

# Simulations uncover why some supernova explosions produce so much manganese and nickel

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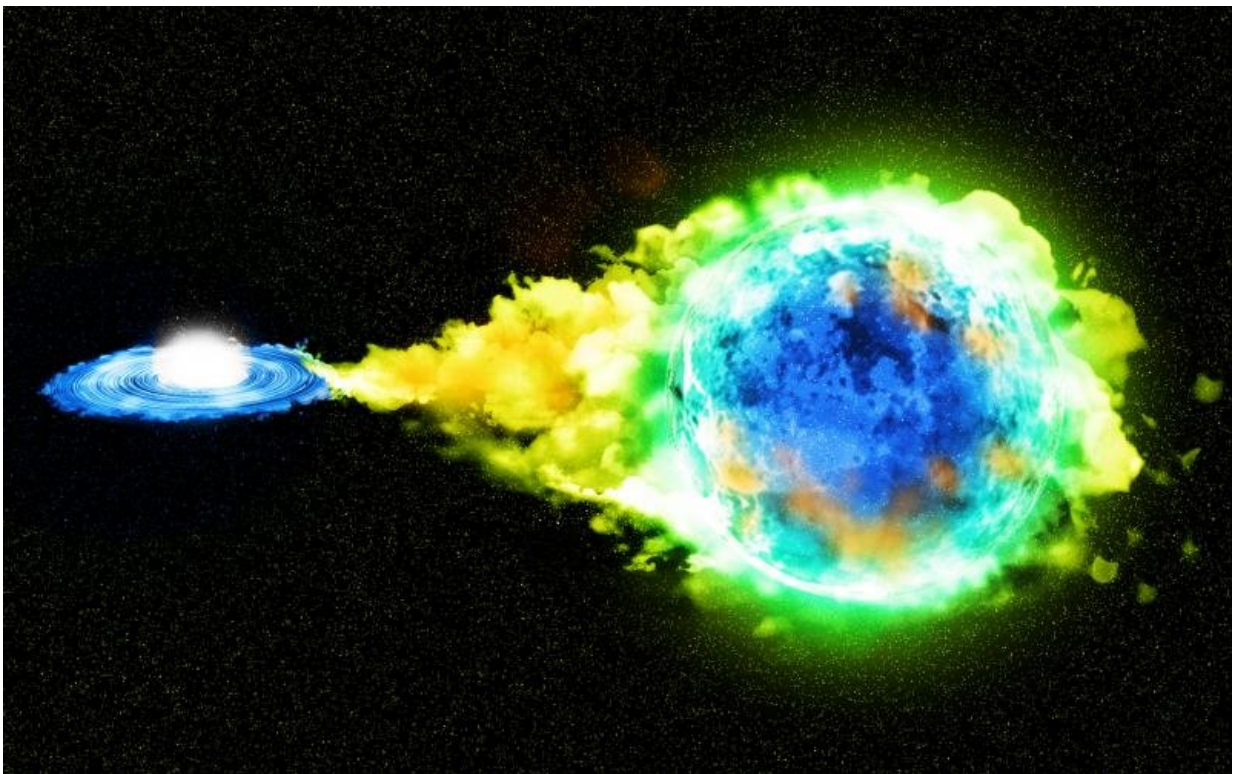


Figure 1: An artist's conception of a single-degenerate Type Ia supernova scenario. Due to the stronger gravitational force from the white dwarf on the left, the outer material of the bigger, slightly evolving main-sequence star on the right is torn away and it flows onto the white dwarf, eventually increasing the mass of the white dwarf toward the Chandrasekhar mass. This carbon-oxygen white dwarf will later explode as a Type Ia supernova. Credit: Kavli IPMU

Researchers have found white dwarf stars with masses close to the maximum stable mass (called the Chandrasekhar mass) are likely to produce large amounts of manganese, iron, and nickel after they orbit another star and explode as Type Ia supernovae.

A Type Ia supernova is a thermonuclear explosion of a carbon-oxygen white dwarf star with a companion star orbiting it, also known as a binary system. In the universe, Type Ia supernovae are the main production sites for iron-peak elements, including [manganese](#), iron, and nickel, and some intermediate mass elements including silicon and sulfur.

