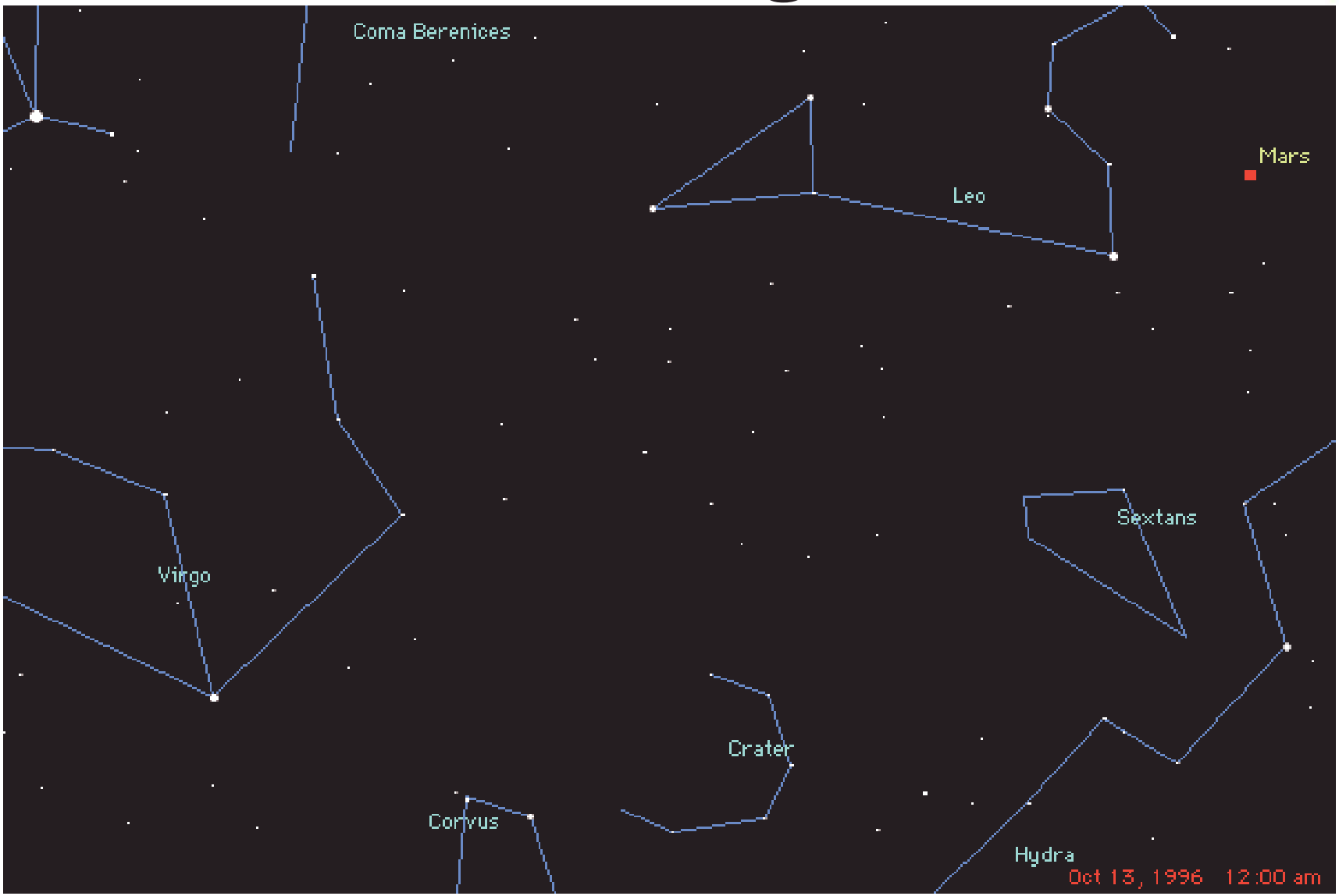
- Homework #1 is due Friday at 11:50am!
- Planetarium shows are getting full.
- Solar Observing starts next Monday!
- Nighttime observing starts in < 2 weeks.

Outline

- Dance of the Planets– Planetary motion
- Tycho Brahe and his observations
- Johannes Kepler and his interpretation
  - 3 laws
    - Orbits are on ellipses
    - An orbit sweeps out equal area in equal time
    - An orbital period is related to the semimajor axis of the orbit.

