Kepler’s Laws

- 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 Tyco’s observations. Discovery of his three laws.

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<th>Year</th>
<th>Event</th>
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<td>1473–1543</td>
<td>Copernicus</td>
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<td>1492</td>
<td>Columbus sails</td>
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<td>1546–1601</td>
<td>Tycho Brahe</td>
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<td>1564–1616</td>
<td>Shakespeare</td>
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<td>1571–1630</td>
<td>Johannes Kepler</td>
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<td>1607</td>
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<td>1636</td>
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<td>1642–1727</td>
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Kepler & Tycho

Their meeting at Benatek (in Chechoslavakia): …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.

Period of Mars

• 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°
  – in 364+364+(56-22)=762 days
• Period of Mars is how long to move 360°
  – 762×360/394 = 696 days.
  – Actual period is 687 days.
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°.
  - 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.