Chapter 13:
UNIVERSAL GRAVITATION

Chapter 13: Universal Gravitation

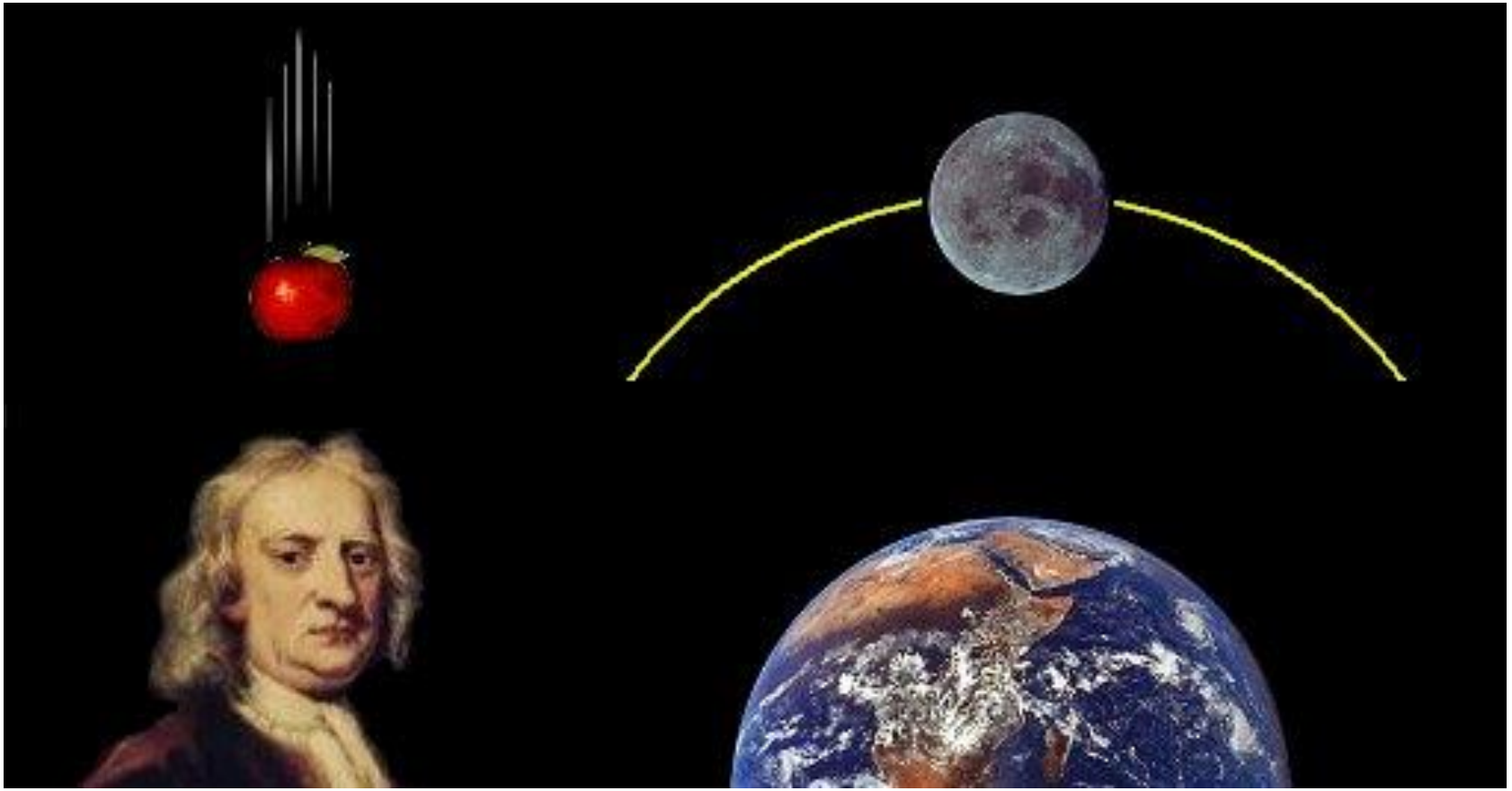
I. The Falling Apple (13.1)

A. **Isaac Newton** (1642-1727)

1. Formulated ideas based on earlier work by **Galileo** (concept of inertia)

2. Concept– if object undergoes **change in speed or direction**, then a **force** is responsible

B. Related “falling apple”, to the motion of the moon (falling around the earth)

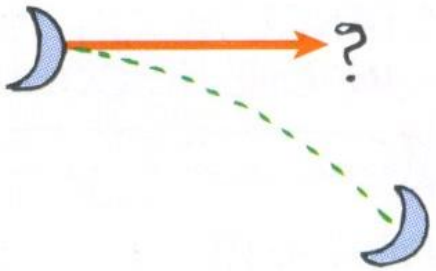


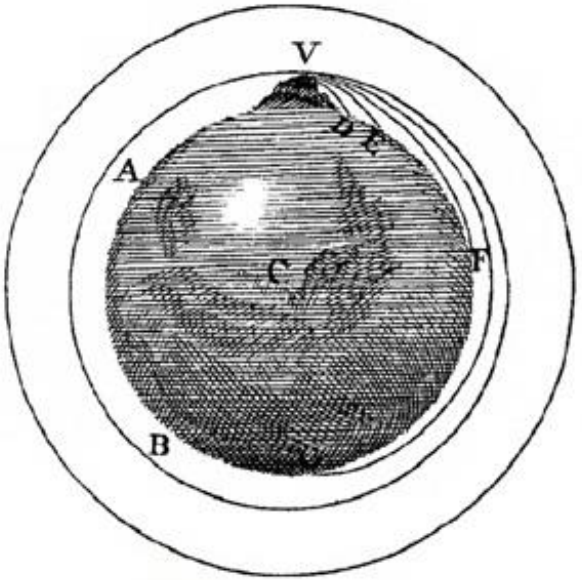
II. The Falling Moon (13.2)

A. Newton hypothesized that moon was simply a **projectile** circling Earth under the attraction of gravity

1. Newton had to test hypothesis

2. Compared fall of apple to fall of moon

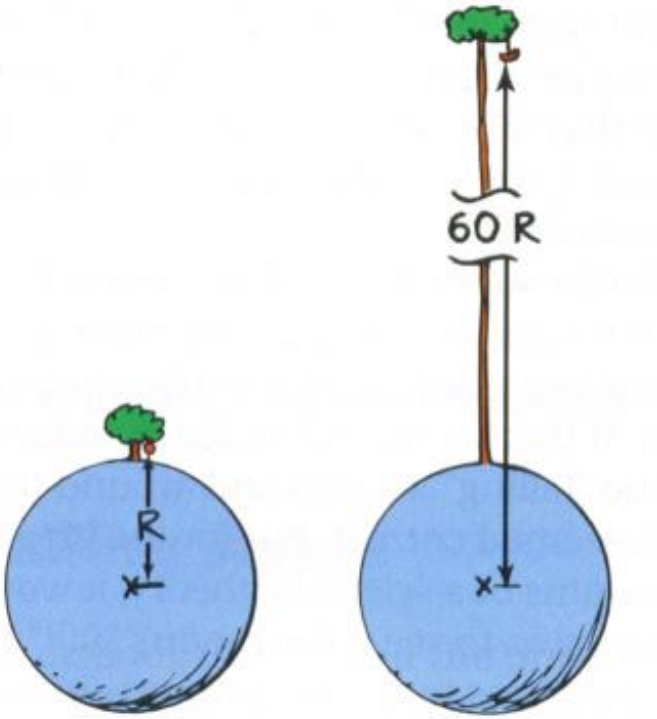




3. Newton reasoned that gravitational attraction was "**diluted**" **by distance**

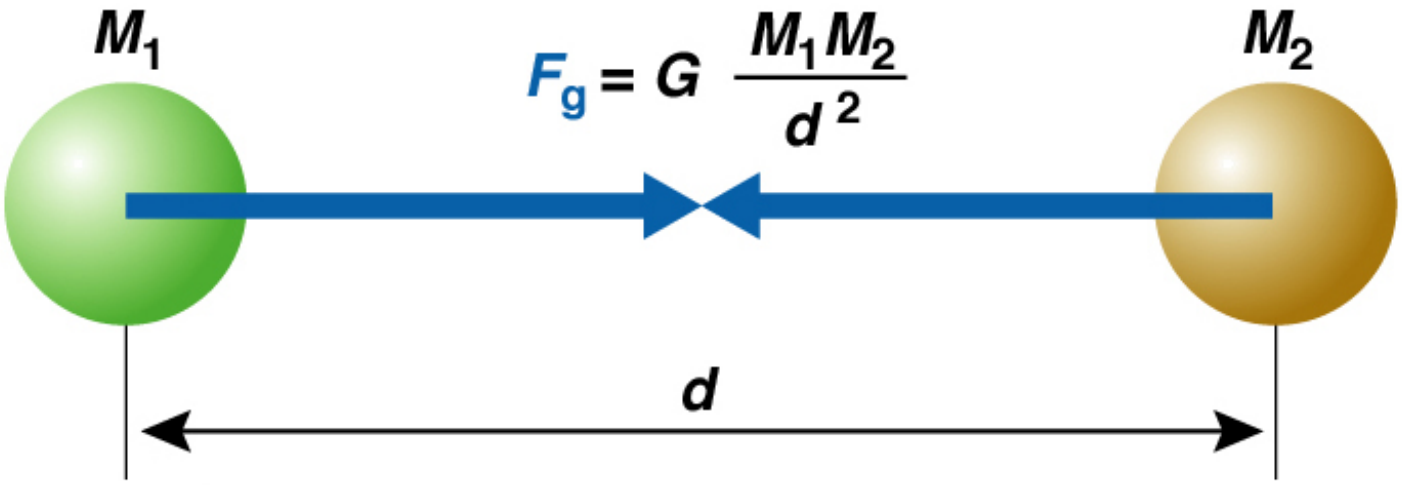
a. Moon is 60 times farther from the center of the Earth than the apple

