PHYSICS

Relativity Passes a Tough Cosmic Test

Continents drift, empires rise and fall, stock markets whipsaw, but photons just keep rolling along. That reassuring idea—that the speed of light is independent of the velocity of the light source—has been a central postulate of special relativity for almost a century. Now, a rigorous test has shown that it is indeed true, to at least 20 decimal places.

On 29 April, at the April meeting of the American Physical Society in Long Beach, California, astronomer Kenneth Brecher of Boston University will report how he confirmed Einstein's assumption by studying distant gamma ray bursts, violent explosions at the edge of the observable universe. Astronomers see the bursts as fleeting pulses of high-energy radiation, some less than a millisecond long, which they plot as peaked graphs of brightness versus time known as light curves.

Nobody knows what gamma ray bursts are or where they get their staggering power. Even so, Brecher says, it's safe to assume that any matter capable of emitting such energetic radiation must be hurtling through space at relativistic speeds, at least a few percent of the 300,000-kilometer-a-second speed of light. And if the explosion flings particles in many directions, sources of the radiation must start out moving at different velocities with respect to Earth.

If the speed of light did depend on the motion of the source, Brecher says, that "velocity dispersion" would give some photons slightly higher speeds than others. During the billions of years it takes the photons to reach Earth, those tiny differences would smear out the light curve of a gamma ray burst, spreading the peak over a longer time.

By analyzing the light curves of a number of gamma ray bursts with extremely rapid brightness variations, Brecher found that any light speed differences must be smaller than 3 billionths of a millimeter per second. "The speed of light is really constant to a precision of one part in 10^{20}," he says.

Bradley Schaefer, an astronomer at Yale University who has used gamma ray bursts to test other tenets of relativity, points out a possible weak point in Brecher's argument: velocity dispersion. "How do you know that the gamma rays aren't emitted by things that have the same velocity?" he says. "You can concoct some finely tuned scenarios where that is not the case." That's possible, Brecher says, but he thinks such scenarios—in which gamma rays reaching Earth all came from particles with the same velocity relative to us—would have to be hopelessly contrived.

Why do astronomers bother torture-testing a theory that almost nobody doubts is true? Schaefer describes the relativity tests as "anomaly searches." "We push as hard as we can, hoping that something breaks," he says. "Who knows what kind of subtle discrepancies we may find? That would be big news and would lead to a new important step" in physics. Brecher agrees: "No one expects great deviations, but one should test the theories as well as one can."

–GOVERT SCHILLING

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ASTRONOMY

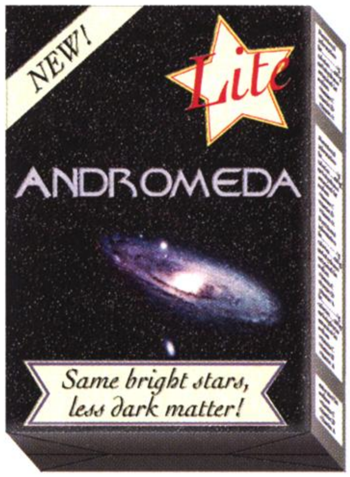
Milky Way Looks Like Big Kid on the Block

Fellow citizens of the Milky Way, take heart. No longer do you have to settle for second best. If two British astronomers are right, our underdog galaxy is, in fact, the heavyweight champion of the neighborhood.

The neighborhood in question is the Local Group, a collection of some 30 galaxies in a region of space about 8 million light-years across. For decades, astronomers have believed that the heftiest of those galaxies is Andromeda. Earlier estimates put its mass at about twice that of the Milky Way, because it is larger and brighter and contains twice as many globular star clusters—spherical collections of hundreds of thousands of stars. But that's "poor evidence," says astronomer Wyn Evans of Oxford University in the United Kingdom. Measurements of brightness, he points out, focus on the visible disk of a galaxy while ignoring the spherical halo of dark, unseen matter that surrounds it. Because Andromeda's disk is more massive than its counterpart in the Milky Way, astronomers assumed that Andromeda's total mass, including the halo, would also be larger.

