(a)(i) A Galaxy Moves Away From The Earth At A Speed Of 3.9 104 Km/s.The Speed Of Light Is 3.0 105 Km/s.Light

(a)(i) A Galaxy Moves Away From The Earth At A Speed Of 3.9 10^4 Km/s. The Speed Of Light Is 3.0 10^5 Km/s. Light

Introduction to Galactic Motion and the Speed of Light

Understanding the movement of galaxies relative to Earth provides vital insights into the universe's structure, expansion, and history. When a galaxy moves away from us at a certain velocity, it influences how we interpret cosmic phenomena such as redshift, universe expansion, and the age of the cosmos. In this article, we explore the case where a galaxy recedes from Earth at a speed of 39,000 km/s, considering the implications of this velocity in relation to the speed of light, which is 300,000 km/s. We will delve into concepts such as Hubble's Law, redshift, the scale of cosmic expansion, and the significance of such velocities in modern astrophysics.

Understanding the Galaxy's Recession Speed

What Does a Speed of 3.9 x 10^4 Km/s Mean?

A galaxy moving away from Earth at 39,000 km/s is moving at a significant fraction of the speed of light. To put this into context:

- Recession velocity: 39,000 km/s
- Speed of light (c): 300,000 km/s

This means the galaxy's speed is approximately 13% of the speed of light:

\[
\frac{39,000\, \text{km/s}}{300,000\, \text{km/s}} = 0.13 \text{ or } 13\%
\]

This is a substantial velocity in cosmic terms, indicating the galaxy is receding rapidly, possibly due to the expansion of the universe.

Implications of High Recession Speeds

- Cosmic expansion: Such high velocities support the theory that the universe is expanding

uniformly.
- Redshift measurement: The observed shift in the galaxy's light spectrum (redshift) is directly related to its velocity.
- Distance estimation: Hubble's Law connects recession velocity to the galaxy's distance from Earth.

Hubble's Law and Its Significance

Fundamentals of Hubble's Law

Edwin Hubble discovered that galaxies are moving away from us at speeds proportional to their distances, summarized by:

$$
v = H_0 \times d
$$

Where:

- v = recession velocity of the galaxy
- H_0 = Hubble's constant (~70 km/s/Mpc)
- d = distance from Earth in megaparsecs (Mpc)

This law provides a way to estimate the distance to galaxies based on their observed velocities.

Calculating Distance Using Hubble's Law

Given the galaxy's velocity ($v = 39,000\, \text{km/s}$):

$$
d = \frac{v}{H_0}
$$

Assuming $H_0 \approx 70\, \text{km/s/Mpc}$:

$$
d = \frac{39,000\, \text{km/s}}{70\, \text{km/s/Mpc}} \approx 557\, \text{Mpc}
$$

This indicates the galaxy is approximately 557 Megaparsecs away, illustrating the vast scale of the universe.

Redshift and Its Relationship with Galaxy Velocity

Understanding Redshift (z)

Redshift refers to the phenomenon where light from receding objects shifts toward longer wavelengths (the red end of the spectrum). It is quantified by:

$$
z = \frac{\lambda_{\text{observed}} - \lambda_{\text{emitted}}}{\lambda_{\text{emitted}}}
$$

For relatively low velocities compared to the speed of light, redshift relates to velocity via:

$$
z \approx \frac{v}{c}
$$

For higher velocities, relativistic effects must be considered.

Calculating Redshift for the Given Galaxy

Using the non-relativistic approximation:

$$
z \approx \frac{39,000\, \text{km/s}}{300,000\, \text{km/s}} = 0.13
$$

This means the galaxy's light has been shifted by about 13%, a clear indicator of its high recession speed.

Relativistic Effects at High Velocities

Why Relativity Matters

At speeds approaching a significant fraction of the speed of light, classical physics no longer suffices. Instead, Einstein's theory of special relativity must be applied to accurately describe the galaxy's motion and the resulting redshift.

Relativistic Doppler Shift Formula

The relativistic Doppler effect relates redshift to velocity:

$$
1 + z = \sqrt{\frac{1 + v/c}{1 - v/c}}
$$

Plugging in $v = 0.13c$:

$$
1 + z = \sqrt{\frac{1 + 0.13}{1 - 0.13}} = \sqrt{\frac{1.13}{0.87}} \approx 1.14
$$

Thus, $z \approx 0.14$, consistent with earlier estimates, confirming the importance of relativistic corrections.

The Expanding Universe and Cosmic Scale

The Big Picture: Universe Expansion

The observation that galaxies move away from us at speeds proportional to their distances supports the Big Bang theory. The universe is not static; space itself is expanding, causing galaxies to recede from each other.

