Electron-eating neon causes star to collapse

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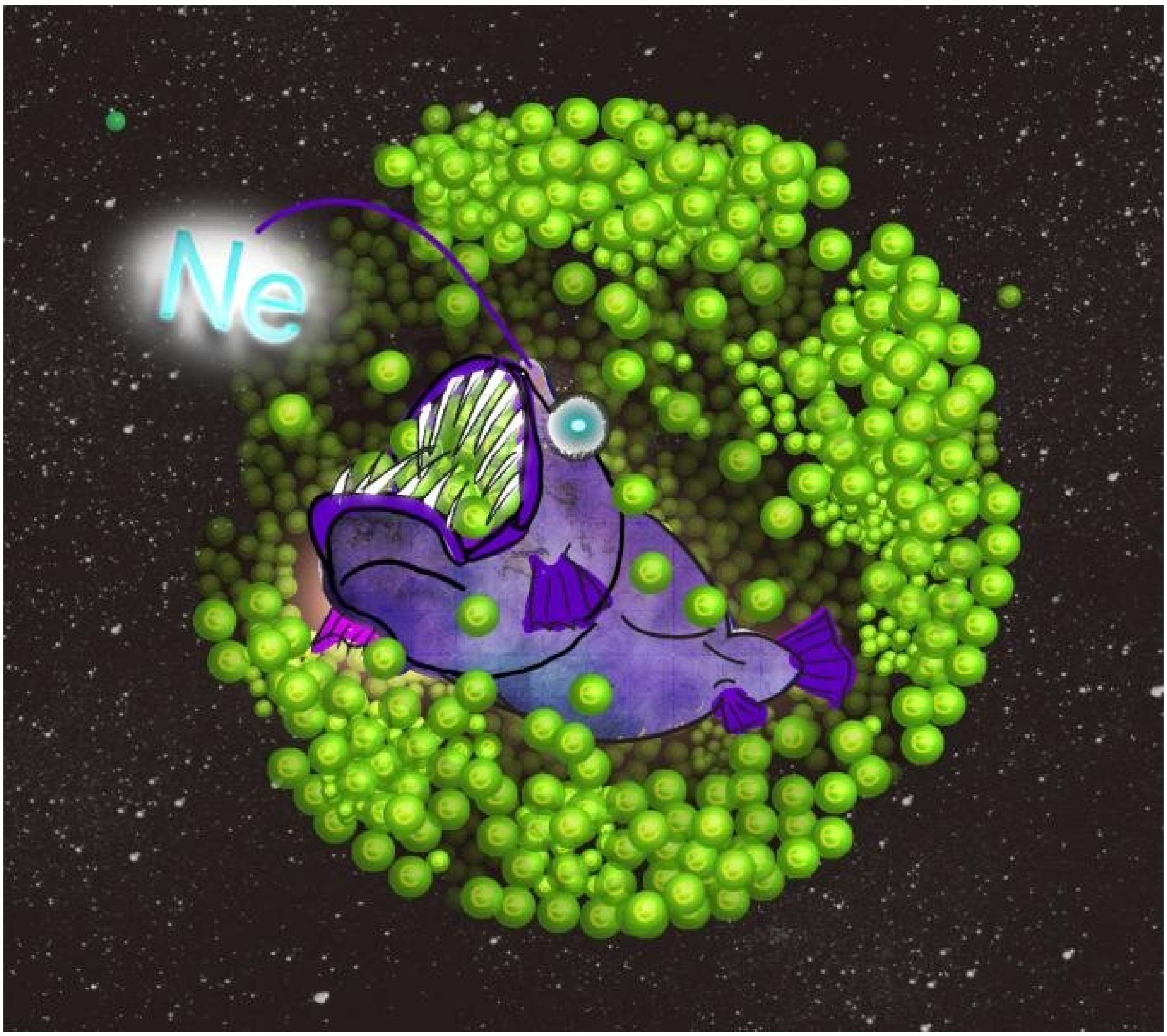

Figure 1: An artist's impression shows how an imaginary neon footballfish eats away at the electrons inside a star core. Credit: Kavli IPMU

An international team of researchers has found that neon inside a certain massive star can consume the electrons in the core, a process called electron capture, which causes the star to collapse into a neutron star and produce a supernova.

The researchers were interested in studying the final fate of stars within a mass range of eight to 10 solar masses, or eight to 10 times the mass of the sun. This mass range is important because it includes the boundary between whether a star has a large enough mass to undergo a supernova explosion to form a neutron star, or has a smaller mass to form a white dwarf star without becoming a supernova.

An eight- to 10-solar-mass star commonly forms a core composed of oxygen, magnesium and neon (figure 1). The core is rich in degenerate electrons, meaning there is an abundance of electrons in a dense space with high enough energy to sustain the core against gravity. Once the core density is high enough, the electrons are consumed by magnesium and then neon, which are also found inside the core. Past studies have confirmed that magnesium and neon can start eating away at the electrons once the mass of the core has grown close to Chandrasekhar's limiting mass, a process called electron capture, but there has been debate about whether electron capture can cause neutron star formation. A multi-institutional team of researchers studied the evolution of an 8.4-solar-mass star and ran computer simulations on it to find an answer.

