Notice PLEASE

- **TIMESTEP (Wednesday; 5 pm in N305)**

The mass of Sirius A ≈ 2 M_{Sun}. Use the diagram to estimate the mass of Sirius B.

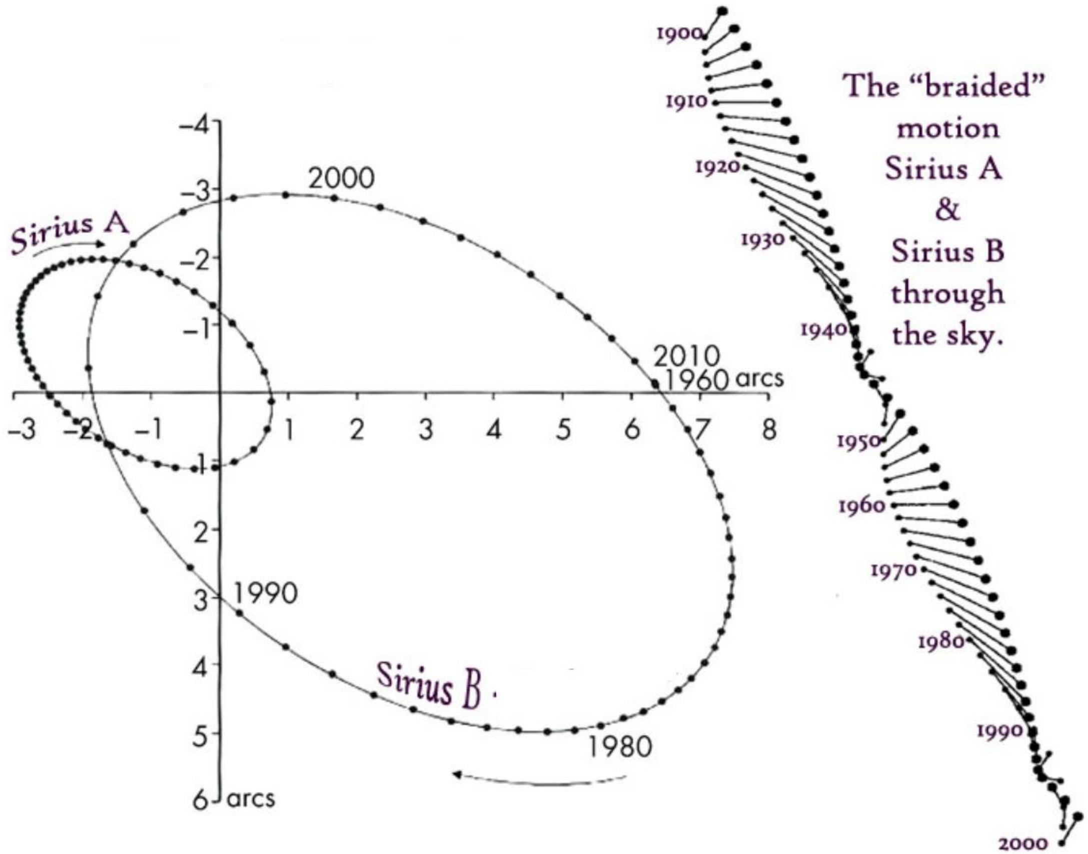


Figure 14.2: The orbits of Sirius A and B about the common centre of mass of the binary system, and their projection on the sky.

