Standard Type Ia supernovae have a surprisingly large range of masses

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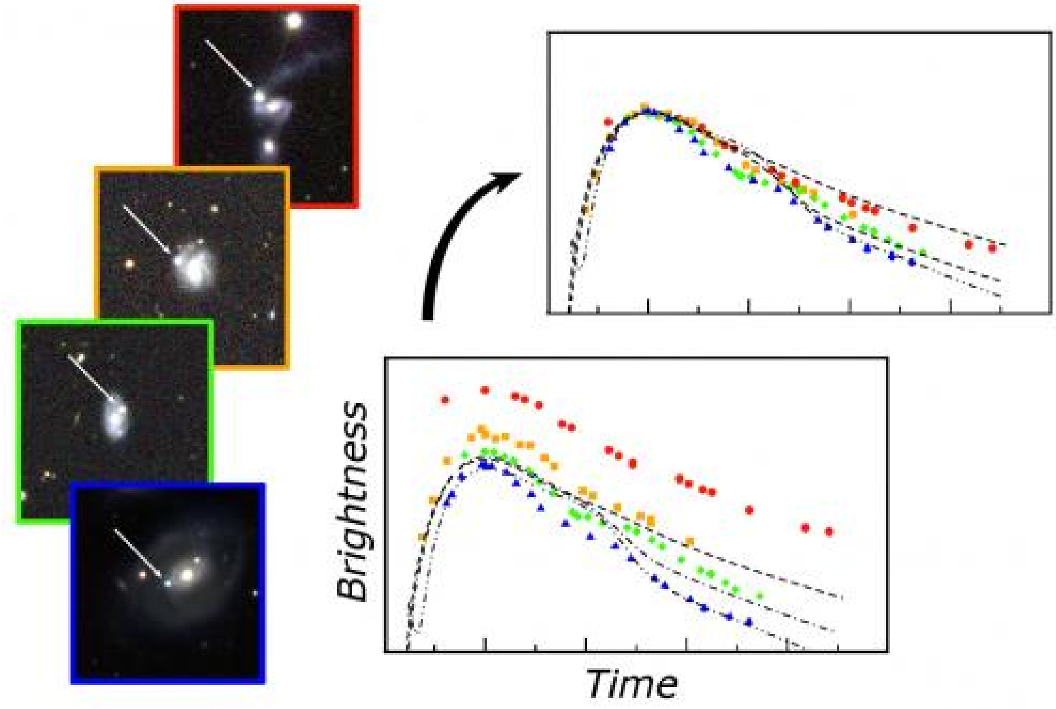

Type Ia supernovae result from the explosions of white dwarf stars. These supernovae vary widely in peak brightness, how long they stay bright, and how they fade away, as the lower graph shows. Theoretical models (dashed black lines) seek to account for the differences, for example why faint supernovae fade quickly and bright supernovae fade slowly. A new analysis by the Nearby Supernova Factory indicates that when peak brightnesses are accounted for, as shown in the upper graph, the late-time behaviors of faint and bright supernovae provide solid evidence that the white dwarfs that caused the explosions had different masses, even though the resulting blasts are all "standard candles."

(Phys.org) —Sixteen years ago two teams of supernova hunters, one led by Saul Perlmutter of the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab), the other by Brian Schmidt of the Australian National University, declared that the expansion of the universe is accelerating – a Nobel Prize-winning discovery tantamount to the discovery of dark energy. Both teams measured how fast the universe was expanding at different times in its history by comparing the brightnesses and redshifts of Type Ia supernovae, the best cosmological "standard candles."

These dazzling supernovae are remarkably similar in brightness, given that they are the massive thermonuclear explosions of white dwarf stars, which pack roughly the mass of our sun into a ball the size of Earth. Based on their colors and how fast they brighten and fade away, the brightnesses of different Type Ia supernovae can be standardized to within about 10 percent, yielding accurate gauges for measuring cosmic distances.

Until recently, scientists thought they knew why Type Ia supernovae are all so much alike. But their favorite scenario was wrong.

The assumption was that carbon-oxygen white dwarf stars, the progenitors of the supernovae, capture additional mass by stripping it from a companion star or by merging with another white dwarf; when they approach the Chandrasekhar limit (40 percent more massive than our sun) they experience thermonuclear runaway. Type Ia brightnesses were so similar, scientists thought, because the amounts of fuel and the explosion mechanisms were always the same.

"The Chandrasekhar mass limit has long been put forward by cosmologists as the most likely reason why Type Ia supernovae brightnesses are so uniform, and more importantly, why they are not expected to change systematically at higher redshifts," says cosmologist

Greg Aldering, who leads the international Nearby Supernova Factory (SNfactory) based in Berkeley Lab's Physics Division. "The Chandrasekhar limit is set by quantum mechanics and must apply equally, even for the most distant supernovae."

But a new analysis of normal Type Ia supernovae, led by SNfactory member Richard Scalzo of the Australian National University, a former Berkeley Lab postdoc, shows that in fact they have a range of masses. Most are near or slightly below the Chandrasekhar mass, and about one percent somehow manage to exceed it.