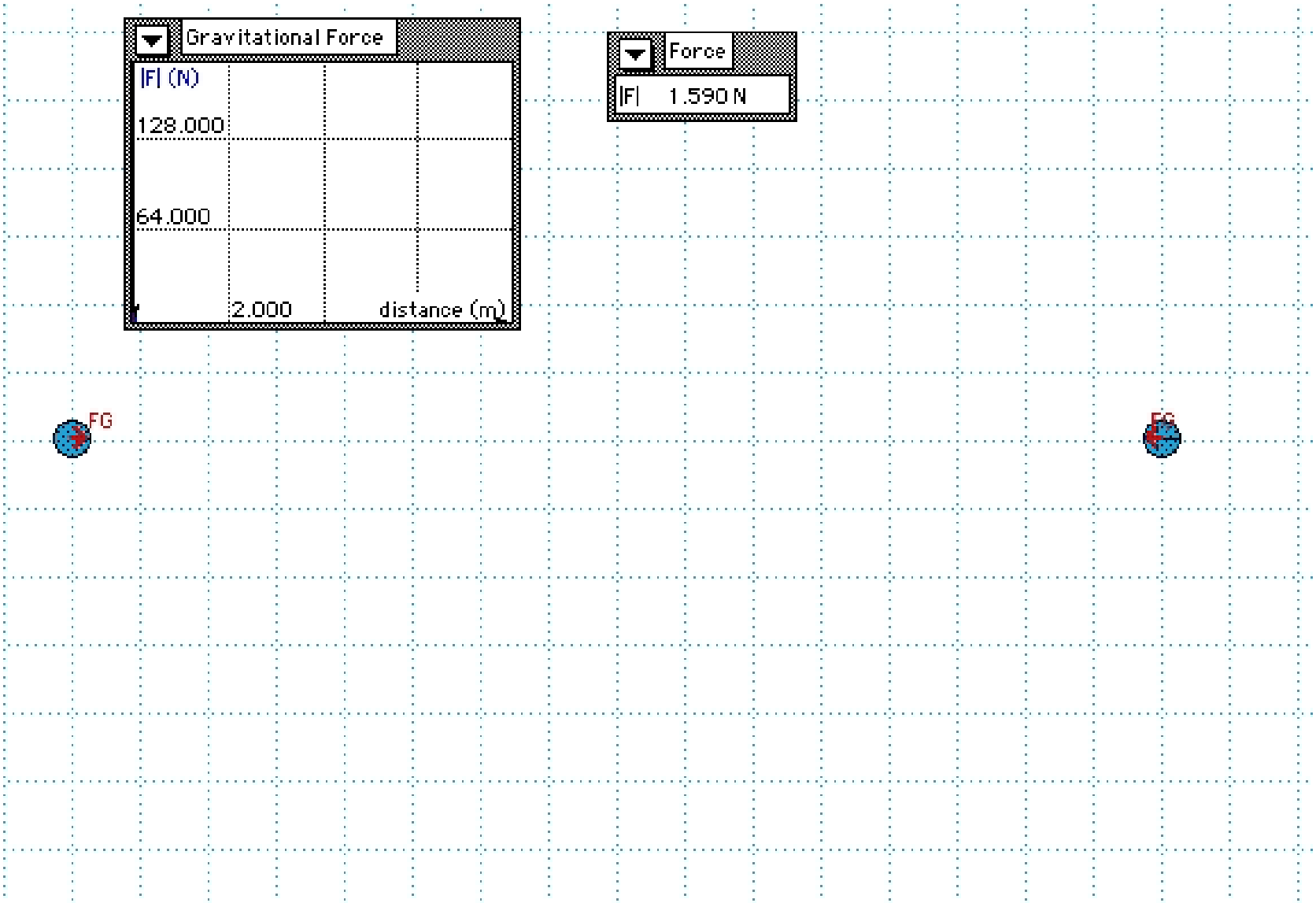
b. Calculated difference to be $1/(60)^2$



B. Newton waited 20 years to prove hypothesis

1. Invented a new math (**Calculus**) to explain theory
2. Published his findings– **The Law of Universal Gravitation**. (applied to all objects in the universe)



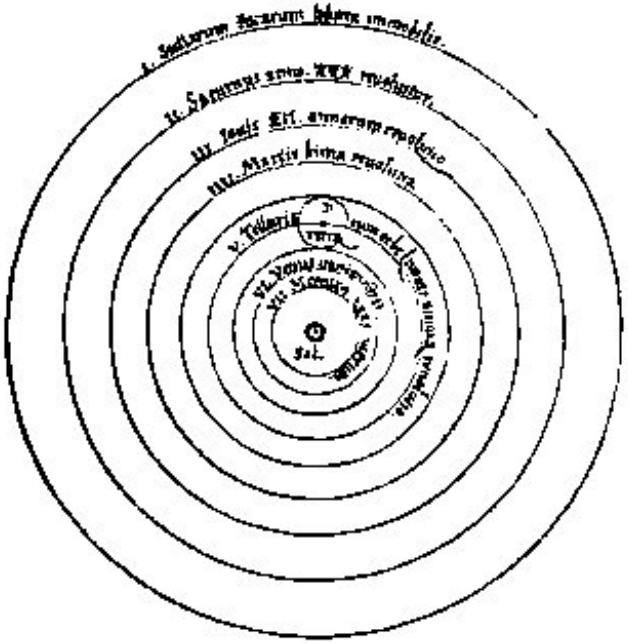

Gravitational Force
|F| (N)
128.000
64.000
2.000
distance (m)
Force
|F| 1.590 N
FG
FG

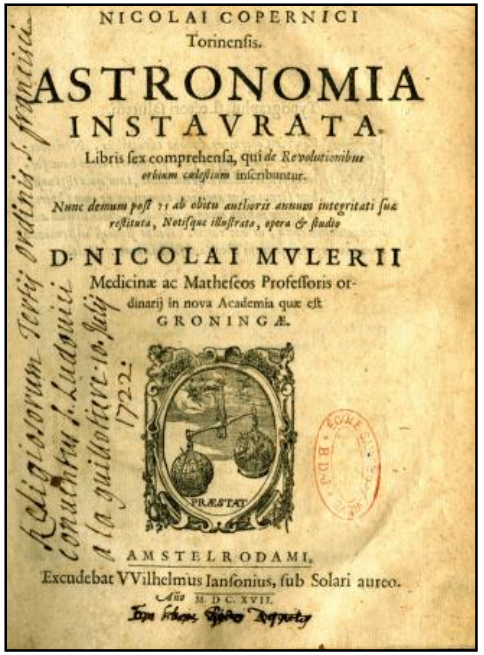
III. The Falling Earth (13.3)

A. Newton's theory confirmed **Coperincan** theory of the solar system.

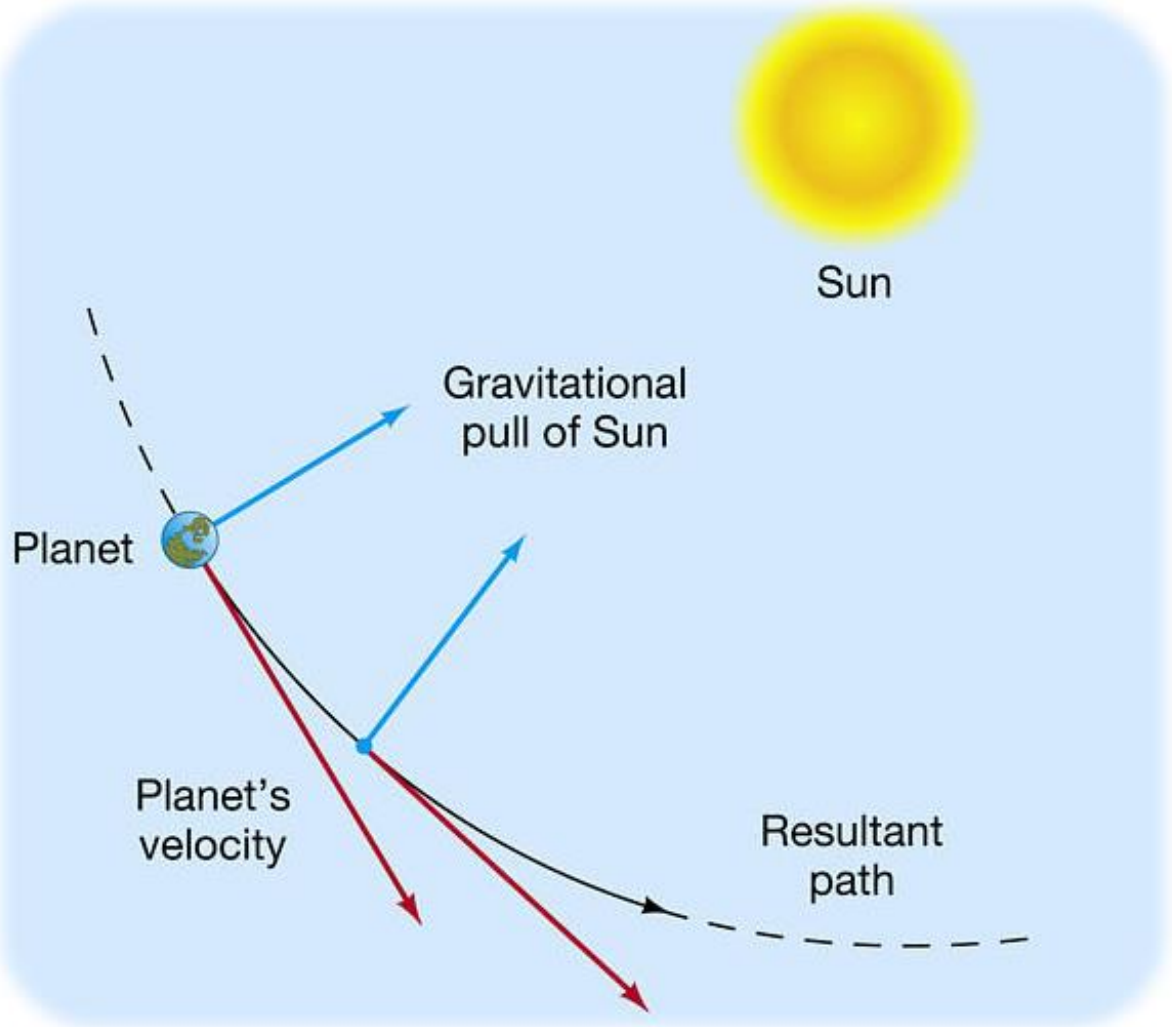
1. Earth no longer considered center of universe

2. Earth not even center of solar system





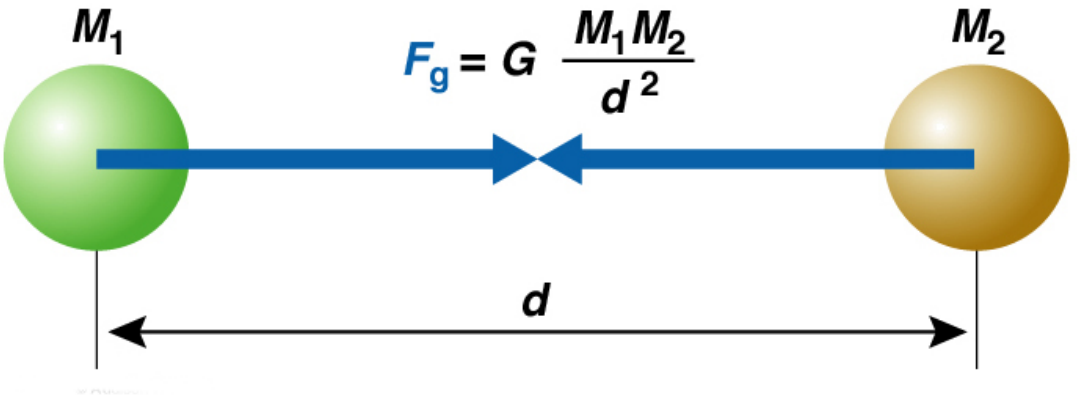
B. Planets **tangential velocities** enough to keep in orbit



