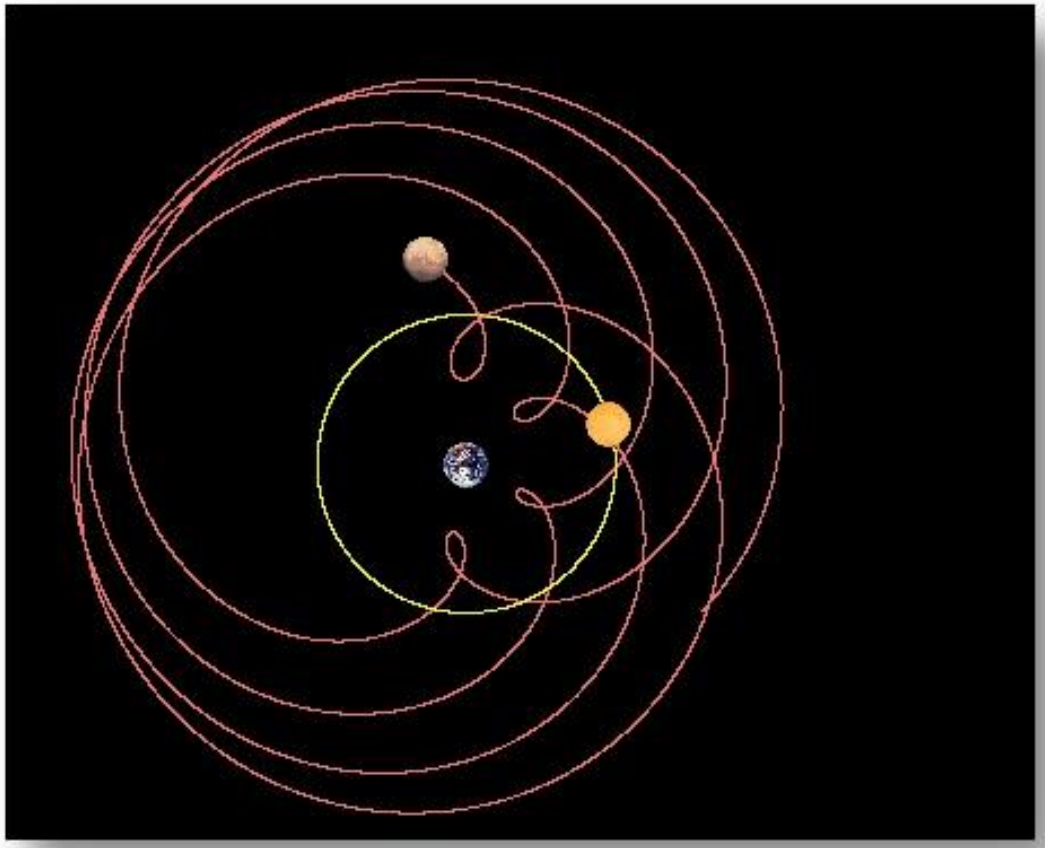
Understanding Planetary Motion

- Use experimental observations (made prior to telescopes) to understand motion of the planets. Period is “easy”, distances and orbit shape are “hard” (except Venus and Mercury are easier)
- Leads to Kepler’s 3 laws of planetary motion
- Provides experimental observations which are later explained by physics developed by Galileo, Newton and others

Models of the Solar System

Ptolemaic – Geocentric - very, very wrong

- Earth at center and motionless
- Sun and other planets orbit the Earth on circles within circles.



Think Tilt-a-Whirl at Cornfest

Works very badly for Mercury and Venus which clearly are orbiting the Sun

Orbit of Mercury

As Mercury (and Venus) are between the Earth and Sun, their orbits are ~trivial to understand

- Sometimes do as PHYS 162 exercise (see web page)
- Mercury always near the Sun, either at early evening or morning. Measure Merc-Sun angle at maximum separation from Sun

