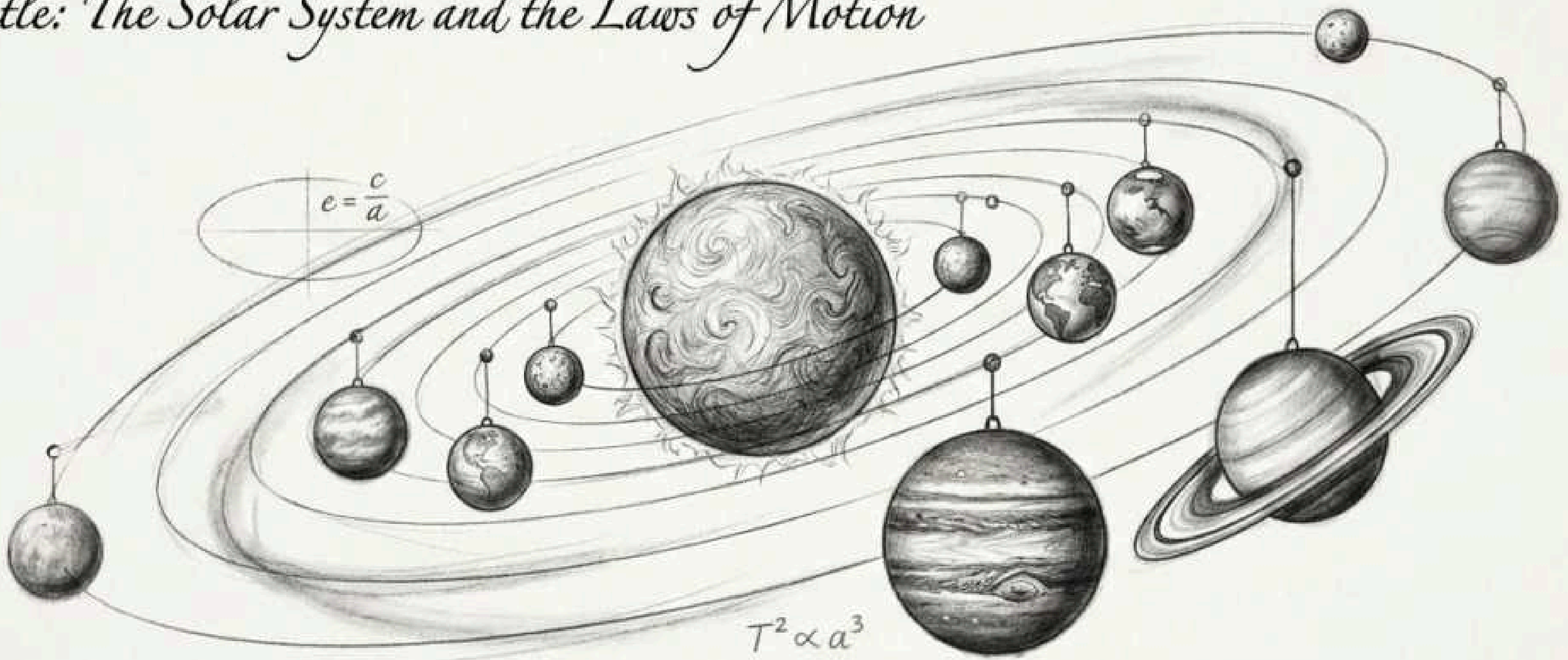
# ASTR 101 B: Lecture 2

## Subtitle: The Solar System and the Laws of Motion




*At a glance — The Solar System, its formation, and Kepler's and Newton's laws of motion and gravity.*

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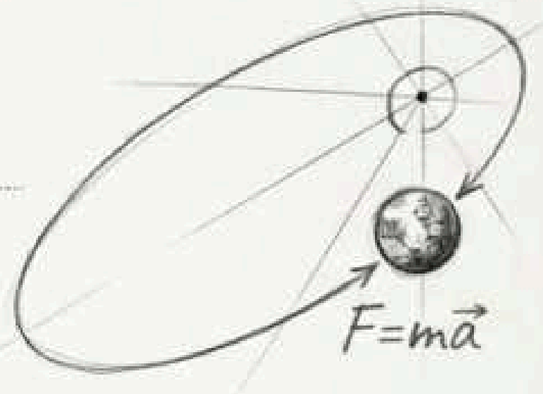
## Phase 1: What is there?

A tour of the Solar System. Stepping onto the lowest rung of the cosmic ladder more larger than a planet.



## Phase 2: How did it form?

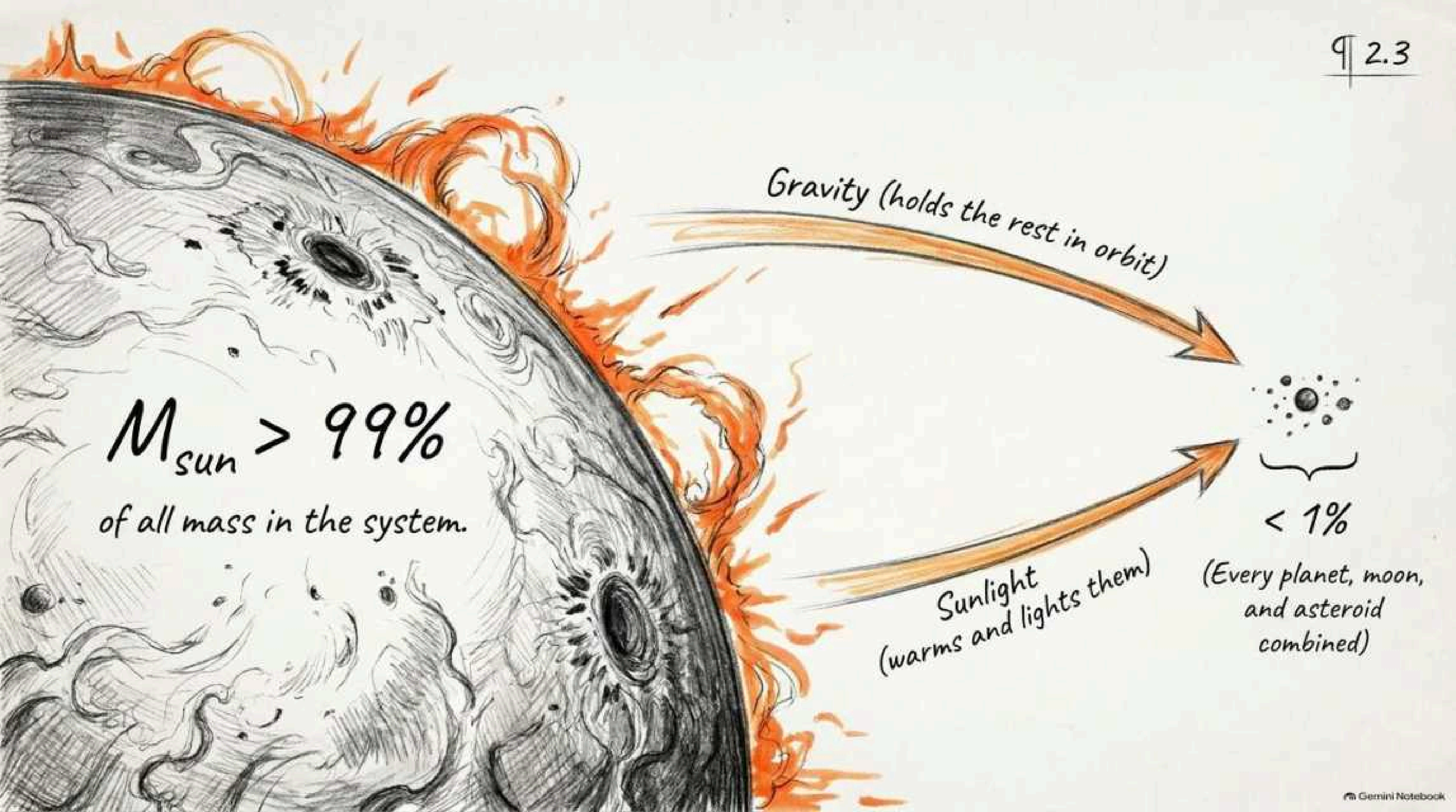
The story of its creation.




## Phase 3: Why does it move?

The laws of motion from Kepler and Newton.

