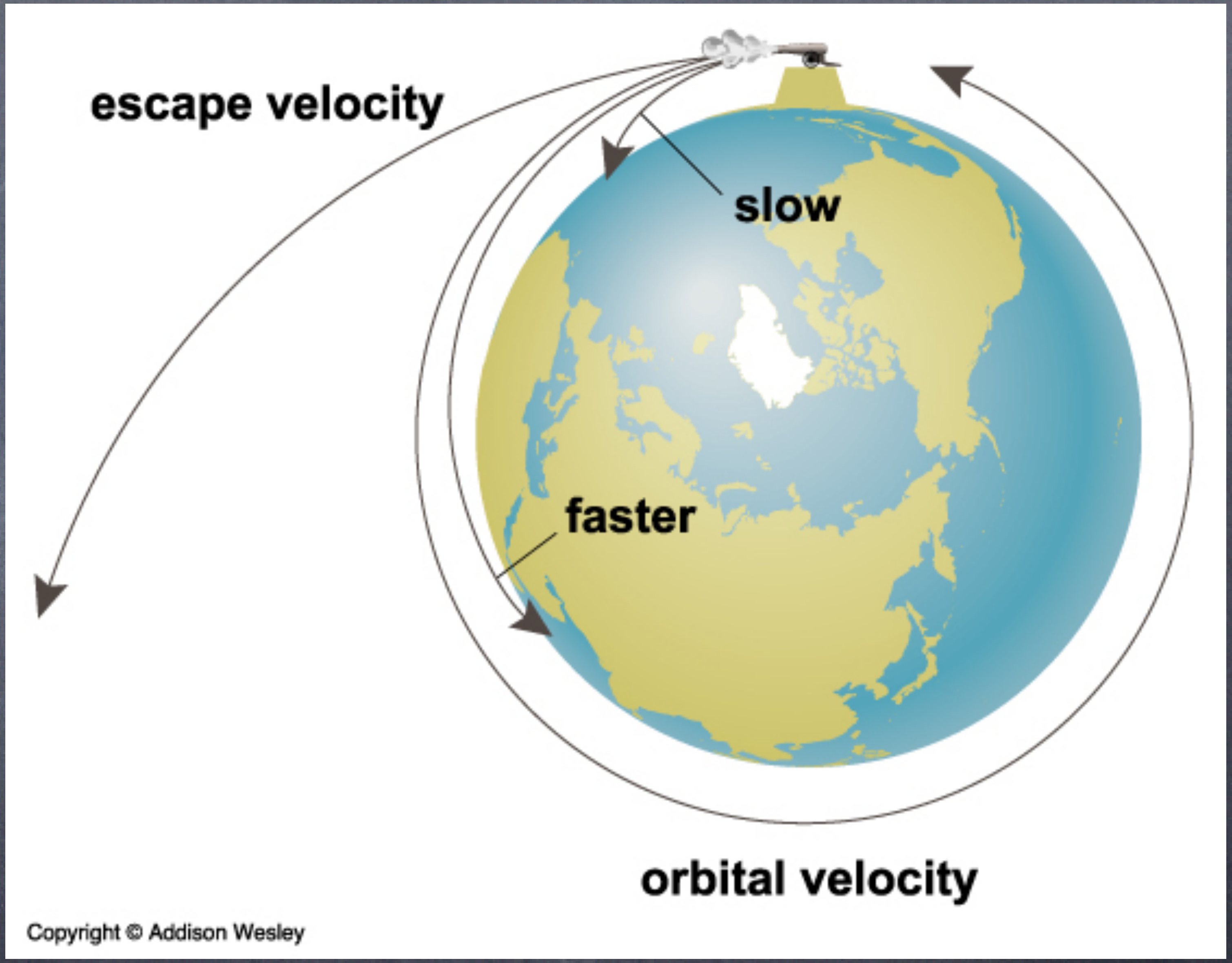
Gravity in Action

Orbits and rockets

- • The orbiting of an artificial satellite or the Moon around the Earth implies that there is a force present. Otherwise, these objects would go flying off into space in a straight line according to the Law of Inertia. The central force of gravity is the key to holding these objects in their orbits.
- • To place an object into orbit, the spacecraft must have enough velocity along the orbit. Too little velocity and the spacecraft will fall back to Earth. Too much velocity and the object will escape into space. The exact orbital velocity needed depends on the mass of the planet & the orbital altitude (Law of Gravity equation).
- • The above gives us guidance on how to go from one planet to the next. To go to Mercury, a spacecraft must reduce its velocity relative to that of the Earth going around the Sun so that it can ``fall" toward the center of the solar system. On the other hand, the Galileo spacecraft heading toward Jupiter had to increase its velocity to move outward away from the Sun.

How fast do they fly?

