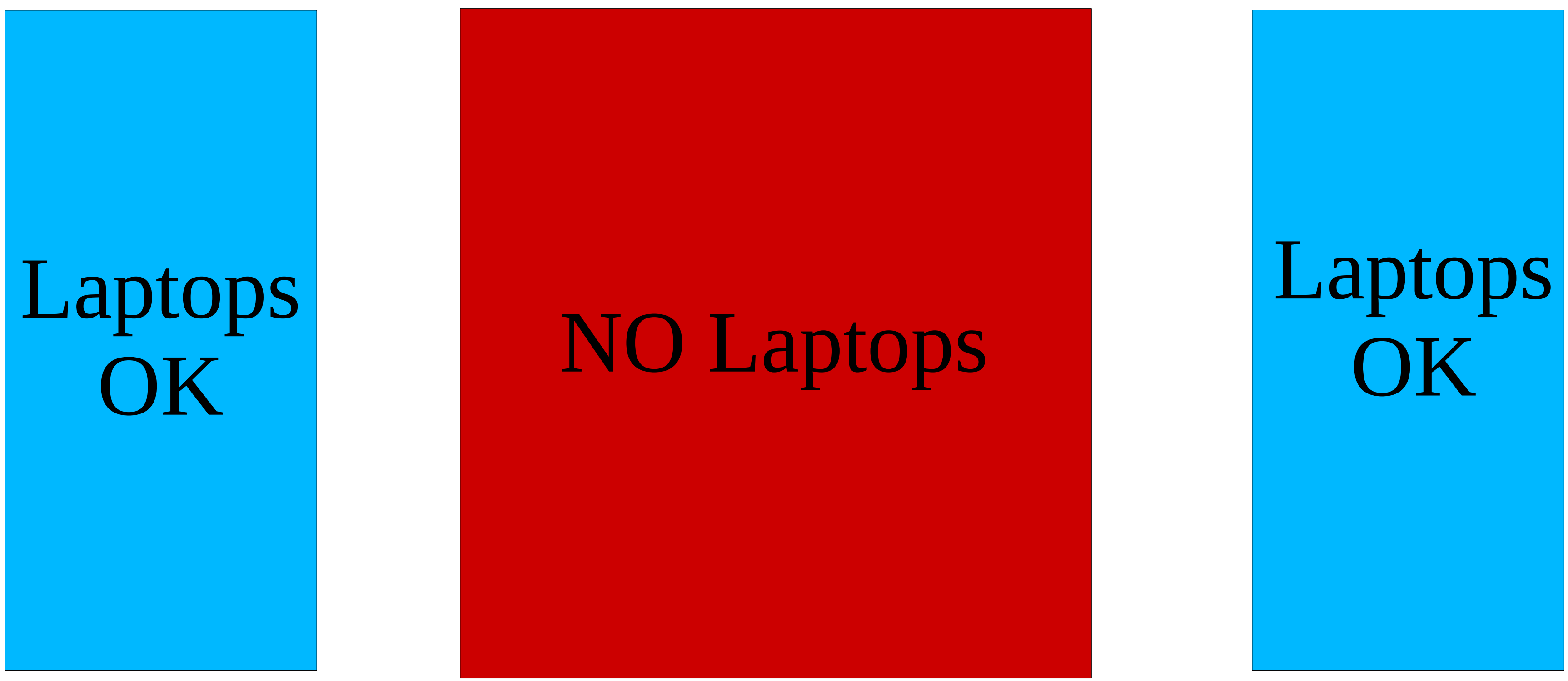
ASTR 200 Reminder
Center section = 'no laptop' zone



ASTR 200 – Frontiers of Astrophysics

www.astro.ubc.ca/people/gladman/a200.html

UBC

Physics and Astronomy

The importance of planetary motion

- The study of planetary motion was the critical driver that constantly pushed the forefront of:
  - Astronomy
  - Mathematics

  from the time of ancient civilizations through to Kepler
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  from the time of ancient civilizations through to Kepler
- This was 'positional astronomy' at the forefront.
- Could one develop a mathematical model that could make quantitative predictions of where the planets would be in the sky in the future, to the limit of the most precise observations?
    - Prompts the question of what is 'science', as opposed to description...

