THE EXPANDING UNIVERSE: Two teams deliver a crazy result that changes our view of the nature of the cosmos

In 1998 Saul Perlmutter and Brian Schmidt and their teams: the Supernova Cosmology Project and the High-z Supernova Search Team, independently announced that the expansion of the Universe was accelerating.

It had been thought that as the Universe expanded, the gravity of matter would slow the cosmic expansion. But, instead, measuring the distances to exploding stars more than 5 billion light years away, both teams came up with the one crazy result.

In September 2007 the teams will receive the $500,000 Gruber Cosmology Prize for their achievement.

“I thought I was going to get massacred,” said Brian Schmidt with a rueful laugh. “It was just such a crazy result.” Schmidt led the High-z Supernova Search team from his base at the Mount Stromlo observatory in Australia.

“There was a lot of nervous laughter,” said Saul Perlmutter, a University of California, Berkeley scientist and leader of the Supernova Cosmology Project.

The two team leaders were both feeling anxious as they were faced with a seemingly crazy scientific result.

Their nerves were understandable. It was the late 1990s, and each was leading one of two rival teams that had been working on the same thorny scientific problem. Both teams had independently come up with the same findings, which, if shown to be correct, would overturn more than half a century of cosmological theory. Each had done everything they could to double-check that no errors had been made, and so they were pretty confident with their conclusions. Still, the nerves remained.

The cosmological conundrum the teams had been investigating involved nothing less than determining the ultimate fate of the universe itself. For decades it had been more or less assumed that the expansion of the universe must be slowing down, as the combined gravity of all the matter in the cosmos should act to rein in the expansion caused by the Big Bang 13.7 billion years ago. It seemed that the only remaining question was, would there be enough total gravity to eventually halt and reverse the expansion or would it keep going forever, but just get slower and slower as time went on?

There was a third possibility, but it was one that hardly anyone took seriously, partly because of a lack of evidence, but mostly because it didn't fit with the prevailing cosmological views. And it was this—the universe might not only continue expanding, but the expansion might get faster and faster as the eons ticked by.

An accelerating expansion of the universe? What a preposterous idea.

Yet this was exactly what Perlmutter and Schmidt's teams had found.

A BRIEF HISTORY OF COSMOLOGY

For thousands of years, mankind has wondered how big the universe is. The initial assumption was that the Earth was flat and the sky was a kind of dome surrounding and enclosing the ground. As astronomical knowledge developed over the centuries, it became clear that Earth was not only round, but also that it was just one of many planets that inhabit our Solar System. Later insights revealed that we live inside a large galaxy called the Milky Way, home to billions of star systems.

Then, in the early decades of the 20th Century, astronomers realized there were other galaxies in space far beyond our own. Our horizon had just become a whole lot bigger. Toward the end of the 1920s, American astronomer Edwin Hubble presented observational evidence that the galaxies are all moving away from us and from one another. Not only that, but the further away they are, the faster they recede.

Albert Einstein's General Theory of Relativity had implied that the universe would begin contracting if something didn't prevent it. As the accepted wisdom of the time was that the universe was static in size, he had added to his equations a fudge factor called the 'cosmological constant' that would act in opposition to the force of gravity to keep the universe stable.

But the work of Hubble and others showed that receding galaxies fit in nicely with the idea of an expanding universe, and that General Relativity would hold true if the cosmological constant was removed. The conclusion was obvious—the universe is expanding, and Einstein's fudge factor was no longer needed. He lamented that introducing it had been the 'biggest blunder' of his life.

Finally cosmologists realized that the universe must have expanded from an initial big bang. After the Big Bang, the universe went through a brief period of rapid expansion. Then it began to slow down due to the combined gravitational pull of all the 'stuff' that had been created in the Big Bang. As time went on, the universe would have continued expanding, but at progressively slower rates. If there were just enough 'stuff', it would eventually peter out many billions of years from now. If there were more than enough stuff, the expansion would halt and then reverse—the cosmos would begin to collapse in on itself, leading to a gnaB giB (a Big Bang in reverse).

Until around a decade ago, the common wisdom was that there was probably not enough stuff in the universe to stop the expansion and lead to a collapse. There was probably just enough for the universe to continue to expand but at a slower and slower rate.

