The Double Degenerate Progenitor Model of Type Ia Supernovae Formation

Type Ia supernovae, also known as SN Ia, are a product of a thermonuclear reaction and the subsequent explosion of a binary system of stars in which at least one of the two stars is a white dwarf (Ruiter, 2019). This phenomenon is highly transient in nature which makes it extremely challenging to study which configurations of the progenitors form these supernovae. Therefore, an unresolved research question surrounding Type Ia supernovae is the underlying mechanism of their formation, which is further explored in this paper. Currently, there are two proposed mechanisms by which these supernovae detonate. Firstly, according to the single degenerate progenitor model, the white dwarf continuously orbits around the other star, gradually increasing in mass until it reaches the Chandrasekhar limit, which is the maximum mass a white dwarf can attain, and subsequently explodes (Ruiter, 2019). In contrast, in the double degenerate progenitor model, two white dwarfs in a binary system collide with each other and release energy (Ruiter, 2019). This paper argues in favor of the double degenerate model due to multiple scientific observations that support its existence and the unlikely possibility that white dwarfs can independently reach the Chandrasekhar limit due to their distinct chemical properties.

Firstly, a large body of empirical evidence supports the existence of the double degenerate progenitor model. As mentioned above, in a single degenerate progenitor model, a white dwarf gains substantial mass from its neighboring star to its Chandrasekhar limit and explodes (Ruiter, 2019). As stated by Geier et al. (2013), a compact binary system CD-30 ° 11223 confirms the evidence of a helium precipitate that is released from the massive companion star. The result is the explosion of the white dwarf leading to a Type Ia supernova via a thermonuclear reaction (Geier et al., 2013). This explosion results in a strong ultraviolet pulse, detected by the iPTF14atg, thereby proving the existence of a companion star (Geier et al., 2013). Additionally, as argued by Fink et al. (2018), when a white dwarf explodes independently, the resulting supernova explosions release high energy and very bright light. However, both of these incidents have not been generally observed in the formation of Type Ia supernovae. In fact, the presence of helium deposits and the existence of the ultraviolet pulse provide strong evidence of a double explosion (Geier et al., 2013). Therefore, the fact that Type Ia supernovae are formed by the collision of two stars is supported by the existence of carbon, oxygen, and helium.

Secondly, there are two previous real-life observations of supernova explosions that further support the existence of the double degenerate progenitor model. As mentioned above, in a double degenerate progenitor model, two stars in which at least one is a white dwarf, merge and cause explosions. This phenomenon was observed in the SN 1006 explosion vestige by Naumann-Godo et al. (2008) and the KSN 2011b explosion observed by the Kepler spacecraft of NASA (Johnson & Chandler, 2015). Both of these real-time observations led to the conclusion that supernova explosions are a result of the collision of two dwarfs merging together. For instance, when KSN 2011b was detected by NASA, no companion stars were detected (Johnson & Chandler, 2015). In fact, two distinct stars were visible that were closely orbiting each other to ultimately collide (Johnson & Chandler, 2015). Additionally, when studying the light variation curve of KSN 2011b, there was no visible bulge in the region of the aqua color, which is strong evidence of the double degenerate progenitor model for a supernova formation (Johnson & Chandler, 2015). Similarly, back in 1006 A. D., a similar phenomenon was noted in the formation of the SN 1006 supernovae, later confirmed by the HESS Gamma Ray Observatory in 2010 (Gardner & Milne, 1965). Together, these two instances provide strong support for the existence of the double degenerate progenitor model in the absence of companion stars and visible bulges in the aqua color.

Thirdly, experimental data shows that white dwarfs need to reach and even cross the Chandrasekhar limit in order to extract mass from the companion star and explode.
This is highly unlikely because white dwarfs exist in the form of electron degeneracy, the pressure of which prevents white dwarfs from automatically collapsing if they have a lower mass than the Chandrasekhar limit (Ruiter, 2019). Therefore, these white dwarfs must collide with another white dwarf to reach the Chandrasekhar limit and explode (Ruiter, 2019). This means that the single degenerate model is practically impossible to attain given the properties of the white dwarf. The Chandrasekhar limit refers to the maximum mass a white dwarf can withstand before undergoing an explosion caused by instability (Livio & Mazzali, 2018). The only way through which white dwarfs can extract mass and cross the Chandrasekhar limit is by merging with another white dwarf, which will then result in the formation of Type Ia supernovae (Ruiter, 2019). Due to a lack of additional mechanisms that can drive the supernova formation, only the two degenerate progenitor models are validated, out of which the double degenerate progenitor model has abundant evidence in research.