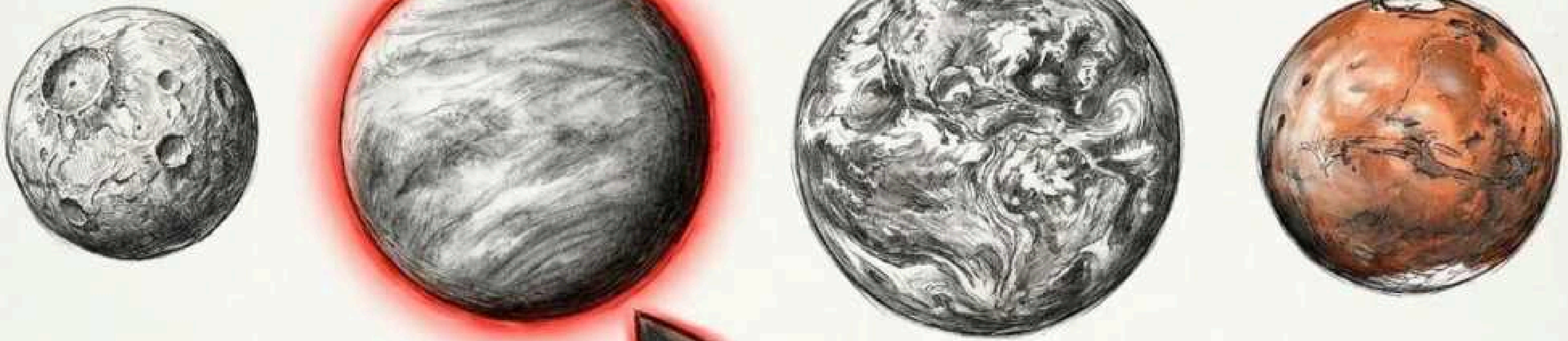
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# The Terrestrial Planets

¶ 2.4



- ✓ Small
- ✓ Rocky
- ✓ Dense
- ✓ Solid Surface
- ✓ Few/No Moons
- ✓ No Rings

Hottest planet (hotter than Mercury). Thick $CO_2$ atmosphere traps heat in in a runaway greenhouse effect.

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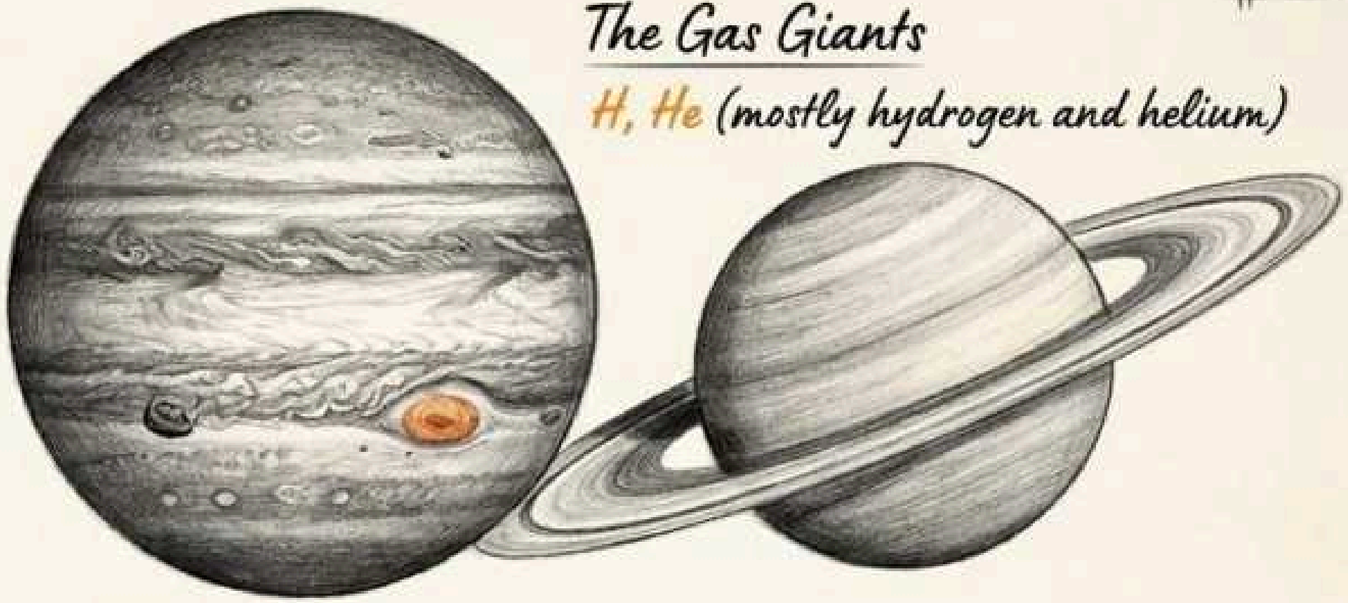


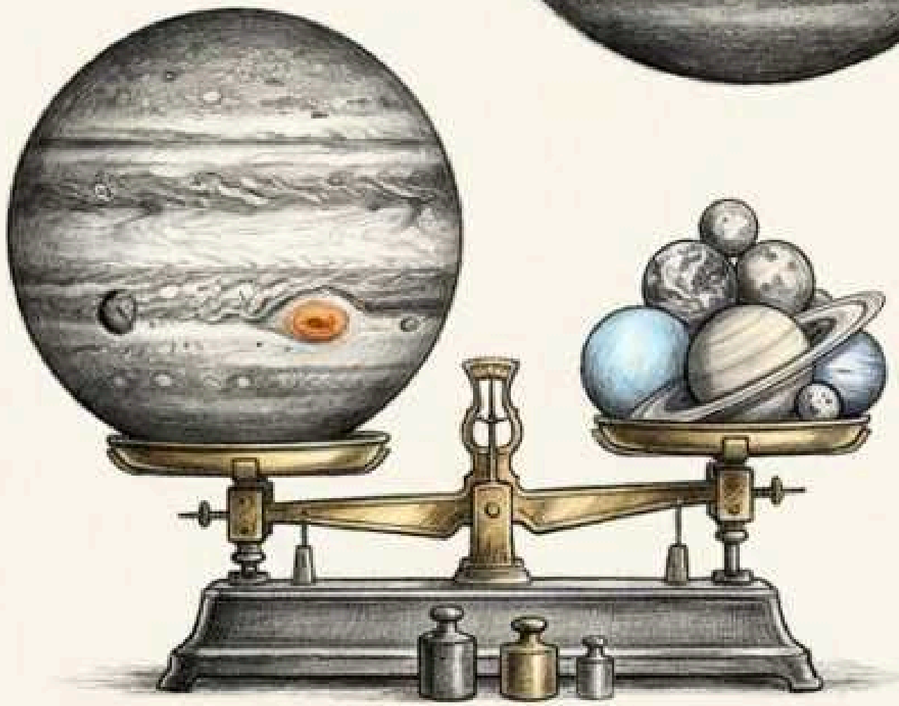
## The Asteroid Belt

Rocky debris left over from planet building, lying just beyond Mars.

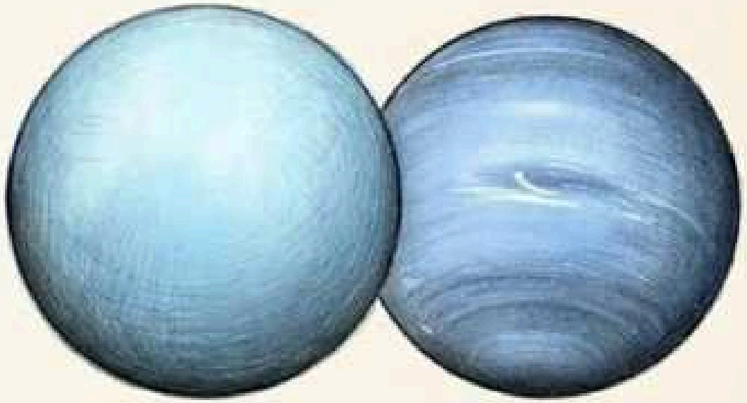
## The Gas Giants

H, He (mostly hydrogen and helium)





Jupiter outweighs all other planets put together, more than twice over.



