Spring 2014

PHYS-2010

Lecture 23

Clicker Question

Room Frequency BA

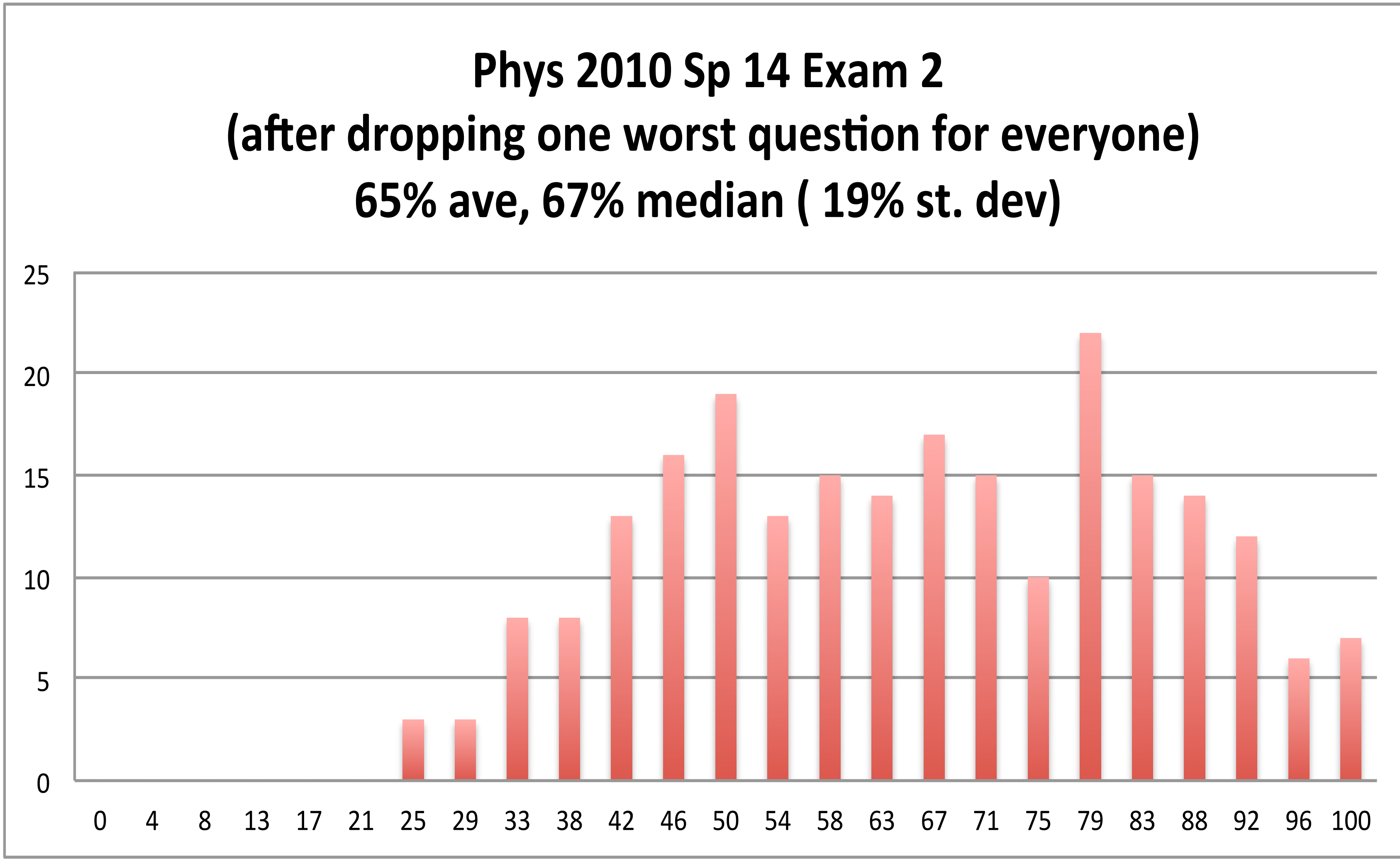
Astronauts aboard the International Space Station float around, experiencing weightlessness.

Why is this?

A) The force of gravity from the earth is zero on the Space Station
B) The force of gravity is much, much weaker on the Space Station
C) The Space Station has the "inertial dampers" turned on.
D) The Space Station is in circular orbit around the earth.
E) The Space Station generates an anti-gravity field.

Announcements

- Finish Giancoli Chapter 5, start Chapter 6.
- **No Written homework** this week!
- **CAPA # 8** is due next Tuesday.
- Exam solutions are posted on D2L.
- Exam results will be posted by the weekend's end.


Phys 2010 Sp 14 Exam 2
(after dropping one worst question for everyone)
65% ave, 67% median (19% st. dev)
25
20
15
10
5
0
0 4 8 13 17 21 25 29 33 38 42 46 50 54 58 63 67 71 75 79 83 88 92 96 100

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Newton's 2nd law and law of gravity:

$$mg = F_g = G\frac{mM}{R_E^2} \rightarrow g = a_g = G\frac{M}{R_E^2}$$

Gravity at the surface of the Earth:

$$a = \frac{GM_E}{R_E^{\ 2}} = \left(6.67\times10^{-11}Nm^2/kg^2\right)\frac{\left(5.98\times10^{24}kg\right)}{\left(6.37\times10^{6}m\right)^2} = 9.81m/s^2$$