One counterargument that is presented to the double degenerate progenitor model is the existence of other theoretically possible models that explain the white dwarf explosion without reaching the Chandrasekhar limit. For instance, Livio and Mazzali (2018) have proposed that white dwarfs have a strong gravitational pull that allows it is to accrete mass from their surroundings. As a result, they have the capability to explode independently. This theory is also supported by the chemical properties of a white dwarf. Composed of carbon and oxygen, a white dwarf is capable of creating a runaway hot nucleus that triggers a nuclear fusion reaction (Livio

& Mazzali, 2018). The result is a Type Ia supernova explosion without reaching the Chandrasekhar limit (Livio & Mazzali, 2018). However, given the normal evolution order of stars, white dwarfs do not explode themselves, especially because this phenomenon is not supported by convincing research data (Ruiter, 2019). There is sufficiently more observational data supporting the double degenerate progenitor model for Type Ia supernovae formation. There is also no substantial evidence that the hydrogen and helium of a white dwarf can trigger an independent explosion without reaching the critical Chandrasekhar limit (Livio & Mazzali, 2018). While multiple white dwarfs could merge and explode, there is no astronomical model simulation to suggest that such a phenomenon can form a tight system with angular momenta, such as the binary star system, as proven by the ultraviolet pulse (Livio & Mazzali, 2018).

In conclusion, based on recent observational data by NASA and other researchers, the formation method of Type Ia supernovae is primarily supported by the double degenerate progenitor model in which two white dwarfs merge and collide (Livio & Mazzali, 2018). While studying Type Ia supernova formation has a broader implication that the universe is actively changing and expanding, it cannot be the sole method of studying the forces of this universe because the merging of the two white dwarfs leads to significant changes in their matter and the subsequent collision generates different luminosity (Ruiter, 2019). To better understand the role of both progenitor models in supernova creations, it is important to continuously and closely monitor the onset of these explosions to gather a large set of well-observed real-time events. For future studies, one question that needs to be answered is, what changes occur in Type Ia supernovae formations over the long term after the collision? This will allow researchers to map the variation in the explosion mechanism and the possible role of the two progenitor models.

References

Fink, M., Kromer, M., Hillebrandt, W., Ropke, F. K., Pakmor, R., Seitenzahl, I. R., & Sim, S. A. (2018). Thermonuclear explosions of rapidly differentially rotating white dwarfs: Candidates for superluminous Type Ia supernovae? *Astronomy & Astrophysics*, *618*, 1-12.

Gardner, F. F., & Milne, D. K. (1965). The supernova of AD 1006. *The Astronomical Journal*, *70*, 754-755.

Geier, S., Marsh, T. R., Wang, B., Dunlap, B., Barlow, B. N., Schaffenroth, V., Chen, X., Irrgang, A., Maxted, P. F. L., Ziegerer, E., Kupfer, T., Miszalski, B., Heber, U., Han, Z., Shporer, A., Telting, J. H., Gansicke, B. T., Ostensen, R. H., O'Toole, S. J., & Napiwotzki, R. (2013). A progenitor binary and an ejected mass donor remnant of faint type Ia supernovae. *Astronomy & Astrophysics*, *554*, 1-10.

Johnson, M., & Chandler, L. (2015, May 20). *NASA spacecraft capture rare, early moments of baby Supernovae*. NASA. www.nasa.gov/ames/kepler/nasa-spacecraft-capture-rare-early-moments-of-baby-supernovae.

Livio, M., & Mazzali, P. (2018). On the progenitors of Type Ia Supernovae. *Physical Reports*, *736*, 1-23. DOI: 10.1016/j.physrep.2018.02.002.

Naumann-Godo, M., Beilicke, M., Hauser, D., Lemoine-Goumard, M., & De Naurois, M.. (2008). Discovery of SN 1006 in VHE gamma-rays by HESS. In *AIP Conference Proceedings*, *1085*(1), 304-307.

Ruiter, A. J. (2019). Type Ia supernova sub-classes and progenitor origin. *Proceedings of the International Astronomical Union*, *15*(357), 1-15.