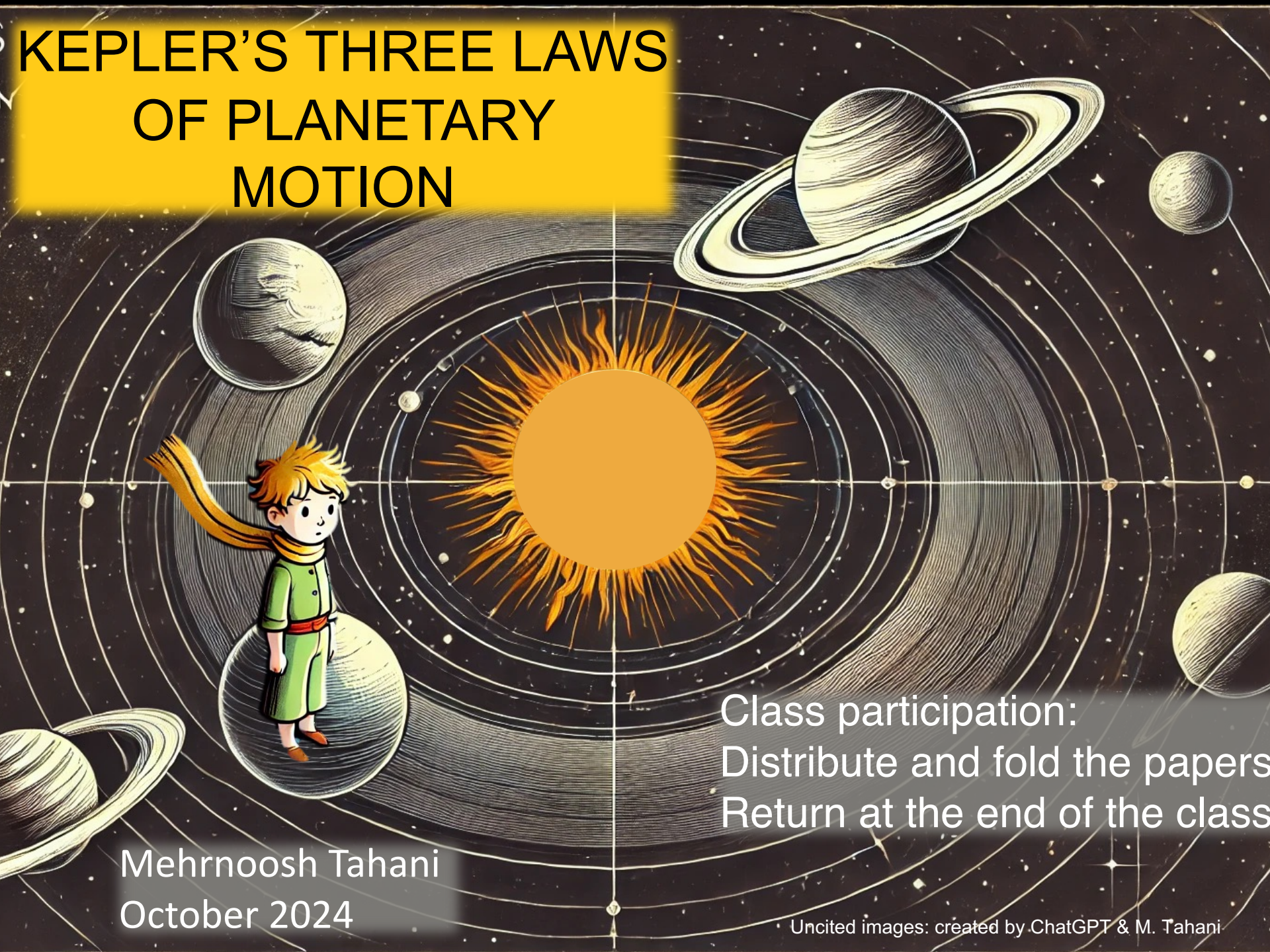
KEPLER'S THREE LAWS OF PLANETARY MOTION



Class participation:
Distribute and fold the papers
Return at the end of the class

Mehrnoosh Tahani
October 2024

Uncited images: created by ChatGPT & M. Tahani

KEPLER'S THREE LAWS OF PLANETARY MOTION

Review of what we know

Motion of planets

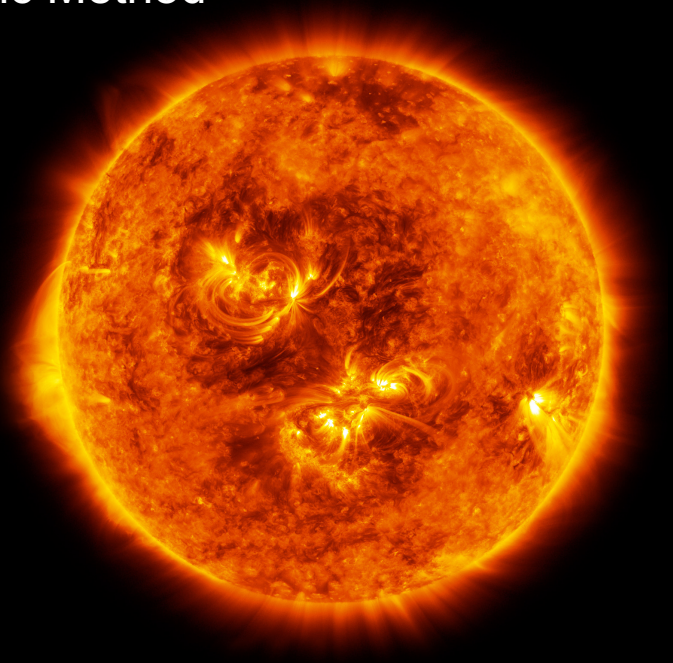
2 views: geocentric & heliocentric

Historical context & Observations

Observe phenomena → Formulate Hypothesis → Test hypothesis via rigorous experiment → Establish theory Based on repeated Validation of results