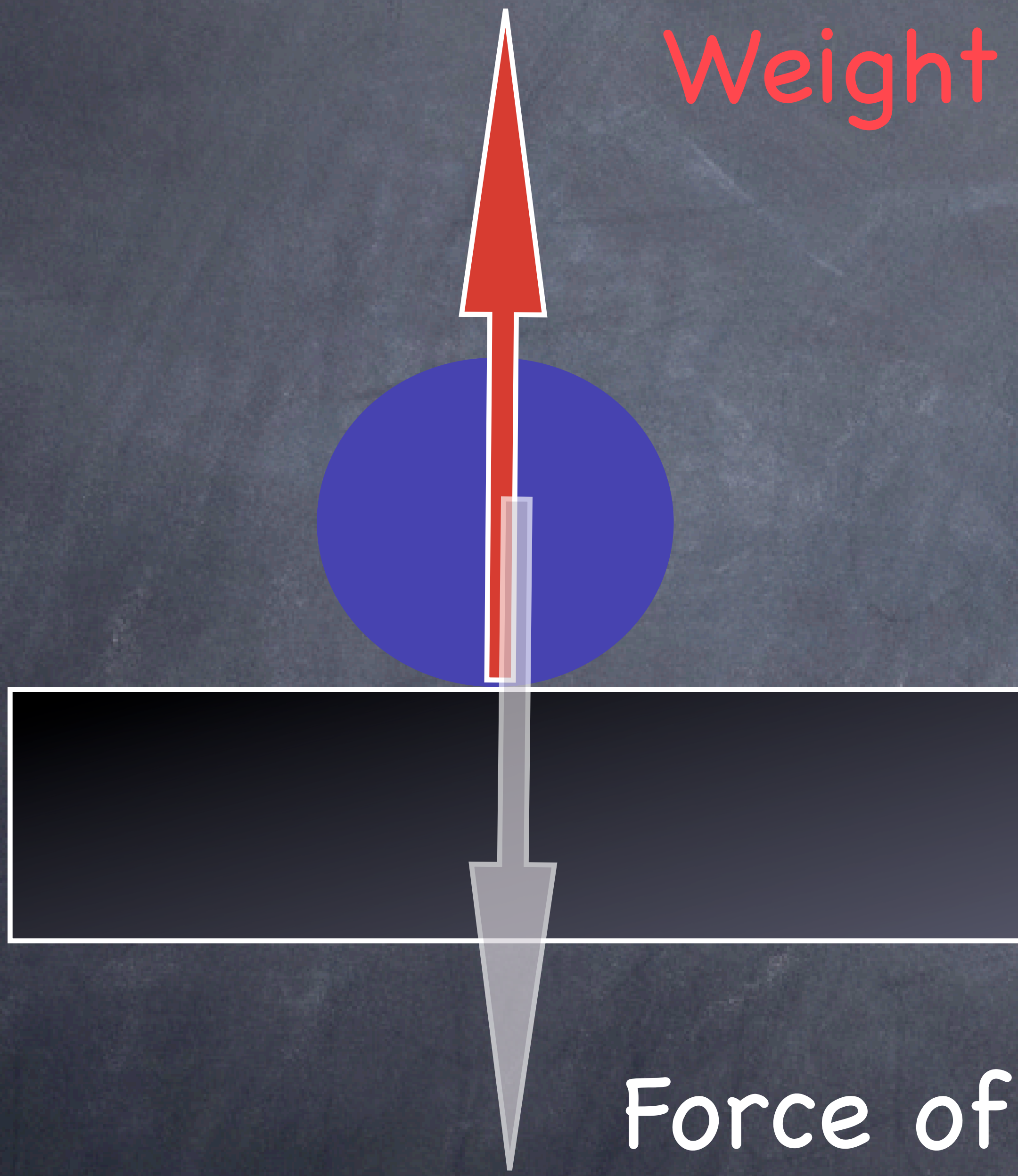
- To get to the orbit around the Earth: 7km/s
- To move away ("escape") from the Earth: 11km/s
- Velocity of the Moon around the Earth: 1km/s
- Velocity of the Earth around the Sun: 30km/s
- Velocity of the Sun around the center of our Galaxy: 220km/s



Weight and Weightlessness

Why do astronauts appear to be ``weightless" on the Space Shuttle if gravity is present? This is an illusion. The Space Shuttle is really free falling toward the Earth constantly but because of its orbital speed, it misses the edge of the Earth. Any free-falling objects appear to be weightless (person dropped from an airplane in an enclosed box) because both the object and the container are falling at the same rate.

