Supernovae

Stellar explosions come in two main varieties: gravitational supernovae, which occur at the end of the life cycle of massive stars, and thermonuclear supernovae, which involve binary stars of low mass.

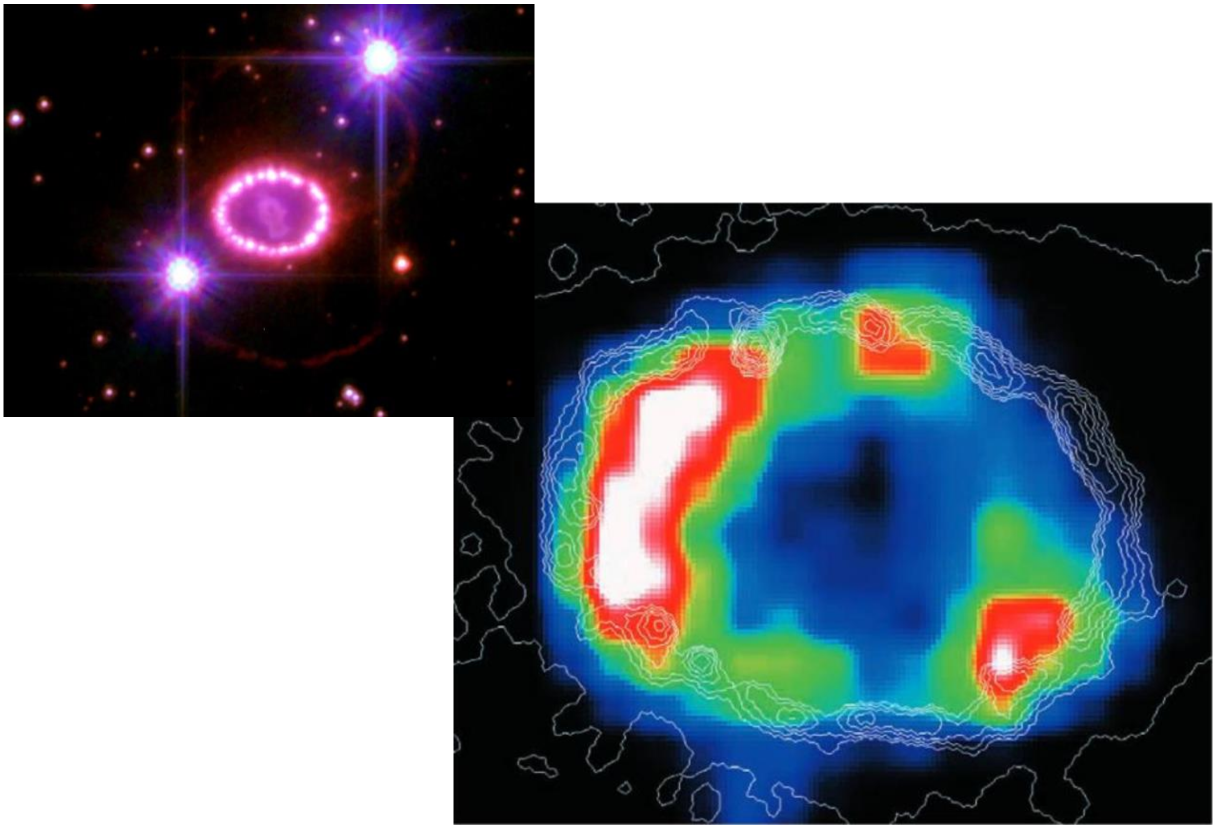
Stars with masses greater than 8–10 $M_{\odot}$ derive their brilliance from nuclear fusion reactions, which produce increasingly heavy atomic nuclei. When the star starts producing iron nuclei, the most stable of all nuclei, three key phenomena combine to hasten the star's catastrophic demise.

• Nuclear fusion reactions generate more and more neutrinos. These carry away an increasing amount of energy that can no longer counteract the gravitational collapse of the core.

• Photons produced by fusion reactions lose their energy as they break up iron nuclei. They have less and less energy to maintain the equilibrium of the stellar core.

• Electrons and protons give in to the weak interaction and form neutrons. With the equilibrium disrupted, the core collapses, all the faster as electrons are no longer present to counteract the process. Before they disappeared, they exerted a form of pressure that resisted the collapse of the core. The result is the formation of a gigantic agglomerate of neutrons which, upon reaching an extreme level of compression, expands as a rubber ball compressed in your fist. This is followed by a tremendous shock wave that ejects the star's other layers, heating them to extremely high temperatures. The heated matter emits an intense burst of light (luminosity: 109 $L_{\odot}$), characteristic of a supernova.

The shock wave continues to expand through the surrounding interstellar medium for about a century, with the ejected matter



Credit: NASA/ESA/P. Challis & R. Kirshner (Harvard-Smithsonian Center for Astrophysics), X-ray image, D. Burrows (PSU); optical contours, NASA/ESA/P. Challis (Harvard-Smithsonian Center for Astrophysics)

dispersing unhindered. Over the next ten thousand years, the propagation of matter gradually slows. It will take many more millenia for the remnants of the explosion to fully dilute into the interstellar medium. All that remains of the stellar core is an ultra-compact object, either a neutron star or a black hole.

In a binary star system, where two stars orbit a common gravity centre, conditions are sometimes met for the outer layers of one star to be accreted by the other. If the second star is a white dwarf, the matter falling onto its surface can heat and compress to the point of triggering explosive nuclear reactions. If the white dwarf's mass is close to the stability limit (1.4 $M_\odot$), the process triggers the nuclear conflagration of the star, its explosion and the synthesis of 0.5 $M_\odot$ of radioactive nickel dispersed into space. As in the case of gravitational supernovae, the explosion remnants will take hundred thousand years to dilute into the interstellar medium.

Supernova SN 1987A

SN 1987 is a gravitational supernova detected in February 1987 in the Large Magellanic Cloud galaxy.
Top: An optical image recorded by the Hubble Space Telescope, showing the bright ring radiated by matter heated by the explosion shock wave.
Bottom: A larger-scale image of the same ring recorded in the X-ray band by the Chandra Space Telescope.

Translated from 'Les supernovæ',* **Passeport pour les deux infinis**, IN2P3/Dunod, https://pass2i.ijclab.in2p3.fr/ (French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG***