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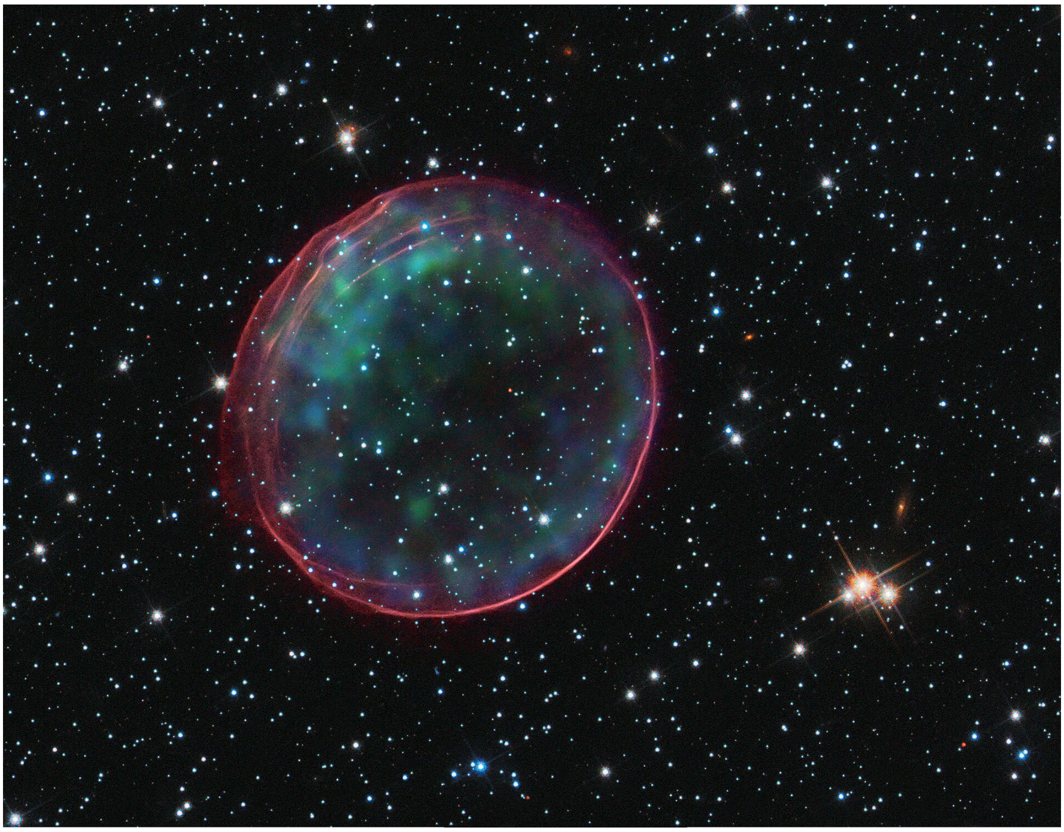
Press Release

From Supernova Light a Sharper View of the Universe

A new SISSA study published in Nature Astronomy unveils a novel method for deriving highly precise estimates of cosmic distances and more robust cosmological measurements, an approach that could prove essential for decoding the vast quantity of data expected from the next generation of observatories.



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Supernovae help astronomers measure how the Universe expands over time, but correctly interpreting this signal is far from straightforward: the light that reaches us is affected by multiple factors, making truly precise measurements extremely difficult. In a new study published in *Nature Astronomy*, Konstantin Karchev and Roberto Trotta of SISSA, together with Raúl Jiménez of the University of Barcelona, introduce CIGaRS (Combined Inference and Galaxy-Related Standardisation), a method based on artificial intelligence and neural networks that disentangles the intrinsic effects on the luminosity of these stellar explosions from environmental ones, such as interstellar dust and the expansion of the Universe. This makes it possible to extract far more information without requiring additional data, such as spectroscopic analyses.

