The star that burns twice as bright

An helium explosion heralds the end of a dying star

An international astronomical team led by Ji-an Jiang (a graduate student of the University of Tokyo), Mamoru Doi (U. Tokyo), Keiichi Maeda (Kyoto University) and Toshikazu Shigeyama (U. Tokyo), called "the MUSSES team", has found the evidence that the brightest stellar explosions in our universe could be triggered by the helium nuclear explosion at the surface of a white dwarf. The conclusion was reached by examining observational data of a type Ia supernova discovered within a day of the explosion by the MUSSES project using the wide-field camera "Hyper Suprime-Cam" mounted on the 8.2-m Subaru telescope, and simulating light curves and spectra based on various explosion scenarios using the supercomputer ATERUI. This study was reported in *Nature* published on Oct. 5, 2017 (Japanese Standard Time).

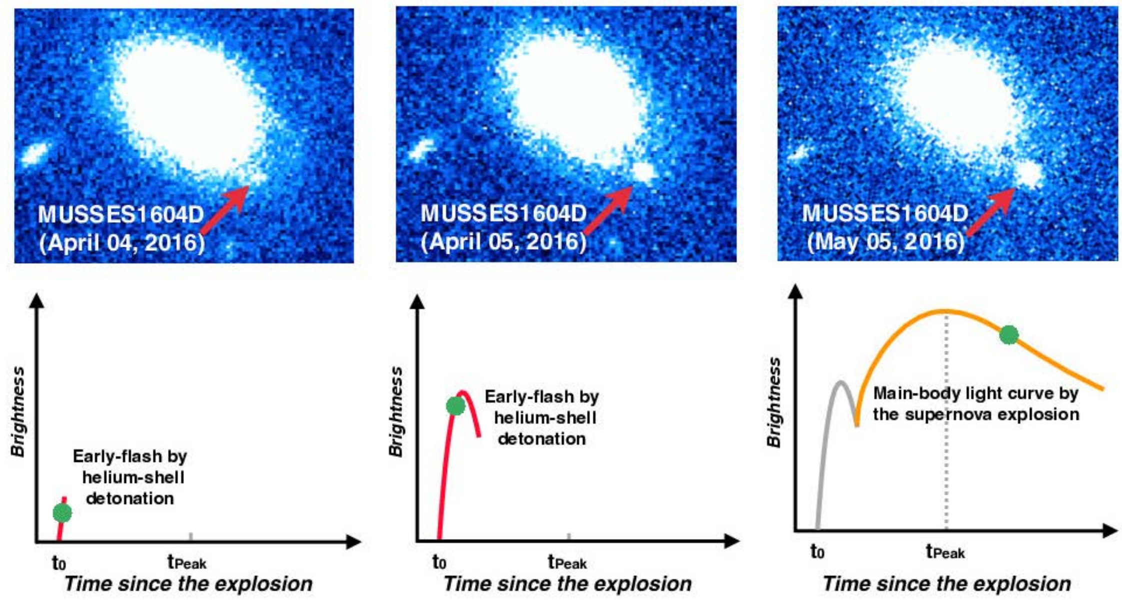

Figure 1

The first two-days observations of the type Ia supernova (named MUSSES1604D) with Subaru/Hyper Suprime-Cam and follow-up observations with the Gemini-North telescope one month after the first observation. The bottom panels show schematic pictures of the light curve evolution. Credit: Institute of Astronomy, the University of Tokyo.

Many stars end their lives through a spectacular explosion. Most massive stars will explode as a supernova. Though a white dwarf is a remnant of an intermediate mass star like our Sun, it may explode as well if it is a member of a close binary star system where two stars orbit around each other. This type of supernovae is classified as Ia.

Because of the uniform and extremely high brightness (about 5 billion times brighter than our Sun) of type Ia supernovae, they are widely used as the standard candle for the distance measurement in astronomy. The most successful example using type Ia supernovae is the discovery of the accelerating expansion of our universe (Nobel prize in physics 2011). Though the great success has been made in the type Ia supernova cosmology, researchers are still puzzled by the essential issues of what the progenitor systems of type Ia supernovae are and how type Ia supernova explosions are ignited.

To find new clues and figure out these long-standing issues, Jiang and his collaborators aimed to catch a type Ia supernovae within a few days, or even a day, after their explosions (hereafter "early-phase type Ia supernovae"). This was conducted using the Hyper Suprime-Cam mounted on the Subaru telescope, the most powerful survey facility in the world. Their scientific project was established in 2016, named "MUSSES", an abbreviation of "the MUlti-band Subaru Survey for Early-phase type Ia supernovae (SNe Ia)", and include researchers from the University of Tokyo, Kyoto University, the National Astronomical Observatory of Japan (NAOJ) and other institutions in Japan and foreign countries.

"We discovered over 100 supernova candidates in a single night with Subaru/Hyper Suprime-Cam. Among them, a type Ia supernova soon after the explosion, within a day, has been identified. Surprisingly, the supernova in the first few days was much brighter than expected," said Jiang.