IV. Newton's Law of Universal Gravitation (13.4)

A. Law states: ***every object attracts every other object with a force that for any two objects is directly proportional to the mass of each object***

1. The **greater the mass** the **greater the attraction**
2. The **farther away the objects** are from each other, the **less the force of attraction** between them



B. Law expressed as:

$$F \propto \frac{m_1 m_2}{d^2}$$

m_1 is mass of one object
m_2 is mass of other
d is distance between their centers

C. **The Universal Gravitational Constant (G)**

1. The above equation is a **proportional** form of law.

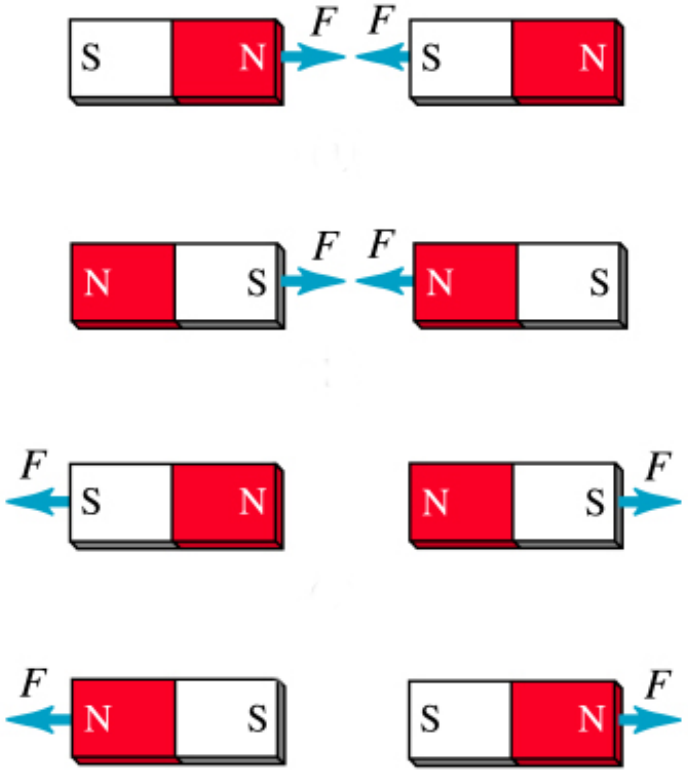
2. Can be expressed exactly when ***universal gravitational constant (G)*** is introduced

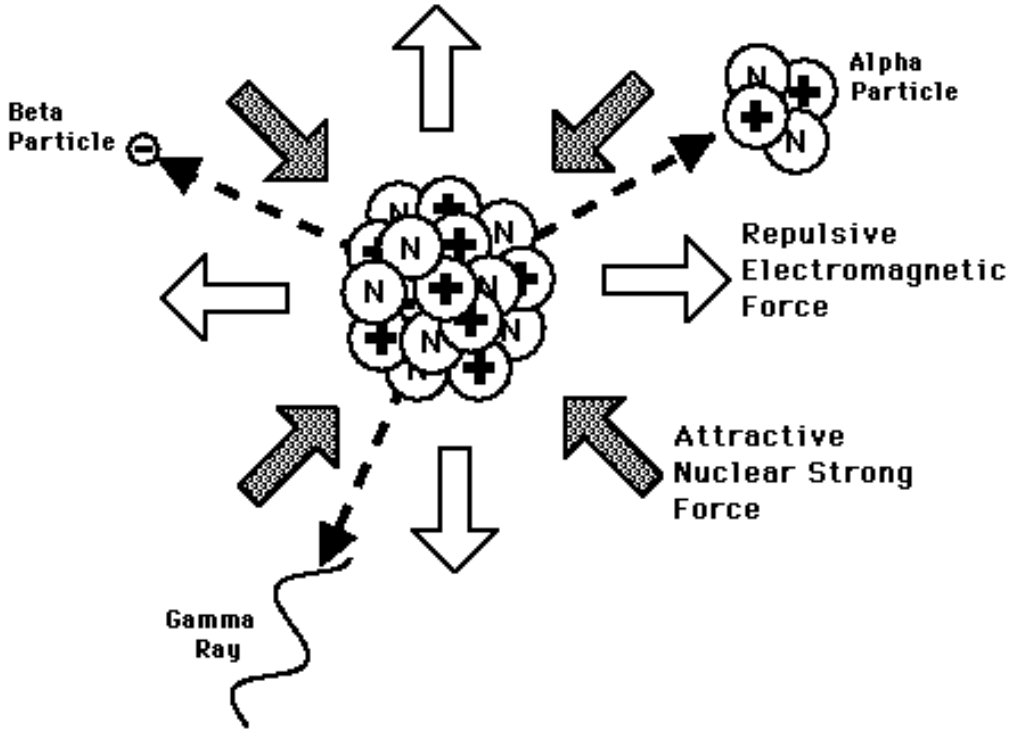
a. Value of G first measured 150 years later by Henry Cavendish

b. $G = 6.67 X 10^{-11} N \cdot m / kg^2$

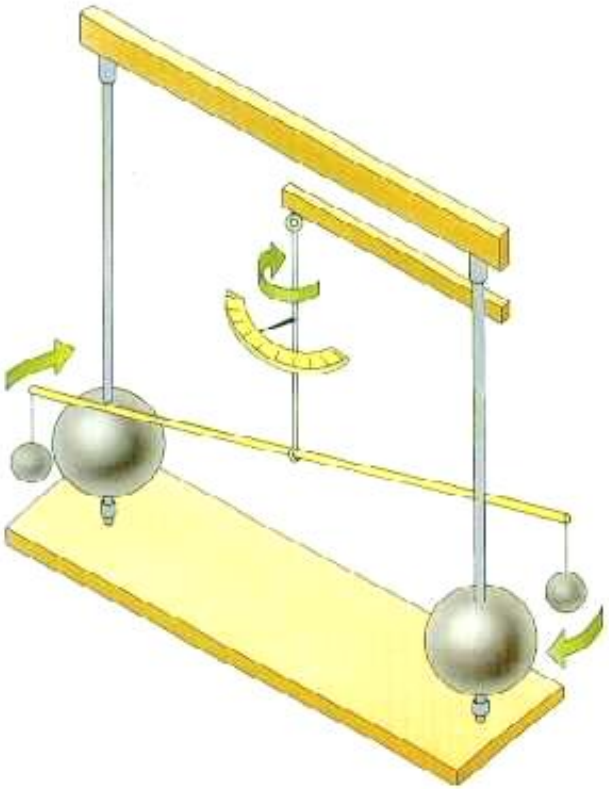
$$F = G \frac{m_1 m_2}{d^2}$$

3. Value of ***G*** tells us that force of **gravity** is a **very weak force** (weakest of known four fundamental forces (electromagnetic and two known nuclear forces

