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

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.)

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.

Small angle approximation

- Measure angles in radians
  - $2\pi$ radians = 360 °
  - $\text{Arc} = \text{radius} \times \text{angle}$
    - For entire circle,
      - $\text{arc} = \text{circumference} = 2\pi R$
      - $\text{angle} = 2\pi$
    - For small angles, arc is approximately equal to the chord.
  - $\text{Chord} = \text{radius} \times \text{angle}$
- Application
  - Baseline = Distance * angle
  - $1000\text{km} = \text{Distance} \times \frac{1}{8} (\pi/180)$
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 = 1000 km / 400,000 km
    = 1/400 = (180/π) / 400 = 1/7 degree
- Mars
  - Angle = baseline/distance = 1000 km / 80,000,000 km
    = 1/80,000 = (180/π) / 80,000 = 0.0007 degree using Heliopolis & 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 7000 km.
  - Angle = baseline/distance = 7000 km / 80,000,000 km
    = 9 × 10⁻⁵ rad = 5 × 10⁻³ degree
    = 18 arcsec
  - Shift is 18 times width of the star with modern telescope

To frame the world

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

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

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.