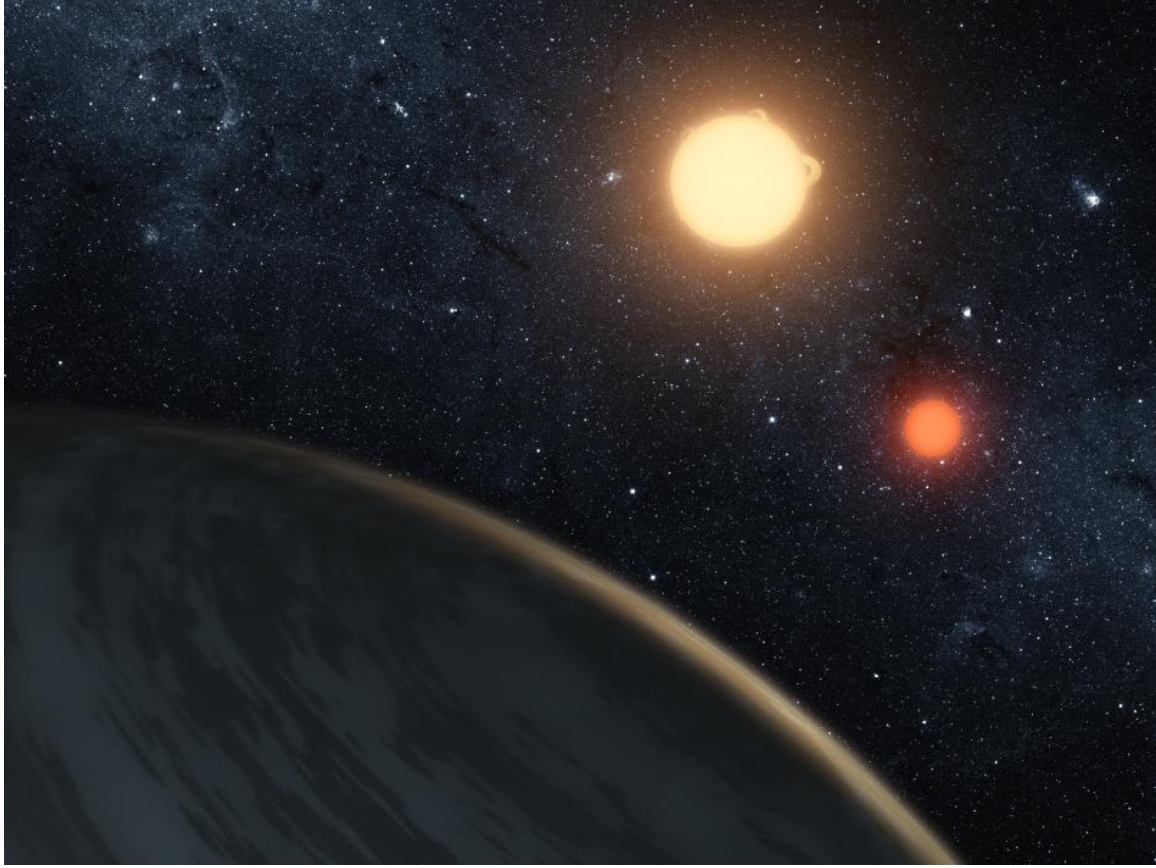
Announcements

- **The first exam is Wednesday, Sept. 21.**
- Astronomy tutorial: Tuesday 3-5, 7-9 pm in 310 VAN
- Office hours: Tuesday 1–3 pm, Wednesday 10-11 am, or by appointment in 702 VAN
- Remember to set clicker channel to 44

Kepler confirms first planet orbiting two stars

Luke in sunset scene



The existence of a world with a double sunset, as portrayed in the film Star Wars more than 30 years ago, is now scientific fact. NASA's Kepler mission has made the first unambiguous detection of a circumbinary planet -- a planet orbiting two stars -- 200 light-years from Earth.

Unlike Star Wars' Tatooine, the planet is cold, gaseous and not thought to harbor life, but its discovery demonstrates the diversity of planets in our galaxy. Previous research has hinted at the existence of circumbinary planets, but clear confirmation proved elusive. Kepler detected such a planet, known as Kepler-16b, by observing transits, where the brightness of a parent star dims from the planet crossing in front of it.