Gravity at the Space Station Orbit above the Earth

h ~ 300 km = 3 x 10^5 meters:

$$a = \frac{GM_E}{(R_E+h)^2} = \left(6.67\times10^{-11}Nm^2/kg^2\right)\frac{\left(5.98\times10^{24}kg\right)}{\left(6.37\times10^{6}m + 3\times10^{5}m\right)^2}$$

$$= 8.43m/s^2$$

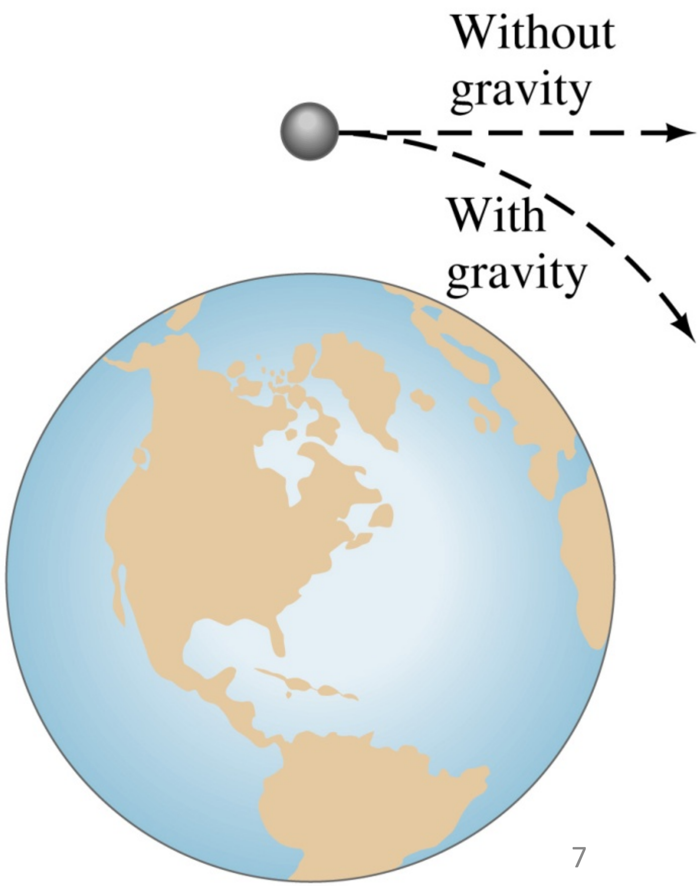
Gravitational acceleration is a little weaker, but not so much.

Satellites and "Weightlessness"

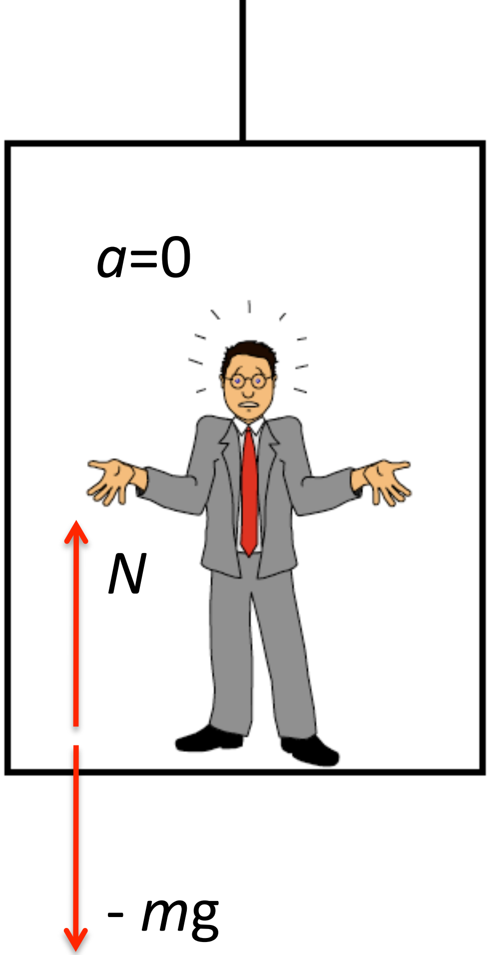
Satellites are routinely put into orbit around the Earth. The tangential speed must be high enough so that the satellite does not return to Earth, and not so high that it escapes Earth's gravity altogether.

The satellite is kept in orbit by its speed – it is continually falling, but the Earth curves from underneath it.

Because of its continual falling, it is considered to be "weightless".



“Weightlessness” and “Free Fall”



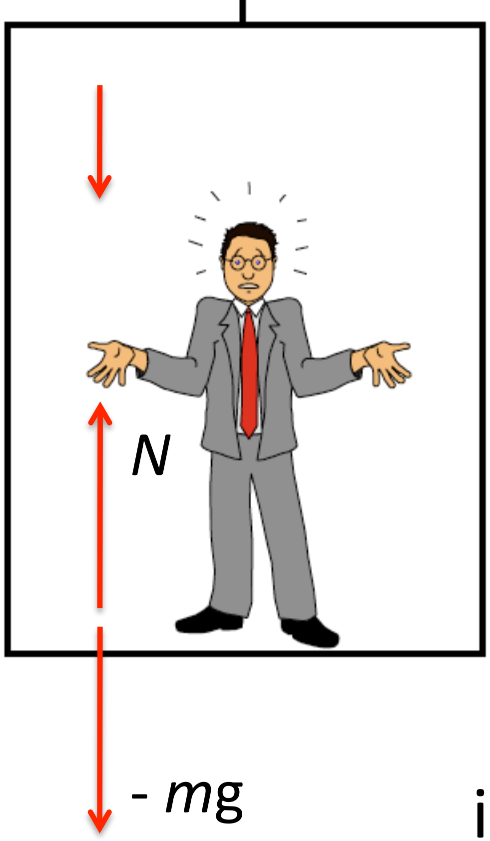
$$F_{net} = ma = N - mg = 0$$

$$N = mg$$

If the person were on a scale,
it would read their regular weight.