So scientists set out to determine which scenario was correct. "It was the perfect problem," says Perlmutter.

A DARK SECRET

Observational astronomers had come up with conflicting results. Some had found evidence that the universe must have close to the 'critical mass' needed to make it continue to expand forever, but just get slower and slower.

Over the years many scientists, both observational and theoretical, had given a lot of attention to this issue. It had become clear that the universe contained not only the normal matter (for example, stars, galaxies) we can see, but also an unknown quantity of invisible stuff dubbed 'dark matter'. Studies of the spin of galaxies, and the movement of galaxy clusters, had shown that they just didn't have a sufficient amount of normal matter to produce enough gravity to hold those galaxies or clusters together. They should have flung themselves apart. But since they obviously weren't flinging themselves apart, there must have been something else there to contribute extra gravity. Dark matter.

And it had to be a lot of dark matter—perhaps as much as two thirds of the total mass of the universe. It seemed that only a small fraction of the cosmos was composed of normal stuff, and the rest was of stuff we couldn't see.

As if this wasn't a big enough concept to come to terms with, there also were conflicting ideas about how much total matter—normal and dark—there was. Some found that there was close to the critical mass, others argued that you would need to have an enormous amount of dark matter to reach that magical figure.

Meanwhile, quietly, some theorists were beginning to suggest that maybe Einstein's cosmological constant would need to be revived to help beef up and explain the total mass/energy content of the cosmos.

But 'the general preference was that the most likely, the most elegant, solution would be that the universe had critical mass,' says Perlmutter, and that it would go on expanding forever but at increasingly slower rates. So his and Schmidt's teams set out to test this idea, using solid measurements and rigorous scientific methods.

THE DISTANCE PROBLEM

Imagine you're on a dark country road at night, and you see headlights coming toward you in the far distance. From experience, you know that headlights are all pretty much the same brightness, so by seeing how bright they seem to be, you can pretty well guess how far away the oncoming car actually is. If you had some sort of device to measure the headlights' brightness, you could get an accurate figure.

Astronomers use the same technique when studying galaxies in deep space. For many years they used a certain kind of star known as a 'Cepheid variable', which changes its light output in a highly predictable manner, making them all appear to be basically the same. By spotting a Cepheid in a distant galaxy and measuring its apparent brightness, they could compare this with what they knew to be its true intrinsic brightness; the difference could be plugged into a simple equation to gauge the star's (and galaxy's) distance.

But as astronomers looked deeper and deeper into space, Cepheids became too faint and too hard to see. They needed something brighter, something that stood out at huge distances. Fortunately, there is something that fits the bill.

It's called a Type Ia supernova, a kind of exploding star which, like Cepheids, all look much the same no matter where or when they occur. But they're much brighter than Cepheids, so they can be seen in galaxies billions of light-years away.

Because of the time delay in the light reaching us from those galaxies, we actually see them as they were when the light left them, hundreds of millions or billions of years before. Looking further in distance means looking further back in time.

Knowing intrinsically how bright the supernovae are all one has to do is measure how bright they appear to be, and from the difference you can work out how far away they must be in light-years. Multiplying that figure by the speed of light, tells you how long ago the light left the galaxies.

The ability to gauge these distances was just one part of an even bigger nut that astronomers had been trying to crack for many years. They wanted to see how the expansion rate of the universe had changed over time since the Big Bang. Was it slowing down, speeding up or staying constant? The way to do this is to combine the distance measurements with another fundamental measurement. As space has been expanding since the Big Bang, the light from those distant galaxies has been traveling through it and has therefore been 'stretched' by the expansion. The stretching of the light makes its wavelength shift toward the red end of the spectrum—this is known as redshift.

By measuring the redshift of galaxies at different distances from us, and combining that with their distance measurements, scientists could get snapshots of the universe's expansion rate at different times in its history. And that would enable them to work out if it is going slower or faster or remaining constant.

"We now had a way of doing it, using the supernovae," says Perlmutter. "We would be able to tell if the universe was going to last forever."