Mars Retrograde



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Tycho Brahe (1580)

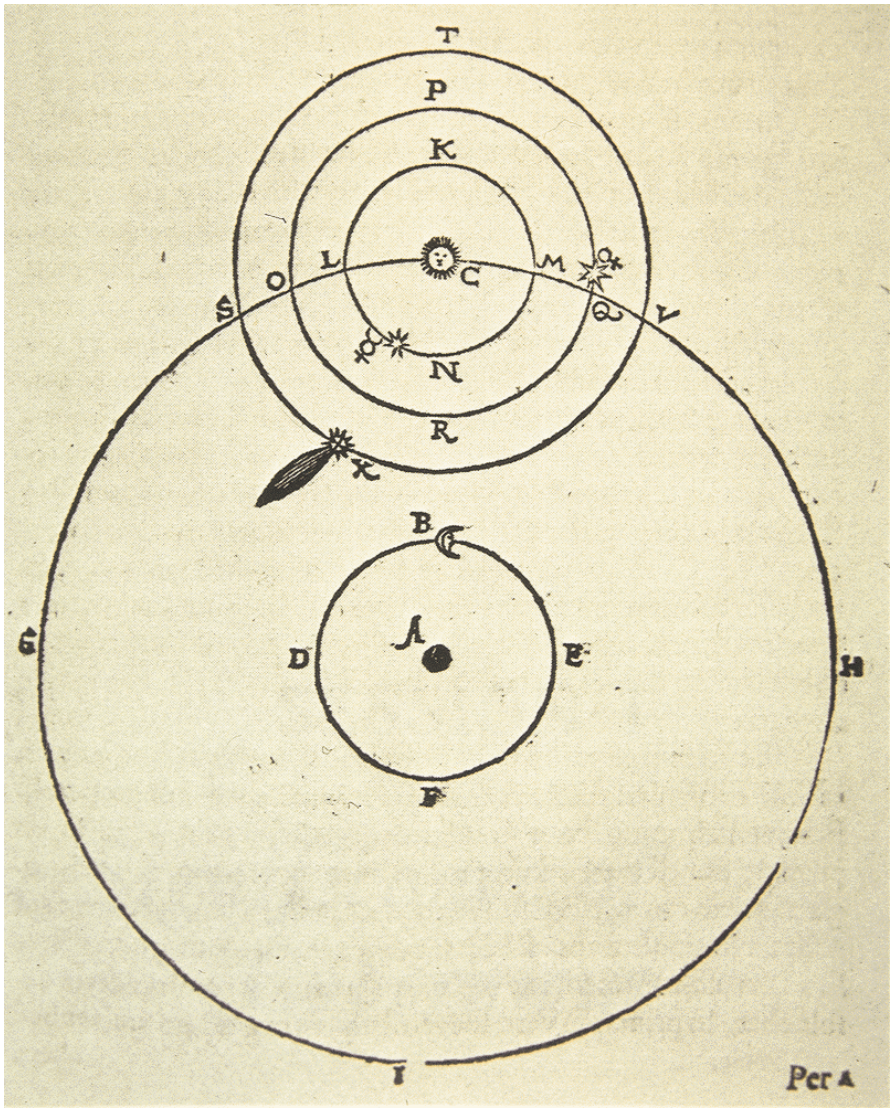
- Spent his life producing a catalog of carefully observed stars and planets using “state-of-the-art” observatory
- No telescopes!
- Yes, had a metal nose, but did not die from burst bladder

Uraniborg

Accurate measurements to about 1 minute of arc (1/15 the diameter of the moon)

Tycho's Model

- Data did not fit with geocentric view
- Developed a new model that tried to keep the geocentric viable– but too complicated
- Thought that the Laws of nature demanded a geocentric cosmology



http://es.rice.edu/ES/humsoc/Galileo/People/tycho_brahe.html

Johannes Kepler (1600)

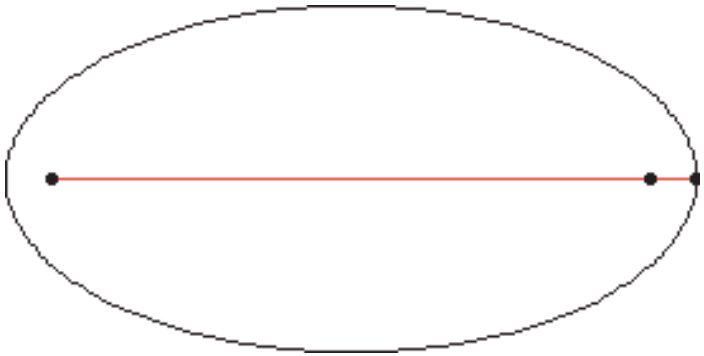
- Tycho's assistant in Prague
- After Tycho's death, succeeded Tycho's position and had access to the excellent data
- How to fit the heliocentric model to data of Mars?

