Chapter 3: Historical Astronomy and the Discovery of Natural Law (Astro 4 version)

- For Astro 4, we skip forward to the end of the Dark Ages, and the scientific Renaissance
- Galileo, and the discoveries of the laws of motion.
- Galileo and the foundations of mechanics
- Kepler and the laws of planetary motion

Chap 3 - Key Points

- Know each of Kepler's 3 laws and what they mean
- Galileo's experiments showed: all things fall (on Earth) identically regardless of their mass
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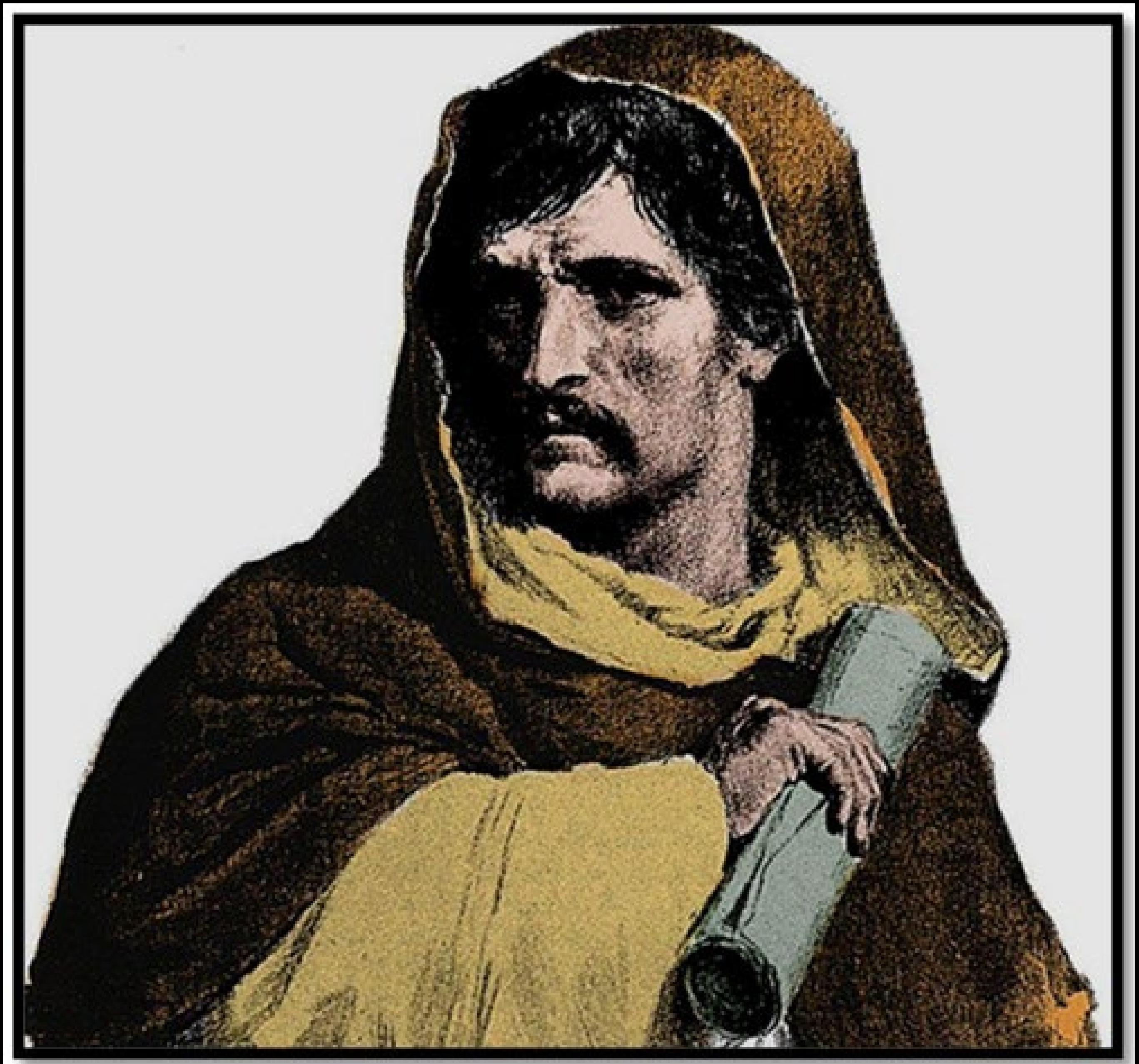
Giordano Bruno