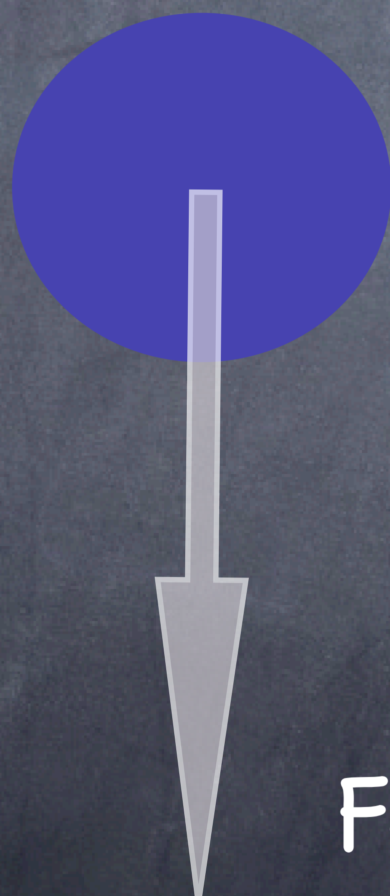
Weight and gravity



If I am standing on a floor,
my weight = gravity

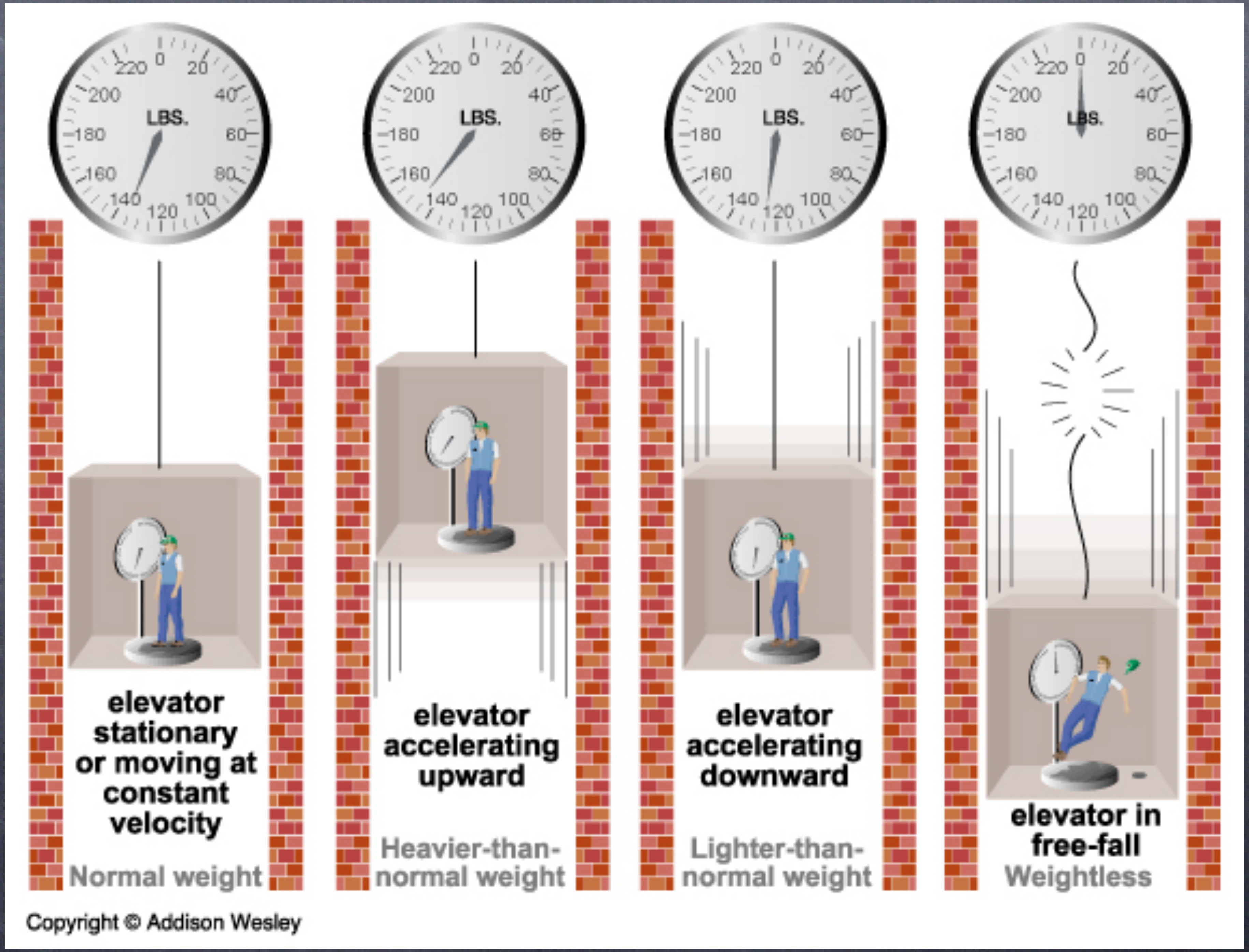
Weight and gravity

If there is no floor, nothing pushes my up. I do not have weight



