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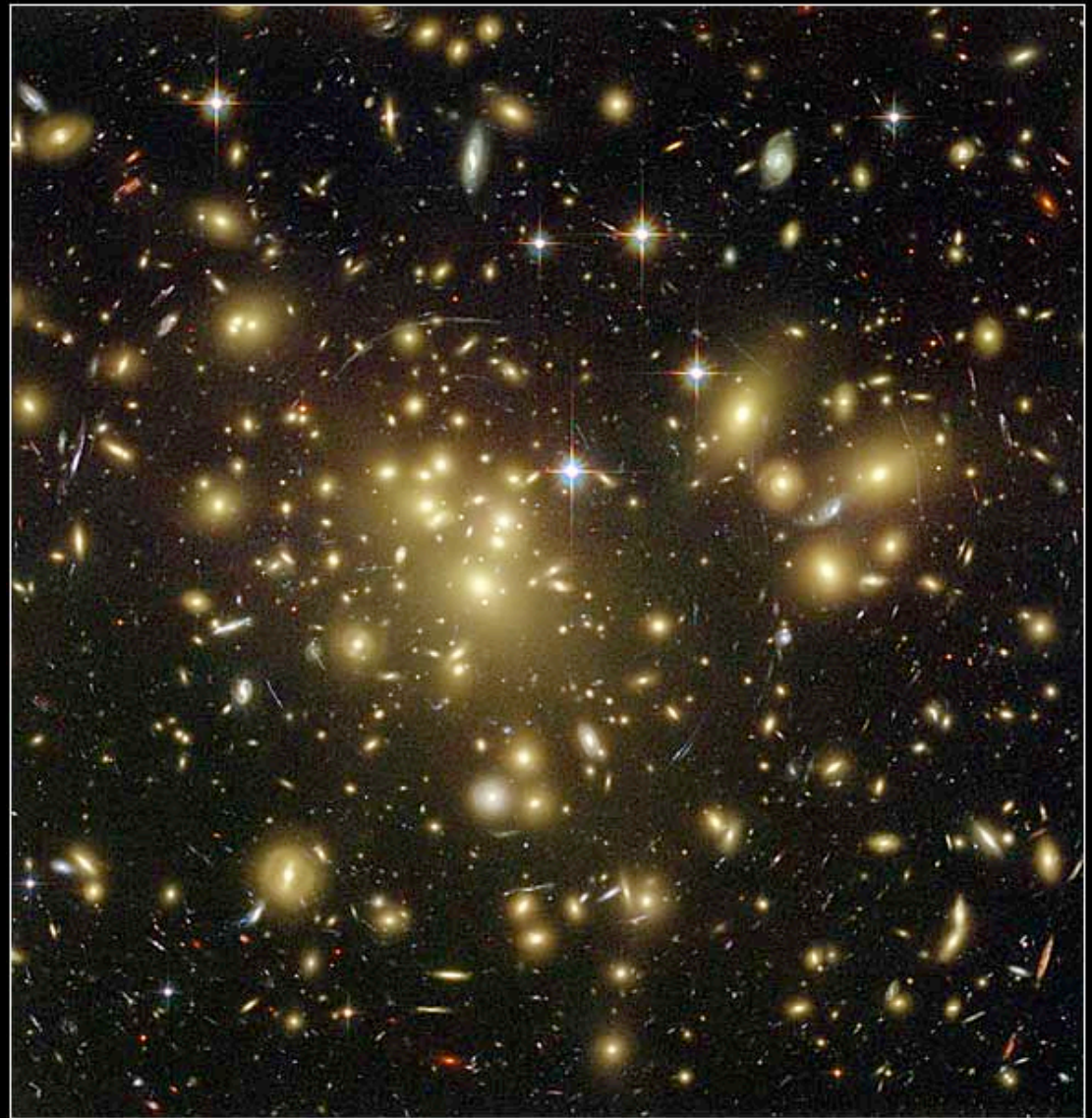
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Physics 140 –
Fall 2007
15 November:
lecture #21

Image of Darth
Vader removed

Galaxy Cluster Abell 1689

HST ■ ACS



NASA, N. Benitez (JHU), T. Broadhurst (Hebrew Univ.), H. Ford (JHU),
M. Clampin (STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory),
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Approximating the earth as a sphere of uniform density, at what radius *inside* the earth is the gravitational acceleration equal to the value that would be felt a height of $3R_E$ above Earth's surface?