A TALE OF TWO TEAMS

Thus the stage was set for a potential breakthrough in cosmology. Perlmutter and his colleagues had been studying supernovae since the beginning of the 1980s. In 1988 he formally put together the Supernova Cosmology Project to measure the deceleration of the expansion. The problem was extremely challenging. Up to that time only one sufficiently distant supernova had ever been discovered (weeks past its peak brightness, so its brightness could not be calibrated well), and searching for such targets was considered likely to be a hit and miss affair at best. Observatories were loath to allocate valuable telescope time simply in the hope of spotting a distant supernova. But with the team's development of a special wide-field electronic camera, cutting-edge image-analysis software, and a novel strategy for scheduling observations, they were able to come up with a way of repeatedly scanning thousands of galaxies, sufficient numbers that 'batches' of more than half-a-dozen supernovae were guaranteed to show up—and timed so that they would be discovered while they were still brightening. The batches of distant supernovae started to roll in, semester after semester, year after year.

In 1994 Schmidt, along with Nick Suntzeff of the Cerro Tololo Interamerican Observatory, put together the High-Z Supernova Search Team to also tackle the problem. Their team too was made up of supernova researchers who, over the past 25 years, had worked to understand these titanic stellar explosions. Using large optical telescopes in Hawaii and Chile, they began hunting for distant supernovae.

Working completely independently, the teams set about conducting the extremely detailed observations and calculations needed to build up a picture of galaxy redshifts and distances. It wasn't long before a disturbing trend began to appear.

Each team's measurements showed that the expansion was actually accelerating. "The data didn't behave like we expected it would," says Schmidt. In fact, this was so unexpected that they just didn't believe it at first. Lots more observations and much more number crunching followed, and with these refinements came the realization that the unthinkable must actually be true…the expansion was accelerating after all.

For months the teams tried to figure out where they might possibly have gone wrong, searching for any tiny source of error. 'Our first thought was that once we had taken into account all the calibration steps, and checked the potential sources of uncertainty, the effect would go away,' says Perlmutter. 'But it didn't!'

In the end, both teams had to conclude that their findings were sound, and the data was correct. The expansion of the universe was accelerating.

So they submitted their work for publication in prestigious scientific journals.

Adam Riess was the lead author for the High-Z Supernova Search Team's paper, while Saul Perlmutter led the Supernova Cosmology Project's paper. And then they waited for the furore to erupt.

THE REACTION

In the end they needn't have worried so much. The wider scientific world had known the teams had been working on the problem for years. They also knew there had been vigorous debate between them about the best ways of determining the answer. No one would have been surprised if they had come up with contradictory results, adding fuel to an already sometimes-fiery debate.

So even though the initial response was one of shock, it quickly changed to acceptance. The research was impressively rigorous, and the unanimity between the teams' results was very convincing. It just made the universe work, cosmologically speaking. A few attempts were made to try to propose alternative explanations for the results, but they were quickly abandoned.

Both Perlmutter and Schmidt are quick to point out that, while team leaders often get all the credit, in both cases it really was a full team effort. Many individuals from different institutions all around the world worked on the problem.

In fact, between the two teams, almost all the world's top researchers in the supernova field were involved, although many other outstanding individuals had done important foundation work earlier on too.

WHERE TO FROM HERE

The upshot of the teams' work is this: the total matter/energy balance of the universe is believed to be composed of only 5% normal matter, and around 25% dark matter, with the other 70% attributed to the expansion force, which has been dubbed 'dark energy'.

Having worked out that the expansion is accelerating, and that dark energy exists, the challenge now is to determine what exactly dark energy is.

One solution is to bring back Einstein's cosmological constant, as a force that pervades space and acts in the opposite way to gravity—a repulsion effect that makes the universe want to spread out. This is a leading candidate.

A variation on this theme is something called 'quintessence', a similar force but one that might change with time (as opposed to the cosmological constant, which would remain unchanged no matter how big or old the universe became).

Astronomers are working on ways to refine the redshift/distance measurements in the hope of seeing if the dark energy effect varies depending on where and when in the cosmos you are looking.