“Weightlessness” and “Free Fall”

-a (controlled fall)



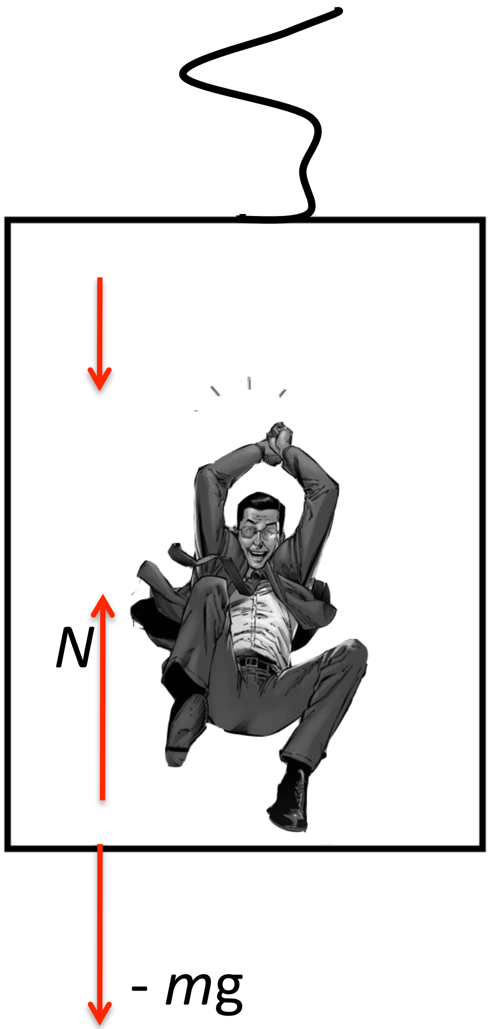
$$F_{net} = ma = N - mg \neq 0$$

$$N = m(g - a) < mg$$

If the person were on a scale,
it would read less than their regular weight.

“Weightlessness” and “Free Fall”

-g (free fall)



Therefore, when gravity alone is operating unopposed by another force (e.g., normal force), the object is said to be **weightless**.

The object is also said to be in **free fall**.

$$N = m(g - a) = m(g - g) = 0$$

Weightless!

If the person were on a scale, it would read zero.

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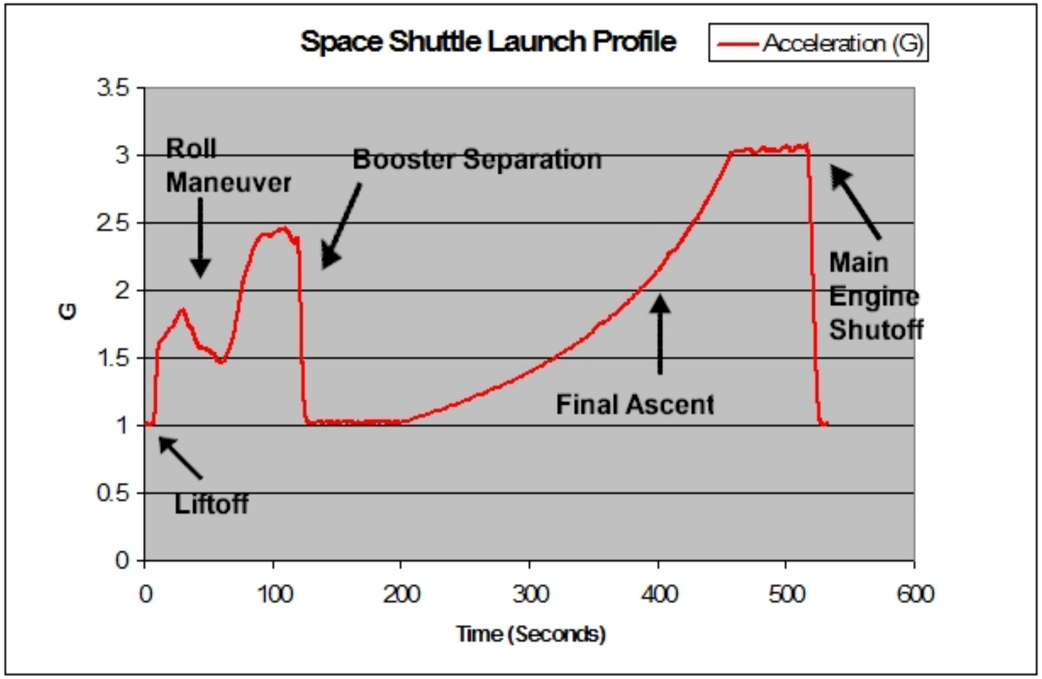


What happens to a person's apparent "weight" as measured on a scale on the shuttle at t=100 seconds, compared to that on Earth ?