Evans and astronomer Mark Wilkinson of Cambridge University decided to put that assumption to the test. Together they analyzed velocity measurements of 37 objects that orbit Andromeda, such as small satellite galaxies and outlying globular clusters and planetary nebulae. Because the objects lie far from Andromeda's center, their speeds are determined by the galaxy's total mass—including the dark matter in the halo. From the speeds, Evans and Wilkinson estimate that Andromeda has a total mass of 1.2 trillion solar masses, about half the mass of the Milky Way, the duo reports in a paper slated for publication in the *Monthly Notices of the Royal Astronomical Society*. "Although the central region [of Andromeda] is certainly bigger and brighter," Evans says, "the total mass turns out to be much less."

"This is a surprising result," says Piet van der Kruit of the University of Groningen, the Netherlands. "Although there is no direct proof, everyone assumes that the proportion between the visible and the dark mass is more or less the same for every galaxy." If Andromeda really does have a lightweight



halo, van der Kruit says, astronomers may have to develop a more complicated picture of how galaxies evolve.

So far, few are rushing to change their minds. "This is a really interesting attempt to determine the mass of [Andromeda]," says Paul Hodge of the University of Washington, Seattle, a leading expert on the Andromeda galaxy, "but I'm a little bit nervous about using the distant, outlying possible satellites." Sidney van den Bergh of the Dominion Astrophysical Observatory in Victoria, Canada, agrees. "I don't believe it yet," he says. "It all depends on the objects you use." Van den Bergh, who has discovered many satellite galaxies of Andromeda and of the Milky Way, says that two of the most distant satellite galaxies cited by Evans and Wilkinson—Pegasus and IC 1613—may not really be part of the Andromeda subgroup. In that case, their velocities may reflect forces other than the gravity of Andromeda, which could make them useless for estimating the galaxy's mass.

Evans concedes that "our error bars are pretty large." But he says new data further support the findings. "Since we submitted our paper, we have acquired additional Keck Telescope measurements on five faint dwarf galaxies that were discovered only in 1998 and 1999," he says. The velocities of the new satellites also point to a skimpier Andromeda.

A final answer must wait for more and better velocity measurements, Evans says. NASA's Space Interferometry Mission and the European Space Agency's Global Astro-

ILLUSTRATION: C. CAIN

metric Interferometer for Astrophysics, slated for launch in 2006 and 2009, respectively, will probably settle the matter.

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ASTROPHYSICS

BOOMERANG Returns With Surprising News

For months, cosmologists have been rumbling with excitement, awaiting a look at the data that an antarctic balloon brought back from the edge of the universe. Now the wait is over. On 27 April, a map published in the journal *Nature* gave scientists their most detailed glimpse yet of the primordial universe, revealing the shape of the cosmos and the distribution of matter shortly after the big bang. It was worth the wait: The data support most cosmologists' view that the universe is "flat," but cast doubt on some key assumptions about the balance of matter it contains or the nature of its early expansion.

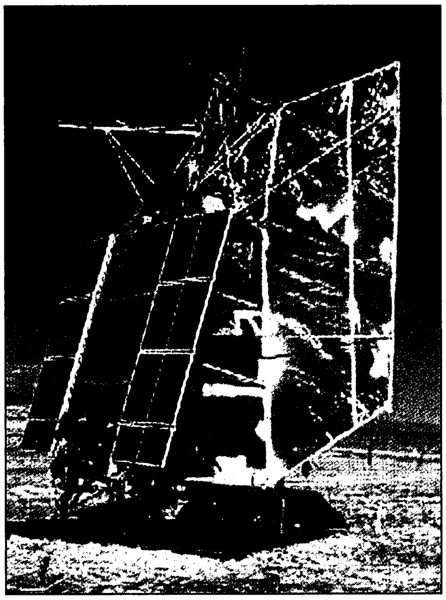
The data came from BOOMERANG, a set of sensitive microwave detectors that a truck-sized helium balloon carried on a 10-day swing around the South Pole in late 1998. During the flight, BOOMERANG (a contorted acronym of "Balloon Observations of Millimetric Extragalactic Radiation and Geophysics") probed a large swatch of sky for fluctuations in microwave radiation, a constant electromagnetic hiss that bombards Earth from all directions, accounting for about 1% of the noise on our television sets. The cosmic microwave background (CMB) is the leftover glow from the big bang.

