3-D supernova simulations reveal mysteries of dying stars

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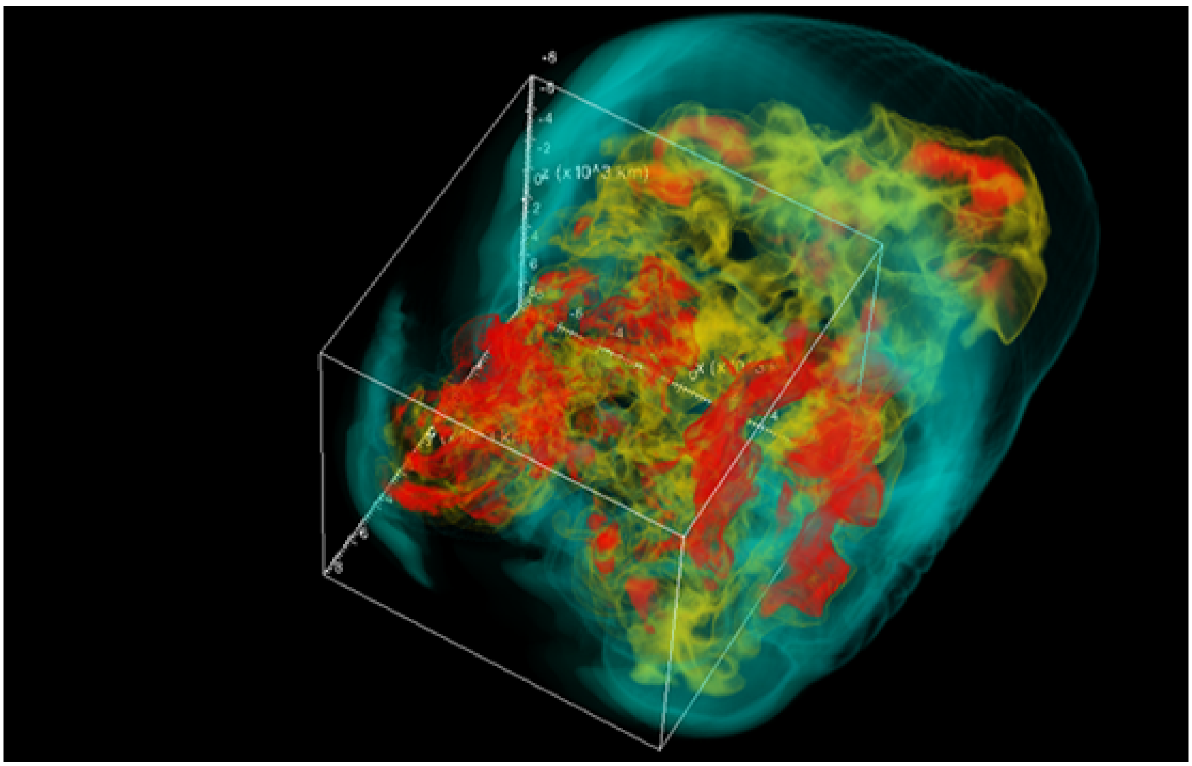

Snapshot of the expansion of the neutrino-heated matter and the supernova shock wave during the explosion of an 18 solar mass star. Credit: Bernhard Müller

An international team of researchers led by a Monash astronomer has created the longest consistent 3-D model of a neutrino-driven supernova explosion to date, helping scientists to better understand the violent deaths of massive stars.

The research, conducted using the supercomputers Raijin and Magnus in Australia, and others in Germany and the UK, was published in the Royal Astronomical Society's journal Monthly Notices.

The largest explosions in the Universe, so-called 'supernovae', occur when stars many times larger than our own Sun reach the end of their lives and exhaust the nuclear fuel at their centres. At this point the innermost part of the star, an iron core itself about 1.5 times as massive as the Sun, succumbs to gravity and collapses to an ultra-dense neutron star within a fraction of a second.

"Scientists have been puzzled about how the collapse of a star turns into an explosion," said the lead author of the research, Dr Bernhard Müller, from the School of Physics and Astronomy, and the Monash Centre for Astrophysics.

"The research team worked on a solution to this problem, and the most promising theory suggests that light and weak interacting particles called neutrinos are the key to this."

Vast numbers of neutrinos are emitted from the surface of the young neutron star, and if the heating caused by the initial collapse is sufficiently strong, the neutrino-heated matter drives an expanding shock wave through the star and the collapse is reversed.

"Scientists have long attempted to show that this idea works with the help of computer simulations, but the computer models often still fail to explode, and can't be run long enough to reproduce observed supernovae," Dr Müller said.

"What is crucial for success in 3-D is the violent churning of hot and cold material behind the shock wave, which develops naturally due to the neutrino heating."

The team, comprising researchers from Monash University (Australia), Queen's University Belfast, and the Max Planck Institute for Astrophysics (Germany), simulated the fusion of oxygen to silicon in a star 18 times the size of our Sun, for the last six minutes before the supernova.

They found that they could obtain a successful explosion because the collapsing silicon-oxygen shell was strongly stirred already.

They then followed the explosion for more than 2 seconds. Although it still takes about a day for the shock to reach the surface, they could tell that the explosion and the left-over neutron star were starting to look like the ones that we observe in nature.

"It's reassuring that we now get plausible explosion models without having to tweak them by hand," said Dr Bernhard Müller.

More information: Bernhard Müller et al. Supernova simulations from a 3D progenitor model – Impact of perturbations and evolution of explosion properties, *Monthly Notices of the Royal Astronomical Society* (2017). DOI: 10.1093/mnras/stx1962

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