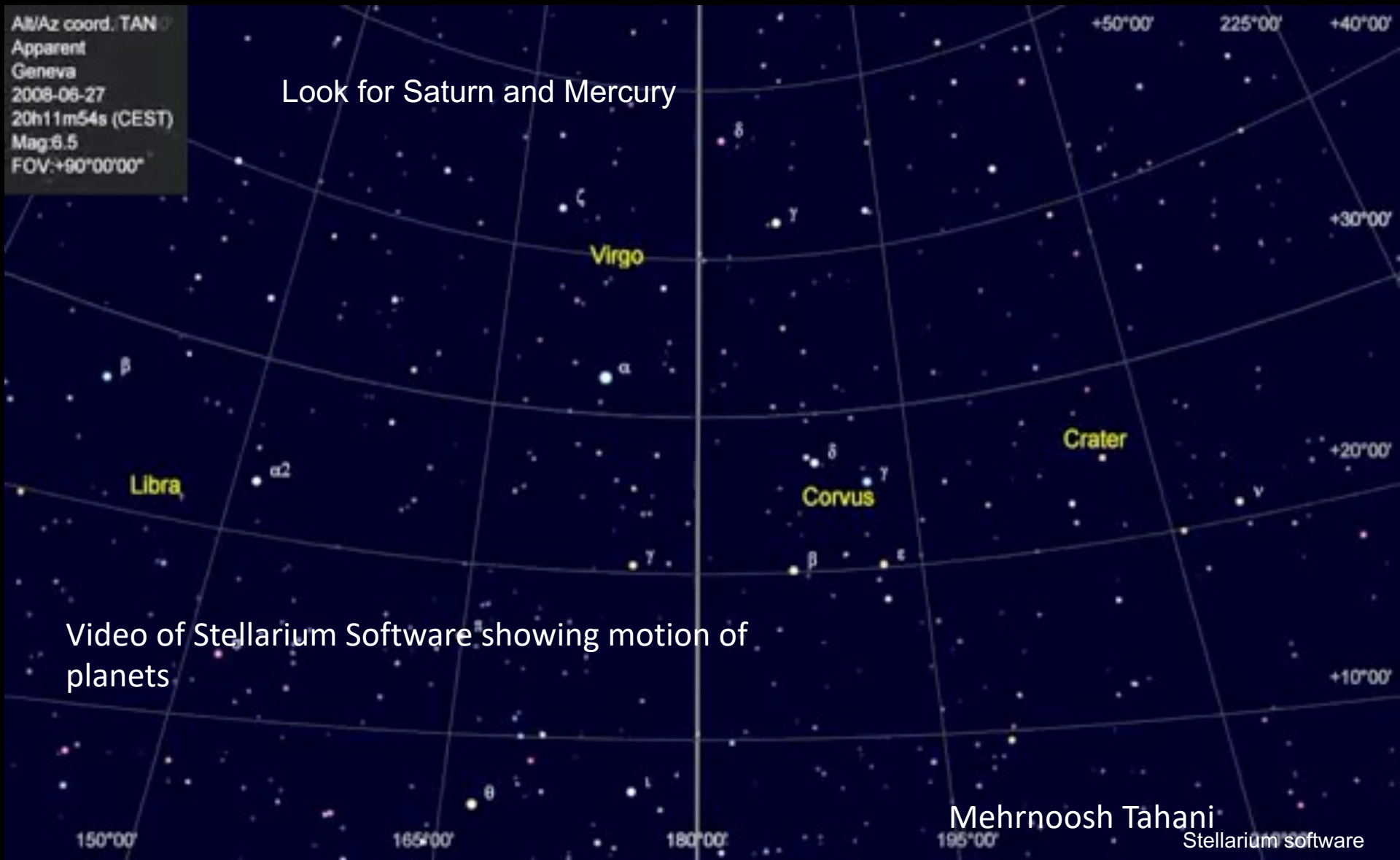
Modify Hypothesis

Scientific Method



Occam's image: onlykutts.com, Sun's image: NASA's Solar Dynamics Observatory

Planets motion in the sky (day to day)

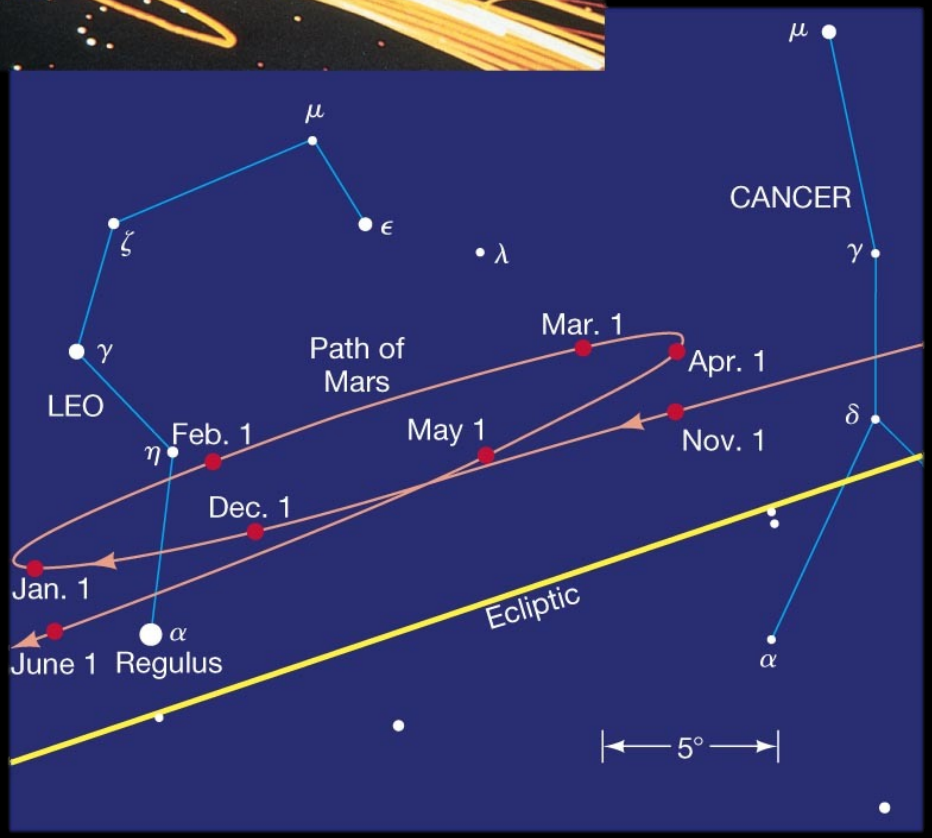


What do you think?

How would you explain the “odd” behaviour of the planets in the sky?

- My thoughts are….
- After our discussion, my thoughts are…

Historical Observations of the Universe



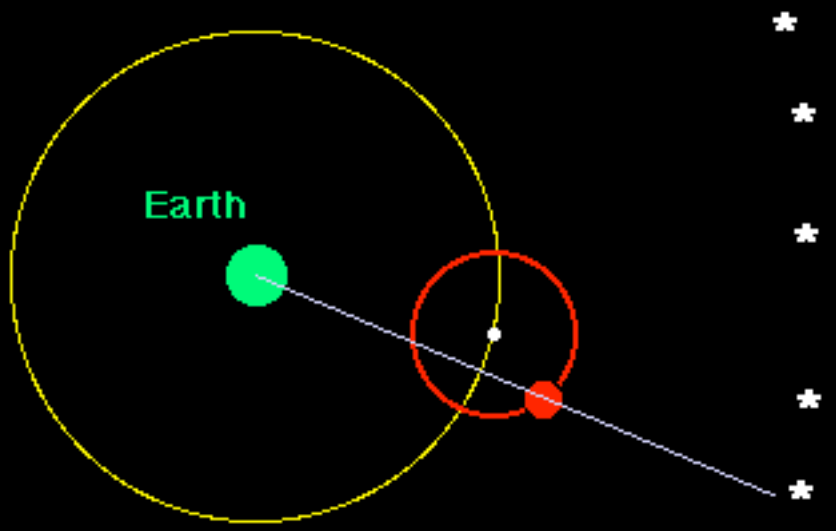
- Sun, Moon, and stars all have simple movements in the sky
- Planets:
  - Move with respect to fixed stars
  - Change in brightness
  - Observed planet motion can be complicated:
    - Change speed
    - Direct (prograde) motion
    - Can undergo retrograde motion

Image: MasteringAstronomy

Historical Observations of the Universe
Geocentric Universe

Most famous for his detailed models of planetary motion.

