ACES Measurements May Exceed Expectations

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Abstract:

The European Space Agency ACES project (Atomic Clock Ensemble in Space) is an international scientific mission whose purpose is the extremely precise comparison of atomic clocks on Earth and in space. A possible synchronous rate of a clock on the ISS satellite with a clock on Earth would imply that gravity does not affect the frequency of radio waves or light. The gravitational shift measured in past experiments could therefore relate to wavelength rather than frequency.

An autonomous influence of physical conditions (gravity, velocity, etc.) acting separately on frequency and separately on wavelength opens the question of the speed of light itself.

A possible synchronous rate of clocks on the ISS and on Earth would also increase interest in independent measurements of the frequency and wavelength of light under various conditions.

The three experiments described below allow us to estimate how close previous measurements may already have come to the expected results of the ACES mission. Earlier experiments were often not carried out consistently enough for this question to be resolved conclusively. The following discussion therefore attempts to give this issue greater attention.

Introduction

The development of physics usually progresses step by step, although from time-to-time circumstances arise that enable major advances in the understanding of natural laws. The ACES experiment may represent one such step.

The ACES system is installed on the International Space Station (ISS) and contains two highly accurate atomic clocks: a cesium clock and a hydrogen clock. The main goal of the project is to measure differences in the flow of time between clocks on Earth and clocks in orbit. The project uses a microwave link between the ISS and ground stations, enabling extremely precise time comparisons.

If ACES measurements were eventually to confirm synchronous clock rates on Earth and in orbit, this would require a new model for understanding the propagation of light. Let us imagine such a model and call it the **Classical Model of Light**, or simply the **Classical Model**.

In brief, the model may be described as follows: space and time are absolute, and light leaves its source with velocity ccc relative to the source. Ether does not exist; the velocity of light is determined by the source of light itself. Motion of the observer affects the observed frequency, but not the wavelength.

At the receiver, the velocity of the observer is added to the velocity of light emitted from the source (c+v)(c+v)(c+v). The Classical Model of Light is at this stage only a hypothesis, which we shall attempt to confirm or refute primarily through ACES measurements, but also through other experiments.

Indications of the Classical Model of Light have appeared in measurements for quite some time. However, many such measurements were not analyzed deeply enough to confirm its suggested properties unambiguously. Let us therefore examine several experiments which, if carried out completely and consistently, could help resolve these dilemmas. Some experiments may not have received sufficient attention because their results did not fit established interpretations of physical phenomena. The following sections describe three measurements that have triggered debates about the nature of light for decades.

Pioneer Anomaly

The Pioneer 10 and Pioneer 11 spacecraft were among the first probes intended for exploration of the outer Solar System and interstellar space. They were launched in 1972 and 1973. Researchers use two methods to determine their velocities: Doppler measurements of radio signals and measurements of the signal travel time to the spacecraft and back.

Within the relativistic interpretation, the two methods yield different spacecraft velocities. This phenomenon became known as the *Pioneer anomaly*. It triggered extensive discussions. The discrepancy between the measured velocities is small, but measurable.

Measurements of spacecraft distance and velocity based on radio signal travel time can be interpreted in two ways: relativistically or within the Classical Model. In the Classical Model, light leaves the source with velocity ccc, while at the receiver the signal arrives with velocity c−vc-vc−v if the receiver is moving away from the source with velocity vvv.

From the Earth's perspective, both models assume that the radio signal travels from Earth to the spacecraft with velocity ccc. The relativistic model assumes that the return signal also travels with velocity ccc, whereas the Classical Model assumes that the signal leaves the spacecraft with velocity ccc relative to the spacecraft and therefore travels relative to Earth with velocity c−vc-vc−v. In this case the spacecraft velocity vvv is approximately 12 km/s.

According to the Classical Model, the return signal therefore requires more time to travel from the spacecraft to Earth than predicted by the relativistic interpretation. Consequently, the two models assign different spacecraft velocities to the same measured signal travel times.

In the Classical Model, the spacecraft velocity obtained from signal travel times agrees with the Doppler measurements. The relativistic interpretation, however, yields different spacecraft velocities depending on whether they are measured by Doppler shift or by signal travel time.

