CORE CONCEPTS

Core Concept: Supernovae and the accelerating universe

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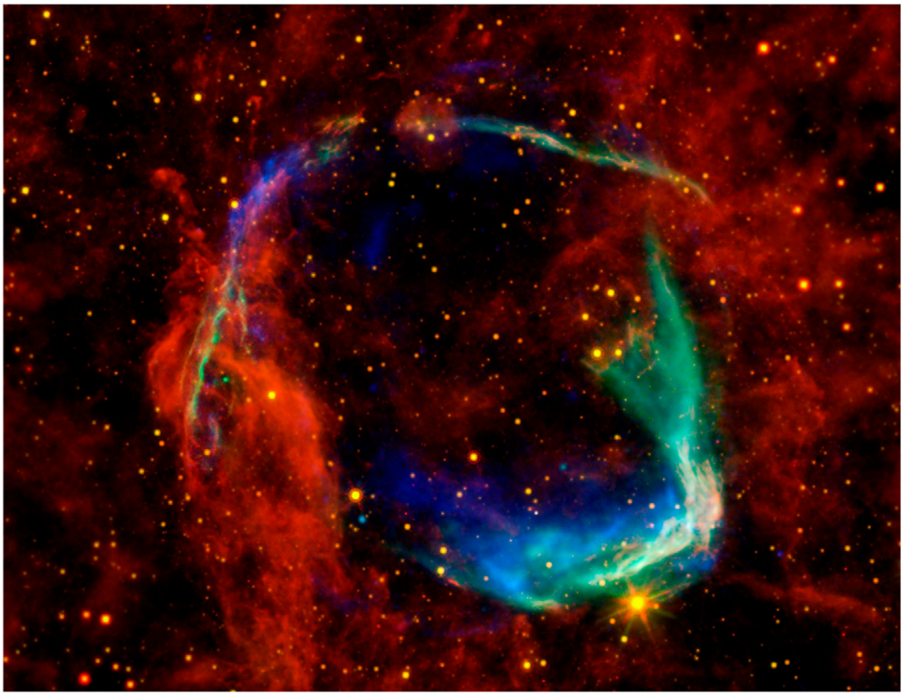
Astronomers Walter Baade and Fritz Zwicky were haunted by two celestial apparitions. It was the early 1930s, and the star-like specters had appeared—and disappeared—from the skies well before either astronomer had been born. But the brief, bright phenomena had transfixed onlookers. Veteran observer Tycho Brahe, for example, was moved to proclaim one a "miracle" when it materialized above his head in 1572; Ernst Hartwig reported another glowing in our neighboring galaxy, Andromeda, in 1885.

Baade and Zwicky calculated that the object in Andromeda had poured out as much radiation in 25 days as our sun does in 10 million years. Such objects, which the researchers dubbed "super-novae," presented "a very curious puzzle," they wrote in one of two PNAS papers published in 1934 (1). Today, astronomers believe the 1572 and 1885 events, as well as others recorded hundreds of years earlier, were each a kind of stellar explosion known as a type Ia supernova (2). The physics behind such blasts is still somewhat puzzling, involving one or possibly two stellar corpses known as white dwarfs (3, 4).

However, in the last two decades type Ia supernovae have illuminated an even more curious—and spookier—puzzle: the existence of a mysterious entity, dubbed "dark energy," that is pushing space itself apart at ever faster rates. Identifying that entity—and in the process, the fate of the cosmos—may hinge on making ever more sensitive measurements of type Ia blasts from the ground and from space.

Lighting the Way

Type Ia supernovae all detonate with about the same brightness. This makes them excellent gauges of astronomical distances: the dimmer they appear, the farther away they must lie. So in the 1990s, two teams set out to use supernovae to study how fast the universe had been expanding several billion years ago, when the supernovae exploded. The teams expected that the expansion, which had begun with the Big Bang nearly 14 billion years ago, was gradually slowing down, thanks to the pull of all of the matter in the universe. "What we found instead was that it was speeding up," says Adam Riess of Johns Hopkins University in Baltimore, MD, a leader of one of the teams. Other observations, including of the earliest light to travel through the universe, known as the cosmic microwave background radiation, later confirmed that finding.



Chinese astronomers documented the first stellar explosion in 185 AD, noting it as a "guest star." Dubbed RCW 86, studies of its remains, seen here, suggest it was a type Ia supernova, the same kind used to discover dark energy. Image courtesy of the following: X-ray, NASA/CXC/SAO and ESA; Infared, NASA/JPL-Caltech/B. Williams (NCSU).

