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BLOWING IN THE (STELLAR) WIND

Researchers analyze the elements emitted from an unusual star just before it explodes

REHOVOT, ISRAEL—May 21, 2014—When a supernova – the explosion of a giant star —was discovered last year, astrophysicists, with the help of telescopes around the globe, rushed to observe the fireworks. With its dramatic dying flares, this star – a rare type more than 10 times the mass of our sun – can tell us something about the life of these fascinating cosmic bodies, as well as helping paint the picture of how all the heavier elements in the universe are formed.

To understand the star that produced the supernova, the researchers identified the mix of elements that was thrown off right before the explosion began. Prof. Avishay Gal-Yam of the Weizmann Institute of Science's Department of Particle Physics and Astrophysics explains that the star can be identified by the proportion of such elements as carbon, oxygen, and nitrogen detected in the material ejected into space. These elements are created in the nuclear fusion that powers some stars. For example, in our own sun, hydrogen – the lightest atom – fuses to make helium and stops there; but in the massive, hot stars, fusion continues as helium atoms unite to form heavier elements, all the way up to iron.

Scientists believe that such stars are layered like onions: The heaviest elements – iron, for example – are located in the core, while the lighter ones make up the outside layers. At the stars' outermost edges are stellar winds, which blow the material found there out to space. In stars like the one that exploded last year, the wind is so forceful that it can throw off a mass equal to that of our sun every 10,000 years. At some point in the star's life, the lightweight hydrogen making up its outer layer runs out, and it begins tossing out its helium, oxygen, carbon, and nitrogen.

Somewhere under the surface is a layer where hydrogen, helium, and the heavier elements all meet. This layer must be high enough to hold hydrogen but still hot enough to produce the extreme temperatures needed for nuclear fusion. Scientists are

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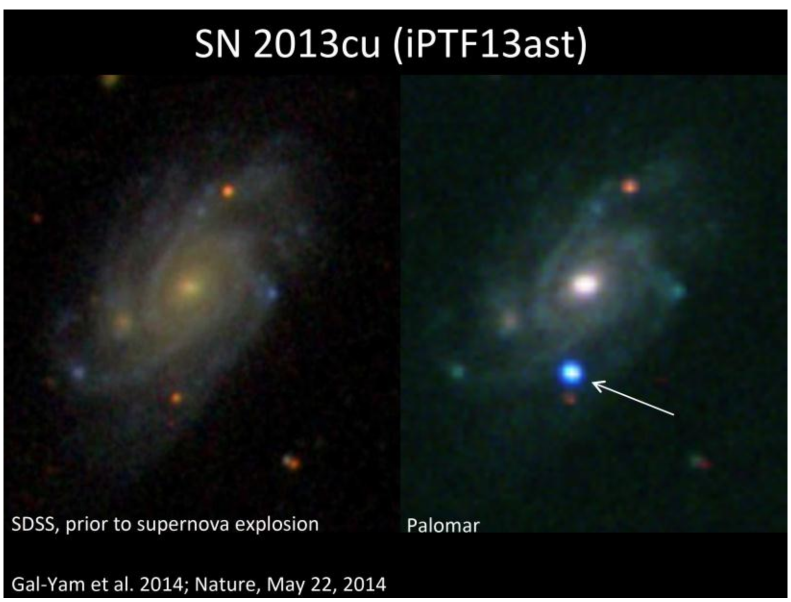
particularly interested in this layer, as it is where nitrogen is formed. Unlike carbon, with six protons (three fused helium atoms), or oxygen, with eight (four heliums), nitrogen has an odd number of protons – seven. This means nitrogen must be the result of fusion between even and odd atoms; for example, three heliums and a hydrogen. Thus, measuring the amount of nitrogen could reveal what lies underneath the skin of such stars.

While the wind keeps sweeping away the star's outer layers, the star's core continues to amass iron until it becomes so heavy that it is no longer stable. At that point, the core collapses in a sudden, violent motion, hurling its outer layers off and producing a brilliant supernova.

Detecting the elements ejected in stellar wind just before such an explosion can only be accomplished within a small window of time – up to a day or so after the terminal blast. This is because intense radiation produced by the explosion shock strips electrons from their atoms. Telescopes equipped with spectrographs aimed at the supernova can pick up the elements' spectra – light that is emitted when the electrons are reunited with the atoms. But they must make their observations quickly, before the rapidly expanding debris from the explosion is swept up by the remnants of the wind, erasing this last trace of the dying star.



The star in question, shortly before it exploded in a supernova. Courtesy of Prof. Avishay Gal-Yam, Weizmann Institute of Science.

Last year, the race to observe the spectra of the supernova's wind began with the robotic telescopes at the Palomar Observatory in

California, part of the intermediate Palomar Transient Factory (iPTF) project led by Prof. Shri Kulkarni of the California Institute of Technology (Caltech). These robotic telescopes are programmed to find transient events – sudden changes in the night sky that could be new supernovae – and alert team members about the sightings. Halfway around the world, Dr. Iair Arcavi, then a doctoral student in Prof. Gal-Yam's group, received the notification. While researchers in the U.S. were still asleep, he assessed the finding, realized its significance, and contacted Dr. Assaf Horesh, then a postdoctoral fellow at Caltech (who has since joined the Weizmann team). Dr. Horesh then conducted spectroscopic observations at the Keck Observatory in Hawaii, which is farther west than Palomar and could thus extend the nighttime viewing of the supernova. Acting quickly, he managed to record the emission spectra of the material thrown to the wind a mere 15 hours after the star exploded.

Working backward from the post-blast observations, Prof. Gal-Yam, Dr. Arcavi, Dr. Horesh, and their colleagues assessed the recorded spectra and showed that the supernova indeed had a nitrogen-rich wind, similar to those of the so-called Wolf-Rayet stars (very large, massive stars that lose mass rapidly due to extremely high stellar winds) we know in our galaxy. This is the first time, says Prof. Gal-Yam, that this feat has been accomplished. Appearing in *Nature* online on May 21, 2014, the findings will be published in the journal's May 22 issue.

Now that the team has shown that the combination of efficient global organization and mobilization of telescopes around the world can work to capture such fleeting events, they hope that further sightings of infant supernova explosions will be possible. Understanding how these stars live and die is important, Prof. Gal-Yam says, and not just because it gives us a window on the workings of the universe: "All the heavier elements in the universe – those with a mass larger than that of helium – are created in the fusion furnaces of large stars and dispersed through supernova explosions. So many questions – about the origins and the relative abundance of different elements – go back to these processes taking place throughout the cosmos."

The intermediate Palomar Transient Factory (iPTF) — led by the California Institute of Technology (Caltech) — started searching the skies for certain types of stars and related phenomena this past February (2014). The iPTF was built on the legacy of the Palomar Transient Factory (PTF), designed in 2008 to systematically chart the transient sky by using a robotic observing system mounted on the 48-inch Samuel Oschin Telescope on Palomar Mountain near San Diego, California. The iPTF is a scientific collaboration of the California Institute of Technology; Los Alamos National Laboratory; the University of Wisconsin, Milwaukee; the Oskar Klein Center; the Weizmann Institute of Science; the TANGO Program of the University System of Taiwan; and the Kavli Institute for the Physics and Mathematics of the Universe.

Dr. Avishay Gal Yam's research is supported by the Helen and Martin Kimmel Award for Innovative Investigation; the Nella and Leon Benoziyo Center for Astrophysics; and the Peter and Patricia Gruber Awards.

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