

Kepler attacks Mars—15 Sep

- Answers for Hwk1 will be on Angel.
- Questions on Hwk 2.
- Public observing at MSU Observatory
 - Fri & Sat, 9-11 weather permitting.
- The discovery of the laws of motion, the first science.
 - *De Revolutionibus Orbium Coelestium*, Copernicus, 1543
 - *Astronomia Nova*, Kepler, 1609
 - *Philosophiae Naturalis Principia Mathematica*, Newton, 1687
- How Kepler figured out the path of Mars from Tycho's observations. Discovery of his three laws.



Kepler at 39, Sternwarte Kremsmünster
<http://members.nexta.at/stewar/>

Copernicus	1473–1543
Columbus sails	1492
Tycho Brahe	1546–1601
Shakespeare	1564–1616
Johannes Kepler	1571–1630
Jamestown	1607
King James Bible	1611
Harvard College	1636
Isaac Newton	1642–1727



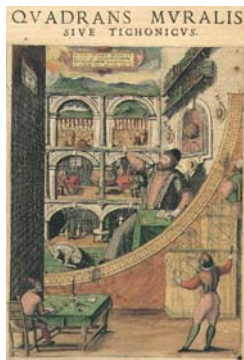
What is fake on Tycho?

Tycho Brahe's Observations

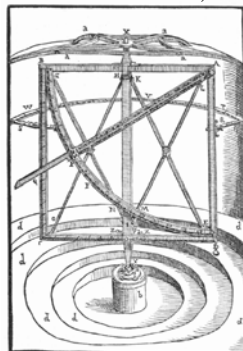
- On Uraniborg, Tycho measured positions of the planets for 20 years
- Highly accurate & reliable
 - Accuracy limited by human eye, not by instruments. Superseded only with telescopes.
 - Tycho measured & compensated for instrument flexure, the biggest error.



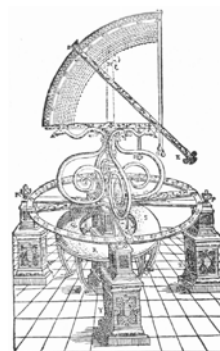
Uraniborg.



Great quadrant (1582)



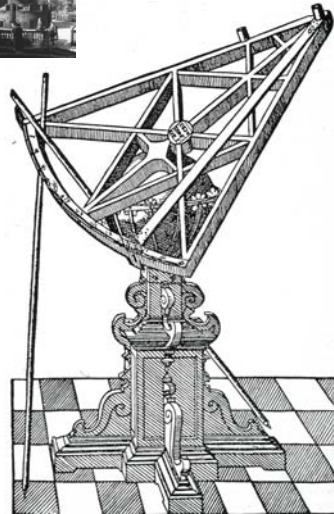
Revolving steel quadrant, 2 m radius (1588)



Brass azimuthal quadrant, 65 cm radius (ca 1576)



Sextants at Uraniborg



Great quadrant (1582)

Kepler & Tycho

Their meeting at Benatek (in Chechoslovakia): ...on 4 February 1600, Tycho de Brahe and Johannes Keplerus, co-founders of a new universe, met face to face, silver nose to scabby cheek. Tycho was fifty-three, Kepler, twenty-nine. Tycho was an aristocrat, Kepler a plebian. —Koestler, *The Sleepwalkers*, p302

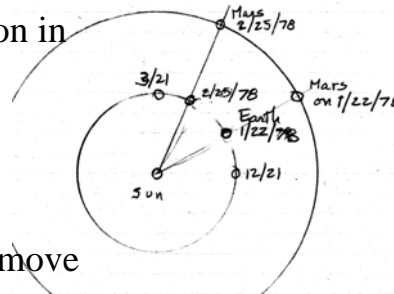


How did Kepler figure out Mars' orbit from Tycho's observations?

- Tycho's observations are 2 dimensional
- Orbit is 3 dimensional
- Two examples
 - Determine the period of Mars
 - Opposition occurred on 22 January 1978
 - Next opposition: 25 February 1980 (56th day)
 - Determine a point on Mars' orbit.
 - Kepler had to do this for many points.

- Observations
 - Opposition occurred on 22 January 1978
 - Next opposition: 25 February 1980 (56th day of the year)
- For there not to be an opposition in between,
 - Mars has traveled $360 + (56 - 22)360/364 = 394^\circ$
 - in $364 + 364 + (56 - 22) = 762$ days
- Period of Mars is how long to move 360°
 - $762 \times 360 / 394 = 696$ days.
 - Actual period is 687 days.

Period of Mars

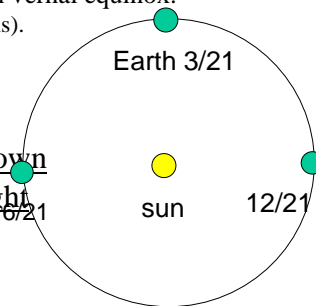


Path of Mars

- Observations
 - On 21 March 1978, the right ascension of Mars is 7hr 46min (116.5° from the sun on the vernal equinox).
 - On 5 February 1980 (one Martian year later), Mars is at 11hr 03min (165.8°).
- Where is Mars? Pretend to be Kepler who has just arrived at Tycho Brahe's observatory, Hven, in 1600. We are figuring out a point on Mars' path using the observations of our boss, Tycho Brahe.

Coordinate system

- Observations
 - On 21 March 1978, the right ascension of Mars is 7hr 46min (116.5° from the sun on the vernal equinox).
 - Sky coordinates, right ascension & declination, which does not change for stars.
 - Declination: angle from celestial equator
 - A star at declination 0° is on equator
 - Polaris (near north pole) is at declination $+90^\circ$.
 - Right ascension: angle from location of sun on vernal equinox.
 - Increases CCW (in same direction as earth turns).
 - Measured in hr-min-sec or degrees.
1. It is 3/21. Which direction is RA=0hr?
 - A. up B. left C. down D. right
 2. It is 12/21. Which direction is RA=0hr? down
 3. It is 3/21. Which direction is RA=6hr? right



How Kepler determined Mars' path

- Observations
 - On 21 March 1978, the right ascension of Mars is 7hr 46min (116.5° from the sun on the vernal equinox).
 - On 5 February 1980 (one Martian year later), Mars is at 11hr 03min (165.8°).
- Where is Mars? Pretend to be Kepler in 1600.
 1. On 3/21/78, in what direction is Mars?
 - A. N B. S C. E D. NE E. SE
 2. A point on the path of Mars is at the intersection of the line drawn on the two dates. Would this be true for any two dates? What is the reason?
 - A. Y.
 - B. N.

Determining one point on Mars' orbit

- Observations
 - On 21 March 1978, the right ascension of Mars is 7hr 46min (116.5° from the sun on the vernal equinox).
 - On 1 Jan 1980, Mars is at 11hr 06min (166.5°).
 - On 15 Jan 1980, Mars is at 11hr 12min (168.0°).
 - On 6 February 1980 (one Martian year later), Mars is at 11hr 02min (165.5°).
 - On 1 Mar 1980, Mars is at 10hr 30min (157.5°).
- 1. Which point is on Mars' orbit?