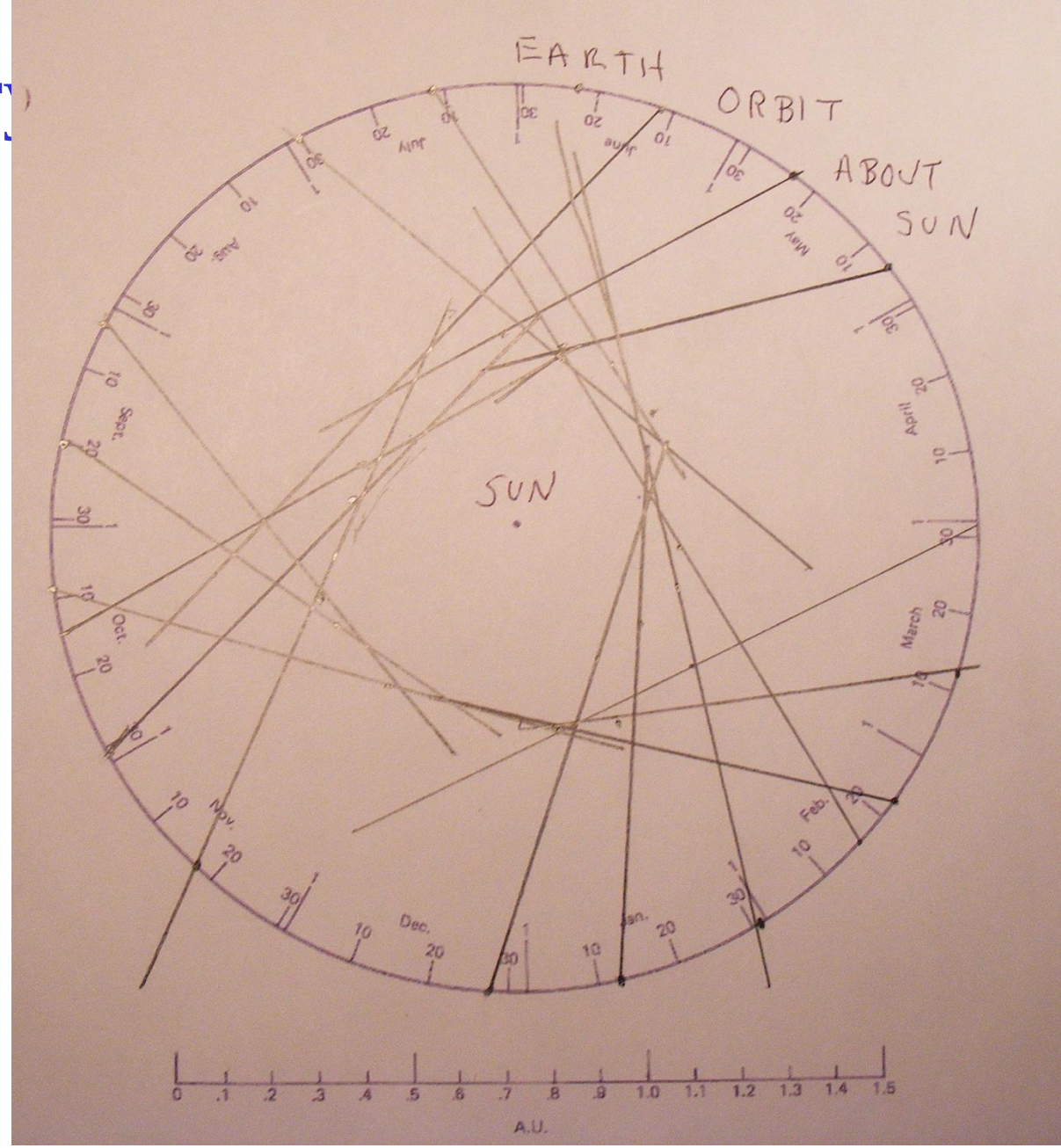
Table 21–1 Maximum Elongations for Mercury

February	16,	1967	18°	east
March	31		28°	west
June	12		25°	east
July	30		20°	west
October	9		25°	east
November	18		19°	west
January	31,	1968	18°	east
March	13		27°	west
May	24		23°	east
July	11		21°	west
September	20		26°	east
October	31		18°	west
January	13,	1969	18°	east
February	23		26°	west
May	6		21°	east
June	23		23°	west
September	3		27°	east
October	15		18°	west
December	28		19°	east

Orbit of Mercury

Given day/year, draw line at Merc-Sun angle.