- Complex (used over 80 epicycles)
- Accurate predictions



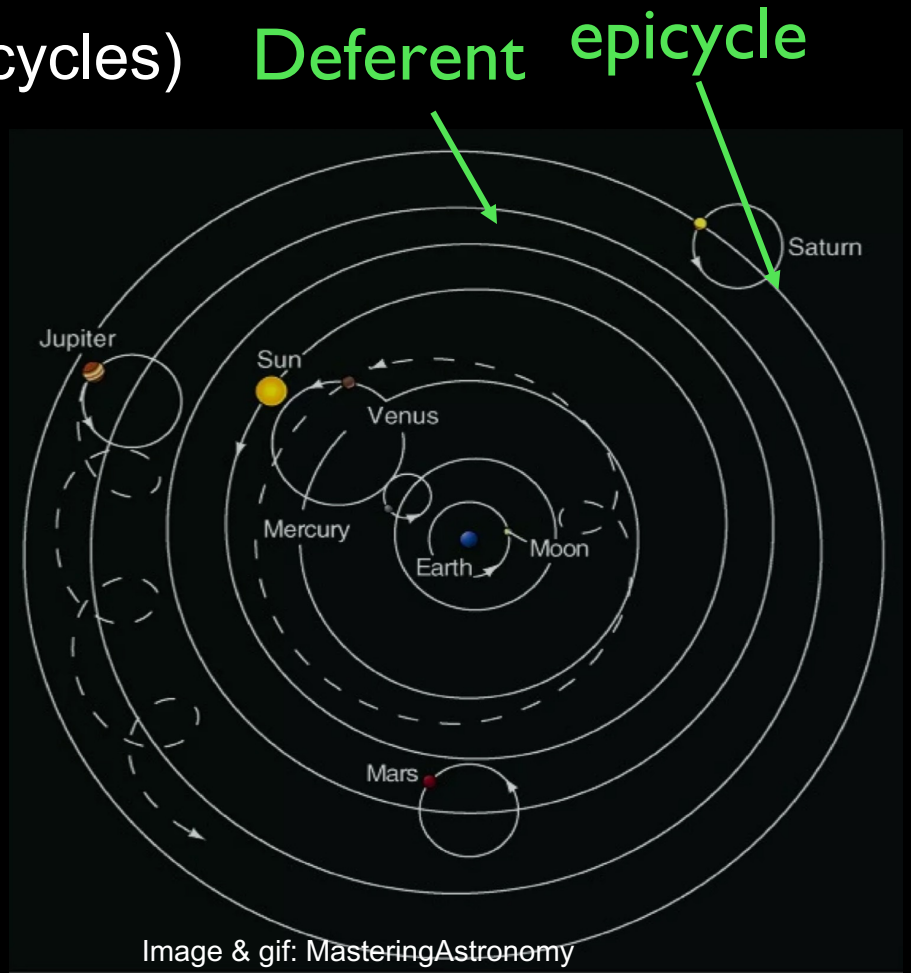
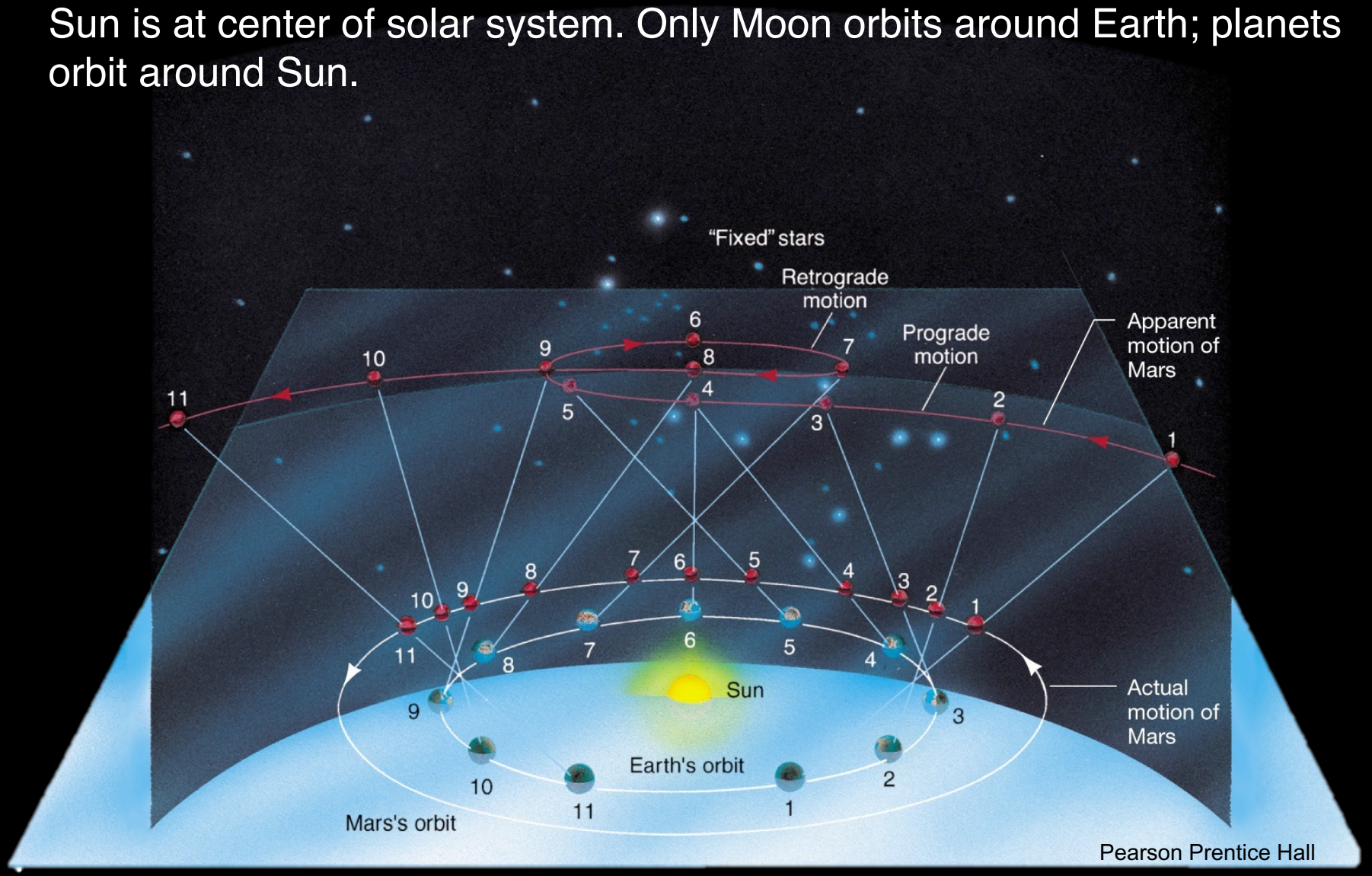


Image & gif: MasteringAstronomy

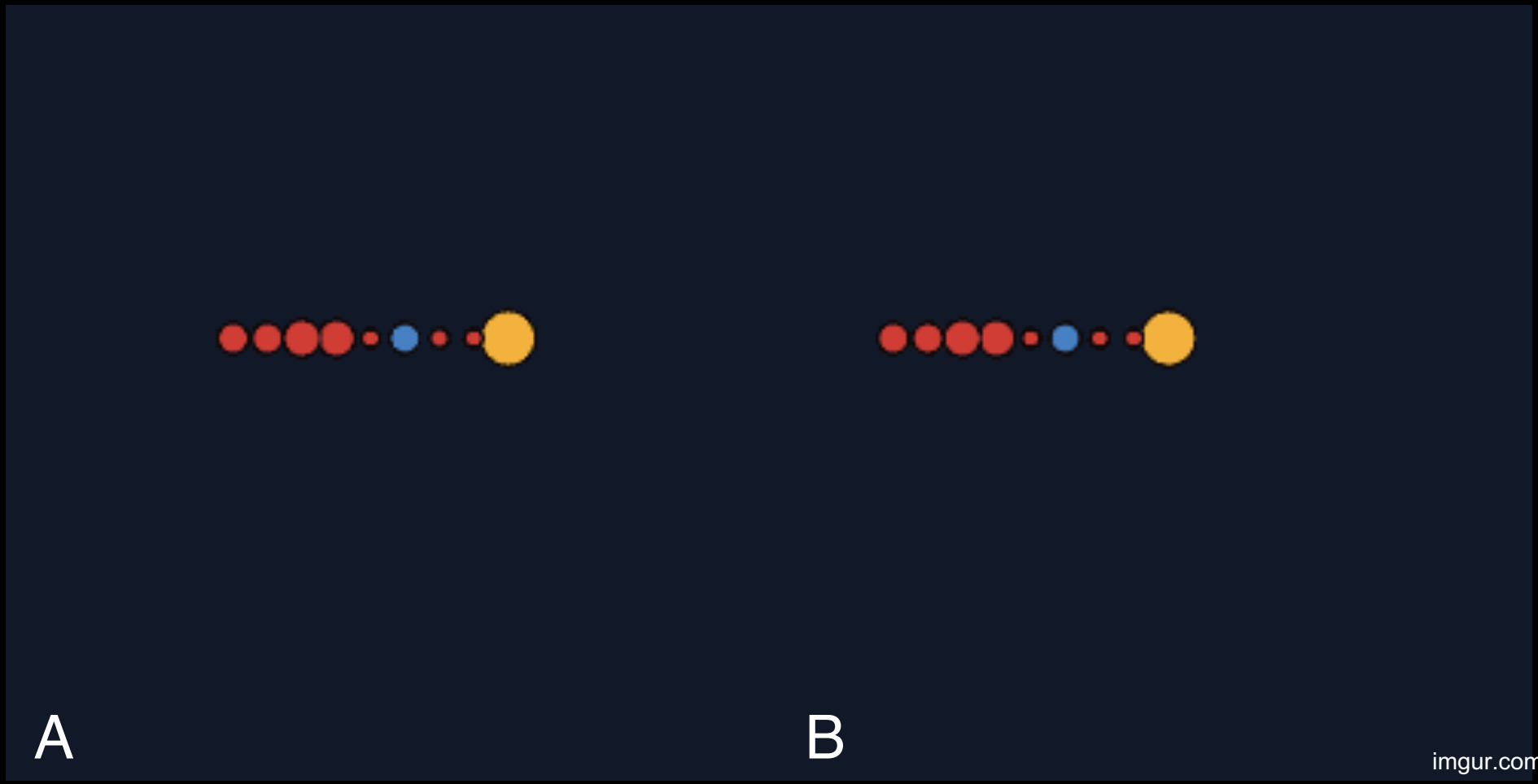
Heliocentric Model of the Solar System

Sun is at center of solar system. Only Moon orbits around Earth; planets orbit around Sun.