Thanks to:

Alex Garvin, Ellie Haugen, Stacy Kapitanek, and Jeremy Tinkler for questions.

The test will be based on the homework, the clicker questions, and the review questions at the end of each lecture. The best way to study for the test is to review those and the lecture notes. If you feel you need more help with the material, then read the book or come to astronomy tutorial or office hours.

Equation sheet

Radius	Distance
Moon = 1.7×10^6 m	Earth-Moon = 3.8×10^8 m
Earth = 6.4×10^6 m	Sun-Earth = 1.5×10^{11} m
Jupiter = 7.1×10^7 m	Sun-Jupiter = 7.8×10^{11} m
Sun = 7.0×10^8 m	Sun-Proxima Centauri = 4×10^{16} m

1 light-year = 9.5×10^{15} m
1 parsec = 3.26 light-years
Parallax formula: $d = 1/p$ for d in pc, p in arcseconds
Small angle formula for S, d in meters, α in arcseconds: $S = \alpha d/206265$

You should have a notion of relative distances without numbers, e.g. being able to put distances to astronomical objects (from the Moon to the observable Universe) in order.

Today's lecture

- Phases of the moon exercise
- Review
- Millionaire astronomer

Phases of the Moon

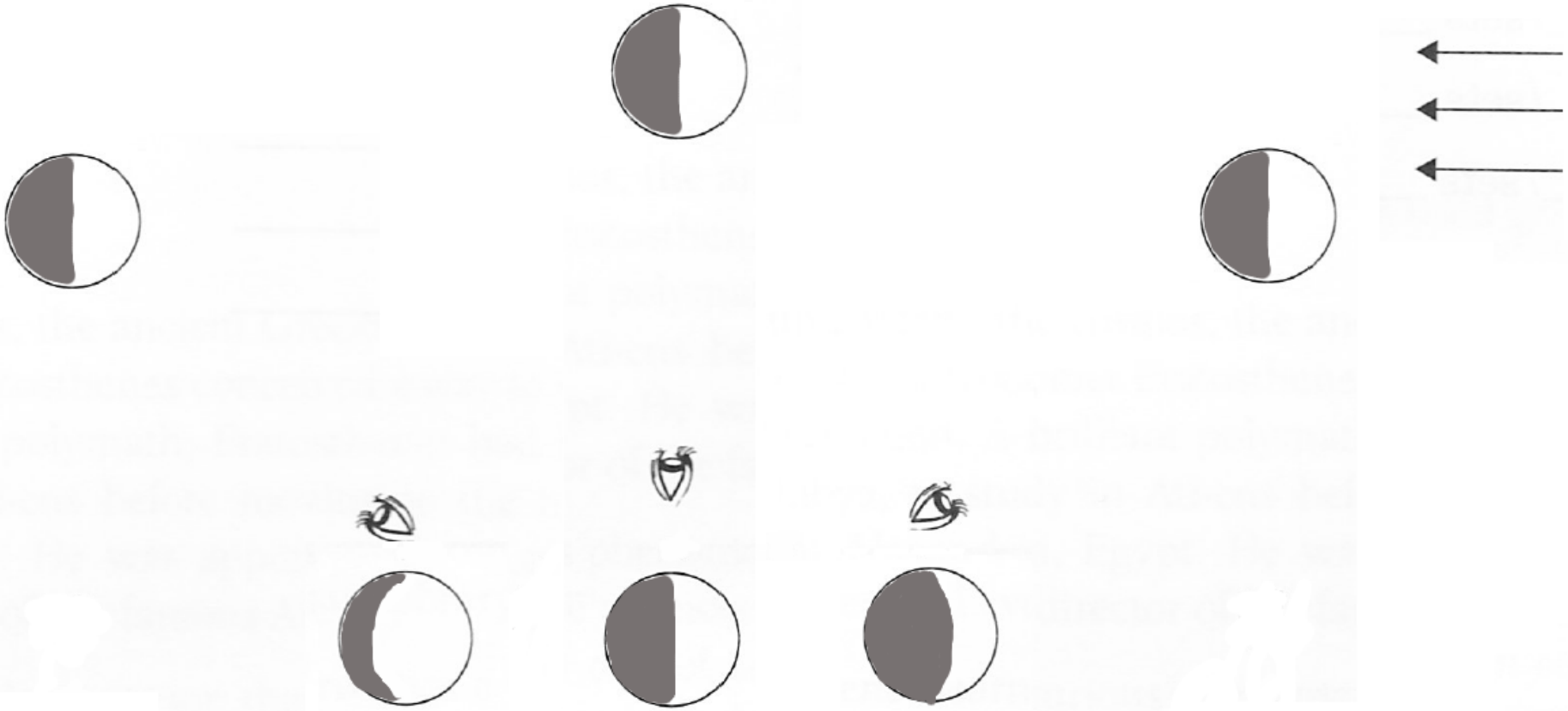
- Top part of worksheet is a view of the Earth and Moon looking down at the North pole. The Sun is off to the right. The moon orbits the Earth in the same direction that the Earth spins (and that the Earth orbits the Sun).
- You will shade the diagram so dark means not illuminated.
- Shade in the part of Earth not illuminated by the Sun. Those are the parts of the Earth where it is night. Does this agree with the times marked on the figure?
- From your diagram, when does the Sun rise?