Force of gravity

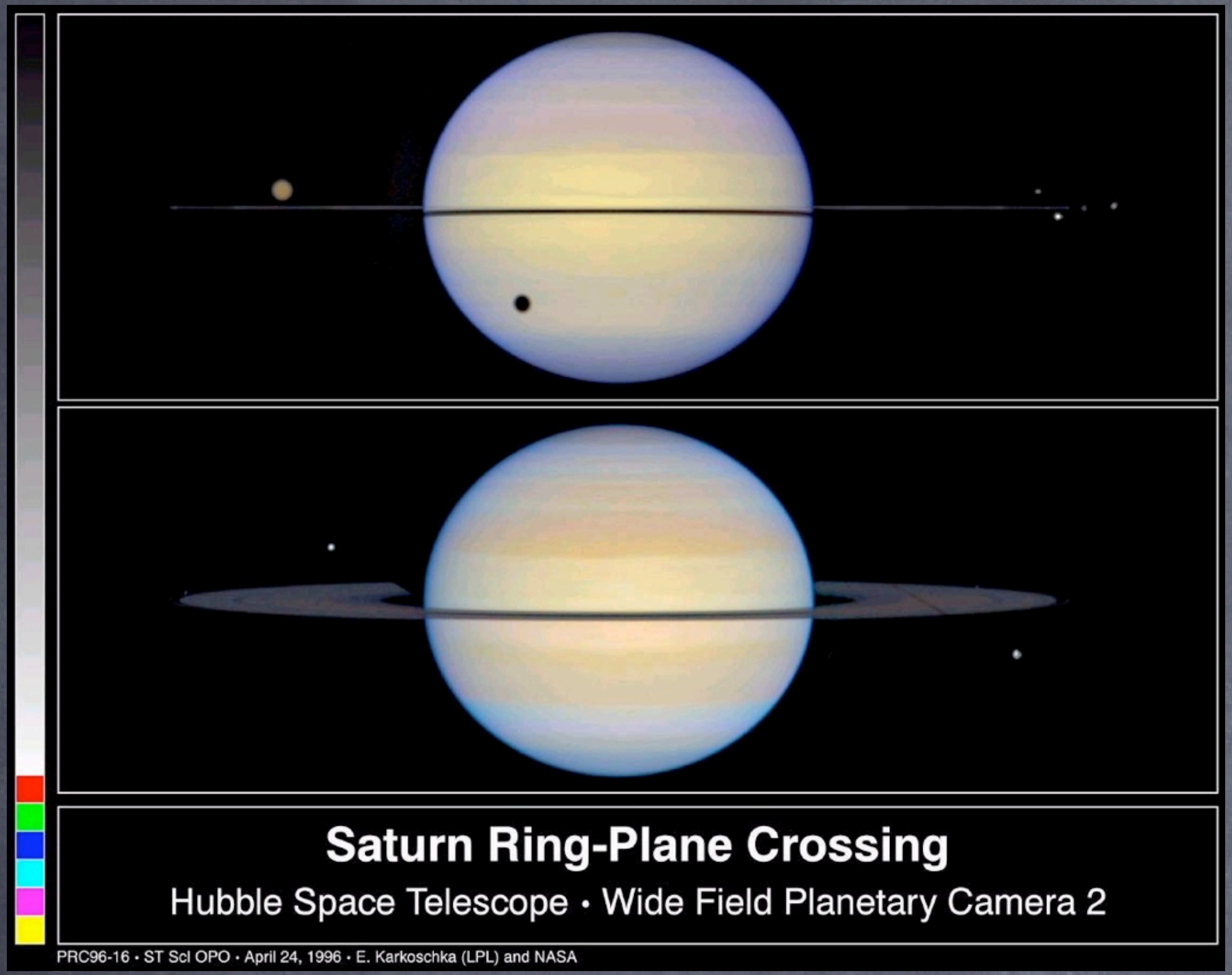
Weight and Weightlessness



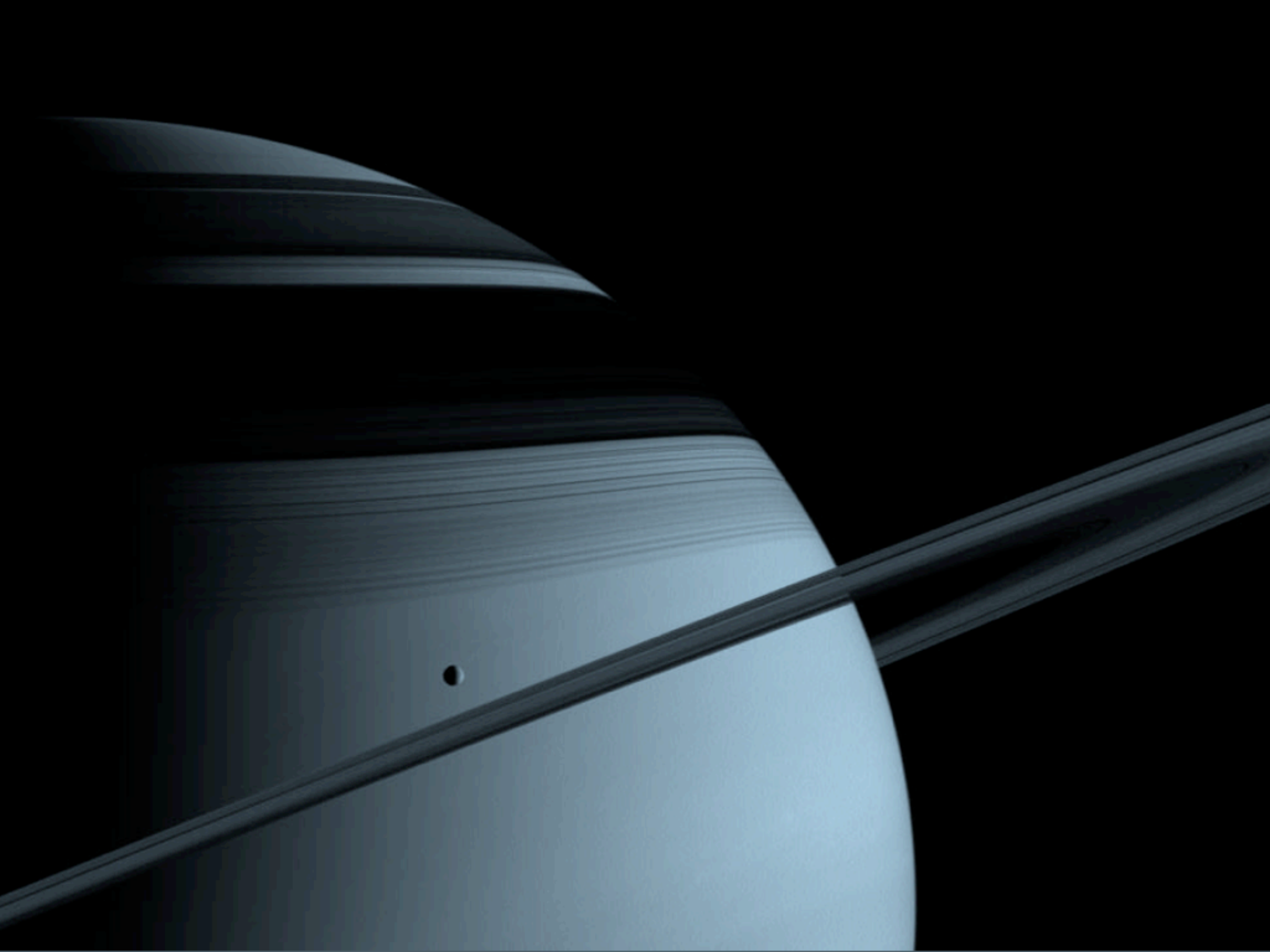
Weight and Mass

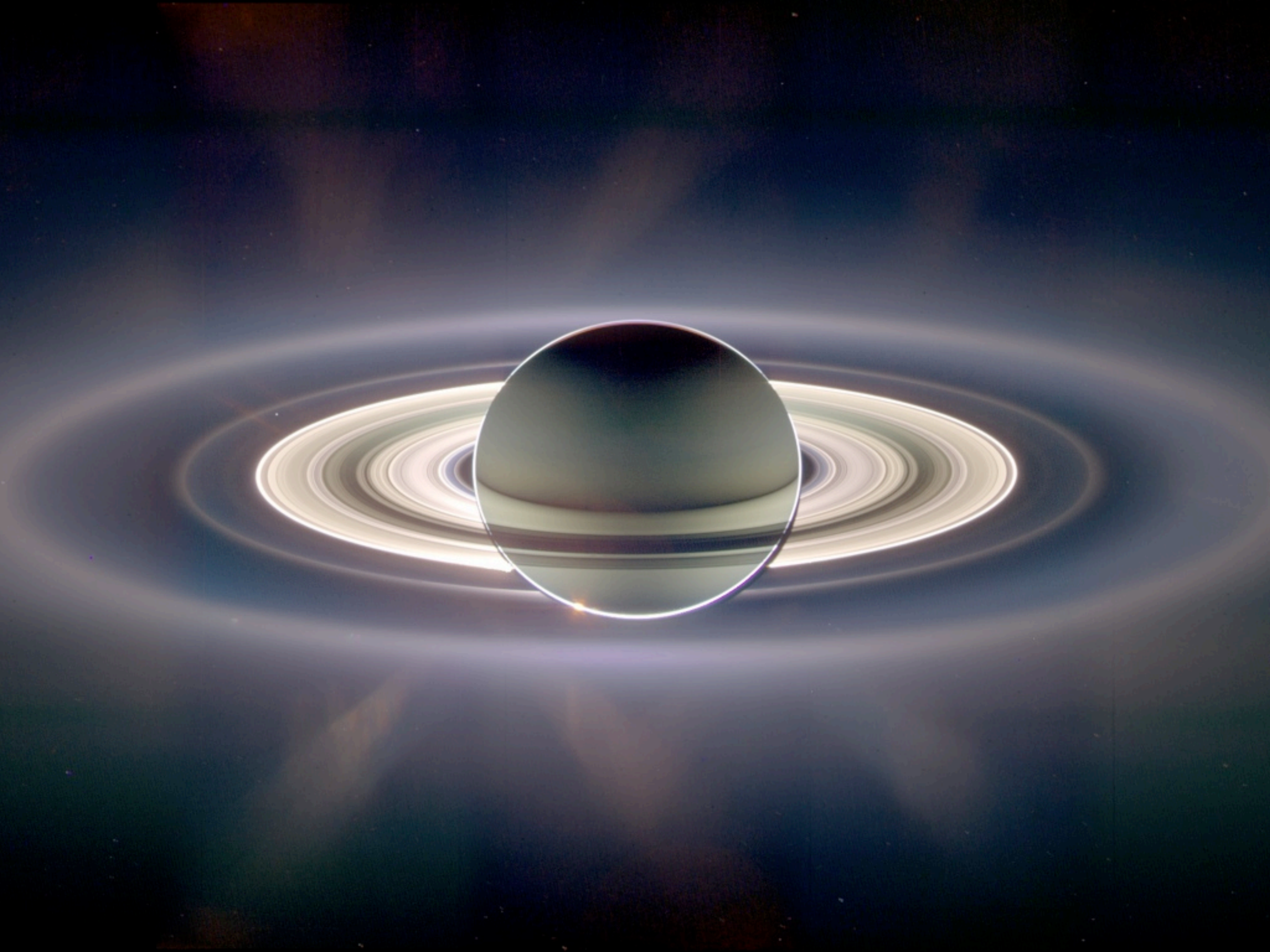
- My weight on the Earth is equal to the force, with which the Earth pulls me down.
- My weight on the surface of the Moon will be smaller, because Moon's gravity is weaker
- My mass does not depend where I am: the same on the Moon and on the Earth.