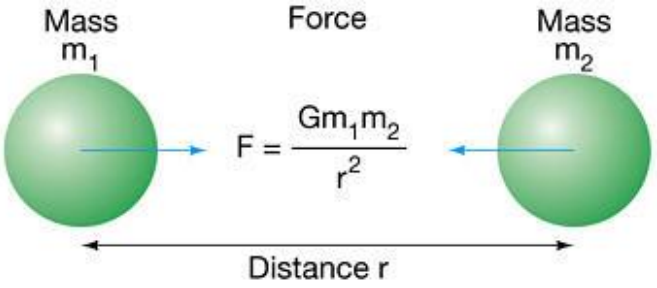


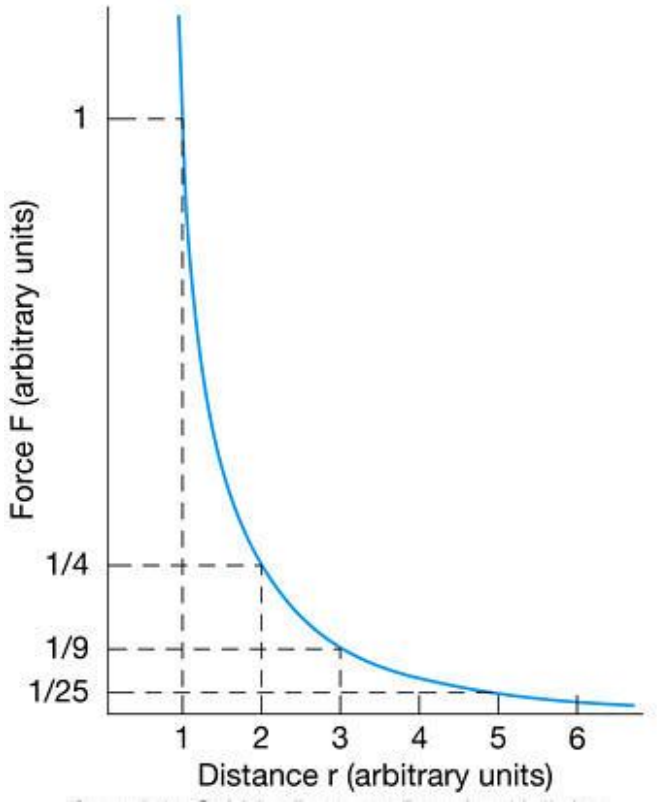


D. Cavendish used value of G to calculate the mass of the Earth (**mass of Earth = 6 X 10^{24} kilograms**)



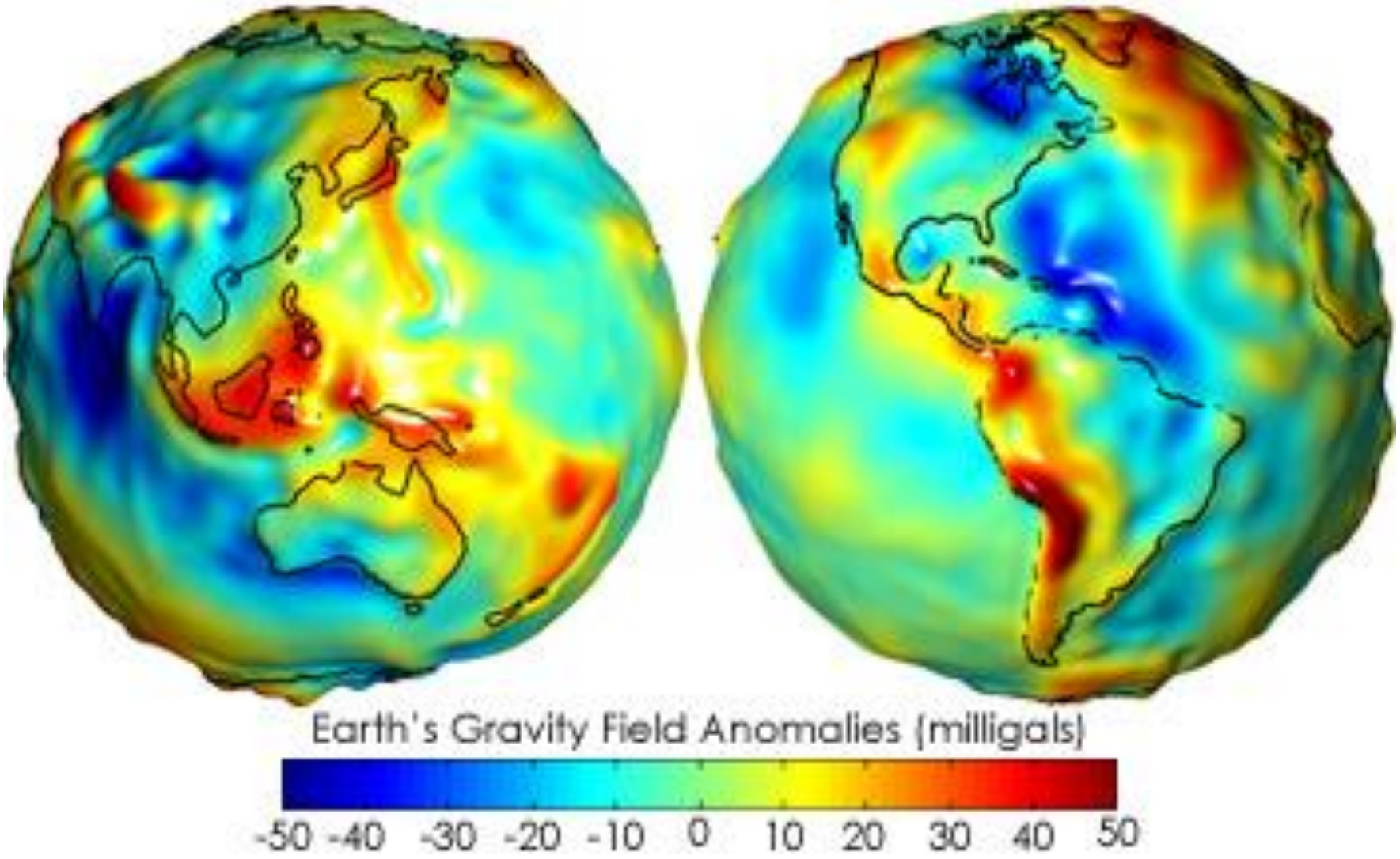
V. Gravity and Distance: The Inverse Square Law (13.5)





A. Inverse Square Law– when **quantity varies** as the **inverse square** of its **distance** from its source

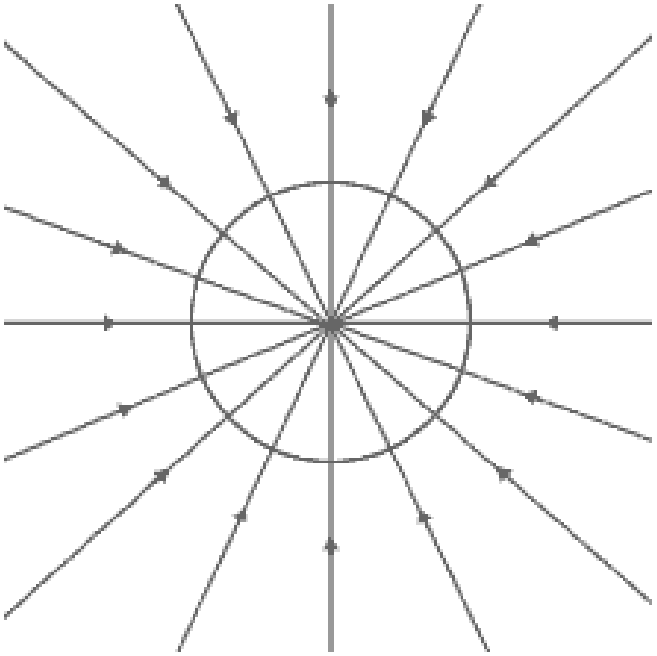
B. Also applies to light, radiation, and sound


Earth's Gravity Field Anomalies (milligals)
-50 -40 -30 -20 -10 0 10 20 30 40 50

I. Gravitational Fields (13.6)

A. **Gravitational Field**– force field that surrounds massive objects

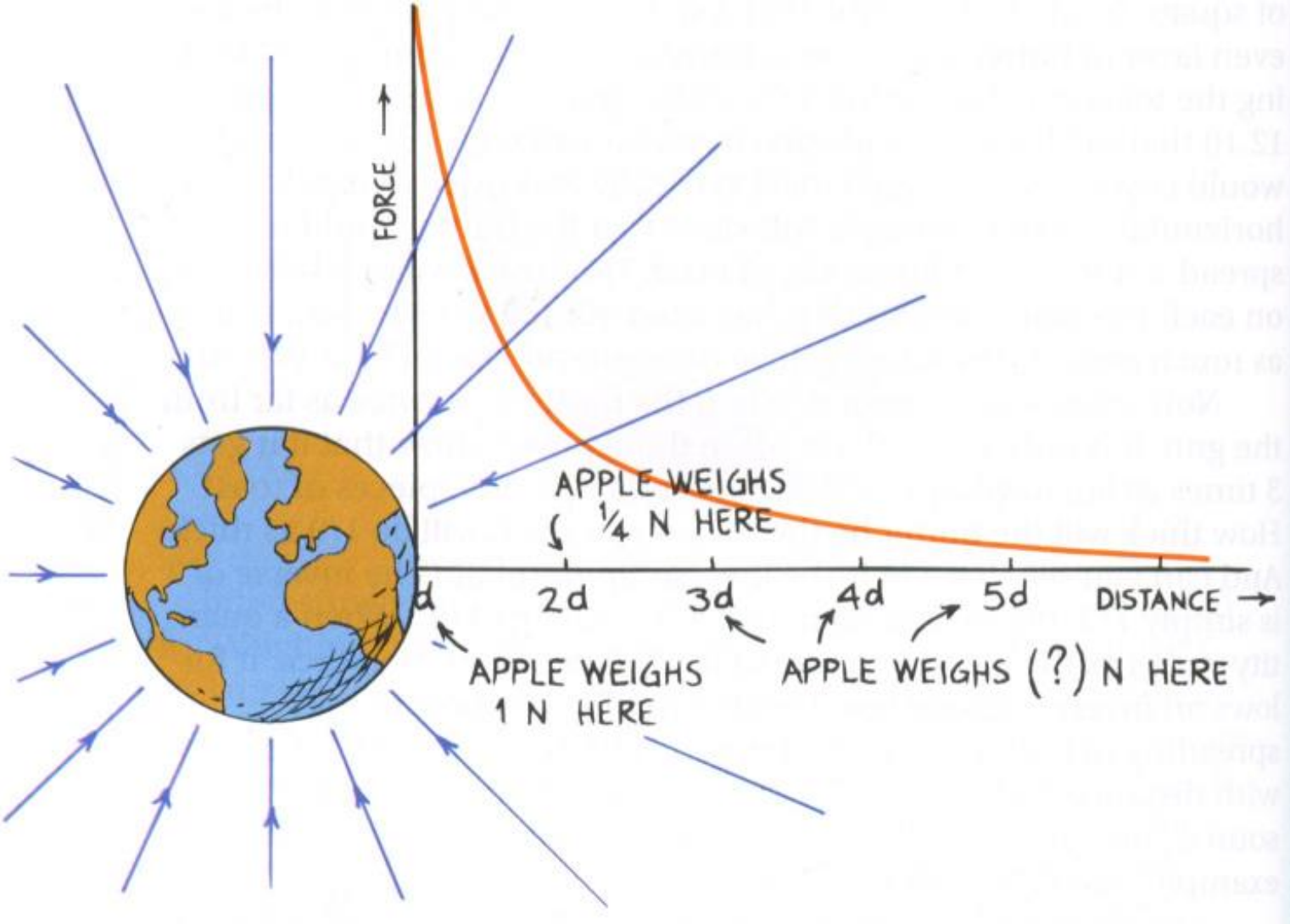
B. Can be represented by <u>imaginary</u> **field lines.**



C. The strength of Earth's gravitational field is the **force per unit mass** exerted by Earth on any object.

$$g = \frac{F}{m} = 9.8\,{}^{N}\!/_{kg} = 9.8\,{}^{m}\!/_{s^2}$$

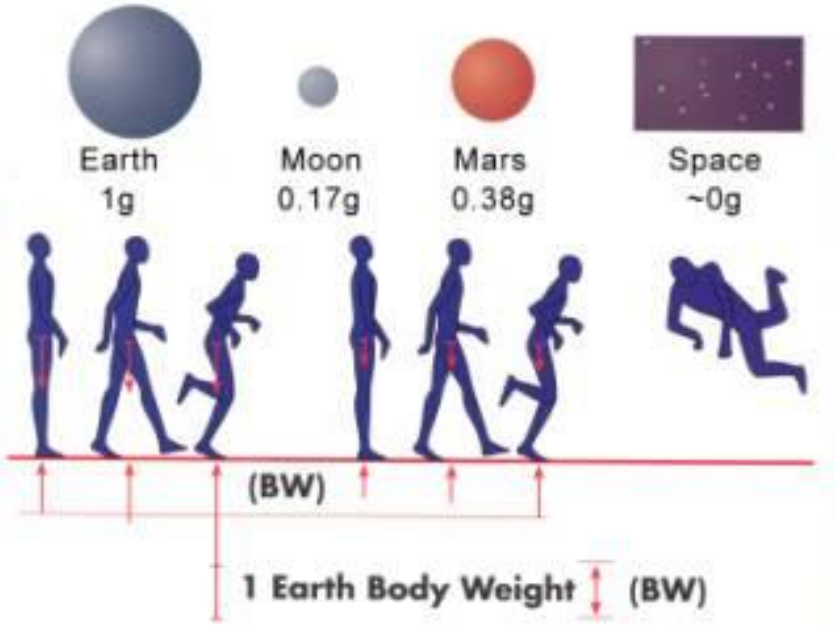
D. The strength of its force on objects follows the **inverse-square law** (so ***g*** weakens with increasing distance from Earth



