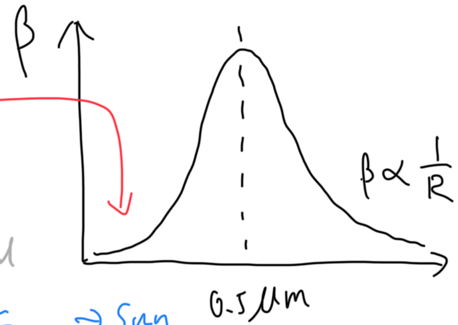
Q_{pr}: coefficient, how well the particle absorb or reflect photons

$$F_g = \frac{G M_{sun} m}{r^2} = \frac{G M_{sun}}{r^2} \frac{4}{3}\pi R^3 \rho$$

$$\beta = \left|\frac{F_{rad}}{F_g}\right| \propto \frac{Q_{pr}}{\rho R}$$

independent of r

how to understand



$$F_{tot} = F_g - F_{rad} = F_g(1-\beta)$$

reduced solar mass

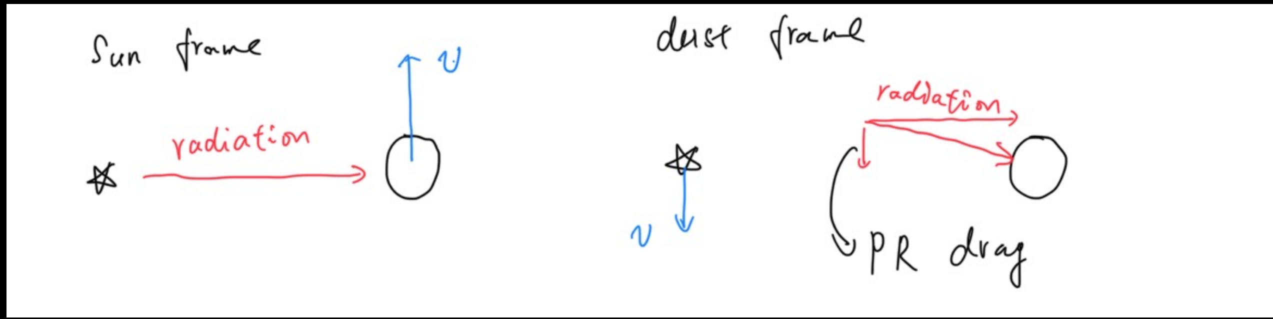
> 0 : F_{tot} → Sun

< 0 : F_{tot} away from the Sun

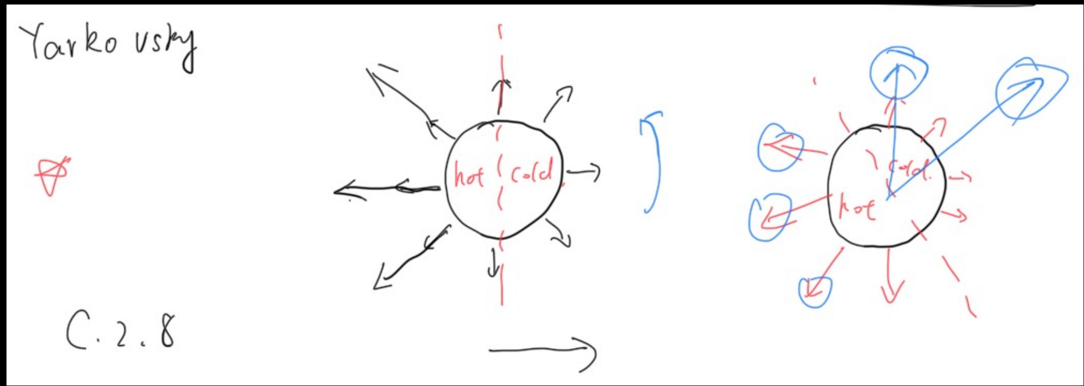
$\beta > 1$, $F_{tot} < 0$, repelled unconditionally

dust released from circular orbits, $\beta > 0.5$, repelled (Assignment 1 P5)