Aspects of scientific theories

- What properties does a 'theory' have that makes it '*scientific*'?

Aspects of scientific theories

- What key properties does a 'theory' have that makes it '*scientific*'?

- Explains a set of observations, not just one
- Makes predictions, rather than just explaining past observations, based on physical principles
- In astronomy, this usually means *quantitative* predictions that are verifiable via *measurement*
- Because predictions are made, the theory is thus in principle **falsifiable**
    - **This is an absolute...must be possible in principle**

Ptolemaic astronomy

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    - The observational accuracy with which planetary positions were measured (until Tycho Brahe) was 10'
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  - Unfortunately, it is completely wrong
  - The theory's basic constructs do not exist/are wrong

The Heliocentric Paradigm

- Probably logical to you that Sun is center of solar System, but:
  - How could Earth be spinning once/day?
    - We'd be moving VERY fast near the equator
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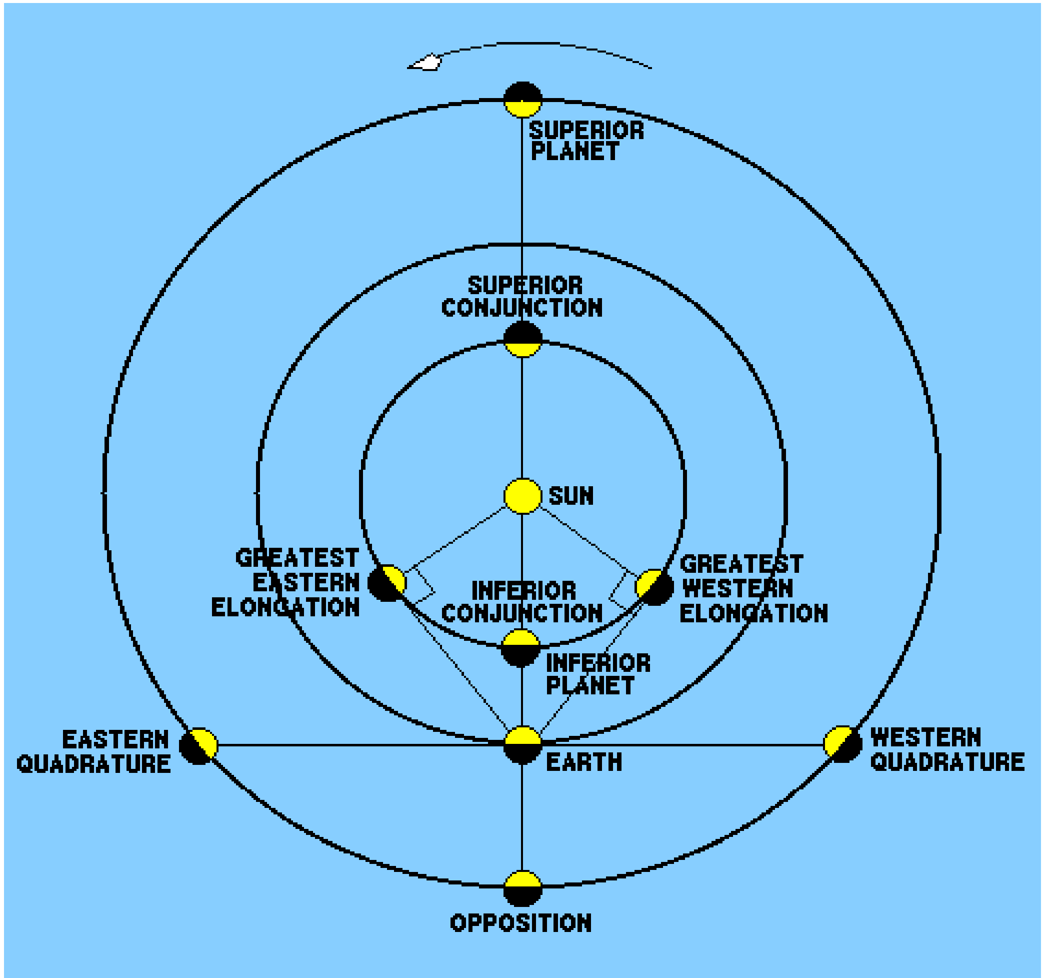
    - The ancients couldn't imagine this
  - And although a heliocentric Solar System, with Earth and the other planets in circular orbits was aesthetically appealing, it did NOT (reproduce the observations)/(make predictions) as well as Ptolomaic theory
  - Note that a heliocentric solar system COULD produce retrograde planetary motion (the greeks knew this!)