## The Ice Giants

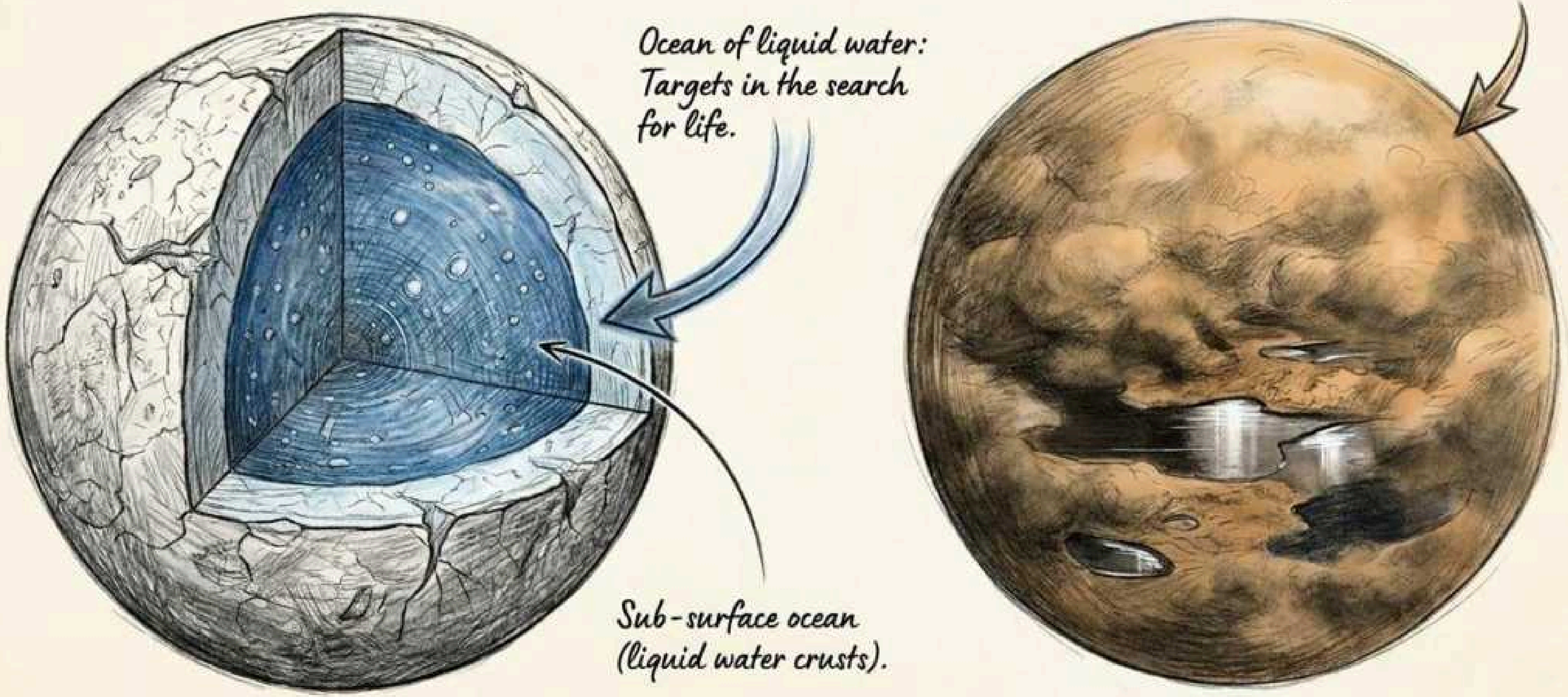
$H_2O$, $NH_3$, $CH_4$

(water, ammonia, methane)

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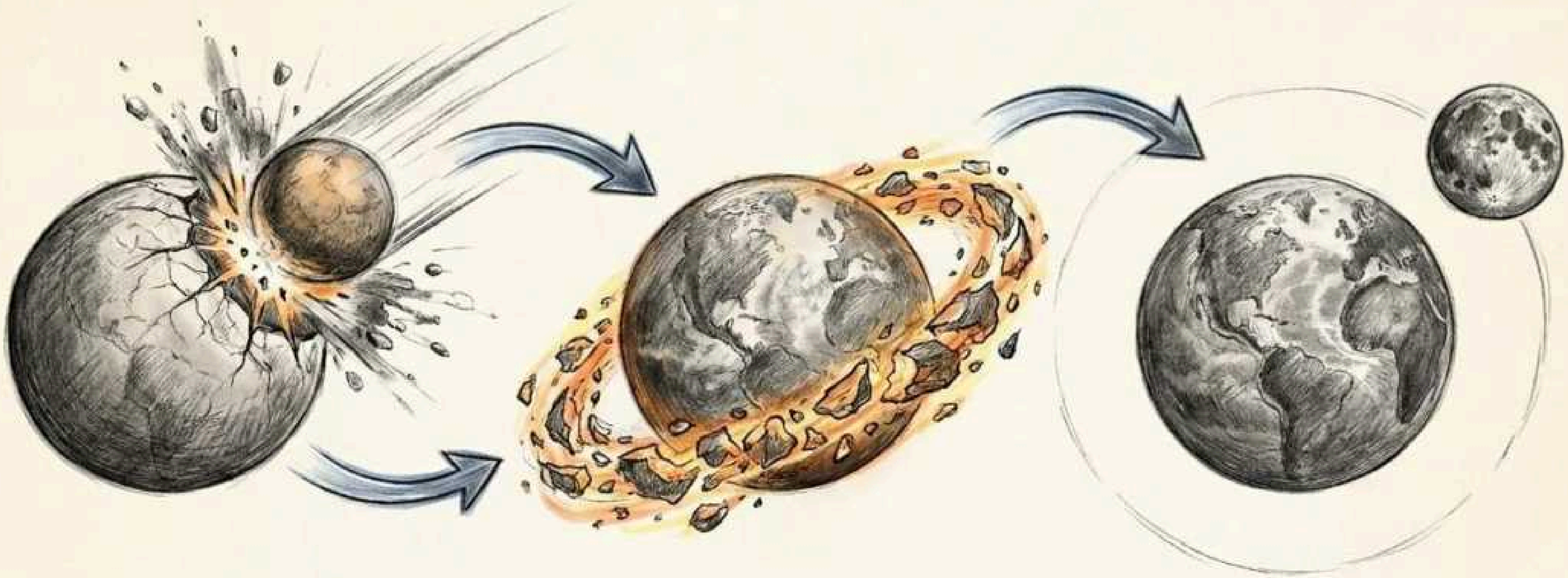
# Worlds in their own right

The giants have many moons and all have rings (although only Saturn's are bright).




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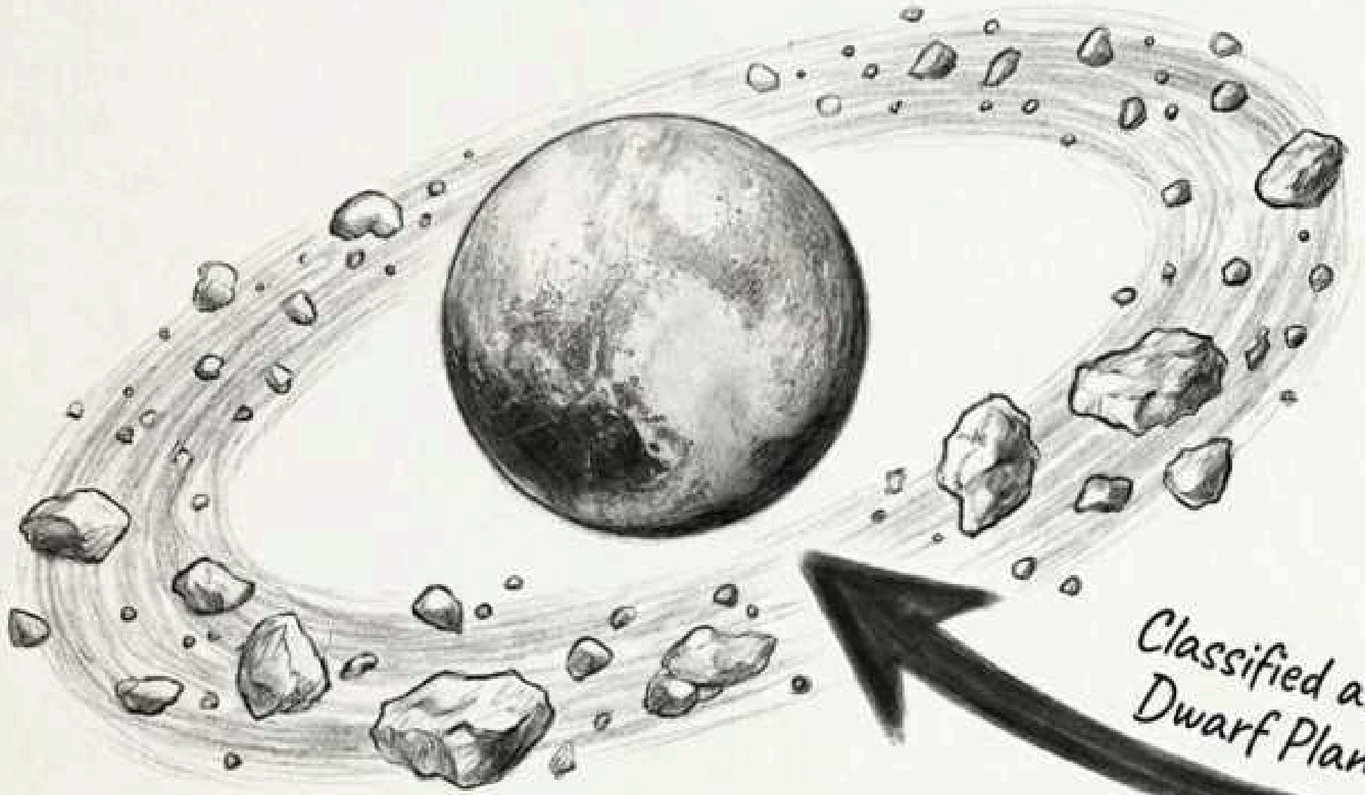
# Born in a Catastrophe



