甲南大学 KONAN UNIVERSITY　　国立天文台 NAOJ　　広島大学

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Masayuki Yamanaka (Taro Hirao Foundation Researcher) and his colleagues revealed the origin of 'extraordinary over-luminous supernovae' using observational data obtained through the Optical Infrared Synergetic Telescopes for Education and Research

- **The group observed an ‘extraordinary over-luminous supernova’ and discovered a strong near-infrared emission.**
- **The group demonstrated that the origin of this class of supernovae can be explained by the ‘accretion scenario’.**

Using data obtained through the Optical and Infrared Synergetic Telescopes for Education and Research (OISTER) in Japan, Masayuki Yamanaka, a Taro Hirao Foundation Researcher at Konan University, demonstrated that the origin of extraordinary supernovae can be explained by the ‘accretion scenario.’ While Type Ia (pronounced as “One-A”, *1) supernovae have been used as powerful tools to accurately measure the distances to distant galaxies, their origin has remained unclear for more than three decades. Further puzzles have been added in recent years, including the discovery of ‘the extraordinary supernovae’. The researchers discovered an anomalously strong infrared emission from ‘the extraordinary supernova’ SN 2012dn, which has never been observed in other Type Ia supernovae to date. Through detailed analysis, the researchers concluded that the infrared emission comes from the material ejected from the progenitor system. This research was published in ‘Publications of the Astronomical Society of Japan’ on May 18, 2016.

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Authors：Masayuki YAMANAKA, Keiichi MAEDA, Masaomi TANAKA, Nozomu TOMINAGA, Koji S. KAWABATA, Katsutoshi TAKAKI, Miho KAWABATA, Tatsuya NAKAOKA, Issei UENO, Hiroshi AKITAYA, Takahiro NAGAYAMA, Jun TAKAHASHI, Satoshi HONDA,Toshihiro OMODAKA, Ryo MIYANOSHITA, Takashi NAGAO, Makoto WATANABE, Mizuki ISOGAI, Akira ARAI, Ryosuke ITOH, Takahiro UI , Makoto UEMURA, Michitoshi YOSHIDA, Hidekazu HANAYAMA, Daisuke KURODA, Nobuharu UKITA, Kenshi YANAGISAWA, Hideyuki IZUMIURA, Yoshihiko SAITO, Kazunari MASUMOTO, Rikako ONO, Ryo NOGUCHI, Katsura MATSUMOTO, Daisaku NOGAMI, Tomoki MOROKUMA, Yumiko OASA, and Kazuhiro SEKIGUCHI
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１．Background

Type Ia (“One-A”) supernovae have brightnesses similar to that of an entire galaxy. (We will refer to them simply as ‘supernovae’ in what follows, although other types of supernovae exist as well.) The intrinsic brightness is similar for all of the supernovae, and furthermore there is a verified relation showing that the brighter the supernova is, the slower its brightnesss fades (*2). These properties enable us to measure correctly the distances to distant galaxies by observing supernovae within them. In the late 1990’s, the accelerating expansion of the Universe was discovered by using the properties of Type Ia supernovae. Drs. Perlmutter, Riess, and Schmidt were awarded the Novel Prize in Physics in 2011 for this work.

However, the origin of these supernovae remained undetermined for more than three decades despite intensive debate. There are two popular scenarios, ‘accretion’ or ‘merger’, as the path to the supernova explosion. Both scenarios consider a ‘binary system,’ i.e., two stars orbiting around each other. In the case of a binary system composed of a ‘white dwarf (*3)’ and a normal star, material is moved from the companion star onto the surface the white dwarf. In this way, the white dwarf reaches a limiting mass, triggering a supernova explosion. This scenario is called the ‘accretion scenario’. However, several ‘extraordinary supernovae’ have been discovered (including the research by our group in 2009), which require a very massive white dwarf as the exploding star, with a mass well beyond the limiting-mass of a (usual) white dwarf. Such ‘extraordinary supernovae’ cannot be simply explained by the standard ‘accretion scenario’. For example, the gravitation energy of the white dwarf must be supported by some means, e.g., by a rapid rotation. The ‘merger scenario,’ in which two white dwarfs collide with each other, creating a massive white dwarf whose mass exceeds the limiting mass, was suggested to explain these cases.