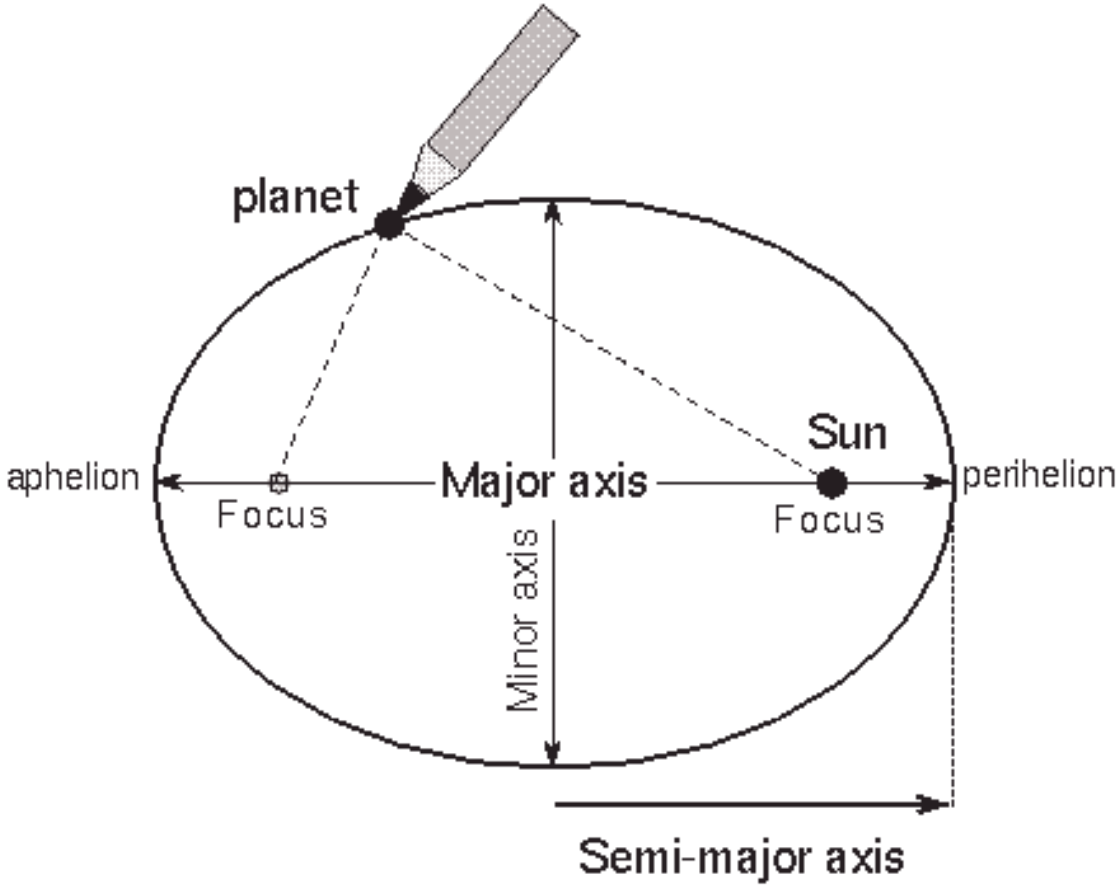
Johannes Kepler (1600)

There was a problem. The data was so good that it could not be fit with the heliocentric model if only circles were used.

Then, he began to work with the ellipse.

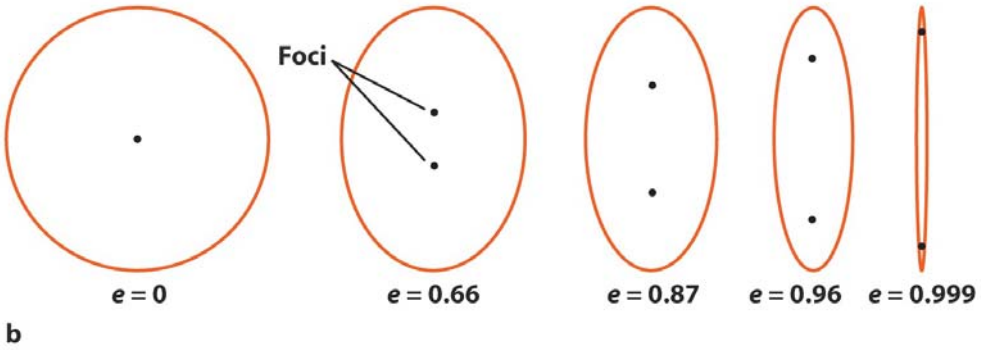
Kepler's 1st Law: Orbits of planets are ellipses with the Sun at one focus





Orbits of planets are ellipses with the Sun at one focus

Not a perfect circle, but ellipses with varying eccentricity.