The Classical Model therefore appears to gain support from these measurements. Supporters of relativity, on the other hand, have proposed explanations involving *thermal radiation* as the cause of the unexpected spacecraft velocity. Such an explanation does not address the essential question. The issue is not the origin of an unexpected spacecraft acceleration, but rather why the two measurement methods within the relativistic framework do not yield identical velocities.

Sagnac Interferometer

On a rotating platform, several mirrors are arranged so that a light beam travels along a circular path, reflecting from mirror to mirror. One beam propagates in the direction of rotation, while the other propagates in the opposite direction. The two beams require different travel times depending on the rotational speed of the platform. They eventually arrive at a detector, which measures their phase difference.

For a long time, the Sagnac effect was regarded as difficult to reconcile with relativity. After considerable effort, researchers eventually found a relativistic explanation.

In the Classical Model, rotation of the interferometer causes the mirrors in one direction to move toward the light beam and in the other direction to move away from it. With each reflection, the velocity of one beam increases while the velocity of the other decreases.

In the Classical Model, the two beams therefore leave the interferometer toward the detector with different velocities, meaning that detector distance influences the measured result. In the relativistic interpretation, both beams travel toward the detector with the same velocity, and detector distance is therefore irrelevant.

By repeating the experiment with different detector distances, it should be possible to determine which model objectively explains the operation of the interferometer. Such an experiment has not been carried out, even though it would be crucial for testing relativity. ACES measurements may also provide new insight into this question.

Hale–Bopp

Measurements of Comet Hale–Bopp were among the most remarkable astronomical observations of the 1990s. Because of its great brightness, the comet was especially suitable for spectroscopic and photometric studies.

Astronomers analyzed the comet’s spectral lines and used them to determine its velocity. They observed that a significant portion of the comet’s light showed no spectral-line shift, which could be interpreted as if the comet were stationary. This triggered discussions about possible explanations.

The authors of the experiment suggested that the measured light originated from Earth’s ionosphere rather than from the comet itself. This assumption could have been tested by redirecting the telescope away from the comet toward dark sky, where only ionospheric light would remain. However, this control measurement was not performed. Their assumption therefore remains unresolved, despite being crucial for interpretation of the experiment.

In a mathematical transformation within Euclidean space, the velocity of the receiver influences the observed frequency of a wave according to the Doppler law. The observer’s velocity, however, does not influence wavelength. For water waves or sound waves, such a transformation is intuitively understandable.

If light is treated within the Classical Model, a similar mathematical transformation may also be allowed for electromagnetic waves. In this transformation, different observer velocities influence the observed frequency of light, but not its wavelength.

The Hale–Bopp measurements therefore raise the question of what the instruments were actually detecting. Perhaps the instruments primarily measured wavelength rather than frequency. If light behaves according to the Classical Model, the expected Doppler shift could not have been observed.

This leads to the realization that physics has not devoted sufficient attention to systematic experiments that separately measure the sensitivity of different instruments to frequency and wavelength. This remains an important challenge for future research.

One such experiment would be simple, yet apparently unexplored. Velocities of solar eruptions could be measured once using an optical prism and once using a diffraction grating.

If the two measurements produced different results — for example, if the diffraction grating measured the velocity of solar eruptions while the optical prism did not — two conclusions would follow:

1. an optical prism responds differently to frequency and wavelength than a diffraction grating, and
2. motion affects frequency differently than wavelength.

Such experiments have not received significant attention in the past.

Conclusion

These experiments are discussed because they may indicate an independent variation of frequency and wavelength in light. All three measurements are used by supporters of relativity to support their interpretations. Other experiments related to relativity (GPS, Pound–Rebka, Hafele–Keating, etc.) may likewise be interpreted either as evidence for relativity or as evidence for the Classical Model, depending on the interpreter. We therefore lack pedagogically clear criteria for objectively evaluating confidence in relativity versus the Classical Model.

If ACES measurements were ultimately to demonstrate synchronous clock rates between clocks on the ISS and clocks on Earth, this would provide an answer to the questions raised above and would represent a major step in science.

For such results to gain broad acceptance, repeated verification of ACES measurements — and perhaps even extensions of the experiment — would be required. Additional complementary experiments and renewed analysis of previous measurements would also be necessary. Only then could the results convince a sufficiently large part of the scientific community. Such a development would represent a major shift in scientific thinking.