However, researchers today cannot agree on what kind of binary systems triggers a white dwarf to explode. Moreover, recent extensive observations have revealed a large diversity of nucleosynthesis products, the creation of new atomic nuclei from the existing nuclei in the star by nuclear fusion, of Type Ia supernovae and their remnants, in particular, the amount of manganese, stable nickel, and radioactive isotopes of <sup>56</sup>-nickel and <sup>57</sup>-nickel.

To uncover the origin of such diversities, Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) Project Researcher Shing-Chi Leung and Senior Scientist Ken'ichi Nomoto carried out simulations using the most accurate scheme to date for multi-dimensional hydrodynamics of Type Ia supernova models. They examined how chemical abundance patterns and the creation of new atomic nuclei from existing nucleons depend on white dwarf properties and their progenitors.

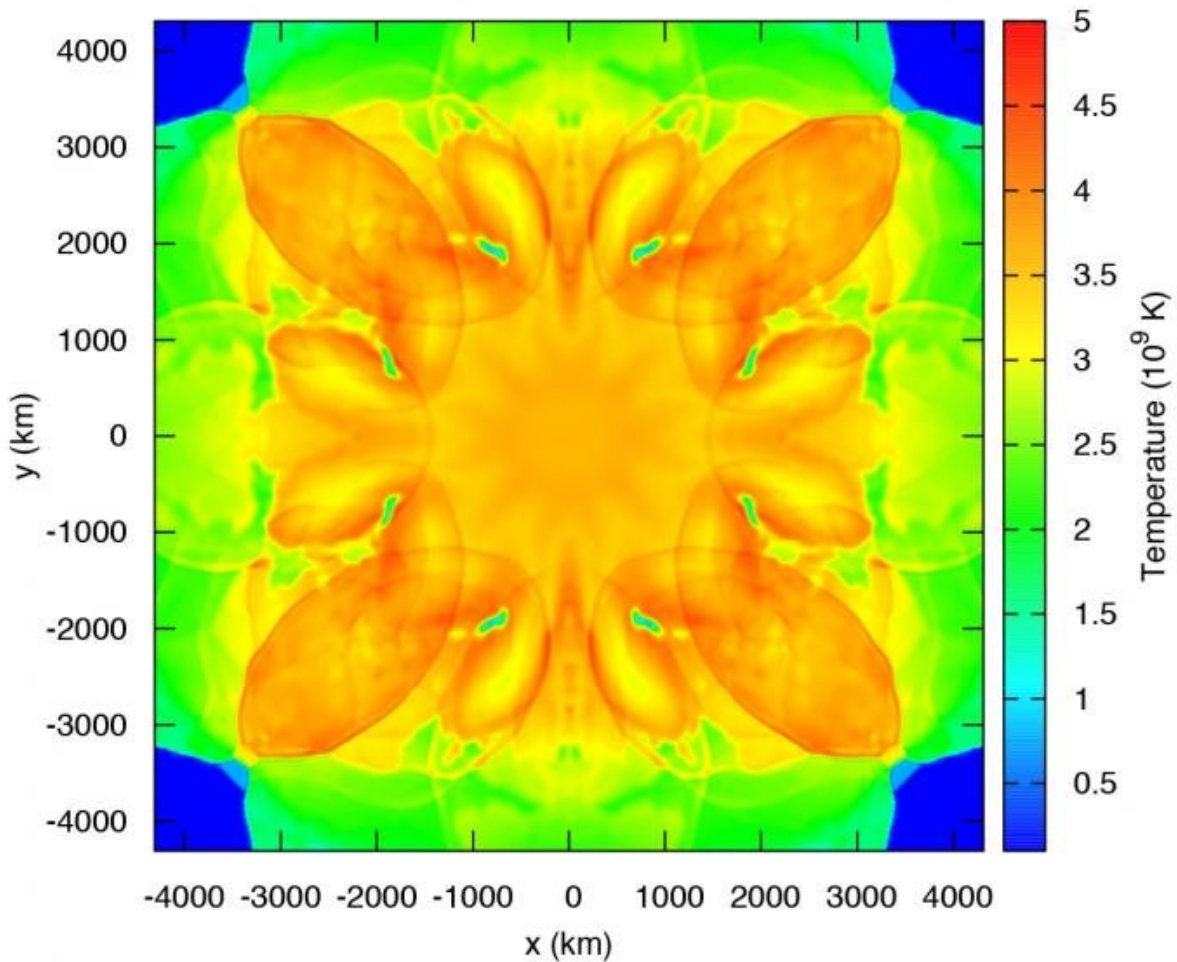


Figure 2: The colour plot of the temperature distribution of the benchmark Type Ia supernova model at about 1 second after explosion. The deflagration model with deflagration-detonation transition is used to produce this result. Credit: Leung et al

