What will be the first evidence to demonstrate that Einstein's theory of General Relativity (GR) must be revised, and when will that be found?

What might prove Einstein wrong?

This year, the SLAC Summer Institute, a two-week-long series of physics lectures for young scientists, focused on gravity and Einstein's theories of relativity. Even though there has never been any observation that violates special or general relativity, many physicists believe that Einstein's theories are not the final word. Hence a contest among participants of the Summer Institute asked for answers to the question above.

A few dozen entries, some serious and some not, were submitted and judged by a panel of six experts in the field: JoAnne Hewett, Sean Carroll, Michael Peskin, Keith Dienes, Tom Rizzo, and Joe Lykken. Contest organizer JoAnne Hewett says, "the responses were quite varied–people clearly had a lot of fun with this."

The winner was Niklaus Berger, from the Institute for Particle Physics, ETH Zürich, who predicted that the observation of an unusual acceleration of a spacecraft traveling through our solar system will prove that GR needs to be modified. Other entries suggested that GR is accurate, complete, and will never need to be modified; that the discovery of a neutron star/black hole binary system will indicate a different theory from GR; and that a future theoretical unification of GR with quantum mechanics will predict new types of particles not supported by either theory individually, and those particles will be found using a future particle accelerator.

Here are the entries that were recognized as noteworthy by the judges along with some explanatory comments. The answers printed here have been abbreviated and edited for clarity.

Text and comments: David Harris

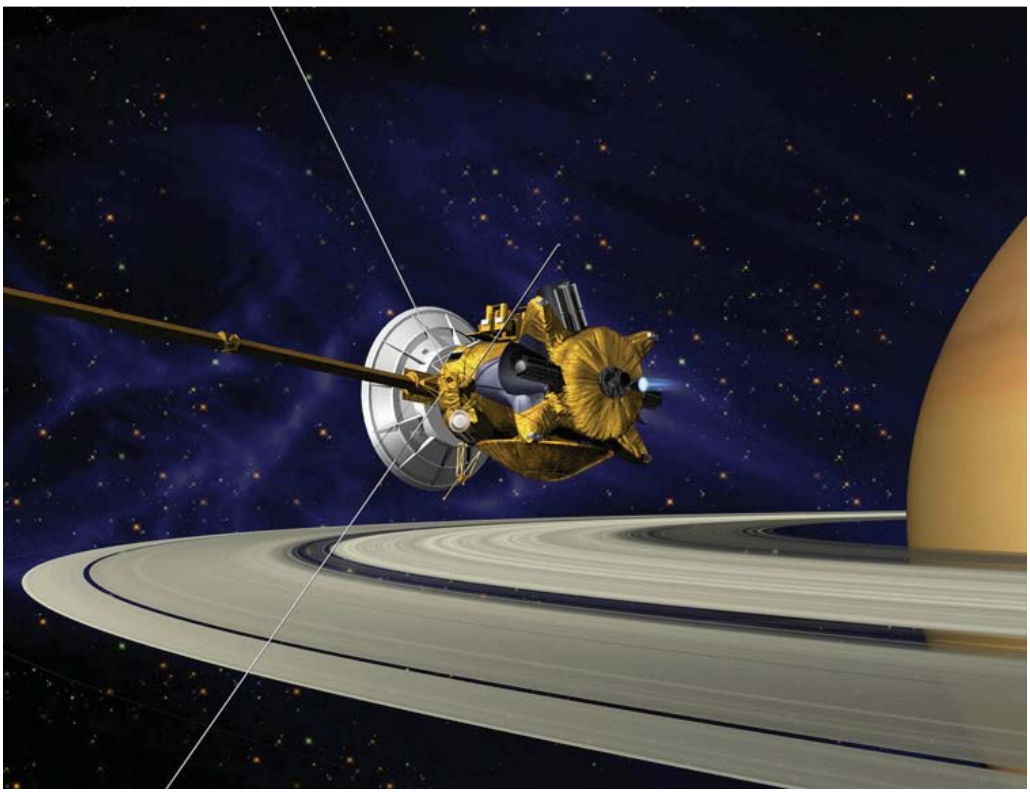

Image: NASA/JPL-Caltech

Artist's interpretation of the Cassini spacecraft orbiting Saturn. Cassini is a cooperative project of NASA, the European Space Agency, and the Italian Space Agency.

Winner

The Cassini spacecraft will exhibit anomalous acceleration towards the sun ("Pioneer anomaly"). A specifically designed follow-up mission will then confirm this and find oscillating anomalous accelerations out to five times Pluto's orbital radius. Taking into account timescales for landing space missions and reaching the outer solar system, this will probably happen around 2050.

Niklaus Berger, Institute for Particle Physics, ETH Zürich

Comment: The Pioneer anomaly is an as-yet-unexplained acceleration that the Pioneer spacecraft seems to experience. Berger's answer suggests the acceleration is due to a modification of GR, and that the Cassini spacecraft will confirm the anomalous acceleration.

Runner up

About six weeks.

Clare Cramer, University of Washington

Comment: Cramer is a member of the Eöt-Wash group that conducts tabletop precision experiments to look for deviations from Newtonian gravity at short distances. Her response fueled rumors of an imminent discovery announcement. The leader of the research group, Eric Adelberger, has confirmed that the group measured a departure from Newtonian gravity, but that they need to check if it is a real effect or just an artifact of the experiment design. More experiments are being conducted to test the observation.

Honorable mention

I think that the most likely (first) violation for Einstein's GR will be in terms of Lorentz violation: the existence of a preferred frame in GR.

Such a breakdown is predicted by string theory (the string scale), loop quantum gravity, and doubly special relativity. It shows up in many theories, but it is not indicative of any of them.

Another piece of "evidence" for this prejudice is that GR does not possess a scale if the cosmological constant, Λ, is zero. Even if Λ does not equal zero, GR does not possess a scale if Λ comes from field theory (e.g. vacuum energy): the scale is hidden in field theory in this instance. Yet the phrase "quantum gravity" implies the introduction of a scale, which must arise in GR somehow.

Damien Martin, University of California, Davis

Comment: Various theoretical proposals suggest that not only might GR fail at some point, but that the special theory of relativity might also only be approximate: the laws of nature may prefer a special frame of reference for the universe, violating the Lorentz symmetry inherent to special relativity and GR. The last paragraph of this entry suggests that physicists should actually expect a violation of special relativity and general relativity. Those two theories do not predict any characteristic energy or length scale for the universe, but various theoretical and experimental hints suggest that there is a characteristic scale.

Honorable mention

Recent supernovae observations have provided evidence (if the data is not misinterpreted) that the expansion of the universe is undergoing a late-time acceleration. This acceleration can be explained in the framework of standard cosmology by dark energy. If the acceleration is due to dark energy, the expansion history of the universe (as seen in measurements of the distance-redshift relation) should be consistent with the rate at which clusters of galaxies grow. Deviations from this consistency would be a signature of the breakdown of general relativity at very large scales of the universe.

Razieh Behkam, Arizona State University

Comment: Astronomical observations allow cosmologists to reconstruct the history of the universe. If this history shows a pattern of growth of clusters of galaxies at odds with the predictions of dark energy and general relativity for the expansion of the universe, then perhaps GR will need to be modified.