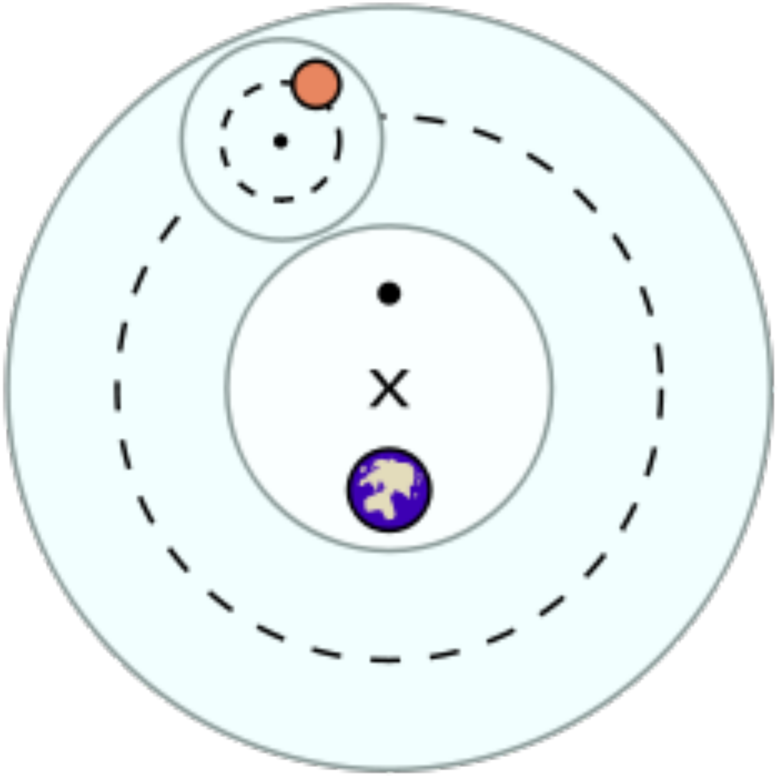
A) Stays the same

B) Increases

C) Decreases

ORBITS AND KEPLER'S LAWS

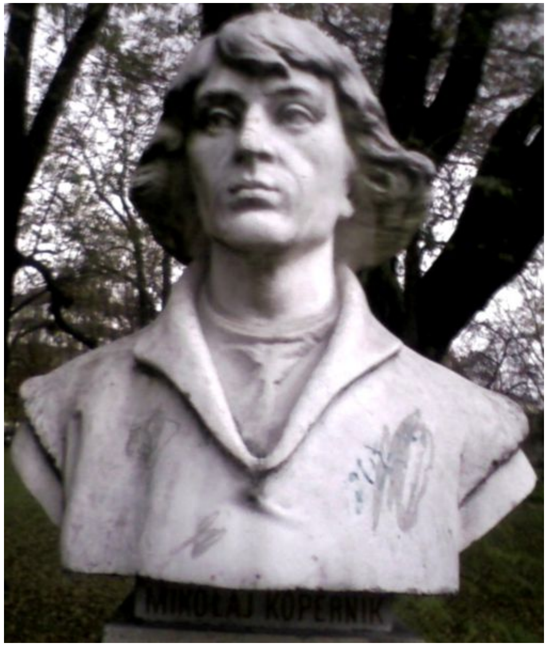
Earth at the Center of Everything



Geocentrism
- Epicyles
- Equant
- Deferent

Claudius Ptolemaeus
(Ptolemy)
90 – 168 AD

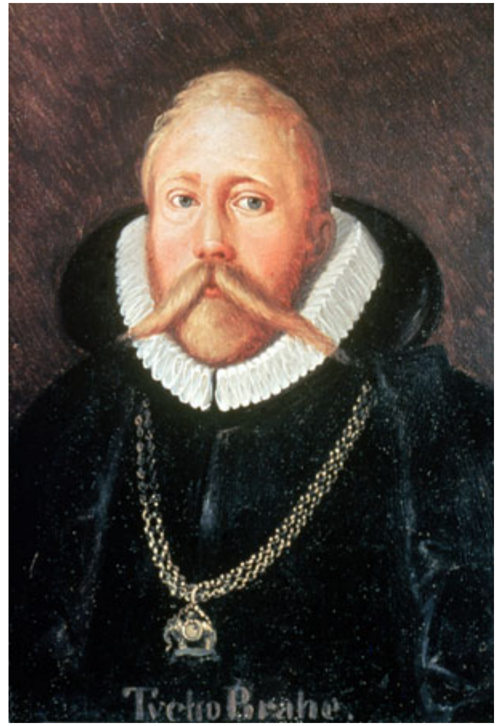
Heliocentrism (Sun at the Center)



Nicolaus Copernicus
1473-1543

De revolutionibus orbium coelestium
(On the Revolutions of the Celestial Spheres)

Heliocentrism



Tycho Brahe
1546-1601

astronomical observations

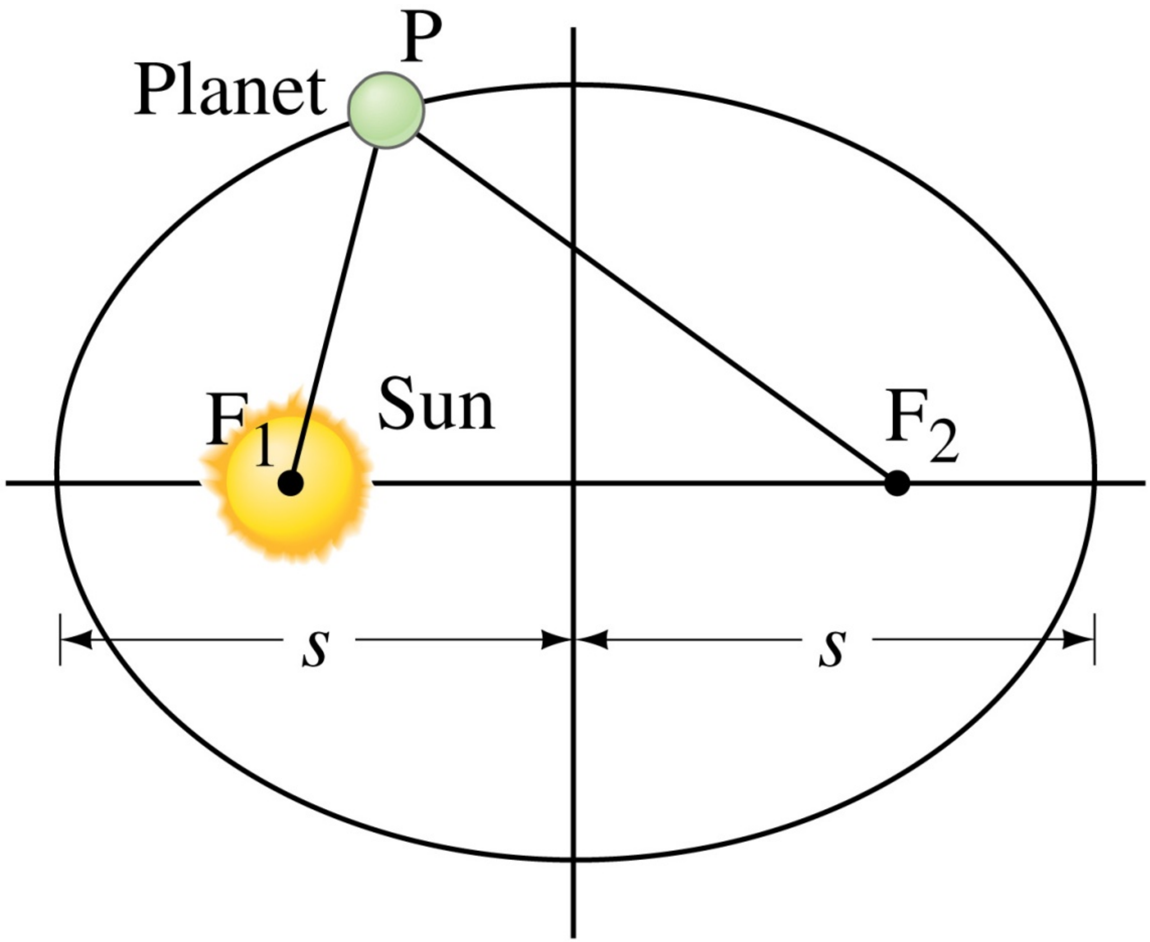
Johannes Kepler
1571-1630

Three Laws

Epitome astronomia Copernicanae
(Epitome of Copernican Astronomy)