"The most important and unique part of this study is that this is so far the largest parameter survey in the parameter space for the Type Ia supernova yield using the Chandrasekhar mass white dwarf," said Leung.

A particularly interesting case was the supernova remnant 3C 397. 3C

397 is located in the Galaxy about 5.5 kpc from the center on the galactic disk. Its abundance ratios of stable manganese/iron and nickel/iron were found to be two and four times that of the Sun respectively. Leung and Nomoto found the abundance ratios among manganese, [iron](#) and [nickel](#) are sensitive to white dwarf mass and metallicity (how abundant it is in elements heavier than hydrogen and helium). The measured values of 3C 397 can be explained if the white dwarf has a mass as high as the Chandrasekhar mass and high metallicity.

The results suggest remnant 3C 397 could not be the result of an explosion of a white dwarf with relatively low mass (a sub-Chandrasekhar mass). Moreover, the white dwarf should have a metallicity higher than the Sun's metallicity, in contrast to the neighboring stars which have a typically lower metallicity.

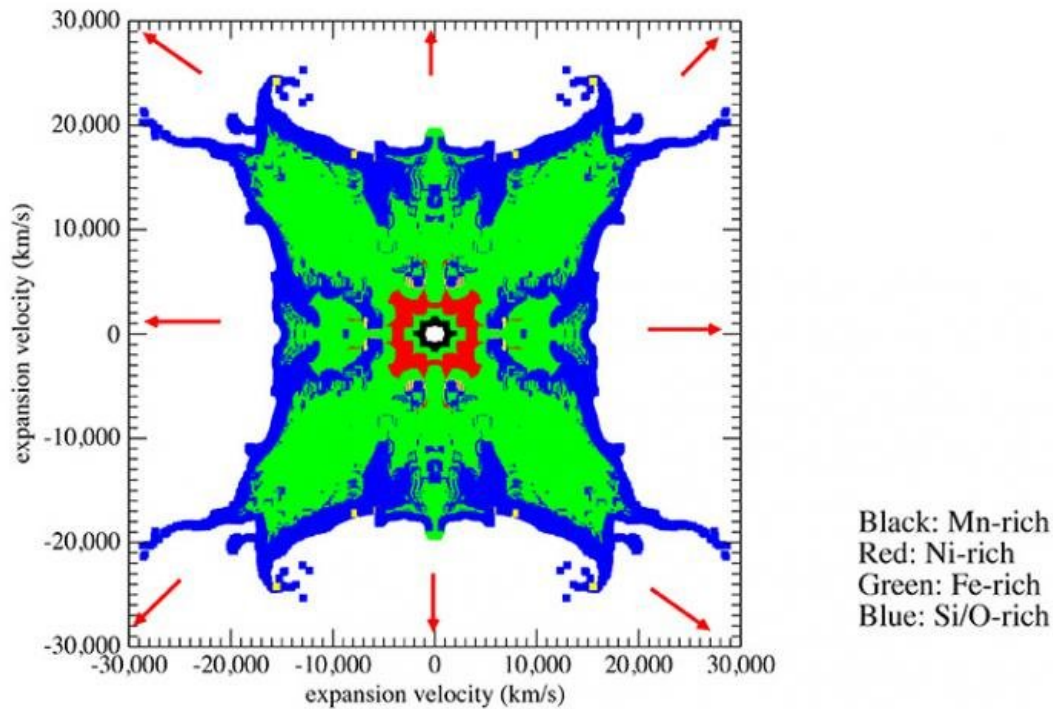


Figure 3: Distributions of representative elements ejecta velocity in the typical Type Ia supernova after all major nuclear reactions have ended. Colours represent the sites where the corresponding elements are produced. The arrow indicates the motion of ejecta's. Credit: Leung et al.