1. $R_E/2$

2. $R_E/3$

3. $R_E/4$

4. $R_E/9$

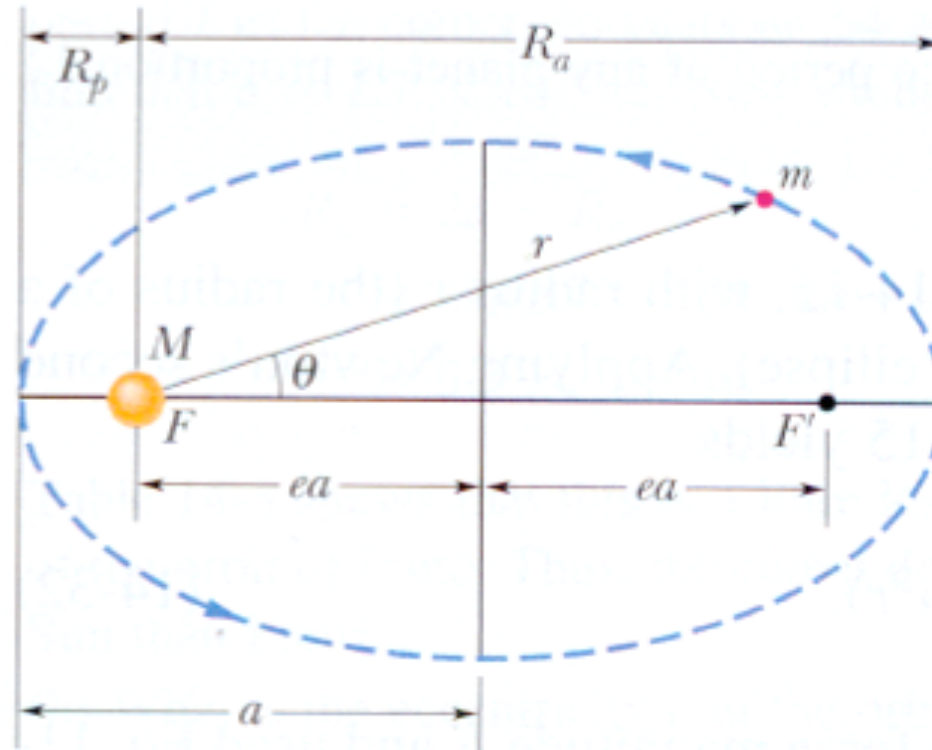
 5. $R_E/16$

Kepler's laws of planetary motion

- 1) Planets move in ellipses of semi-major axis a with the sun at a focus.

perihelion -

$R_p = a(1-e)$
closest point
in sun-planet
orbit



aphelion -

$R_a = a(1+e)$
farthest point
in sun-planet
orbit

An ellipse has **eccentricity** e , where ea is the distance from the center to a focus.

- 2) Planetary orbits sweep out equal areas in equal times.

This law reflects the fact that gravity is a **central force**. Since gravity acts along the radial direction connecting two bodies, it produces no torque on either. For a planet of mass m , the angular momentum of the orbit is conserved and determines the rate of area A swept out by its orbit

$$\frac{dA}{dt} = \frac{L}{2m}$$

- 3) The square of the orbital period is proportional to the cube of the semi-major axis (and inversely to the Sun's mass M)

$$T^2 = \frac{4\pi^2}{GM} a^3$$

A collection of circular orbits around Earth

Radius	Period	Description	Speed
r_E	1.4 hr	Orbiting at surface	7900 m/s
$r_E + 200 \text{ km}$	1.5 hr	Low orbit (space shuttle)	7790 m/s
$r_E + 2 r_E$	7.3 hr	Intermediate orbit	4540 m/s
$r_E + 5.6 r_E$	1 day	Geosynchronous orbit	3090 m/s
$r_E + 19 r_E$	5.3 days	Distant orbit	1770 m/s
r_{moon}	27.5 days	Lunar orbit	1025 m/s

mechanical energy and orbit families

Consider an asteroid of mass m in (an arbitrary) orbit around a much larger planet of mass M . The *mechanical energy* of the two-body system

$$E_{\text{mec}} = K + U = \frac{1}{2}mv^2 - G\frac{Mm}{r}$$

is a conserved quantity that determines the nature of the orbit.

Different *families of orbits* result from different signs of E_{mec} .

family	E_{mec}	eccentricity e	orbit
bound	< 0	< 1 (0)	ellipse (circle)
just unbound	$= 0$	$= 1$	parabola
really unbound	> 0	> 1	hyperbola

Bound (negative energy) orbits

If two bodies of masses m and M are in a gravitationally bound orbit, the *mechanical energy* determines the *size of the orbit*, defined as the *semi-major axis* a , of the two-body system

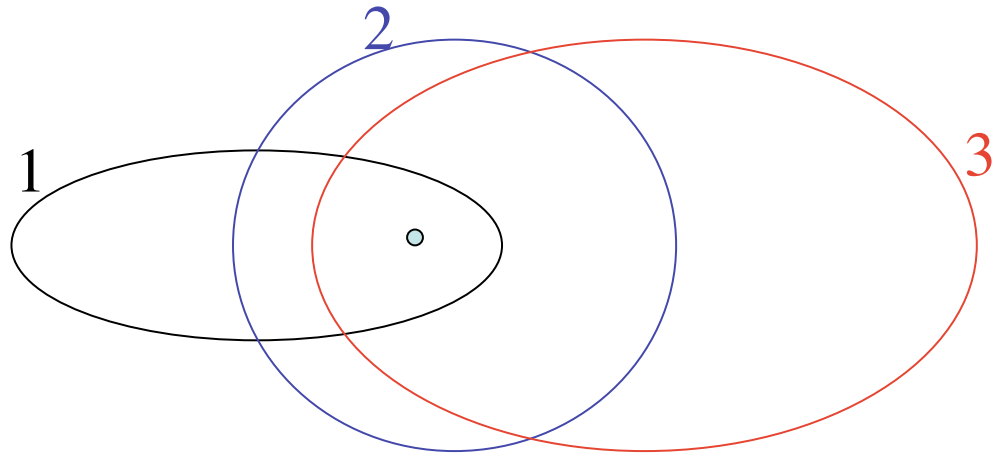
$$E_{\text{mec}} = - \frac{GMm}{2a}$$

while the *angular momentum* L determines the *shape of the orbit*, defined by the *eccentricity* e

$$L^2 = GMm^2 a (1-e^2)$$

For a set of bodies in *circular orbits* around a large mass M , the square of the orbital speed decreases inversely with distance r

$$v^2 = GM / r$$



Which orbit has the *smallest* angular momentum?



1.

2.

3.

4. more information is needed



<http://cfa-www.harvard.edu/~bmcleod/castle.html>