## To Frame the World—19 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

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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.
- "A clear picture is 90% of clear thinking."
- 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
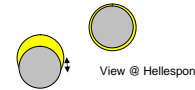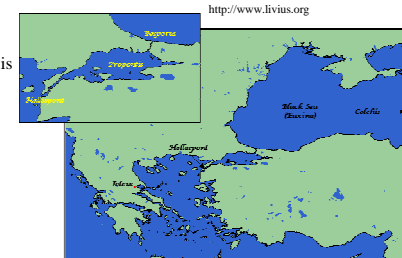
View @ Hellespont

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.

Moon
Distance Moon
Sun from H
Hellespont
ang
baseline
Sun from A
ang
Alexandria
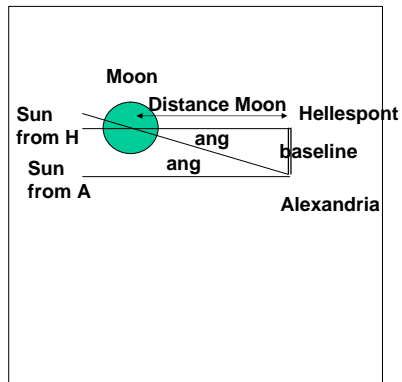
Small angle approximation

- 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 (π/180)

Arc

Chord

Chord
Arc
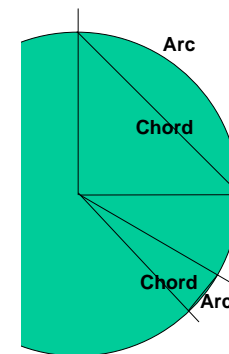
Difficulties

- Small angles are hard to measure
  - Naked eye 0.03 deg
  - Telescope used under ideal conditions: 0.1 arcsec=0.00003 deg
  - Modern telescope with modern detector: 0.0000003 deg
  - Moon
    - Angle=baseline/distance=1000km/400,000km
    - $=1/400=(180/\pi)/400=1/7$ degree
  - Mars
    - Angle=baseline/distance=1000km/80,000,000km
    - $=1/80,000=(180/\pi)/80,000=0.0007$ degree 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
    - $=9\times10^{-5}$rad $=5\times10^{-3}$degree
    - $=18$arcsec
  - Shift is 18 times width of the star with modern telescope

Mars ○ ○ **Star**
from Paris

○ **Mars & star**
from Cayenne
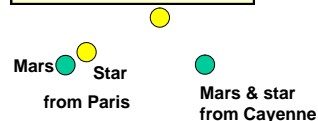
To frame the world

A. Size of Earth measured

B. Periods of planets measured

C. K finds Mars orbit (1601)

D. K discovers 3rd law (1618)

E. Cassini + Richer measure Earth-Mars distance (1672) using Paris-Cayenne baseline

3. Sun-Jupiter distance in feet

1. Sun-Mars distance in AU   2. Sun-Mars distance in feet

1. Draw an idea map for getting result 1, the Sun-Mars distance in AU.

2. Draw an idea map for result 2.

3. Same for 3.