Paper Review of *Observational Clues to the Progenitors of Type Ia Supernovae*
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1 Introduction

Type Ia Supernovae (SNe Ia) are bright supernovae from binary systems that show no Hydrogen emission lines, popular for their use as distance indicators [8]. By studying the chemical composition and energetics of SNe Ia, we are able to infer that this type of supernovae involves the thermonuclear combustion of a degenerate stellar core [5]. In other words, we have found that Carbon-Oxygen ignition in a white dwarf (WD) star adequately models observational data from SNe Ia. From the spectral evolution of these supernovae, we have found that a typical explosion consists of $0.6M_\odot$ of ^{56}Ni and similarly for other intermediate-mass elements adding up to near the Chandrasekhar limit $M_{Ch} = 1.44M_\odot$ [5]. We have seen from our study that a polytropic stellar model is reasonable in our study of degenerate gas, which WDs and neutron stars are prime examples of. Specifically, we have seen how the Chandrasekhar limit comes about, by using the relativistic, degenerate case of the electron gas pressure which implied a polytrope of $n = 3$. In O. R. Pols' textbook, Equation 4.21, while defined in terms of complicated constants, accurately predicts the Chandrasekhar limit, Equation 4.22 using $\mu_e = 2$ [6].

$$M = 4\pi\Theta_3 \left(\frac{K}{\pi G}\right)^{3/2}$$

$$M_{Ch} = 5.836\mu_e^{-2} M_\odot \approx 1.46M_\odot$$

From this, we can clearly see how theoretical predictions from the pressure equation of state and the polytropic equation verify the consistency between the nature of WDs and data from SNe Ia. Recent analysis of SN 2011fe shows that the observational light curve is reasonably consistent with the radioactive decay of near-Iron elements like Nickel and Cobalt, which is another strong observational evidence [2]. Additionally, the nuclear binding energy released by $0.6M_\odot$ of Carbon and Oxygen fusing into ^{56}Ni is $1.1 \times 10^{51} erg$ while the gravitational binding energy of a WD near the Chandrasekhar limit is $0.5 \times 10^{51} erg$ [5]. This means that the nuclear energy released by the intermediate-mass elements is just enough to unbind a WD, which makes SNe Ia energetically possible. This is another evidence suggesting Carbon-Oxygen ignition in WDs as the origin of SNe Ia.

2 Progenitor Models

Other than being able to line up theoretical scenarios with observational data, we do not understand much about SNe Ia [5]. In particular, the origin and evolution of the WDs that go through this type of supernovae are not well-understood. Specifically, we are interested in the progenitor problem, or discussing what triggers the WD for it to begin accumulating mass until it eventually ignites and explodes [5]. Currently, we work with mainly two progenitor models: single-degenerate and double-degenerate. Both are multiple star systems, but the difference is that the single-degenerate model contains only one WD while the double-degenerate contains two WDs. Let us consider these cases separately.

2.1 Single-degenerate Models

The WD's companion in a single-degenerate model varies significantly. It could be a main sequence star, a giant, a Helium star, etc. as long as it is capable of transferring mass to the WD by overflowing the Roche-lobe or by stellar winds [5]. Theoretically speaking, for each of the different scenarios mentioned, the rate of accretion is dictated in order for the WD to accumulate mass, since the supernova cannot happen without the WD reaching approximately the Chandrasekhar limit. A recent study suggests that there may be additional challenges of specifically Helium accretion that may result in an accretion-induced collapse into a neutron star rather than a supernova [9]. Controlling the accretion rate is the main difficulty in constructing a single-degenerate progenitor model, but at the same time, this wide range of possibilities for the structure of a one WD binary system results in a large range of possibilities for the growth of the WD [5].

2.2 Double-degenerate Models

The double-degenerate model, by virtue of being a WD-WD binary system, likely ends up taking a more spherical geometry rather than an accretion disk scenario, and involves rapid mass transfer of Carbon and Oxygen between the components [5]. In this model, the growth of the WDs is not a problem, but it has also been suggested that the high mass accretion rate may, in some cases, induce a collapse into a neutron star in a non-SN Ia fashion [5]. Some WD binaries merge violently in a situation where the more massive component engulfs the secondary WD. In such situation, Carbon ignition may be possible in regions of high temperature and density, and could possibly induce a SNe Ia before hitting the Chandrasekhar limit [5], a very intriguing conclusion.

2.3 Linking theory and observations

With these progenitor models in mind, we see that the gap in our knowledge with regards to the progenitor problem is coming from details of binary evolution, specifically the common-envelope phase most pre-SNe Ia systems undergo [5]. In order to match up theory with observational evidence more effectively, we use a calculation tool called Binary Population Synthesis (BPS) modeling, which is essentially constructing a model through a population study of binaries with similar initial parameters [5]. In what is remaining of the paper, Maoz *et al.* give us five approaches of taking observational data that could help us better our understanding of the theory behind SNe Ia. For this paper review, we will focus on one example from each approach.