- Do for many years
- Mercury orbiting Sun, but not circle (actually ellipse)
- Also gives size of Merc orbit relative to Earth's
- Greeks observed this, Kelper/Brahe did more accurately



Copernican - Heliocentric

- Sun at center
- All planets move about Sun on circles on circles
- Earth revolves on axis once per day
- Catholic Church adopts Ptolemaic as “revealed truth” in 13th Century (when first Universities in Europe began). Copernican model published in 1543 with detailed comparisons to observations (after Copernicus’ death so Church would not punish him)
- Sidenote: Ptolemy was greek/egyptian (100-170 AD) whose books where the only ones who survived. From antiquity some (Ptolemy, Hipparchus) preferred geocentric while others (Aristarchus,Seleacus,Pliny,Seneca,Archimedes?) preferred Heliocentric. Obsession with circles part of problem in understanding correct model

Copernican vs Geocentric vs Catholic Church

- Bruno was burned at the stake in 1600 in Rome for stating Copernicus was correct
- *"Innumerable suns exist; innumerable earths revolve around these suns in a manner similar to the way the seven planets revolve around our sun. Living beings inhabit these worlds."* — Giordano Bruno

Campo d'Fiore Rome

also has farmer's market and 4 nice inexpensive restaurants

Other Models

- Tycho Brahe's - Earth at center but other planets orbit the Sun (effectively the same as Copernican) but keeps Earth as "most important" location
- Kepler's - Sun at center with planets orbiting the Sun in elliptical paths CORRECT

- Differentiate models by comparing predictions with observations

SCIENTIFIC METHOD

need best observations as possible

Brahe and Kepler

- Brahe led team which collected data on position of planets (1580-1600 no telescopes)
- Kepler (mathematician) hired by Brahe to analyze data. Determined 3 Laws of planetary motion (1600-1630)
- Input - 20 years of data on:

angular position of planets

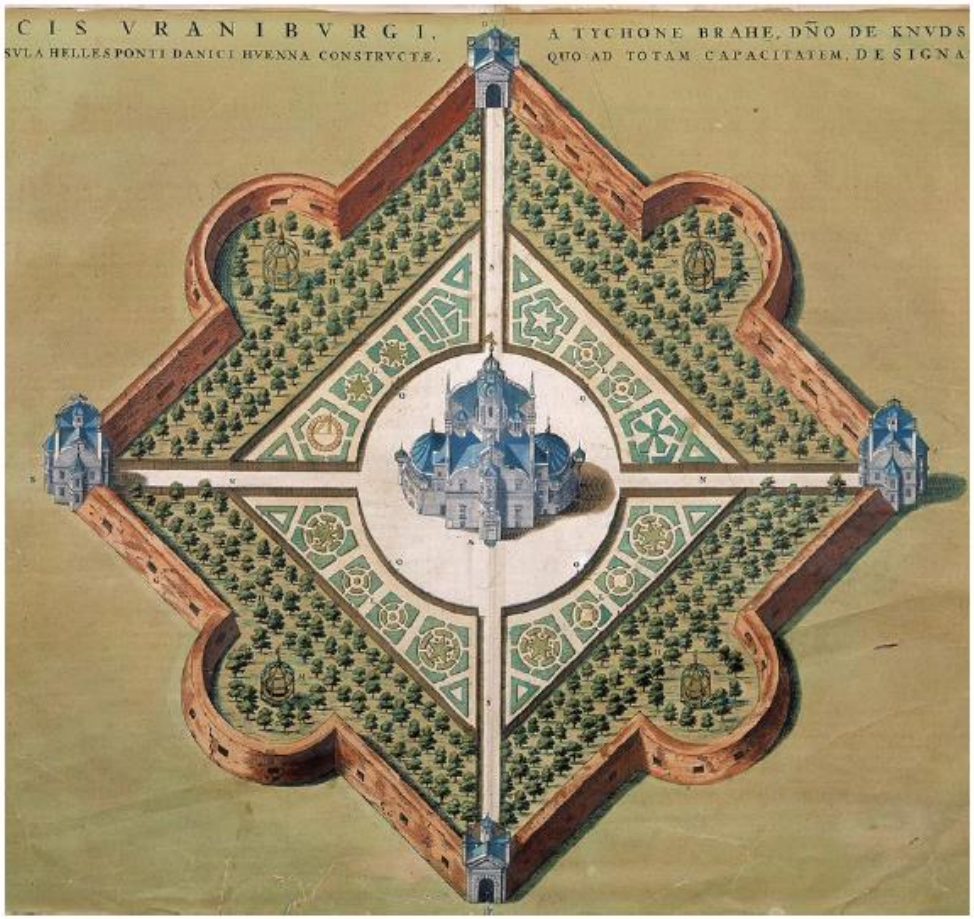
approximate distances from Earth (accurate relative distances)