Copernican geometry

- The most basic observational quantity was the orbital period *P* of a planet (when it returned to the same location in absolute space)
    - 'sidereal' period (wrt stars)
- Since the observing platform (Earth) is moving, the names of planetary configurations (Fig 2.8) are needed terminology
- Although drawn for circular case, they apply in general



Synodic period

- The time interval between repeating a configuration
  - Synodic = with respect to Sun
  - Example, one conjunction to another
- Text derives the two cases, but the general case is:

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- If use units of years and one of the planets is Earth, the above expression becomes simple:
  - Example: Outer planet --->
  - Think about limits!

$$P_{syn} = \frac{P_{outer}}{P_{outer} - 1} \quad [yr]$$

Transition to the heliocentric paradigm

- In the late 1500s, the world's best observer was Tycho Brahe, who used cleverly constructed large-scale instruments (not telescopes) to improve observational accuracy of stellar and planetary positions to about 1 arcmin (instead of 10')
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- These better observations could NOT be reproduced with the Ptolemaic system (nor the Copernican)
- Tycho tried to create different systems, but could not succeed
- He was working with Johannes Kepler, the best theorist of the time.
  - Once Tycho died and Kepler had all Brahe's observations, Kepler was able to make progress

Kepler's Laws

- The First Law (1609) 'Law of ellipses'
  - Planets travel on elliptical orbits around the Sun, where the Sun is located at one focus.
- The Second Law (1609) 'Equal Areas'
  - The radius vector from the Sun to the planet traces out equal areas in equal times
- The Third Law (1619) 'The Harmonic Law'
  - The square of a planet's orbital period is proportional to the cube of the planet's elliptical semi-major axis.

A revolution, but not quite modern astrophysics

- Kepler's laws was a description of the motion of the planets
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A revolution, but not quite modern astrophysics

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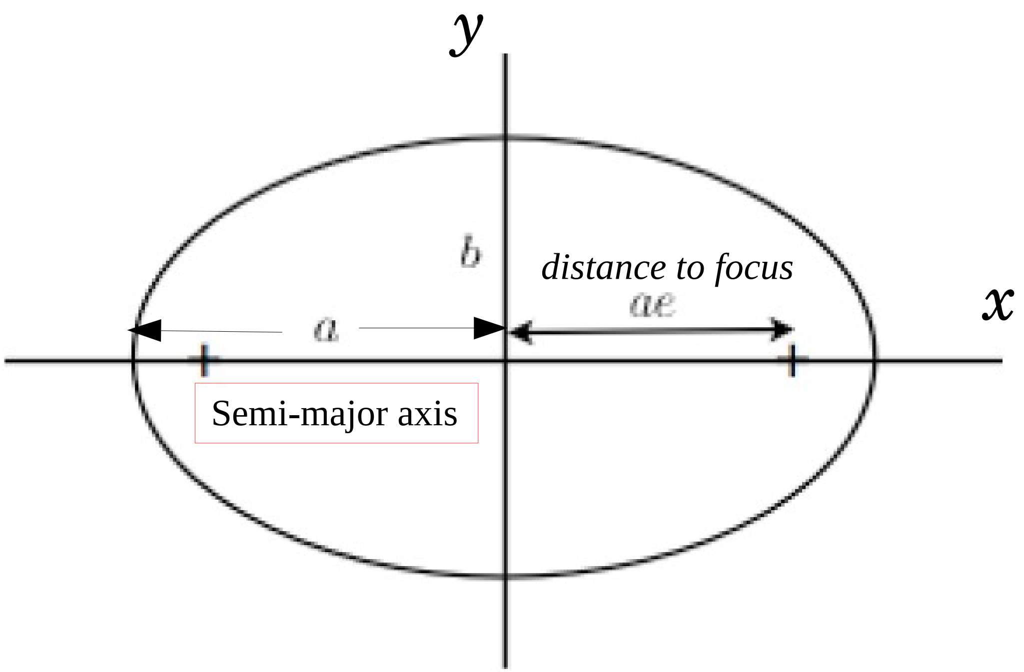
- Kepler did not understand WHY the planets obeyed these laws, but ALL KNOWN observations were explained, and all predictions were verified to the limit of available precision.
- To Kepler's mind, he was seeing a set of rules ``that God created'' to govern the motions of the heavens.
  - To him, there was no reason those rules would apply here on Earth
  - Like at the time of the greeks, there was a conceptual separation between the rules on Earth and in the heavens