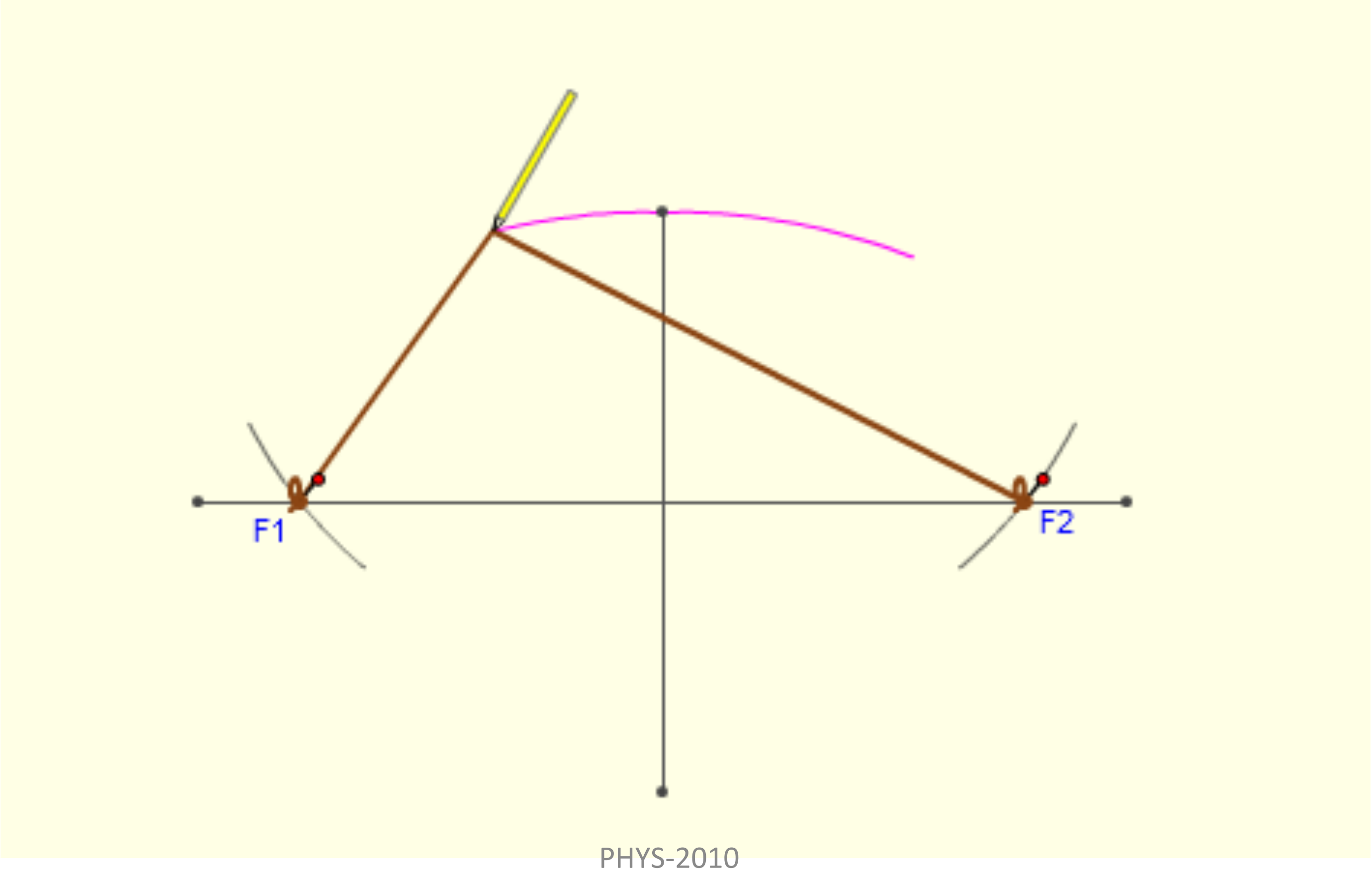
Kepler's Laws of Planetary Motion

Law #1: The orbit of each planet is an ellipse, with the Sun at one focus.