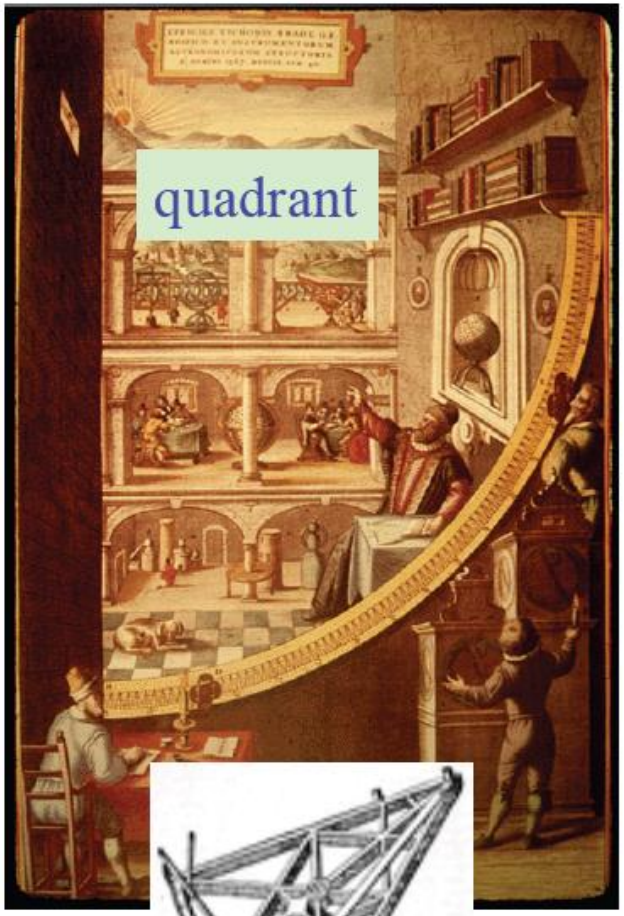
- Few "modern" tools (no calculus, no graph paper, no log tables), just Euclidan geometry

Observations of Brahe 1580-1600

- Brahe was a Danish nobleman who became famous after observing a supernova and showing it was “far away”
- Danish king provided funding and an island where Brahe set up an observatory – no telescopes just (essentially) sextants - that is long sticks to measure angles which could be flipped to measure both E-W and N-S angle at same time