## Theory Evidence

This collision model perfectly explains two mysteries:
1) Why the Moon is so large compared to Earth, and 2) Why its rocks are so similar to Earth's rocks.

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The Kuiper belt (vast ring of icy bodies beyond Neptune).

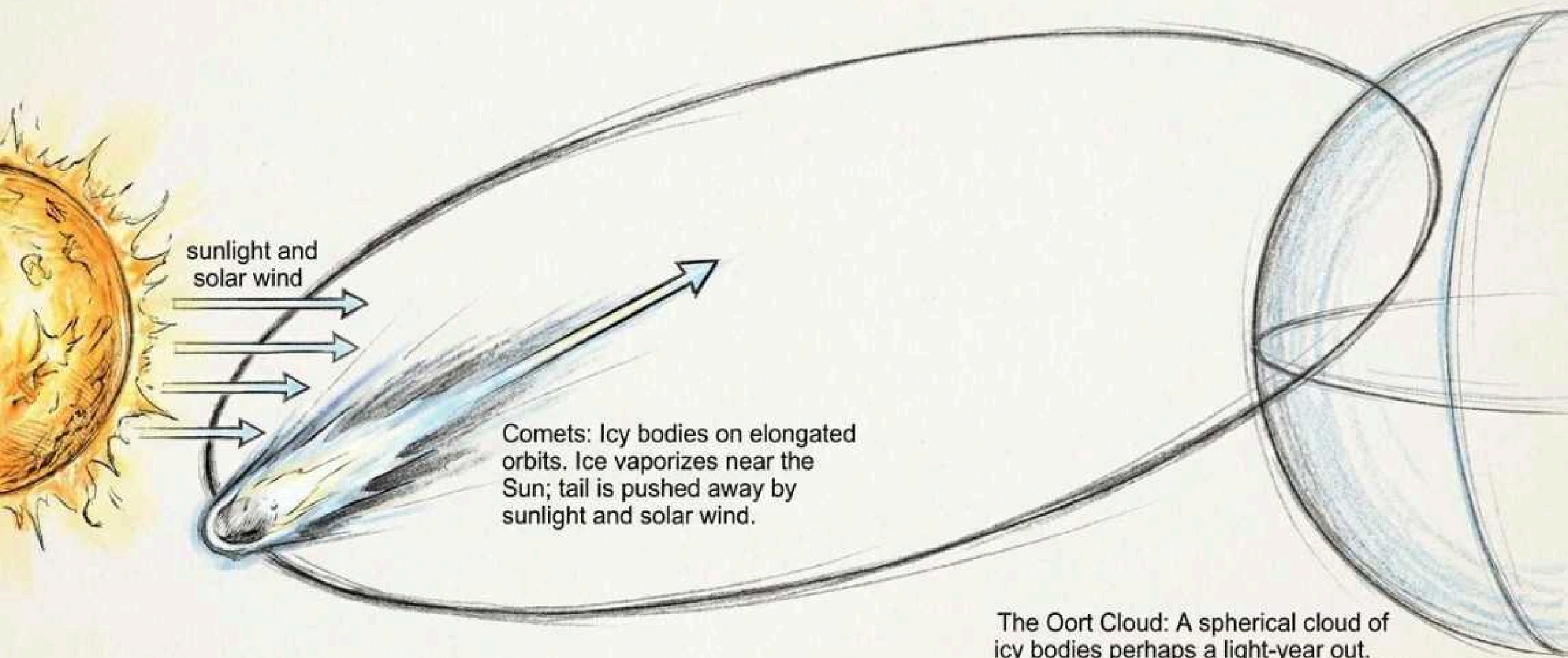
Classified as a Dwarf Planet.

A decision about naming, not a discovery that changed Pluto itself.

## 2006 IAU Planet Definition

1. Orbits the Sun (✓)
2. Is round (✓)
3. Has cleared its orbit of other objects (✗ - Fails here)

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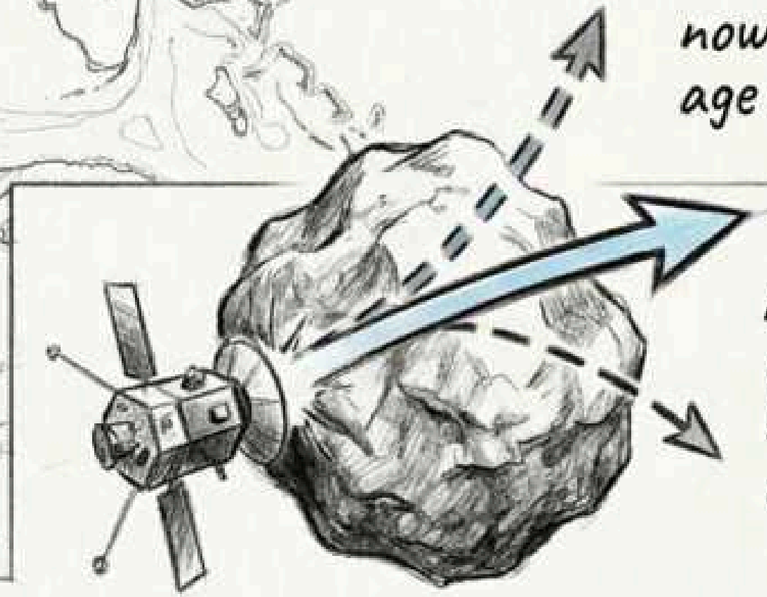

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# Impacts shape every world.





