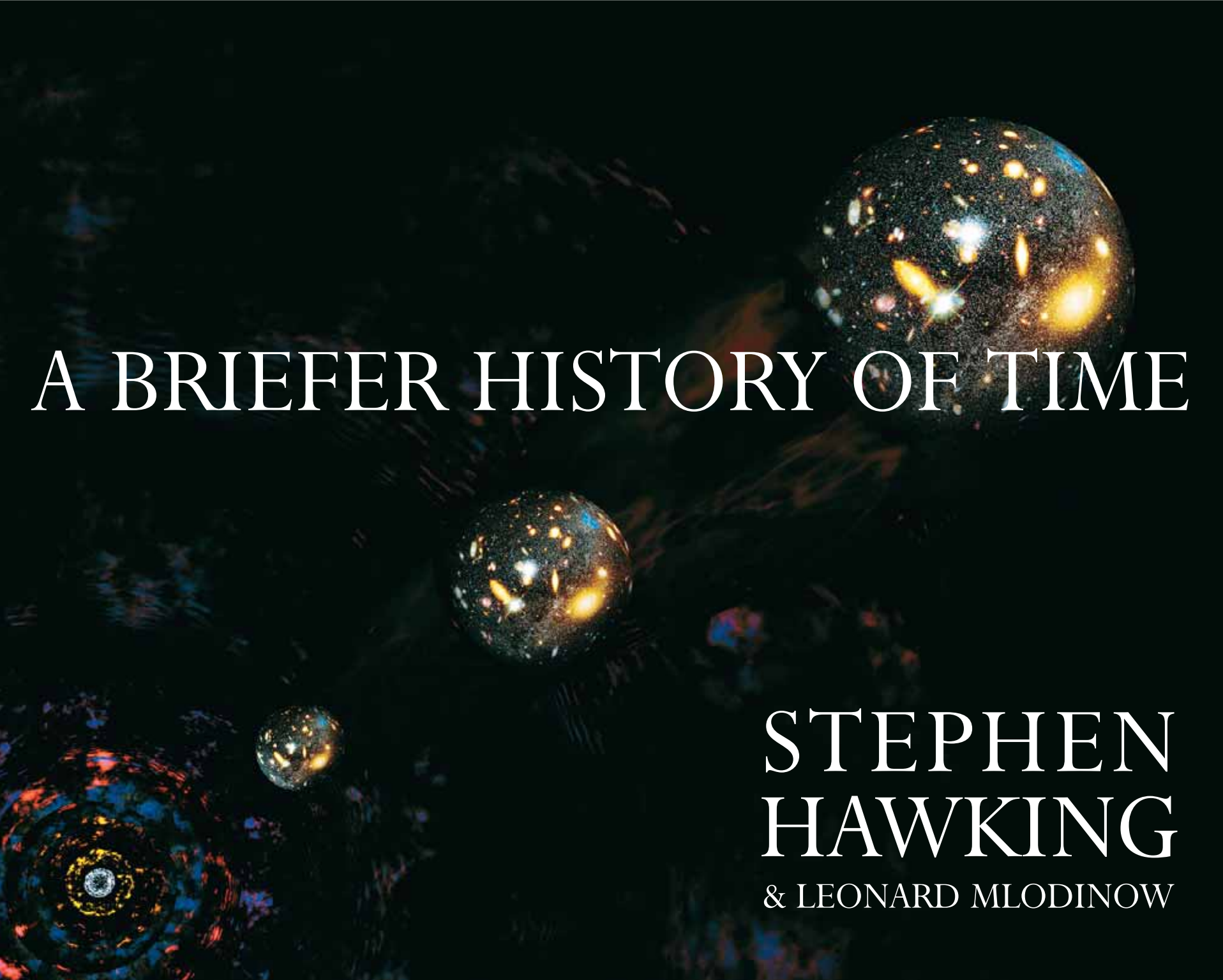
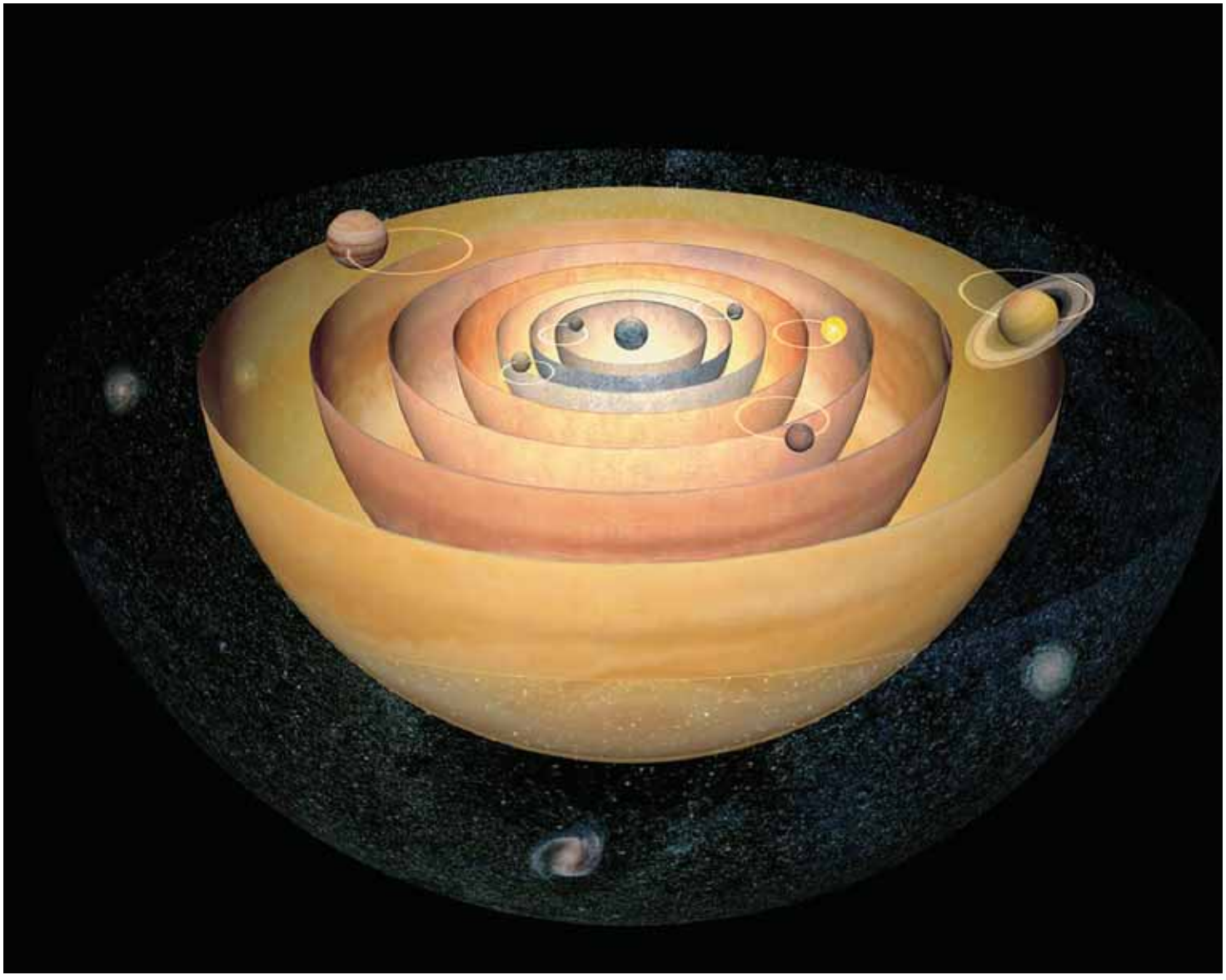


A BRIEFER HISTORY OF TIME

STEPHEN HAWKING
& LEONARD MLODINOW

Coming over the Horizon

Because the earth is a sphere, the mast and sails of a ship coming over the horizon show themselves before its hull.



Ptolemy's Model

In Ptolemy's model, the earth stood at the center of the universe, surrounded by eight spheres carrying all the known heavenly bodies.

Atoms to Galaxies

In the first half of the twentieth century, physicists extended the reach of their theories from the everyday world of Isaac Newton to both the smallest and the largest extremes of our universe.

Gravitational Attraction of Composite Bodies

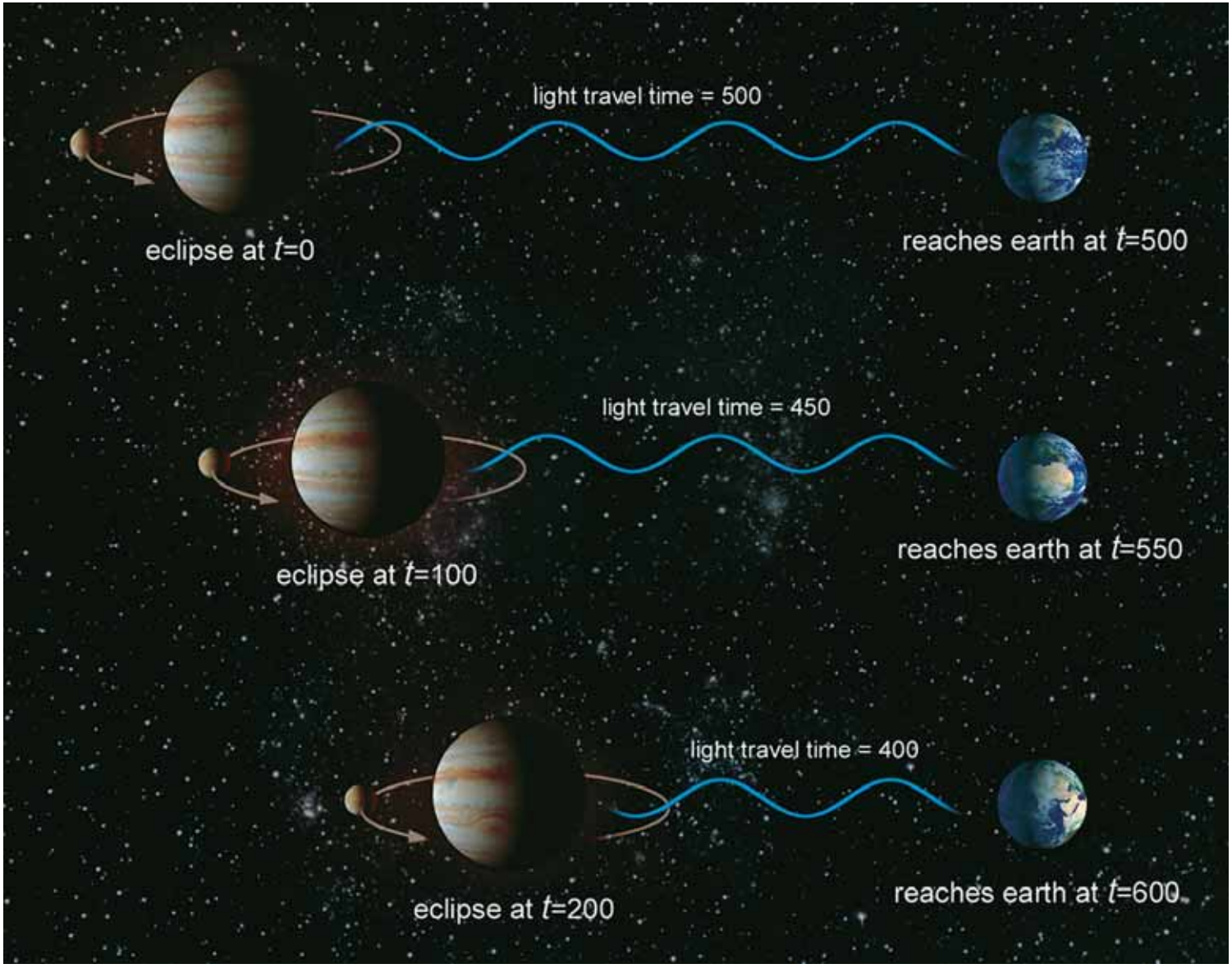
If the mass of a body is doubled, so is the gravitational force that it exerts.

Relativity of Distance

The distance—and the path—that an object travels can look different to different observers.

