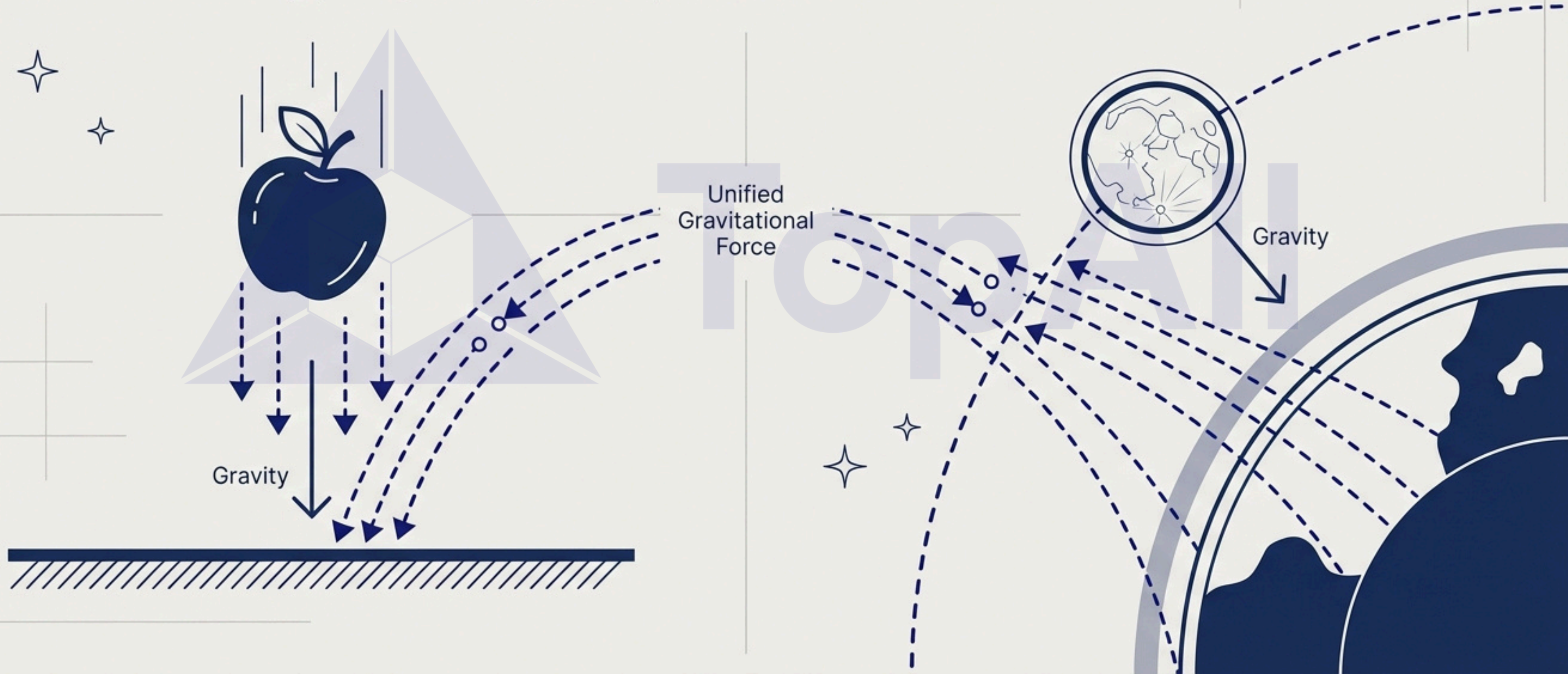


Universal Law of Gravitation

One law for apples, Earth, and planets.



Newton's Conceptual Leap

The same force governs falling bodies and celestial motion.

Newton realized that the Moon's centripetal acceleration and an apple's falling acceleration both decrease in exact proportion to the inverse square of their distance from Earth's center.