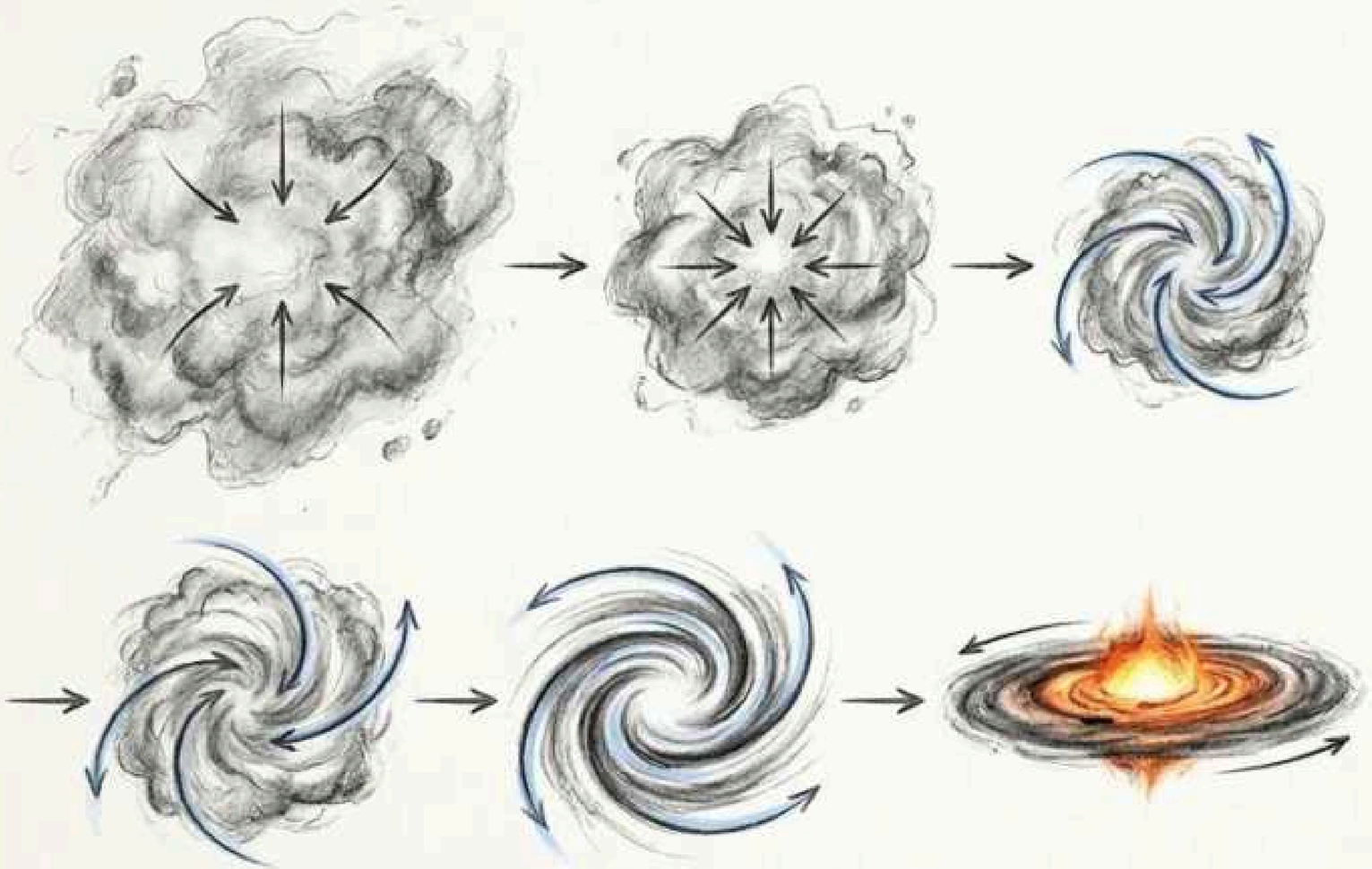

66 million years ago, a ~10km wide asteroid struck what is now Mexico, helping end the age of the dinosaurs.



Astronomers survey for Earth-crossing asteroids. Spacecraft have proven small asteroids can be nudged off course.

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# The Nebular Hypothesis (How it formed)



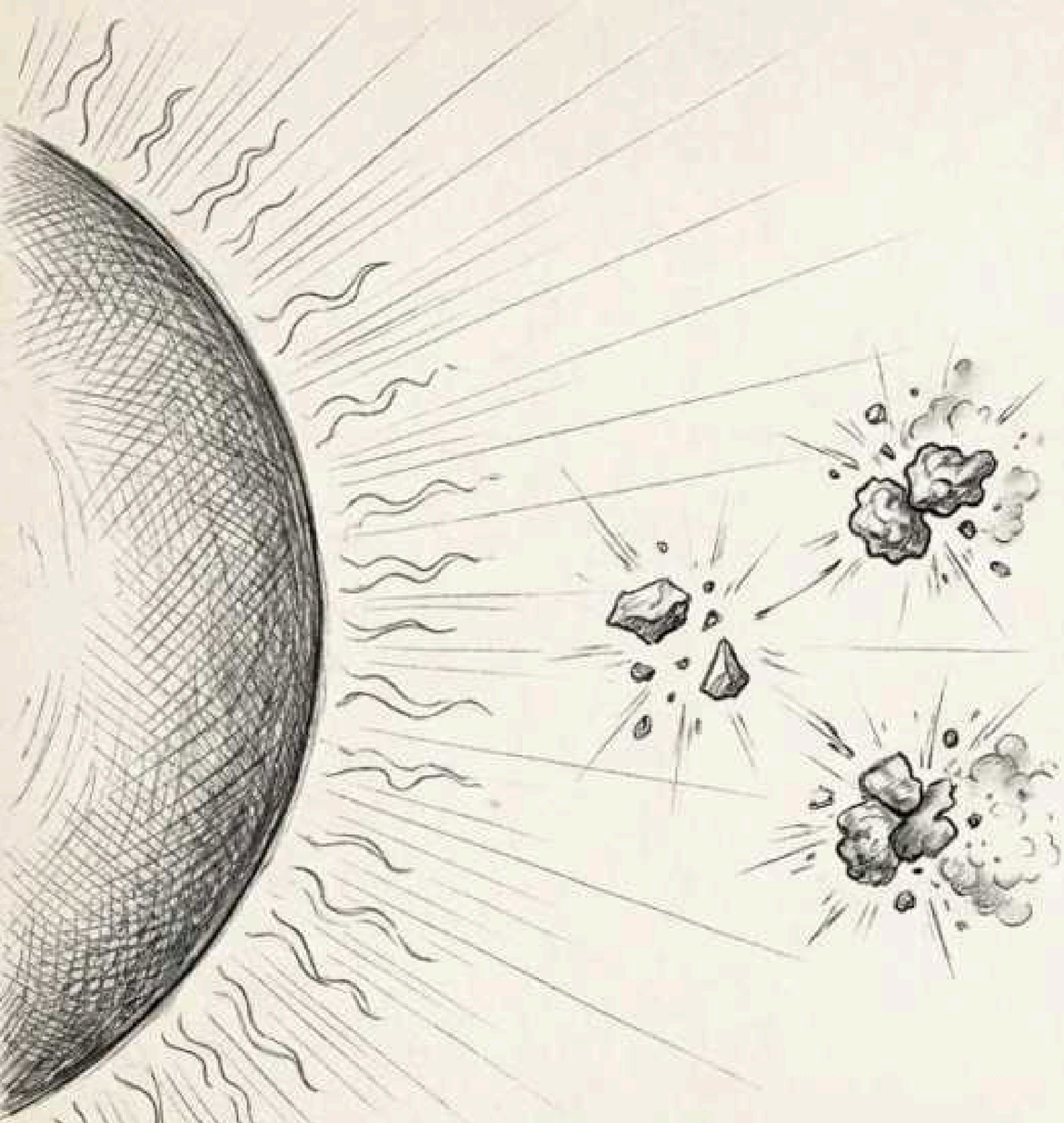
Gravity collapses the cloud → Shrinks and spins faster → Flattens into a disk. Most material falls to the center to become the Sun.