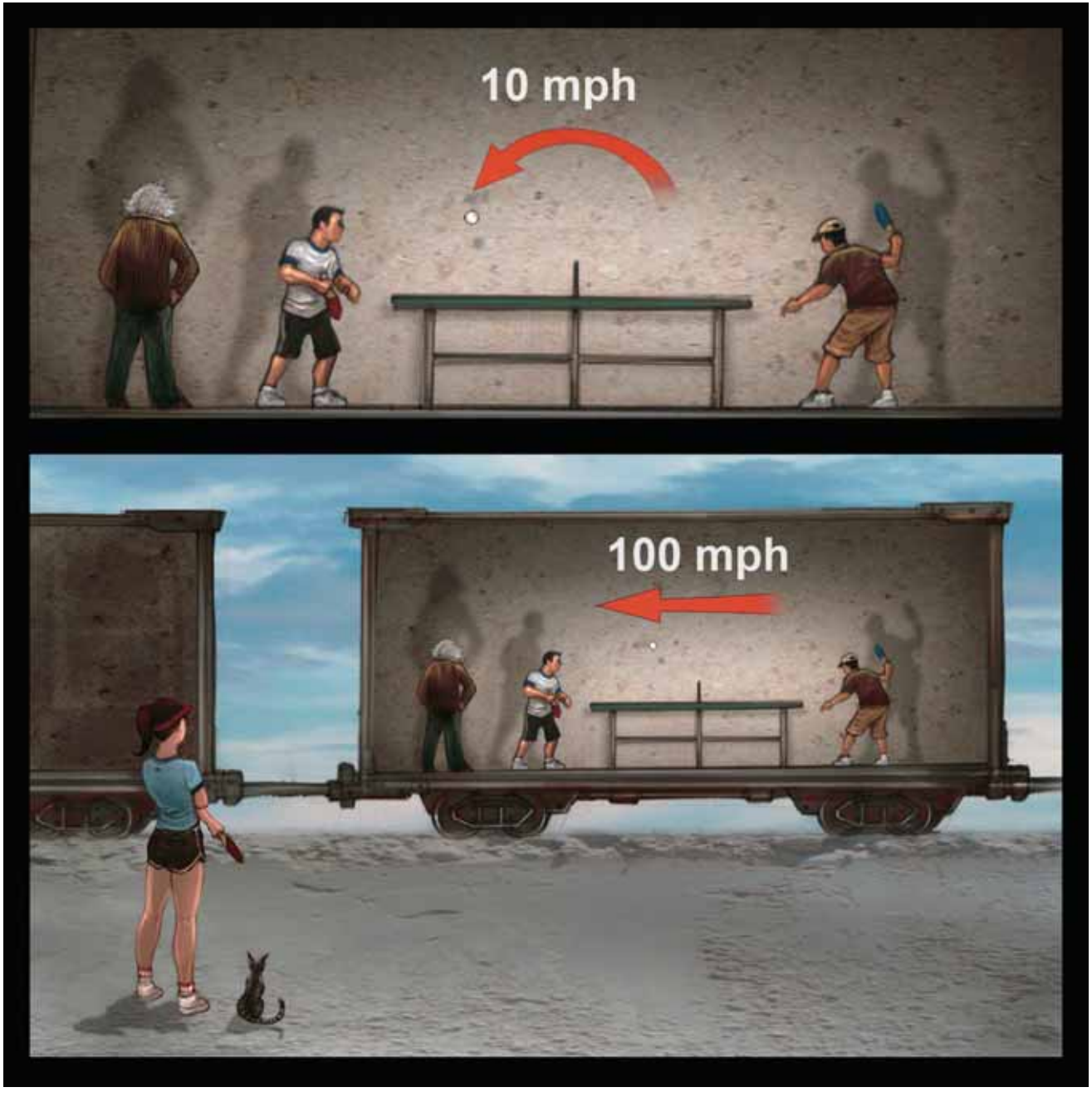
The Speed of Light and the Timing of Eclipses

The observed times of the eclipses of Jupiter's moons depend on both the actual time of the eclipses and the time it takes their light to travel from Jupiter to the earth. Thus the eclipses seem to appear more frequently when Jupiter is moving toward the earth, and less frequently when it is moving away. This effect is exaggerated here for clarity.



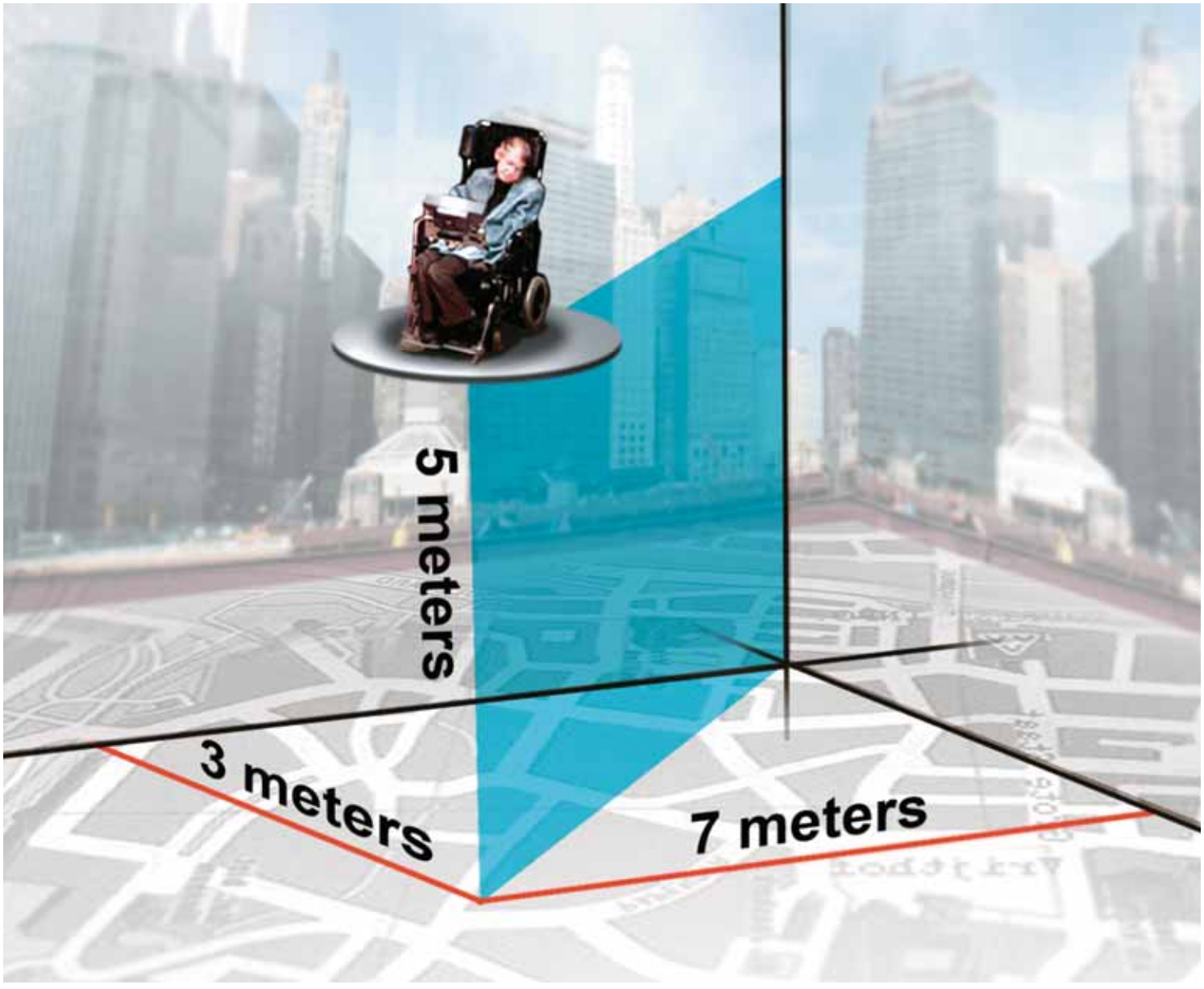
Wavelength

The wavelength of a wave is the distance between successive peaks or troughs.



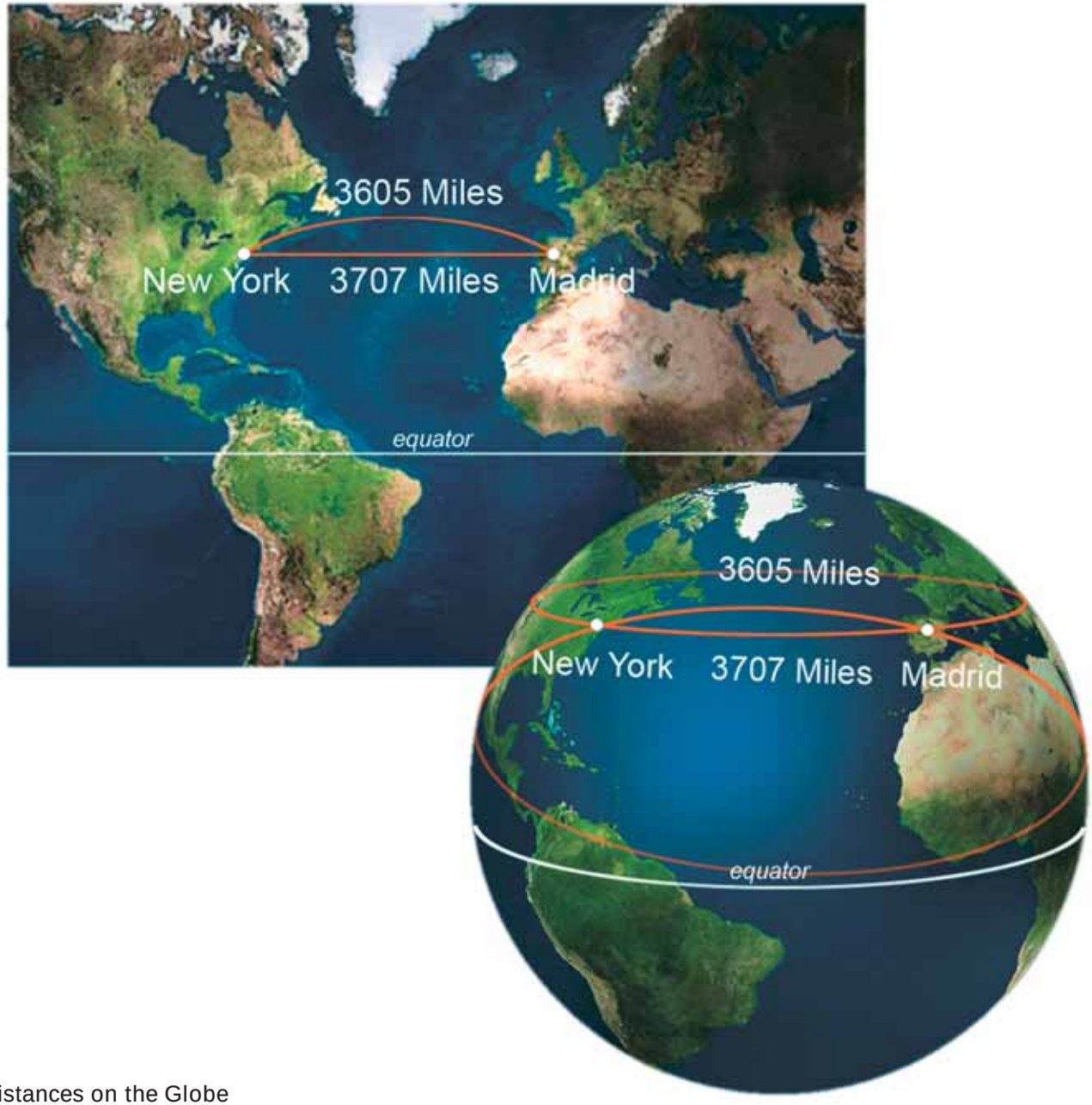
Different Speeds of Ping-Pong Balls

According to the theory of relativity, although they may disagree, every observer's measurement of an object's speed is equally valid.



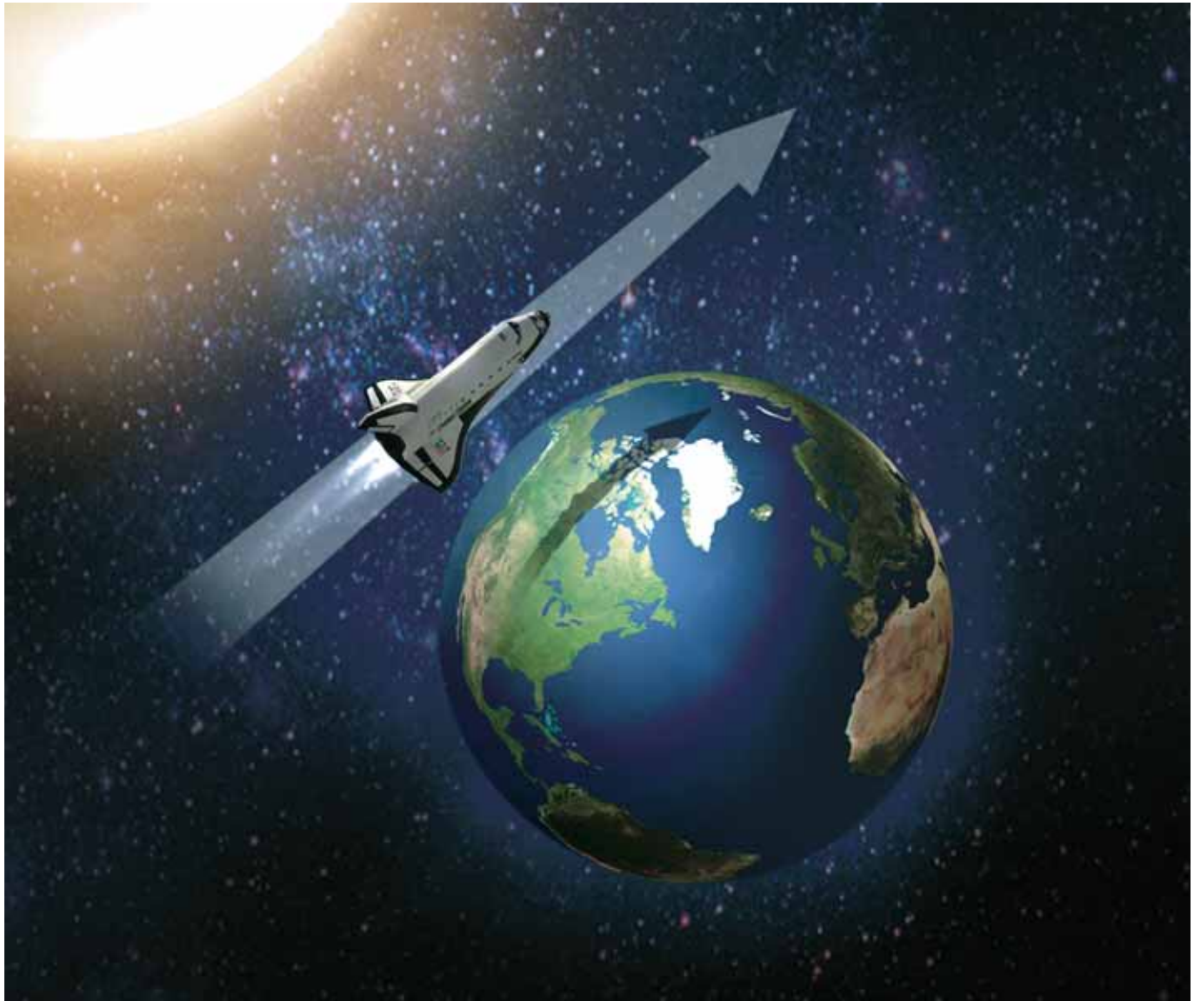
Coordinates in Space

When we say that space has three dimensions, we mean that it takes three numbers, or *coordinates,* to specify a point. If we add time to our description, then space becomes space-time, with four dimensions.