In order to figure out the origin of this initial flash, followed by somewhat peculiar color and spectral evolution, intensive computational simulations were conducted, in part using the supercomputer ATERUI at NAOJ, conducted by Keiichi Maeda and Toshikazu Shigeyama, based on different kinds of theoretical models. They finally confirmed that the features of this supernova are not consistent with predictions from most of scenarios, but instead, all observational characteristics of this supernova can be explained by a specific explosion mechanism.

In this scenario, the accumulation of helium on the surface of the white dwarf first ignites explosive helium burning and shock waves generated by this precursor event propagate inward. The shock waves eventually ignite the carbon burning in the core of the white dwarf. The bright flash is then created in the first few days by the energy released, provided by unstable nucleosynthesis products from the helium burning.

“Once we noticed the possibility of this helium detonation scenario, everything about this supernova was just readily explained. This is the first robust evidence that one theoretically predicted stellar explosion mechanism proposed in early 1980's, does truly exist in our universe. The next question is if such a mechanism is unique or rather common in type Ia supernovae in general," said Maeda.

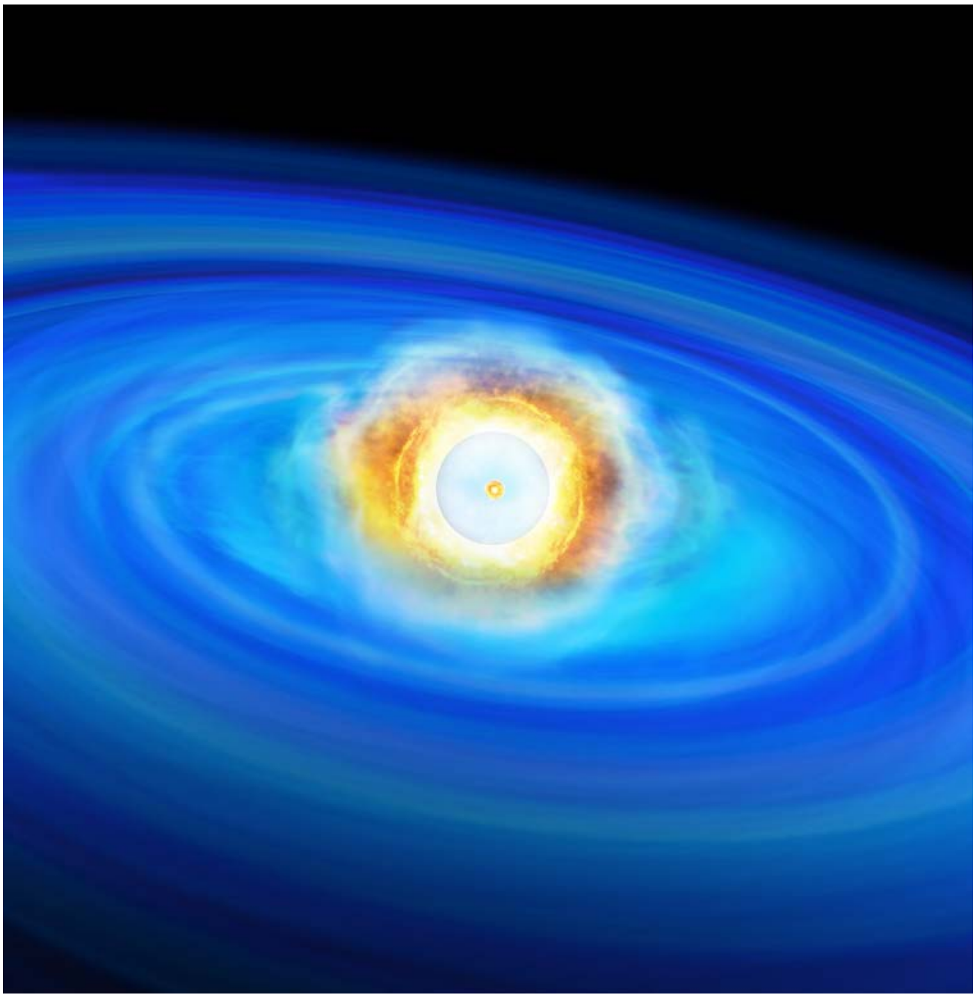

Figure 2
The astronomical art of a pre-explosion white dwarf triggered by the helium explosion at its surface. The nuclear explosion of the surface helium layer triggers inward shock waves, and the central carbon nuclear fusion is subsequently ignited.
Credit: Institute of Astronomy, the University of Tokyo.

This result answers how the explosion of type Ia supernovae can be ignited for the first time, and has opened the door to the essential understanding of these spectacular phenomena. Moreover, considering the significance for using type Ia supernovae in cosmology, this finding also brings the researchers new ideas to further promote the accuracy of the cosmological use of type Ia supernovae.

Jiang's team will carry out further investigations by continuously running the MUSSES project. "We are expecting to find many more supernovae within a day of the explosion, which should bring us further insight on the mechanism of supernovae. A more precise understanding of their history and behavior will help all researchers to perform more accurate cosmological measurement," concludes Doi.

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