A Chemical Signature of First-Generation Very-Massive Stars

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First-generation stars are objects formed in the early Universe from gas clouds containing only hydrogen and helium. They are the probable precursors of the formation of the Universe's structure and chemical enrichment. Recent numerical simulations suggest that a fraction of very-massive stars with masses exceeding one hundred times that of the Sun could have formed in the early Universe, even though the large majority of first stars formed with masses of ten to a hundred times that of the Sun [1]. Their strong UV radiation and energetic explosions are likely to have had a significant impact on the evolution of stellar systems.

Supernova explosions ejected elements formed by the first massive stars and dispersed them into the gas that formed the next generations of stars. Stars with masses slightly less than the Sun's have very long lifetimes enough to survive until now. The Milky Way contains such low-mass stars with low overall metal content, including the elements produced by the first massive stars. The distinctive chemical abundance patterns of these stars can be used to estimate the masses of the first stars.

High-resolution spectroscopy for low-mass stars with low metallicity determines their chemical abundances and identifies stars that recorded the abundance patterns associated with the first stars that had several tens of solar masses and produced large amounts of carbon and other light elements [2]. However, no previous research of low-mass metal-poor Milky-Way stars has found the signature of supernova explosions of very-massive stars with more than 100 solar masses, which synthesize large amounts of iron but little carbon.

Searches for such stars require larger surveys of very metal-poor stars, which was realized by the Sloan Digital Sky Survey (SDSS). We selected candidates for very metal-poor stars from the SDSS spectra, and used the High Dispersion Spectrograph mounted on the Subaru Telescope to conduct a high-resolution spectroscopic follow-up of a large sample of low-mass metal-poor stars. We discovered a star, SDSS J001820.5-093939.2 (SDSS J0018-0939), that exhibits a very peculiar set of chemical abundance ratios [3]. Whereas the star contains an amount of iron 300 times lower than the Sun's, it is significantly deficient in lighter elements such as carbon and magnesium.

Nucleosynthesis models for supernova explosions of massive stars, which successfully reproduce the abundance ratios found in most of the early-generation stars previously known, do not readily explain the chemical abundance ratios observed in the newly discovered star (Figure 1). Rather, explosion models of very-massive stars can explain both the relatively high abundance ratio of iron as well as the low abundances of lighter elements. This means that this star most likely preserves the elemental abundance ratios produced by a first-generation very-massive star.

Further modeling of chemical yields of first-generation very-massive stars is strongly desired. If more detailed study of this star confirms the existence of very-massive stars, this new discovery will provide strong support for the predictions of the mass distribution of first stars.

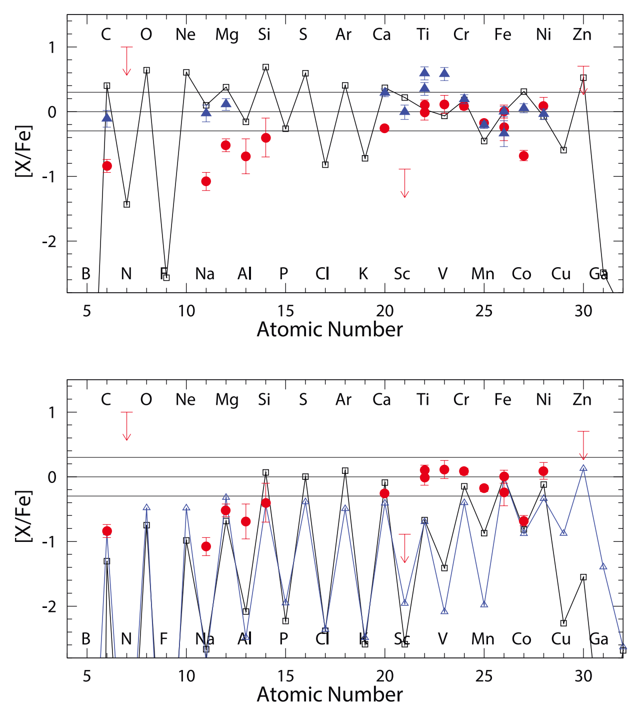

Figure 1: Elemental abundances measured for SDSS J0018-0939 (circles) and a comparison star (triangles) compared with supernova nucleosythesis models. (upper) The abundance pattern of the comparison star is explained by a core-collapse supernova model, whereas that of SDSS J0018-0939 is not reproduced by possible variations of the models. Cobalt and Scandium, as well as heavy neutron-capture elements, are also deficient. (lower) Some basic features of the abundance pattern of SDSS J0018-0939 are explained by supernova nucleosynthesis models for very massive stars.

References

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