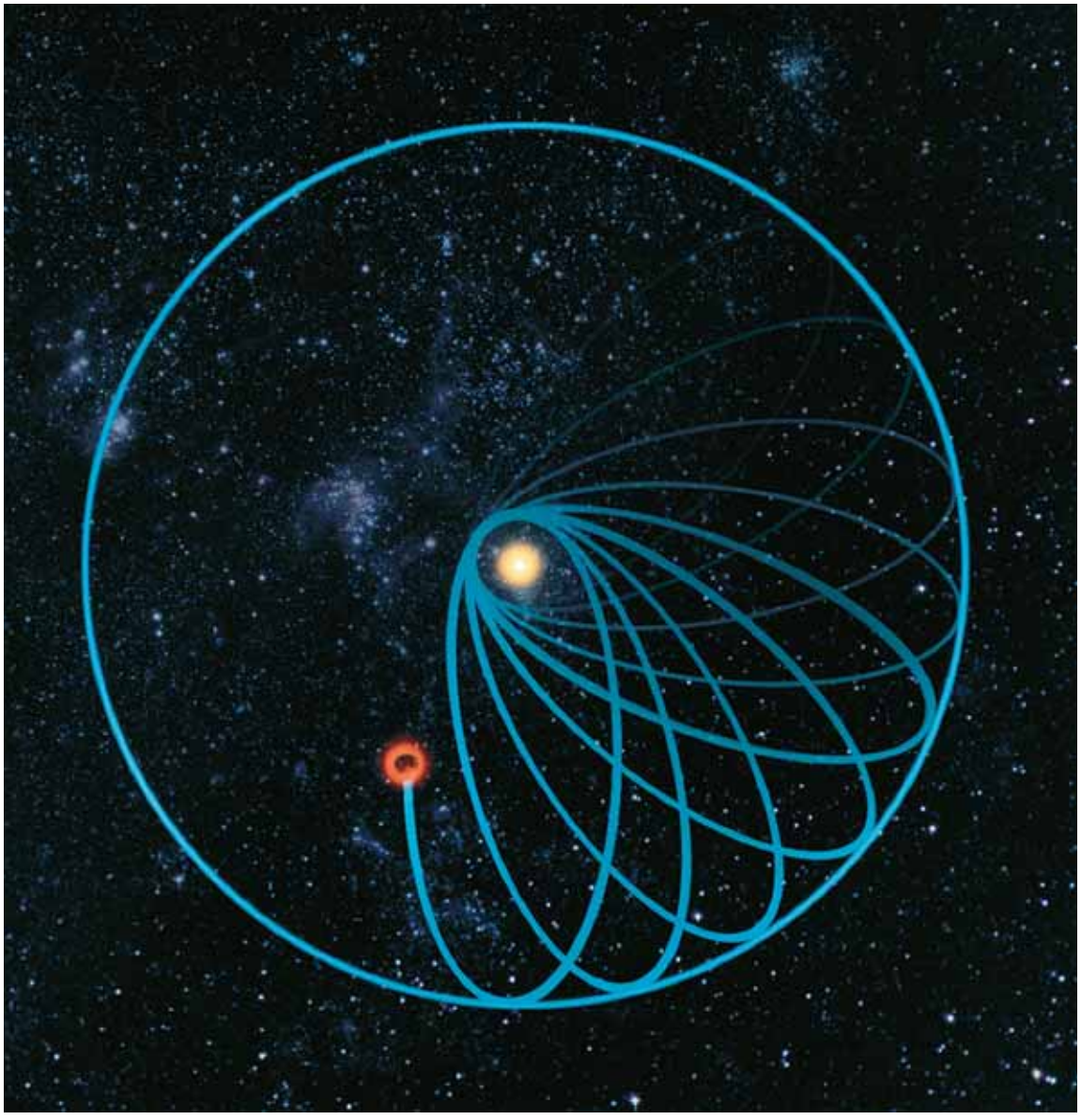


Distances on the Globe

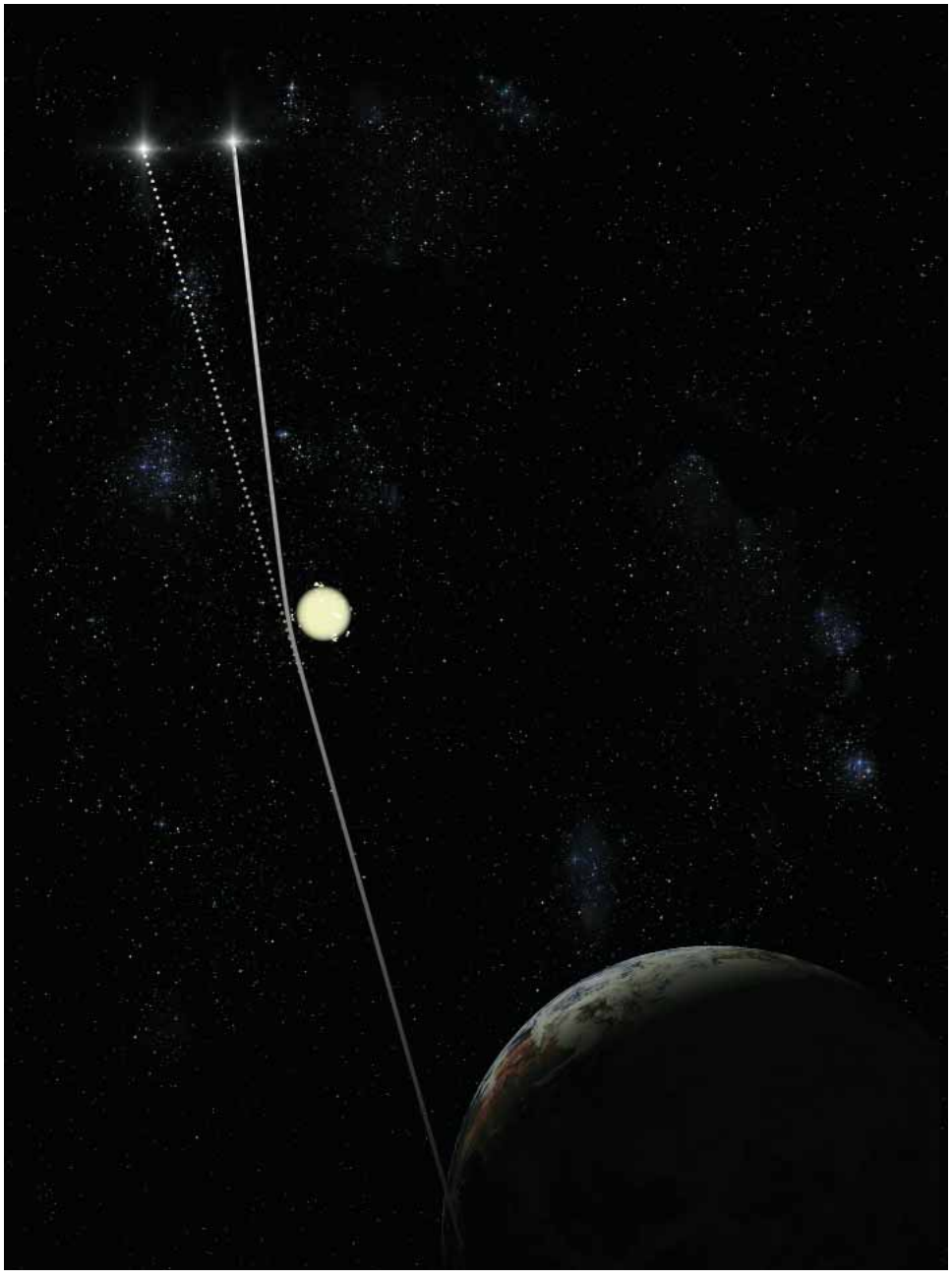
The shortest distance between two points on the globe is along a great circle, which does not correspond to a straight line if you are looking at a flat map.



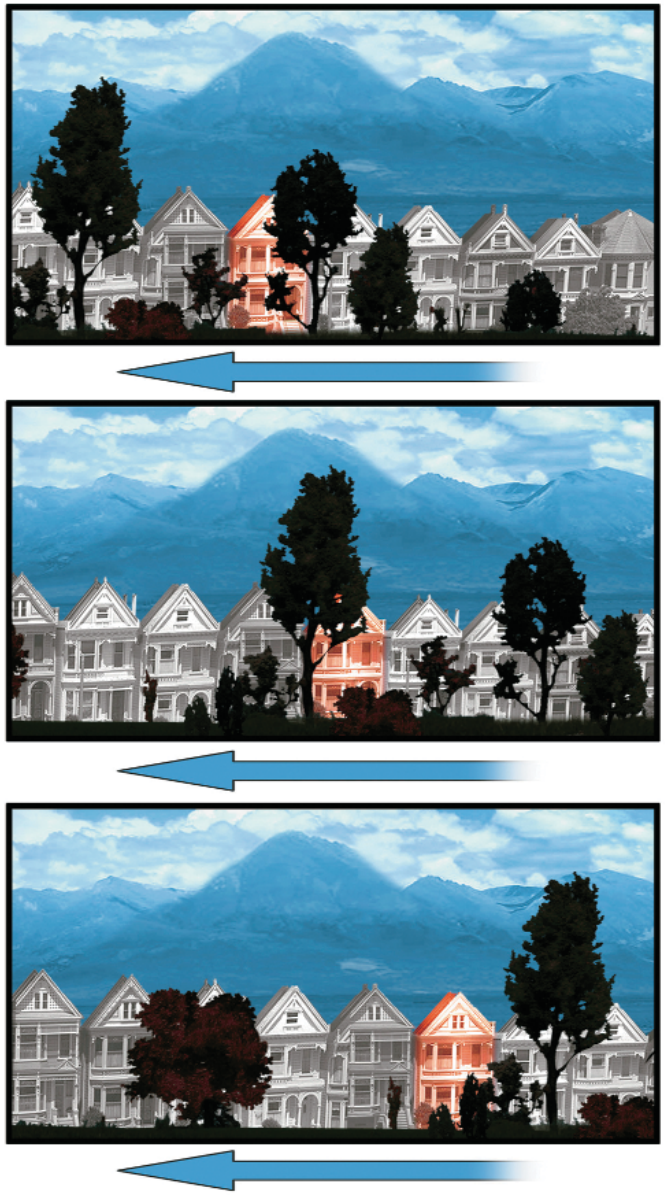
Path of a Spacecraft's Shadow
Projected onto the two-dimensional globe, the path of a spacecraft flying along a straight line in space will appear curved.



Precession of Mercury's Orbit
As Mercury repeatedly orbits the sun, the long axis of its elliptical path slowly rotates, coming full circle roughly every 360,000 years.



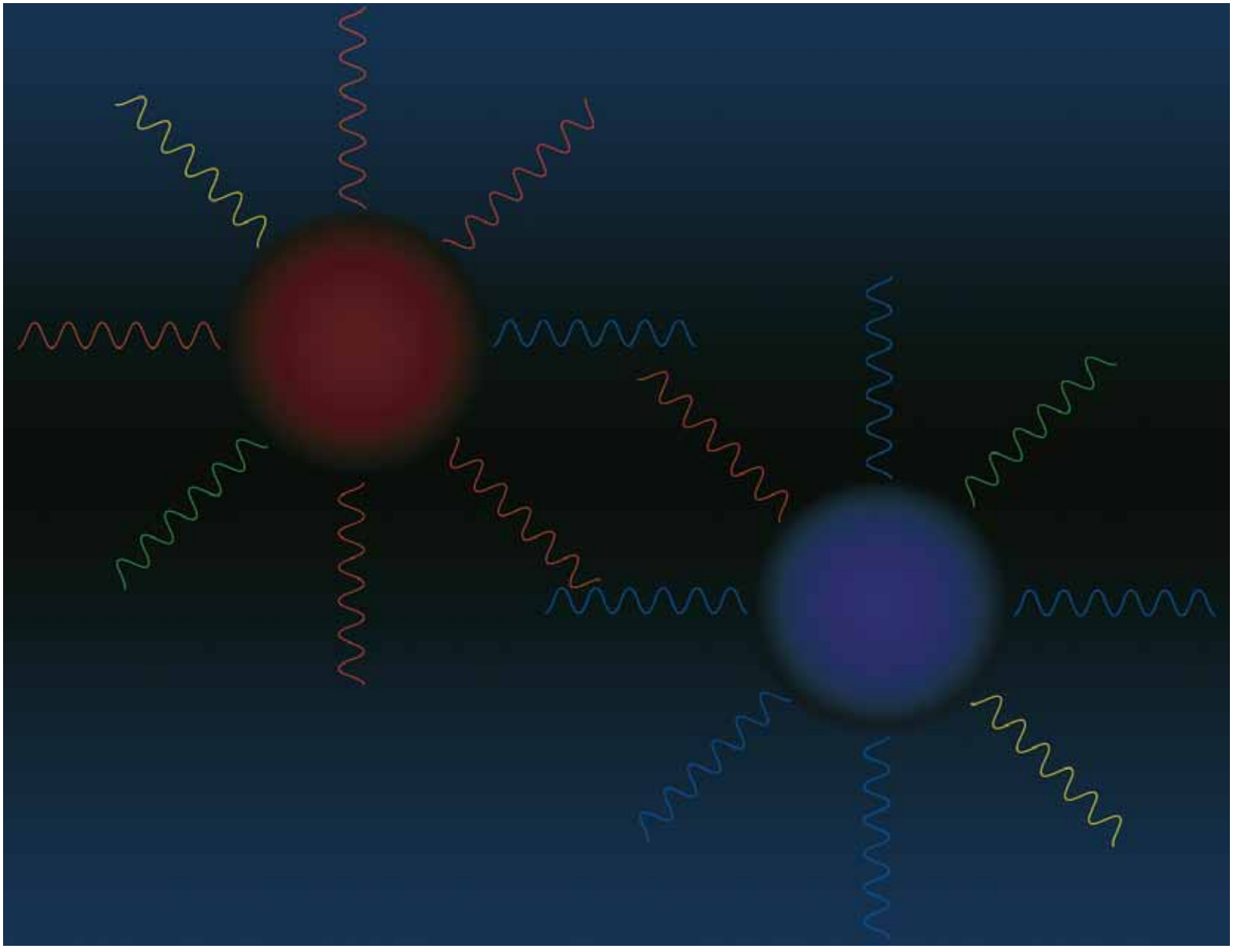
Bending of Light Near the Sun
When the sun lies almost directly between the earth and a distant star, its gravitational field deflects the star's light, altering its apparent position.