  A=Noon, B=6 pm, C=midnight, D=6 am

- Now shade in each of the 8 moons set around the Earth.

Phases of the Moon

- The bottom row of Moons represents how someone on Earth would see the Moon at that phase. Imagine you are on Earth looking at a ball illuminated as shown by the circle with the corresponding letter in the top diagram, then shade the bottom Moon accordingly.
- Might do A+E, then C+G, then fill in.



What phase of the Moon is A?

A) Full
B) New
C) First quarter
D) Last quarter
E) Cheese

What phase of the Moon is G?

A) Full
B) New
C) First quarter
D) Last quarter
E) Cheese

When is the full Moon directly overhead? (What time of day)

A) Noon
B) 6 pm
C) Midnight
D) 6 am

When does the full Moon set?

A) Noon
B) 6 pm
C) Midnight
D) 6 am

When does the first quarter Moon rise?

A) Noon
B) 6 pm
C) Midnight
D) 6 am

When does a waxing cresent Moon set?

A) Noon
B) 3 pm
C) 6 pm
D) 9 pm
E) Midnight
F) 3 am
G) 6 am
H) 9 am

waxing = increasing, waning = decreasing

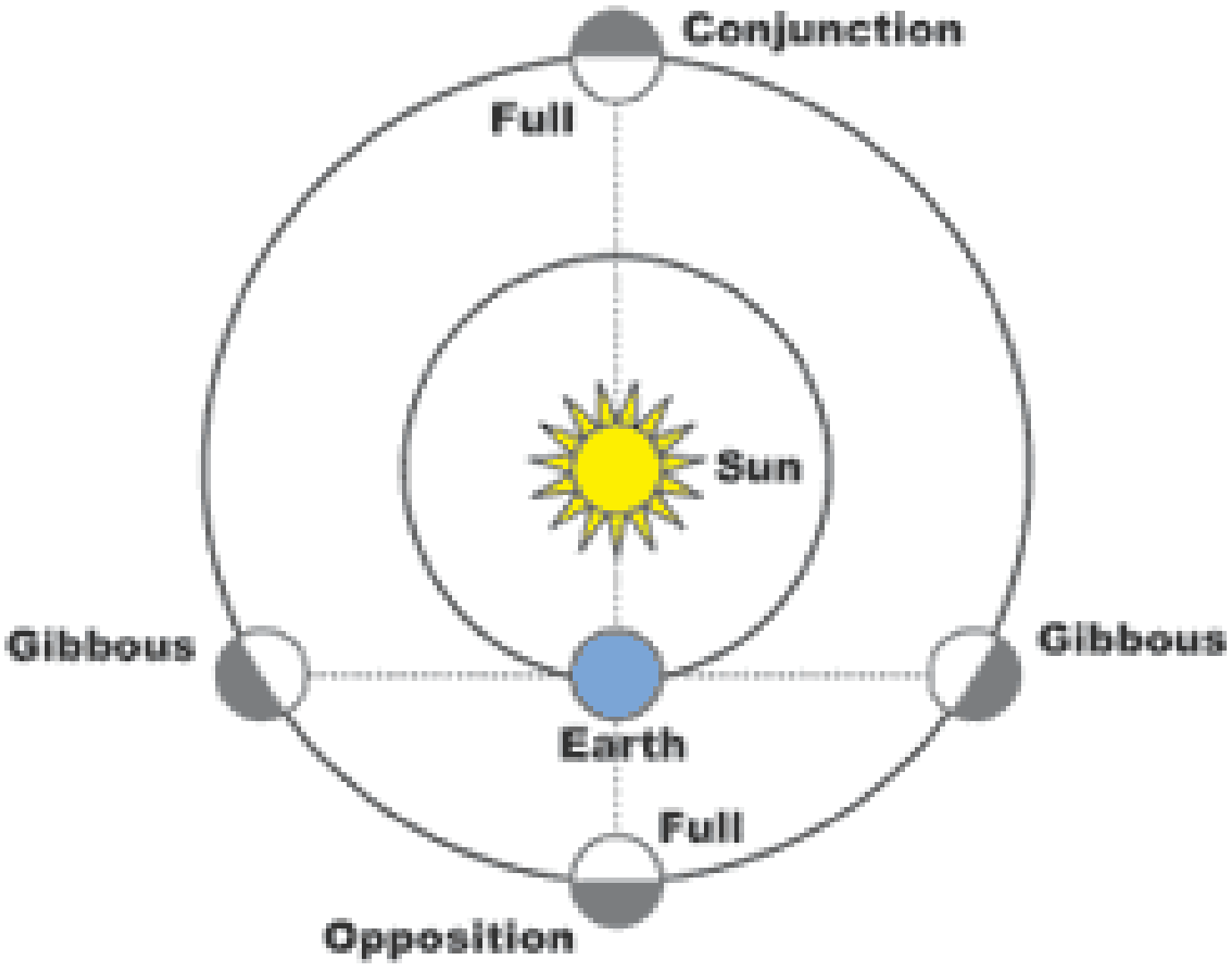
When Mars is full it must rise

A) At dawn
B) At sunset
C) At either dawn or sunset
D) None of the above

How to solve?