２. Results

Masayuki Yamanaka, a Taro Hirao Foundation Researcher, and his colleagues performed observations of the ‘extraordinary supernova’ candidate SN 2012dn (Figure 1, *4) using 11 telescopes through OISTER (Figure 2). This supernova is the closest example of an extraordinary supernova, and thus is expected to yield the most detailed observational data for the extraordinary supernovae. Immediately after the discovery of this supernova, Yamanaka noticed the potential importance of this object as a mile stone in the study of the origin of the extraordinary supernovae, and requested observations using OISTER telescopes. Especially, they expected to obtain new information on the supernova properties through the infrared-wavelength observations. The observations continued until 150 days after supernova was first observed.

As a result of this observing campaign, they discovered an anomalously strong infrared emission for this object which cannot be seen in typical supernovae. The groups performed detailed analysis of the infrared emission. They concluded that material ejected from the progenitor system is responsible for this emission. The material was heated by the supernova light and emitted the infrared light. The distance to the material from the central supernova was estimated to be around 0.2 light-year (Figure 3). This is the first time that the emission from materials ejected from the progenitor system was observationally obtained and confirmed for a Type Ia supernova. The mass of the ejected material strongly supports the ‘accretion scenario’ which is the leading scenario to explain the supernova (Figure 4). For the accretion scenario, gas is transferred onto the surface of the white dwarf from the companion star in the binary system. A part of the material escapes from the gravitational potential of the system, forming a dense gas surrounding the pre-supernovae-explosion star system and SN 2012dn exploded while surrounded by this dense gas.

On the other hand, the supernova explosion could also occur from the merger of two white dwarfs as suggested by the ‘merger scenario.’ For this scenario, it takes a very long time from the formation of the two white dwarfs to the merger. The surrounding material should therefore diffuse away and almost disappear entirely before the supernova occurs. Thus, the signature of ejected material from the pre-explosion system, like the one the researchers discovered, is strong evidence for the ‘accretion scenario.’

3. Expectations to the future

Uncovering the origin of the ‘extraordinary’ supernovae can have strong impacts on various branches of astronomy. This is key to understanding the origin of typical supernovae, and whether or not it is the same as the origin of the ‘extraordinary supernovae.’ Such studies will be accelerated thanks to the present findings. It also remains to be clarified how the pre-explosion white dwarf star was able to grow beyond the limiting mass. Rapid rotation of the white dwarf may be a favored scenario to explain it, but a rapidly rotating massive white dwarf beyond the limiting mass has yet to be observed. The idea to explore the possible existence of surrounding material around the supernova using infrared emissions was actually based on a theoretical prediction presented by a few members in the present research group before the discovery of the infrared emission from SN 2012dn. Indeed there have been null detections of such a signal from typical supernovae. But with the present findings this issue must be revisited, with deeper infrared observations than performed so far.

We note the impact of this study on the rate of cosmic expansion. The ‘extraordinary’ supernovae should be excluded from the sample for the cosmological research. As the nature of the ‘extraordinary’ supernovae is uncovered, the contamination can be excluded more accurately. Understanding the ‘extraordinary supernovae’ will lead to a more correct measurement of the cosmic expansion rate.

<Notes>

(*1) Type Ia supernova : Supernovae are classified by their spectra (observations which divide the light by wavelengths). We can identify the material in the expanding atmosphere. If hydrogen and helium are not seen and the heavier elements like silicon or iron are visible, the supernova is classified as a Type Ia supernova.