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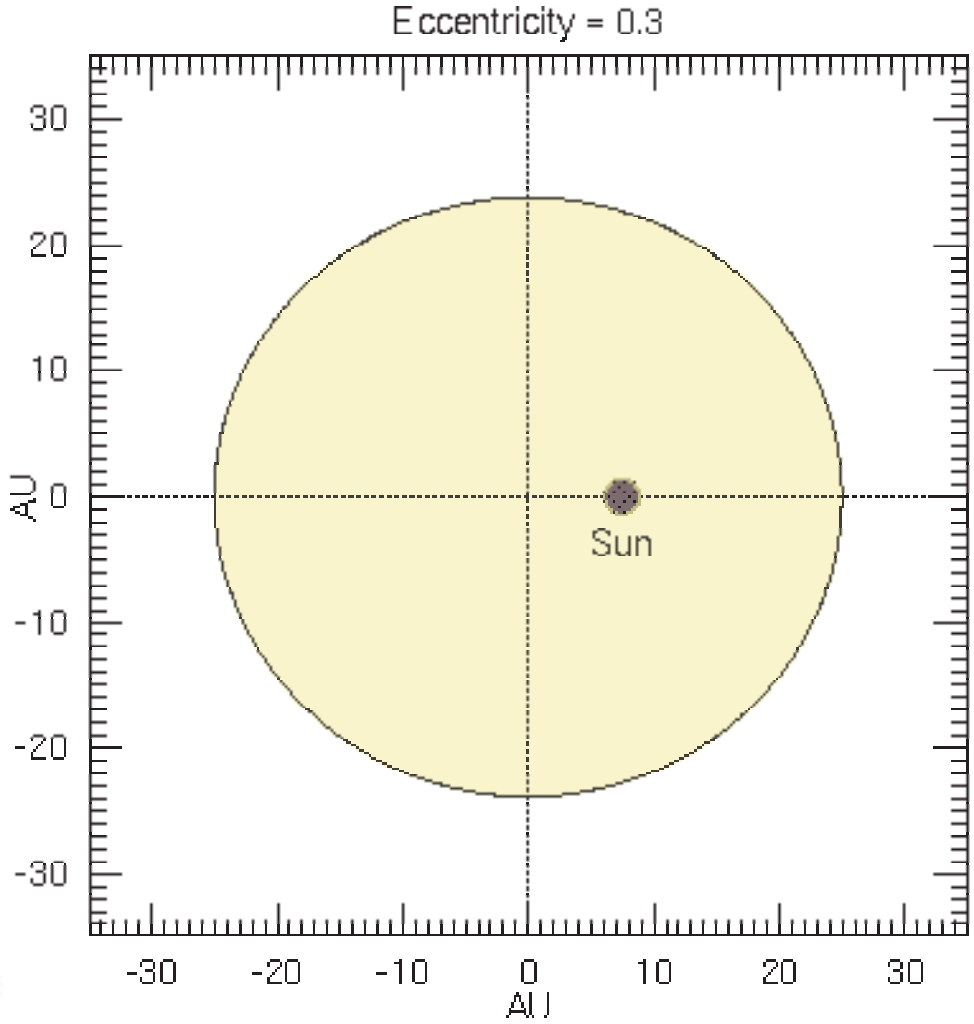
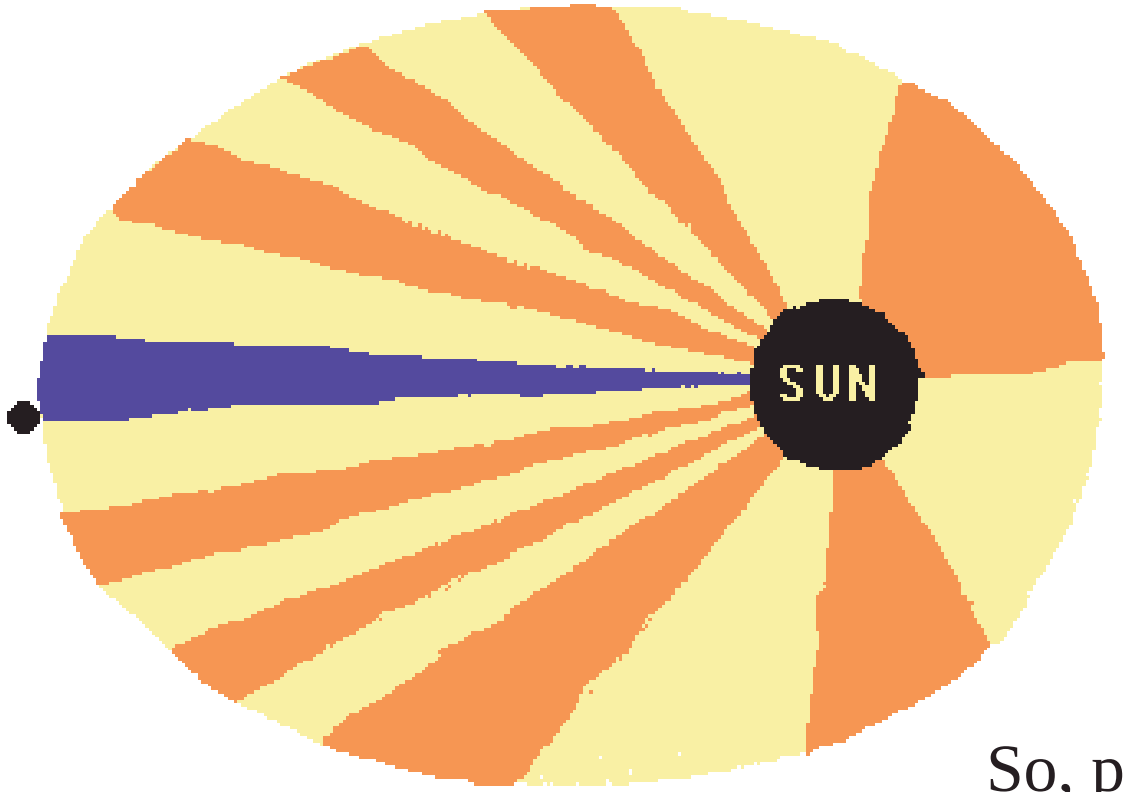


Implications

New Twist– even the Sun isn't at the center of the solar system now. How does that change our view of the Universe and our place in it?