Parallax

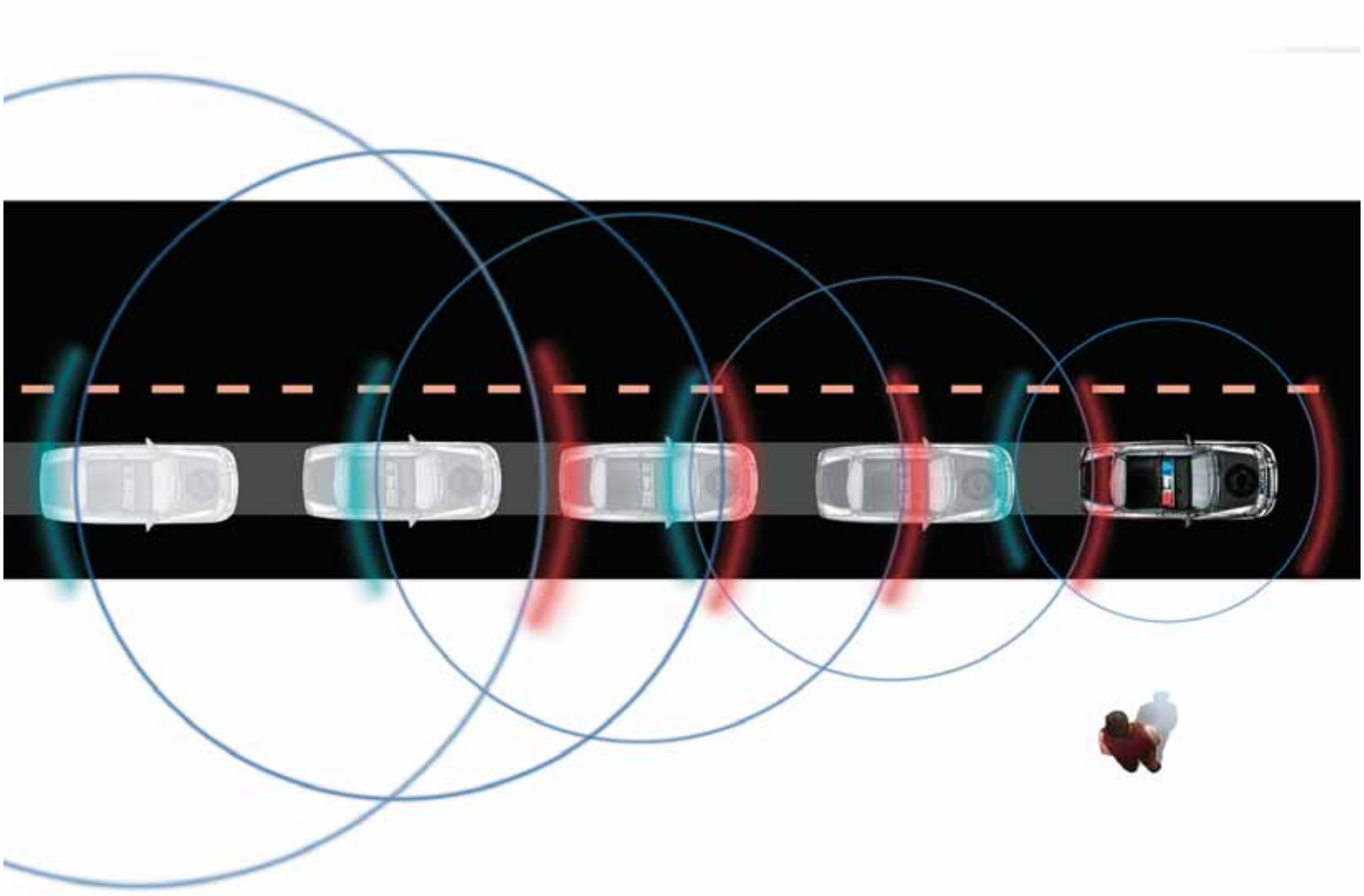
Whether you are moving down a road or through space, the relative position of nearer and farther objects changes as you go. A measure of that change can be used to determine the relative distance of the objects.

Stellar Spectrum
By analyzing the component colors of starlight, one can determine both the temperature of a star and the composition of its atmosphere.



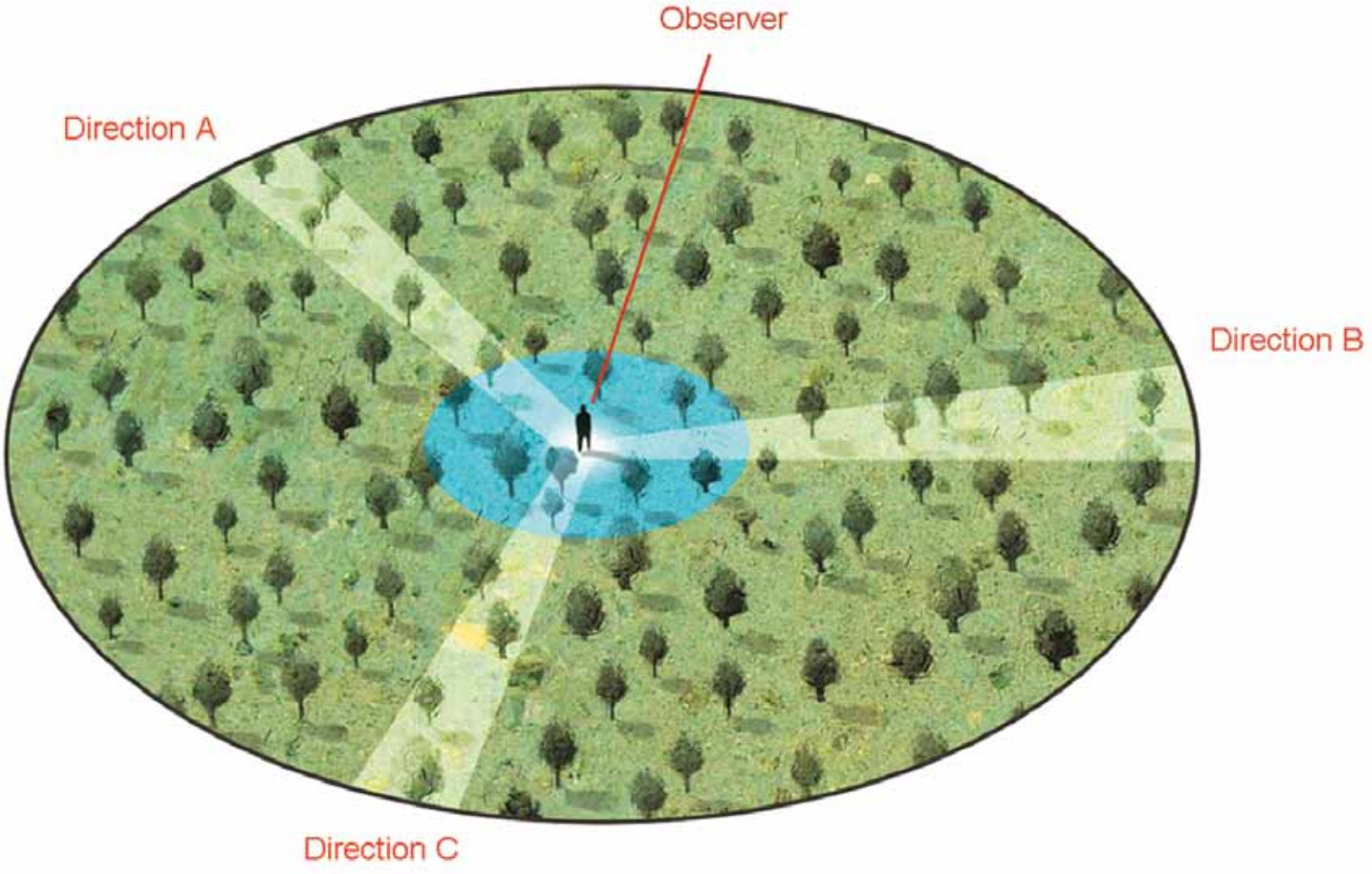
Blackbody Spectrum

All objects—not just stars—emit radiation resulting from the thermal motion of the objects' microscopic constituents. The distribution of frequencies in this radiation is characteristic of an object's temperature.



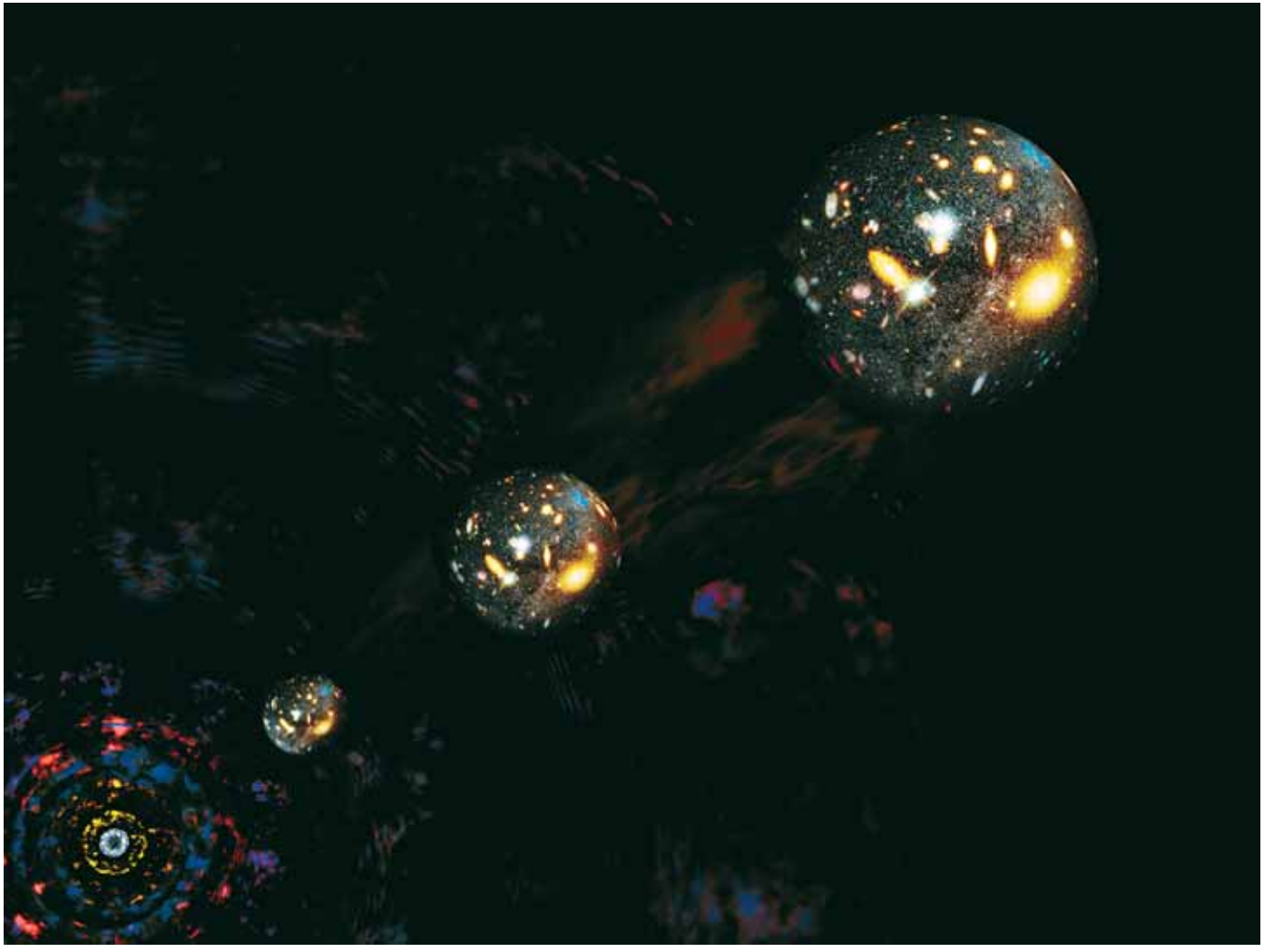
Doppler Effect

When a wave source moves toward an observer, its waves appear to have a shorter wavelength. If the wave source moves away, its waves appear to have a longer wavelength. This is called the Doppler effect.