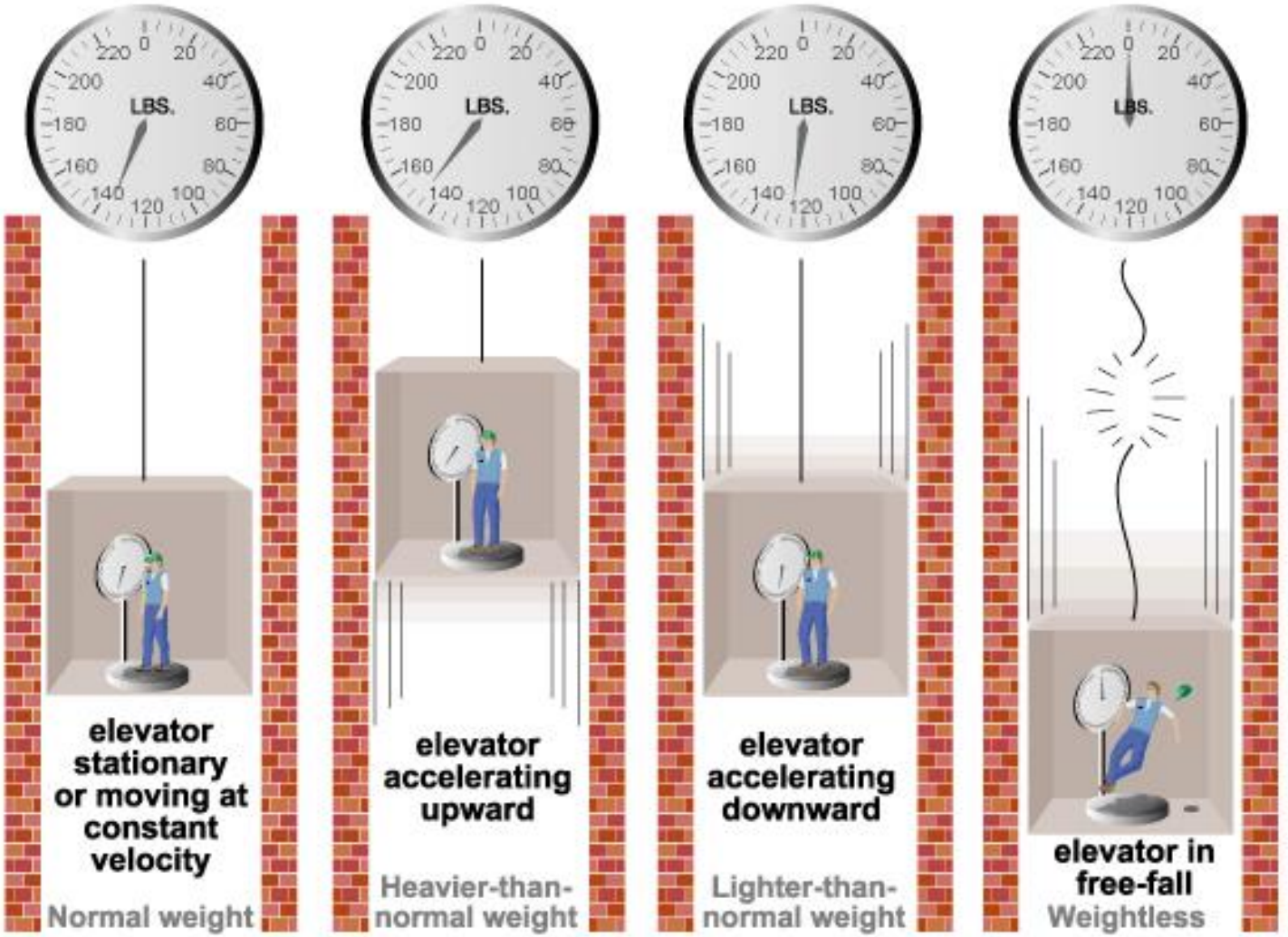
VII. Weight and Weightlessness (13.7)

A. The **force of gravity** causes **acceleration**

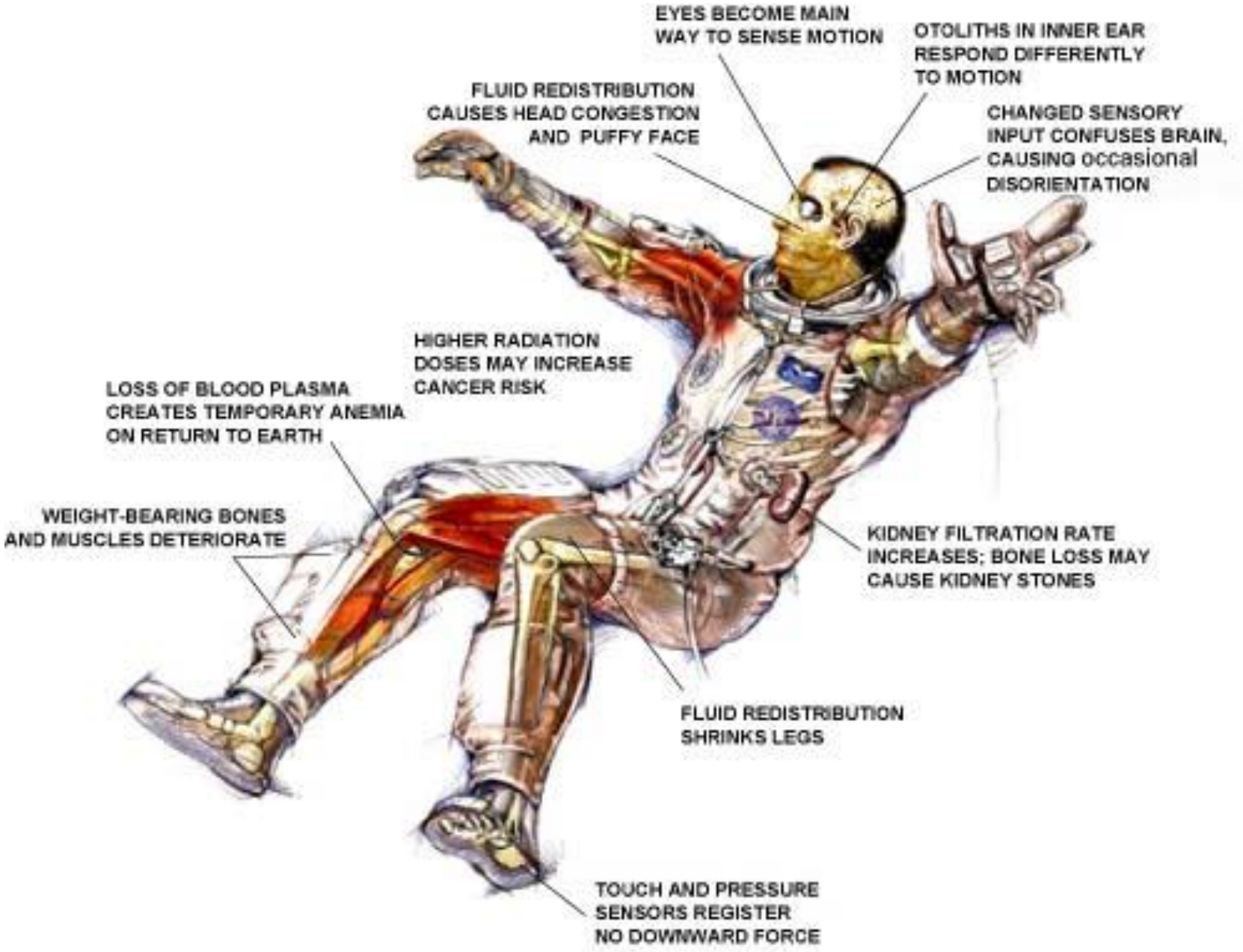
1. Since we are almost always in contact with the Earth, we sense gravity as something that presses us against Earth rather than something that accelerates us
2. This pressing against Earth is what we interpret as **weight**



B. More practical to define weight as the force you exert against a supporting floor (or weighing scales) “you are as heavy as you feel.”



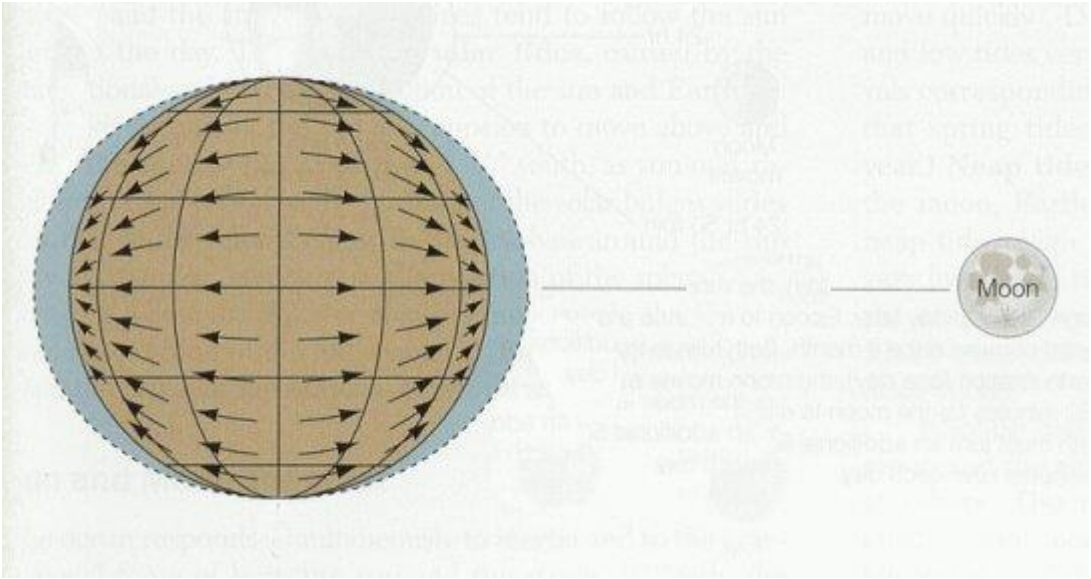
C. **Weightlessness**– is not absence of gravity; rather, it is absence of a support force.