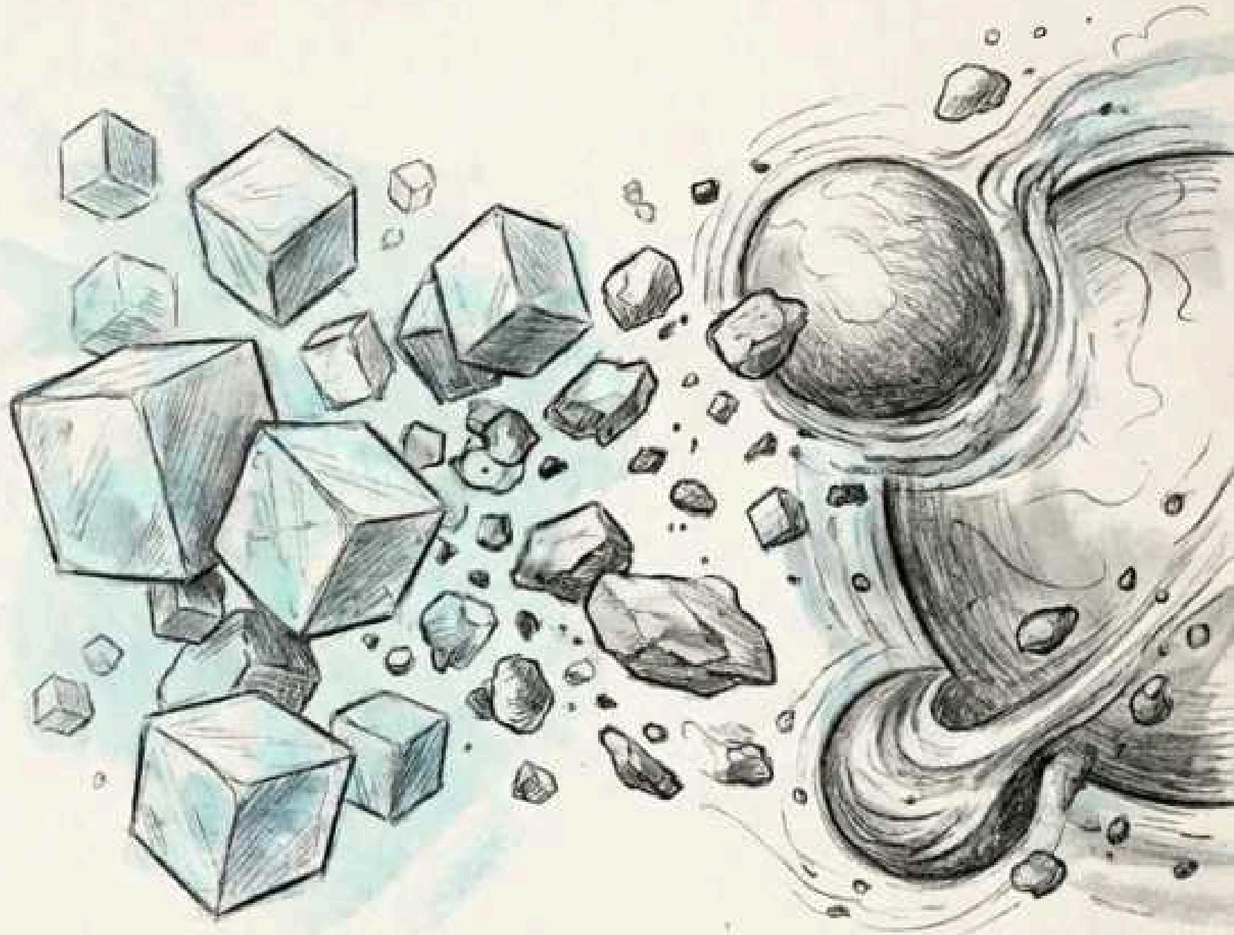
Like a skater pulling in her arms (Conservation of Angular Momentum)

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# THE FROST LINE



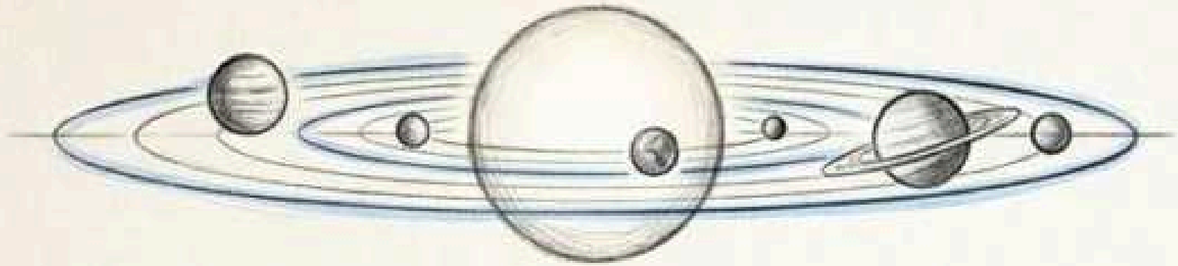
Inside Frost Line: Too hot for ice. Only rock and metal can clump together.



Outside Frost Line: Ice remains solid. Far more material available -> Formation of the Giants.

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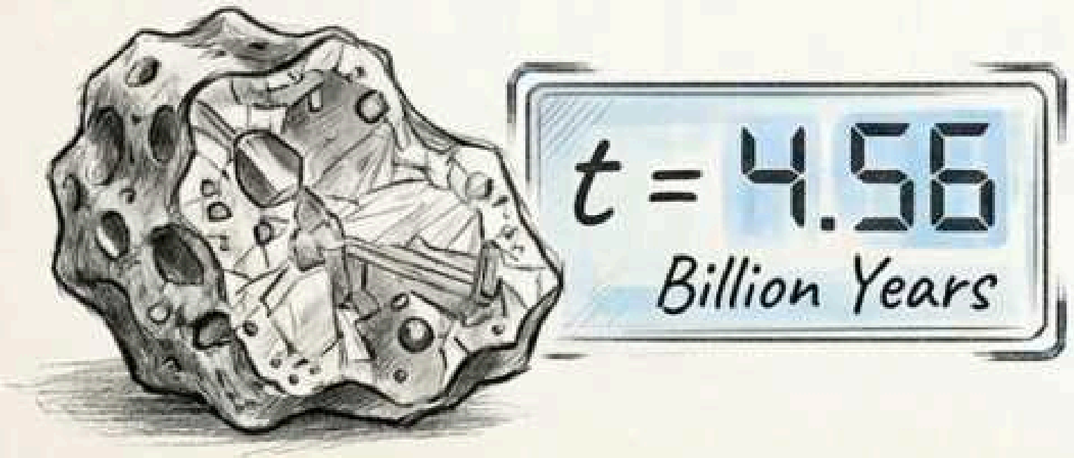
# The Theory Predicts What We See



Coplanar orbits (the old disk)



Uniform spin direction




Radioactive dating agrees with Earth/Moon rocks



Observations of young stars show similar disks

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# Tycho Brahe's Careful Observations

Tycho Brahe's Careful Observations

Date: 1590.12.15
Planet: Mars
Altitude: 32.1°
Time: 23:45

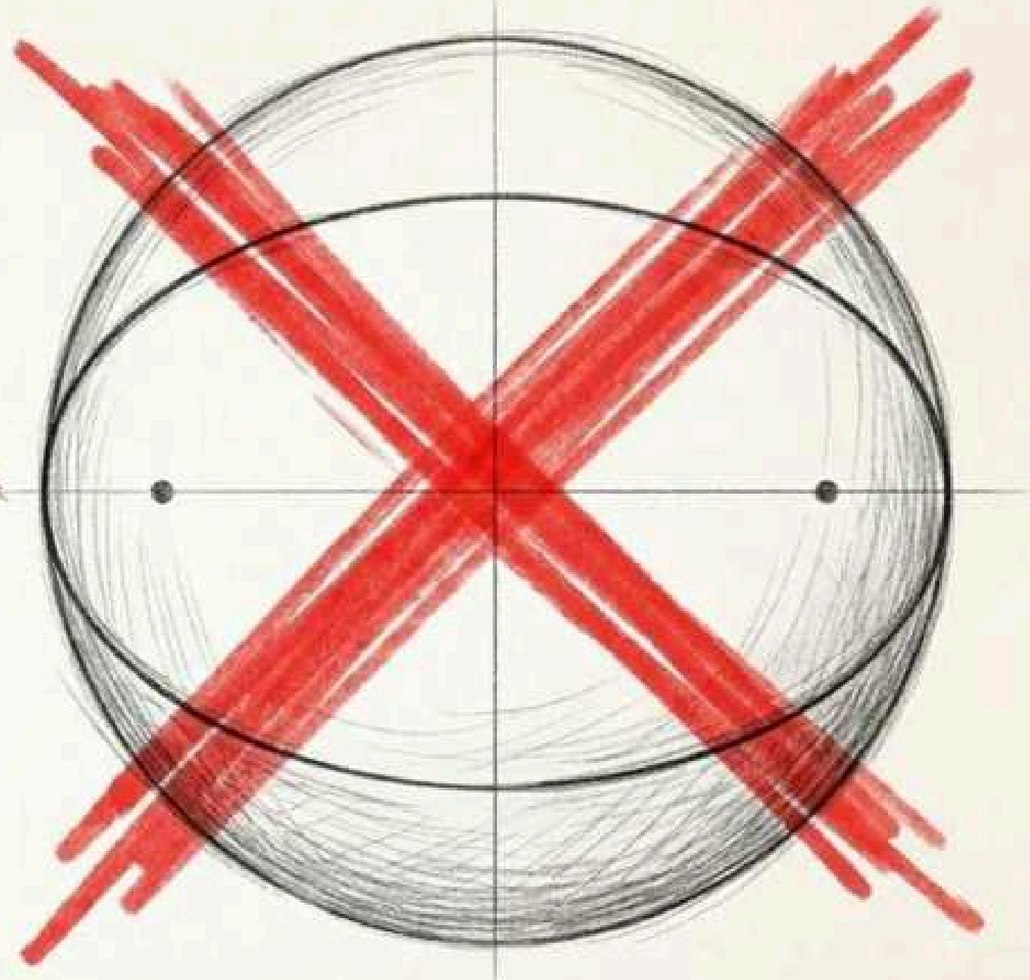
| Planet: | Azimuth: | Altitude: |
|---|---|---|
| Mars | 125.4° | 32.1° |
| Mars | 54.3° | 20.9° |
| Mars | 33.1° | 01:15 |