3 Observational Evidences

3.1 Recurrent Novae as Potential Progenitor Population

One approach is to look at populations of systems which may be progenitors of SNe Ia. Astronomers have long had suspicions that cataclysmic variables called novae are related to Type Ia Supernovae [7]. Recurrent novae are novae which we have fortunately had the chance to observe multiple outbursts within the last century or so [5]. Theory predicts that the high frequency of outbursts is suggestive of a high mass white dwarf and also a high accretion rate, thus making recurrent novae progenitors of Type Ia Supernovae [5]. Moreover, many mass estimates of these systems within our galaxy have been quite large, close to the Chandrasekhar limit, which aligns with the theory of recurrent novae as progenitors [5]. However, alternative views challenge the feasibility of mass growth within these systems. U Sco, for example, has given us observational data that suggests that its latest outburst in 2010 has given off more mass than it had accumulated over the years [5]. Thus, in general, our standpoint still remains uncertain regarding novae as progenitors to Type Ia Supernovae.

3.2 Pre-Explosion Evidence from SN 2011fe

SN 2011fe was a well-studied supernova that is considered to be a typical Type Ia Supernova [5]. The pre-explosion data of SN 2011fe from the Hubble Space Telescope when examined in the different cases of the single-degenerate scenario strongly rules out reg giant stars and any stars more massive than $3.5M_{\odot}$, and there were no detections of Helium stars in the area either [5]. This immediately tells us that the donor of the WD was most likely a main-sequence or a sub-giant star of mass less than $3.5M_{\odot}$ [5]. Other observational evidence also reject bright supersoft X-ray sources and apply other spectral restrictions, but allow faint supersoft sources [5]. However, the double-degenerate case is not limited by pre-explosion data [5].

3.3 Early Light Curve and Spectral Evolution of SN 2011fe

Early light curve analysis of supernovae in general gives us a lot of information that help us put restrictions on the original system. The time between explosion and shock breakout, pre-explosion radii, the function of abundance of ^{56}Ni in the ejecta, and the impact of the supernova on its companion (if there is one) are all potentially inferences we can make from early light curve data [5]. SN 2011fe, once again, gave us some of the best data we have seen for during the explosion, giving us great insight in regards to the progenitor problem [5]. By well-studied light curves in many electromagnetic ranges and comparing them to theory and data from other Type Ia supernovae, we were able to infer that there were significant amounts of ^{56}Ni in the ejecta, completely ruling out the option of a red giant as the donor, and arguing against most of the traditional single-degenerate scenarios [5].

3.4 Post-Explosion Evidence and the Search for Surviving Companions

In the single-degenerate case, the donor star will survive the supernova explosion [5], and would act as a primary source of the progenitor to SNe Ia. For example, in the case of Tycho's SN of 1572, astronomers have reached various conclusions regarding the possibility of a surviving donor.

Based on Keck spectra and HST imaging, Kerzendorf *et al.* have argued against most traditional single-degenerate models including giant, sub-giant, and main-sequence stars as a donor [3], while Bedin *et al.* advocate for a surviving donor, a star called Tycho-G [1]. Although predictions of a survivor can potentially give us great insight on the progenitor problem, the problem still remains that the inference is largely subjective due to our lack of understanding of details of binary evolution.

3.5 SN Ia rates and the delay-time distribution

SN Ia rates and their dependence on environment and cosmic type give us further clues for the progenitor problem [5]. As we study the dependence of SN Ia rates on the stellar population's age distribution, we can find the age distribution of the SN Ia progenitors and compare them with our theoretical timescales for the different progenitor models [5]. We also define the delay-time distribution (DTD) to be the distribution of time between star formation and SN Ia explosion, and it has become increasingly popular to study the observational DTDs to obtain SN Ia rate measurements [5]. For example, through a survey study of stellar populations and DTDs of various SNe Ia, researchers have found that SN Ia rates change with the host-galaxy color and Hubble type [4], an important observational clue to the progenitor problem.

4 Summary

According to our data from SNe Ia, we are statistically certain that this type of supernovae are related to the Carbon-Oxygen ignition in a WD star. Besides this big picture, we know very little about SNe Ia. Specifically, the origin and evolution of WDs before SNe Ia are still not well-understood. Thus, we are interested in the progenitor problem - what triggers the WD to begin mass accretion before ignition and explosion in SNe Ia? To begin to solve this problem, we turn to observational clues. The five main approaches suggested by Maoz *et al.* are population studies of potential progenitors, pre-explosion evidence, data from during the explosion, post-explosion evidence, and finally SN Ia rates and the delay-time distribution. We have looked at an example from each of these approaches including the case of SN 2011fe, the recent, very well-studied supernova. However, as we have seen, the progenitor problem is far from coming to a conclusion.

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