The Sirius AB Star System

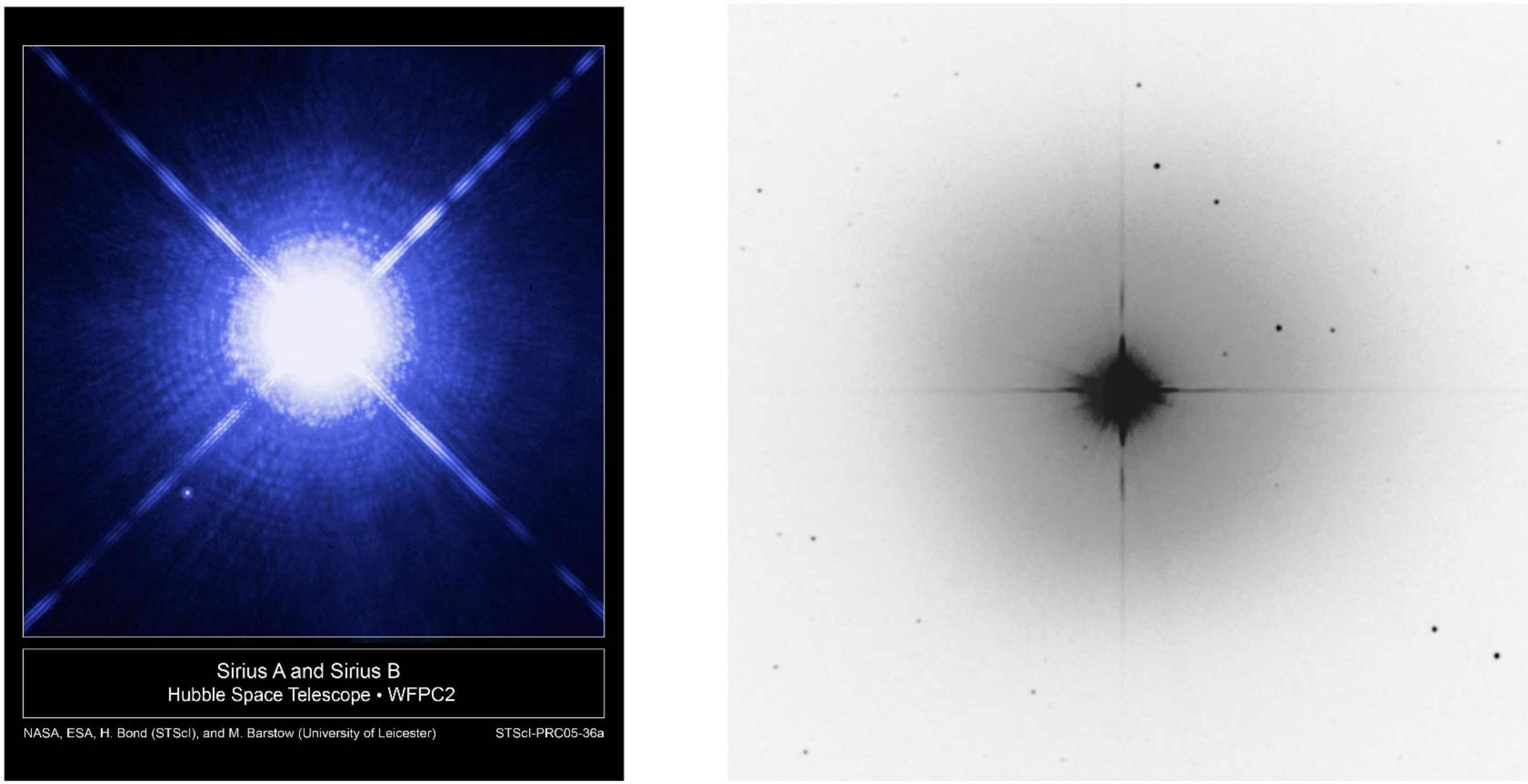


Figure 14.1: Sirius A and B, as seen by the 2.5 m *Hubble Space Telescope* (left) and a ground-based 18-in Celestron (right).

M71: Globular Cluster

Virial Theorem

$$2\langle T\rangle + \langle U\rangle = 0$$

- **$2T = Nmv^2 = Mv^2$**

- **m is individual mass**
- **N is number of objects with mass (m) and average speed (v)**

- **$U = -\alpha GM^2/R$**
- **α is a constant depending on how the mass is distributed**
- **R is the object's radius**

- **$Mv^2 = \alpha GM^2/R$**
- **$M = v^2R/\alpha G$ = "virial mass"**

Meaning of “velocity dispersion”

The average speed of the stars is -22.34 +/- 3.29 km/sec.

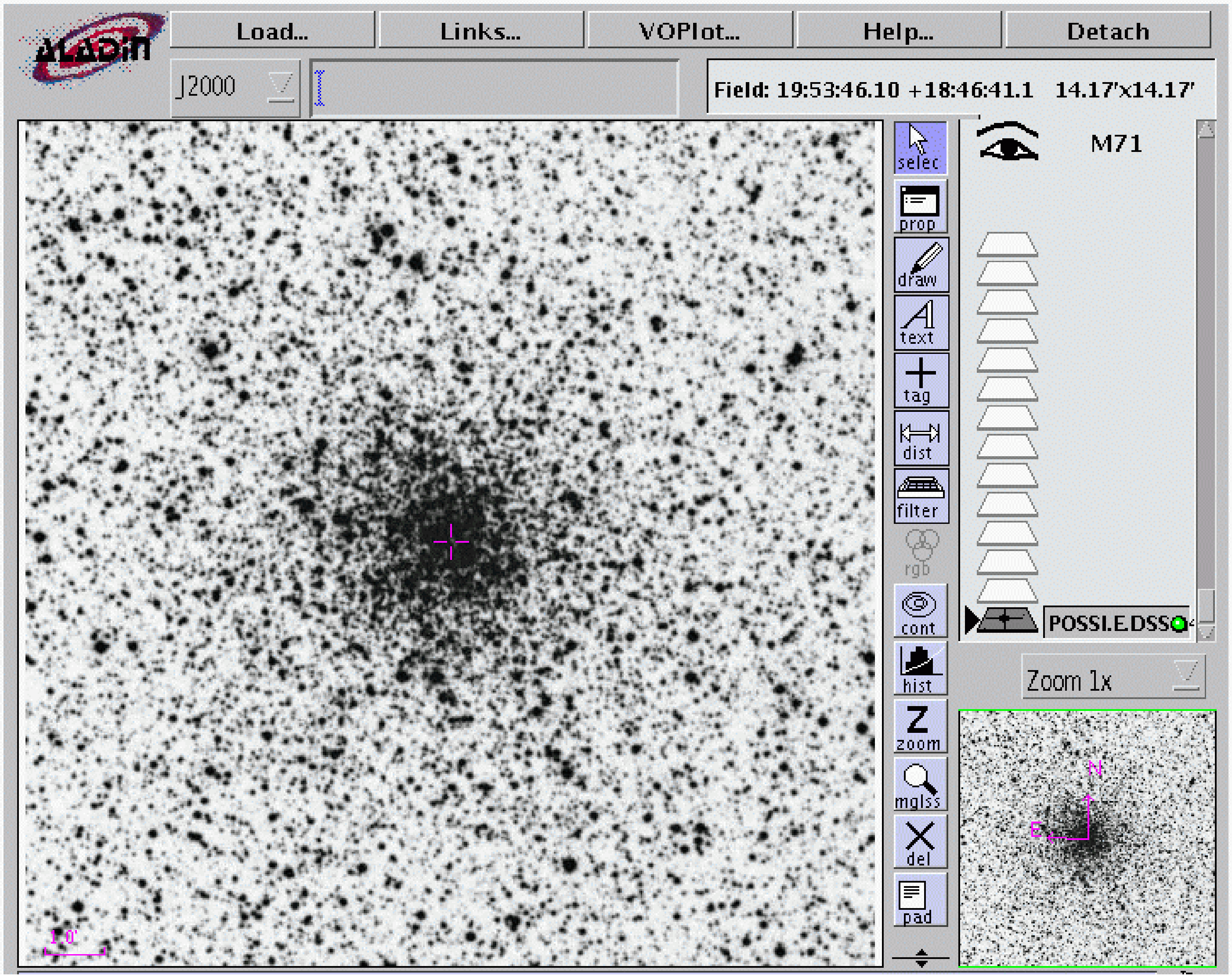
The “velocity dispersion” (v) of 3.29 km/sec is a measure of the internal motion of the stars within the cluster.

