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Neutrinos Before Collapse

In the hours before the star collapses and explodes as a supernova, the rapid evolution of material in its core creates a multitude of neutrinos. Observing these pre-supernova neutrinos may help us understand the final stages of a massive star's life — but they've never been looked for or detected. Stellar neutrinos can be created through two processes: thermal processes and beta processes. Thermal processes - for example, pair production in which a particle/antiparticle pair are created - depend on the thermodynamics of the stellar core. Beta processes - where a proton converts to a neutron or vice versa - are instead linked to the isotopic makeup of the star's core. If we can observe them, beta-process neutrinos may be able to tell us about the last steps of stellar nucleosynthesis in a massive star. But observing these neutrinos is not easy. Neutrinos interact only feebly with matter; out of the ~10^{60} neutrinos released in a supernova explosion, even our most sensitive detectors record just a few of them. Can we detecting the beta-process neutrinos that are released in the final few hours of a massive star's life?

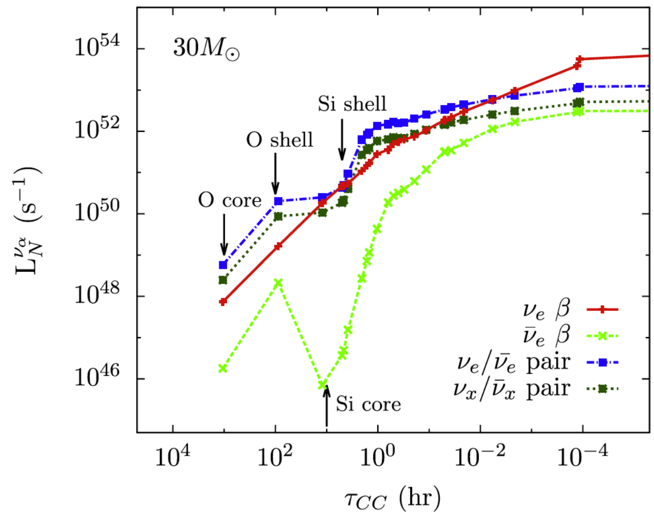

Figure 1. Neutrino luminosities leading up to core collapse. A few hours before collapse, the luminosity of beta-process neutrinos outshines that of any other neutrino flavor or origin. Credit: Patton et al. 2017

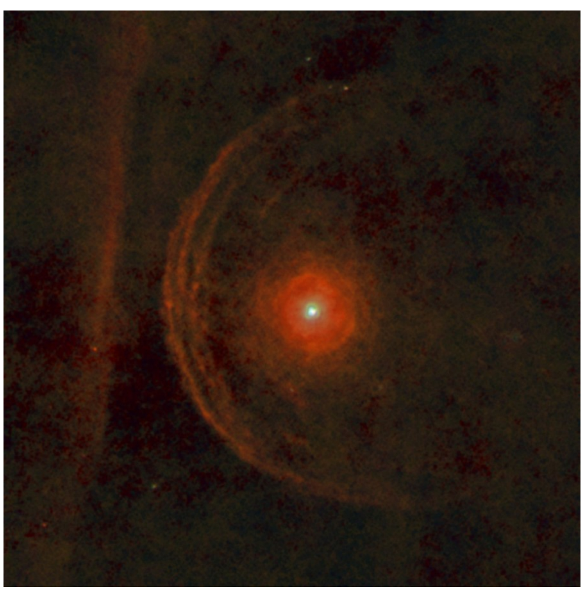

Figure 2. Composite image of Betelgeuse at 70, 100, 160 micron-wavelengths from Herschel PACS. Credit: ESA/Herschel/PACS

To help answer this question, Kelly Patton (University of Washington), Cecilia Lunardini (Arizona State University), Rob Farmer (Anton Pannekoek Institute of Astronomy), and Frank Timmes (Arizona State University, JINA-CEE) used MESA stellar evolution models to explore neutrino production in 15 and 30 solar mass stars from the onset of nuclear fusion at birth to the final moments of collapse. The team finds that in the last few hours before collapse, during which the material in the core is rapidly converted into heavier elements, the flux from beta-process neutrinos rivals that of thermal neutrinos and even exceeds it at high energies. But can we detect them? For a pre-supernova at a distance of ~3000 light-years, the team finds that the electron neutrino flux rises above the background noise from the Sun, nuclear reactors, and radioactive decay within the Earth in the final two hours before collapse. Based on these models, current and future neutrino observatories should be able to detect tens of neutrinos from a pre-supernova within ~3000 light years, about 30% of which would be beta-process neutrinos. As the distance to the star increases, the window within which neutrinos can be observed gradually narrows, until it closes at a distance of about 100,000 light-years. Are there any nearby stars expected soon to go supernova so these predictions can be tested? At a distance of only 650 light-years, the red supergiant star Betelgeuse should produce detectable neutrinos when it explodes — an exciting opportunity for multi-messenger astronomy in the future.

Further Reading:

This work was highlighted by the American Astronomical Society Journals at http://aasnova.org/2018/04/20/capturing-neutrinos-from-a-stars-final-hours