Kepler's 2nd law: The Line that connects the planet to the Sun sweeps out equal areas in equal time

aphelion



perihelion

So, planet moves faster at perihelion.

Kepler's 2nd law:

The Line that connects the planet to the Sun sweeps out equal areas in equal time

Example: Note the inequality of the seasons: spring & summer have 93 days, autumn has 90 days, and winter has 89 days

Earth moves faster during autumn and winter (when it's closer).

Kepler's 1st and 2nd Law

http://csep10.phys.utk.edu/astr162/lect/binaries/visual/keplerold frame.html

Astronomical Unit

Now we need to define the often used term Astronomical Unit or AU. This is simply the average distance of the Earth to the Sun, which is also about the Earth's Semi-Major axis. It is equal to 1.5×10^8 km. Then, we can say that Jupiter for example is 5.2 AU from the Sun, or 5.2 times the distance away as the Earth. Just an easier unit.

Kepler's 3rd Law:

The squares of the orbital sidereal periods of the planets about the Sun are proportional to the cubes of the orbital semimajor axes

Planet	**P (yr)**	**a (AU)**	**P^2**	**a^3**
Mercury	0.24	0.39	0.06	0.06
Venus	0.61	0.72	0.37	0.37
Earth	1.00	1.00	1.00	1.00
Mars	1.88	1.52	3.5	3.5
Jupiter	11.86	5.20	141	141
Saturn	29.46	9.54	868	868

$$P^2 = a^3$$

$$P \times P = a \times a \times a$$

Where P is in years and a is in AU.

Kepler's 3rd Law

Works for Satellites, Moons, Comets, Asteroids, Binary Stars… (a caveat)

Halley's Comet returns every 76 years. What is its semimajor axis?

$P^2 = a^3$ or $a^3 = 76^2 = 5776$

so $a = (5776)^{1/3} = 18$ AU

Kepler's Laws

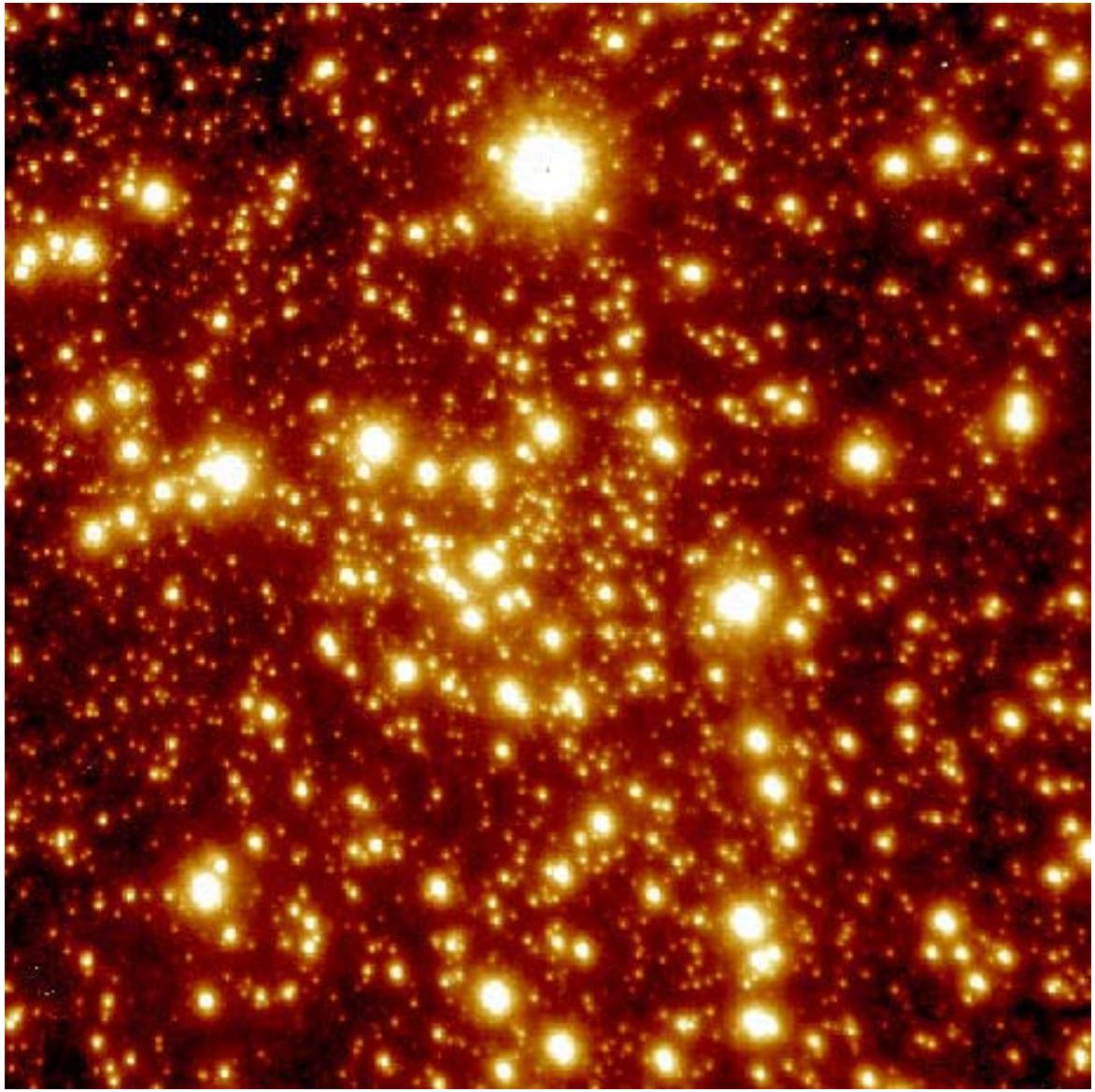
The farther away from the Sun, the longer it takes for the planet to orbit AND the slower it's average orbit speed.