Date: 1591.03.21
Planet: Mars
Azimuth: 178.9°
Altitude: 54.2°
Time: 01:15

Johannes Kepler (Early 1600s)

Date: 1591.03.21
Planet: Mars
Azimuth: 178.9°
Altitude: 54.2°
Time: 01:15

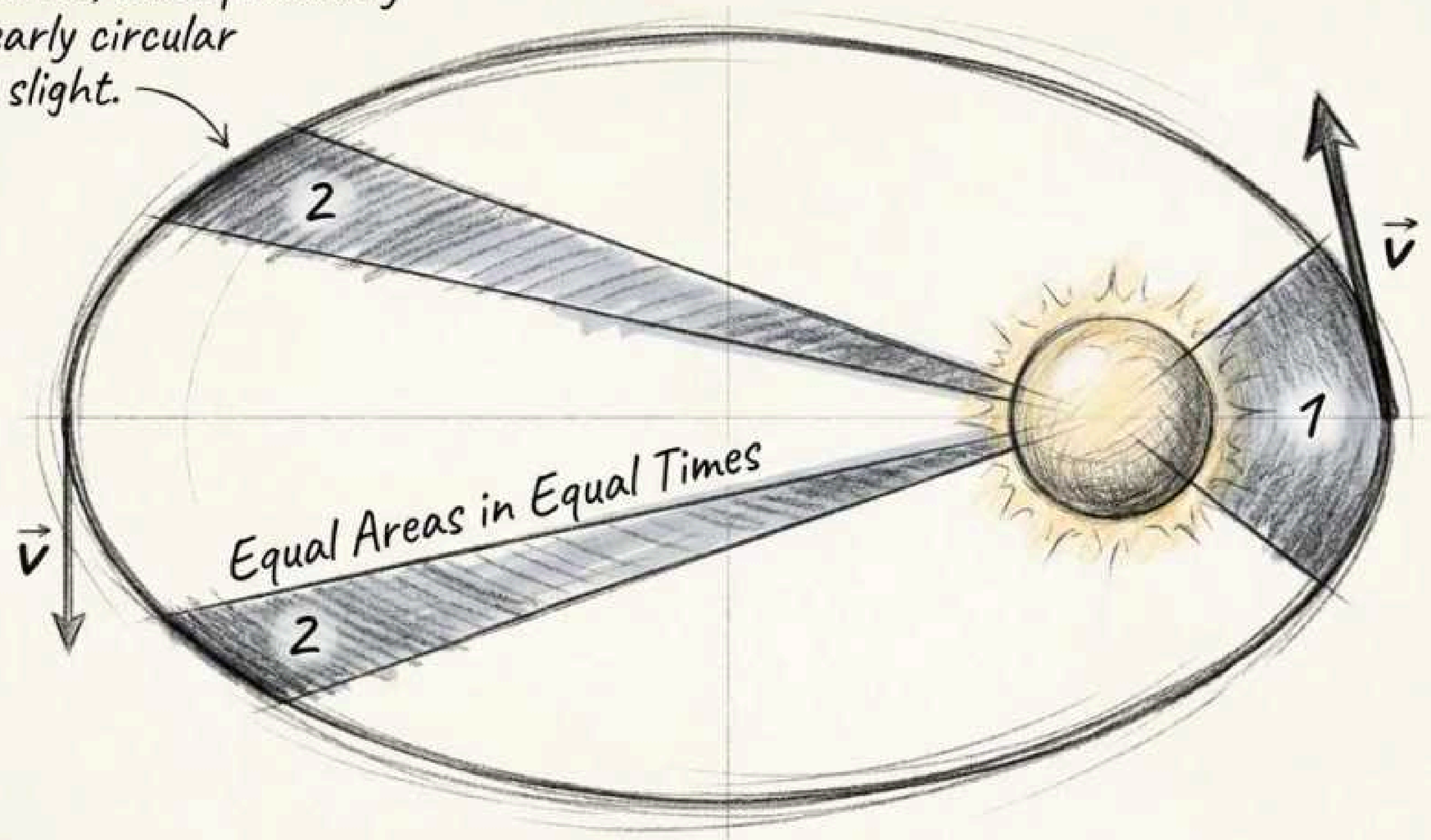
| Planet: | Mars | Altitude: |
|---|---|---|
| 125.4° | 130.7° | 31.7° |
| 179.9° | 94.2° | 32.1° |
| 282.7° | 34.3° | 24.4° |



For thousands of years, people believed planets moved on perfect circles. Kepler used Brahe's raw data to prove this wrong, finding three laws of motion that stand as one of the great achievements of science.

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A stretched circle; most planetary orbits are nearly circular so stretch is slight.




Law 1: Each planet moves on an ellipse, with the Sun at one focus.

Law 2: A planet sweeps out equal areas in equal times (fastest nearest the Sun, slowest when farthest).

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Law 3: Connects size and time. The square of the orbital period (years) equals the cube of the average distance (Astronomical Units).

$$P^2 = a^3$$

The Jupiter Proof (Worked Example):

Distance ($a$) $\approx 5$ AU

$5^3 = 125$

$\sqrt{125} \approx 11.18$

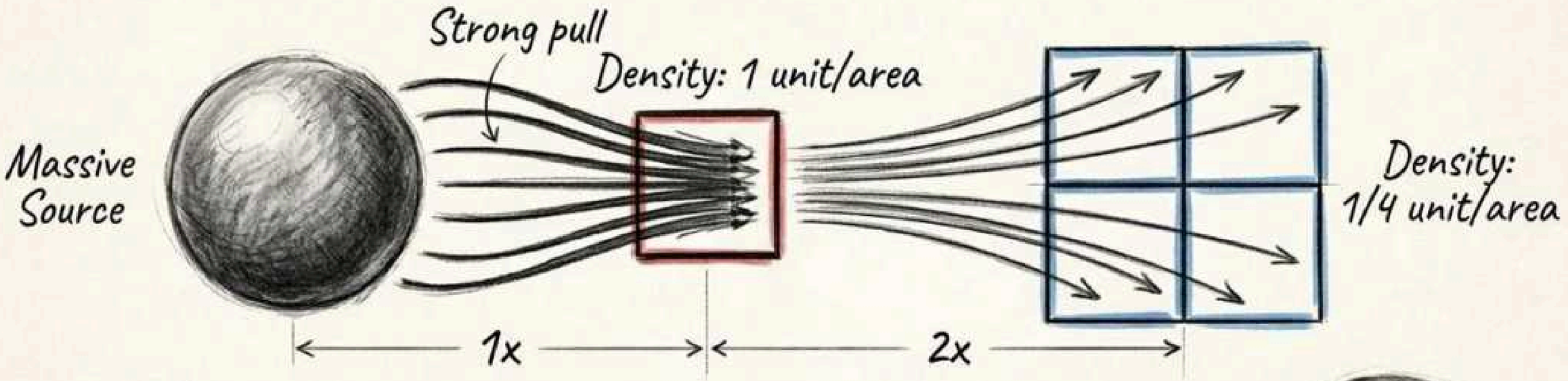
Result: Jupiter's year is indeed $\approx 12$ Earth years.

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Kepler described how orbits worked; Isaac Newton (1687) explained why.

$$F = G\left(\frac{m_1 m_2}{r^2}\right)$$

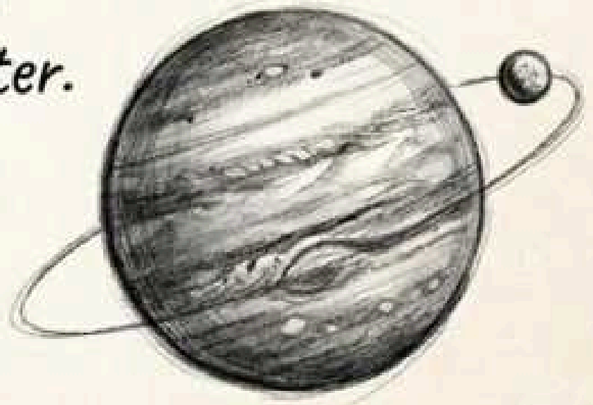
Every mass attracts every other mass. Force grows with mass, weakens with the square of the distance.