- Astronomer, mathematician, and poet of the late 1500's, Bruno advocated the idea that the stars were sun's like ours, likely with planets and some of which likely had life. Brilliantly insightful for that early time!
- How was he rewarded? Imprisoned for 8 years by the Catholic Church, tried for heresy by the Inquisition, then had his tongue cut out, and finally burned at the stake in 1600, in Italy.
- Very tough to get good science done in this environment… this is the environment in which Galileo found himself.

Giordano Bruno



Galileo Galilei

Galileo's actual first telescopes – quality was beneath anything you can buy at a Dollar General store today. But he was a careful observer!

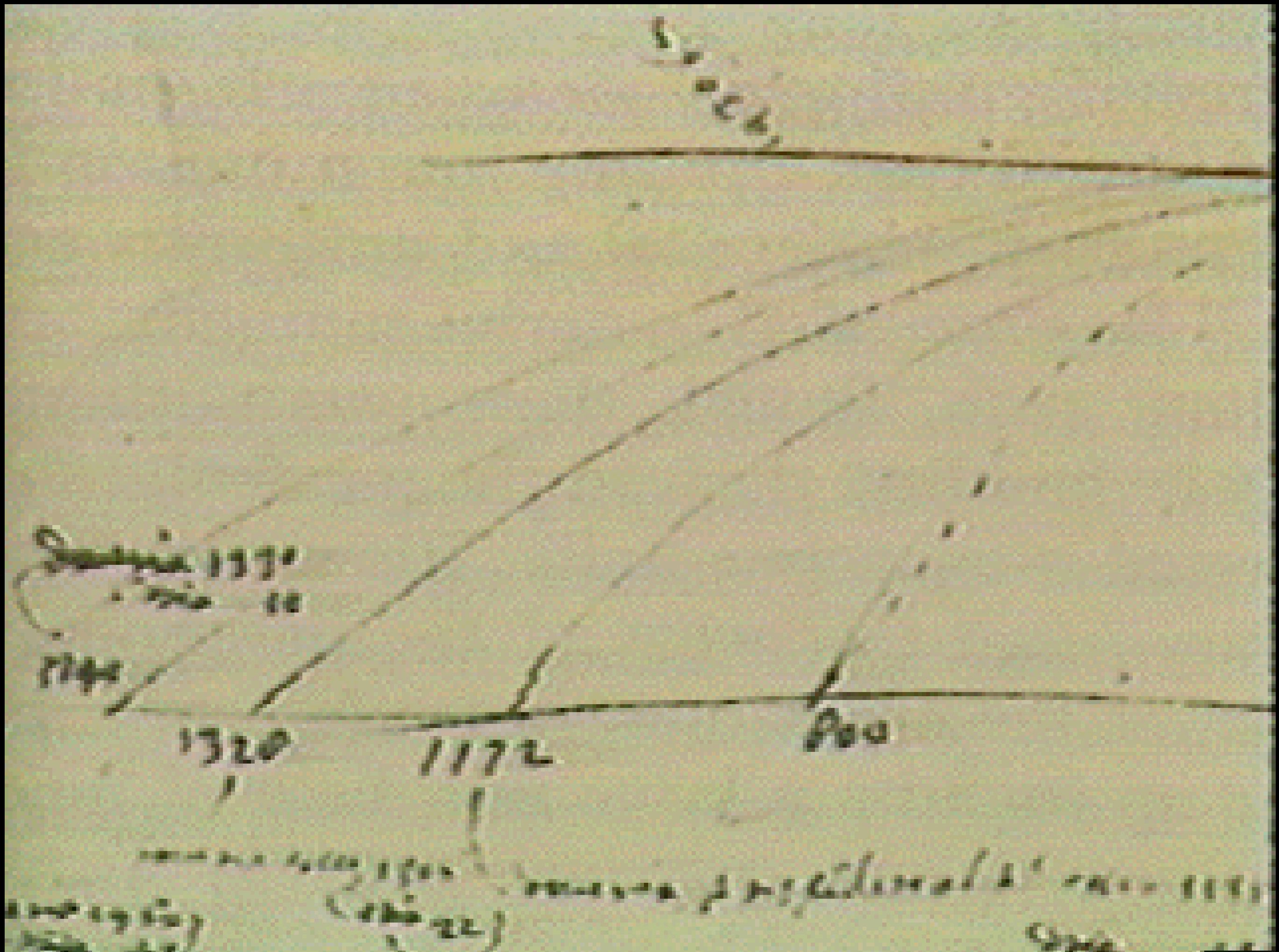
Galileo's Telescopic Discoveries

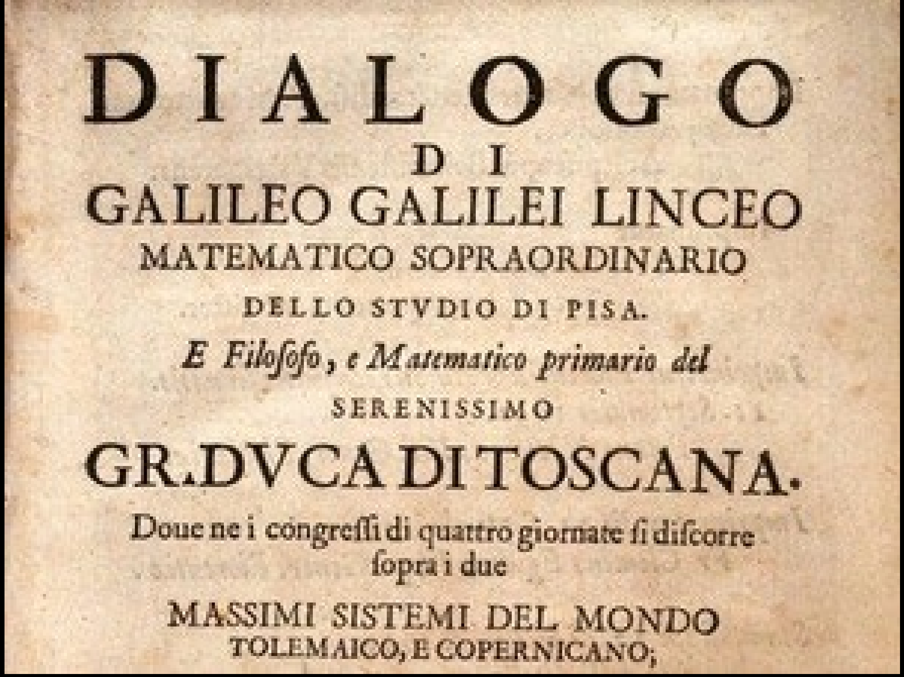
- The telescope was actually invented not by Galileo, but (probably) by Hans Lippershey, who first gained a patent on the telescope, in 1608.
- But Galileo heard about this, and immediately ground his own lenses and built the first astronomical refracting telescope.
- Got him into big trouble with the Catholic Church

He looked through his telescope and saw…

- Craters on the moon
- Spots on the sun
- 4 moons which circled Jupiter and followed it through the sky, rather than circle the Earth
- Saw Venus go through all the phases the moon does, which is not possible if Venus circled the Earth as it did in the Church-approved Ptolemaic model; it must instead orbit the sun
- So these discoveries became…. "awkward"… for his future.

Galileo Also Did Careful Experiments of Falling Objects. A page from his notes, trajectory of objects after falling down an incline plane





- Still, Galileo had been a friend of the man who later became Pope for many years, and this gave him a certain amount of shelter from the wrath of the Church, for the moment.
- But Galileo’s masterful and devastating critique of Jesuit positions on science alienated that large segment of the Catholic Church, and when the political position of Pope Urban weakened, Galileo was sent to the **Inquisition.**

"

In the sciences the authority of thousands of opinions is not worth as much as one tiny spark of reason in an individual man. Besides, the modern observations deprive all former writers of any authority, since if they had seen what we see, they would have judged as we judge.

Galileo Galilei

(LETTER TO MARK WESLER 1612)

- At his trial in 1633, under threat of torture, he told the Inquisition he rejected his scientific positions.
- **The Inquisition** was not impressed, sentenced him to prison anyway, later commuted to house arrest, where he spent the remainder of his life.
- **All of his works, including any he might write in the future, were declared officially banned**.