Technically, “v” is <u>one component</u> of the stars’ 3D velocities. The Doppler Shift of spectral lines measures “radial velocity.”

$$\mathrm{KE}_{\mathrm{avg}} = \frac{1}{2} m v^2 = \frac{1}{2} m (3\sigma_r^2)$$

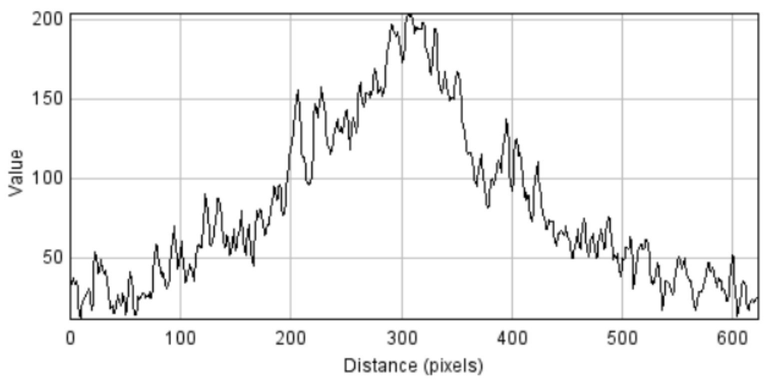
Calculate the Virial Mass of Globular Star Cluster M71