Brahe's Observatory

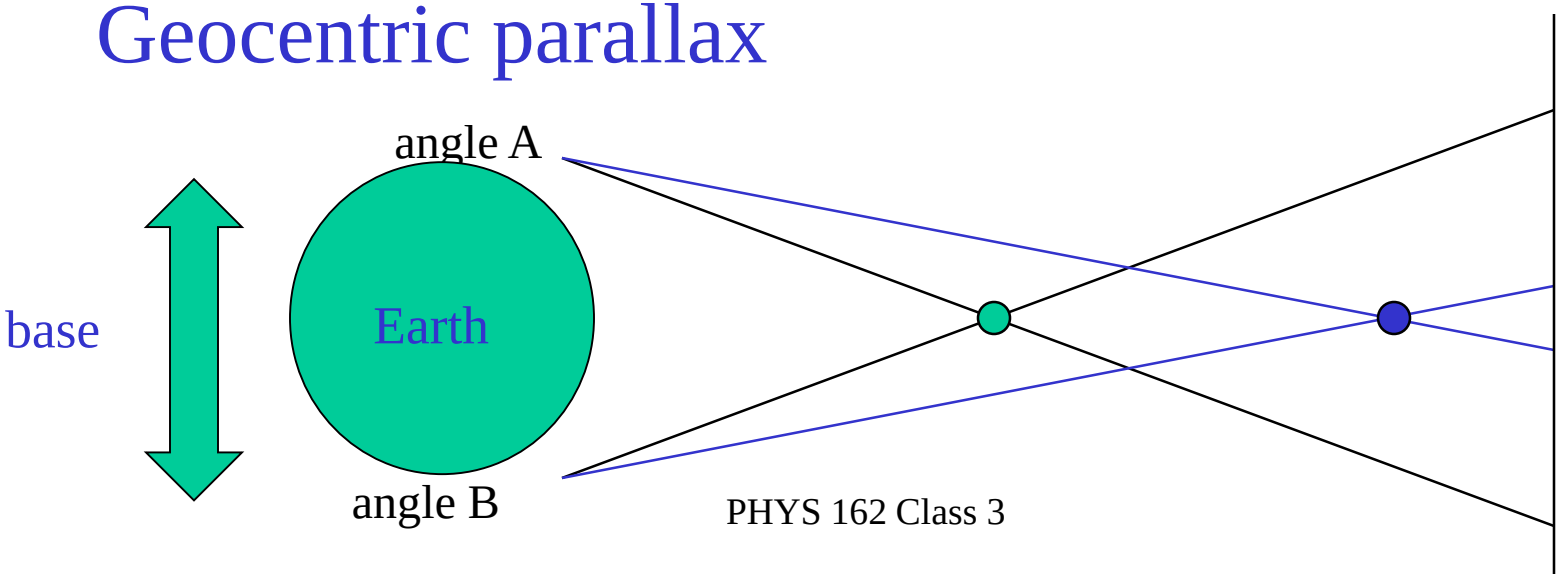




Apparent Shift = Parallax

- Moving observer sees fixed objects shift
- Near objects shift more than far objects
- Due to change in observation point → our eyes for depth perception.

Geocentric parallax

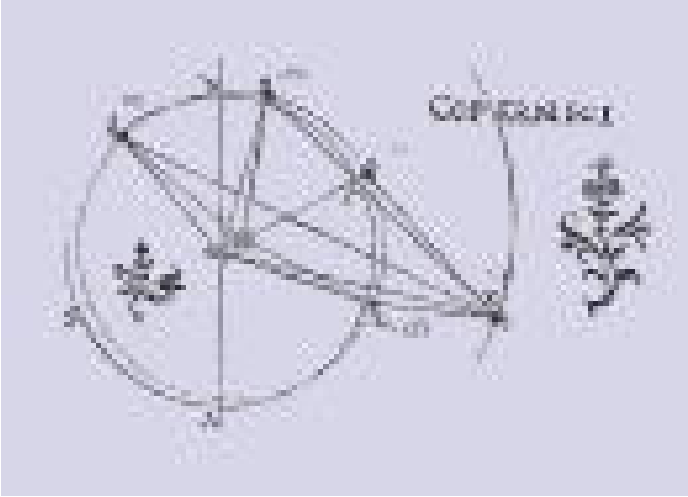


Sources of Parallax

- Heliocentric parallax: sun as base.
- Photos with telescope at two different seasons → use later for stars
- Geocentric parallax: earth as base.
- Measure two or more times in one night.
- Use for planets/Sun/Moon → Brahe's data had distances to planets plus position in sky