But it was too late to stop the Renaissance in science

- Copernicus' "De Revolutionabus" in 1543 had become an underground hit!
- Now the race was on – perfect uniform circular motion, even in the sun-centered model, didn't reproduce the measured positions of the planets accurately.
- What is the true shape and true motion of the planets? To answer, we first need GOOD DATA!
- Enter… ***Tycho Brahe***

Tycho Brahe

Tycho Brahe – Danish Astronomer of late 1500's

- Discovered the supernova of 1572, showed it was far beyond the planets – the first non-planet to be shown to be something other than fixed and constant.
- The King of Denmark was impressed, gave him an island and money to build the best scientific instruments of his day
- His goal: find the true orbits of the planets. Copernicus' sun centered model was elegant, but circular orbits around the sun with constant speed was not consistent with existing observations
- Brahe was an outstanding observer. Measured the precise positions of the planets every clear night for 20 years, with an accuracy of +- 1 arcminute (!)
- That's only 1/30th the angular diameter of the moon.
- But he was a mediocre mathematician. No problem – he had the money – he hired a good one!

Johannes
Kepler

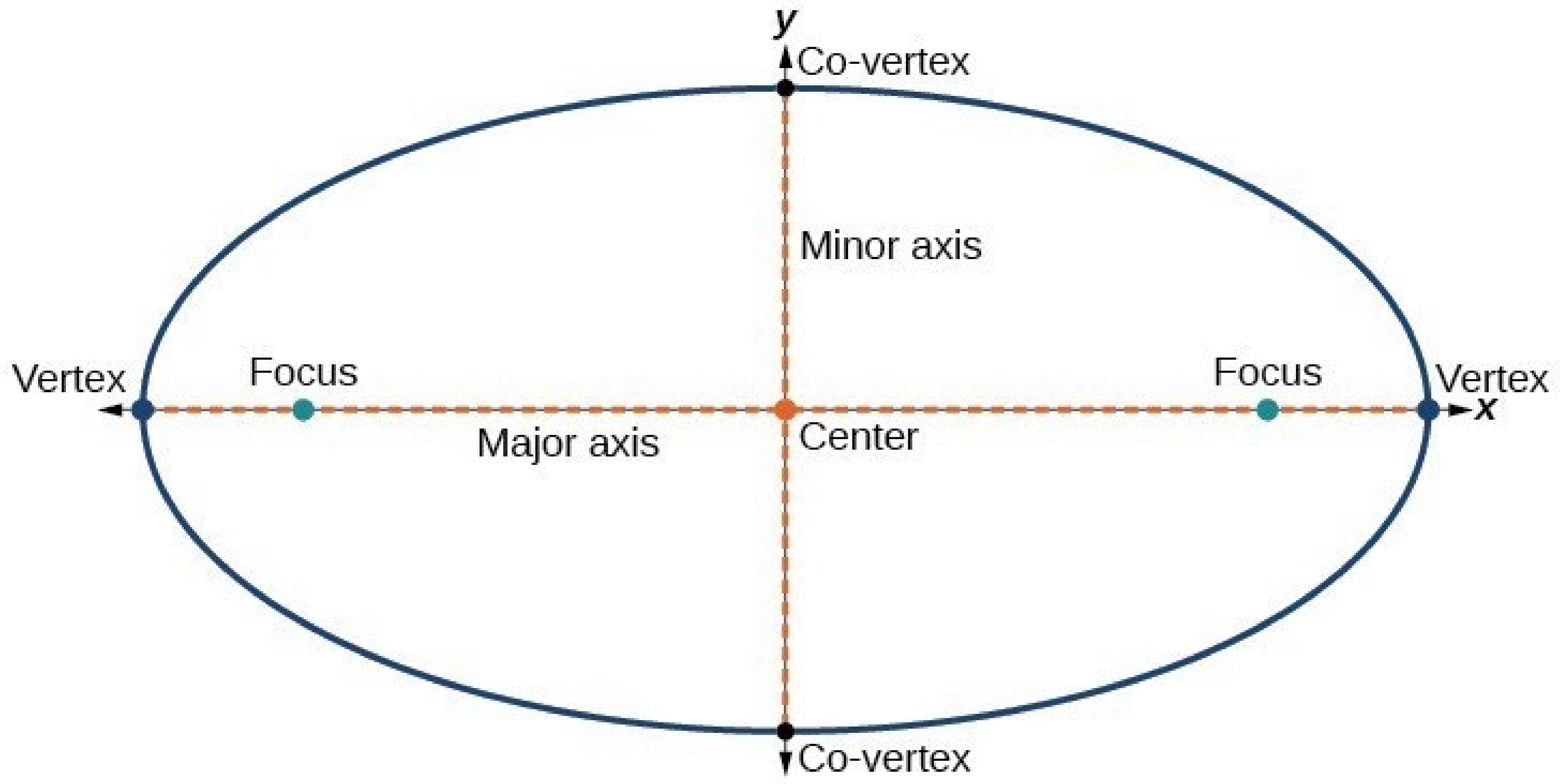
How did Kepler determine the shape of the planetary orbits? He was Very Clever!