Isotropic Forest

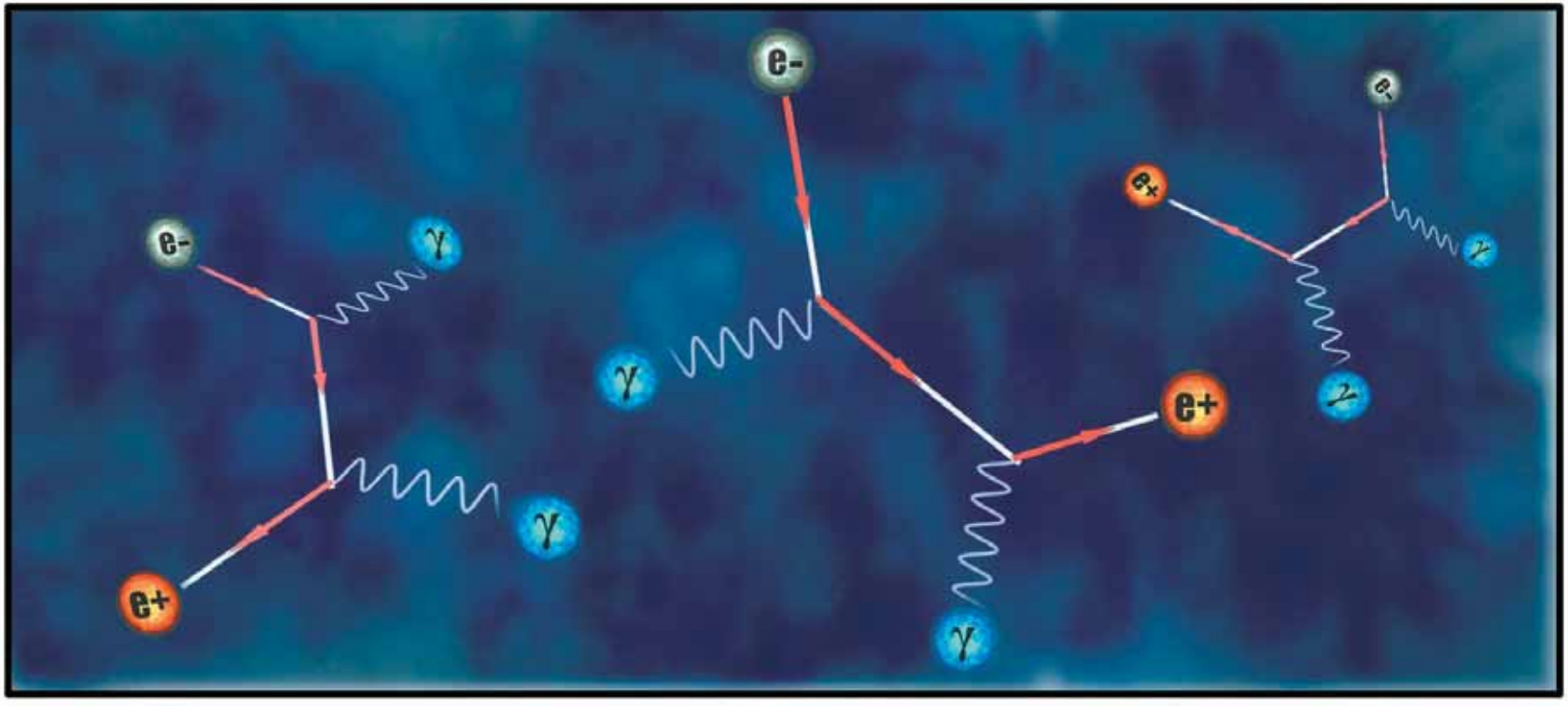
Even if the trees in a forest are uniformly distributed, nearby trees may appear bunched. Similarly, the universe does not look uniform in our local neighborhood, yet on large scales our view appears identical in whichever direction we look.



The Expanding Balloon Universe
As a result of the expansion of the universe, all galaxies are moving directly away from each other. Over time, like spots on an inflating balloon, galaxies that are farther apart increase their separation more than nearer galaxies. Hence, to an observer in any given galaxy, the more distant a galaxy is, the faster it appears to be moving.

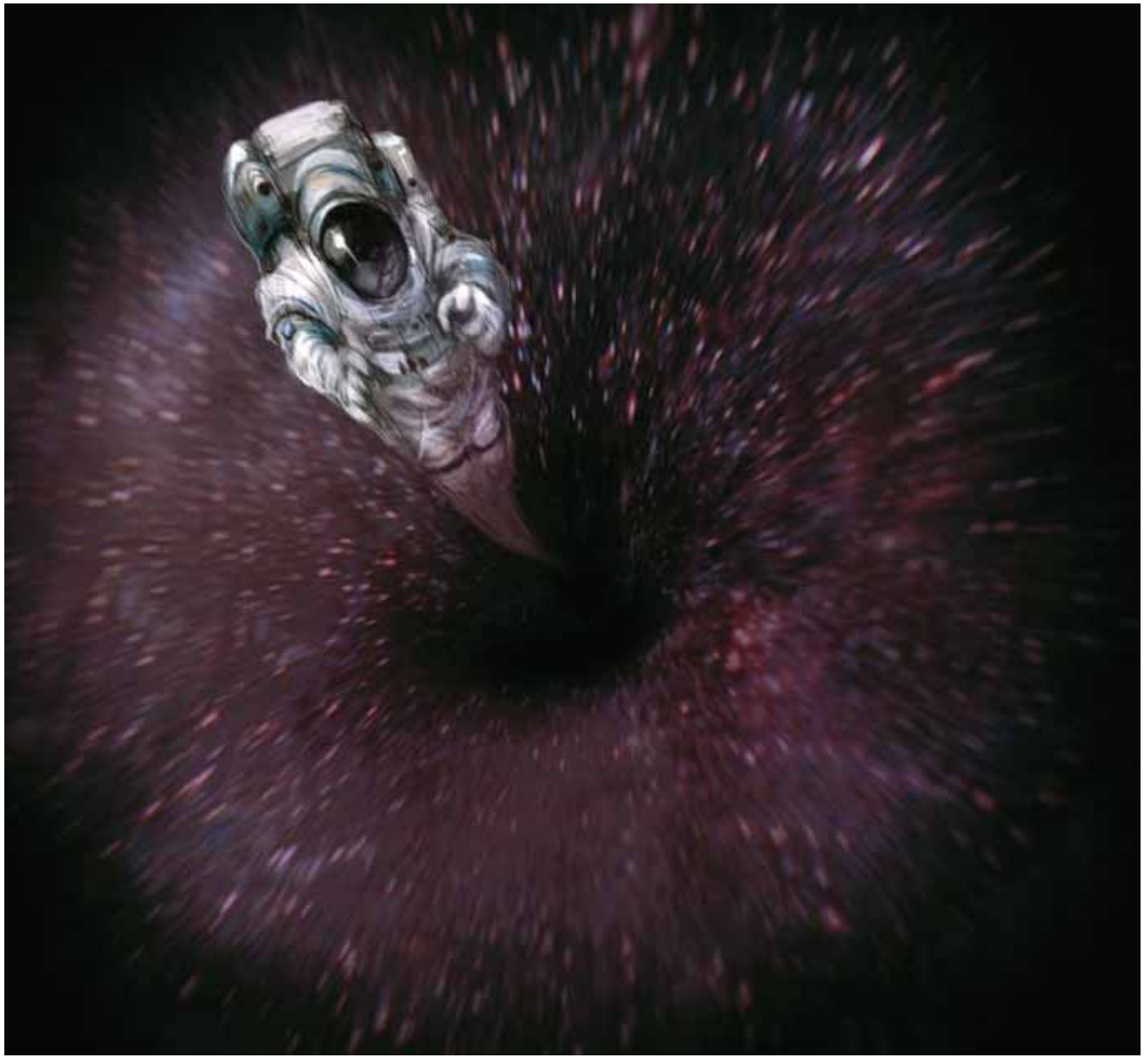
Photon/Electron/Positron Equilibrium

In the early universe, there was a balance between pairs of electrons and positrons colliding to create photons, and the reverse process. As the temperature of the universe dropped, the balance was altered to favor photon creation. Eventually most electrons and positrons in the universe annihilated each other, leaving only the relatively few electrons present today.



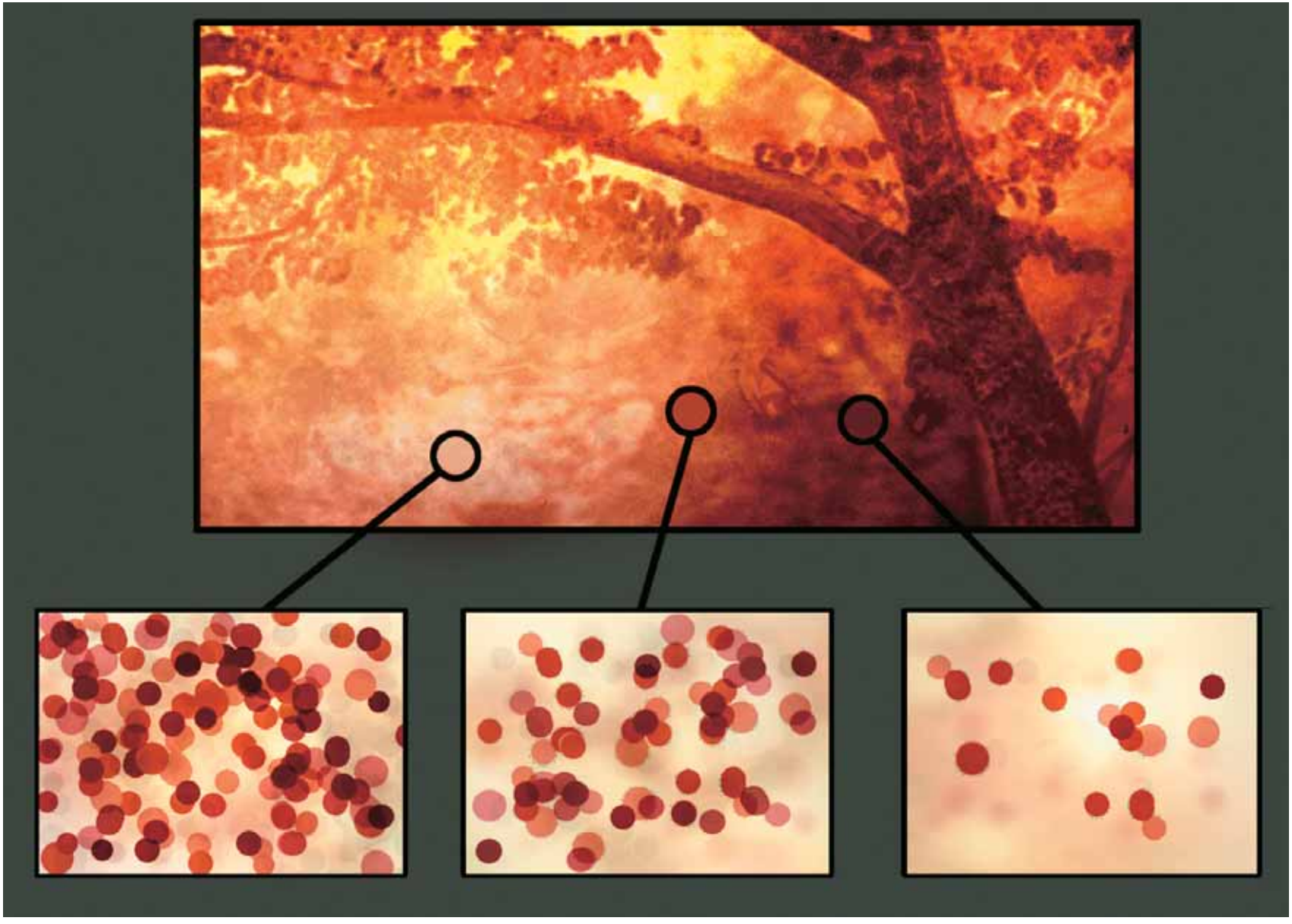
Cannonballs Above and Below Escape Velocity

What goes up need not come down—if it is shot upward faster than the escape velocity.



Tidal Forces

Since gravity weakens with distance, the earth pulls on your head with less force than it pulls on your feet, which are a meter or two closer to the earth's center. The difference is so tiny we cannot feel it, but an astronaut near the surface of a black hole would be literally torn apart.