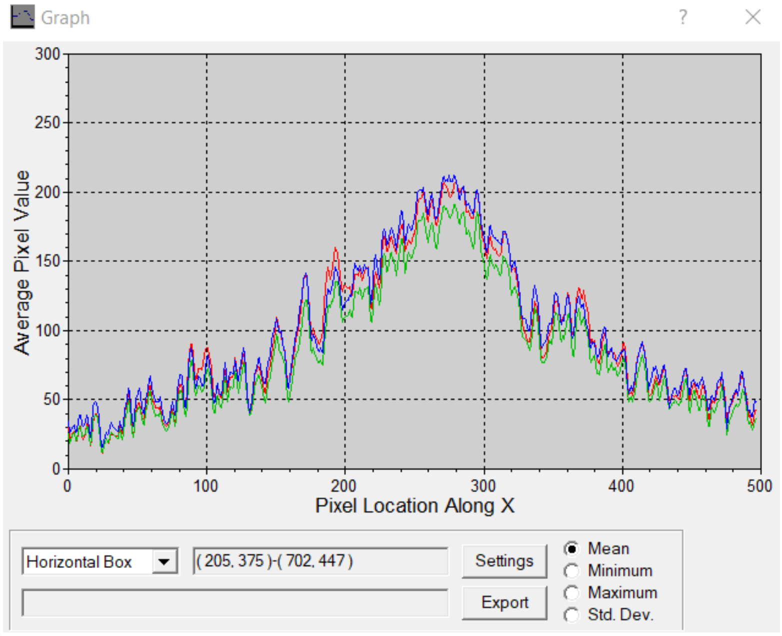
distance = 3.8 kpc



What is "R"?
image processing

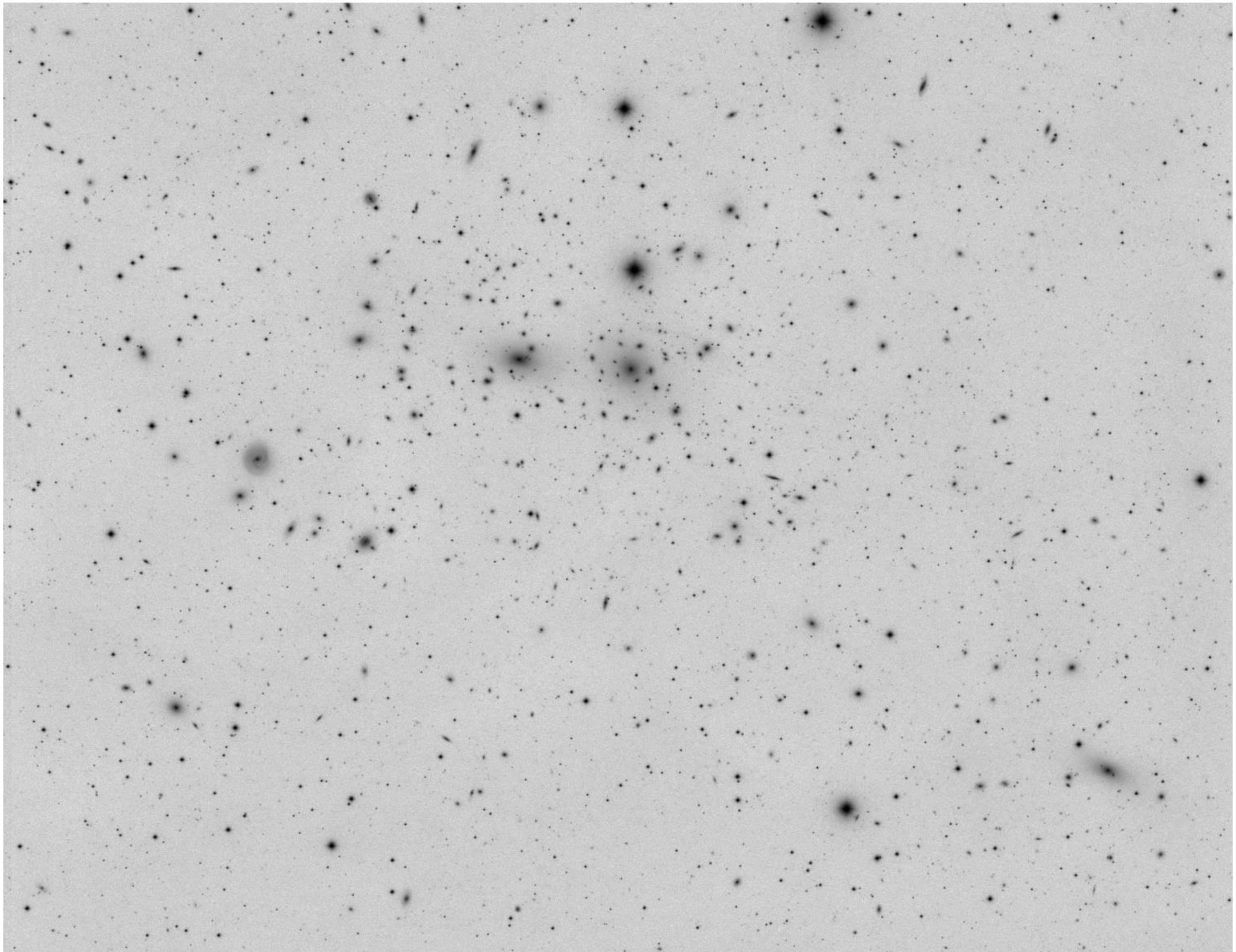
- **Software tools you can download for free:**
  - SAOImage ds9
  - AstroImageJ
  - MaxIm DL





Coma Cluster of Galaxies

~1000 galaxies; 320 Mlyrs distant



Problem
Zwicky: “Dunkle Materie”

- **The Coma Cluster of galaxies:**
  - **~1000 galaxies, each with ~10^9 M_{Sun}**
  - **R = 2 x 10^6 light-years (613 kpc)**
  - **V = 1000 km/sec**

- **Apply the Virial Theorem to calculate the expected virial mass of the cluster:**
  - **$M = v^2 R/\alpha G$**
  - **G = 6.67 x 10^{-8} $cm^3 g^{-1} sec^{-1}$**