Remember Occam's Razor?

What model would you choose?



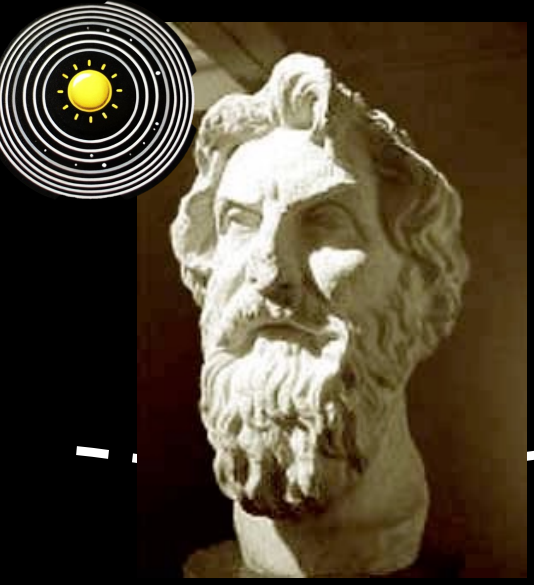
Built the foundation for Kepler's laws of planetary motion!

History & Kepler:

- Adopted heliocentric view

- Developed the 3 laws of planetary motion using detailed observations by Tycho Brahe

Mehrnoosh Tahani

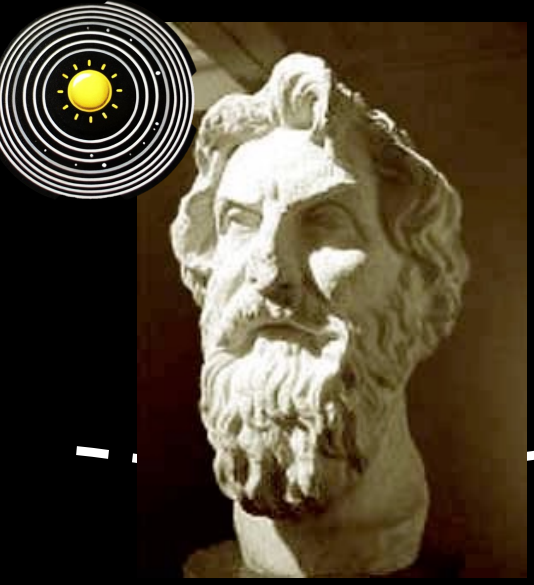


Aristarchus (320 - 230 BC)

Ptolemy (100 - 170 AD)

Nicolaus Copernicus
(1473 - 1543)

Images: Pearson; MasteringAstronomy

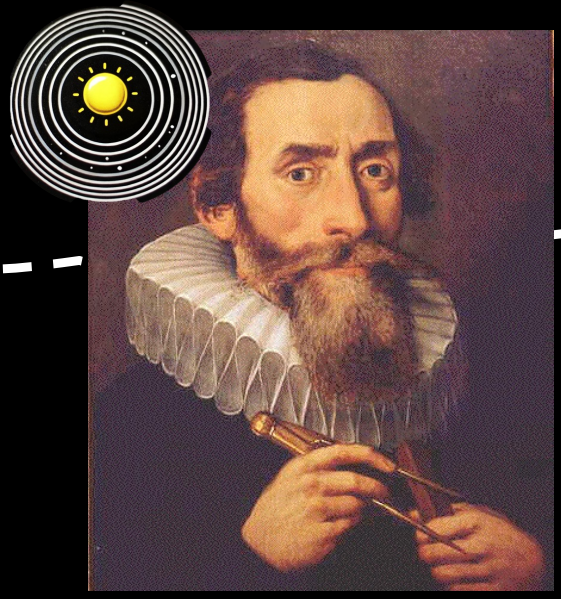


Aristarchus (320 - 230 BC)

Ptolemy (100 - 170 AD)

Nicolaus Copernicus
(1473 - 1543)

Tycho Brahe (1546 - 1601)

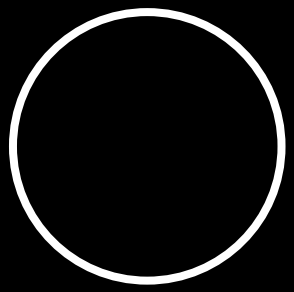


Johannes Kepler (1571 - 1630)

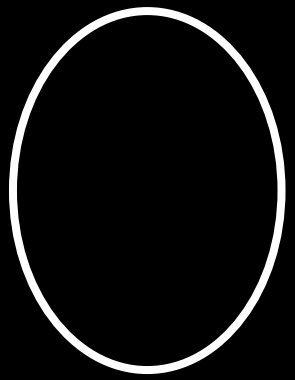
Galileo (1564 - 1642)

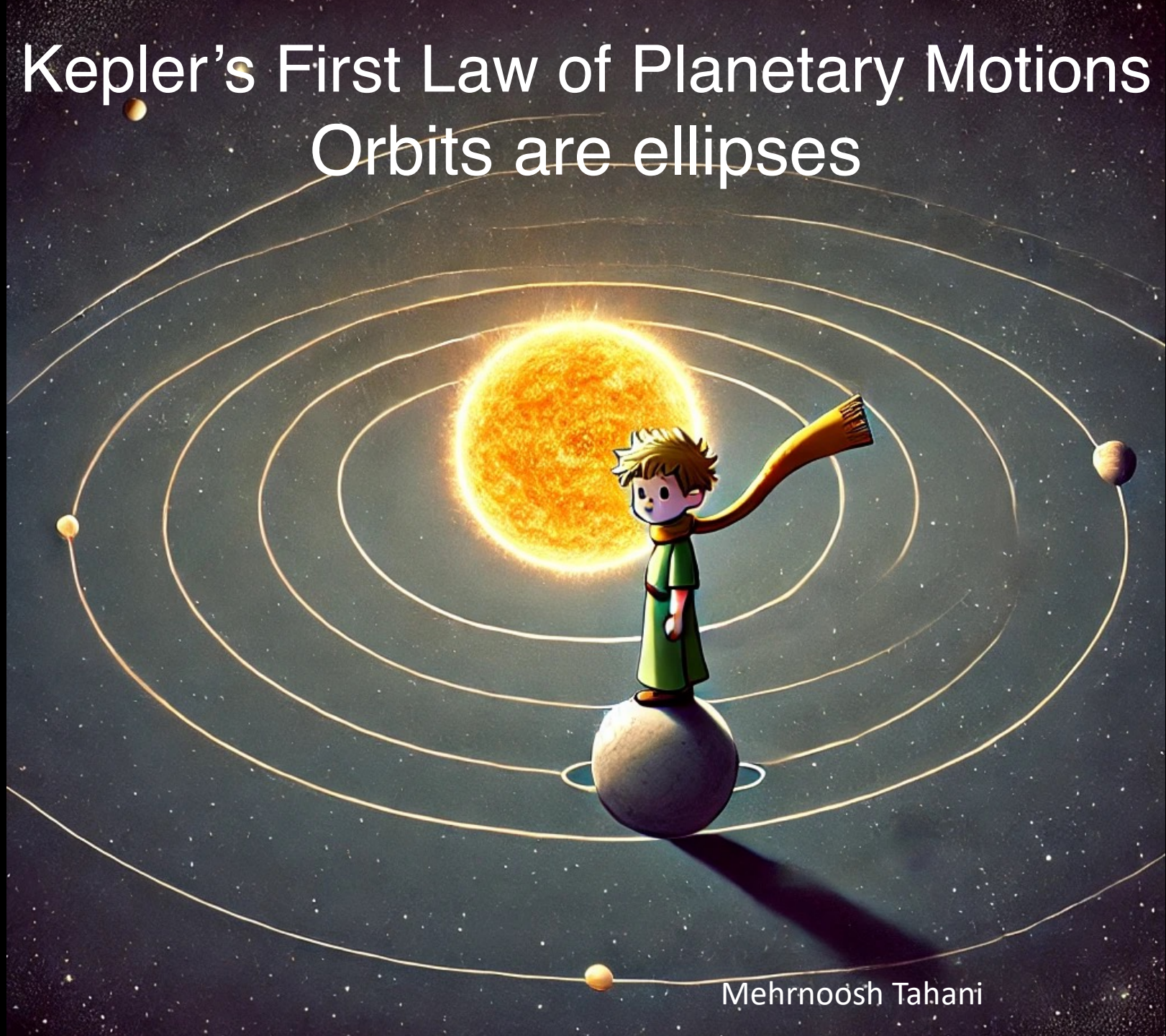
Kepler's First Law of Planetary Motions
Orbits are ellipses