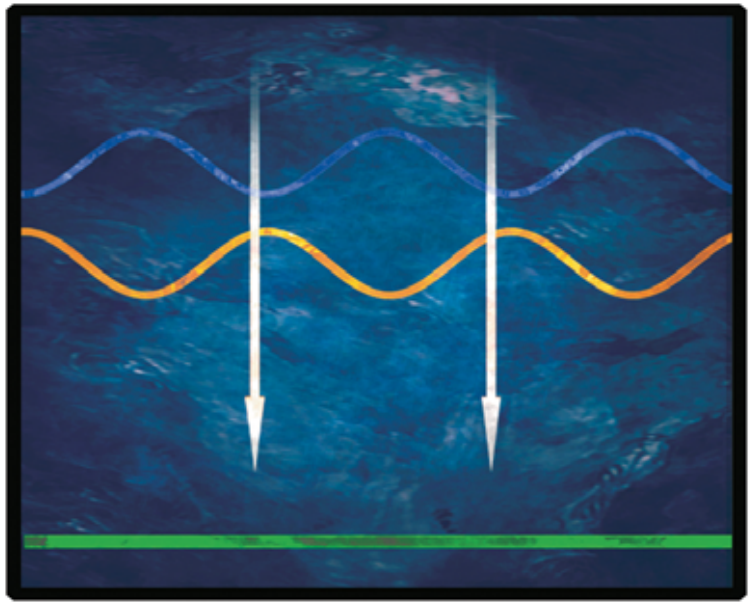


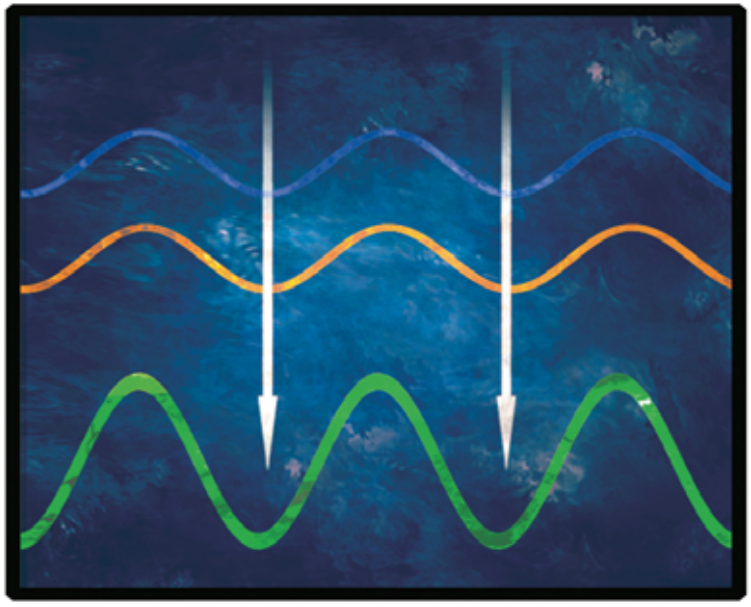
Faintest Possible Light

Faint light means fewer photons. The faintest possible light of any color is the light carried by a single photon.

Smeared Quantum Position

According to quantum theory, one cannot pinpoint an object's position and velocity with infinite precision, nor can one predict exactly the course of future events.



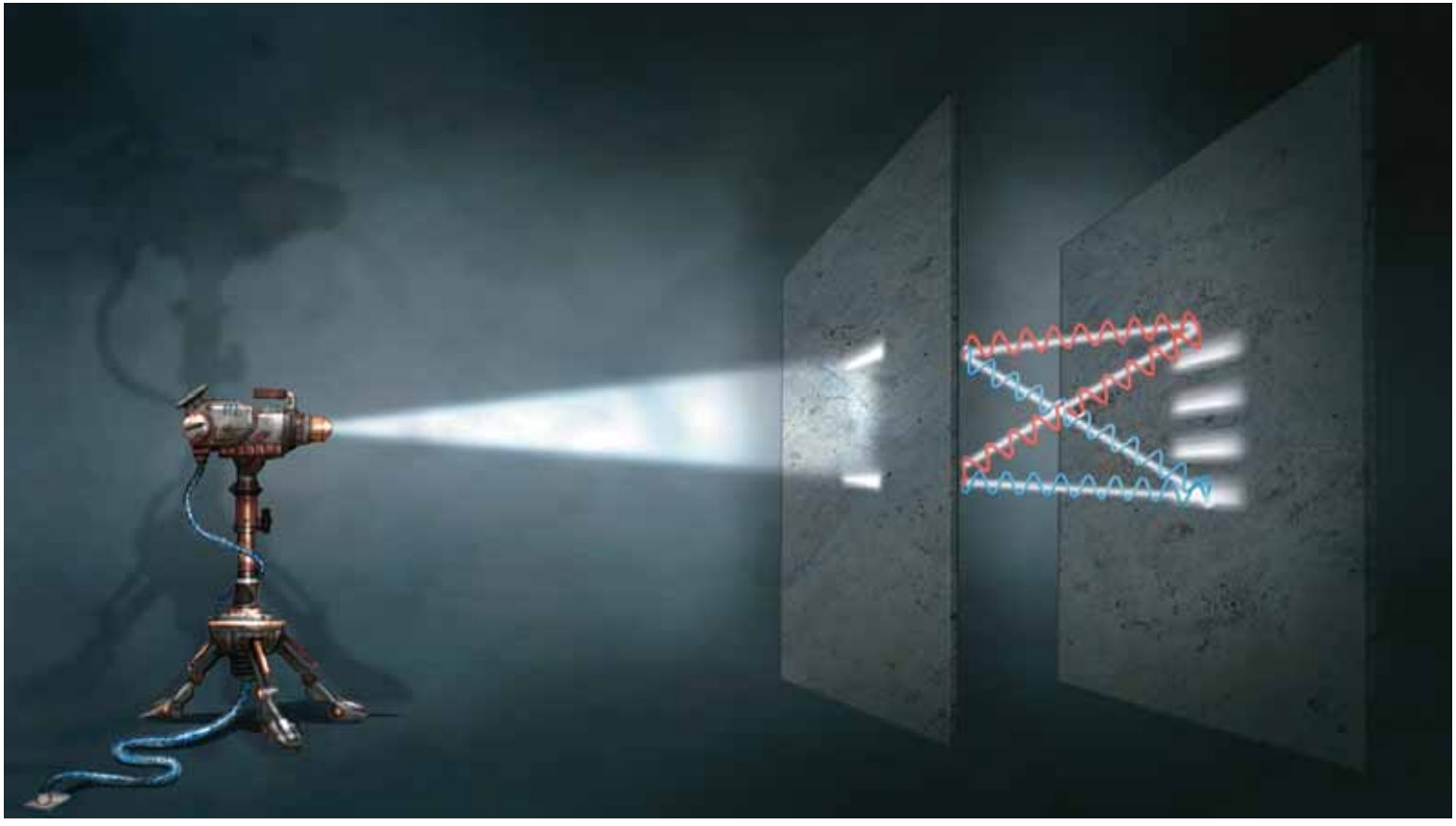


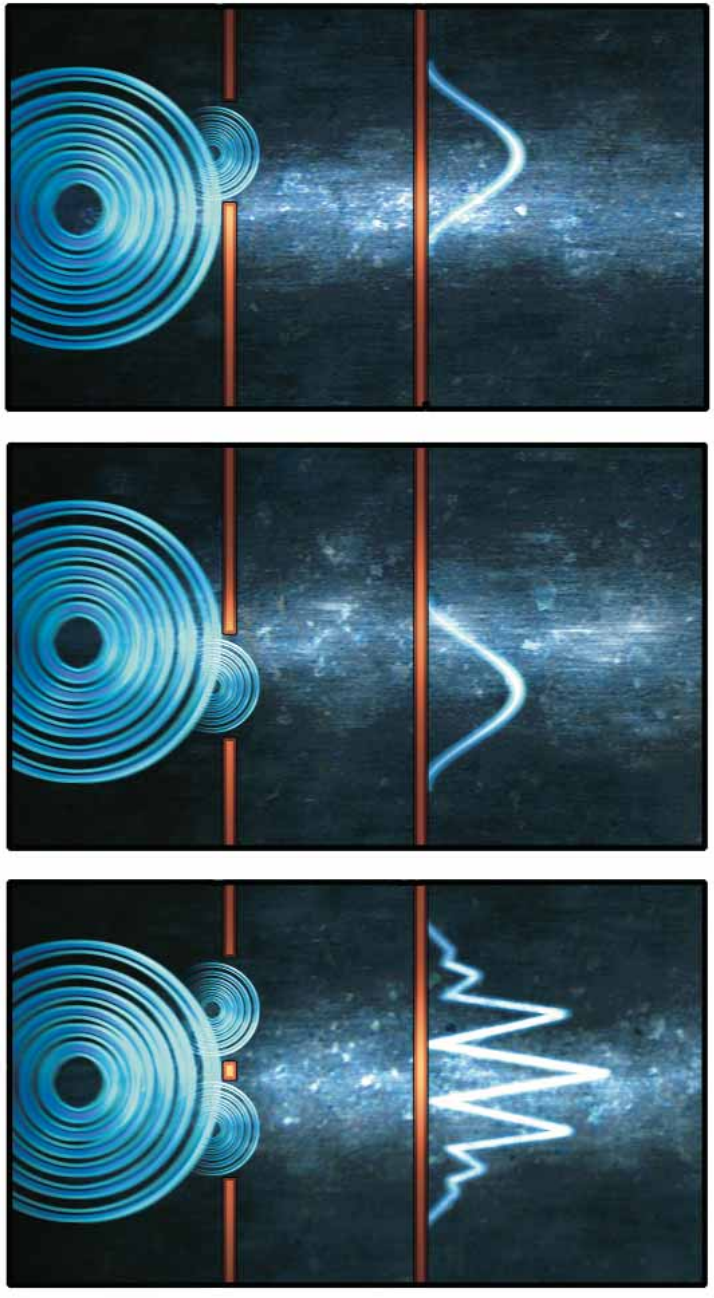
In and Out of Phase

If the crests and troughs of two waves coincide, they result in a stronger wave, but if one wave's crests coincide with another's troughs, the two waves cancel each other.

Path Distances and Interference

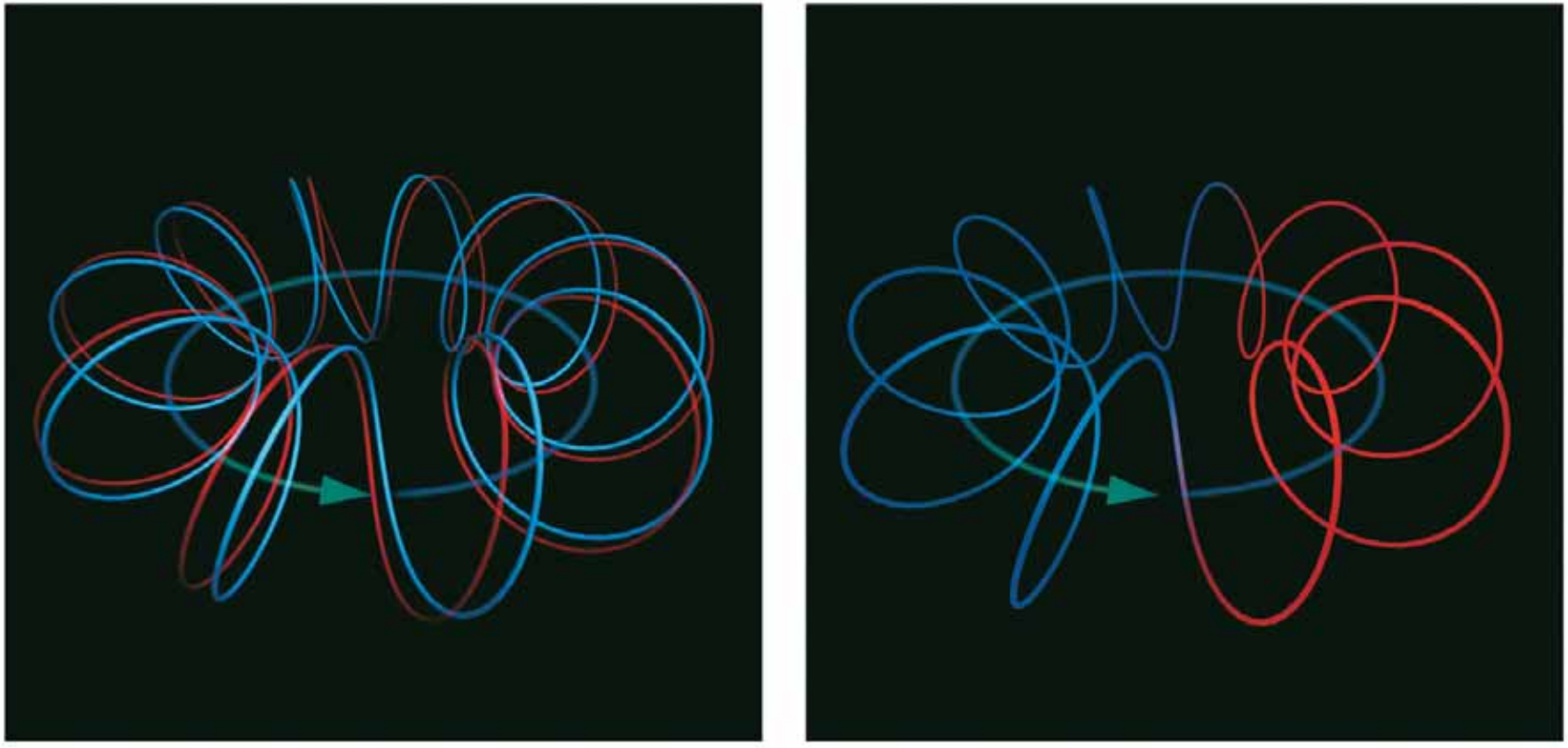
In the two-slit experiment, the distance that waves must travel from the top and bottom slits to the screen varies with height along the screen. The result is that the waves reinforce each other at certain heights and cancel at others, forming an interference pattern.