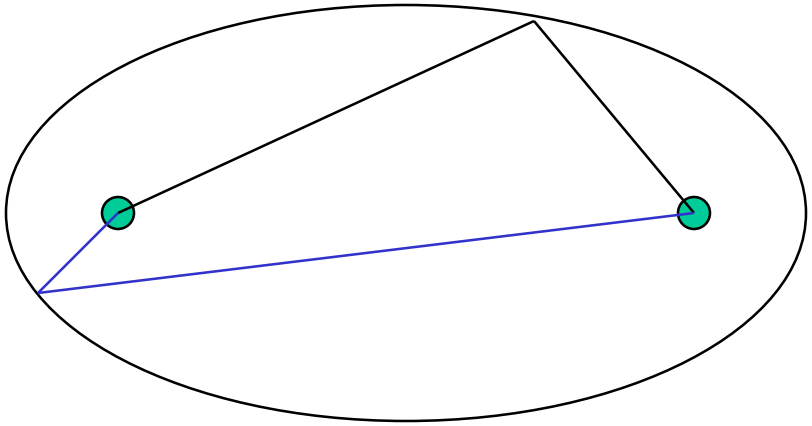
Kepler's Laws of Motion

- Kepler: correct orbital shape and determined some relationships between the orbits of different planets
- Big step: Earth's orbit about the Sun also wasn't a circle – mostly he used relative location of Mars after repeated orbits around the Sun (Mars is close and so most accurate measurements)



Kepler's Laws of Planetary Motion (1630)

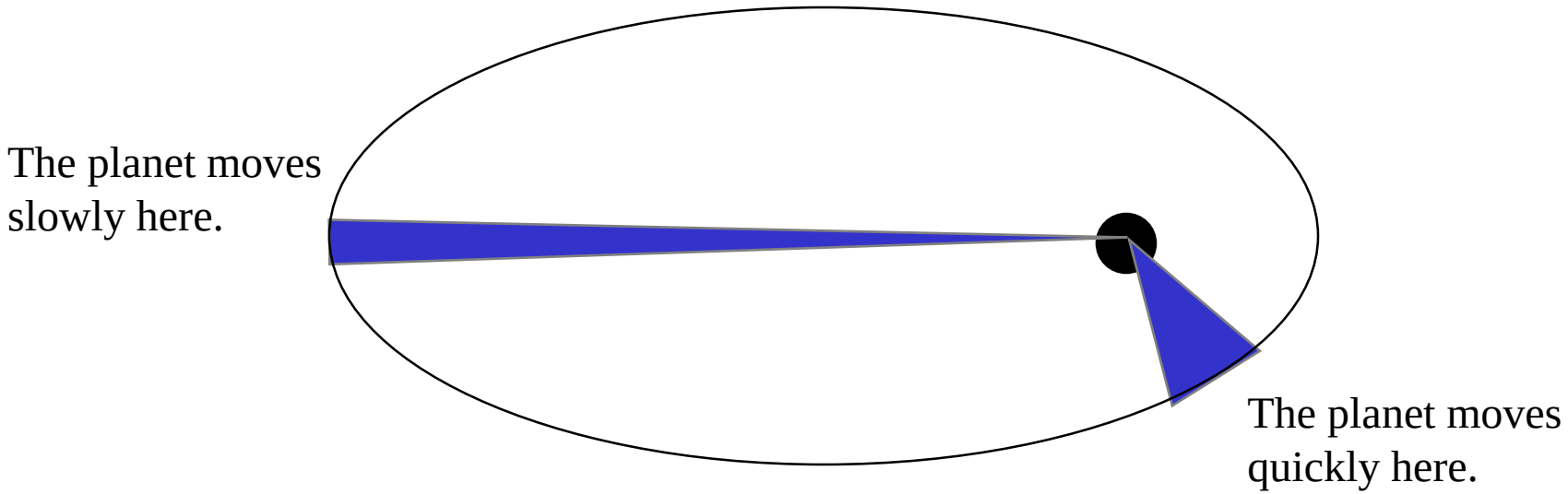
FIRST LAW: The orbit of a planet is an ellipse with the sun at one focus.



A line connecting the two foci in the ellipse always has the same length.