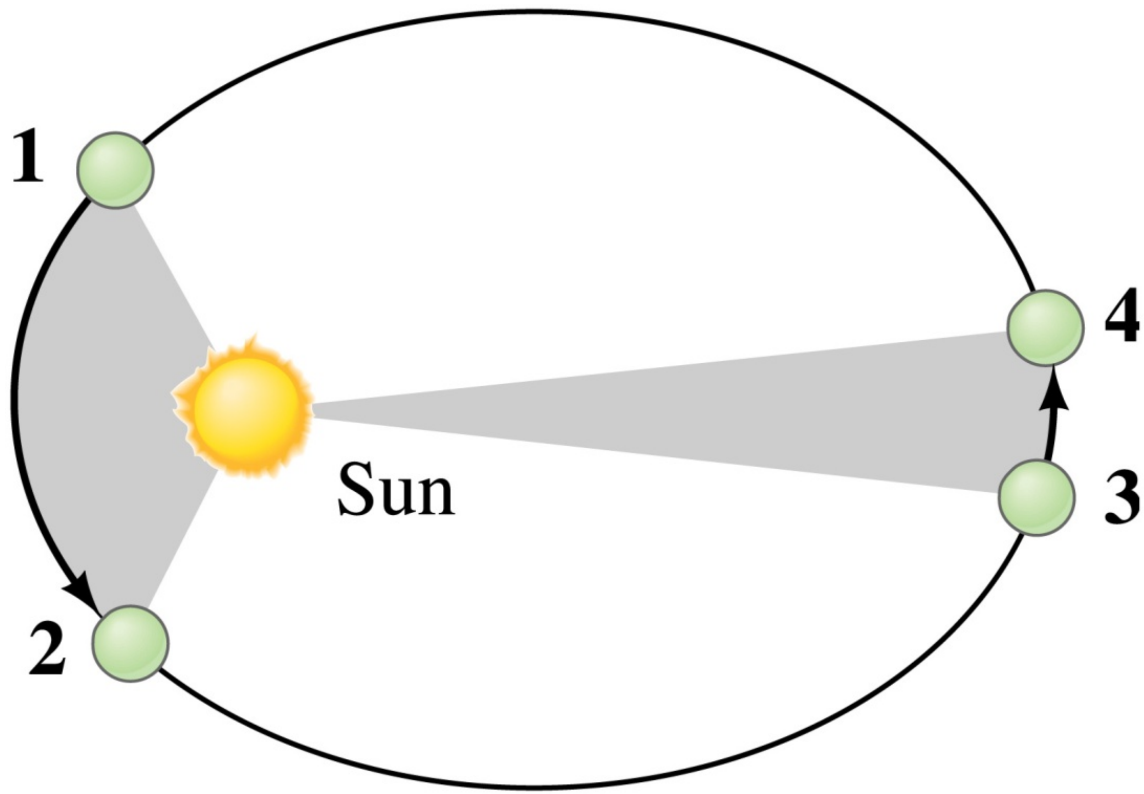
Elliptical Geometry

The sum of the distances from any point P on the ellipse to those two foci is constant and equal to the major diameter ($PF_1 + PF_2 = 2a$).



Kepler's Laws of Planetary Motion

Law#2: An imaginary line drawn from each planet to the Sun sweeps out equal areas in equal times.



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Notice how a planet with an elliptical orbit moves closer to and further away from the Sun. The point of closest approach to the Sun is called **perihelion**. The furthest point is called **aphelion**.

At which position is the asteroid moving at the largest magnitude velocity?

A) Far left (aphelion)

B) Far right (perihelion)

C) Top

D) Bottom

E) Same velocity magnitude everywhere

Kepler's Laws of Planetary Motion

Law #3: The ratio of the square of a planet's orbital period is proportional to the cube of its mean distance from the Sun.

$$T^2 \propto R^3$$

$$\frac{R^3}{T^2} = const$$

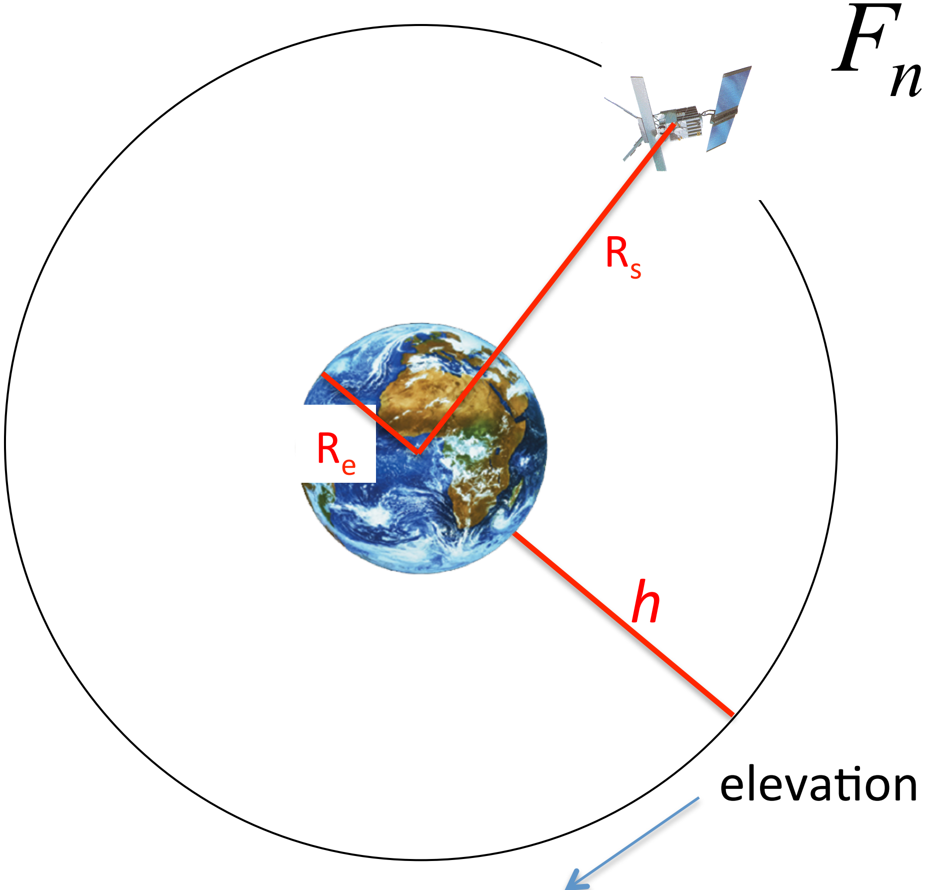
TABLE 5–2 Planetary Data Applied to Kepler's Third Law

Planet	Mean Distance from Sun, s (10^6 km)	Period, T (Earth years)	s^3/T^2 (10^{24} km^3/y^2)
Mercury	57.9	0.241	3.34
Venus	108.2		
Earth	149.6		
Mars	227.9		
Jupiter	778.3		
Saturn	1427		
Uranus	2870		
Neptune	4497		
Pluto	5900		

$$\frac{R^3}{T^2} = 3.35 \times 10^{24} \, km^3 / yr^2$$

What is the relationship between **velocity** and **orbit Radius**?