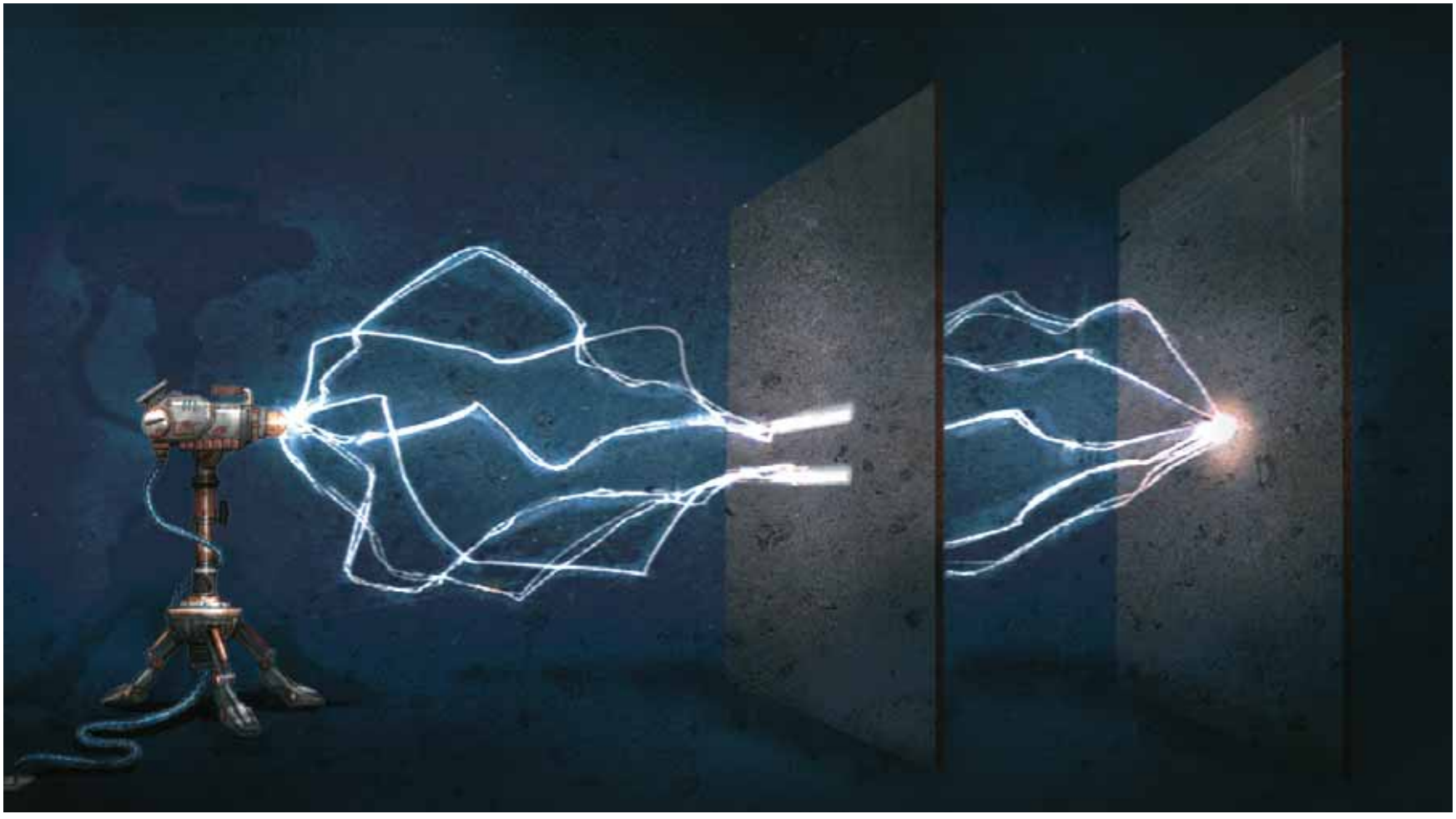
Electron Interference

Because of interference, the result of sending a beam of electrons through two slits does not correspond to the result of sending the electrons through each slit separately.



Waves in Atomic Orbits

Niels Bohr imagined the atom as consisting of electron waves endlessly circling atomic nuclei. In his picture, only orbits with circumferences corresponding to a whole number of electron wavelengths could survive without destructive interference.

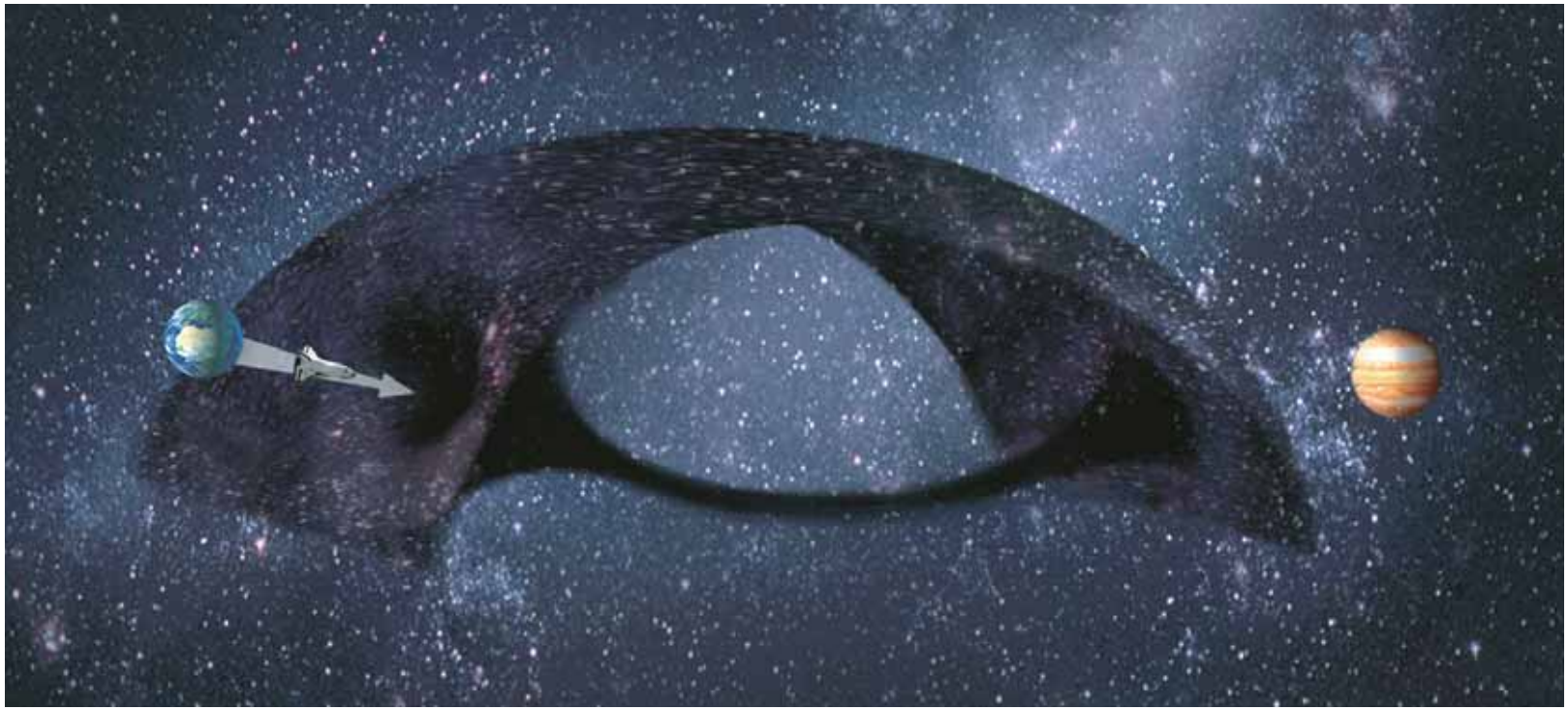


Many Electron Paths

In Richard Feynman's formulation of quantum theory, a particle, such as this one moving from source to screen, takes every possible path.

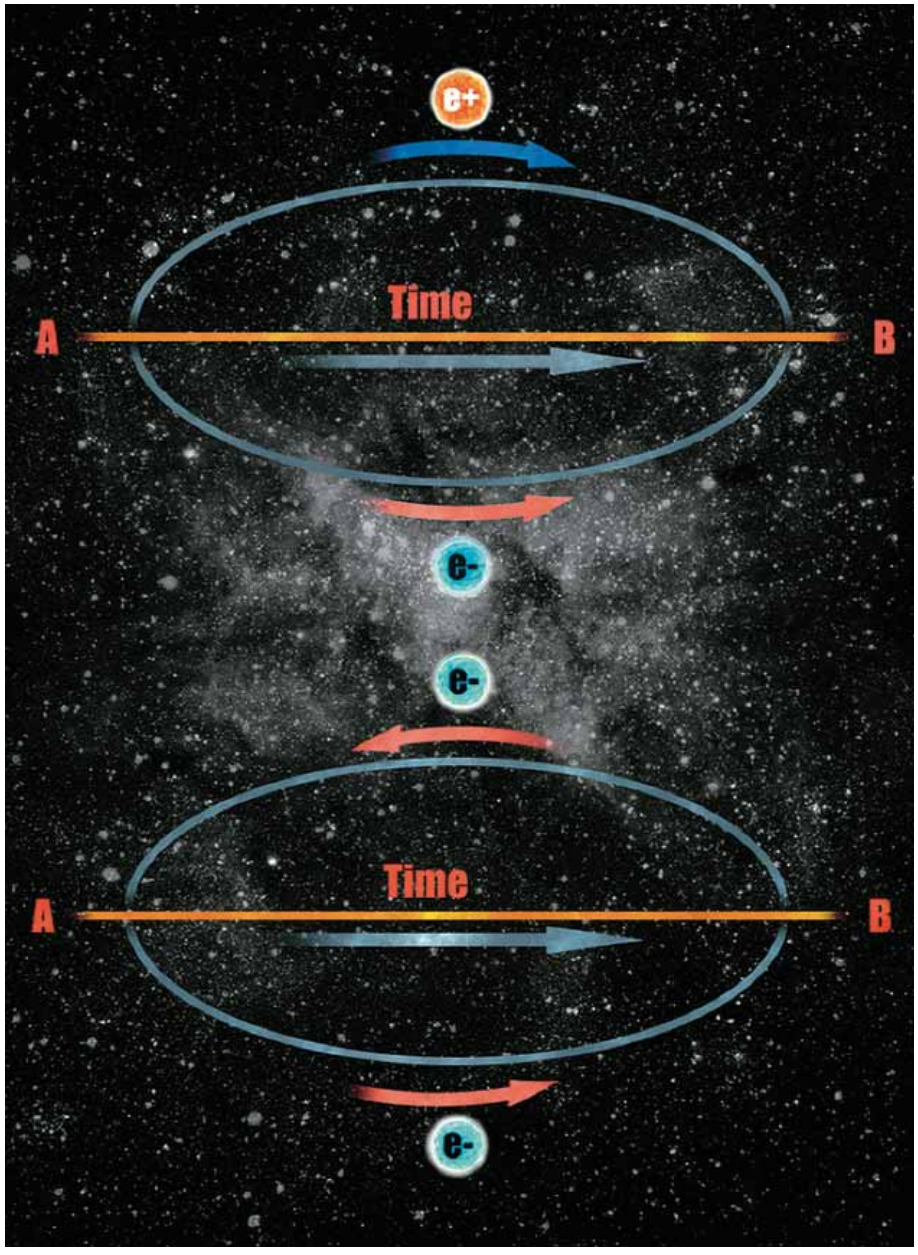
Time Machine

The authors in a time machine.

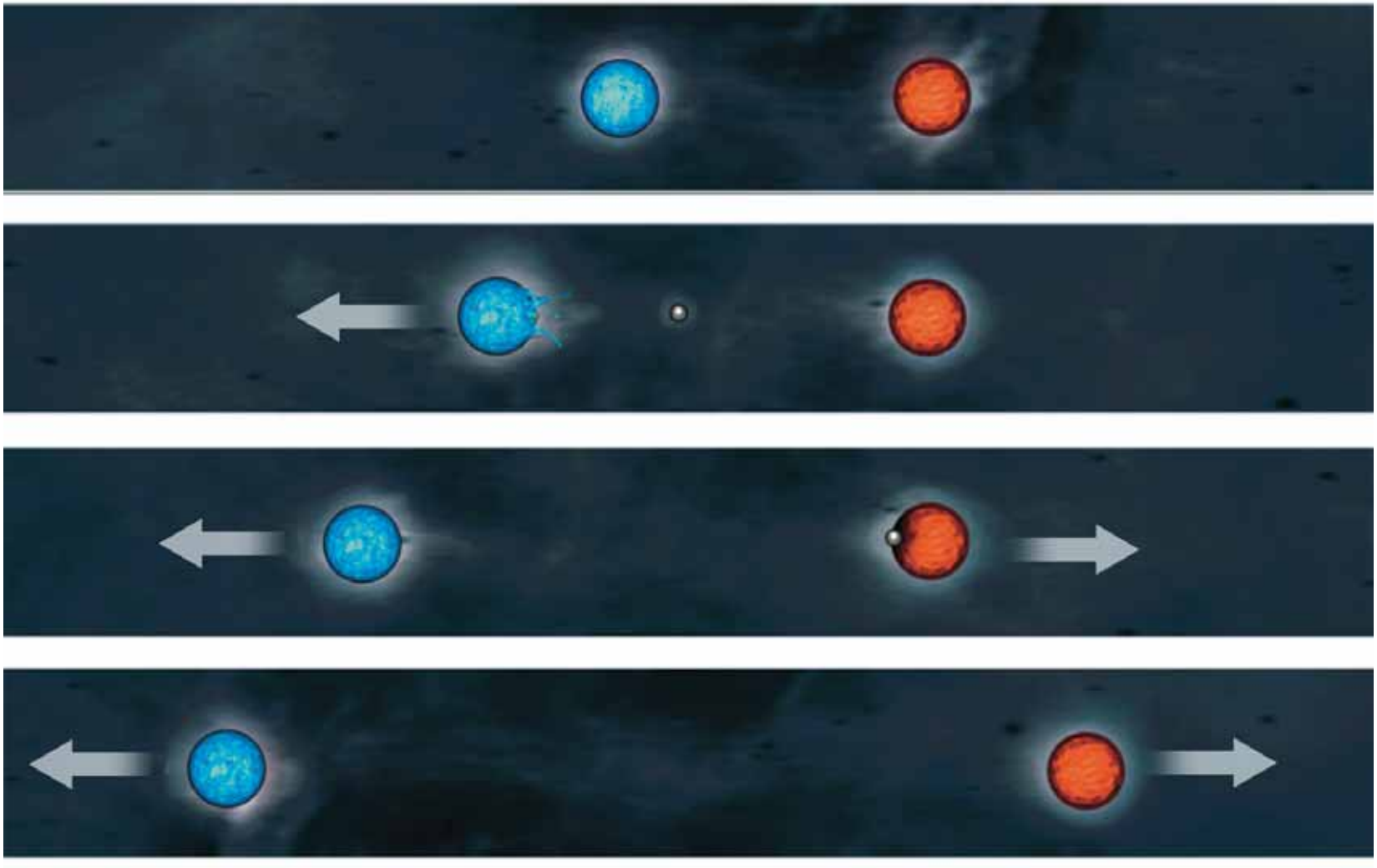


Wormhole

If wormholes exist, they could provide shortcuts between distant points in space.