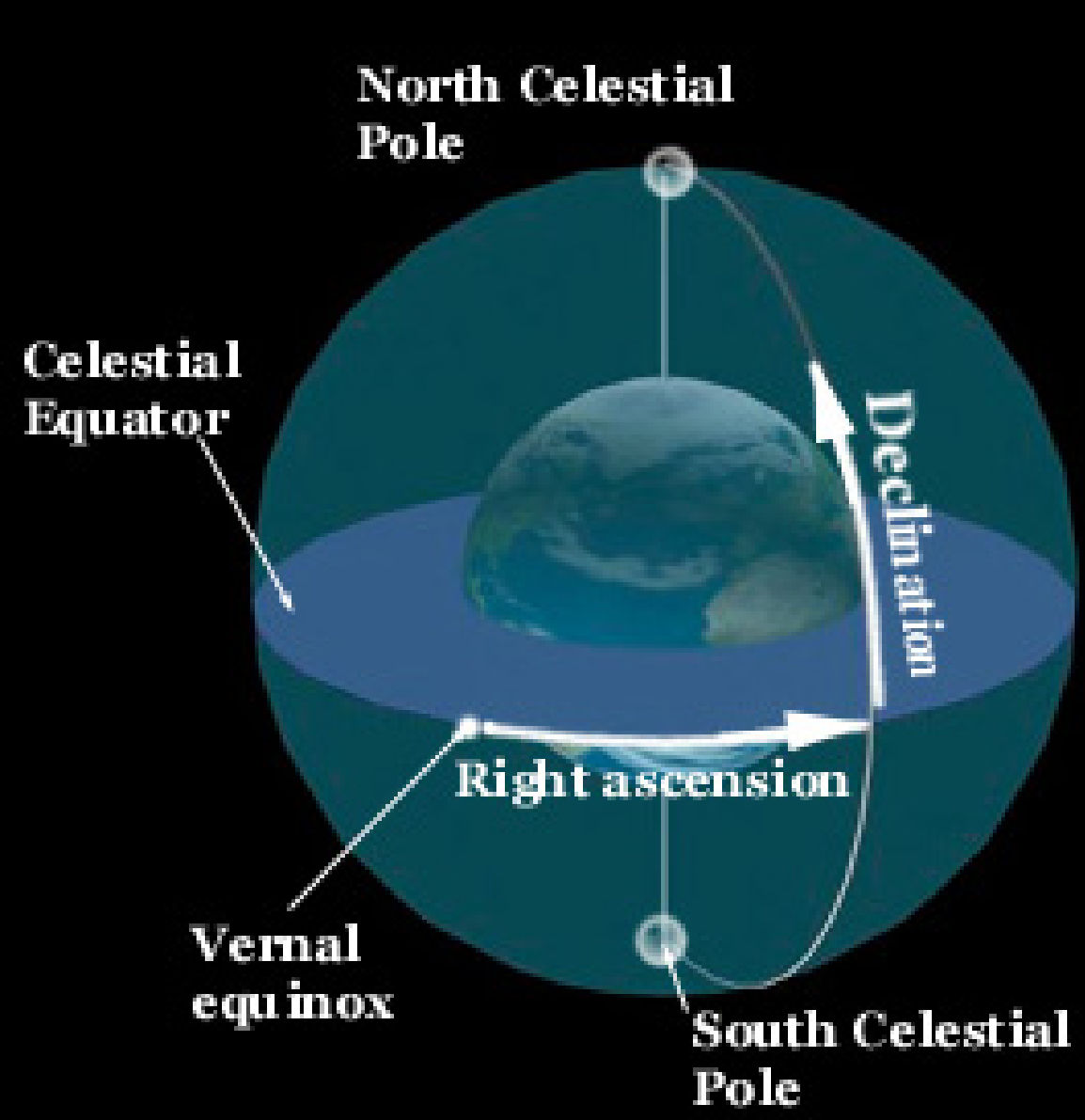
- Draw a diagram
- What are the essential elements?
  - Sun, Earth, Mars
- Is Mars closer to the Earth or farther away?
- Draw one Sun, one Earth, then Mars at several places around orbit
- Figure out where Mars looks full, then figure out