(*2) Brightness : There are two methods for describing the brightness of an astronomical object. The actual observed brightness is called the ‘apparently brightness.’ On the other hand, the brightness calculated using the distance to the object and transformed into the luminosity per unit of time is called the ‘absolute brightness.’ We can estimate the distance to galaxies using Type Ia supernovae because their absolute brightness is known.

(*3) White dwarf : A white dwarf is a very dense star which has a mass similar to the Sun and a volume similar to the Earth. This type of star has a certain limiting mass based on special relativity and quantum physics. Because the explosion occurs when the star’s mass grows to be about the same as the limiting mass, the brightnesses of these supernovae are believed to be similar.

(*4) SN 2012dn : This SN was discovered in galaxy ESO 462-G016 (in roughly the direction of the boundary region between Sagittarius and Capricornus) at the distance of 130 mega-light-years from the Earth on July 8, 2012. The similarity of SN 2012dn to the previous 'extraordinary supernova' was pointed out.

< Figures>

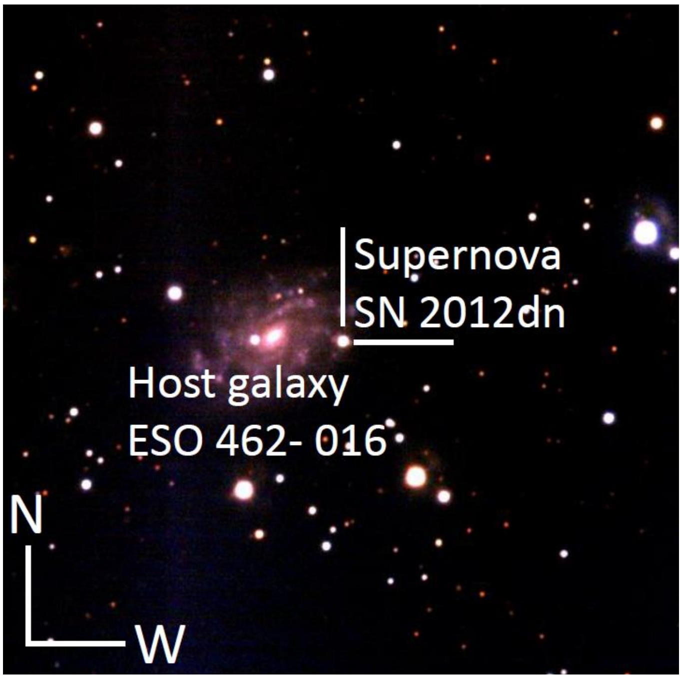
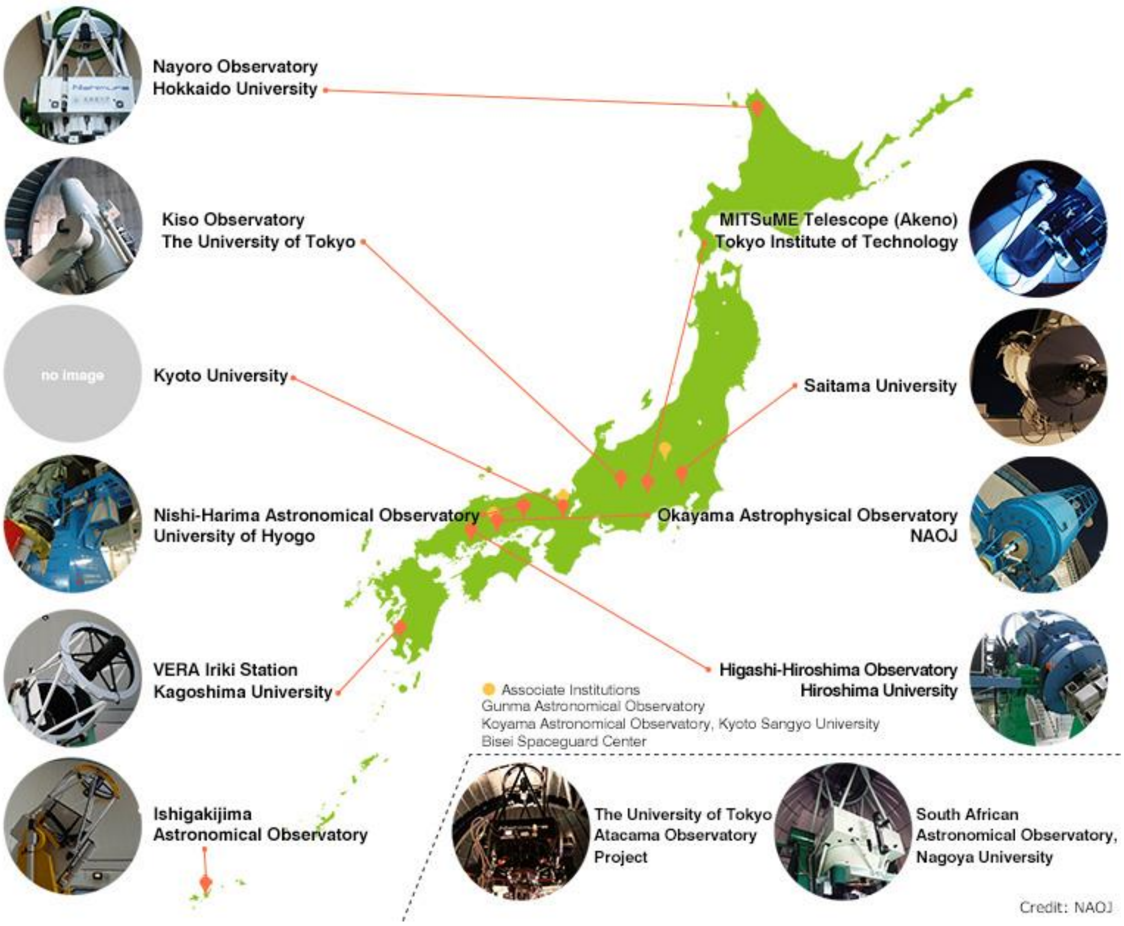