EYES BECOME MAIN WAY TO SENSE MOTION
OTOLITHS IN INNER EAR RESPOND DIFFERENTLY TO MOTION
FLUID REDISTRIBUTION CAUSES HEAD CONGESTION AND PUFFY FACE
CHANGED SENSORY INPUT CONFUSES BRAIN, CAUSING occasional DISORIENTATION
HIGHER RADIATION DOSES MAY INCREASE CANCER RISK
LOSS OF BLOOD PLASMA CREATES TEMPORARY ANEMIA ON RETURN TO EARTH
WEIGHT-BEARING BONES AND MUSCLES DETERIORATE
KIDNEY FILTRATION RATE INCREASES; BONE LOSS MAY CAUSE KIDNEY STONES
FLUID REDISTRIBUTION SHRINKS LEGS
TOUCH AND PRESSURE SENSORS REGISTER NO DOWNWARD FORCE

IX. Ocean Tides (13.9)

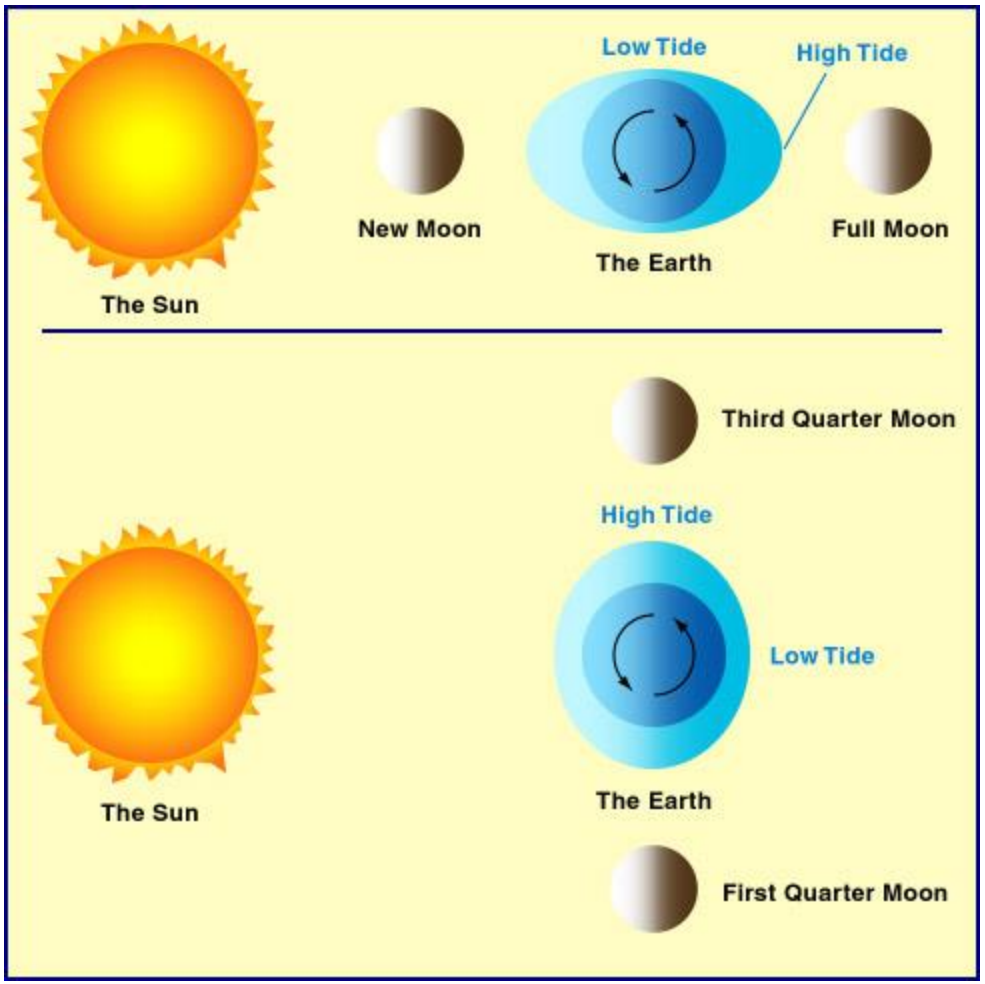
A. Newton showed that the ocean tides are caused by differences in the gravitational pull of the moon on opposite sides of earth

1. Oceans bulge about 1 meter on opposite sides of Earth
2. Because Earth spins, the tides change as Earth rotates



B. Sun also contributes to tides

1. Sun's pull 180 times greater than moon, but contributes only half as much as the moon

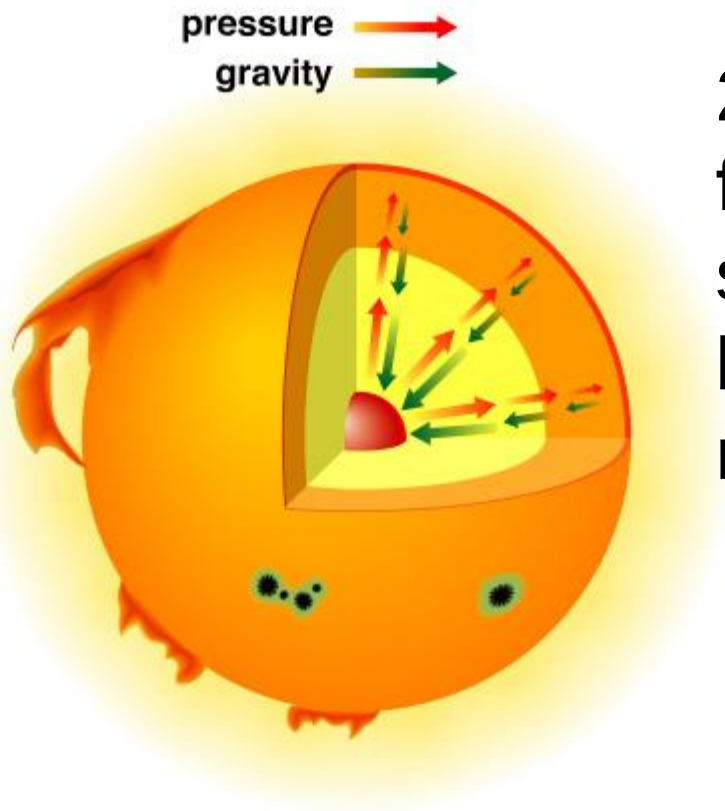


2. Because difference in gravitational pullby sun on opposite sides of Earth very small (0.017% compared to 6.7% for moon's gravitation)

X. Black Holes (13.10)

A. There are two main processes going on continuously in stars like our sun.

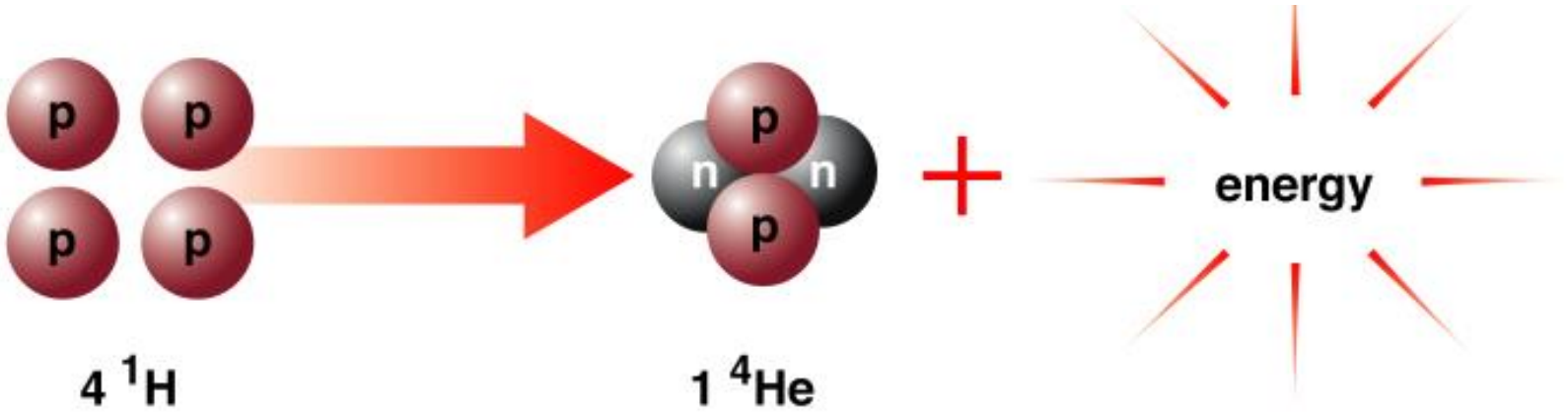
1. **Process of Gravitation**– tends to crunch all solar material toward the center

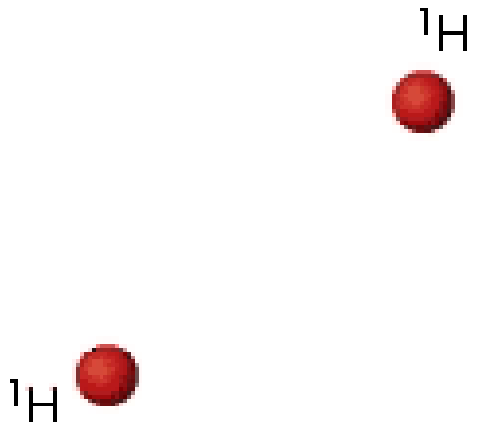


2. Process of **thermonuclear fusion**-consisting of reactions similar to those in a hydrogen bomb. Tend to blow solar material outward

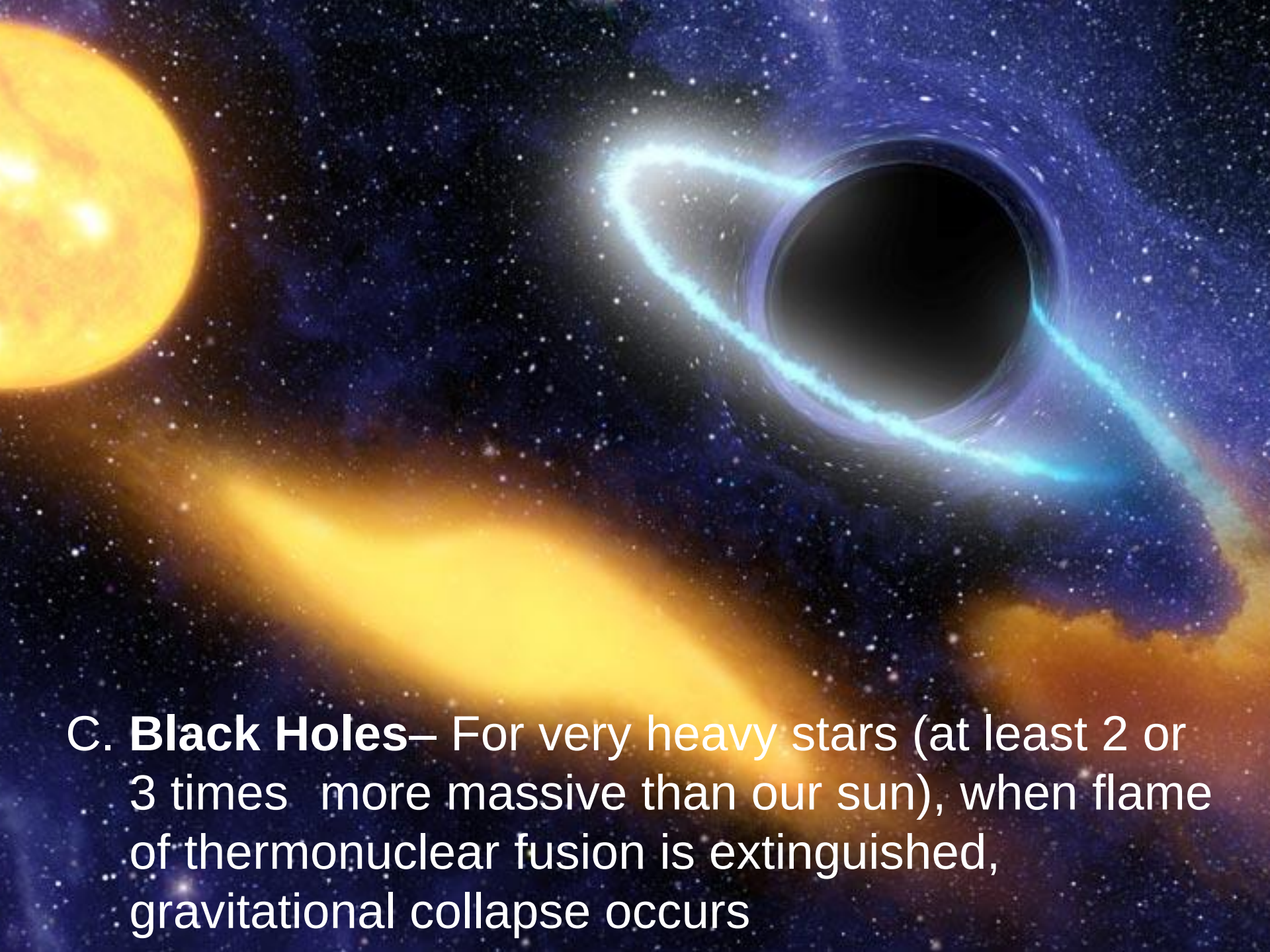
B. Two processes balance each other, resulting in given size for sun.

