The explosion at the surface sets out the final journey of a dying star

Abstract

An international astronomical group lead by Ji-an Jiang, a PhD student from the University of Tokyo discovered a Type Ia supernova (named as "MUSSES1604D") within one day after the explosion by using the world-best wide-field camera mounted on the 8.2-m Subaru telescope, the Hyper Suprime-Cam. Follow-up observations carried out by eight telescopes over the world show that MUSSES1604D is significantly different from previously observed objects, especially for the abnormal brightness variance in the first few days after the explosion. Our further analysis surprisingly found that the peculiar features observed for MUSSES1604D can be perfectly explained by a specific explosion model which indicates that the explosion of the helium elements at the white dwarf surface will ultimately ignites the core explosion. This finding is the first robust evidence that one theoretical predicted stellar explosion scenario proposed in early 1980's, does truly exist in our universe.

Research background

Most of stars end their lives through a spectacular explosion. Previous studies indicate that the explosion of a white dwarf through specific channel(s) will produce one of the most amazing phenomena in the universe, so-called the Type Ia supernova (SN Ia). Because most of SNe Ia have roughly the same brightness, which enables astronomers to use them for the cosmological distance measurement. The most successful example is using SNe Ia to demonstrate the accelerating expansion of our universe (Nobel prize in physics 2011). Though the great success has been made in SN Ia cosmology, we are still puzzled by the essential issues that what the progenitor systems of SNe Ia are and How SN Ia explosions were ignited. For the progenitor issue, there are two popular scenarios: The single degenerate scenario indicates that the SN explosion will happen when the white dwarf reaches to the Chandrasekhar-mass limit by accreting mass from a neighbor star; The double degenerate scenario claims that the merger of two white dwarfs accounts for the SN Ia. So far, we are not completely sure whether both two scenarios or only one of them truly exist. On the other hand, the explosion mechanisms of SNe Ia are also under debate. In the past half centuries, astrophysicists proposed various kinds of theories to explain How SNe Ia explode while none of them has been firmly testified by astronomical observations because neither of them can perfectly explain the observed SNe Ia and there is no robust evidence to support any model. In order to find new clues to figure out these long-standing issues, we aim to catch SNe Ia within a few days after their explosions (hereafter "early-phase SNe Ia") by using the world-best wide-field camera mounted on the 8.2-m Subaru telescope, the Hyper Suprime-Cam. The scientific project was established in 2016, named as "MUSSES", an abbreviation of "the MUlti-band Subaru Survey for Early-phase SNe Ia" (The Principle Investigator: Ji-an Jiang).

Details of our work

One of the primary goals of MUSSES is to confirm the progenitor system of SNe Ia by finding the footprint of the interaction between the exploded ejecta and the neighbor star (this phenomenon is called "companion-ejecta interaction") with the early-phase SN Ia light curves. In April 2016, we successfully discovered a SN Ia soon after the explosion (named as "MUSSES1604D") with the 8.2-m Subaru telescope, which was over 100 times fainter than its peak brightness during the first observation. The early-phase Subaru observations indicate that MUSSES1604D shows abnormal brightness variance in the first few days after the explosion, which might be the evidence of the companion-ejecta interaction for our first impression.

However, with the follow-up observations carried out by eight telescopes over the world, we found that MUSSES1604D is even more special than our thought: As a SN Ia with normal brightness, its peculiar color evolution from very early time and specific absorption features in the around-max spectrum are significantly different from any SN Ia observed before.

In order to figure out the origin of the peculiarities observed for MUSSES1604D, numerous computational simulations were conducted based on different kinds of theoretical models. After more than 3-months discussions and testing, we confirmed that the peculiar features of MUSSES1604D are not consistent with the predictions from the companion-ejecta interaction as what we originally expected, but instead, we surprisingly found that not only the early-phase light curve behavior but also the abnormal color and spectral features can be perfectly explained by a specific explosion mechanism, in which the accumulation of helium at the surface of the white dwarf first ignites explosive helium burning and shock waves generated by this precursor event propagate inward and eventually ignite carbon burning in the core of the white dwarf. In addition, our simulation results suggest that the progenitor white dwarf of MUSSES1604D could be very massive, which means this explosion mechanism may happen in a much larger white dwarf mass range than our original idea. In a word, our finding is the first robust evidence that one theoretically predicted stellar explosion mechanism proposed in early 1980's, does truly exist in our universe.

Prospects

The discovery of MUSSES1604D in the very dawn of its emergence answers how the explosion of SNe Ia can be ignited for the first time and has opened the door to the essential understanding of these spectacular phenomena in our universe. In addition, considering the significance for using SNe Ia in cosmology, this finding also brings us new ideas to further promote the accuracy of the cosmological use of SNe Ia.
By continuously carrying out the MUSSES project, we are able to to find more SNe Ia with peculiar photometric behaviors at early time. We look forward to making new breakthroughs with those interesting objects in the near future.