Novel features of r-process nucleosynthesis shed light on origin of heavy elements

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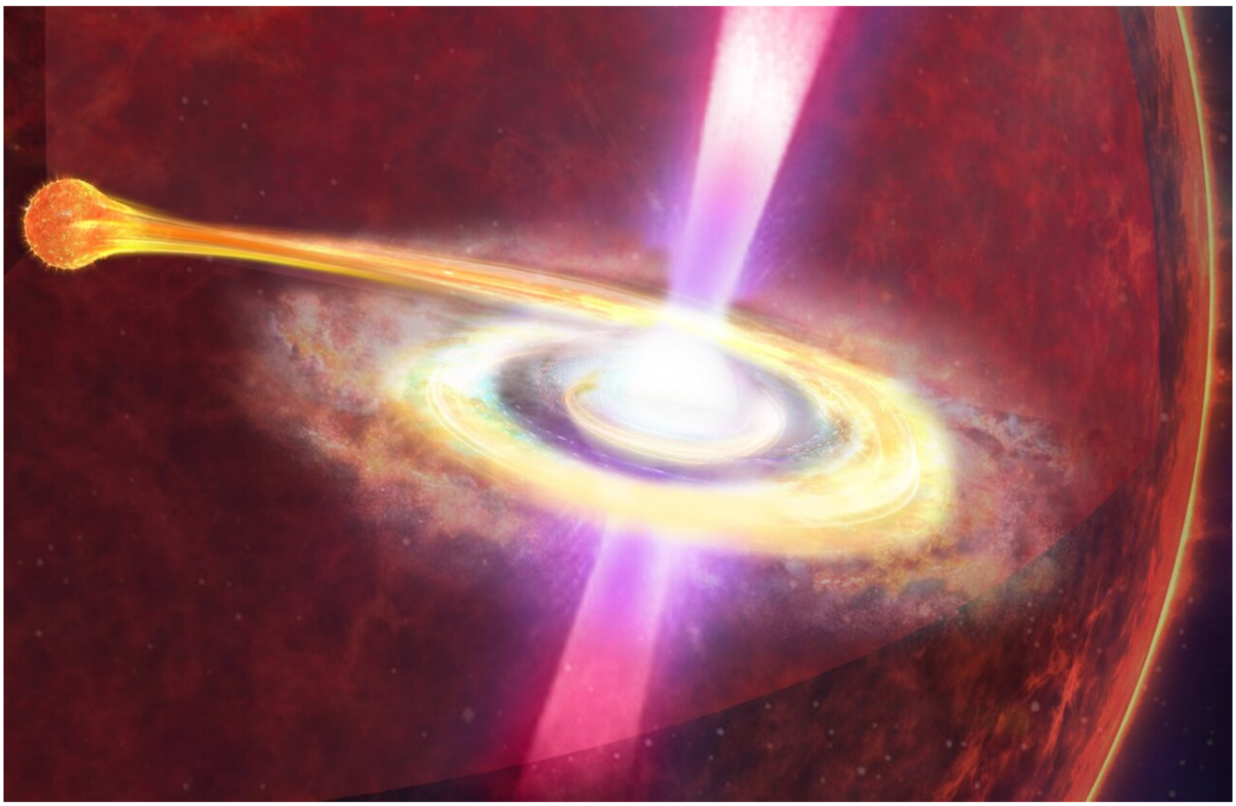

Artistic representation of Common envelop jet supernovae. Credit: IMP

In a study published in *The Astrophysical Journal*, scientists have proposed the features of the rapid neutron capture process (r-process) nucleosynthesis in a novel scenario: common envelop jet supernovae (CEJSNe). The study sheds new light on the origin of elements, especially beyond the lanthanides.

The origin of elements heavier than iron is one of the key questions in the physics community. Fusion burning in the stars produces elements up to iron while heavier ones are not able to be reached due to the Coulomb repulsion. However, the explosive environment could offer enough temperature and density to generate them. The r-process occurring in such an environment is believed to produce about half of the elements heavier than iron.

In 2017, the discovery of the gravitational wave and its afterglow of the neutron star merger event GW081708 uniquely confirmed the occurrence of the r-process for the first time. However, subsequent studies cast doubt on the fact that the neutron star merger is the only site of the r-process, as the abundance of lanthanides produced by the neutron star merger is significantly less than what has been observed in metal-poor stars.

Therefore, the roles of other sites, like collapsars and magnetohydrodynamic supernovae, should be irreplaceable in r-process.

Dr. Jin Shilun, from the Institute of Modern Physics (IMP) of the Chinese Academy of Sciences (CAS), and his collaborator from Technion, Israel, presented the features of r-process in the novel site CEJSNe for the first time.

CEJSNe refers to a neutron star remnant of the supernova and a red supergiant from the late phase of a massive binary system. The red supergiant expands and engulfs the neutron star, which spirals-in inside the red supergiant's envelope and then inside its core. Once entering the core, the neutron star accretes mass via an accretion disk at a very high rate, and the energetic and dense jets that are produced can provide proper conditions for r-process nucleosynthesis.

Scientists showed that CEJSNe can produce the most abundant elements heavier than lanthanide among current r-process scenarios. By comparing the Log(Xla) vs Log(Ir/Eu), which is a new quantity to show the relative strength of lanthanide and elements in the third peak, they found the anti-correlation between CEJSNe and other r-process models.

"This finding means that abundant lanthanide and heavier elements can't be generated in a single event, which would be a critical feature for further research on r-process. CEJSNe is also critical for explaining the characteristics of the r-enhanced metal-poor stars," said Dr. Jin.

This work not only paves a new way for better understanding the secrets hidden in r-process, but also guides experimentalists for various measurements.

As exotic isotopes from the High Intensity Accelerator Facility (HIAF) will be available soon in China, the key nuclear properties relevant to the r-process in CEJSNe are expected to be unveiled.

More information: Shilun Jin et al, Robust r-process Nucleosynthesis beyond Lanthanides in the Common Envelop Jet Supernovae, *The Astrophysical Journal* (2024). DOI: 10.3847/1538-4357/ad5f8e

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