1. If fusion rate increases, the sun will get bigger and hotter. (“red giant”)
2. If fusion decreases, sun will get cooler and smaller. (“black dwarf”)

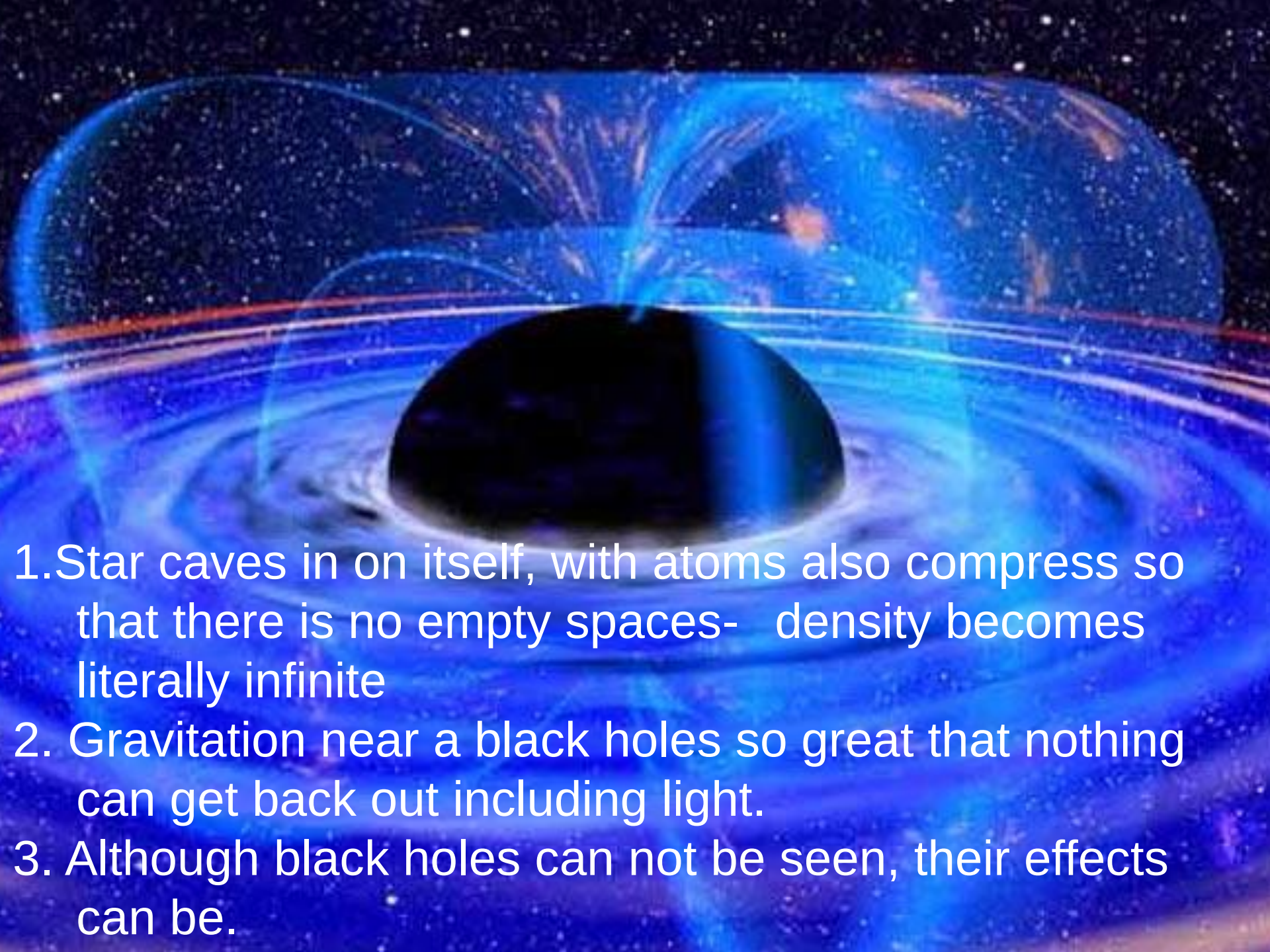




A



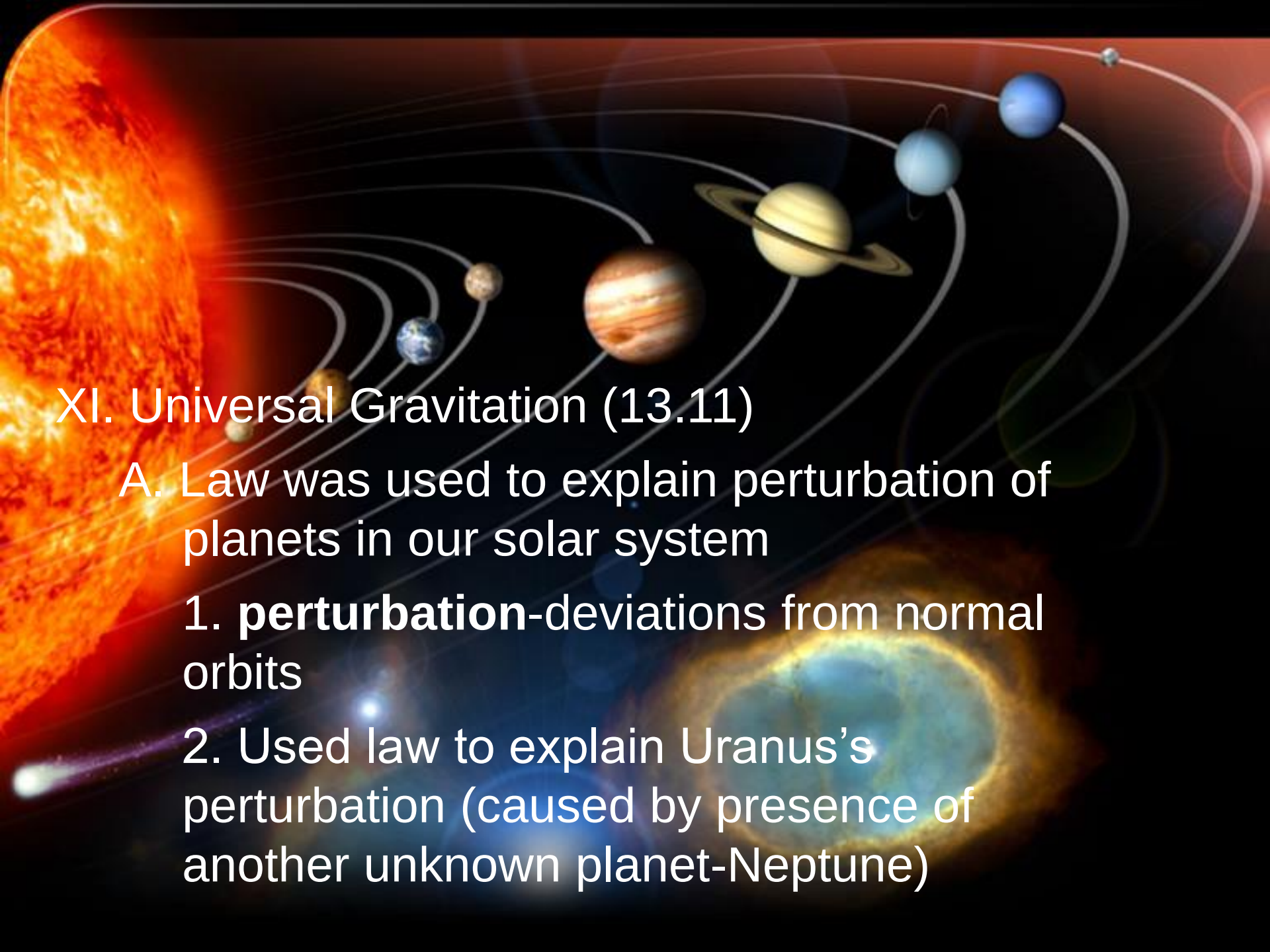
C. **Black Holes**– For very heavy stars (at least 2 or 3 times more massive than our sun), when flame of thermonuclear fusion is extinguished, gravitational collapse occurs



1.Star caves in on itself, with atoms also compress so that there is no empty spaces- density becomes literally infinite

2. Gravitation near a black holes so great that nothing can get back out including light.

3. Although black holes can not be seen, their effects can be.



XI. Universal Gravitation (13.11)

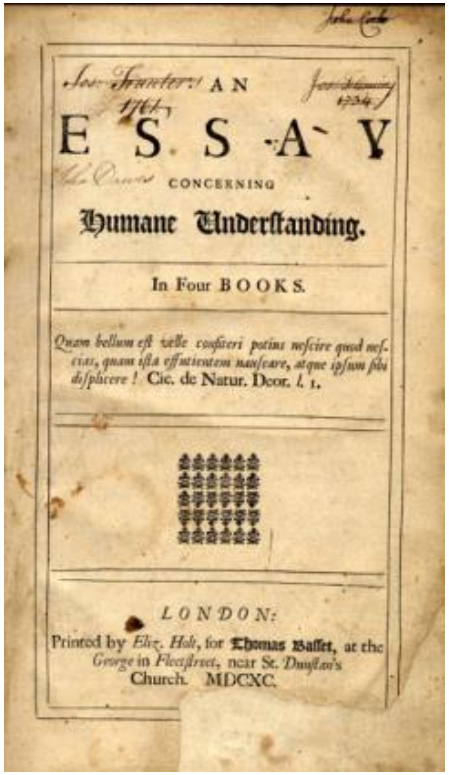
A. Law was used to explain perturbation of planets in our solar system

1. **perturbation**-deviations from normal orbits

2. Used law to explain Uranus's perturbation (caused by presence of another unknown planet-Neptune)

B. Theory dramatically affected **science** and **society**

1. Ushered in the **Age of Reason** or **Century of Enlightenment.**
2. Nurtured the thinking of scientists, artists, writers, and philosophers of the 1700's



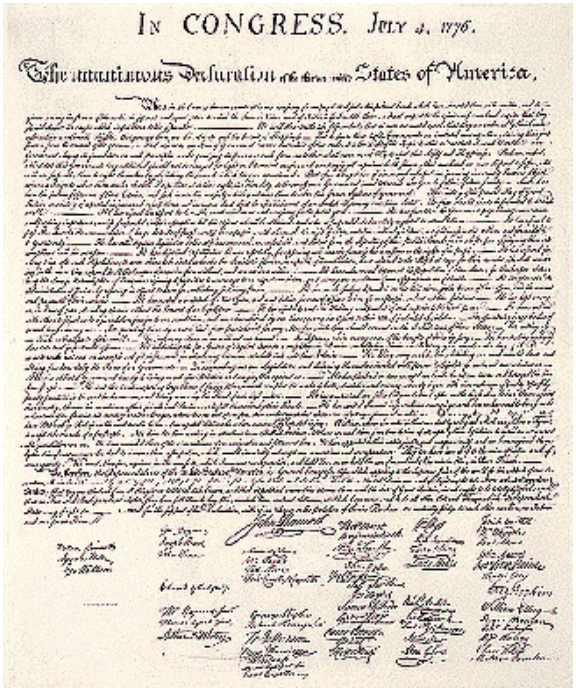
AN
ESSAY
CONCERNING
Humane Understanding.
In Four BOOKS.

