To Frame the World—17 Sept

- Kepler found orbit of Mars relative to earth's orbit.
- Goal was to measure the absolute distance (in miles or km) of the solar system
- Cassini & Richer 1672

Giovanni Domenico Cassini, (1625 - 1712)
engraving by N. Dupuis
www.sil.si.edu/digitalcollections/hst/scientific-identity/fullsize/SIL14-C1-18a.jpg

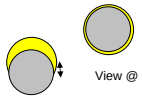
First test

- See practice test (link is on the syllabus http://www.pa.msu.edu/courses/AST207)
  - A few questions with verbal, numeric, or graphical answers.
  - No multiple-choice questions.
- Material covered today will be on the test.
- First test is low risk: it counts only 5% of course grade.
- Homework 3 must be handed by start of class on Fri, 19th.
  - Answers will be posted after class on Fri. See link on syllabus.
- Class on Fri is "Missouri Club"
  - You must ask a question, preferably a question of detail.
  - "How do you do question 3" is not detailed enough.
- You may bring one sheet of notes to use for Test 1.

Hipparchus measures the moon's distance~200BC

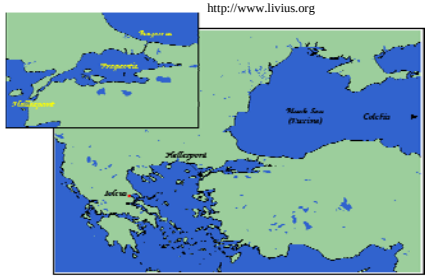
- At the Hellespont, the solar eclipse of 189BC was total. (Sparta defeated Athens there in 405 BC.)
- In Alexandria, the moon covered ¼ of the sun.
- Draw a picture to show the relationship between the sun, the moon, the two locations, and the difference between a total & ¼ eclipse. (The diameter of the sun is ½ degree.)

http://www.livius.org



View @ Hellespont

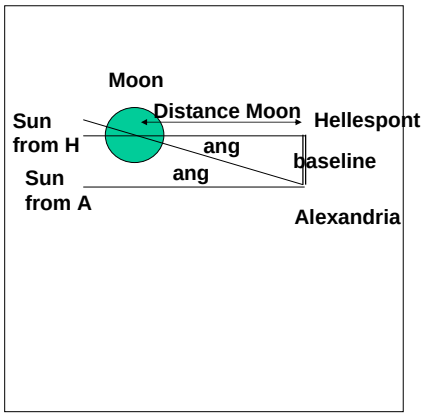
View in Alexandria.
Moon is offset by 1/4 diameter of sun



http://mkatz.web.wesleyan.edu/medea_lecture/hellespont.gif

What triangle did Hipparchus use?

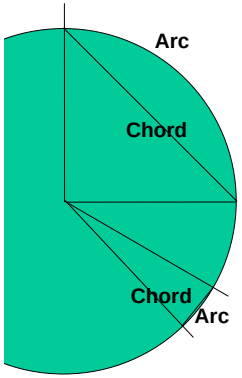
- Parts of triangle
  - Angle is due to parallax: moon in foreground shifts with respect to sun in the background.
  - One leg of triangle is the baseline.
  - Other leg is distance to moon
- Method of parallax.
  - Angle is the "parallactic shift."



Small angle approximation

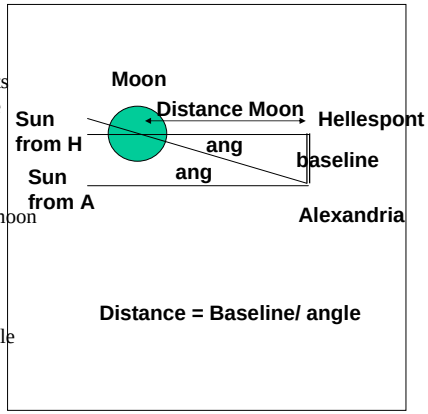
- Measure angles in radians
  - 2π radians = 360 °
- Arc = radius × angle
  - For entire circle,
    - arc = circumference = $2\pi R$
    - angle = 2π
- For small angles, arc is approximately equal to the chord.

  Chord = radius × angle
- Application
  - Baseline = Distance × angle
  - 1000km=Distance × 1/8°



Method of parallax

- Parts of triangle
  - Angle is due to parallax: moon in foreground shifts with respect to sun in the background.
  - One leg of triangle is the baseline.
  - Other leg is distance to moon
- Method of parallax.
  - Angle is the "parallactic shift."
  - Distance = Baseline/ angle



Difficulties

- Small angles are hard to measure
  - Naked eye 1/30° = 1/1700 rad = 6e-4 rad = 600 μrad
  - Modern telescope used under ideal conditions: 5 μrad
  - Modern telescope with correction for atmospheric turbulence: 0.5 μrad
  - Moon using Hellespont & Alexandria

    Angle = baseline/distance = 1000km / 400,000km

    = 1/400 rad = 2500 μrad (1/7°)
  - Mars

    Angle = baseline/distance = 1000km / 80,000,000km

    = 13 μrad using Hellespont & Alexandria
- Need a reference nearby in the sky
  - Measuring with a reference on the ground is impossible.

Cassini & Richer 1672

- Angle=baseline/distance
- What baseline should C&R use to measure distance to Mars?

Cassini & Richer 1672

- Angle=baseline/distance
- What baseline should C&R use to measure distance to Mars?
- Cayenne-Paris baseline is 7000km.
  - Angle=baseline/distance=7000 km/80,000,000km
    = 90μrad
  - Shift is 18 times width of the star with modern telescope

Mars Star

from Paris

Mars & star from Cayenne

Cassini & Richer 1672

- We are pretending to be Jean Richer and Giovanni Cassini in 1672. We are measuring the distance to Mars by making observations from Paris and Cayenne.
- Facing the screen, hold a pencil at arms length. Without moving the pencil, look at it with your left and then your right eye. The pencil tip shifts with respect to the screen.

1. What corresponds to Mars?
   A. Left eye or right eye
   B. Tip of pencil
   C. Something in the screen
   D. The shift of the pencil tip with respect to the screen.
2. What corresponds to Paris?
3. What corresponds to the star?
4. What is proportional to the parallax angle?
5. If Mars were closer, the shift is
   A. larger.
   B. same.
   C. smaller.
6. If Paris and Cayenne were farther apart, the shift is
   A. larger.
   B. same.
   C. smaller.

Mars Star

from Paris

Mars & star from Cayenne

For Fri

- We pretend to be M. Cassini. We will propose a grand plan to "Frame the World" to the king of France. How will the expedition to Cayenne determine the distance to every planet?