where Mars is relative to the Sun when full

Phases of Mars



When Mars is full it must rise

A) At dawn
B) At sunset
C) At either dawn or sunset
D) None of the above

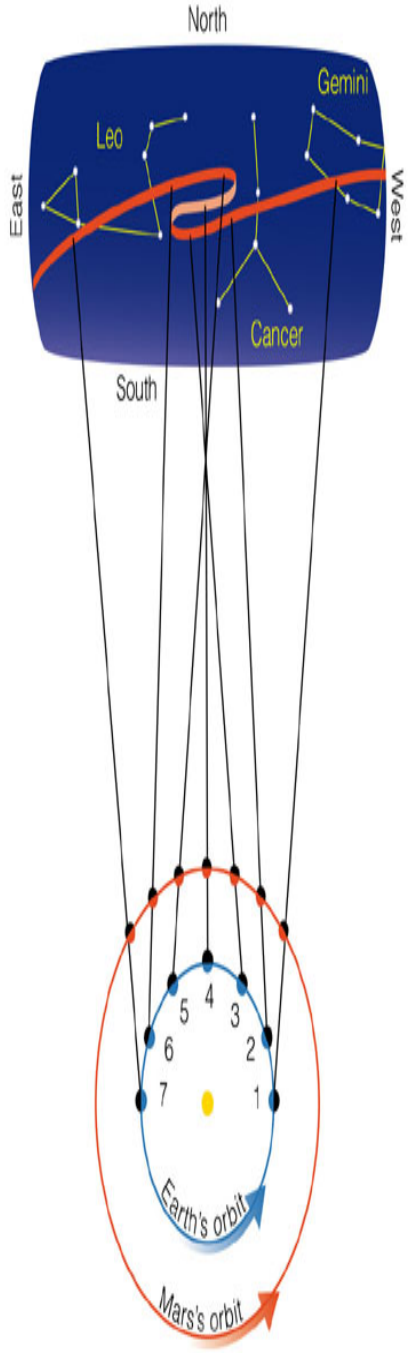


Coordinates are:

Declination = degrees North or South of the equator.