Kepler's Laws

http://csep10.phys.utk.edu/astr162/lect/binaries/visual/keplerold frame.html

Kepler's Laws: A Black Hole

A group in Munich is using Kepler's Laws to determine the mass of the black hole in the center of our galaxy using deep near-infrared observations.

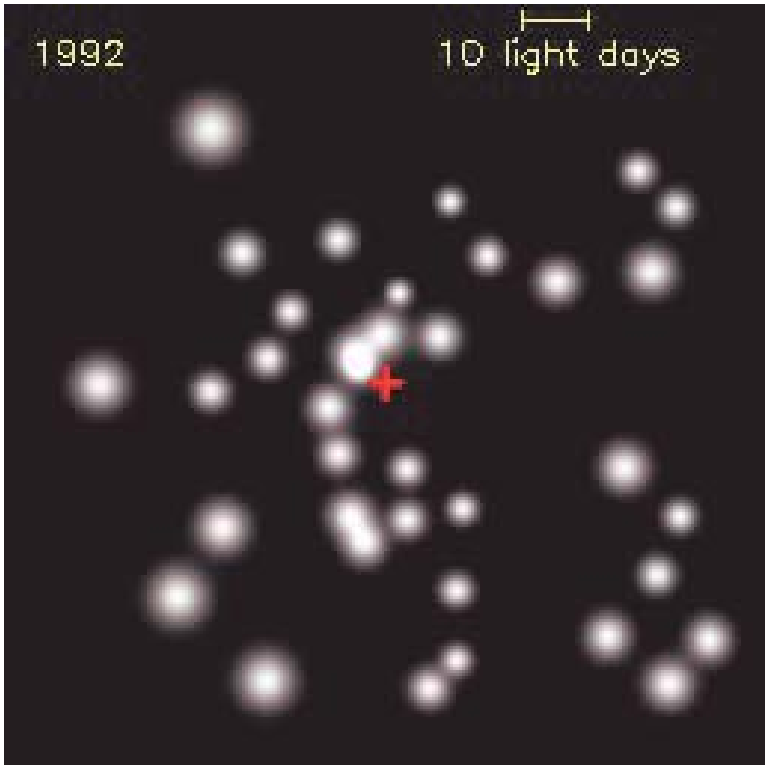


http://www.mpe.mpg.de/www_ir/GC/intro.html

Application of Kepler's Laws

By using the deepest images of stars toward the Galactic Center, they have been able to detected a full orbit of a star with a period of 15.2 years and Semimajor axis of 950 AU.

That means that the black hole is about 2.6 million solar masses!!!