- Kepler’s data was 20 years of careful positional measurements from Danish astronomer Tycho Brahe.
- Basically, a table of **times** and **positions** of the planets.
- He figured, let’s start with a promising planet and once we’ve figured it out we can then streamline the work on the other planets.
- Mars was the obvious choice: Brahe’s data had 10 full orbits, so he could check that it really followed the same path every time, and it was already known a constant speed circular orbit didn’t fit the data.

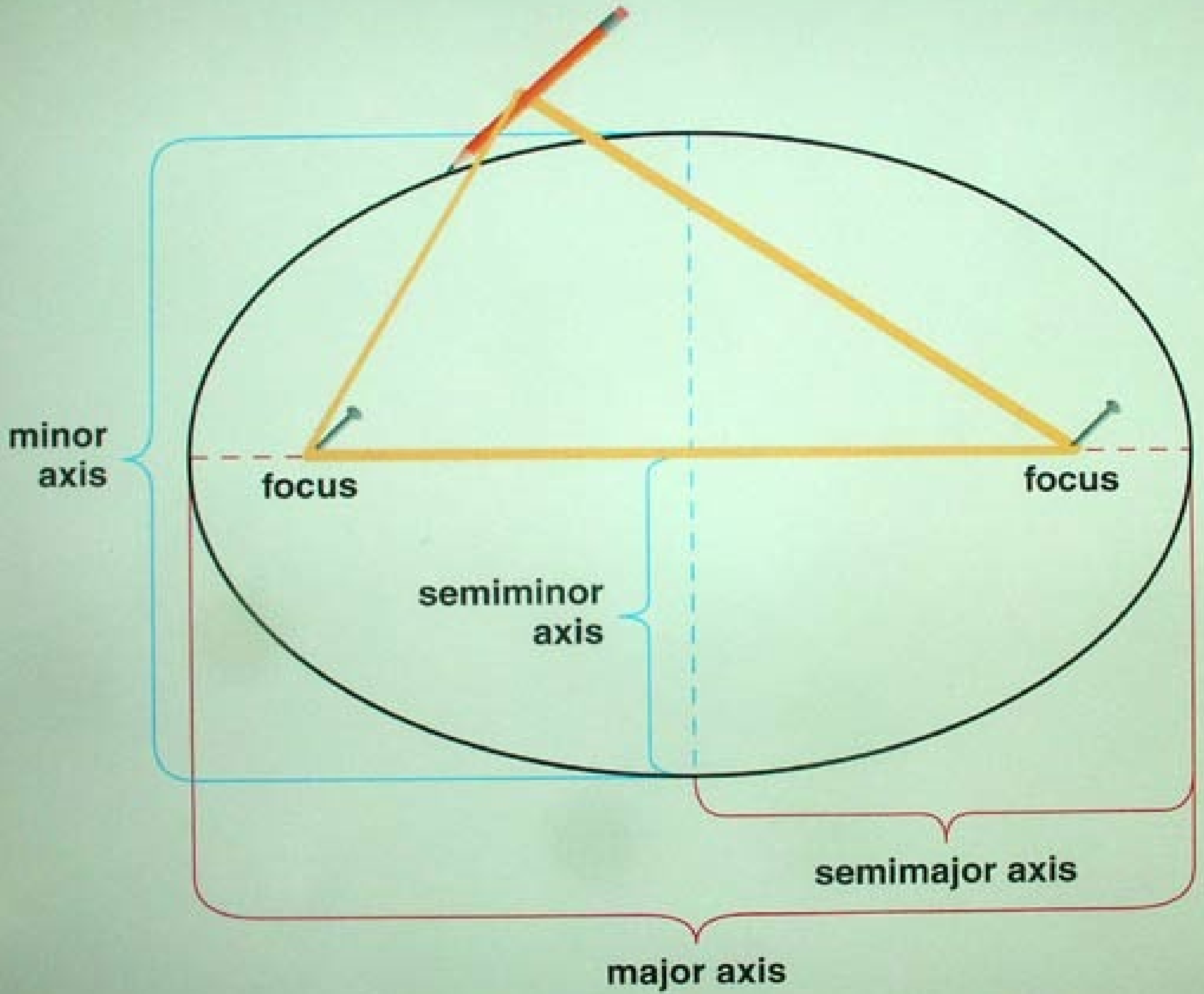
Kepler's 1st Law

- ***Planets will orbit in ellipses, with the sun at one focus***
- Like this…

The sun is at the Focus, not at the center



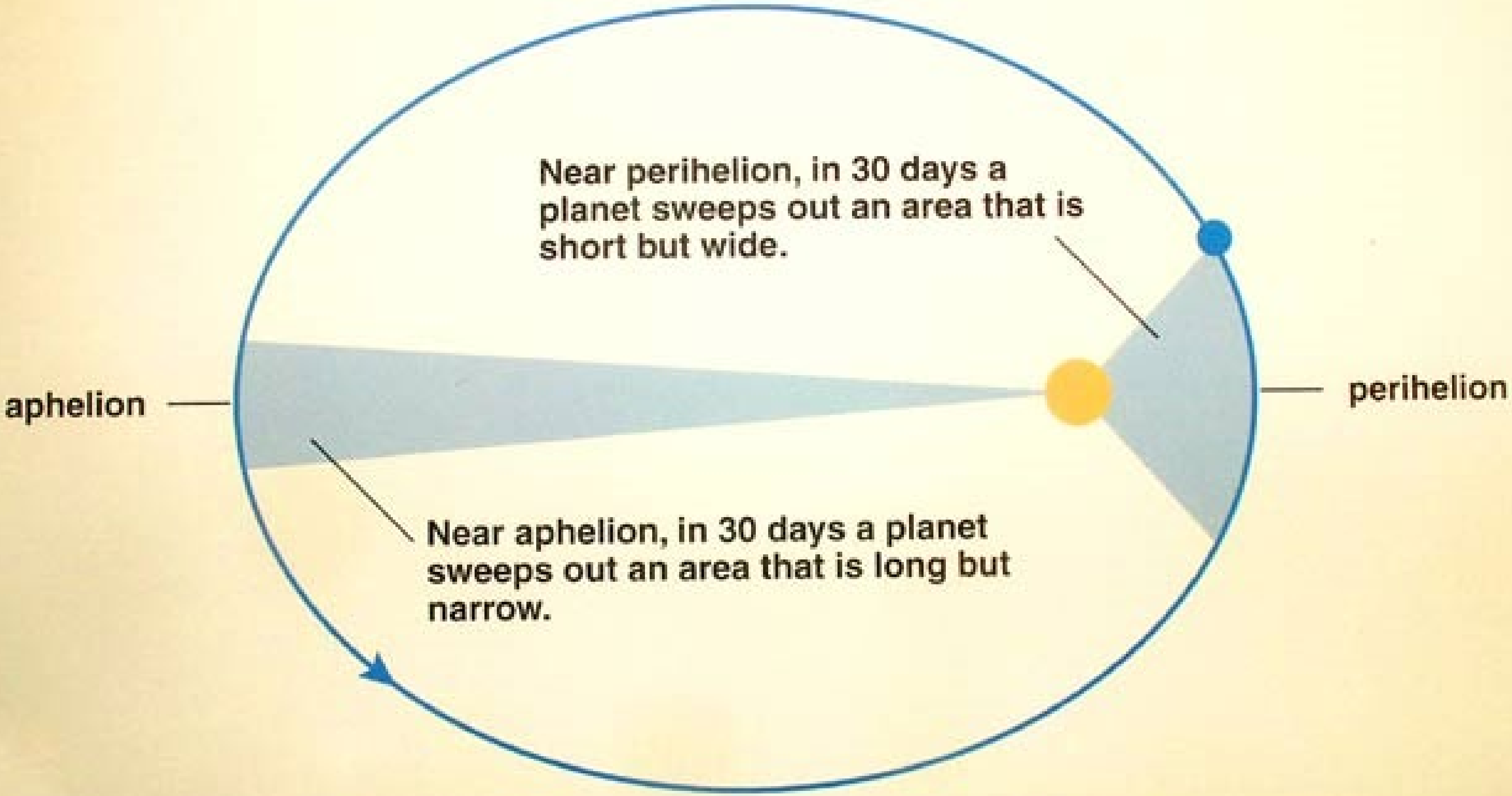
Drawing an ellipse



Kepler's 2nd Law

- **The sun-to-planet line sweeps out equal areas in equal times**
- Often called the "Equal Area Law"
- Pick any time interval you want. The sun-to-planet radius sweeps through the same area during that time interval, regardless of where it is in the orbit.
- Said another way – the rate at which the sun-to-planet line sweeps out area, is constant throughout the orbit.

Figure 5.9 Kepler's second law



The areas swept out in 30-day periods are all equal.

An Animation showing the Meaning of Kepler's 2nd Law: "The Sun-to-Planet Line Sweeps Out Equal Areas In Equal Times"