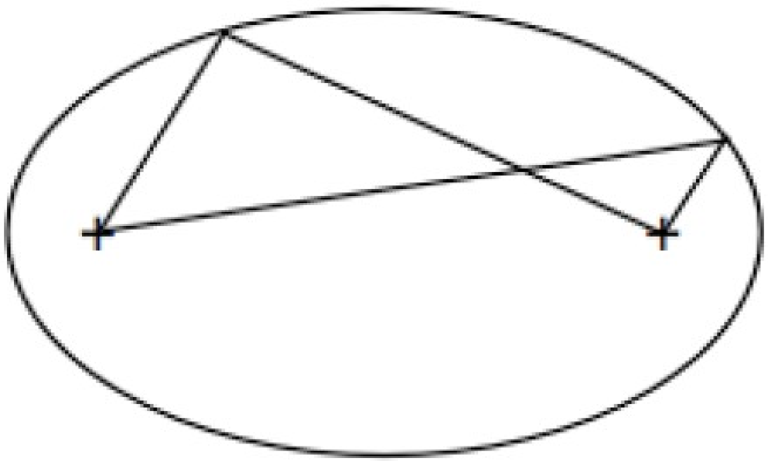
Properties of an ellipse

- An ellipse is a curve for which the sum of the distances to two points called *foci* is a constant.
- It can be characterized by two parameters, *semi-major axis* length a and *eccentricity* e.
- From this it follow that the semi-minor axis length is $b = a\sqrt{1 - e^2}$.
- In Cartesian coordinates, equation of the ellipse is