Type Ia supernovae are among the most valuable phenomena in cosmology because they can serve as distance indicators: by observing how bright they appear, astronomers can use them as “standardisable candles” to measure cosmic distances and reconstruct the history of the Universe’s expansion. Their observed brightness, however, depends not only on the physics of the explosion itself, but also on factors linked to the progenitor star, such as age and chemical composition, as well as on dust and, more generally, on the properties of the host galaxy in which the explosion occurs. Information of this kind can be studied in particularly rich detail through spectroscopy, which measures not only how much light arrives, but also how that light is distributed across different wavelengths. Obtaining detailed spectra for large samples of supernovae, however, is far more difficult than simply collecting their brightness.

“Today, spectroscopy remains the richest tool for studying a supernova, because it allows us to see many details of its physics and of the environment in which it explodes,” explains Roberto Trotta, professor of Theoretical Physics at SISSA and co-author of the study. “The problem is that collecting detailed, homogeneous spectra at multiple epochs for very large samples will be impossible, given the sheer volume of data expected in the coming years. For this reason, in the cosmology of the near future, it will become increasingly important to extract reliable information even from photometric data alone—that is, from the brightness of supernovae.”

One example of the standard correction used when only brightness measurements are available is the so-called “mass step”. It has been observed that supernovae in more massive galaxies display, on average, a slightly different luminosity from those exploding in less massive galaxies. The data are therefore corrected by introducing a small step in luminosity depending on whether the galaxy is larger or smaller than 10 billion solar masses, although the exact threshold may vary from one sample to another. This is, however, essentially a workaround: galaxy mass is not the direct cause of the effect, but rather a proxy that bundles together several stellar and galactic factors that are much more difficult to measure directly.

CIGaRS tackles the problem in an innovative way. It brings together in a single model galaxy evolution, dust effects, the rate at which Type Ia supernovae appear over cosmic time, and the observable properties of the explosions -

something that had never been done before. In this way, it is able to interpret simultaneously all the factors that shape the light we observe, rather than correcting for them separately through successive steps. This makes it possible to reconstruct and exploit far more information using photometric data alone. This approach will be essential over the next ten years. Major photometric surveys have only just begun, including the Legacy Survey of Space and Time at the Vera Rubin Observatory in Chile, which is expected to discover millions of new supernovae, including at least one hundred thousand Type Ia events each year.

To test the method, the authors first built a simulated catalogue containing 1,578 selected supernovae, designed to be representative of the size of current supernova catalogues. They then extended this to a catalogue roughly ten times larger, with nearly 16,000 objects, constructed to resemble what the Vera Rubin Observatory might collect in a single month.

CIGaRS proved capable of simultaneously reconstructing several distinct yet interconnected quantities: the cosmological parameters that describe the expansion of the Universe; the distribution of delay times between the formation of a star and its explosion as a supernova; and the contribution of factors such as stellar age, chemical composition, and any residual effects linked to the host galaxy. The precision achieved from these data that use only images is comparable to that obtained in previous analyses based on spectroscopic data.

The simulations show that the age and chemical composition of the progenitor star leave different signatures in the observed data. In particular, the star's chemical composition tends to produce an effect similar to the aforementioned mass step - the step-like difference in luminosity observed between supernovae hosted in more or less massive galaxies - whereas stellar age produces a more gradual variation. The study also shows that these effects are small compared with other sources of variability, such as the colour of the light and interference from dust, and that this is precisely why they are difficult to disentangle using standard techniques.

The clearest advantage, however, is for cosmology. According to the study, applying this approach to large samples observed only photometrically would improve the precision of cosmological measurements by about a factor of four compared with methods that can rely only on the small fraction of supernovae also observed spectroscopically - which may amount to just 1% of the total.
In practical terms, this would make it possible to use the full observational dataset far more effectively, instead of relying on only a tiny subset and

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effectively wasting 99% of the data.

“With next-generation surveys, we will have enormous numbers of supernovae—datasets so rich that they can no longer be analysed using traditional methods,” Roberto Trotta concludes. “What we need, therefore, are new methods capable of analysing these large catalogues in a robust way, not only to extract ever more information, but also to turn those data into new physics.”

Useful Links
Nature Astronomy

IMAGE
A supernova remnant (SNR 0509-67.5) in the Large Magellanic Cloud
Crediti:
X-ray: NASA/CXC/SAO/J.Hughes et al, Optical: NASA/ESA/Hubble Heritage Team (STScI/AURA) Accession number: snr0509_469

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