- https://upload.wikimedia.org/wikipedia/commons/6/69/Kepler-second-law.gif
- And a YouTube 9 sec video
- This law is an example of a more general rule – *Conservation of Angular Momentum*
- *We'll talk more about why, in Chapter 4*

Kepler's 3rd Law

- Kepler found, after he'd determined the orbits of all the 5 planets that were known then, that the **larger the orbit, the longer it took to orbit the sun.**
- He asked – is there a simple, quantitative law that describes this? He searched…
- **Size** of the orbit? There's many ways one might try and quantify the size of an orbit.
- ***List some for me, gang!.....***

Let go!

- Be creative; don't try to remember what some book said. Pretend you're Kepler and he didn't HAVE a book to look up the answer.
- Don't over-try to be "right". No one knew what was "right".
- Be Kepler, come up with the many different measurements you could make which are aspects of the orbit's size
- Something which could be expressed as a length.
- If you come up with a number of different ones, you're doing it "right"!

Here's a Few…

- Circumference of the orbit
- Square root of (area of the orbit) = sqrt(Area)
- Longest diameter
- Shortest diameter
- Sqrt(long * short diameters)
- Time averaged distance to the sun
- Spacially averaged distance to the sun
- **But, Kepler could find no simple precise quantitative relation that worked, between most of these and the period of the orbit**

Kepler Tried Many and Found No Pattern, Until…

- … he tried the following…
- **(Period)^2 = K a^3** **where K is the same for all planets**
- This is **Kepler's 3rd Law**
- Where **a** = semi-major axis = half the longest diameter of the orbit, and period is how long it takes to go around the sun
- What about **K**? **K** is a dimensional constant. The same number for all objects orbiting the sun
- Let's pause and consider Dimensions *vs*. Units…

Dimensions *vs.* Units

- **Dimensions;** the basic physical things that describe the universe… mass, length, time, and derived dimensions from these: energy, temperature, luminosity,…
- **Units:** These are the arbitrary measuring rods we humans invent to actually put numbers to physical dimensions. For length, we could use miles, inches, light years, microns, meters, cubits, furlongs, etc… all are “units of length”

Soon we'll See how Newton Derived Kepler's Laws from pure deduction from his laws of motion and of Gravity

- We'll see that this little law – Kepler's 3rd law… $\mathbf{P^2 = Ka^3}$
- …Turns into what is probably the single most useful and valuable equation in all of astronomy. A story to be continued in the next slide show….

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