Unveiling the double origin of cosmic dust in the distant Universe

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Credit: ESO

Two billion years after the Big Bang, the Universe was still very young. However, thousands of huge galaxies, rich in stars and dust, were already formed. An international study, led by SISSA—Scuola Internazionale Superiore di Studi Avanzati, now explains how this was possible. Scientists combined observational and theoretical methods to identify the physical processes behind their evolution and, for the first time, found evidence for a rapid growth of dust due to a high concentration of metals in the distant Universe. The study, published in *Astronomy & Astrophysics*, offers a new approach to investigate the evolutionary phase of massive objects.

Since their initial discovery 20 years ago, very distant and massive galaxies that form a prodigious amount of young stars—so-called 'dusty' (star-forming) galaxies—represent a serious challenge for astronomers:

"On one hand, they are difficult to detect because they reside in dense regions of the distant Universe and contain dusty particles which absorb most of the optical light radiated by young stars," explains Darko Donevski, postdoctoral fellow at SISSA. "On the other hand, many of these dusty 'giants' have been formed when the Universe was very young, sometimes even less than 1 billion years old, and scientists have been wondering how could such large amount of dust have been produced so early in time."

The study of these exotic objects is now possible thanks to the Atacama Large Millimeter/submillimeter Array (ALMA). This interferometer of 66 telescopes in the Atacama Desert of northern Chile is able to detect the infrared light which penetrates the dusty clouds, revealing the presence of newly forming stars. However, the origin of large amount of dust at early cosmic time is still an open question to astronomers. "Throughout many years scientists thought that production of cosmic dust was exclusively due to supernovae explosion. However, recent theoretical works suggest that dust can also grow through collisions of particles of cold, metal-rich gas which fills the galaxies," explains the researcher.

An international team of researchers from institutions based in Europe, US, Canada and South Africa, led by Donevski, combined observational and theoretical methods to study 300 distant, dusty galaxies in order to unveil the origin of these 'giants.' In particular, they inferred the physical properties of these dusty galaxies by fitting their spectral energy distributions. "We found a huge amount of dust mass in most of our galaxies. Our estimates showed that supernovae explosions could not be responsible for all of it and a part had to be produced through particle collisions in the gaseous metal-rich environment around massive stars, as previously supposed by theoretical models" says Donevski. "This is the first time that observational data support the existence of both production mechanisms."

Scientists also looked at dust to star mass ratio over time to study how efficiently galaxies create and destroy dust during their evolution. "This allowed us to identify dust life cycle in two different populations of galaxies: normal, so-called 'main-sequence," galaxies, which are slowly evolving, and more extreme, rapidly evolving galaxies, called 'starbursts,'" said Lara Pantoni, Ph.D. student at SISSA, who developed the analytic model used for data interpretation. The model shows the great potential in describing differences in these two groups of observed galaxies. "Interestingly, we also showed that irrespective of their distance, stellar mass or size, compact 'starburst' galaxies always have dust-to-stellar mass ratio higher than the normal galaxies."

To fully evaluate the observational findings, the team of astronomers also confronted their data with the state-of-the-art galaxy simulations. They used SIMBA, a new suite that simulates the formation and evolution of millions of galaxies since the beginning of the Universe to present time, tracking all their physical properties, including dust mass. "Up to now, theoretical models had problems in matching both galaxy dust and stellar properties simultaneously. However, our new cosmological simulation suite, SIMBA, could reproduce most of the observed data," explains Desika Narayanan, professor of astronomy at the University of Florida and member of the DAWN institute in Copenhagen.

"Our study shows that dust production in 'giants' is dominated by very rapid growth of particles through their collisions with gas. Thus, it provides the first strong proof that dust formation occurs both during stars death and in the space between these massive stars, as assumed from theoretical studies," concludes Donevski. "Moreover, it offers a new mixed approach to investigate the evolution of massive objects in the distant Universe that will be tested with future space telescopes such as the James Webb Space Telescope."

More information: D. Donevski et al, In pursuit of giants, *Astronomy & Astrophysics* (2020). DOI: 10.1051/0004-6361/202038405

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