Gazing into the History of the Universe: How Stars and Supernovae Shape the Chemistry of Galaxy Clusters

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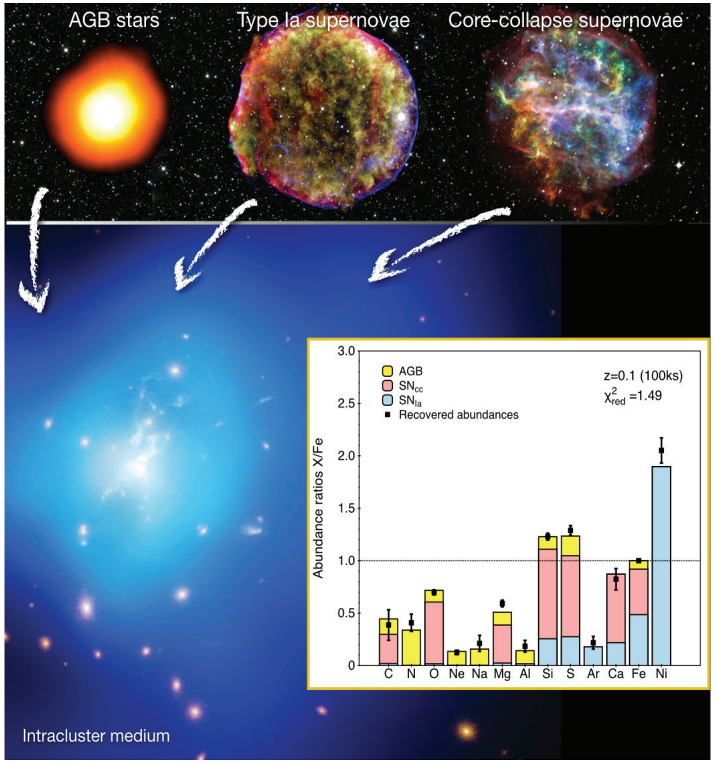

Metal enrichment of the hot, X-ray emitting intracluster medium with asymptotic giant branch (AGB) stars, as well as Type Ia and core-collapse supernovae (originating, respectively, from exploding white dwarfs and exploding massive stars). The X-IFU instrument onboard Athena will measure these elemental abundances with unprecedented accuracy, revealing the processes within stars and supernovae that create these metals. Credit: ESA/NASA/CfA/SAO/CXC/MIT/STScI/JPL-Caltech/MPIA. Plot from Mernier, Cucchetti et al. 2020, A&A, 642: A90.

As Carl Sagan famously observed, “We are made of star-stuff”. He couldn’t be more right: most chemical elements that compose our planet Earth (and us!) – C, N, O, but also Mg, Si, Ca, and Fe – were created in the burning cores of stars. This happens either near the end of a star’s life or at the finale when they explode as supernovae. Though we know what we are made of, we still don’t know exactly how and when these elements were formed. Understanding the complexity of stellar objects is the key to this answer. For instance, how many massive stars were born compared to low-mass stars, and which fraction of them contributed to the creation of heavy elements when they exploded? What is the true nature of the so-called Type Ia supernovae that occur when white dwarf stars that are devoid of hydrogen explode as thermonuclear bombs?

Quite spectacularly, while some of these freshly created heavy elements (a.k.a. “metals”) shape new stars and planets, most escape their galaxy hosts. They expand to fill the largest scales of our Universe - the hot, X-ray emitting gas (10 to 100 million K) that surrounds galaxy clusters like a halo. Detected with X-ray telescopes, the spectral emission lines of this gas can be studied to trace these elements. Measuring elemental abundances of this gas constitutes a unique opportunity to constrain (and, ultimately, understand) the nature and the physics of the trillions of stars and supernovae that have exploded since the cosmic dawn.

With the exquisite spectral resolution offered by its X-IFU instrument, *Athena* will push this concept to the next level. In a recent study, we used cosmological simulations in which specific (asymptotic giant branch) stars and (core-collapse and Type Ia) supernovae models were set to enrich chemically galaxy clusters over cosmic times. We then analysed simulated X-IFU spectra to predict how *Athena* would see such clusters, and which values of their chemical abundances it would measure for 14 different elements (from C to Ni). Not only these measured abundances correspond remarkably well to those injected into the simulations, but our mock observations allowed us to recover the right input set of models among more than 17,000 other possibilities! Undeniably, *Athena* will revolutionise our understanding of the largest-scale structures of our Universe, as well as the journey of metals that enrich them.