Circle

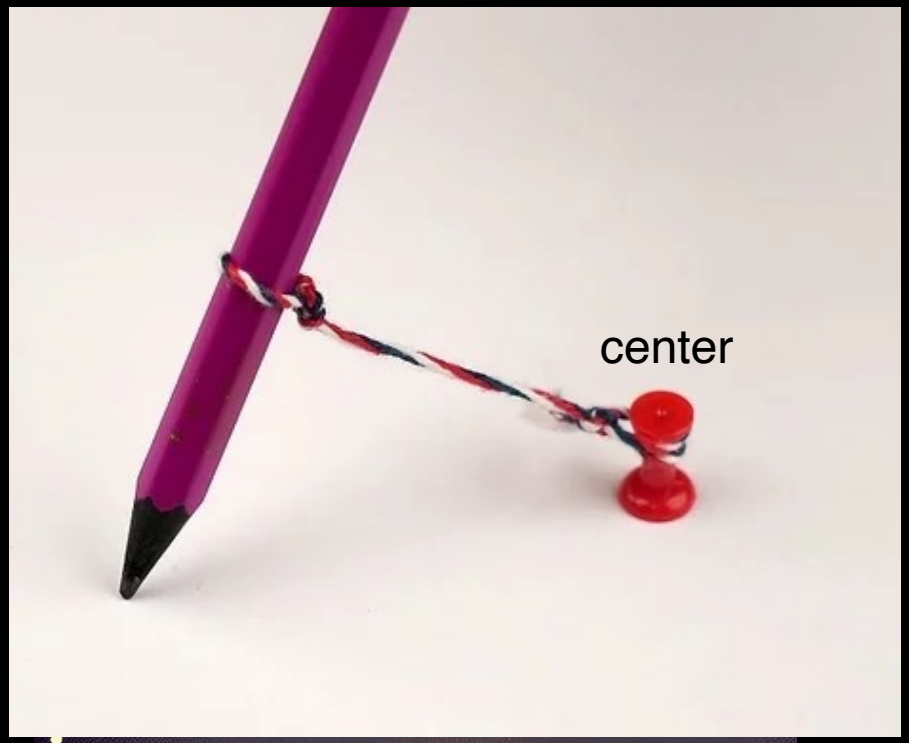


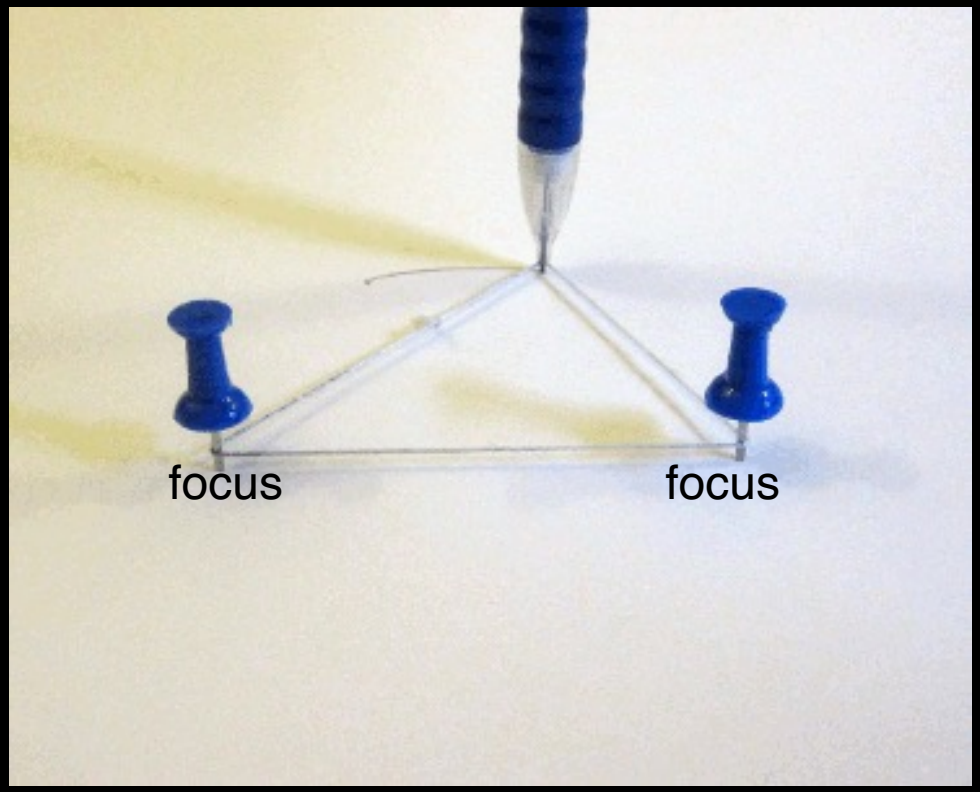
Ellipse



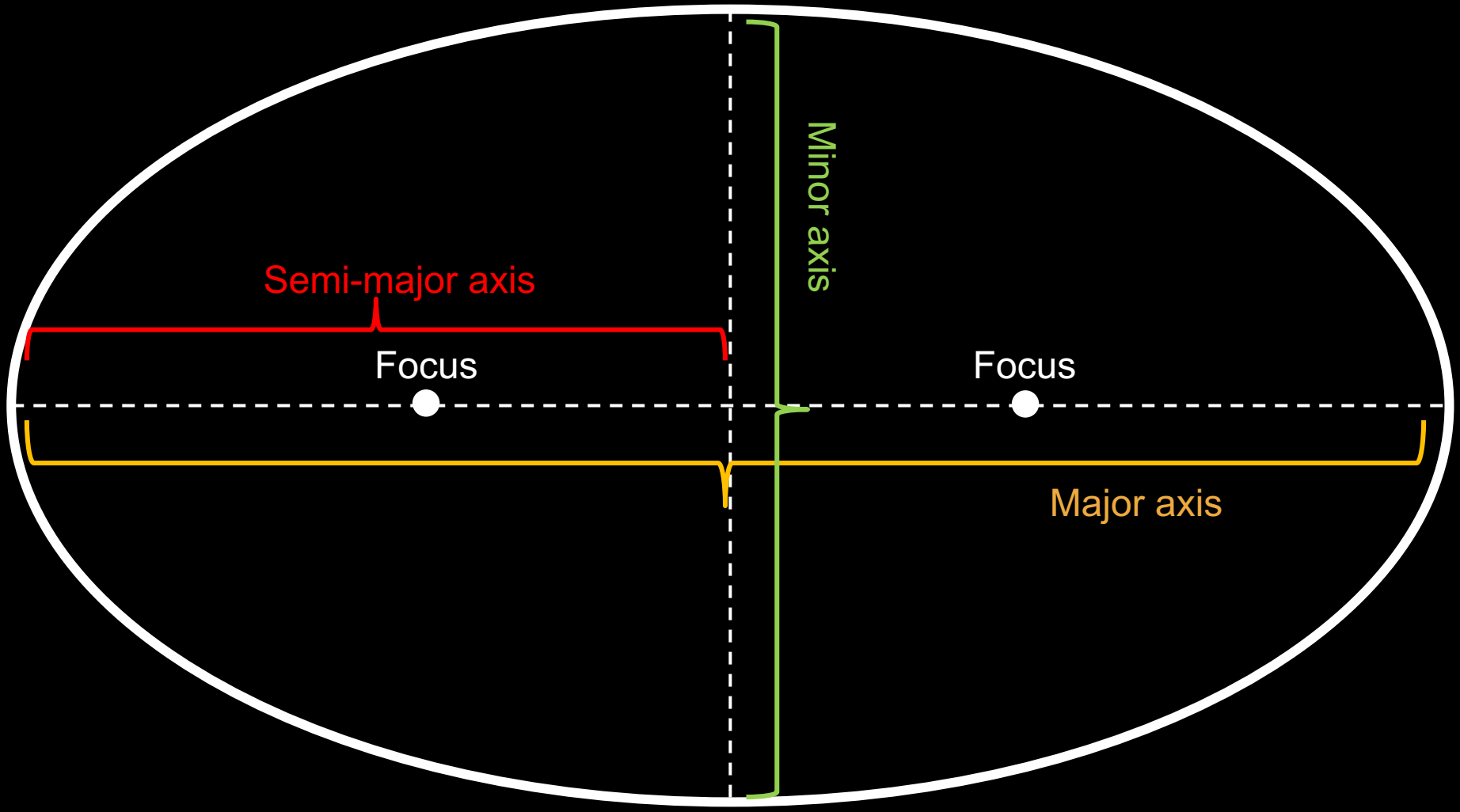


Mehrnoosh Tahani



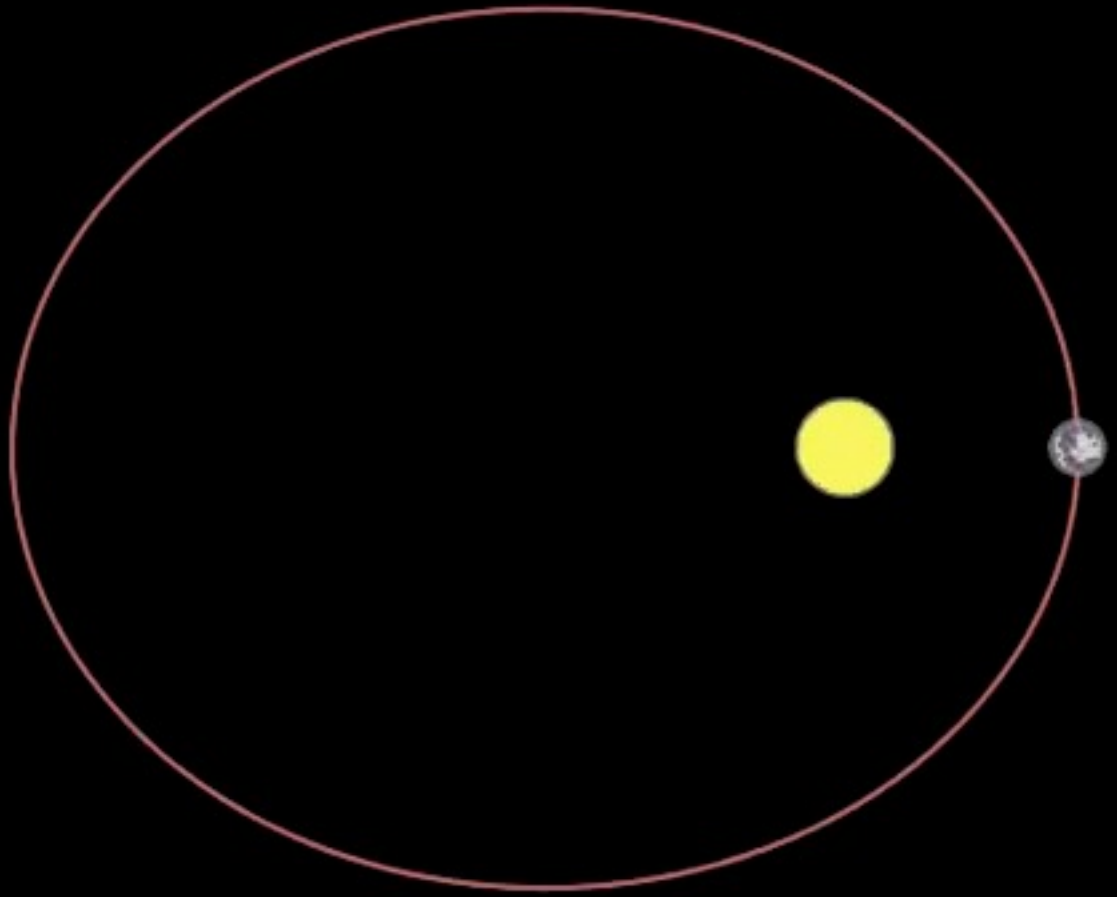


Orbits are ellipses with the Sun at one focus.