"This is probably the farthest light that can be observed," says Phil Mauskopf, an astrophysicist at the University of Massachusetts, Amherst, and one of 36 scientists on the international team that masterminded the project. Soon after the birth of the universe, photons were tightly coupled to the hot plasma that made up most of the universe. Light and matter acted as a single fluid. But about 300,000 years after the big bang, the universe cooled enough for the plasma to condense, and the photons escaped from their cage of matter. The CMB is a snapshot of that moment. Thus, by looking at little fluctuations in the CMB, astronomers can map the ripples in the light-matter fluid just as the photons broke free. "You're looking at the surface of the early universe," Mauskopf says.

Unfortunately, the microwave background is so faint that noise from the ground and the atmosphere tend to swamp the signal from the heavens. To escape the racket, the scientists sent their microwave telescope up in a balloon, lofting it into a wind current that circles Antarctica. True to its name, BOOMERANG swung around the South Pole, returning 10 days later almost exactly to its starting point. Because the instrument was aloft for so long and had very sensitive detectors, it was able to measure the CMB over a wide area with great precision and with very low noise.

"It's really the first high-resolution map across a large part of the sky," says Wayne Hu, a cosmologist at the Institute for Advanced Study in Princeton, New Jersey. The balloon experiment has a resolution of about one-third of a degree; the famous COBE satellite, which first detected larger scale fluctuations in 1992, has a resolution of about 7 degrees.

The results are exciting—and in some cases surprising. According to relativity theory, the four-dimensional "sheet" of space and time that we live on can be curved. For years, astrophysicists have been figuring out the ways in which curved space might distort the images of distant objects, in hopes that astronomers would be able to tell by looking just which sort of space we live in—spherelike, saddle-shaped, or neither.



On ice. Five-meter-high BOOMERANG apparatus during testing at McMurdo Station, Antarctica.

CREDIT: BOOMERANG TEAM

"The best part is nobody has to know all of this any more, because the universe is flat," says Scott Dodelson of the Fermi National Accelerator Laboratory in Batavia, Illinois. BOOMERANG and other recent CMB experiments show that the fluctuations are not distorted as theory says they would be in curved space. But whereas a flat universe is what astronomers expected, another bit of BOOMERANG data took them by surprise. According to theory, the ripples in the microwave background ought to exist on many different scales, each contributing a "peak" to the data. BOOMERANG saw a peak corresponding to roughly 1-degree–sized fluctuations and theoretically should have spotted a half-degree peak as well. It didn't.

"With the simplest models, [the peak] should have been higher," Hu says. "It should have been detected." University of Pennsylvania physicist Max Tegmark is excited by the surprise. "That is extremely interesting," he says. "The mischievous side of me wanted that to happen."

The missing peak means that simple models of how the universe formed and what holds it together cannot be correct. To explain the observations, cosmologists must add some new wrinkles, but each has its own problems. "You can raise the amount of ordinary matter, baryons, in the universe, pushing up the first peak and pushing down the second," Hu says. "But you have to push it up significantly, something like 20% to 50%." You could jack up the amount of dark matter in the universe as well, or "tilt" the properties of the engine that drives inflation, or lengthen the plasma phase of the universe. But each of those models requires rethinking basic assumptions, Tegmark says. "You'd have to be violent to one of the sacred cows of cosmology." If he had to choose, Tegmark says he would rather add matter than accept the tilt or late-recombination theories. "Those are the two lesser evils of those four." Hu, on the other hand, favors a combination of extra matter and tilt.

The news is not all bad for the Standard Model, Tegmark says; the shape of the 1-degree peak eliminates some alternative theories to the inflationary model, such as the ones that assume that "topological defects" rather than inflation were responsible for the structure of the universe. "With topological defects, you only predict one peak, but a very broad one. This peak is way too narrow," says Tegmark. "This really means that most of the rivals to the standard theory just died." Thus, variants of the Standard Model are really the only game in town.

Which variants prevail will depend heavily upon future results. Much of the BOOMERANG data has yet to be processed, and soon NASA will be launching a microwave-sensing satellite, MAP, which might catch sight of the second and even a yet-to-be-discovered third peak. That would tell scientists just how much invisible dark matter and baryonic matter there is in the universe and would help nail down the values of 10 or so cosmological parameters, such as the cosmological constant. "The measurements that come out of that are going to be much more sensitive ways of weighing the universe than other cosmological tools," says Tegmark. "To me, this experiment really signifies the beginning of a new era."

–CHARLES SEIFE