The Apple
 $g \approx 9.8 \text{ m/s}^2$

The Evidence:

$$60^2 = 3600$$

$$\frac{9.8}{0.0027} \approx 3600$$



The Moon
Centripetal acceleration
 $a_m \approx 0.0027 \text{ m/s}^2$

20px

20px

The Universal Law



Gravitational Force

Universal Gravitational Constant
($6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2$)

Product of the two masses
(Directly proportional)

$$F = G \frac{m_1 m_2}{r^2}$$

Square of the distance between them
(Inversely proportional)



You've Learned the Theory. Let's Test Them Now.

$$E=mc^2$$



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A Central and Attractive Force



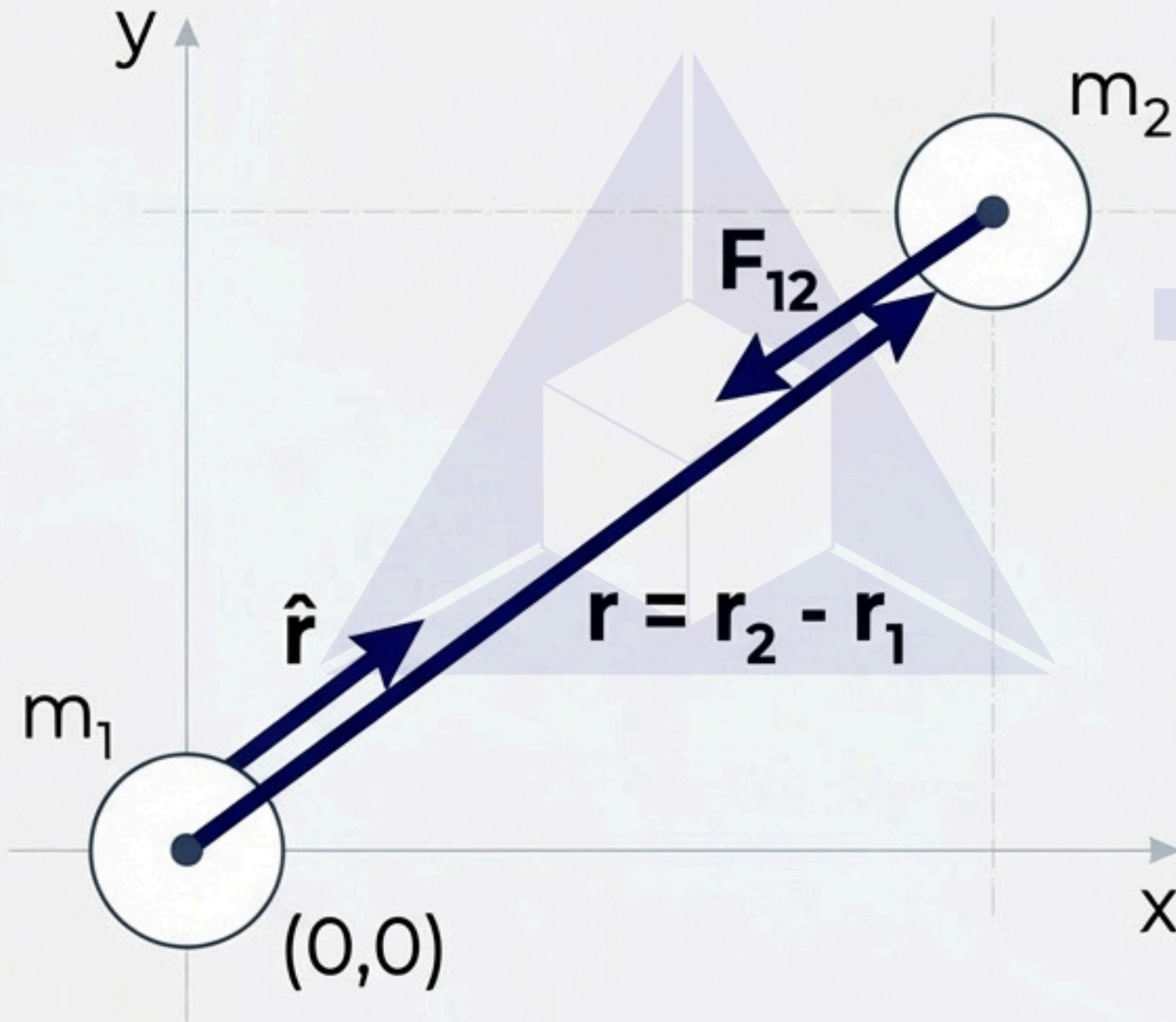
Acts along the line joining centers.

The force is always directed along the imaginary axis connecting the two point masses.

It is always attractive.