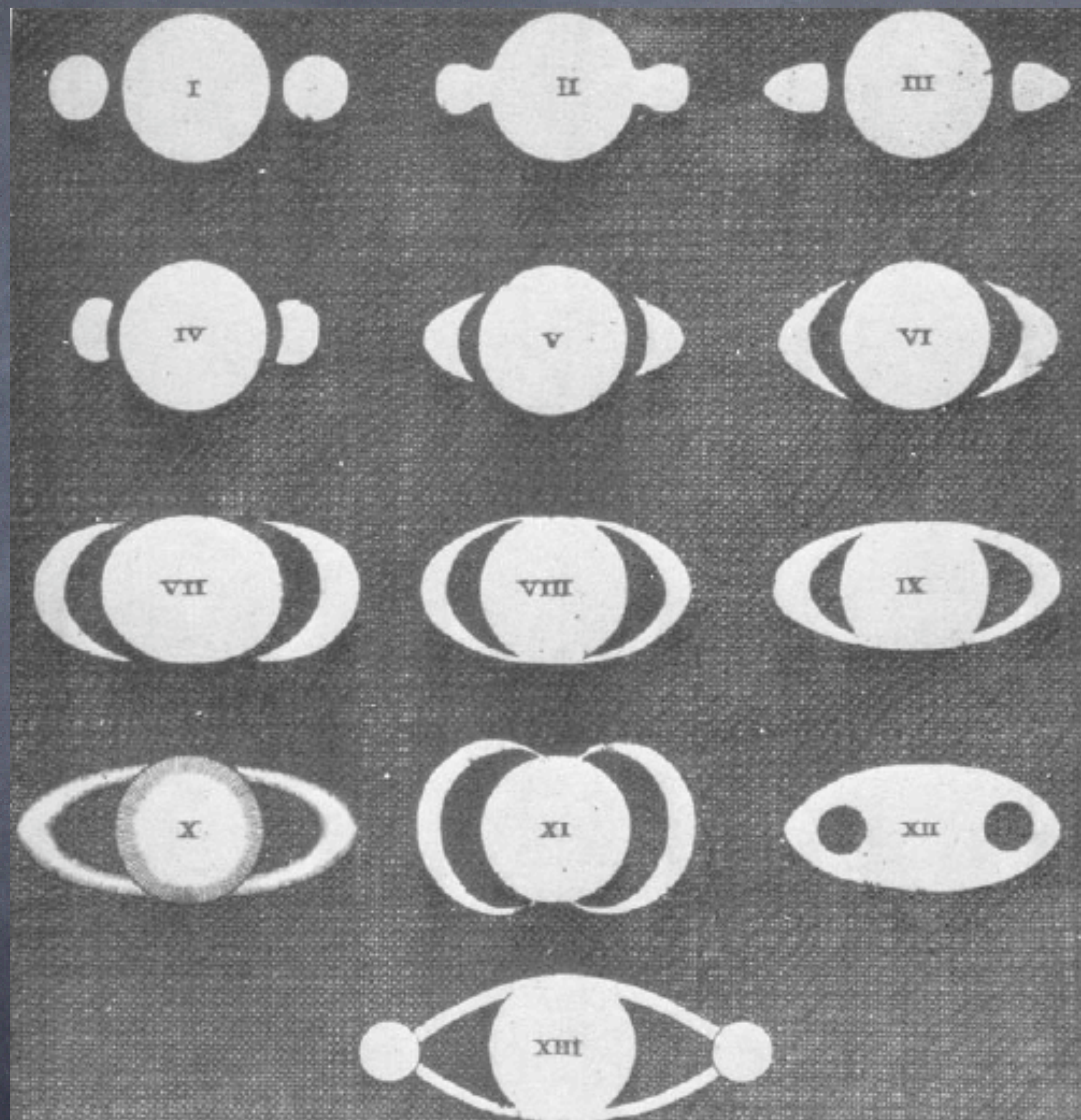
The Rings of Saturn



- The rings of Saturn are a good example of gravity in action. The rings are believed to be the remnants of the material from which Saturn formed. The rings are relatively thin - less than 5 km in width; this flattening was caused by the rapid circular motion of the rings. The rings are actually made of rocky material covered with ice that range in size from small stones to a small car.
- Each rock in the ring follows an orbit around Saturn obeying Kepler's Laws of Planetary Motion. So, you can predict the orbits of the rings.