The r^{-2} Effects of Gravity:
tides, Roche Limit, Hill Sphere

- **bdbsdbwdgb**

Compare Tides on Earth: Moon and Sun

$$\frac{dF_{moon}}{dr} = \frac{2GMm}{r^3}$$

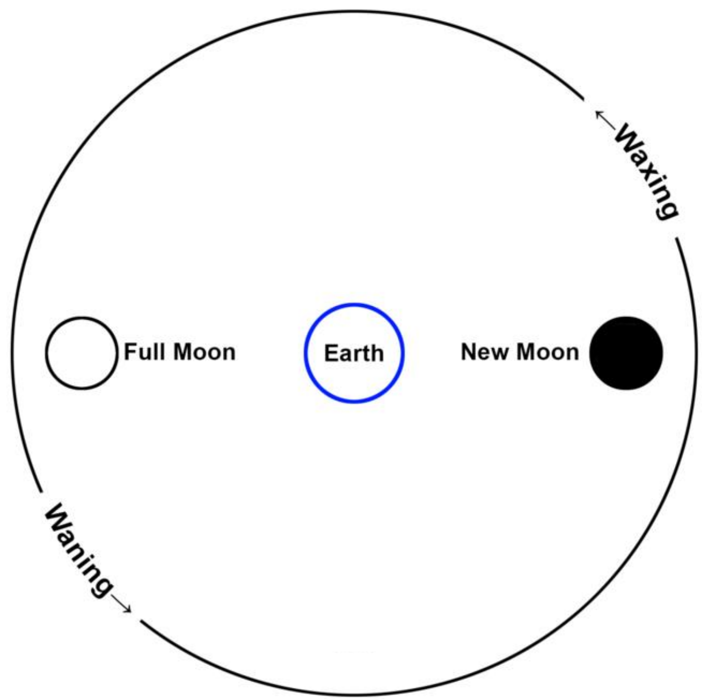
M_{sun} = 2.0×10^{30} kg

M_{moon} = 7.3×10^{22} kg

Distance to Moon = 3.8×10^{5} km

Which lunar phase produces the highest tides on Earth?

By what percentage?

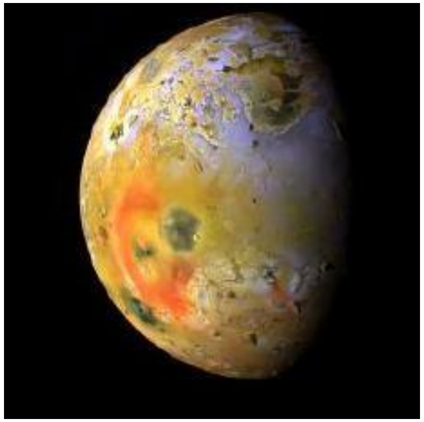


Friday's class: The moon causes a 6.8% variation in force across Earth's diameter.

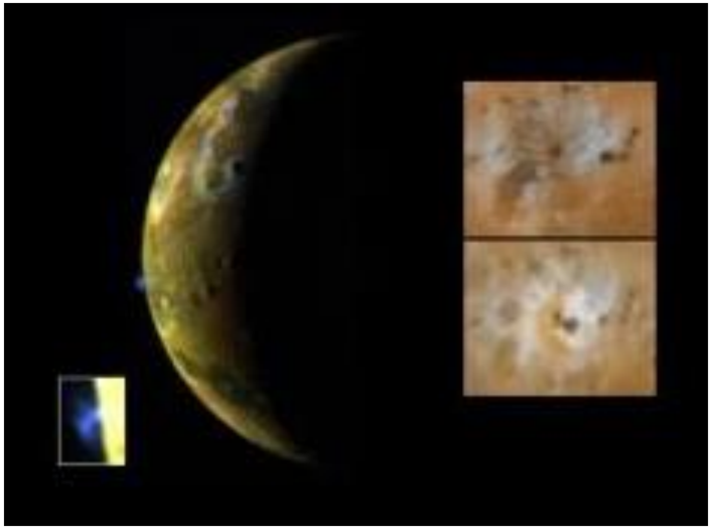
100 Volcanoes in Action!