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

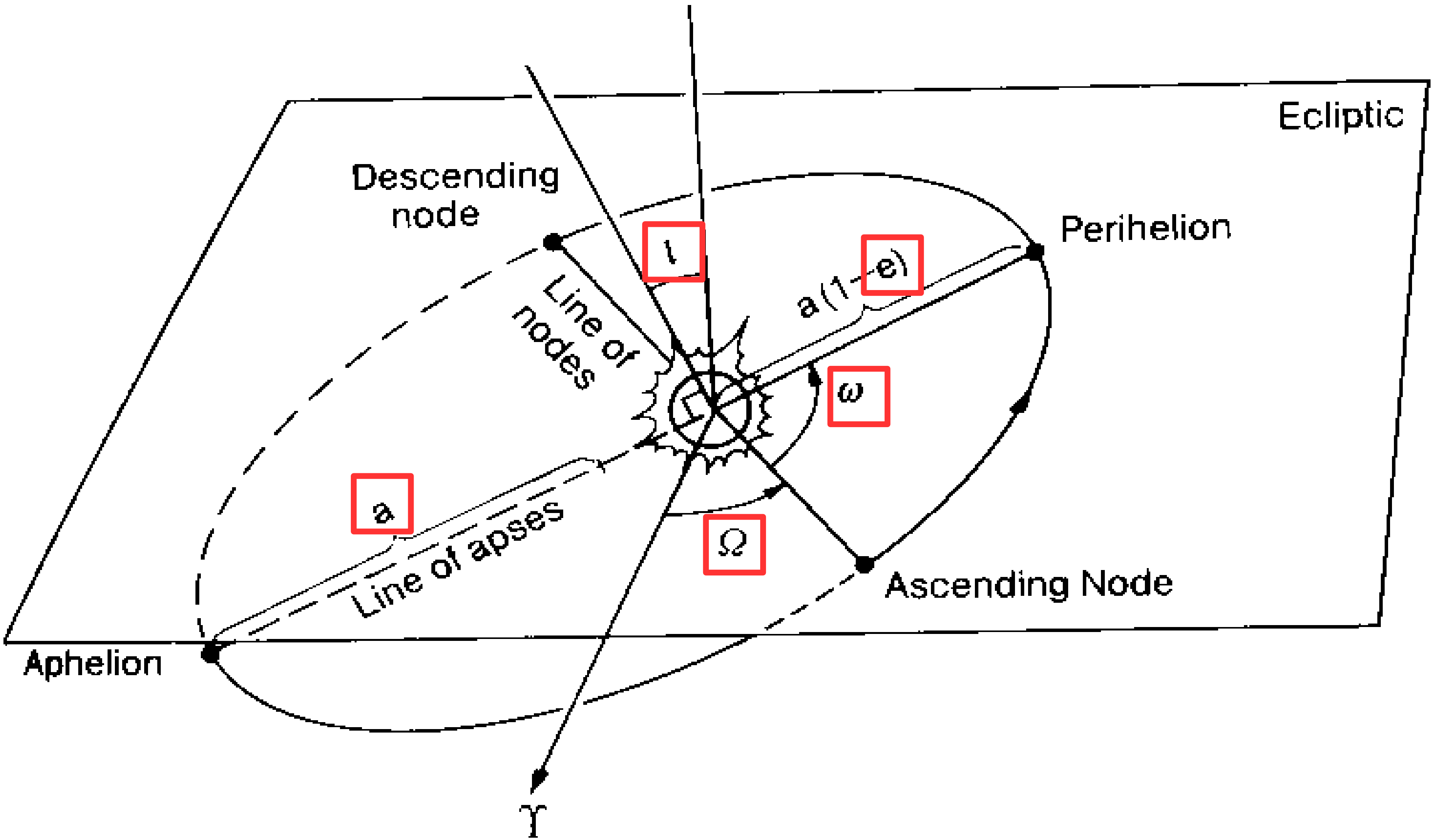
- Can show area is $A = \pi a b$



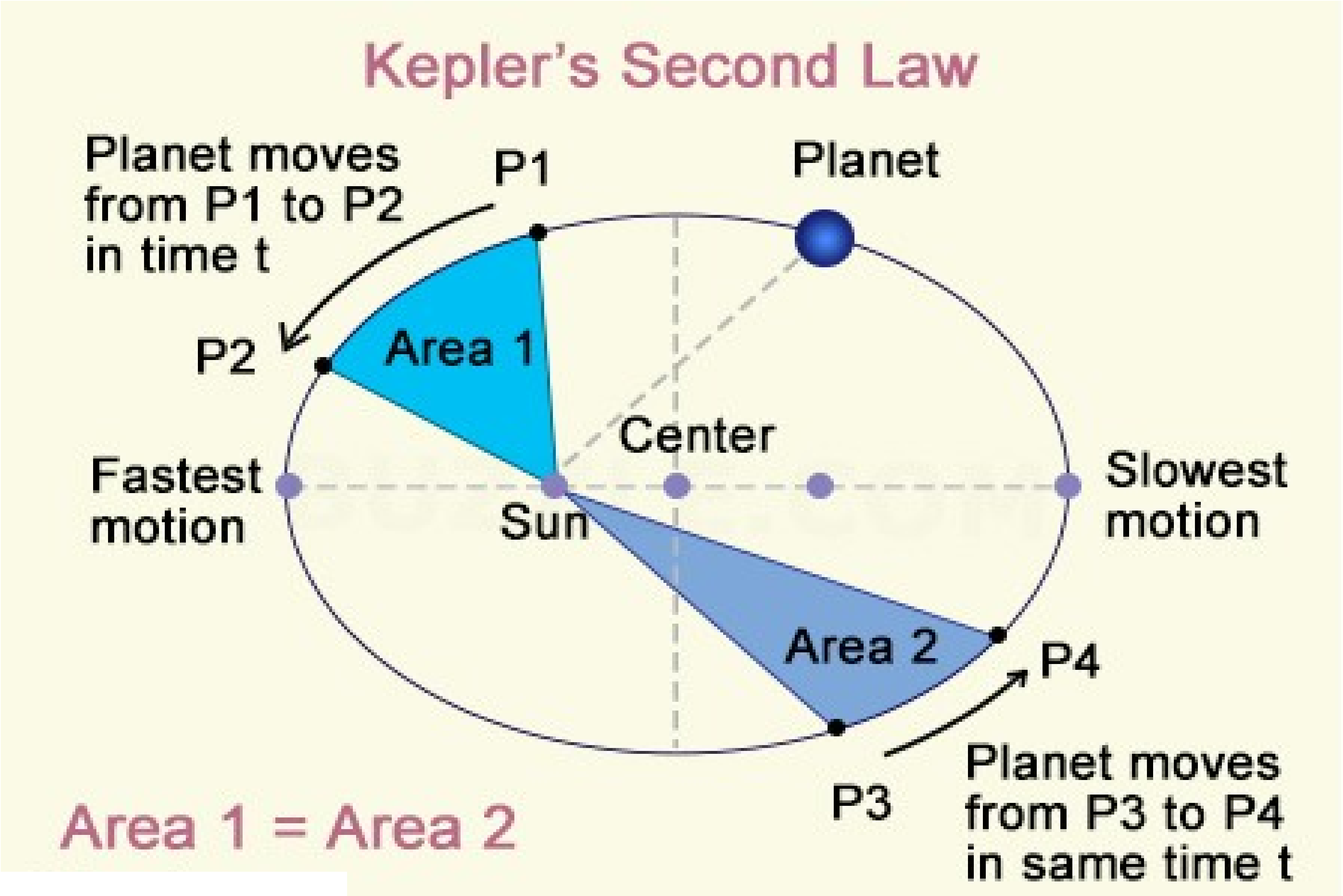


'Orbital elements' are the parameters that describe the shape and orientation of the orbit