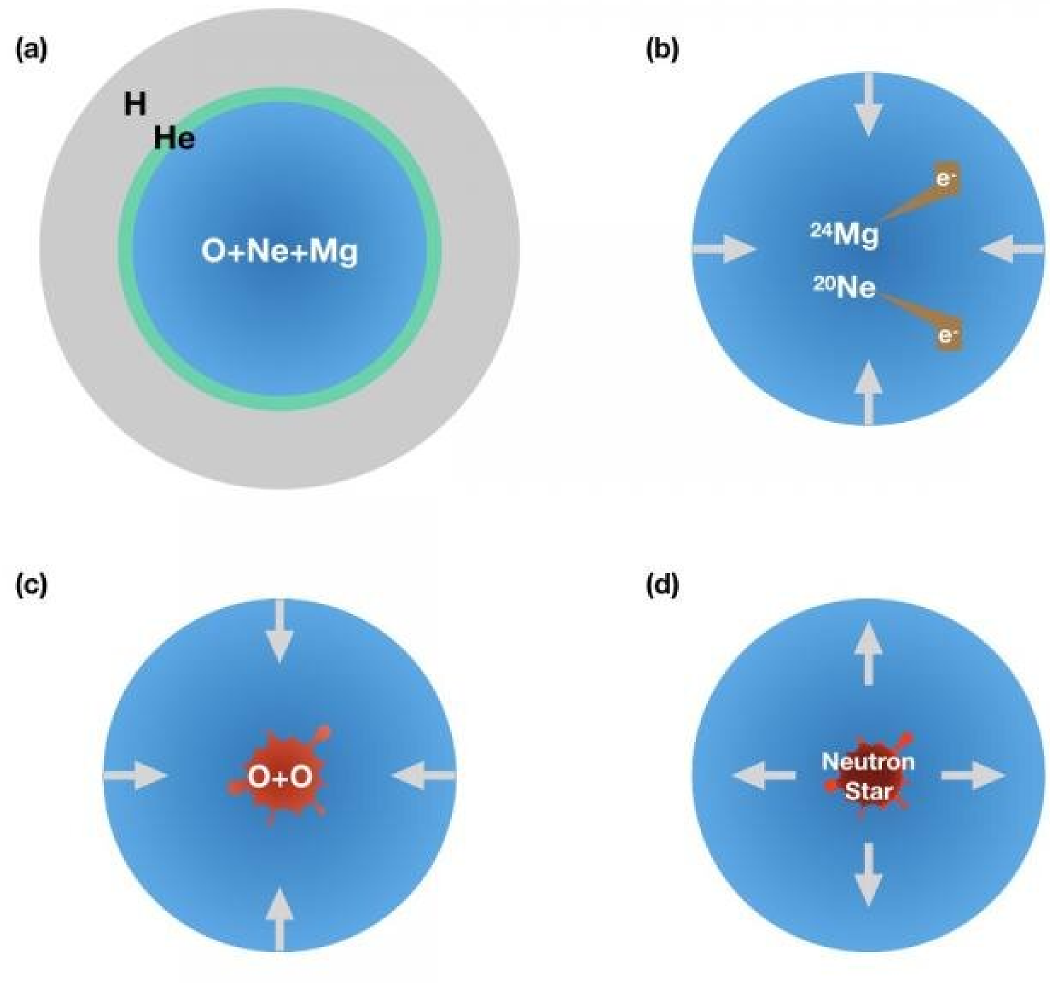

Figure 2: (a) A star core contains oxygen, neon, and magnesium. Once the core density becomes high enough, (b) magnesium and neon begin eating electrons and inducing a collapse. (c) Then oxygen burning is ignited and produces iron-group-nuclei and free-protons, which eat more and more electrons to promote further collapse of the core. (d) Finally, the collapsing core becomes a neutron star in the center, and the outer layer explodes to produce a supernova. Credit: Zha et al

Using newly updated data by Suzuki for density-dependent and temperature-dependent electron capture rates, they simulated the evolution of the star's core, which is supported by the pressure of degenerate electrons against the star's own gravity. As magnesium and mainly neon eat the electrons, the number of electrons decreased and the core rapidly shrunk (Figure 2).

The electron capture also released heat. When the central density of the core exceeded 10^{10} g/cm^3, oxygen in the core started to burn materials in the central region of the core, turning them into iron-group nuclei such as iron and nickel. The temperature became so hot that protons became free and escaped. Then the electrons became easier to capture by free protons and iron-group-nuclei, and the density was so high that the core collapsed without producing a thermonuclear explosion.

With the new electron capture rates, oxygen burning was found to take place slightly off-center. Nevertheless, the collapse formed a neutron star and caused a supernova explosion, showing that an electron-capture supernova can occur.