It provides important clues to the controversial discussion of whether the mass of the white dwarf is close to the Chandrasekhar mass, or sub-Chandrasekhar [mass](#), when it explodes as a Type Ia supernova.



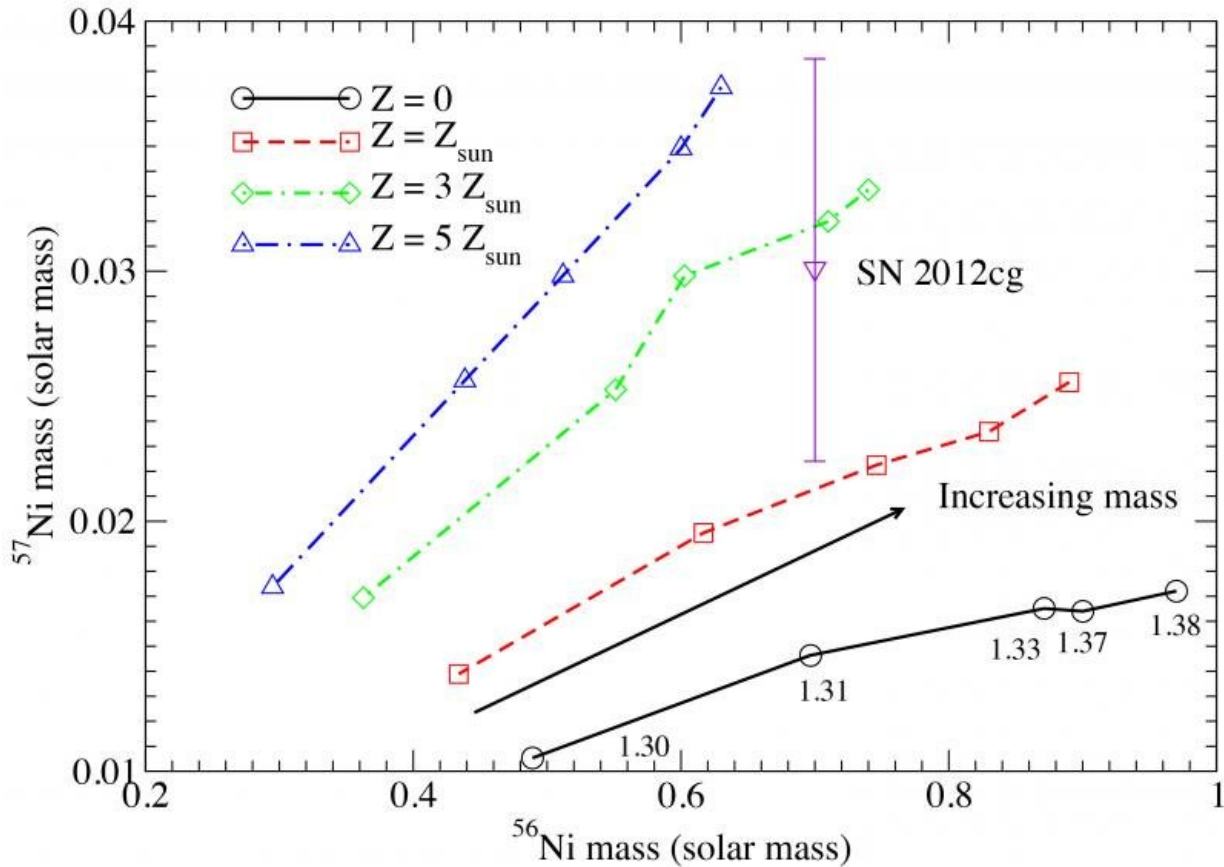


Figure 4: The  $^{57}\text{Ni}$  against  $^{56}\text{Ni}$  for the models presented in this work. The observed data from Type Ia supernova SN 2012cg is also included. The data points along the line in the described direction stand for white dwarf models of masses from 1.30 to 1.38 solar mass respectively. Credit: Leung et al.

The results will be useful in future studies of chemical evolution of galaxies for a wide range of metallicities, and encourage researchers to include super-solar metallicity models as a complete set of stellar models.