- In this course we are not worrying about the orientation, so the only orbital elements we discussed were *a* and *e*.

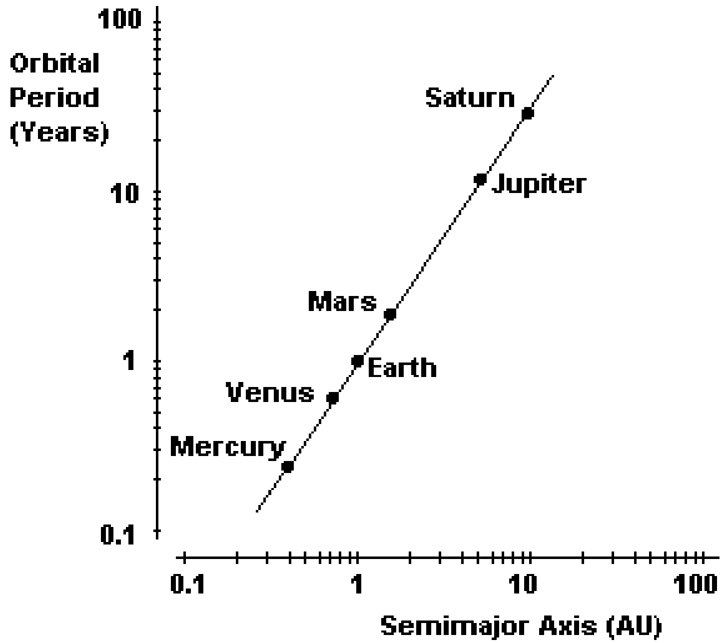


Planets do not move at CONSTANT speed!