But there is another possibility, one that many scientists find disturbing. Maybe there is no such thing as a dark energy that acts against gravity. Perhaps it is our understanding of gravity that is faulty. If gravity doesn't behave the way we think it does over very large distances, or if it has changed its nature at different stages of the universe's history, then maybe Einstein's General Theory of Relativity needs replacing or modifying. But General Relativity has stood up against every test thrown at it so far, so to most scientists the idea that it might need changing is something that makes them very uncomfortable. Yet the possibility cannot be ignored.

So could it be that, having already overturned one long-cherished astronomical concept with their research, the two teams' 1998 findings will lead to the overturning of another?

"I'm an agnostic when it comes to this," says Schmidt, preferring to wait until the facts are in before choosing sides.

“There’s a lot of optimism that the answer can be found,” adds Perlmutter, who is now the principal investigator for a proposed space telescope that might help solve the problem.

Only time will tell.

What is a supernova?

Supernovae come in two main types. One of them, called Type II, occurs when a massive star runs out of its internal nuclear fuel and explodes. The burst of light emitted can for a short while outshine all the other stars in its host galaxy combined.
The other kind of supernova is called Type Ia. It too can produce enough light to put an entire galaxy to shame, but via a different physical process. When an ‘ordinary’ star (such as our Sun) reaches the end of its life, it blows off its outer layers and leaves only the core, which becomes a tiny white dwarf star—a dying ember. If the white dwarf happens to have a normal companion star in a binary orbit, it can filch some of that star’s gas, slowly siphoning the gas onto its own surface and building up its mass. When the dwarf’s mass reaches a critical limit, a cataclysmic nuclear explosion takes place that destroys it.

The useful thing about Type Ia supernovae is that they have the remarkable characteristic of producing essentially the same amount of explosive energy—ie. light and heat, spread out over the same amount of time. One Type Ia looks like another. This makes them ideal to use as ‘standard candles.’ For example, by comparing the brightness of both nearby and distant Type Ia supernovae, it is possible to accurately gauge how far away the more distant ones are. These sorts of measurements were crucial to the two teams’ efforts to understand the expansion of the universe.

Brian Schmidt’s profile

Brian Schmidt is a Federation Fellow at Mount Stromlo Observatory (part of the Australian National University) near Canberra, Australia. Raised in Montana and Alaska, he studied astronomy and physics at the University of Arizona and gained his PhD at Harvard University in 1993. The very next year he jumped into the cosmic expansion debate, forming the High-Z Supernova Search Team, which brought together 20 leading astronomers from around the world and revealed the accelerating expansion of the universe. The team’s co-discovery of the accelerating expansion jointly won for it (along with Saul Perlmutter’s team) Science magazine’s Breakthrough of the Year for 1998. Schmidt has been awarded many prizes and accolades for his work, including jointly winning the prestigious Shaw Prize in 2006 (along with colleague Adam Riess and Saul Perlmutter). He’s still involved with supernova research, and is currently heading up the SkyMapper project, a new super-sophisticated telescope being built at Siding Spring Observatory in New South Wales, Australia, that will scan the southern sky and produce incredibly detailed images and copious data on the cosmos.

Saul Perlmutter's Profile

Saul Perlmutter is Professor in the Department of Physics at the University of California, Berkeley, and Senior Scientist at the Lawrence Berkeley National Laboratory. He received his BA in physics from Harvard University in 1981 and his PhD in physics at the University of California, Berkeley in 1986. He has been heavily involved in cosmological studies for over 20 years, including dark matter, gravitational lensing and using supernovae as probes of the universe. He instituted and led the Supernova Cosmology Project which, along with Brian Schmidt's High-Z Supernova Search Team, discovered the accelerating expansion of the universe. The team's co-discovery jointly won for it (along with Brian Schmidt's team) Science magazine's Breakthrough of the Year for 1998. He has received many awards and prizes during his career, including California Scientist of the Year in 2003, and the Shaw Prize in 2006 (jointly with Adam Riess and Brian Schmidt). He's also a member of the National Academy of Sciences. Perlmutter remains active in research that uses supernovae, and is the developer and principle investigator for the Supernova Acceleration Probe (SNAP) space mission that is intended to help narrow down the nature of the dark energy. He's hopeful that this mission, or one like it, will soon be approved.

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