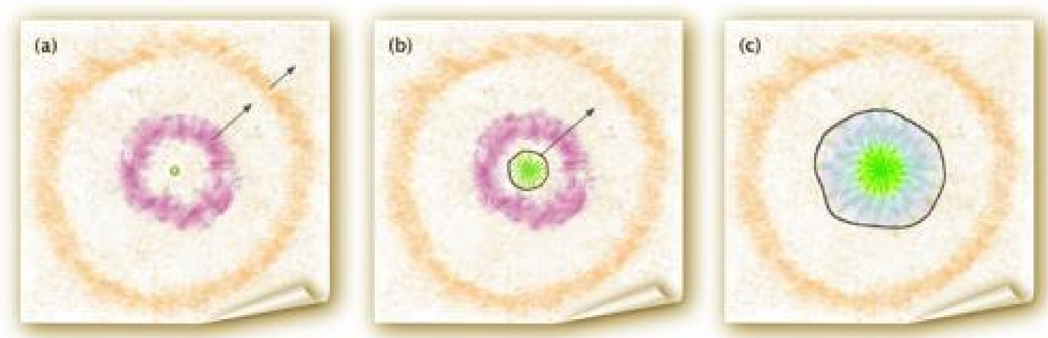
Forecasting explosion: Massive stellar burst, before supernova

February 6 2013



This is a qualitative sketch of a proposed model for SN2010mc. Panel A shows the supernova on the day it detonated. An inner shell (purple) represents the material ejected by the precursor star about one month earlier from the penultimate outburst. An outer shell (orange) is made up of material ejected by the precursor star prior to the penultimate burst. Panel B shows SN2010mc at day five. The supernova shock front (grey line) is moving at 10,000 kilometers per second, ionizing the inner and outer shells along the way, producing the broad and narrow hydrogen emission lines that astronomers on Earth detect. Panel C shows the object at day 20, when the supernova shock engulfs the inner shell. At this point, astronomers only detect a narrow hydrogen emission line. Credit: E. O. Ofek, Weizmann Institute of Science

An automated supernova hunt is shedding new light on the death sequence of massive stars—specifically, the kind that self-destruct in Type IIn supernova explosions.

Digging through the Palomar Transient Factory (PTF) data archive housed at the Department of Energy's National Energy Research Scientific Computing Center (NERSC) at Lawrence Berkeley National Laboratory (Berkeley Lab), astronomers have found the first causal evidence that these massive stars shed huge amounts of material in a "penultimate outburst" before final detonation as supernovae.

A focused search for Type IIn SN precursor bursts, conducted by Eran Ofek of Israel's Weizmann Institute and the PTF team, led to this finding. Their results were published in the February 7, 2013 issue of *Nature*. PTF is an international collaboration that brings together researchers, universities, observatories and Berkeley Lab to hunt for supernovae and other astronomical objects.

The Causal Link

Massive stars—somewhere between eight and 100 times the mass of our Sun—spend much of their lives fusing hydrogen (the lightest element) into increasingly heavier elements, like helium, oxygen, carbon and so on. In the end, there is almost nothing left but an iron core. Eventually, that core collapses, releasing a tremendous amount of energy as neutrinos, magnetic fields and shock waves and destroying the star in the process. From Earth, this explosive event is observed as a supernova. If astronomers detect hydrogen, the event is classified as a Type II supernova. And if the hydrogen-emission line is narrow, the event is classified as a Type IIn (for "narrow").

In the case of Type IIn events, scientists suspected that the narrow emission line occurs as light from the event passes through a thin sphere of hydrogen that was already surrounding the star before it went supernova. Some believed that the dying star might have shed this shell of material before it self-destructed, but until recently there was no evidence to link such an outburst to an actual supernova.

That's where PTF comes in. For almost four years, the PTF team has relied on a robotic telescope mounted on the Palomar Observatory's Samuel Oschin Telescope in Southern California to scan the sky nightly. As soon as observations were taken, the data traveled more than 400 miles to NERSC—via the National Science Foundation's High Performance Wireless Research and Education Network and the Department of Energy's Energy Sciences Network (ESnet)—where computers running software called the Real-Time Transient Detection Pipeline screened the data and identified events for astronomers to follow up on. NERSC also archived this data and allowed collaborators to access it over the Internet through a web-based science gateway, called DeepSky.

On August 25, 2010 the PTF pipeline detected a Type IIn supernova half a billion light years away in the constellation Hercules. Shortly after, Ofek led a search of previous PTF scans of the same stellar neighborhood—using a high-quality pipeline developed by Mark Sullivan, of the University of Southampton—and found the supernova's likely precursor, a massive variable star that had shed a huge amount of mass only 40 days before the supernova was detected. They labeled the event, SN 2010mc.

"After NERSC tools found SN 2010mc, we went back through the archives and found evidence of a previous outburst in the same location and knew that it blew some material out of the star before the final supernova," says Brad Cenko, a UC Berkeley postdoctoral researcher and co-author of the paper. "We've seen evidence of this happening before, but there have been only one or two cases where we've been able to conclusively say when the previous outburst happened."

Ofek and the PTF team developed a scenario and tested it against competing theoretical ideas, using evidence from several sky surveys that were triggered to observe SN 2010mc once it was detected by the

NERSC pipeline. They concluded that the "penultimate outburst" had blown off a hundredth of a solar mass in a shell expanding 2,000 kilometers per second, already 7 billion kilometers away from the supernova when it exploded. Earlier ejecta were detected 10 billion kilometers away, having slowed to a hundred kilometers per second.

After the supernova explosion, high-velocity ejecta passing through shells of earlier debris left a record of varying brightness and spectral features. The observations pointed to the most likely theoretical model of what happened: turbulence-excited gravity waves drove successive episodes of mass loss, finally culminating in the collapse and explosion of the core. Because the stellar outburst occurred very shortly before the supernova, the astronomers suspected that the events were causally linked. Cenko notes that this could have important implications for what processes trigger a supernova.

"I think it is a very interesting object we found, and the way we do our survey and the search at NERSC made it something we were in the unique position to find," says Peter Nugent, a Berkeley Lab senior staff scientist and member of the PTF collaboration.

The Future

Once the team found SN 2010mc's precursor, the team used Sullivan's pipeline to sift through stellar neighborhoods in the PTF archival data where other Type IIn supernovae had previously been detected. According to Nugent, this exercise helped the team identify several other similar cases.

"Although the PTF project is no longer collecting data every night, we are still relying on NERSC resources to sift through our archival data," says Nugent. "This recent discovery shows us that there is still a lot that we can learn from the archival data at NERSC, and gives us some insights into how we may design future experiments to further investigate these events."

More information: dx.doi.org/10.1038/nature11877

Provided by Lawrence Berkeley National Laboratory