The Third Law

- It was another 10 years before Kepler discovered and published the Harmonic Law :



$$P^2 \propto a^3$$

- This is a proportionality; a lot of physics is buried in the constant!
- Kepler didn't know the physics, but he could just express it in units based on the problem and define the constant away.
- If semimajor axis and period are in units of Earth's, then

$$P^2_{yr} = a^3_{au}$$

Holds for objects Kepler didn't know of

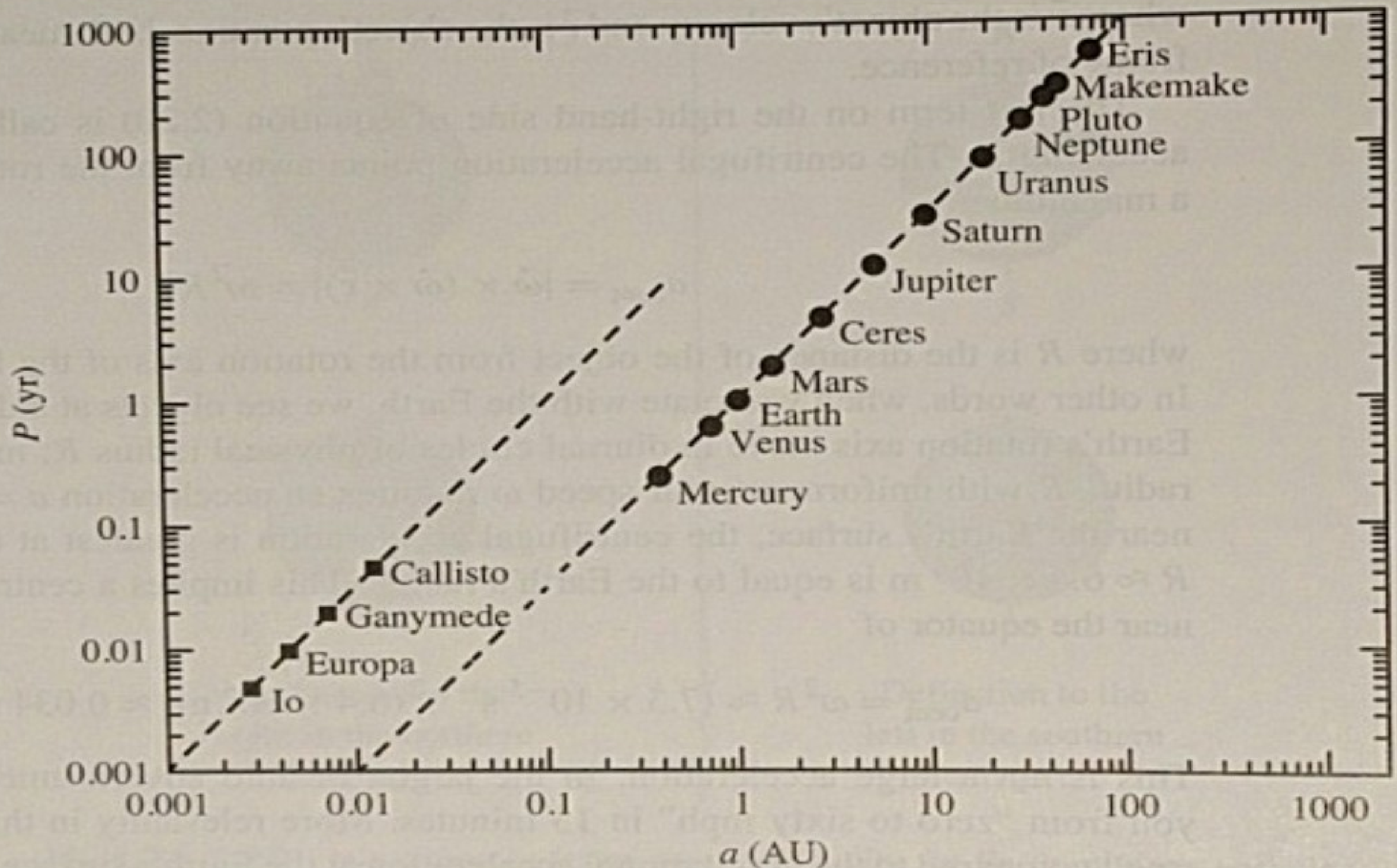


FIGURE 2.19 Orbital period P versus semimajor axis a for planets and dwarf planets orbiting the Sun (circular dots) and for the Galilean satellites orbiting Jupiter (square dots).

Question: what is up with the moons orbiting Jupiter????