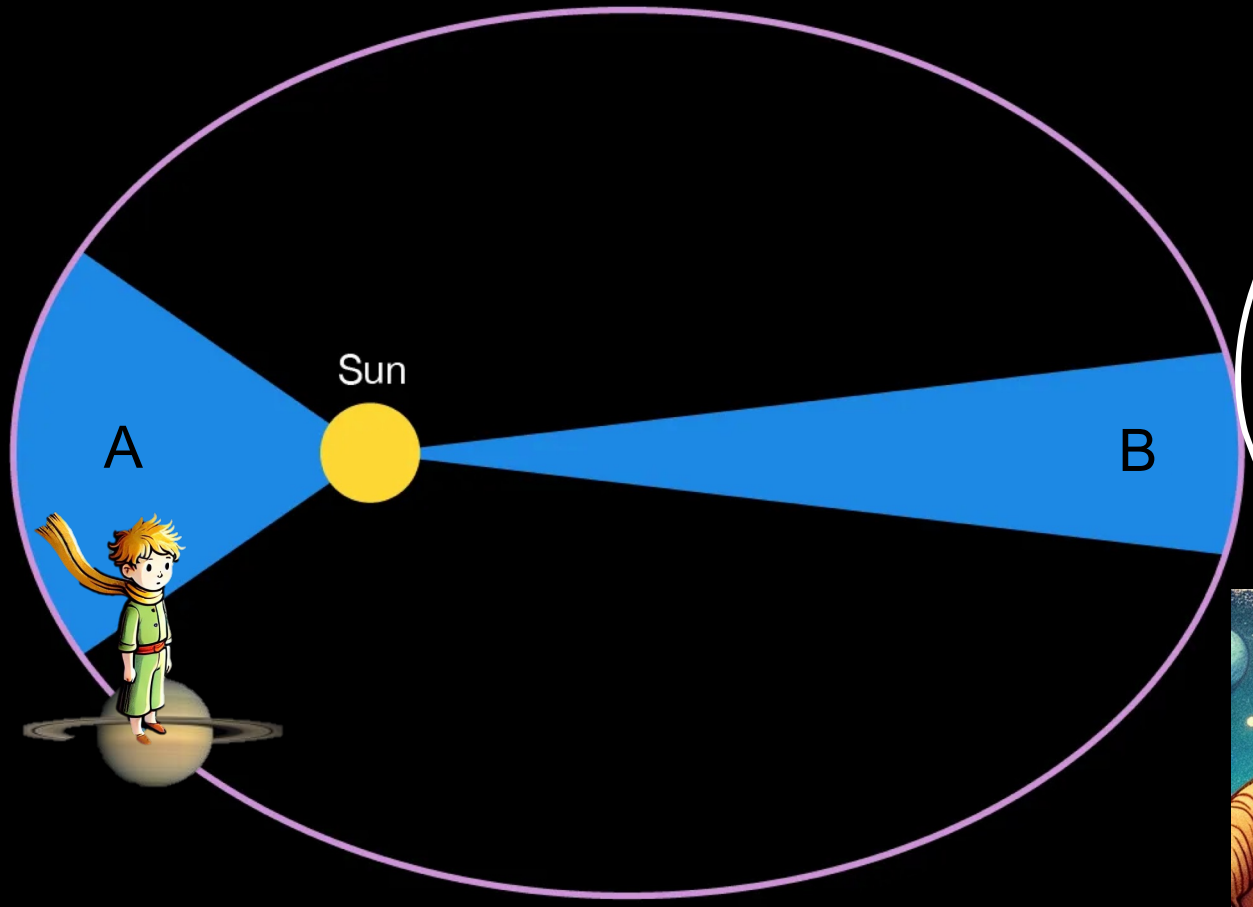
Eccentricity = distance between foci / major axis

Kepler's Second Law of Planetary Motions



A line drawn between the Sun & the planet sweeps out equal areas in equal time (law of areas).