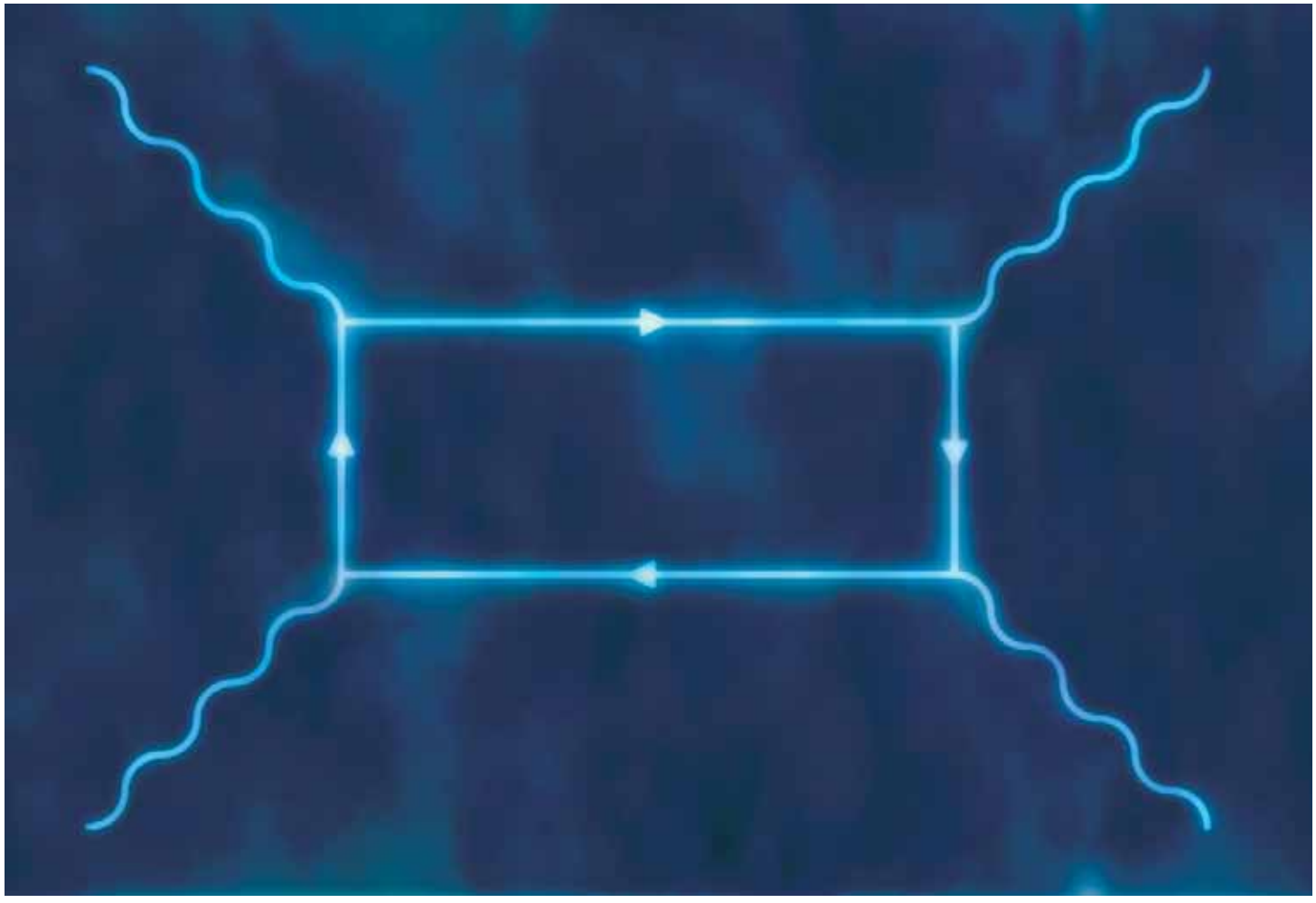


Antiparticle à la Feynman
An antiparticle can be regarded as a particle traveling backward in time.
A virtual particle/antiparticle pair can therefore be thought of as a particle moving on a closed loop in space-time.



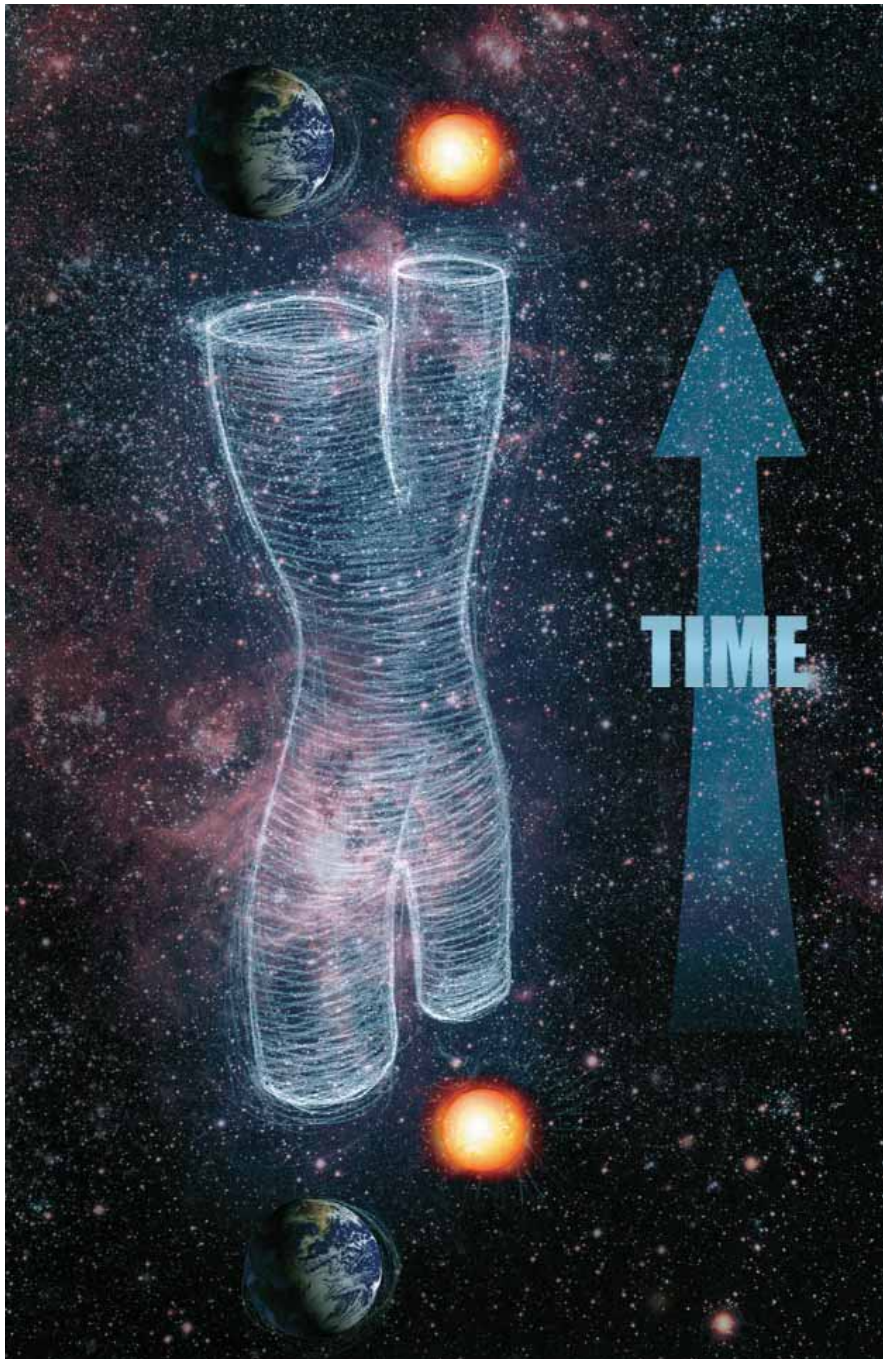
Particle Exchange

According to quantum theory, forces arise from the exchange of force-carrying particles.

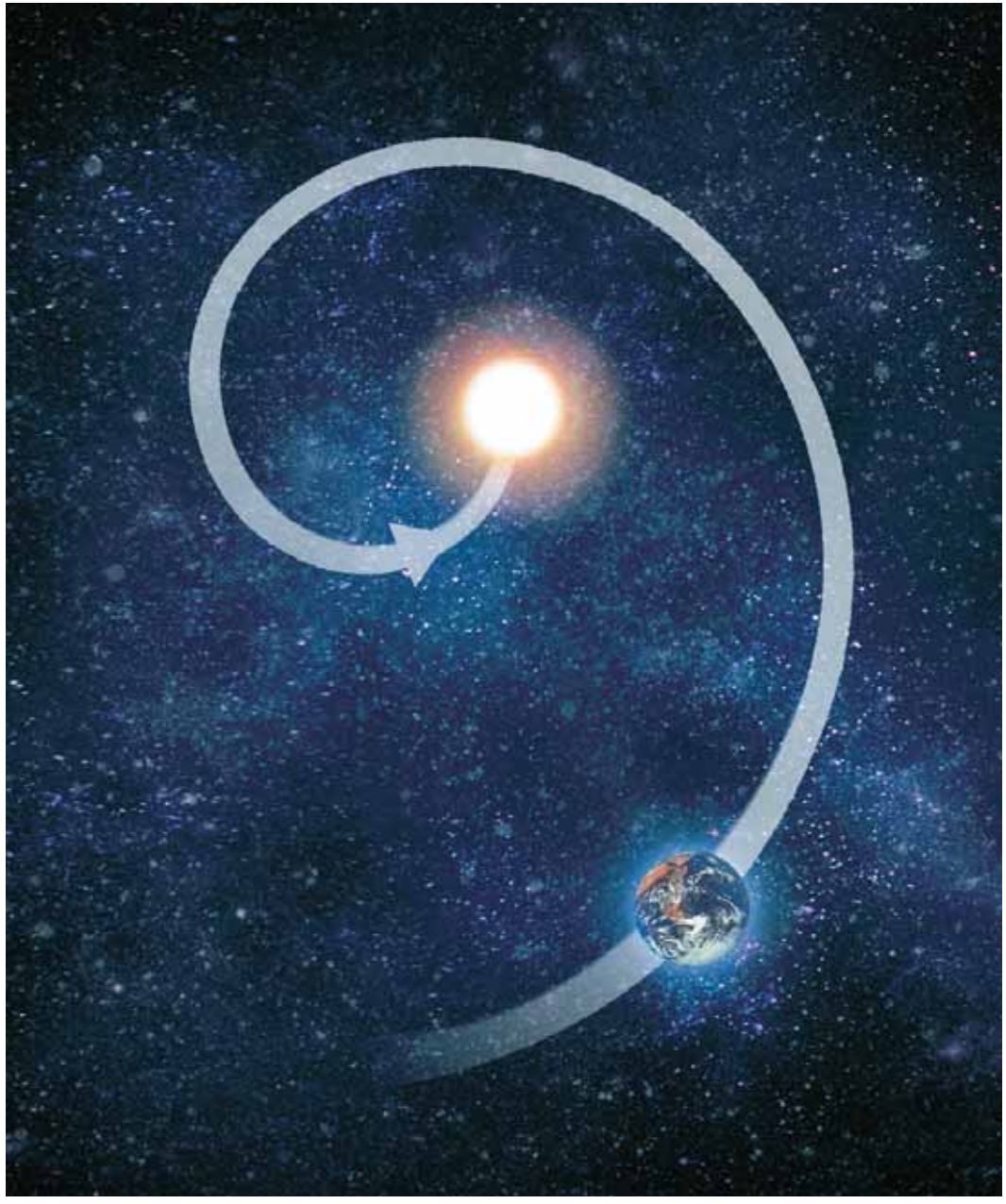


Feynman Diagram of Virtual Particle/Antiparticle Pair

The uncertainty principle, as applied to the electron, dictates that even in empty space virtual particle/antiparticle pairs appear and then annihilate each other.



Feynman Diagrams in String Theory
In string theories, long-range forces are viewed as being caused by connecting tubes rather than the interchange of force-carrying particles.



The Importance of Being Three-Dimensional

In more than three space dimensions, planetary orbits would be unstable and planets would either fall into the sun or escape its attraction altogether.

From Turtles to Curved Space

Ancient and modern views of the universe.

A BRIEFER HISTORY OF TIME

A BRIEFER HISTORY OF TIME

STEPHEN HAWKING & LEONARD MLODINOW


A BRIEFER HISTORY OF TIME