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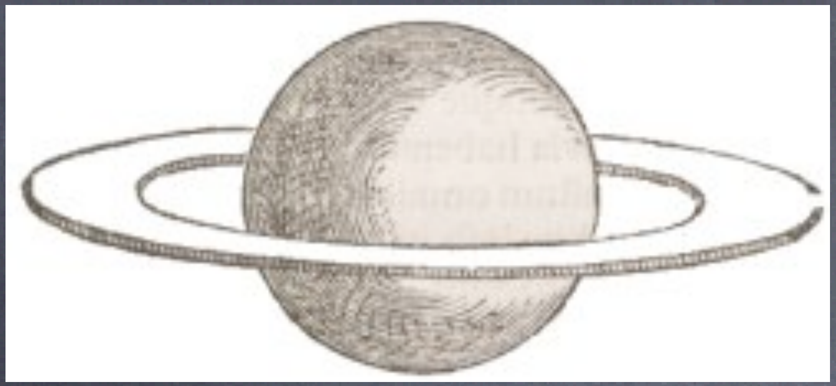


Christiaan Huygens *Systema Saturnium...* (1659)

Systema Saturnium opens with the preface to Prince Leopold. In this preface Huygens declares that Saturn, its ring, and its satellite forms a system which **supports the Copernican** system of a heliocentric universe. Then his discussion turns to the discovery of Saturn's moon and the determination of its **orbital period around Saturn. Huygens derives a value of 15 days, 23 hours**, and 13 minutes (not far off from the **modern value of 15 days, 22 hours**, and 41 minutes).

Honoré **Fabri (1607-1688)**, a Jesuit astronomer in Rome. The Fabri treatise pulled no punches and attacked Huygens's characterization of observations of Saturn, spoke ill of Huygens's telescopes, described his ring theory as fantastic, called some observations "pure fiction," and **attacked his Copernican arguments**. It then argued in favor of **Fabri's theory that Saturn was accompanied by four satellites: two dark ones near the planet and two bright ones** farther out. The darker satellites partially obscured the brighter ones at times, creating the appearance of handles on each side of Saturn.

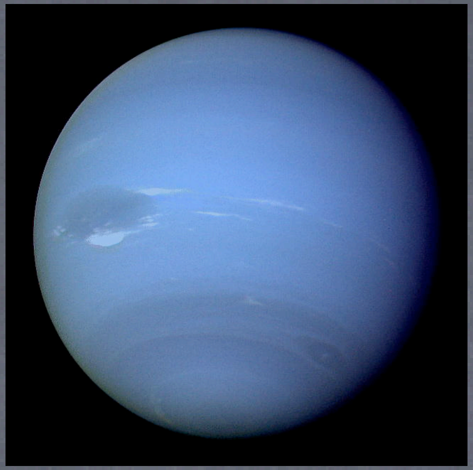
The concept of a ring around Saturn was generally accepted by **1670**. What remained a mystery was the exact nature of the ring.

Was it a solid thick ring as **Huygens** proposed? Always a point of contention, Huygens's theory was weakened by the discovery of a gap in the supposedly solid ring by Giovanni Domenico **Cassini**, the director of the Paris Observatory, in **1675**. Cassini also believed that the ring was actually composed of a **large number of small satellites** orbiting Saturn.

In **1785**, Pierre Simon, Marquis de **Laplace** demonstrated the mathematical instablility of solid rings orbiting around Saturn.

James Clerk Maxwell wrote a mathematical essay in **1857** which destroyed the notion of a solid ring. His proof noted that the only possible explanation for the ring was that it was composed of small particles orbiting the planet and dense enough to give the appearance of a ring.

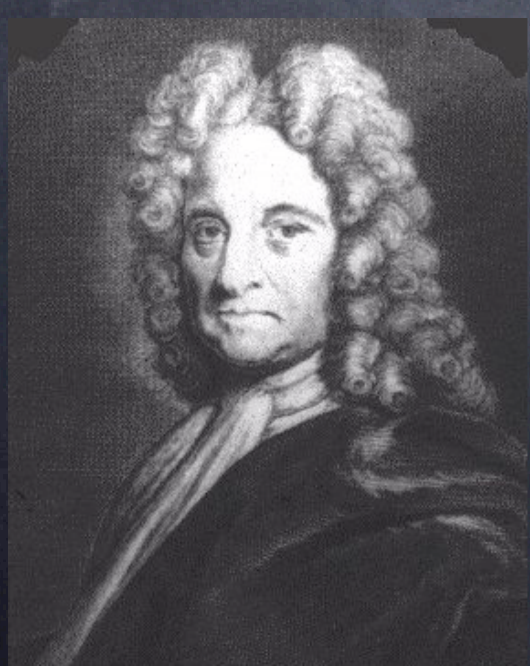
The Discoveries of Neptune and Pluto



- Neptune was discovered in 1846 as a direct consequence of Newton's Law of Gravity.
- Following the visual discovery of Uranus in 1781 by William Herschel, further observations of Uranus showed that it did not exactly follow the predicted path. How could this be?
- The only way the orbit of Uranus could be perturbed would be by another massive object (a planet) which was outside the orbit of Uranus. If massive enough, it would exert a gravitational pull on Uranus & cause its orbit to be slightly distorted.
- Using Newton's laws of gravity & motion, one can work backward from the orbital perturbations to predict approximately the mass and orbit of the mystery planet: *Adams (England) and LeVerier (France)*. Observers used these predicted positions to discover Neptune in the middle of the *19th century by a German astronomer*.
- A similar prediction about the perturbation of the orbit of Neptune led *Clyde Tombaugh* to search for & eventually discover the planet Pluto in 1930. Pluto, however, turned out to be much less massive than predicted. Also, we know today that the supposed perturbations in Neptune's orbit do not exist. So, Pluto's discovery was pure serendipity.