Double the distance, and the pull falls to one quarter.



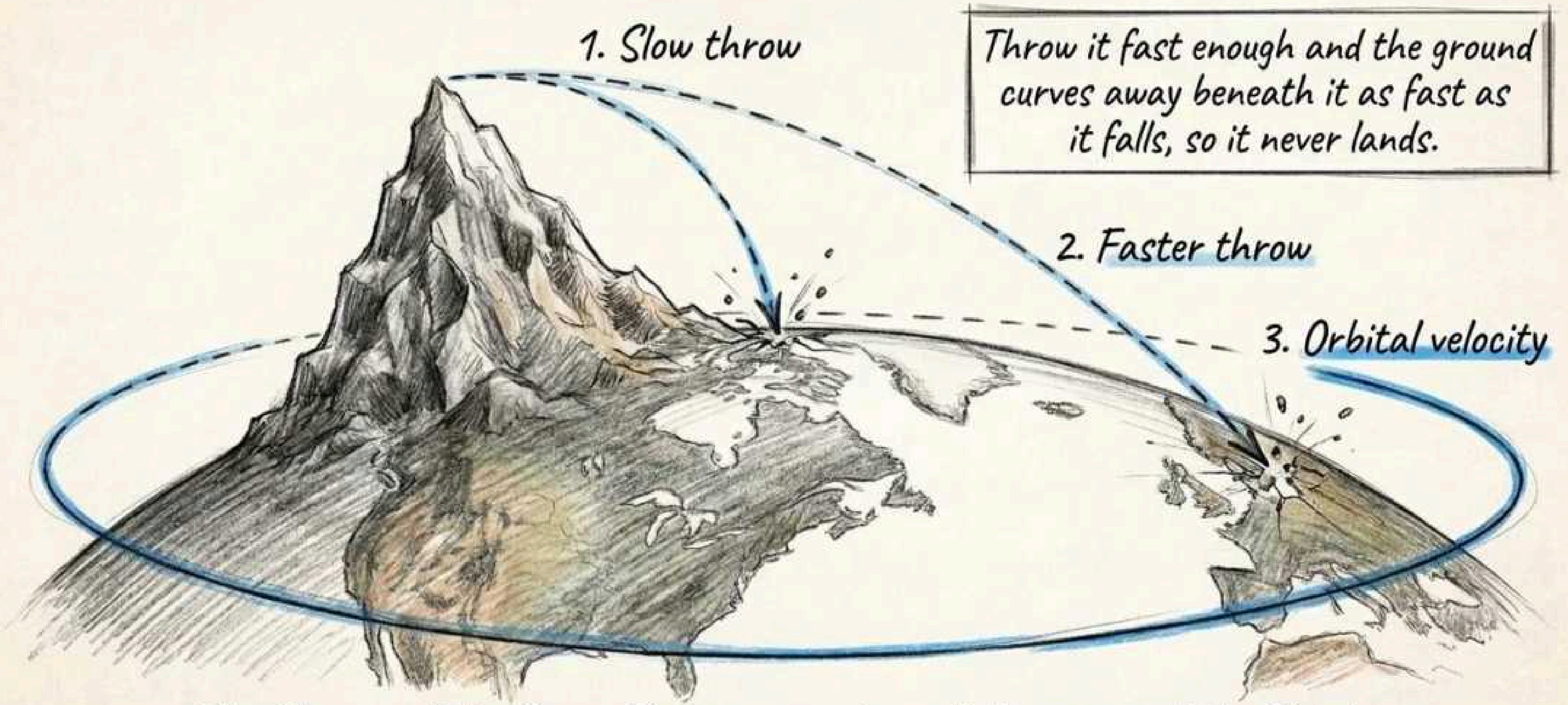
{ A single law explains falling apples and orbiting planets alike. }



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# Newton's Key Insight: An orbit is a kind of falling.

¶ 2.18



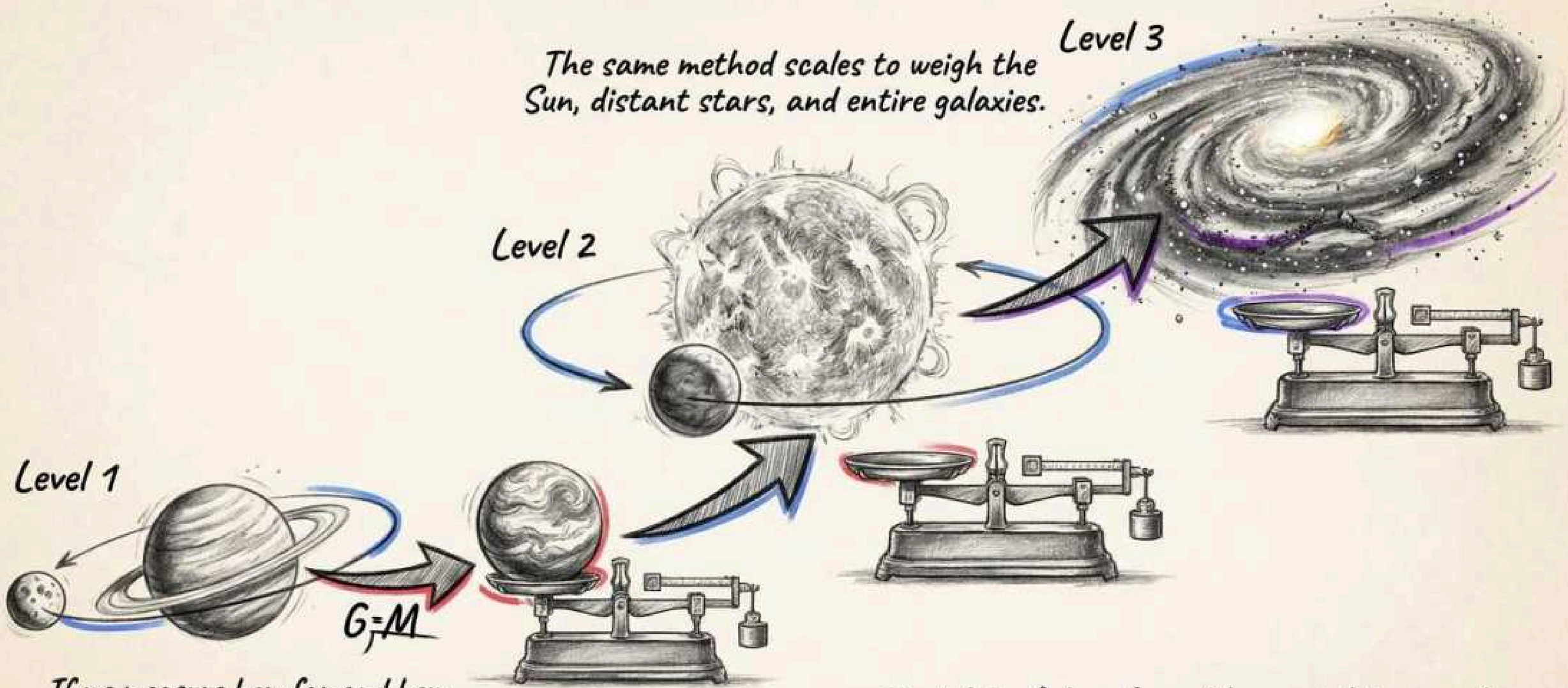

The Moon and the Space Station are always falling around the Earth.

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# Weighing the Untouchable



The same method scales to weigh the Sun, distant stars, and entire galaxies.




If we measure how far and how fast a moon orbits a planet, Newton's law gives the planet's mass.

**Insight:** A law found by watching apples becomes a tool for weighing the whole universe.

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Question to take away:
Earth's gravity up here is still ~90% as strong as on the ground. So why does the astronaut float?

Hint: Think about falling.

Next in Lecture 3:
We turn from motion to Light, and ask how we learn about objects that are far away.

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