The discovery of the cosmic acceleration earned Riess and two other leaders of the teams, Brian P. Schmidt and Saul Perlmutter, the Nobel Prize in physics in 2011. But no one knows the identity of the phantom that is driving the phenomenon. Labeled dark energy by University of Chicago cosmologist Michael Turner, it might be a set property of space itself: a possibility known as the cosmological constant. In that case, any thimbleful of space from any time or place would contain the same amount of dark energy. Or it might be variable, perhaps gaining strength; if so, it could shred the contents of the universe, ripping apart stars and even atoms. Or the acceleration might signal that gravity grows unexpectedly weaker on cosmic scales. "Sadly, there is no model that is compelling," says Ariel Goobar of Stockholm University in Sweden.

Deciphering dark energy will require a number of different techniques. One involves studying how matter has clumped together at different stages in the universe's history, because dark energy counteracts the attractive pull of gravity. Gauging the mass of galaxy clusters from different cosmic epochs is one way to do this, although it cannot pinpoint dark energy's properties with much precision.

Another, more sensitive, technique probes the growth rate of the universe at different times (which translates to different distances from Earth, because light takes time to arrive here). Type Ia supernovae are an excellent

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way to do that, and astronomers have now found about 1,500 candidates, which is about 15 times the number used to discover dark energy in 1998, says Riess. These supernovae have placed one of the best constraints yet on dark energy's properties (5).

Seeking Celestial Signposts

But the vast majority of known type Ia supernovae exploded about 3.5–8 billion years ago, which is too short a span of cosmic history to measure whether dark energy might be changing, Goobar explains. Because the Earth's atmosphere glows at the wavelengths that even more distant supernovae emit, astronomers need space-based telescopes to find supernovae from earlier cosmic times, he says. The Hubble Space Telescope has found a dozen or so type Ia supernovae that popped off up to 11 billion years ago, but astronomers are holding out hope that a space mission called WFIRST-AFTA (for the Wide-Field Infrared Survey Telescope and Astrophysics-Focused Telescope Assets) will find many more if NASA gives it the green light to launch in 2024 (6).

Astronomers will be hunting for closer supernovae well before that, however, using new instruments on the ground. Supernovae located close to the Earth provide a rich bounty of data on the elements present in the conflagrations, which can help interpret the fainter light from those farther away. These supernovae also provide a crucial measurement of recent cosmic expansion.

To catch more of these nearby blasts, researchers are gearing up to install a powerful new camera on a wide-field telescope owned by Caltech, where Fritz Zwicky spent most of his career. Called the Zwicky Transient Facility (ZTF), the setup will survey the entire Northern Hemisphere sky every clear night beginning in 2017, netting objects that vary in brightness on short timescales, including many nearby type Ia supernovae.

A Hazy Outlook

However, simply finding more supernovae is only the first step to understanding dark energy. Astronomers face major observational constraints. If a supernova looks dim, for example, is that because it is far away or because it is partially obscured by intervening dust? There is not enough telescope time available to tell for sure at the moment, so researchers apply the same dust estimate—an average—to each individual supernova measurement. That leaves an estimated 5% uncertainty in the supernova's true brightness, which limits how precisely researchers can measure dark energy's properties. "Even if I had a million more supernovae today, I am still stuck with 5% uncertainty," says Goobar, a ZTF team member.

Achieving greater certainty will require studying the spectra of supernovae and not just measuring their brightness. That will allow researchers to compare the chemical composition of the blasts at a range of distances to see if they all share the same properties and will also reveal how much dust surrounds each supernova, because dust is brighter in some wavelengths than others, says Goobar.

Unfortunately, measuring the spectra must be done in the few weeks when the supernovae are still shining, and it requires a lot of observing time: a scarce commodity at the big telescopes needed to study distant, faint blasts. "It takes a huge amount of telescope resources to split up the light so you can understand the composition and all that," says Andy Howell, who teaches physics at the University of California, Santa Barbara. He is part of a project that is using small telescopes placed all around the world to study the spectra of supernovae that have detonated within the last 1.3 billion years or so.

Over the next couple of years, the project, called the Las Cumbres Observatory Global Telescope Network, should follow about 225 type Ia supernovae, Howell says. More distant blasts could be spectroscopically analyzed in large numbers by a future space telescope such as WFIRST-AFTA.

With any luck, these devices will unlock the secrets of the sprites that haunted Baade and Zwicky by the centennial of their supernova-coining 1934 paper. "Considering the tremendous progress in recent years and the amazing instruments that will become available in the coming decade," says Goobar, "I would think we have every reason to be optimistic."

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3 Maoz D, Mannucci F, Nelemans G (2014) Observational clues to the progenitors of type Ia supernovae. *Annu Rev Astron Astrophys* 52:101–170.
4 Drake N (2014) News feature: How to light a cosmic candle. *Proc Natl Acad Sci USA* 111(33):11909–11911.
5 Betoule M, et al. (2014) Improved cosmological constraints from a joint analysis of the SDSS-II and SNLS supernova samples. *Astronomy and Astrophysics* 568:A22.
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