Leung says the next step of this study would involve further testing their model with more observational data, and to extend it to another subclass

of Type Ia supernovae.

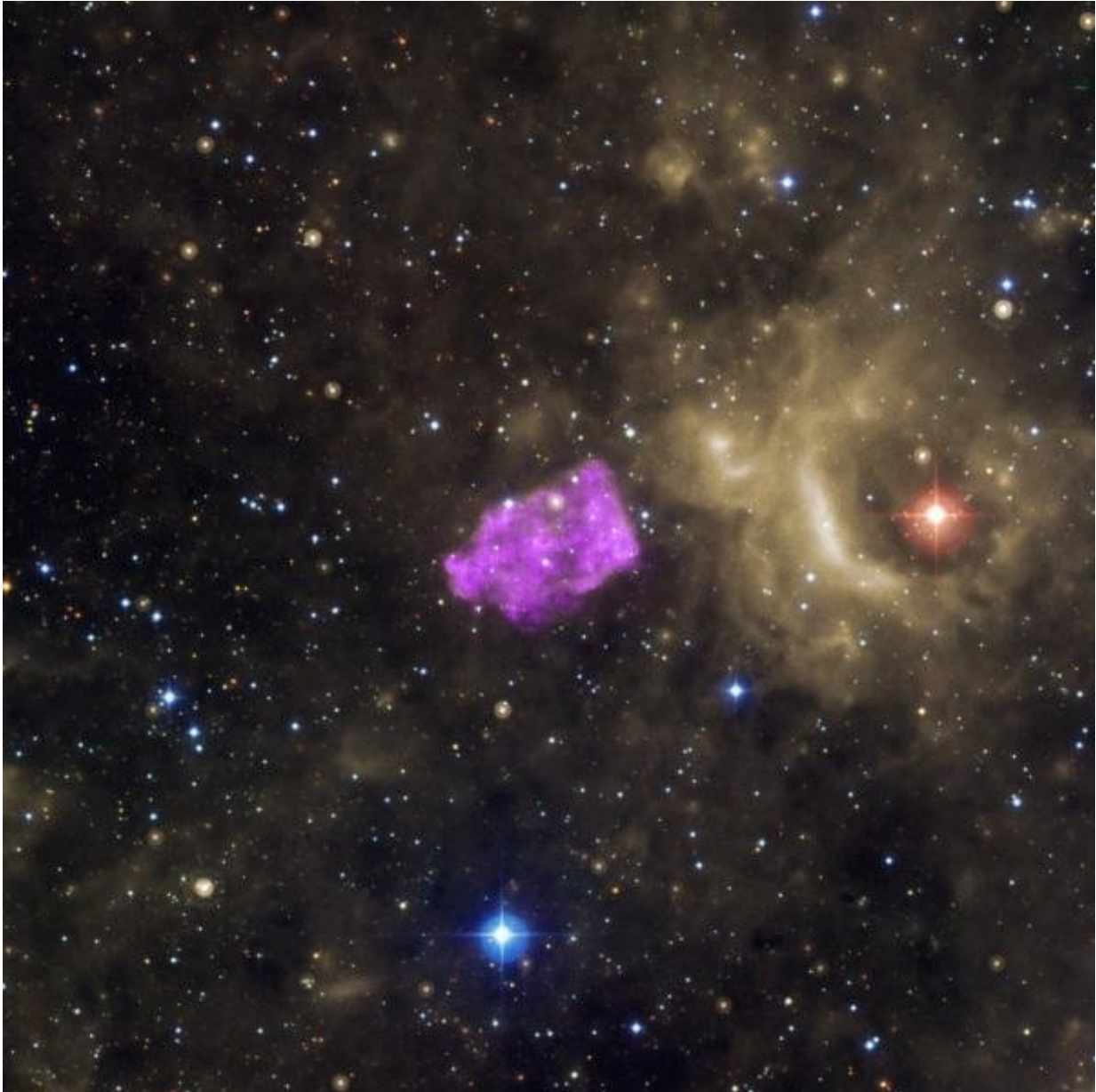


Figure 5: X-ray, optical & infrared composite image of 3C 397. Credit: X-ray: NASA/CXC/Univ of Manitoba/S.Safi-Harb et al, Optical: DSS, Infrared: NASA/JPL-Caltech

These results were published in the July 10 issue of the *Astrophysical Journal*.

