Studying supernovae, finding the origins of life

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Credit: Weizmann Institute of Science

Many stars die with a whimper, subsiding into cool, small stars, but the most massive go out with a bang. These giants produce elements in their cores, and when the stars explode into the spectacular phenomena known as supernovae, the power of the event scatters the elements far into space. You could even say that supernovae are responsible for life on Earth, since the explosions are the source of most of the elements found on our planet and in our bodies.

"Every atom of oxygen or iron on Earth used to be in the center of some star, and it wound up here only because that star died in an explosion and then those elements were mixed with gases in space," says Prof. Avishay Gal-Yam of the Weizmann Institute of Science's Department of Particle Physics and Astrophysics.

With the aid of research satellites and giant telescopes, Prof. Gal-Yam searches the universe for supernovae – hoping to observe them as they happen and investigate the physical processes that take place before and during the explosion. Studying how stars live and die provides Prof. Gal-Yam and his research team with vital clues about the origins and relative abundance of the elements that make up the periodic table.

"Some of the puzzles we're fascinated by are: why is iron far more common than any other metal? And how are nitrogen and calcium made?" he says.

Prof. Gal-Yam and his collaborators made news several years ago when they discovered a new type of supernova that is characterized by a relatively dim explosion and ejects unusually large amounts of calcium and titanium. These calcium-rich supernovae might help explain the relative abundance of calcium in the universe, including on Earth.

Another remarkable recent observation is producing a wealth of data that is helping astronomers answer basic questions about the origins of the universe.

The event – on August 17, 2016 – was the observation of the massive collision of two neutron stars: the densest objects in the universe besides black holes. The crash gave astrophysicists an opportunity to record the gravitational waves predicted by Einstein's theories: "ripples" in the fabric of space-time produced when a massive object, such as a star, is accelerated to high speeds.

Prof. Gal-Yam and his Weizmann colleagues moved quickly to analyze the collision's electromagnetic radiation before it dispersed. Using a measuring technique called spectroscopy, Prof. Gal-Yam found emission profiles matching those of rare heavy-metal elements – convincing evidence that long-ago neutron star collisions produced elements such as iodine, uranium, and gold.

In another first, Prof. Gal-Yam – along with collaborators at several institutions around the world – found evidence that may confirm the existence of a new type of stellar explosion called a pair-instability supernova. Using an image recorded by a telescope at Caltech's Palomar Observatory, the scientists located a massive star that was on the verge of exploding. Unlike most supernovae, which fade over a matter of weeks, this one burned steadily for months at the same brightness. The scientists estimated the star's size at around 200 times the mass of the sun. The explosion generated several suns' worth of radioactive nickel-56 – which is what kept it glowing for so long – and vast quantities of lighter elements, such as carbon and silicon.

In an article published in *Scientific American*, Prof. Gal Yam wrote that pair-instability supernova "are huge factories of the elements, and they produce the most energetic explosions known to science." He also noted that pair-instability supernovae involving stars measuring upwards of 100 solar masses were probably among the first stellar explosions to seed the universe with heavier elements.

Born in Jerusalem, Prof. Gal-Yam earned his Ph.D. in physics and astronomy in 2003 at Tel Aviv University. He received NASA's prestigious Hubble postdoctoral fellowship and spent four years conducting research at the California Institute of Technology (Caltech), then joined the Weizmann Institute in 2007.

Now Prof. Gal-Yam's research is poised to take a historic step forward, thanks to a new project called ULTRASAT: Ultraviolet Transient Astronomy Satellite. An international collaboration between the Weizmann Institute, the Israel Space Agency, Caltech, and NASA, the ULTRASAT mission will launch a small satellite carrying a telescope with an unprecedentedly large field of view.

The initial blast of a supernova is so energetic that the most important information can only be gathered in short ultraviolet (UV) wavelengths. And since UV wavelengths are filtered out by the Earth's atmosphere, these observations can only be made by a space telescope, which is why ULTRASAT is so important. It will observe light in the UV range, and should be able to detect transient events such as the flare-up of a supernova. Once such an event is identified, a satellite communications system will alert high-resolution telescopes around the world in real time, and these will capture the details of the event.

"The mission of ULTRASAT will be to detect supernova explosions within seconds or minutes after they happen, so we can begin our studies immediately," says Prof. Gal-Yam. "A lot of information is lost when you don't detect a supernova right away because the materials mix and disperse and change form."

Until now, finding early-stage supernovae has been mostly a matter of luck, but with ULTRASAT looking out for them, hundreds might be identified. Prof. Gal-Yam says that the satellite – Israel's first – is scheduled to launch sometime in 2019. "This really is a new era of discovery in astrophysics," he says.

Provided by Weizmann Institute of Science