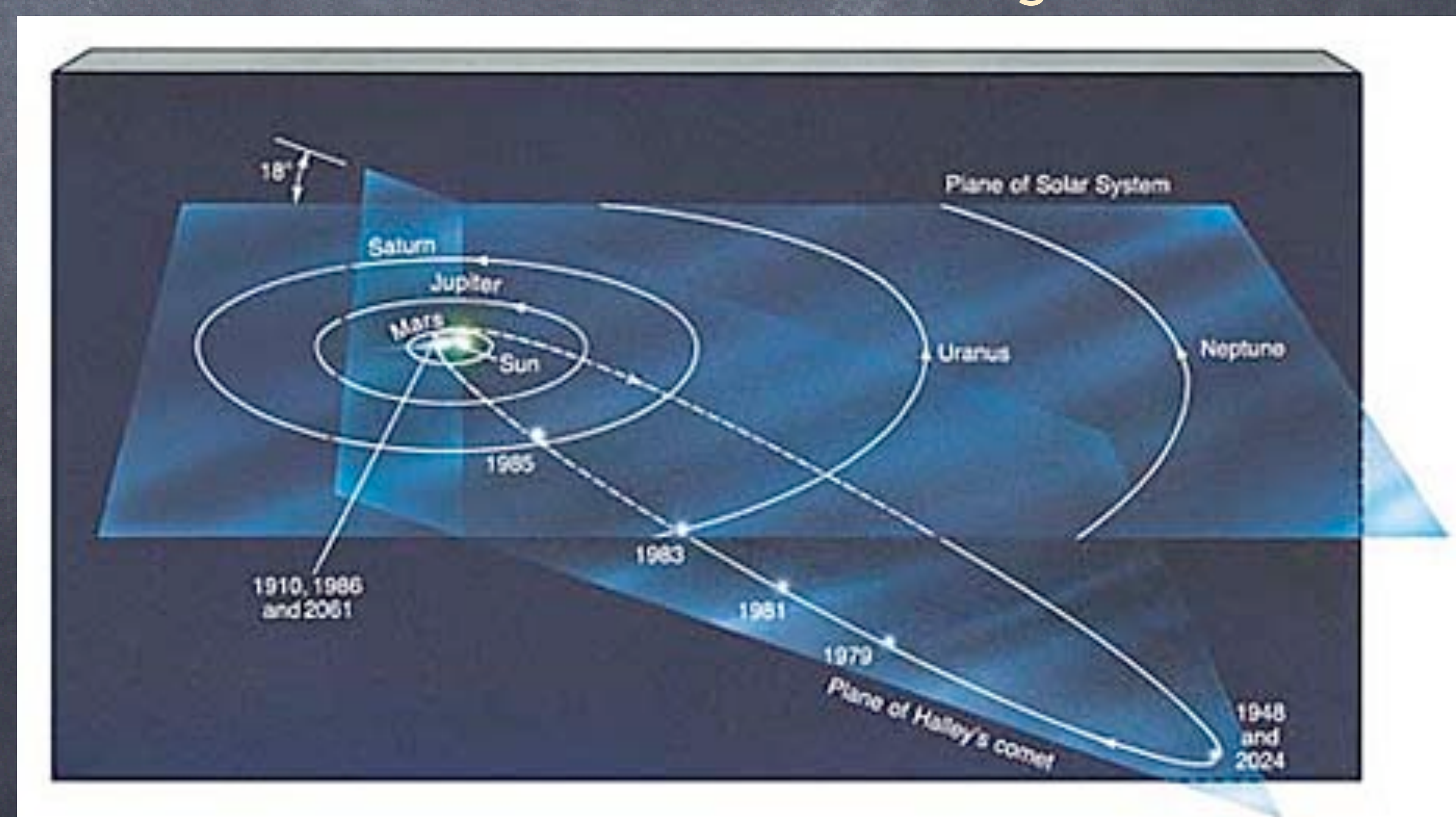
Comets: From Fear to Triumph

- Comets were much feared by peoples of ancient times & the Middle Ages. They were thought to forecast ominous events. For example, one of the earliest recordings of Halley's comet in 1066 coincided with the conquest of England by the Normans - not good for the Saxons!
- However, Halley's comet became a great triumph for Newton's theories. Edmond Halley used Newton's newly developed theories to predict the orbit of what came to be known as Halley's Comet. He predicted that it would reappear every 75 years which was confirmed on its passage near the Earth in 1758.
- Comets are on highly elliptical orbits with the Sun at one focus. They spend most of their time far beyond the orbit of Pluto. Comets are best described as dirty icebergs. The tail is the most spectacular part of the comet - it can be millions of kilometers in length. It is composed of gas molecules which are left behind marking a trail of the comet nucleus.



E.Halley

Orbit



What did we learn:

- Orbit velocity and escape velocity
- Weight, weightlessness, "zero-gravity"
- Mass and weight
- Testing the Newton's law of gravity:
  - Saturn rings (obey Kepler's laws; inner rings have shorter periods)
  - Discovery of Neptune
  - Motion of comets
  - Motion of rockets