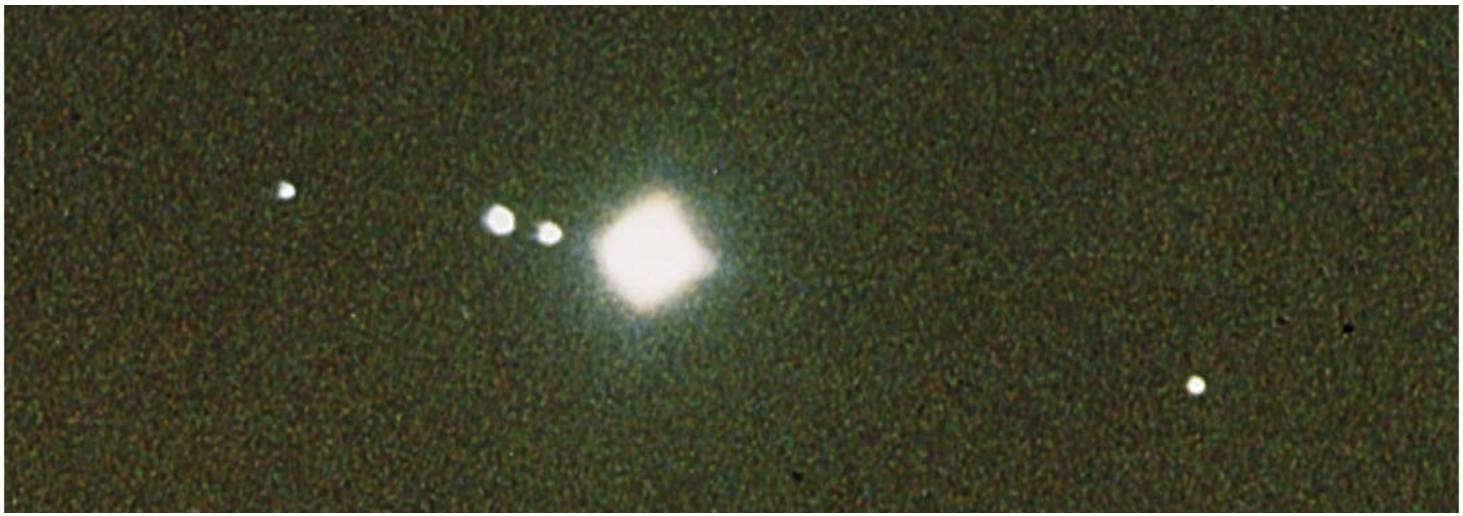


Galileo (1610)

First to systematically use the telescope (but did not invent it).

- Moon has mountains and valleys
- Milky Way consists of faint stars
- Saturn is elongated
- Venus shows phases
- Jupiter has moons (now called Galilean moons)

Wow! Big stuff. The moons of Jupiter did not orbit the Earth!



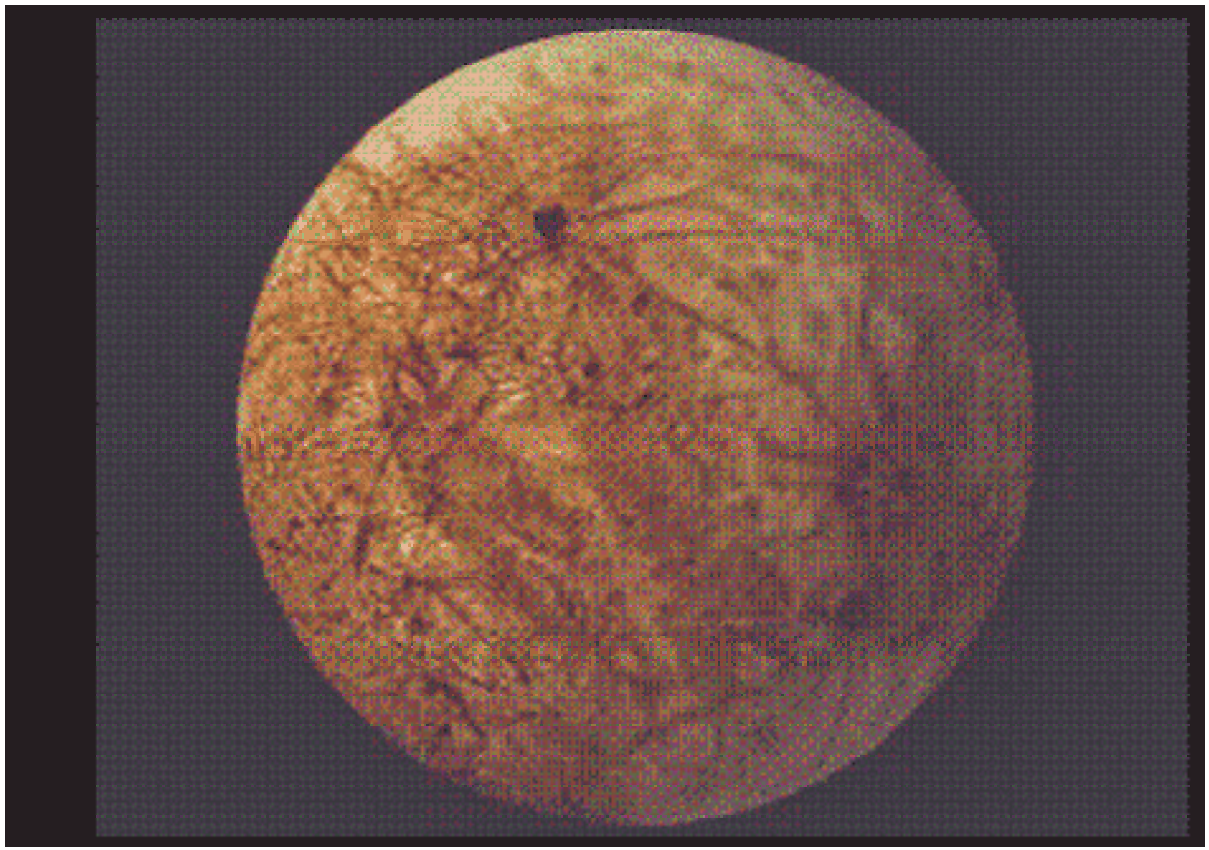
Galilean Moons

Geocentric Cosmology was still preferred model of the Universe and Galileo was declared a Heretic and spent years under house arrest.