Consider $F = ma$ in the radial direction: +inward



$R_s = R_e + h$

$$F_{net} = ma_R = G\frac{mM}{R_s^{\,2}} = m\frac{v^2}{R_s}$$

Force of Gravity Only

Condition for Circular Motion

$$R_s = \frac{GM}{v^2}$$

$$v = \sqrt{\frac{GM}{R_s}}$$

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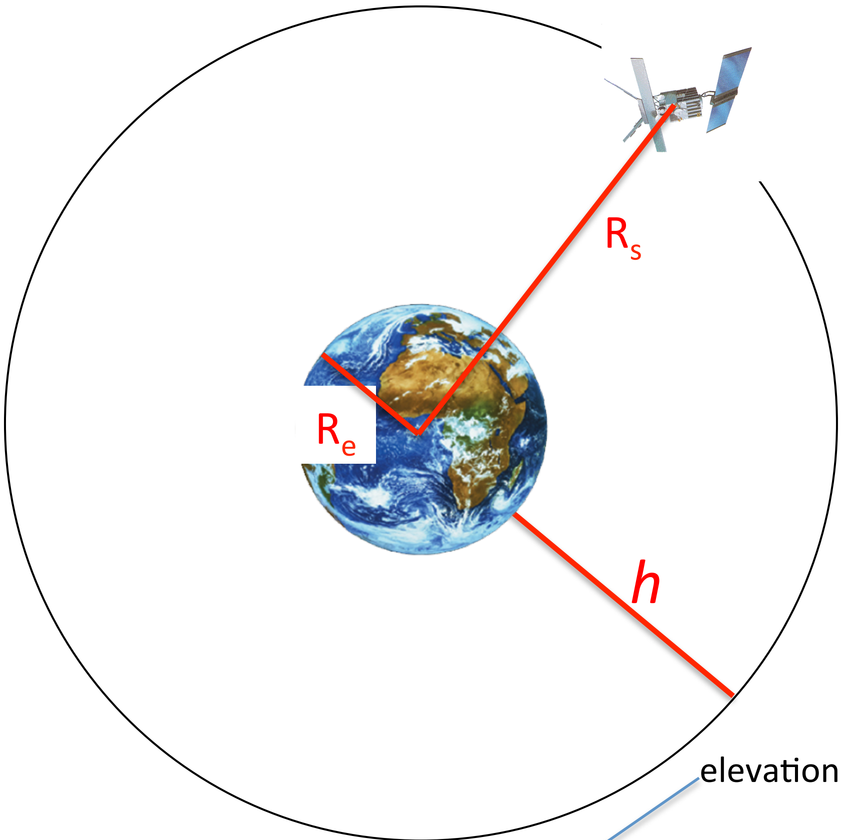

$R_s = R_e + h$

$$v = \sqrt{\frac{GM}{R_s}} \qquad R_s = \frac{GM}{v^2}$$

Satellite 1 is in circular orbit about the Earth and is moving with tangential speed v_1.

Satellite 2 is also in orbit but with speed $v_2 > v_1$.

Satellite 2's orbit radius is:

A) Bigger than Satellite 1's

B) Smaller than Satellite 1's

C) Unclear from the information given.

Clicker Question

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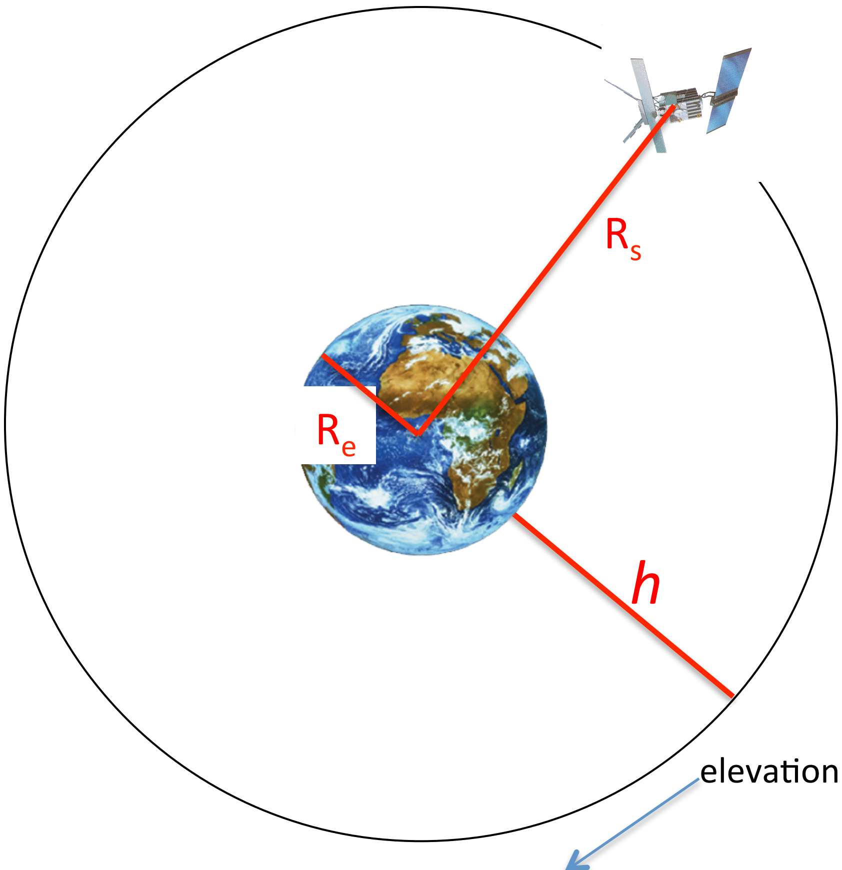


$R_s = R_e + h$

$$v = \sqrt{\frac{GM}{R_s}} \qquad R_s = \frac{GM}{v^2}$$

Satellite 1 is in circular orbit about the Earth with radius R_1.