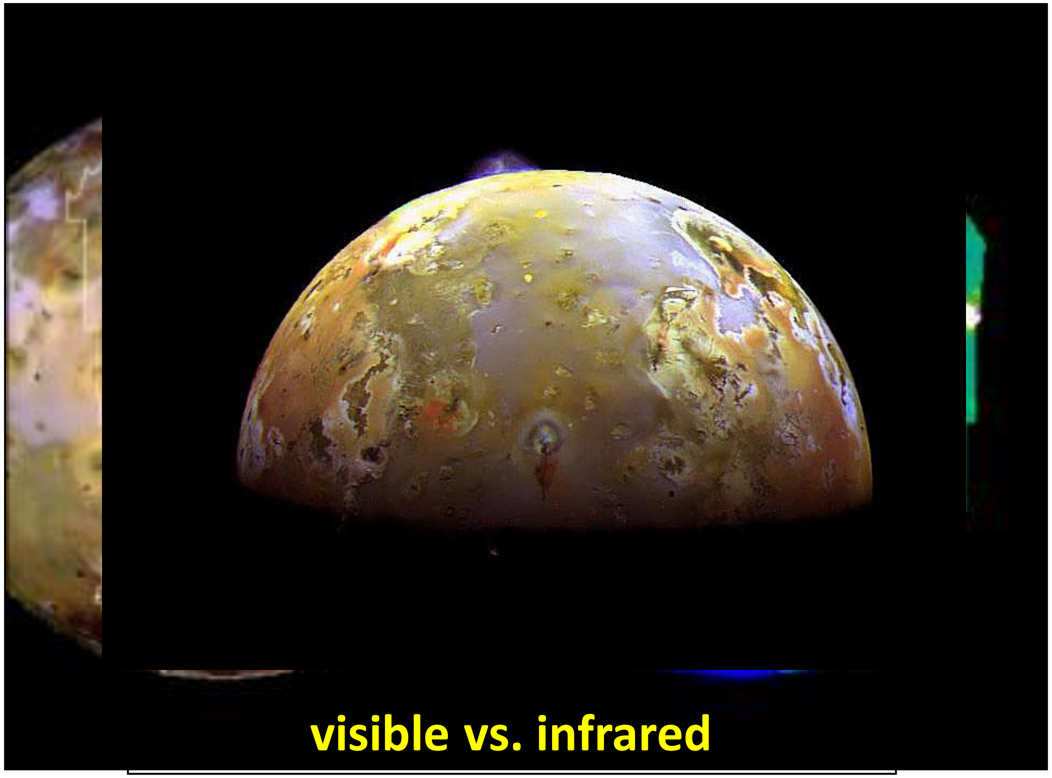
Io has no impact craters

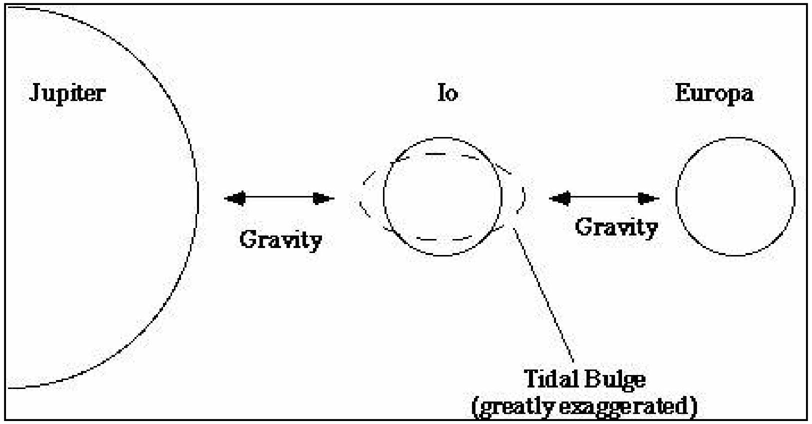
they've been covered up!



Sulfur-based volcanism

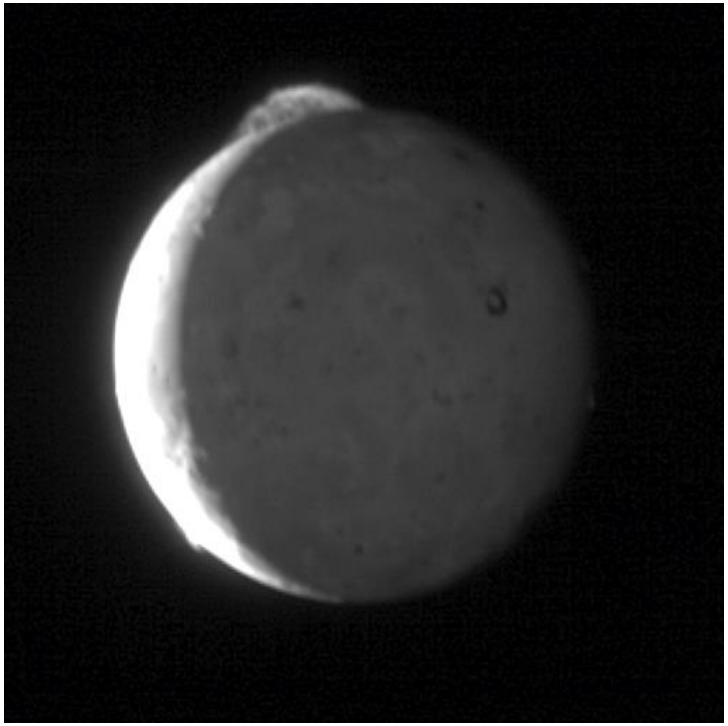


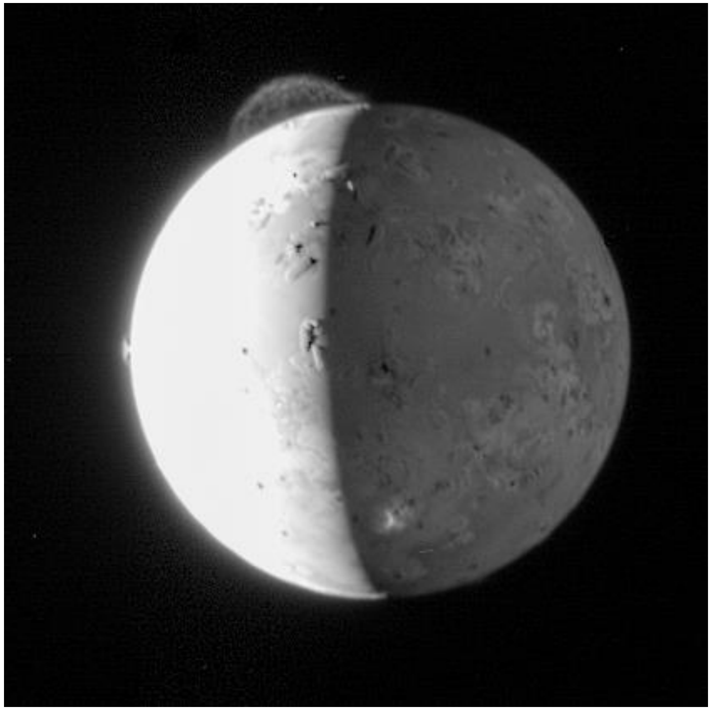




Starry Night: "Io_Europa"