Right ascension = degrees East of the “Vernal equinox”.

Vernal equinox is defined as the position of the Sun on the first day of spring. Note it is a point on the sky, not the earth.



Retrograde motion

- From night to night, Mars usually eastward on the sky (from West to East).
- Sometimes Mars appears to move backwards (westward); this is retrograde motion.
- Retrograde motion occurs when the Earth catches up to and then passes Mars in its orbit

Kepler's laws of planetary motion

Planets farther from the Sun take longer to orbit.

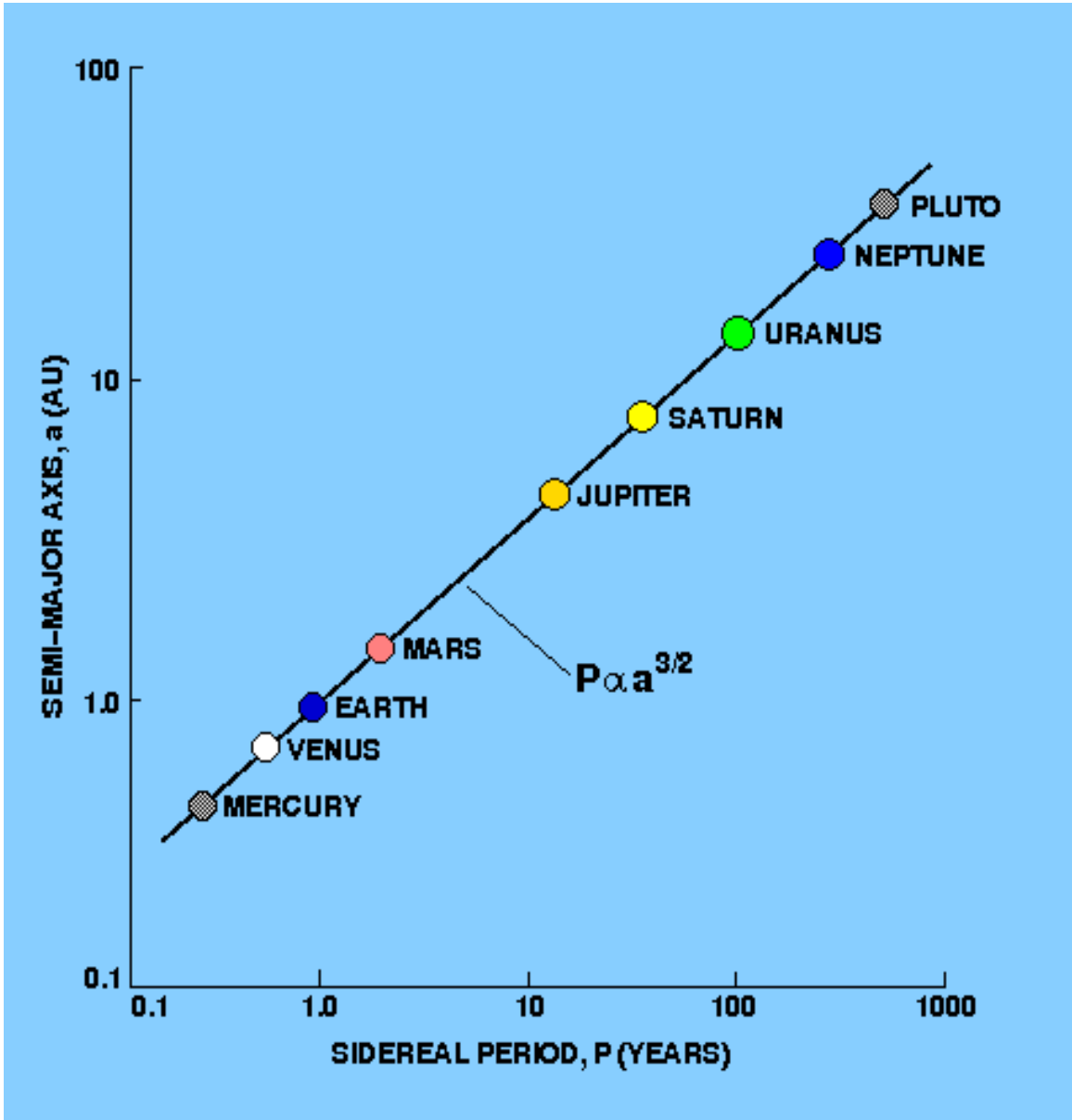
Can read relation from graph.