Satellite 2 is also in circular orbit with a radius R_2 and a speed twice that of Satellite 1.

What is true about the radii?

A) R1 = 2 x R2

B) R1 = ½ x R2

C) R1 = 4 x R2

D) R1 = ¼ x R2

E) Unclear from the information given.

Relationship between orbit radius and period

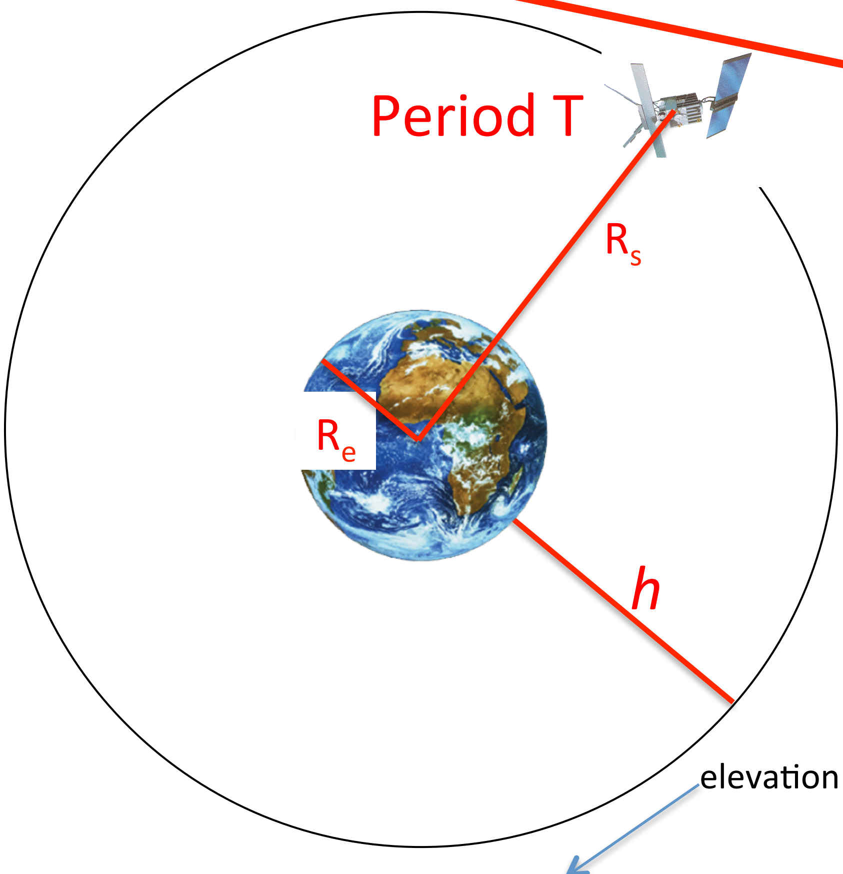
$$v = \sqrt{\frac{GM}{R_s}} \qquad R_s = \frac{GM}{v^2}$$

Eliminate velocity in place of period (T)

$$v = \frac{2\pi R_s}{T}$$

$$v^2 = \frac{GM}{R_s} = \frac{4\pi^2 R_s^2}{T^2}$$

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



$R_s = R_e + h$

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

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Recall Kepler's Empirical Value

$$\frac{R^3}{T^2} = 3.35\times10^{24}\, km^3 / yr^2$$

$$\frac{R_s^3}{T^2} = \frac{GM}{4\pi^2} = \frac{\left(6.67\times10^{-11}\, Nm^2/kg^2\right)\left(1.98\times10^{30}\, kg\right)}{4\pi^2} = 3.3\times10^{18}\, m^3/s^2$$

$$= 3.3\times10^{24}\, km^3 / yr^2$$

Knowledge of a planet's period (easy to measure) allows us to determine it orbital radius.

Where is Mars?

$$\frac{R_s^3}{T^2} = \frac{GM}{4\pi^2} = \text{constant}$$

$$\frac{R_{sun-mars}^3}{T_{mars}{}^2} = \frac{R_{sun-earth}^3}{T_{earth}{}^2} = \text{constant}$$

$$\frac{R_{sun-mars}^3}{R_{sun-earth}^3} = \frac{T_{mars}{}^2}{T_{earth}{}^2}$$

Mars is 1.52 times as far away as the earth is from the sun.

$$\frac{R_{sun-mars}}{R_{sun-earth}} = \left(\frac{T_{mars}}{T_{earth}}\right)^{2/3} = \left(\frac{687 days}{365 days}\right)^{2/3} = 1.52$$

Exoplanets

Upsilon Andromedae is a binary star located about 44 light-years away from the Earth. The primary star is a yellow-white dwarf star that is younger than the Sun. There is a second star that is a red dwarf in a wide orbit.

As of 2010, four confirmed extrasolar planets have been discovered.

The Upsilon Andromedae A system[23]

Companion (in order from star)	Mass	Semimajor axis (AU)	Orbital period (days)	Eccentricity
b	1.4[24] M_J	0.0595 ± 0.0034	4.617136 ± 0.000047	0.013 ± 0.016
c	13.98[24] M_J	0.832 ± 0.048	241.33 ± 0.20	0.224 ± 0.021
d	10.25[24] M_J	2.53 ± 0.15	1278.1 ± 2.9	0.267 ± 0.021
e	≥1.059 ± 0.028[21] M_J	5.2456 ± 0.00067	3848.86 ± 0.74	0.00536 ± 0.00044

$$\frac{R_s^3}{T^2} =$$

(b) → $(0.0595)^3/(4.61)^2 = 9.9\times10^{-6}$ AU^3/days^2

(c) → $(0.832)^3/(241.3)^2 = 9.9\times10^{-6}$ AU^3/days^2

(d) → $(2.53)^3/(1278.1)^2 = 9.9\times10^{-6}$ AU^3/days^2

(e) → $(5.24)^3/(3848.8)^2 = 9.7\times10^{-6}$ AU^3/days^2