Tvastar Plume Movie
(8 min)
1 ton of gas (sulfur, oxygen) escapes Io each second from its volcanoes





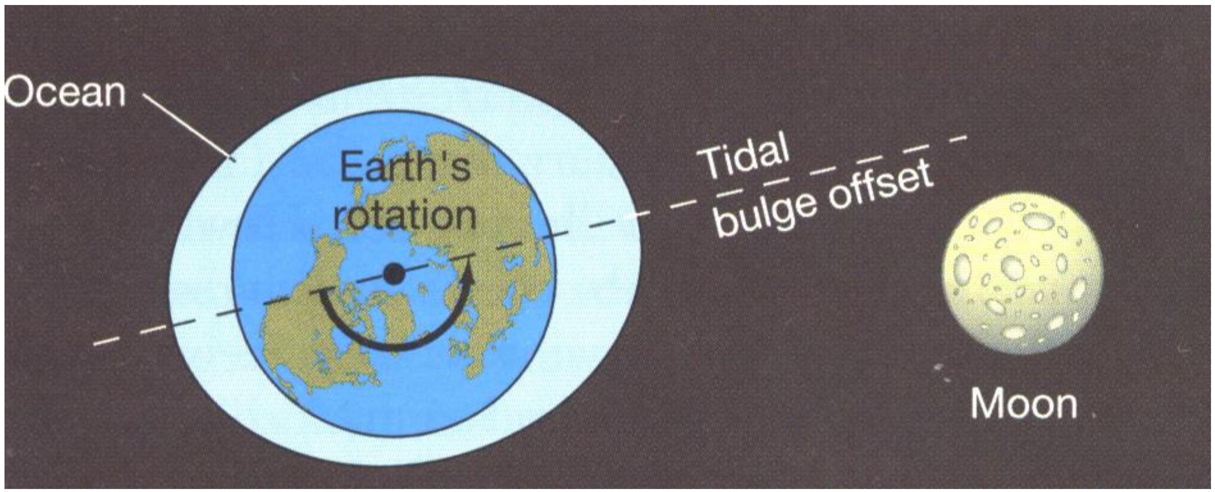
Plume reaches 200 miles high but source is below horizon by 80 miles

Saturn’s Moon Enceladus

Tidal Evolution

Earth rotates faster than the Moon revolves.

Earth-Moon + Pluto-Charon



The Moon slows the Earth 0.002 seconds each century.

The Moon recedes from Earth at 3.8 cm per year:

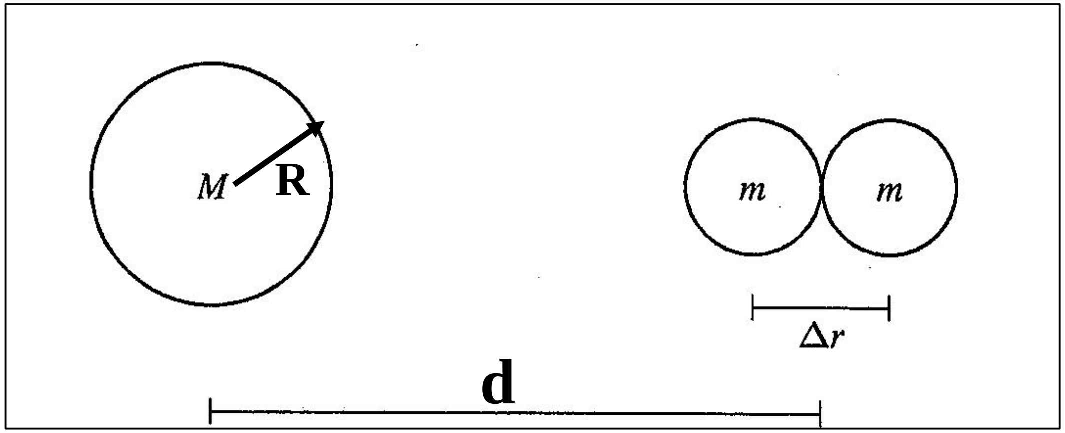
About the rate your fingernails grow!

Someday the Earth AND the Moon will keep same sides toward each other. A day will equal a month (47 of our present days).

Roche Limit (d_R)

depends on satellite's density and rigidity

Did you do the derivation?



$$d_R \approx 2.4\,(\rho_M / \rho_m)^{1/3}\;R$$

$$\frac{d_R}{R} \approx 2.4\,(\rho_M / \rho_m)^{1/3}$$

What assumptions?