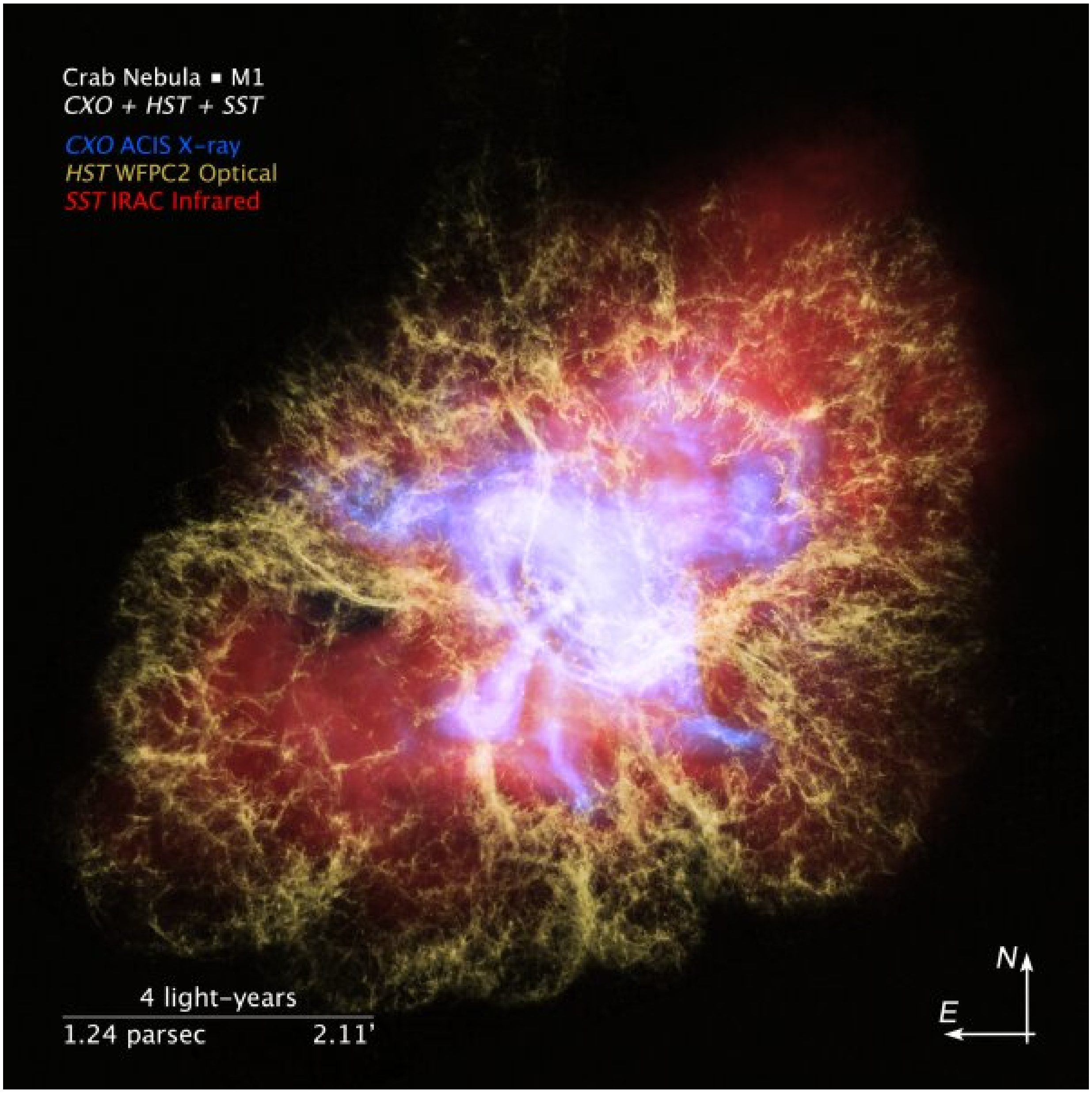

Figure 3: The Crab Nebula, a remnant of the supernova in 1054 (SN 1054; observed by ancient astronomers in China, Japan and Arab). Nomoto et al. (1982) suggested that SN 1054 could be caused by electron capture supernova of a star with the initial mass of about nine times the sun. Credit: NASA, ESA, J. DePasquale (STScI), and R. Hurt (Caltech/IPAC)

A certain mass range of stars with eight to 10 solar masses would form white dwarfs composed of oxygen-magnesium-neon by envelope loss due to stellar wind mass loss. If the wind mass loss is small, on the other hand, the star undergoes the electron capture supernova, as found in their simulation.

The team suggests that the electron capture supernova could explain the properties of the supernova recorded in 1054 that formed the Crab Nebula, as proposed by Nomoto et al. in 1982 (Figure 3).

These results were published in *The Astrophysical Journal* on November 15, 2019.

More information: Shuai Zha et al. Evolution of ONeMg Core in Super-AGB Stars toward Electron-capture Supernovae: Effects of Updated Electron-capture Rate, *The Astrophysical Journal* (2019). DOI: 10.3847/1538-4357/ab4b4b

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