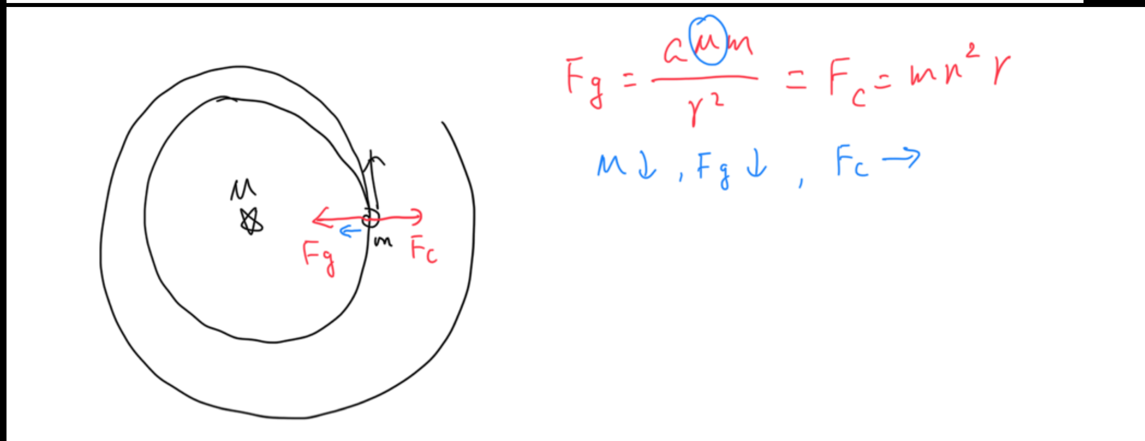
PR drag, alternative view



Yarkovsky effect



Orbits around a mass losing star

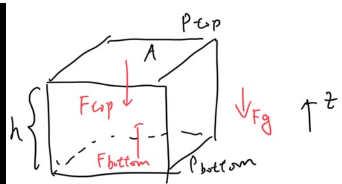


Questions?

Physics and Astrophysics (C3)

- Thermodynamics (C.3.1)
  - Ideal gas law: $p=nkT$
  - 1st law of thermaldynamics (energy conservation): $dQ = dU + PdV$

- Hydrostatics Equilibrium (C.3.2)
  - Additional reading: https://en.wikipedia.org/wiki/Hydrostatic_equilibrium



$$\begin{cases} F_{top} = -P_{top} A \\ F_{bottom} = P_{bottom} A \\ F_g = -mg = -Ah\rho g \end{cases} \Rightarrow \boxed{F_{top} + F_{bottom} + F_g = 0}$$

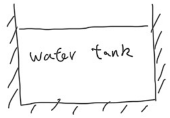
$$-P_{top}A + P_{bottom}A - Ah\rho g = 0 \Rightarrow \underbrace{P_{top} - P_{bottom}}_{\Delta p} = -h\rho g$$

hydrostatic equilibrium

$$\frac{\Delta p}{h} = -\rho g, \quad h \to 0 \Rightarrow \frac{\partial p}{\partial z} = -\rho g$$

may be functions of z

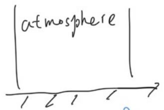
Example ①



$$\frac{\partial p}{\partial z} = -\rho g$$ const, water incompressible

$$\Rightarrow p = -\rho g z$$, go deeper, p linearly increase

Example ②



$$\frac{\partial p}{\partial z} = -\rho g, \quad \rho = \rho(z)$$

$$p = nkT = \frac{\rho}{m_\mu} kT$$

m_μ: mean mol weight. Sometimes $m_\mu = \mu m_a$

$$\frac{kT}{m_\mu}\frac{\partial \rho}{\partial z} = -\rho g \Rightarrow \int_{\rho_0}^{\rho} \frac{\partial \rho}{\rho} = \int_0^z -\frac{m_\mu g}{kT} dz$$

$\frac{m_\mu g}{kT} \to \frac{1}{h(z)}$ scale height

$$\boxed{h = \frac{kT}{m_\mu g}} = \frac{kT(z)}{m_\mu(z)\, g(z)} = h(z)$$ scale height

$$\ln \rho/\rho_0 = -\int_0^z \frac{dz}{h(z)} \Rightarrow \rho = \rho_0 e^{-\int_0^z \frac{dz}{h(z)}}$$

If m_μ, T, g are independent of z, then $h(z) = const$

$$\rho = \rho_0 e^{-\frac{z}{h}} \quad (3.18)$$

$$p \propto \rho \propto e^{-\frac{z}{h}}$$