論文の内容の要旨

SPH simulations of mergers of double white dwarf binaries: Possible progenitors of Type Ia supernovae

(二重白色矮星連星合体の SPH シミュレーション:Ia 型超新星の親星としての検証)

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Type Ia supernovae (SNe Ia) have important roles in the present astronomy as the cosmological standard candle and major producers of iron group elements. Although they have been considered as a thermonuclear explosion of a carbon-oxygen (CO) white dwarf (WD) with nearly the Chandrasekhar limiting mass in a binary system, their progenitors and explosion mechanisms are still unclear.

A merger of double CO WD binary is one of the possible SN Ia progenitors as the double degenerate (DD) scenario, while another progenitor scenario is the single degenerate (SD) scenario, in which a CO WD explodes by accumulating hydrogen or helium-rich matters from its non-degenerate companion.

Recent observations provide several evidence which support the DD scenario, especially, the case of SN 2011fe strongly constrains the SD scenario, and DD progenitors are considered to be more likely.

On the other hand, theoretical studies indicated that the DD model has some difficulties. In particular, according to some representative studies, rapid accretion of the secondary CO WD onto the primary in their merger could ignite off-center carbon burning quiescently, the primary would be converted to an oxygen-neon-magnesium (ONeMg) WD. If the WD pair has a total mass more massive than the Chandrasekhar limiting mass, such system would collapse to a neutron star, not explode as an SN Ia. These were called the accretion induced collapse (AIC).

However, many hydrodynamical simulations using smoothed particle hydrodynamical (SPH) codes were performed recently, and they showed that there are some possible paths in which merging CO WDs could lead to SNe Ia. For examples, Yoon et al. (2007) indicated that the off-center carbon burning could be avoided if some conditions are satisfied, e.g., for a low accretion rate of $< 10^6 \, M_\odot \, \mathrm{yr}^{-1}$ due to sufficient rotational support and slow angular momentum transfer. In such cases, the primary CO

WD can grow its mass without being converted to an ONeMg WD and lead to an SN Ia explosion $\sim 10^6$ yr after the merger.

In another case, Pakmor et al. (2010) showed that carbon detonation could be initiated in the dynamical merger phase of very massive $\sim 0.9\ M_\odot$ CO WDs. They also presented that the detonation waves propagate through the primary CO WD and convert it to radioactive nickel, although the secondary is converted to intermediate elements (e.g., silicon, sulfur). They calculated the light curve and spectra of such events with their radiative transfer code, and found that they could reproduce observational properties of subluminous SNe Ia, such as SN 1991bg-like events. They called such explosion mechanism the violent merger scenario. After that, they also simulated a more massive merger in which masses of CO WDs are $1.1\ M_\odot$ and $0.9\ M_\odot$. They showed that the merger could explain a normal SN Ia, although its highly asymmetric profile seems to be inconsistent with observations.

These studies indicated that the DD scenario could lead to an SN Ia explosion without collapsing to a neutron star along the AIC scenario. However, what CO WD binaries could lead to SNe Ia is still uncertain. Especially, a mass range of merging CO WDs exploding as SNe Ia is significantly important to understand the DD scenario and the nature of SNe Ia.

In this study, we performed three dimensional SPH simulations of CO WD mergers for various mass combinations ranging $0.5 \sim 1.1\ M_\odot$, and examined possibilities leading to SNe Ia. Our simulations have higher numerical resolution than any previous studies and adopt a plausible initial condition. As a result, we find that double CO WD binaries with massive primary and secondary stars ($>\ 0.8\ M_\odot$) could explode during their mergers, along the violent merger scenario. We also derive the critical mass ratio of the violent merger scenario, above which mergers explode as SNe Ia. Our critical mass ratio ($q_{\mathrm{cr}} \sim 0.9$ for $0.9\ M_\odot$) is larger than that obtained by previous study ($q_{\mathrm{cr}} \sim 0.8$ for the same mass). We conclude that this difference mainly comes from differences between our and their initial conditions. We also discuss an impact of the critical mass ratio on the peak brightness distribution of SNe Ia.

Mergers of CO WDs could lead to SNe Ia in their post-merger phase when their primary masses are less than $0.9\ M_\odot$, their mass ratios are less than the critical one of the violent merger scenario, and their total masses exceed the Chandrasekhar mass, although more studies for the post-merger evolution are needed.

We derive a relation between merger outcomes and mass combinations of merging CO WDs, and derive the possible mass range leading to SNe Ia. Using the derived relation, we briefly evaluate a ratio of DD mergers leading to SNe Ia as less than 8%. We also predict the final fate of Henize 2-428, a bipolar planetary nebula, whose central system is recently suggested as a super-Chandrasekhar DD binary. Our consequence indicates that the core of Henize 2-428 would explode as an SN Ia along the violent merger scenario.