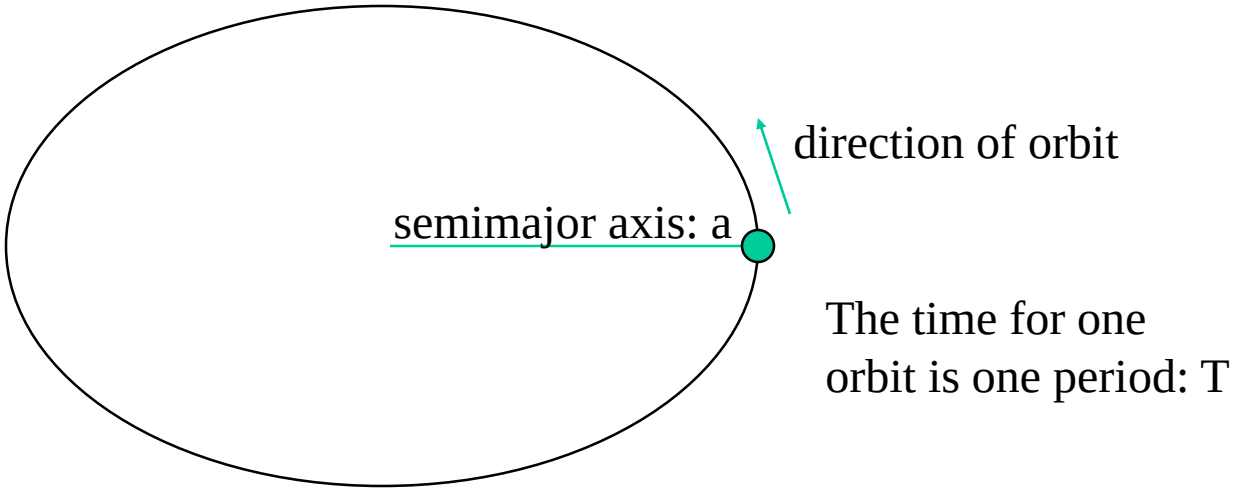
Kepler's Second Law

- The line joining a planet and the sun sweeps equal areas in equal time.



Kepler's Third Law

- The square of a planet's period is proportional to the cube of the length of the orbit's semimajor axis.
- Mathematically, T^2/a^3 = constant.(=1 if use 1 Earth year and 1 AU as units)
- The constant is the same for all objects orbiting the Sun → same process determines all planets' motions



	Mean Distance from Sun	**Sidereal Orbital Period**
	AU	$\boldsymbol{P_e}$
Mercury	0.387	0.241
Venus	0.723	0.615
Earth	1.000	1.000
Mars	1.524	1.881
Jupiter	5.203	11.857
Saturn	9.537	29.424
Uranus	19.191	83.749
Neptune	30.069	163.727

Third Law Example

- Jupiter compared to Earth
- If we measure that it takes Jupiter 11.9 years to orbit the Sun then:

$$\text{distance}^3(\text{Jupiter-Sun}) = \text{period}^2$$

$$\text{distance} = \text{period}^{2/3}$$

$$\text{distance} = (11.9*11.9)^{1/3}$$

$$\text{distance} = (142)^{1/3} = 5.2 \text{ AU}$$

- Kepler: determined the motion of the planets.
- Did not address WHY. Simply what curve best matched orbits and some arithmetical relationships
- WHY: determined by physicists like Galileo and Newton.
- Needed to develop Physics as a science: understand motion, forces, and gravity

Observatory Visit

- If sky clear on Monday 1/30 the class will meet at the Davis Hall Observatory at 7:00 PM. I'll send out e-mail yes/no on Monday afternoon
- 10 EC points if make it to this class. We will then not have class on Tuesday 1/31.
- If sky isn't clear will try to redo week of March 20
- DHO directions: Building just north of LaTourrette. walk up stairs or take elevator to 5th floor. Continue up stairs to 9th floor

Movie – Cosmic Voyage

Looks at the Universe

→ increasing distance scales. to billions of light years

→ decreasing distance scales. to subnuclear scales

Looks at time evolution of Universe over billions of years

→ telescopes look far away are looking back in time

→ accelerators like Fermilab are reproducing how the Universe in the first moments after creation (Rocky Kolb from Fermilab)

reminder: 2 EC points for seeing movie. Pass around signup sheet. Up to 5 points for a paper on any of the movies or colloquium speakers