A NEW PROGENITOR MODEL OF TYPE Ia SUPERNOVAE

Izumi Hachisu[1], Mariko Kato[2], and Hideyuki Saio[3]

[1] Department of Aeronautical Engineering, Kyoto University
Kyoto 606, Japan
[2] Department of Astronomy, Keio University, Yokohama 223, Japan
[3] Department of Astronomy, University of Tokyo, Tokyo 113, Japan

ABSTRACT. A new progenitor model of Type Ia supernovae (SNe Ia) is proposed. The model consists of a carbon-oxygen white dwarf (0.8-1.2 M⊙) and a low-mass red giant star (0.8-1.5 M⊙) with a helium core (0.2-0.4 M⊙). When a red giant fills its inner critical Roche lobe and its mass transfer rate exceeds a critical value, a common envelope state is realized. Then the mass accretion rate onto the white dwarf, i.e., the mass transfer rate is tuned up to be $\dot{M}$= 8.5 x10^{-7}(M_{WD}/M⊙-0.52) M⊙ yr^{-1}, where M_{WD} is the mass of the white dwarf. This rate is high enough to suppress the hydrogen shell flashes, but too low for carbon to be ignited off-center. When the carbon-oxygen core mass grows to the Chandrasekhar limit during the common envelope phase, a Type Ia supernova explosion is expected to occur.

PROGENITOR MODEL

The carbon deflagration model of carbon-oxygen white dwarfs has succeeded in explaining the various observational aspects of Type Ia supernovae (SNe Ia). It has been extensively argued that double carbon-oxygen white dwarf systems are the progenitor of SNe Ia (e.g., Iben and Tutukov 1984; Webbink 1984). Since the scenario was proposed, some suspicions on the scenario have been presented (e.g., Saio and Nomoto 1985; Robinson and Shafter 1987). Although the above suspicions cannot reject the possibility that double carbon-oxygen white dwarfs are the site of SNe Ia, the rate of SNe Ia coming from the double white dwarf progenitor is probably much smaller than that expected by Iben and Tutukov and by Webbink. In this sense, it is worthwhile to search for another way to Type Ia supernovae.

We assume that the progenitor of SNe Ia is a close binary system consisting of a carbon-oxygen (C+O) white dwarf and a low-mass red giant star. This assumption is consistent with the observational fact that SNe Ia appear everywhere in spiral galaxies and even in elliptical galaxies. When the giant fills its inner critical Roche lobe and the mass transfer rate exceeds a critical value, i.e.,

D. McNally (ed.), Highlights of Astronomy, Vol. 8, 175–176.

$$\dot{M}_{cr} = 8.5 \times 10^{-7} (M_{WD}/M_\odot - 0.52)\ M_\odot\ \mathrm{yr}^{-1}, \qquad (1)$$

where M_{WD} is the mass of the white dwarf, a common envelope is formed. The mass transfer rate cannot be determined only by the condition of the mass losing star because of the pressure gradient effect in the common envelope. Then the mass transfer rate is equal to the rate with which the mass accreting component fills/overfills its Roche lobe. In such a situation, the mass transfer rate must be tuned up to be $\dot{M}_2 = -\dot{M}_{cr}$. With this accretion rate the envelope remains to be a red giant size. It should be noted that the mass of the extended envelope around the C+O white dwarf is as small as 10^{-5} M☉ or less for $M_{WD} > 1$ M☉ because the radius of the extended envelope around the white dwarf ranges from a few to several tens solar radii (it is bluer than the Hayashi track).

When the mass ratio is too large, the separation decreases and finally the common envelope overfills the outer critical Roche lobe. Then the helium core and the C+O core spiral-in in the envelope. We do not regard this case as the progenitor of SNe Ia. When the mass ratio is close to or somewhat larger than unity, the separation decreases first and then increases because the mass ratio is reversed. Then the outer critical Roche lobe overflow does not occur and the mass of the C+O white dwarf can grow to the Chandrasekhar limit. This rate ($\dot{M}_{cr}$) is high enough to suppress the hydrogen shell flashes, but too low for carbon to be ignited off-center. When the mass reached the Chandrasekhar limit, a carbon burning ignites at the center to trigger a SN Ia explosion. When the mass transfer rate becomes smaller than the critical value before the C+O white dwarf mass reaches the Chandrasekhar limit, the common envelope disappears. Further, when the mass accretion rate decreases to less than 10^{-7} M☉ yr^{-1}, hydrogen shell flashes occur (nova systems) and it blows off almost all of the accreted material and no SNe Ia are expected to occur.

If the low-mass star is a red giant (helium core mass is about 0.40 M☉), SN Ia explosion is possible for red giant mass of $M_{2,0} > 0.8$ M☉. For $M_{2,0} > 1.5$ M☉, the possible parameter range for $M_{WD,0}$ is small because of the outer critical Roche lobe overflow.

Type Ia supernova is characterized by no hydrogen lines. Just before the supernova explosion, mass of the hydrogen-rich envelope around the C+O white dwarf becomes as small as 10^{-7} M☉. We believe that such mass of the hydrogen is too small to be observable. Assuming the initial masses ranging from 3 to 8 M☉ can leave C+O white dwarf larger than 0.8 M☉, we obtain the rate of 0.012 yr^{-1} in our Galaxy. The full paper of our scenario will appear elsewhere (Hachisu, Kato, and Saio 1988).

REFERENCES

Hachisu, I., Kato, M., and Saio, H. 1988, Ap. J., submitted.
Iben, I. Jr., and Tutukov, A. V. 1984, Ap. J. Suppl., 54, 335.
Robinson, E. L., and Shafter, A. W. 1987, Ap. J., 322, 296.
Saio, H., and Nomoto, K. 1985, Astr. Ap., 150, L21.
Webbink, R. F. 1984, Ap. J., 277, 355.