Where would a planet with an orbital period of 30 years lie on the horizontal axis?

A) 3/10ths of the way from 10 to 100 years

B)1/2 of the way from 10 to 100 years

C) 2/3 of the way from 10 to 100 years



Newton's Law of Gravitation

- The gravitational force exerted by an object is proportional to its mass
- The gravitational force exerted by an object decreases with the square of the distance

- Persons A and B have the same mass. If person B is 3 times as far away from the Sun as person A, then the force of gravity from the Sun on person B is $(1/3)^2 = 1/9$ of that on person A.

When an object moves farther away, its angular size

A) Increases

B) Decreases

C) Stays the same

When an object moves three times farther away, its angular size

A) Increases by a factor of 3

B) Decreases by a factor of 3

C) Stays the same

An object is 2000 m away and has an angular size of 1”. How big is it?

A) Height of a person

B) Size of finger nail on your pinky

C) Size of a grain of salt

D) Length of the Titanic

Small angle formula for S, d in meters, α in arcseconds:

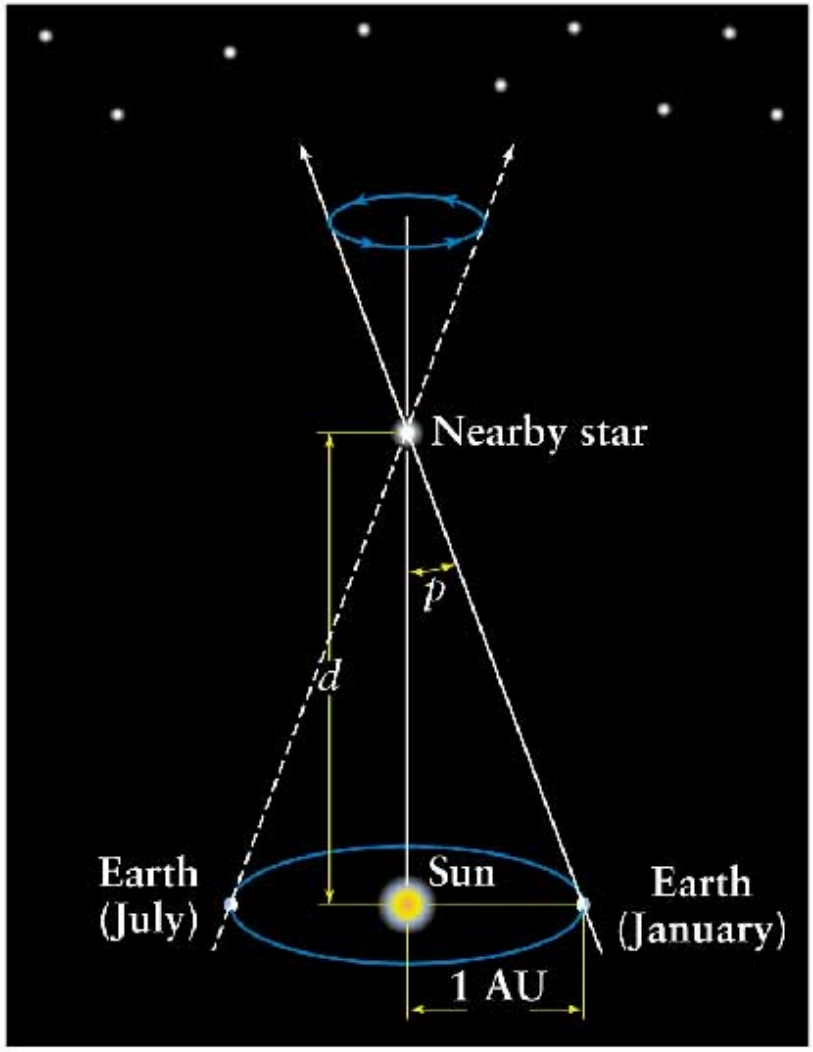
$S = \alpha d/206265$

We have d = 2000 m, α = 1” = 1 arcsecond

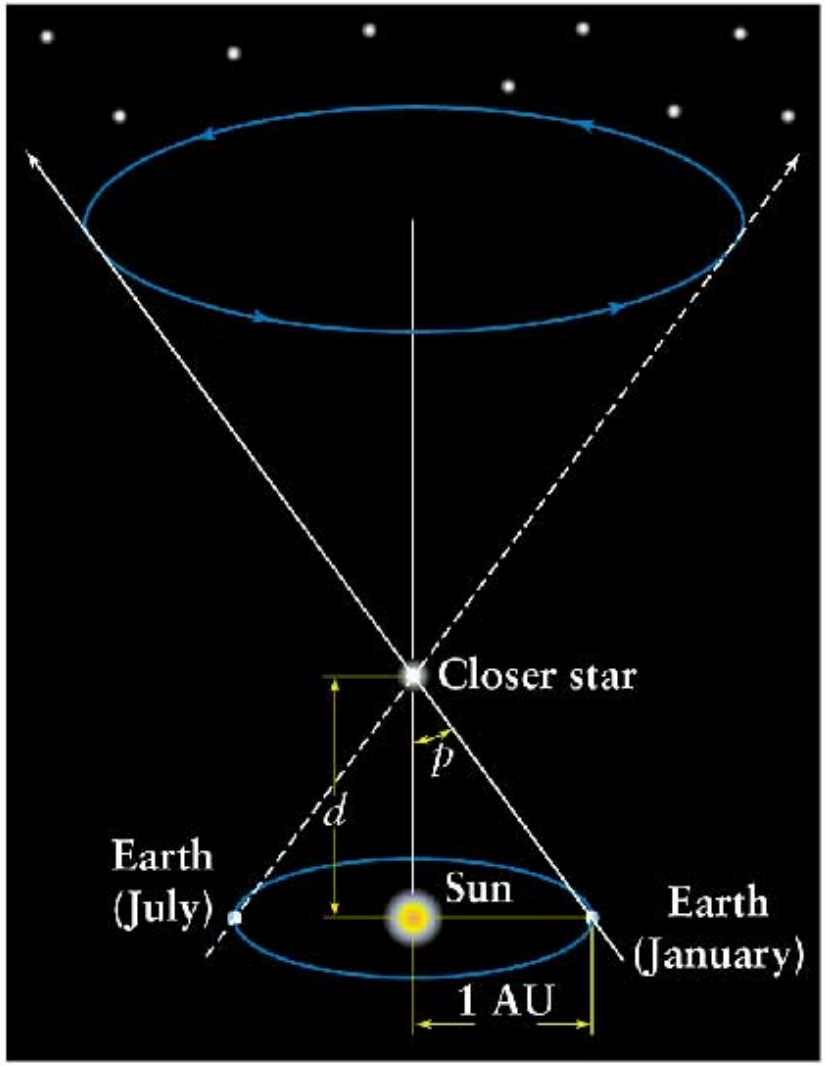
So $S = 1 \times 2000/206265 = 0.0097$ m $\approx 2000/200000 = 1/100$ m = 1 cm

On exam, might need to solve for d or α or go find the numbers.

1° = 1 degree = 60 arc-minutes = 60' = 3600 arc-seconds = 3600”



a



b

Farther star – smaller parallax

Closer star – larger parallax

$d = 1/p$ where d = distance to star in parsecs and p = parallax angle of star in arcseconds

The best parallax measurements made with optical light were done by the Hipparcos satellite and were for stars with parallax of about 0.01 arcseconds. How far away are those stars?

A) 0.01 parsecs
B) 1 parsec
C) 100 parsecs
D) 10,000 parsecs