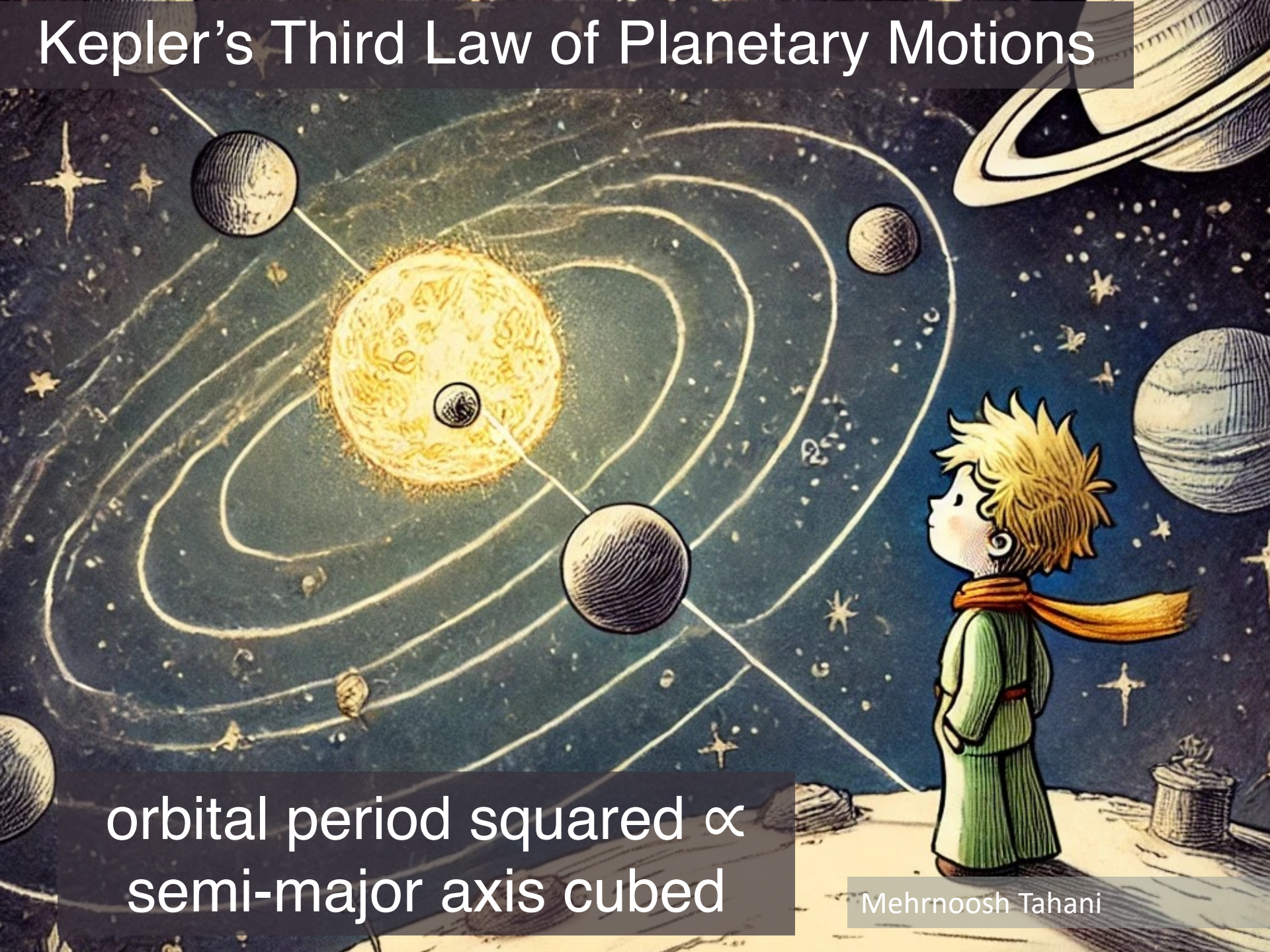
Kepler's Second Law of Planetary Motions



If areas A and B are equal, on which side is the planet moving more slowly?

Mehrnoosh Tahani

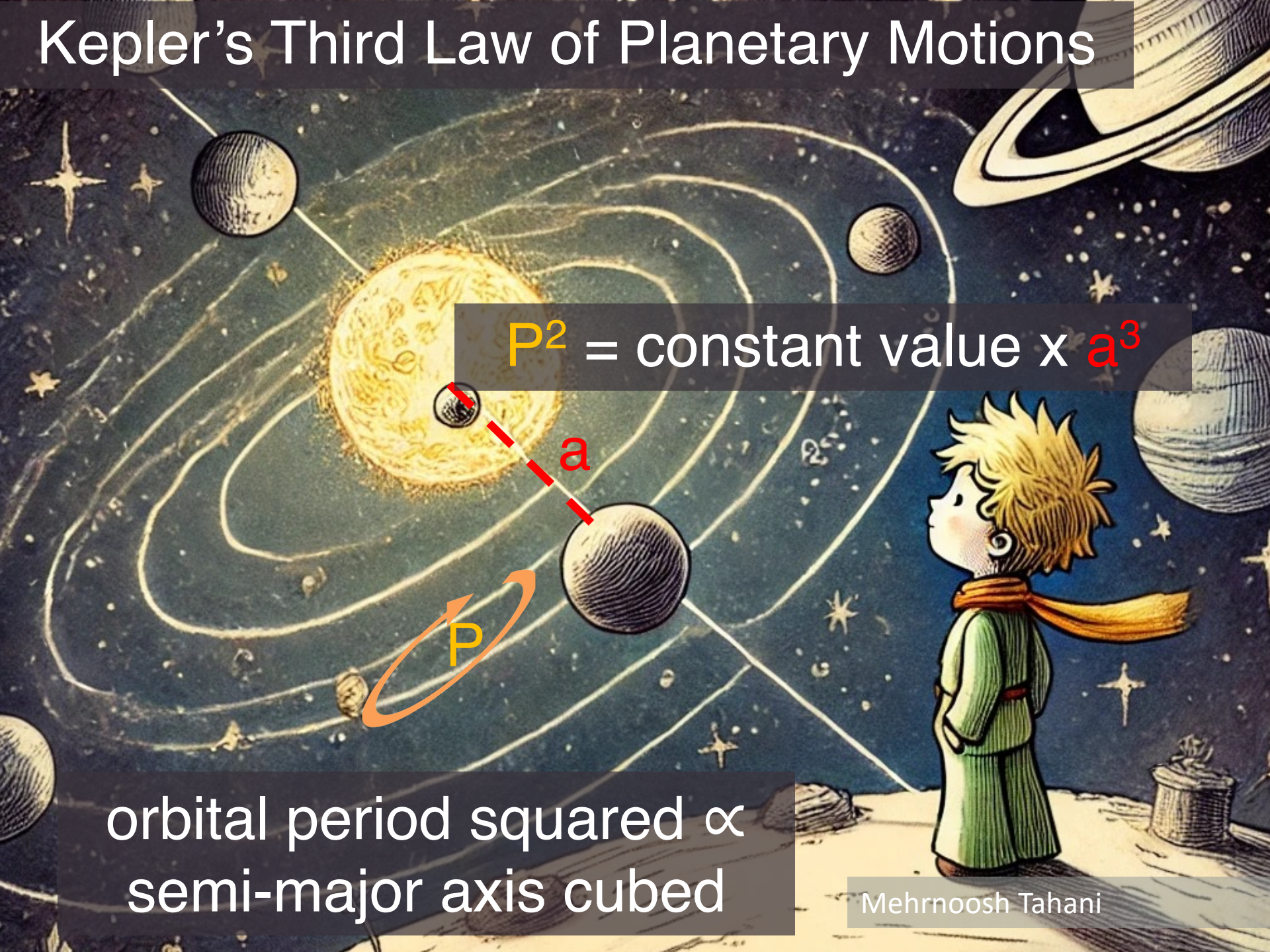
Kepler’s Third Law of Planetary Motions



orbital period squared ∝
semi-major axis cubed

Mehrnoosh Tahani

Kepler's Third Law of Planetary Motions



Practice Question

Mars takes 1.88 years to complete one orbit around the Sun. What is its average distance from the Sun? Provide your answer in Astronomical Units (AU; the average distance from the Sun to the Earth). $P^2 \propto a^3$