Implications of High Recession Velocities

- Cosmic horizon: The universe's expansion limits how far we can see—light from galaxies moving away faster than the speed of light due to space expansion can never reach us.
- Observable universe: The galaxy's high velocity suggests it is near or beyond our cosmic horizon, depending on the universe's age and expansion rate.
- Dark energy: Accelerated expansion observed in distant galaxies points to dark energy's influence, which is responsible for the universe's accelerating expansion.

Understanding the Limitations of Classical Physics

Why Classical Mechanics Fails at High Velocities

Classical physics, including Newtonian mechanics, is inadequate for describing objects moving close to the speed of light. Instead, relativistic physics must be employed to account for effects such as:

- Time dilation
- Length contraction

- Relativistic mass increase

Relativistic Corrections in Cosmology

In high-velocity scenarios, astronomers use Einstein's special relativity to interpret redshifts and velocities accurately, ensuring precise calculations of distances and cosmic parameters.

Conclusion: Significance of Galaxy Recession Speeds in Cosmology

The movement of galaxies at significant fractions of the speed of light, such as 39,000 km/s, is fundamental to understanding the universe's expansion, age, and structure. The interplay between observed velocity, redshift, and distance underpins modern cosmology, illustrating how galaxies serve as cosmic beacons revealing the universe's history. Recognizing the relativistic effects at such high velocities ensures accurate interpretations of astronomical data, deepening our comprehension of the cosmos. As technology advances and observations become more precise, the study of galaxy recession speeds continues to illuminate the universe's mysteries, from its origins to its ultimate fate.

Frequently Asked Questions

What is the speed of the galaxy moving away from Earth in km/s?

The galaxy is moving away from Earth at a speed of 3.9×10^4 km/s.

How does the galaxy's speed compare to the speed of light?

The galaxy is moving at approximately 13% of the speed of light, since 3.9×10^4 km/s is about 13% of 3.0×10^5 km/s.

What is the significance of a galaxy moving away at such a high speed?

Such high speeds indicate the galaxy is receding due to the expansion of the universe, which is a key observation in cosmology and supports the Big Bang theory.

Can the galaxy's speed be considered relativistic? Why or why not?

Since the galaxy's speed is about 13% of the speed of light, relativistic effects are relatively small but may still be considered for precise calculations.

How does this galaxy's recession speed relate to Hubble's Law?

According to Hubble's Law, the velocity of a galaxy moving away from Earth is proportional to its distance; this speed exemplifies the universe's expansion described by the law.

What does the speed of light being 3.0 × 10^5 km/s imply about measuring such galaxy velocities?

Since the galaxy's speed is a significant fraction of the speed of light, relativistic Doppler effects may need to be considered when analyzing its light and redshift.

What is redshift and how is it related to the galaxy's velocity?

Redshift is the increase in wavelength of light from a receding object; the higher the velocity, the greater the redshift observed, indicating the galaxy is moving away.

Why is understanding galaxy velocities important in cosmology?

Measuring galaxy velocities helps determine the rate of universe expansion, infer distances, and understand the universe's history and structure.

Additional Resources

A Galaxy Moves Away From The Earth At A Speed Of 3.9 x 10^4 Km/s. The Speed Of Light Is 3.0 x 10^5 Km/s. Light

Understanding the movement of galaxies relative to Earth is fundamental to unraveling the universe's expansion and evolution. When a galaxy is observed to be receding from us at a notable velocity—such as 39,000 km/s—it provides critical insights into cosmology, the nature of space-time, and the universe's history. This article explores the implications of such a galaxy's motion, the principles underlying these observations, and the broader significance in astrophysics.

Introduction to Galaxy Motion and Cosmology

The universe is dynamic, not static. Since Edwin Hubble’s groundbreaking observations in the early 20th century, astronomers have known that galaxies are generally moving away from each other, indicating an expanding universe. The velocity at which a galaxy recedes from Earth can reveal its distance, the rate of universal expansion, and the underlying cosmological parameters. When a galaxy moves away at 39,000 km/s—more than 13% of the speed of light—it exemplifies the universe's vast scales and the relativistic effects involved.

Understanding the Velocity: 3.9 x 10^4 Km/s

Measuring Galaxy Recession Velocities

Galactic velocities are primarily measured through the redshift of their spectral lines. When a galaxy moves away from us, its emitted light stretches toward longer wavelengths—a phenomenon known as redshift. The degree of this shift, denoted by the redshift parameter z, correlates with the galaxy’s velocity via relativistic Doppler formulas. For velocities approaching a significant fraction of the speed of light, special relativity becomes essential to accurately interpret observations.

Key points:

- Redshift (z): The observed increase in wavelength.
- Relativistic Doppler effect: Adjusts the classical Doppler shift formula for high velocities.
- Velocity calculation: Using the relation $v = c \times \frac{(z+1)^2 - 1}{(z+1)^2 + 1}$ for relativistic speeds.