Quam bellum est velle confiteri potius nescire quod nescias, quam ista effutientem nauseare, atque ipsum sibi displicere! Cic. de Natur. Deor. *l.* 1.

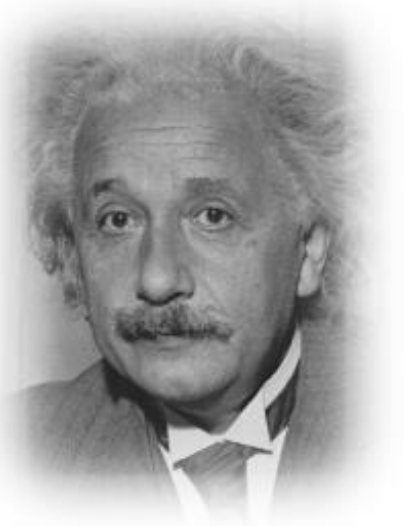
LONDON:
Printed by *Eliz. Holt*, for **Thomas Basset**, at the *George* in *Fleetstreet*, near St. *Dunstan's* Church. MDCXC.

a. **John Locke**– argued that observation and reason, as demonstrated by Newton, should be our best judge and guide in all things

b. Locke and followers modeled system of government that culminated in the **Declaration of Independence** and **Constitution of the United States of America**



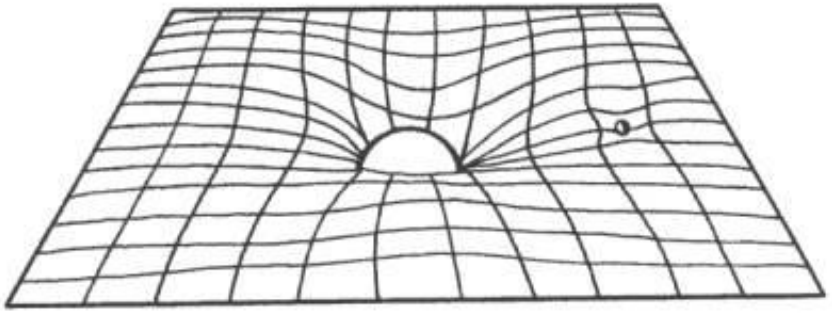
Einstein's Theory of Gravity



Newton's theories did not explain the origin of gravity

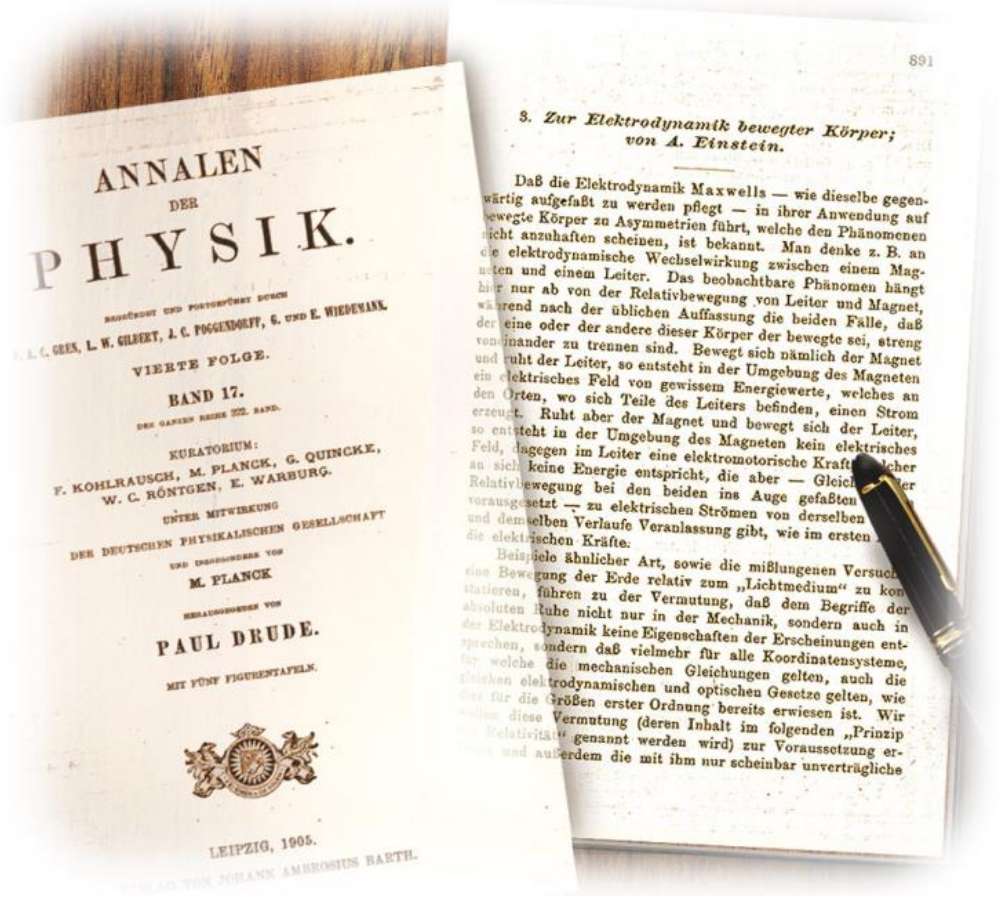
Einstein proposed gravity is ***not*** a force, but an ***effect*** of space itself.

Einstein said a mass changes the space around it, causing ***space to be curved***.



Called the ***General Theory of Relativity***

This theory provides accurate predictions of gravity's effects, but is still not complete. It does not explain how masses curve space



Assessment Questions

1. Newton determined that the pull of Earth's gravity caused both apples and
   a. the moon to fall toward Earth.
   b. the moon to move away from Earth.
   c. the sun to move away from Earth.
   d. stars to fall toward Earth.

Assessment Questions

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Answer: A

Assessment Questions

2. The moon falls toward Earth in the sense that it falls
   a. with an acceleration of 10 m/s^2, as apples fall on Earth.
   b. with an acceleration greater than 10 m/s^2.
   c. beneath the straight-line path it would take without gravity.
   d. above the straight-line path it would take without gravity.

Assessment Questions

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   b. with an acceleration greater than 10 m/s^2.
   c. beneath the straight-line path it would take without gravity.
   d. above the straight-line path it would take without gravity.

Answer: C

Assessment Questions

3. Planets remain in orbit while falling around the sun due to their
   a. tangential velocities.
   b. zero tangential velocities.
   c. accelerations of about 10 m/s^2.
   d. centrifugal forces that keep them up.

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Answer: A

Assessment Questions

4. Newton did not discover gravity, for early humans discovered it whenever they fell. What Newton did discover is that gravity
   a. tells us about why the universe expands.
   b. tells us how to discover new planets.
   c. accounts for the existence of black holes.
   d. extends throughout the universe.

Assessment Questions

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   b. tells us how to discover new planets.
   c. accounts for the existence of black holes.
   d. extends throughout the universe.

Answer: D

Assessment Questions

5. Consider a space probe three times as far from Earth's center. Compared at Earth's surface, its gravitational attraction to Earth at this distance is about
   a. one third as much.
   b. one half as much.
   c. one ninth as much.
   d. zero.

Assessment Questions

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   c. one ninth as much.
   d. zero.

Answer: C

Assessment Questions

6. Compared to the gravitational field of Earth at its surface, Earth's gravitational field at a distance three times as far from Earth's center is about
   a. one third as much.
   b. one half as much.
   c. one ninth as much.
   d. zero.

Assessment Questions

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   b. one half as much.
   c. one ninth as much.
   d. zero.

Answer: C

Assessment Questions

7. Compared to the gravitational field of Earth at its surface, Earth's gravitational field at Earth's center is
   a. zero.
   b. half as much.
   c. twice as much.
   d. three times as much.

Assessment Questions

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   a. zero.
   b. half as much.
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Answer: A

Assessment Questions

8. When an astronaut in orbit is weightless, he or she is
   a. beyond the pull of Earth’s gravity.
   b. still in the pull of Earth’s gravity.
   c. in the pull of interstellar gravity.
   d. beyond the pull of the sun’s gravity.

Assessment Questions

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   c. in the pull of interstellar gravity.
   d. beyond the pull of the sun's gravity.

Answer: B

Assessment Questions

9. The highest ocean tides occur when the Earth and moon are
   a. lined up with the sun.
   b. at right angles to the sun.
   c. at any angle to the sun.
   d. lined up during spring.

Assessment Questions

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   a. lined up with the sun.
   b. at right angles to the sun.
   c. at any angle to the sun.
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Answer: A

Assessment Questions

10. A black hole is
    a. simply a collapsed star.
    b. a two-dimensional surface in space.
    c. barely visible with high-powered telescopes.
    d. a new form of gravity.

Assessment Questions

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    a. simply a collapsed star.
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Answer: A

Assessment Questions

11. Newton's law of universal gravitation had a great impact on society as many scientists, artists, writers, and philosophers hoped that
    a. more complex and universal laws would explain other phenomena of the world.
    b. greater observations would require fewer experimentations.
    c. no further explanation of other phenomena of the world would be required.
    d. studying other phenomena of the world would lead to just as simple and universal laws.

Assessment Questions

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    a. more complex and universal laws would explain other phenomena of the world.
    b. greater observations would require fewer experimentations.
    c. no further explanation of other phenomena of the world would be required.
    d. studying other phenomena of the world would lead to just as simple and universal laws.

Answer: D