Rapidly rotating white dwarf stars can solve missing companion problem for type Ia supernovae

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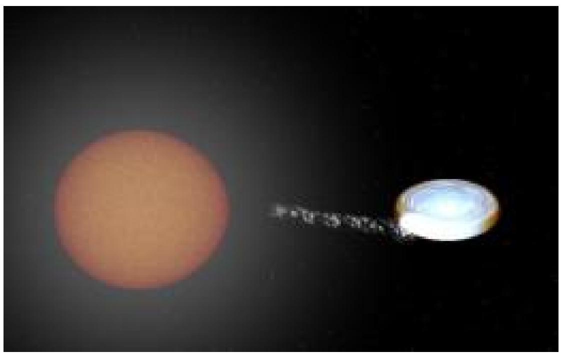

Figure 1: Configuration of progenitor binary system in the case of a red-giant (left) and a white dwarf (right, but too small to be seen). Gas is flowing from the red-giant. The white dwarf accretes a part of the gas through the accretion disk (blue white disk around the white dwarf). T Coronae Borealis and RS Ophiuchi are typical examples.

The research group from the University of Tokyo and Keio University discovered that a Type Ia supernova occurs after its companion star evolves into a faint helium white dwarf in many cases, given the fact that the white dwarf is spinning in the progenitor system.

Supernovae are brilliant explosions of stars. Among them, Type Ia supernovae have been used as "standard candles", which has led to the discovery of the accelerating expansion of the Universe. Type Ia supernovae are also important to study as they are the main producer of iron group elements in the Universe. Type Ia supernovae are accepted as thermonuclear explosions of carbon-oxygen white dwarfs in binary star systems. However, the debate still continues over two possible progenitor scenarios: one is that two carbon-oxygen white dwarfs coalesce and then explode (Double Degenerate [DD] scenario), and the other is that a white dwarf, accreting mass from its companion star, increases its mass and then explodes (Single Degenerate [SD] scenario).

Some recent observations have provided indications of the progenitor binary star systems just before the explosions. For example, the observations of the remnant of Kepler's supernova in 1604 and the recent supernova PTF 11kx have shown evidence that the companion star is a red-giant. These observations support the SD scenario. On the other hand, no companion star was found for the Type Ia supernova SN 2011fe in the nearby galaxy M101. In another example, no companion star is seen inside a supernova remnant in the Large Magellanic Cloud. Such observations have been generally considered unfavorable to the SD scenario but favorable to the DD scenario.

Recently, the research group took into account the fact that the white dwarf is spinning in the progenitor system. They found that, in many cases, a Type Ia supernova occurs after the companion star evolves into a helium white dwarf. Such helium white dwarf companions would be so faint as to be unobservable before and after a Type Ia supernova explosion. This new SD scenario explains in a unified manner why no signatures of the companion star are seen in many Type Ia supernovae, whereas some Type Ia supernovae indicate the presence of the companion star.

Their paper has been published in the September 1, 2012 issue of *The Astrophysical Journal Letters*.

In the SD scenario for Type Ia supernovae, a white dwarf receives gas from its companion star. There are two types of companion stars: a red-giant (Figure 1) and a main-sequence star (Figure 2). The mass of the white dwarf approaching the critical mass limit triggers a thermonuclear explosion in the white dwarf, which grows into a Type Ia supernova.For the spherical white dwarf (adopted in the previous scenario), this critical mass limit is the Chandrasekhar mass (about 1.4 times the mass of the Sun).

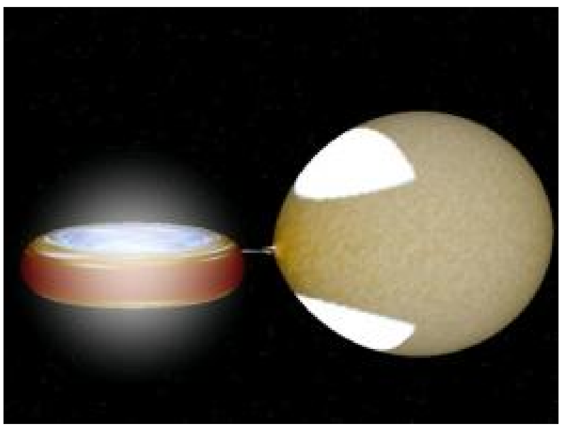

Figure 2: Another configuration of progenitor systems: a very heavy white dwarf (left, but too small to be seen) and a main-sequence star (right). The accretion disk around the white dwarf is rather bright because the mass accretion rate is quite high in this case. U Scorpii is an example. The mass of the white dwarf is so heavy as 1.37 times the mass of the Sun, very close to the Chandrasekhar mass limit. The distance between the two stars is rather short compared with the distance in Figure 1, about one tenth to one hundredth.

When the white dwarf receives gas from its companion, however, the white dwarf gains angular momentum of the gas and should thus be rapidly rotating like a spinning top. Since the centrifugal force makes the central density of the rotating white dwarf lower than the non-rotating star with the same mass, the white dwarf does not explode even when its mass exceeds the Chandrasekhar mass. If the rotation is very fast, it will take a significant amount of time until the white dwarf's spin slows down and the effect of centrifugal force becomes sufficiently small for the explosion to occur. During this spin-down time, the companion star evolves into a helium white dwarf (Figure 3). Such a white dwarf companion is too faint to be detected.

The authors calculated the evolution of the binary star system for this new SD scenario, and found that many of the binary systems contain a faint white dwarf companion when the Type Ia supernova explosion occurs (Figure 3). This is consistent with the no detection of the companion's signature in most of Type Ia supernovae and their remnants.

Figure 3: Configuration of progenitors just before a Type Ia supernova explosion that this study predicts in most cases. The white dwarf (right, unseen) supposed to be exploding becomes too dark and another white dwarf (left slightly seen in red) is also very faint. This study found that most progenitors are observed as in this figure before the explosion. All images copyright Mariko Kato, Keio University

They also found that about a half of the systems have a white dwarf whose mass reaches 1.4 to 1.5 times the mass of the Sun. In the remaining systems, the white dwarf mass exceeds 1.5 times the mass of the Sun. The authors assume that the explosion of a heavier white dwarf is brighter due to a larger amount of nuclear fuel available. Then the distribution of masses of the exploding white dwarfs is consistent with the observed brightness distribution of Type Ia supernovae.

The new SD scenario can also explain the fact that, in most Type Ia supernovae, gases around the exploding star are undetected. The previous SD scenario predicts the existence of gas around the exploding star, so the fact of no detection of surrounding gas has been considered a major difficulty of the SD scenario. The authors found theoretically that in a majority of progenitors just before the explosion, gases have been dispersed during the spin-down time and may be undetected. No presence of gas around the binary before the explosion is statistically consistent with the observations. On the other hand, a small number indicate the presence of gas around the binary, which correspond to the case of PTF11kx and Kepler's supernova.

More information: "Final Fates of Rotating White Dwarfs and Their Companions in the Single Degenerate Model of Type Ia Supernovae" *The Astrophysical Journal Letters*, Volume 756, Number 1, L4, September 1, 2012. doi:10.1088/2041-8205/756/1/L4

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