The SNfactory analysis has been accepted for publication by the *Monthly Notices of the Royal Astronomical Society* and is available online as an arXiv preprint.

A new way to analyze exploding stars

While white dwarf stars are common, Scalzo says, "it's hard to get a Chandrasekhar mass of material together in a natural way." A Type Ia starts in a two-star (or perhaps a three-star) system, because there has to be something from which the white dwarf accumulates enough mass to explode.

Some models picture a single white dwarf borrowing mass from a giant companion. However, says Scalzo, "The most massive newly formed carbon-oxygen white dwarfs are expected to be around 1.2 solar masses, and to approach the Chandrasekhar limit a lot of factors would have to line up just right even for these to accrete the remaining 0.2 solar masses."

If two white dwarfs are orbiting each other they somehow have to get close enough to either collide or gently merge, what Scalzo calls "a tortuously slow process." Because achieving a Chandrasekhar mass seems so unlikely, and because sub-Chandrasekhar white dwarfs are so much more numerous, many recent models have explored how a Type Ia explosion could result from a sub-Chandrasekhar mass – so many, in fact, that Scalzo was motivated to find a simple way to eliminate models that couldn't work.

He and his SNfactory colleagues determined the total energy of the spectra of 19 normal supernovae, 13 discovered by the SNfactory and six discovered by others. All were observed by the SNfactory's unique SNIFS spectrograph (SuperNova Integral Field Spectrograph) on the University of Hawaii's 2.2-meter telescope on Mauna Kea, corrected for ultraviolet and infrared light not observed by SNIFS.

A supernova eruption thoroughly trashes its white dwarf progenitor, so the most practical way to tell how much stuff was in the progenitor is by spectrographically "weighing" the leftover debris, the ejected mass. To do this Scalzo took advantage of a supernova's layered composition.

A Type Ia's visible light is powered by radioactivity from nickel-56, made by burning carbon near the white dwarf's center. Just after the explosion this radiation, in the form of gamma rays, is absorbed by the outer layers – including iron and lighter elements like silicon and sulfur, which consequently heat up and glow in visible wavelengths.

But a month or two later, as the outer layers expand and dissipate, the gamma rays can leak out. The supernova's maximum brightness compared to its brightness at late times depends on how much gamma radiation is absorbed and converted to visible light – which is determined both by the mass of nickel-56 and the mass of the other material piled on top of it.

The SNfactory team compared masses and other factors with light curves: the shape of the graph, whether narrow or wide, that maps how swiftly a supernova achieves its brightest point, how bright it is, and how hastily or languorously it fades away. The typical method of "standardizing" Type Ia supernovae is to compare their light curves and spectra.

"The conventional wisdom holds that the light curve width is determined primarily or exclusively by the nickel-56 mass," Scalzo says, "whereas our results show that there must also be a deep connection with the ejected mass, or between the ejected mass and the amount of nickel-56 created in a particular supernova."

Exploding white dwarf stars, the bottom line

Greg Aldering summarizes the most basic result of the new analysis: "The white dwarfs exploding as Type Ia supernovae have a range of masses, and the resulting light-curve width is directly proportional to the total mass involved in the explosion."

For a supernova whose light falls off quickly, the progenitor is a lot less massive than the Chandrasekhar mass – yet it's still a normal Type Ia, whose luminosity can be confidently standardized to match other normal Type Ia supernovae.

The same is true for a Type Ia that starts from a "classic" progenitor with Chandrasekhar mass, or even more. For the heavyweights, however, the pathway to supernova detonation must be significantly different than for lighter progenitors. These considerations alone were enough to eliminate a number of theoretical models for Type Ia explosions.

Carbon-oxygen white dwarfs are still key. They can't explode on their own, so another star must provide the trigger. For super-Chandrasekhar masses, two C-O white dwarfs could collide violently, or one could accrete mass from a companion star in a way that causes it to spin so fast that angular momentum supports it beyond the Chandrasekhar limit.

More relevant for cosmolology, because more numerous, are models for sub-Chandrasekhar mass. From a companion star, a C-O white dwarf could accumulate helium, which detonates more readily than carbon – the result is a double detonation. Or two white dwarfs could merge. There are other surviving models, but the psychological "safety net" that the Chandrasekhar limit once provided cosmologists has been lost. Still, says Scalzo, the new analysis narrows the possibilities enough for theorists to match their models to observations.

"This is a significant advance in furthering Type Ia supernovae as cosmological probes for the study of dark energy," says Aldering, "likely to lead to further improvements in measuring distances. For instance, light-curve widths provide a measure of the range of the star masses that are producing Type Ia supernovae at each slice in time, well back into the history of the universe."

More information: "Type Ia supernova bolometric light curves and ejected mass estimates from the Nearby Supernova Factory." R. Scalzo, et al. arXiv:1402.6842 [astro-ph.CO] arxiv-web3.library.cornell.edu/abs/1402.6842

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