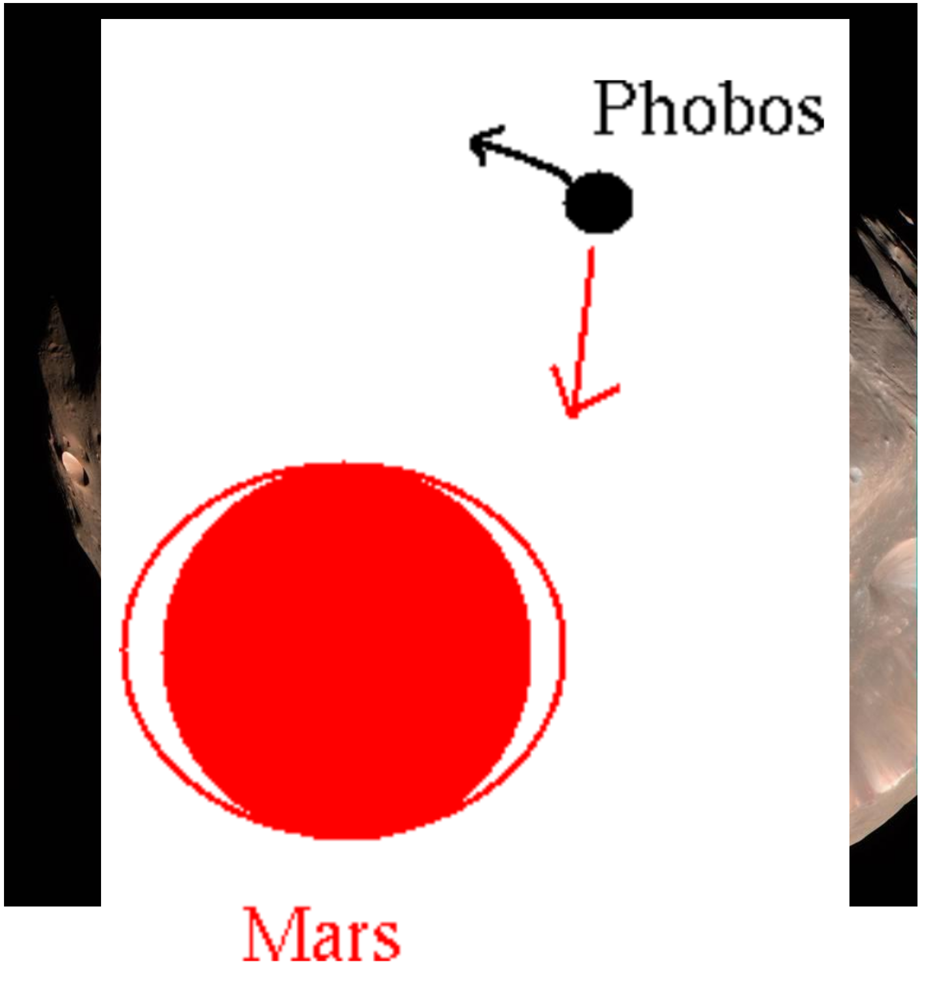
What if?

– $\rho_M = \rho_m$

– $\rho_m < 0.5\ \rho_M$

The r^{-2} Effects of Gravity:
tides, Roche Limit, Hill Sphere

- Phobos is closer to its planet than any other moon in the solar system: 3700 miles.
- Phobos' orbits decreases by about 6.6 feet (2 meters) every hundred years.
- Scientists expect the moon to be pulled apart in 30 to 50 million years. Why?
- The long, shallow grooves lining the surface of Phobos are likely early signs of the structural failure that will ultimately destroy this moon of Mars.



stretch marks ?

Hill Radius ("Sphere")

"instability limit"

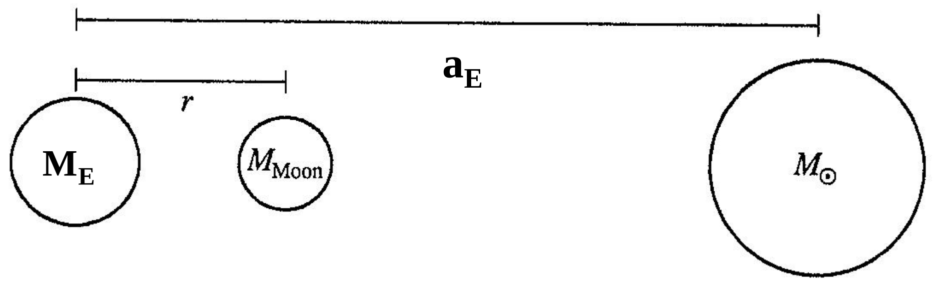


FIGURE 4.9 The Moon and the Earth, with masses M_{Moon} and $M_\oplus$, respectively, form a gravitationally bound system with separation r. The Sun, with mass $M_\odot$ at a distance $a_\oplus$ from the Earth, perturbs the Earth–Moon system. (Not to scale.)

What approach to this equation?

$$d_H \approx (M_E / 2M_\odot)^{1/3}\ a_E$$

Problem

If Jupiter migrated 100x closer to the Sun (i.e., the distance of a typical Hot-Jupiter exoplanet), would the Galilean moons survive?

Calculate the change in Hill radius (r_H).

$M_{Jup} \approx 0.001\ M_{sun}$
Galilean moon distances: $(0.41 – 1.9) \times 10^6$ km