A) 3.53 AU

B) 1.52 AU

Practice Question

Mars takes 1.88 years to complete one orbit around the Sun. What is its average distance from the Sun? Provide your answer in Astronomical Units (AU; the average distance from the Sun to the Earth). $P^2 \propto a^3$

$$\frac{P^2_{\text{Mars}}}{P^2_{\text{Earth}}} = \frac{a^3_{\text{Mars}}}{a^3_{\text{Earth}}} \quad \text{or} \quad \frac{P^2_{\text{Mars}}}{a^3_{\text{Mars}}} = \frac{P^2_{\text{Earth}}}{a^3_{\text{Earth}}} \quad \text{or} \quad \frac{a^3_{\text{Mars}}}{P^2_{\text{Mars}}} = \frac{a^3_{\text{Earth}}}{P^2_{\text{Earth}}}$$

Practice Question

Mars takes 1.88 years to complete one orbit around the Sun. What is its average distance from the Sun? Provide your answer in Astronomical Units (AU; the average distance from the Sun to the Earth). $P^2 \propto a^3$

$$\frac{P^2_{\text{Mars}}}{P^2_{\text{Earth}}} = \frac{a^3_{\text{Mars}}}{a^3_{\text{Earth}}} \quad \text{or} \quad \frac{P^2_{\text{Mars}}}{a^3_{\text{Mars}}} = \frac{P^2_{\text{Earth}}}{a^3_{\text{Earth}}} \quad \text{or} \quad \frac{a^3_{\text{Mars}}}{P^2_{\text{Mars}}} = \frac{a^3_{\text{Earth}}}{P^2_{\text{Earth}}}$$

$$a^3_{\text{Mars}} = \frac{a^3_{\text{Earth}}}{P^2_{\text{Earth}}} \times P^2_{\text{Mars}} \qquad a^3_{\text{Mars}} = \frac{(1\text{year})^3}{(1\text{AU})^2} \times (1.88\text{year})^2$$

Practice Question

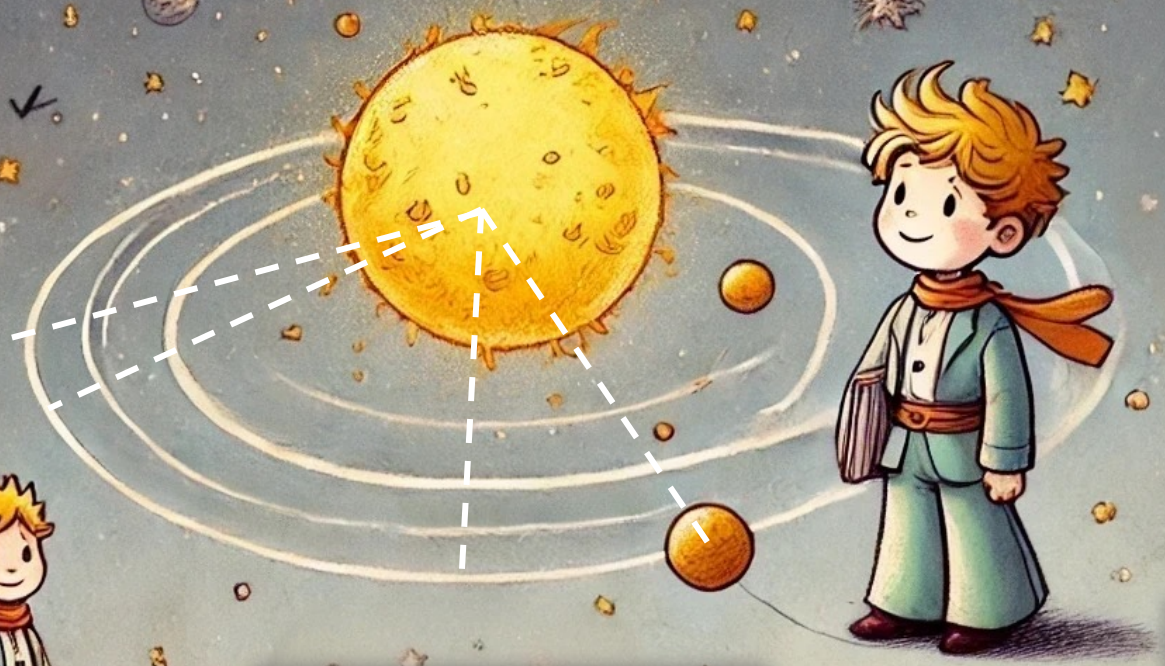
Mars takes 1.88 years to complete one orbit around the Sun. What is its average distance from the Sun? Provide your answer in Astronomical Units (AU; the average distance from the Sun to the Earth). $P^2 \propto a^3$

$$\frac{P^2_{\text{Mars}}}{P^2_{\text{Earth}}} = \frac{a^3_{\text{Mars}}}{a^3_{\text{Earth}}} \quad \text{or} \quad \frac{P^2_{\text{Mars}}}{a^3_{\text{Mars}}} = \frac{P^2_{\text{Earth}}}{a^3_{\text{Earth}}} \quad \text{or} \quad \frac{a^3_{\text{Mars}}}{P^2_{\text{Mars}}} = \frac{a^3_{\text{Earth}}}{P^2_{\text{Earth}}}$$

$$a^3_{\text{Mars}} = \frac{a^3_{\text{Earth}}}{P^2_{\text{Earth}}} \times P^2_{\text{Mars}} \qquad a^3_{\text{Mars}} = \frac{(1\text{year})^3}{(1\text{AU})^2} \times (1.88\text{year})^2$$

$$a^3_{\text{Mars}} = 3.53 \qquad a_{\text{Mars}} = 1.52\text{AU}$$

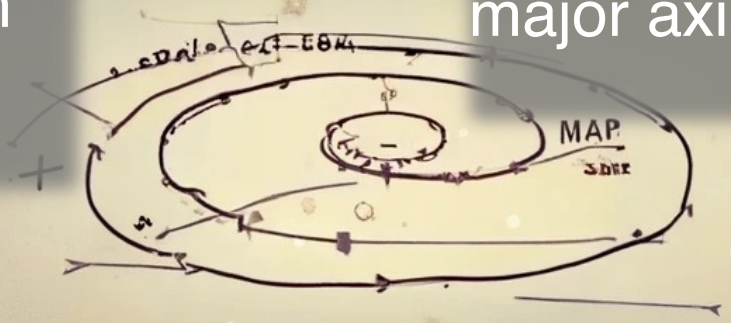
Kepler's Three Laws of Planetary Motion



2) A line drawn between the Sun & the planet sweeps out equal areas in equal time

1) Planetary orbits are ellipses with the Sun at one focus.

3) orbital period squared ∝ semi-major axis cubed



Mehrnoosh Tahani

What do you think?

How do you explain the “odd” behaviour of the planets in the sky?

- After this lecture, my thoughts are….

Choose one of the two following questions and think about them until next time!

1. Among the scientists we mentioned today, who are you most impressed by and why?

2. What are some applications of Kepler's three laws you can think of or find?