Masses pull on each other; they never repel. By Newton's Third Law, force on m_1 due to m_2 is equal and opposite to force on m_2 due to m_1 .

The Law in Vector Form



$$\mathbf{F}_{12} = -G \frac{m_1 m_2}{r^2} \hat{\mathbf{r}}$$

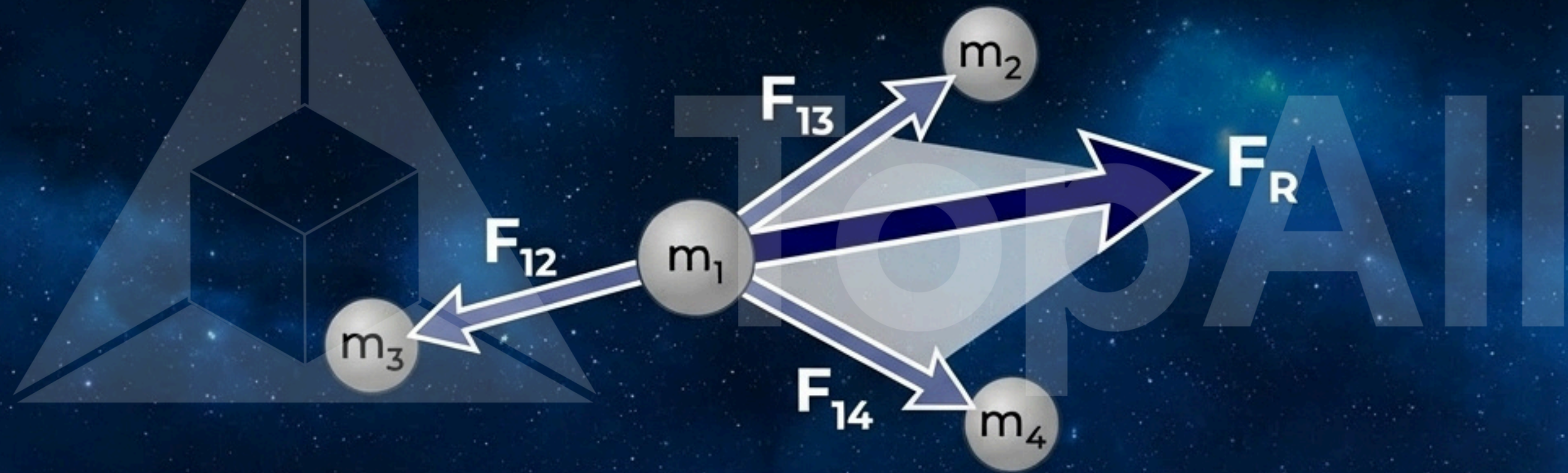
- $\mathbf{F}_{12}$ is the force on body 1 due to body 2.
- $\mathbf{r} = \mathbf{r}_2 - \mathbf{r}_1$ is the vector from m_1 to m_2 .
- The negative sign (-) indicates the force is attractive (points opposite to the unit vector $\hat{\mathbf{r}}$).

Principle of Superposition

How does a mass react to multiple gravitational pulls?



For a collection of point masses, the total force on any one mass is the vector sum of the gravitational forces exerted by all the other individual masses.



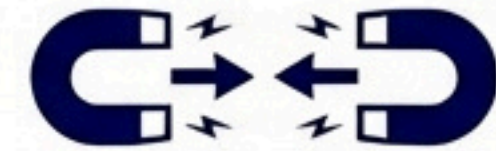
$$\mathbf{F}_R = \mathbf{F}_{12} + \mathbf{F}_{13} + \mathbf{F}_{14} + \dots$$

Exam Focus: Key Takeaways



Universal.

Applies to all matter in the universe, from apples to galaxies.



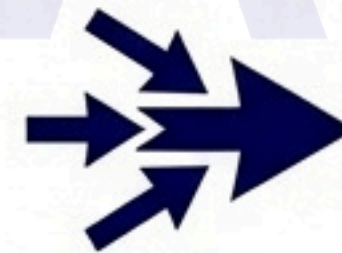
Attractive & Central.

Always pulls masses together along the line joining their centers.



Inverse-Square.

Force weakens rapidly as the square of the distance increases ($1/r^2$).



Vector Addition.

Forces from multiple masses superimpose and add vectorially.



You've Learned the Theory.

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