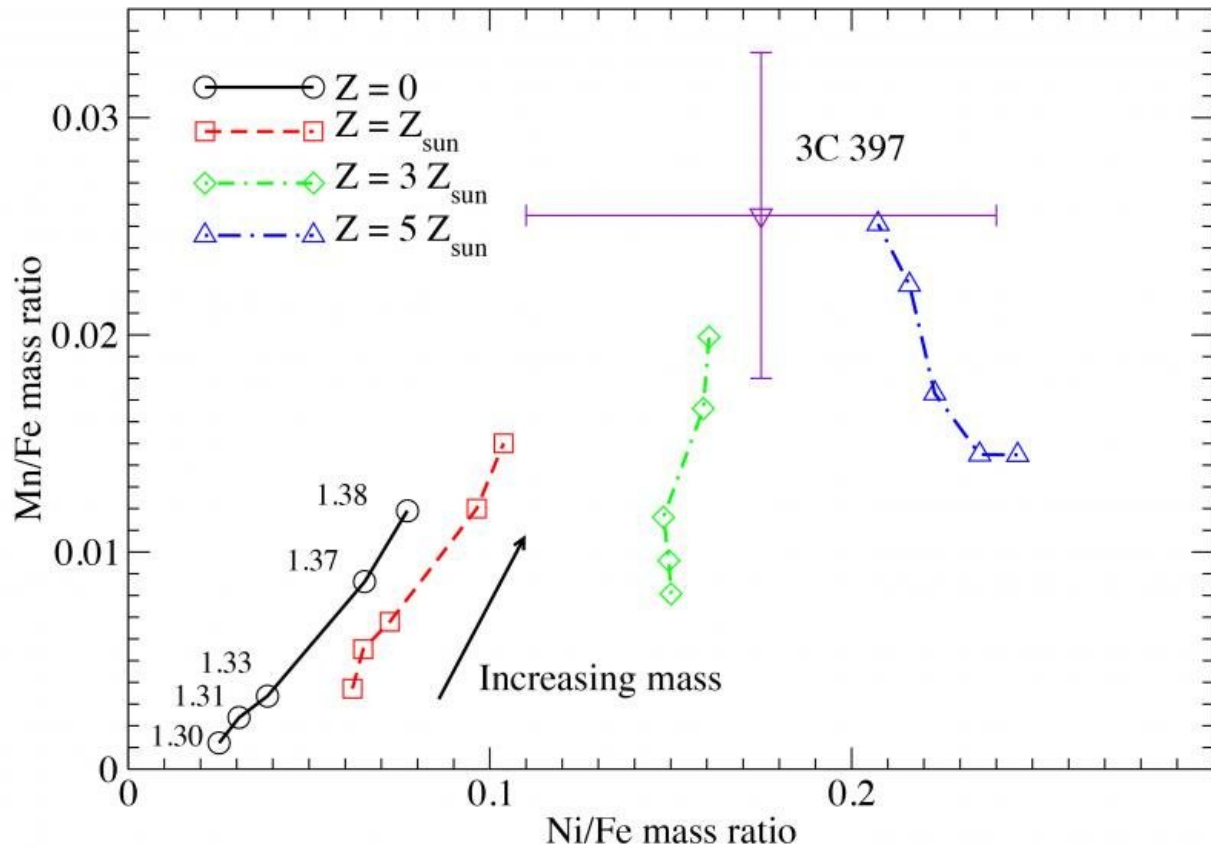


Figure 6: Mass ratio Mn/Fe against Ni/Fe for the models presented in this work. The observed data from Type Ia supernova remnant 3C 397 is also included. The data points along the line in the described direction stand for white dwarf models of masses from 1.30 to 1.38 solar mass respectively. Credit: Leung et al.

**More information:** Shing-Chi Leung et al. Explosive Nucleosynthesis in Near-Chandrasekhar-mass White Dwarf Models for Type Ia Supernovae: Dependence on Model Parameters, *The Astrophysical*



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