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Sonia Fernandez

Luminous Blue Variable Star

Sparkling with an exceptional blue-toned brilliance and exhibiting wild variations in both brightness and spectrum, the luminous blue variable (LBV) is a relatively rare and still somewhat mysterious type of star.

Its appearance tends to fluctuate radically over time, and that has piqued the curiosity of astrophysicists who wonder what processes may be at play.

“The luminous blue variable is a supermassive, unstable star,” said Yan-Fei Jiang, a researcher at UC Santa Barbara’s Kavli Institute for Theoretical Physics (KITP). Unlike our own comparatively smaller and steady-burning Sun, he explained, LBVs have been shown to burn bright and hot, then cool and fade so as to be almost indistinguishable from other stars, only to flare up again. Because of these changes, Jiang added, conventional one-dimensional models have been less than adequate at explaining the special physics of these stars.

However, thanks to special, data-intensive supercomputer modeling conducted at Argonne National Laboratory’s Argonne Leadership Computing Facility (ALCF) for its INCITE program, Jiang and colleagues — Matteo Cantiello of the Flatiron Institute, Lars Bildsten of KITP, Eliot Quataert at UC Berkeley, Omer Blaes of UCSB, and James Stone of Princeton — have now developed a three-dimensional simulation. It not only shows the stages of an LBV as it becomes progressively more luminous, then erupts, but also depicts the physical forces that contribute to that behavior. The simulation was developed also with computational resources from NASA and the National Energy Research Scientific Computing Center, while the overall effort was

supported by the National Science Foundation and the Gordon and Betty Moore Foundation.

The researchers' paper, "Luminous Blue Variable Outbursts from the Variations of Helium Opacity," is the cover story in the journal Nature.

Of particular interest to the researchers are the stars' mass loss rates, which are significant compared to those of less massive stars. Understanding how these stellar bodies lose mass, Jiang said, could lead to greater insights into just how they end their lives as bright supernova.

Among the physical processes never before seen with one-dimensional models are the supersonic turbulent motions — the ripples and wrinkles radiating from the star's deep envelope as it prepares for a series of outbursts.

"These stars can have a surface temperature of about 9,000 degrees Kelvin during these outbursts," Jiang said. That translates to 15,740 degrees Fahrenheit or 8,726 degrees Celsius.

Also seen for the first time in three dimensions is the tremendous expansion of the star immediately before and during the outbursts — phenomena not captured with previous one-dimensional models. The three dimensional simulations show that it is the opacity of the helium that sets the observed temperature during the outburst.

According to Jiang, in a one-dimensional stellar evolution code, helium opacity — the extent to which helium atoms prevent photons (light) from escaping — is not very important in the outer envelope because the gas density at the cooler outer envelope is far too low.

The paper's co-author and KITP Director Lars Bildsten explained that the three-dimensional model demonstrates that "the region deep within the star has such vigorous convection that the layers above that location get pushed out to much larger radii, allowing the material at the location where helium recombines to be much denser." The radiation escaping from the star's hot core pushes on the cooler, opaque outer region to trigger dramatic outbursts during which the star loses large amounts mass. Hence, convection — the same phenomena responsible for thundercloud formation — causes not only variations in the star's radius but also in the amount of mass leaving in the form of a stellar wind.

Additional work is underway on more simulations, according to Jiang, including models of the same stars but with different parameters such as metallicity, rotation and magnetic fields.

“We are trying to understand how these parameters will affect the properties of the stars,” Jiang said. “We are also working on different types of massive stars — the so-called Wolf-Rayet stars — which also show strong mass loss.”

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