In this case, a velocity of 39,000 km/s corresponds to a redshift z of approximately 0.13, indicating the galaxy’s light has been stretched by roughly 13% during its journey.

The Significance of Such High Velocities

A recession speed of 39,000 km/s is substantial but still below the speed of light (300,000 km/s). This highlights the importance of relativistic physics in cosmology. Notably, velocities greater than about 20-30% of the speed of light require relativistic corrections to avoid inaccuracies in distance and age estimations.

The Speed of Light and Its Role in Cosmology

Speed of Light as a Cosmic Speed Limit

The speed of light, denoted as $c = 3.0 \times 10^5$ km/s, is a fundamental constant in physics. It serves as the maximum speed at which information, matter, or energy can travel through space, according to Einstein’s theory of relativity.

Features:

- Universal speed limit: No object with mass can reach or exceed c.

- Relativistic effects: As objects approach c, their mass effectively increases, requiring infinite energy to reach c.
- Cosmological implications: The expansion of space itself can cause galaxies to recede faster than c without violating relativity, because this involves the metric expansion of space rather than motion through space.

Recession Velocities Beyond the Speed of Light

In the expanding universe model, distant galaxies can have recession velocities exceeding c. This does not mean they are moving through space faster than light; rather, space itself is stretching, carrying galaxies apart at superluminal rates. This distinction is crucial in understanding the universe's expansion and interpreting redshift data.

Implications of a Galaxy Moving Away at 39,000 km/s

Hubble's Law and Distance Estimation

Hubble's Law states that the recessional velocity (v) of a galaxy is proportional to its distance (d):

$$v = H_0 \times d$$

where H_0 is the Hubble constant (~70 km/s/Mpc). Using this, a galaxy receding at 39,000 km/s is approximately:

$$d \approx \frac{v}{H_0} \approx \frac{39,000 \text{ km/s}}{70 \text{ km/s/Mpc}} \approx 557 \text{ Mpc}$$

This distance underscores the vast scale of the universe and the importance of precise measurements for understanding cosmic expansion.

Pros:

- Provides a method for estimating the galaxy's distance.
- Supports the model of an expanding universe.

Cons:

- Assumes a constant Hubble parameter, which may vary over cosmic time.
- Does not account for local gravitational influences or peculiar velocities.

Cosmic Microwave Background and Universal Expansion

Galaxies moving away at high velocities contribute to the redshift of the cosmic microwave background (CMB). Observations of such galaxies help refine models of the universe's age, composition, and the nature of dark energy driving accelerated expansion.

Relativistic Effects and Observational Challenges

Time Dilation and Signal Delay

At such high velocities, relativistic effects like time dilation become significant. From Earth’s frame, processes in the galaxy appear slowed down, and signals take billions of years to reach us due to the finite speed of light.

Features:

- Redshifted signals: Light emitted long ago arrives now, representing a look into the galaxy’s past.
- Time dilation: Observed phenomena in the galaxy appear slower than they are locally.

Pros:

- Offers insights into the galaxy’s past state.
- Validates relativistic physics on cosmic scales.

Cons:

- Makes real-time observation impossible; astronomers see the galaxy as it was in the distant past.
- Complicates understanding of current galaxy properties.

Relativistic Beaming and Luminosity

High velocities can cause relativistic beaming, which affects the observed brightness and spectral characteristics. Understanding these effects is crucial for accurate modeling of distant galaxies.

Broader Cosmological Significance

Insights into Universe’s Age and Fate

Measuring galaxies receding at such velocities helps estimate the age of the universe (~13.8 billion years) and predict its ultimate fate—whether it will continue expanding indefinitely, slow down, or eventually contract.

Dark Energy and Accelerated Expansion

Observations of high-velocity galaxies support the discovery of accelerated cosmic expansion, attributed to dark energy. This leads to the understanding that the universe's expansion rate is increasing, influencing models of cosmology.

Testing Theories of Gravity and Cosmology

Data from high-velocity galaxies challenge and refine the theories of gravity, such as General Relativity, especially in regimes involving large scales and high energies.

Conclusion

The phenomenon of a galaxy moving away from Earth at 39,000 km/s, in the context of a light speed of 300,000 km/s, encapsulates many fundamental aspects of modern astrophysics and cosmology. It underscores the importance of relativistic physics in understanding cosmic expansion, the limits imposed by the speed of light, and the vast scales at play in our universe. These observations not only reinforce the expanding universe paradigm but also serve as critical tools for probing the universe’s history, composition, and ultimate destiny. As technology advances, increasingly precise measurements of such high-velocity galaxies will continue to illuminate the profound workings of our cosmos.

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