http://photojournal.jpl.nasa.gov/catalog/PIA01299

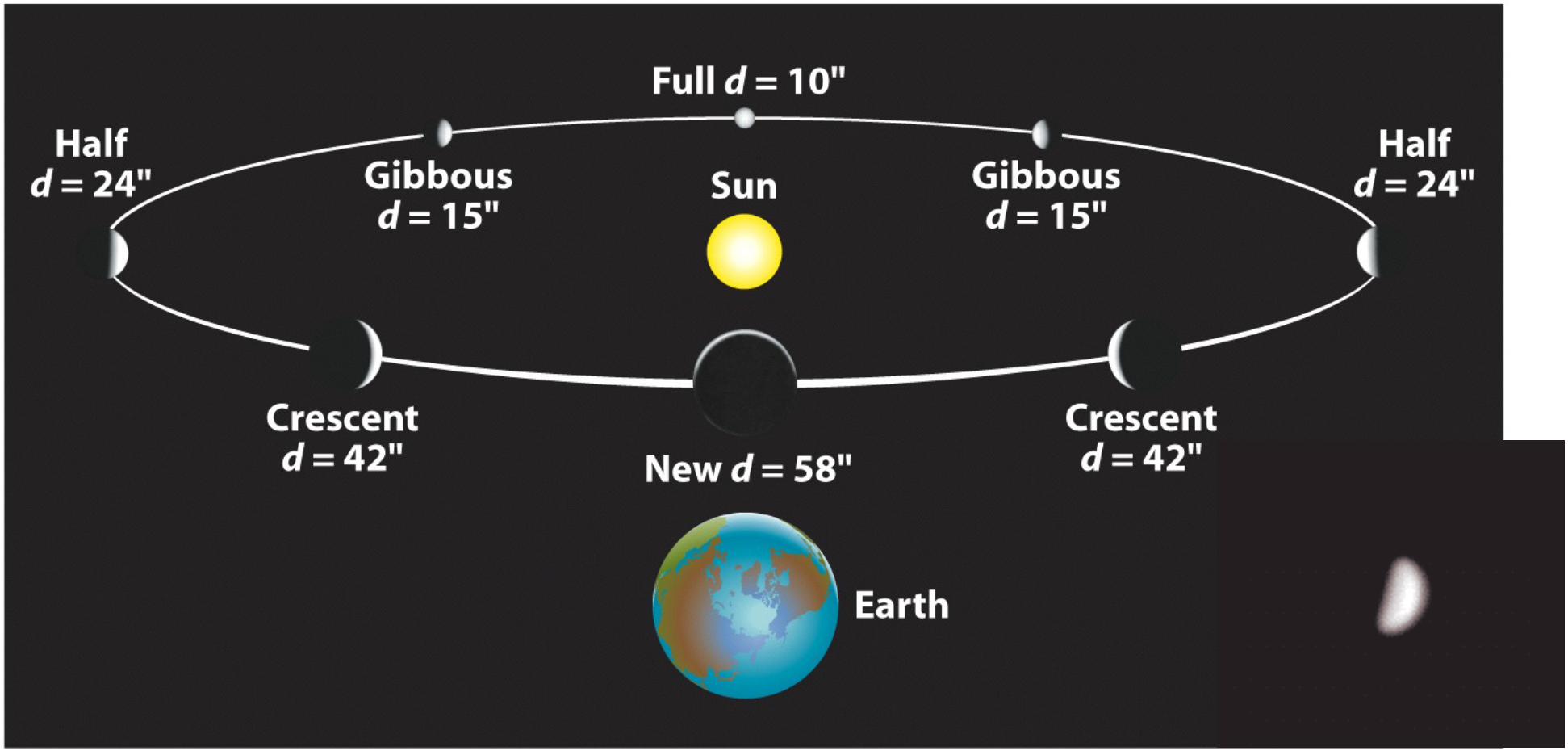
Europa

What was the problem? Galileo's observations directly challenged the Geocentric view that was held by the church. And there was still no why.



http://antwrp.gsfc.nasa.gov/apod/ap010116.html

The Phases of Venus



Could not be explained with the Geocentric model

http://www.calvin.edu/academic/phys/observatory/images/venus/venusb.html

Phases of Venus

Compare the Heliocentric to Geocentric models to explain the phases of Venus.

http://www.astro.ubc.ca/~scharein/a310/SolSysEx/phases/Phases.html

Galileo (1610)

- Disproved Ptolemaic system
- Rome bullied him into recanting (cleared in 1992)
- Now we understand the motions and the fact that the solar system MUST be Heliocentric, but now we need a reason why?

Kepler's Laws

Kepler discovered these patterns in nature by using the data that Tycho collected, BUT the world had to wait until someone could understand the Natural Law that predicts Kepler's Laws.

The real problem: On Earth we're use to things that move but always come quickly to a rest. Why didn't the planets stop?

Isaac Newton

- Gave us a reason why-- GRAVITY.
- Developed fundamental laws of nature.
- Kepler's 3rd law now became a way to probe the structure of the Universe!