Figure 1 :. Image around SN 2012dn obtained by the Kanata Telescope at Higashi-Hiroshima Observatory. SN 2012dn is seen near the center of this figure. The host galaxy ESO 462-G016 is seen at the left side of SN 2012dn. The distance to this galaxy is known to be 130 mega-light-years. Because the supernova is a point source, the expansion cannot be measured, but the evolutions of the brightness and color are obtained.



Credit: NAOJ

Figure 2: Telescopes in the various observatories of universities constituting OISTER. The participants are Okayama Astrophysical Observatory of the National Astronomical Observatory of Japan, Ishigaki-jima Astronomical Observatory, Hiroshima University, Kagoshima University, Hokkaido University, Tokyo Institute of Technology, Nagoya University, Hyogo University, Kyoto Sangyo University, and Osaka Kyoiku University.

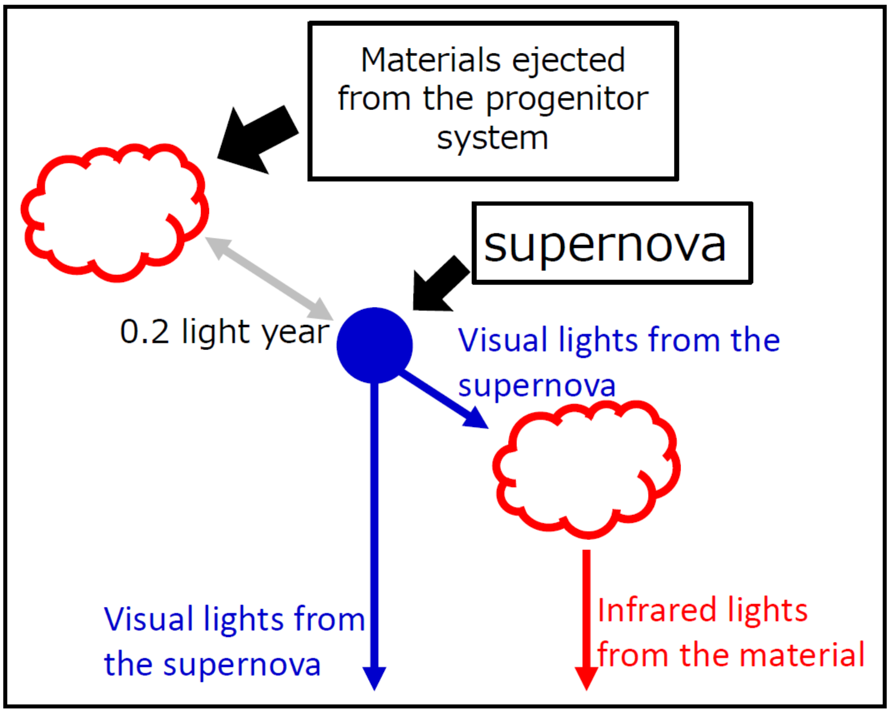


Figure 3: Schematic diagram of SN2012dn in which the material ejected from the pre-explosion star emits the infrared light. These materials were ejected from the progenitor system before the supernovae explosion occurs. The ejected material is heated up by the supernova light and re-emits the infrared light in the direction of the Earth. The distance to the material from the central supernova was estimated to be 0.2 light-year.

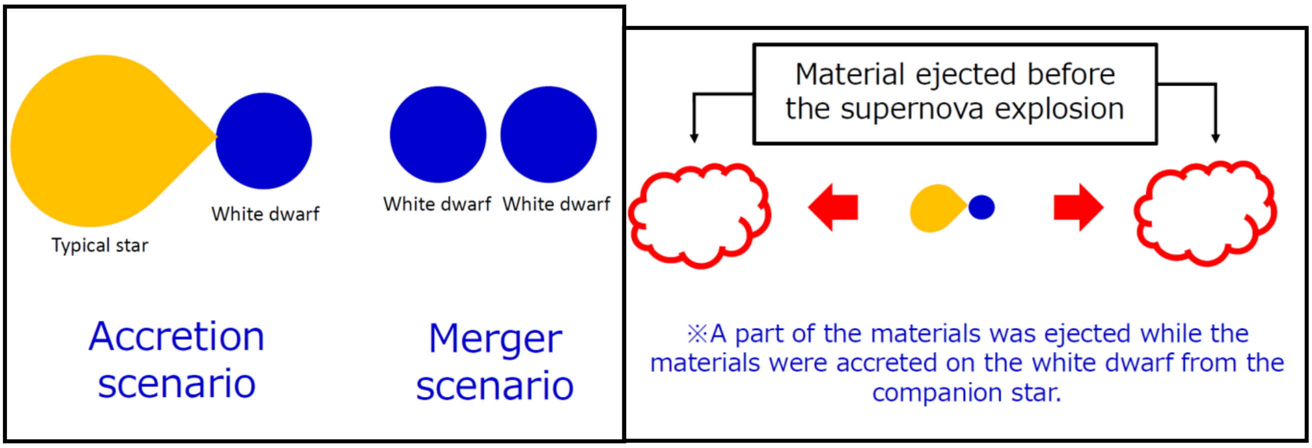


Figure 4: (left) Schematic picture of two scenarios for the ‘extraordinary supernova'. The stars orbit each other at a very close distance (for example, the distance is roughly several times the solar radius). The material emitting the infrared light is gas which was ejected during the mass transfer to the white dwarf from the companion star. This material must be explained by the ‘accretion scenario’ (right hand).

Contact persons

[About this research]

Masayuki Yamanaka, Taro Hirao Foundation Researcher, Department of Physics,
Faculty of Science and Engineering, Konan University
TEL: 082+09-9712-8410, Email : yamanaka@center.konan-u.ac.jp