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THE CIRCUMSTELLAR MATTER IN PRE–SUPERNOVAE OF TYPE Ia

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RESUMEN

Los vientos de pre-supernova de las supernovas de tipo I son muy difíciles de detectar: son de baja masa, bastante lentos (cientos de km s^{-1}) y casi inmediatamente son barridos por la envoltura en expansión de la SN, cuya velocidad es muy alta. Ninguna SN de tipo Ia ha sido observada en radio. No obstante, las SNe 1981B y 1990M dan evidencias de la existencia de una envoltura circunestelar, revelada por líneas de hidrógeno en el espectro del pre-máximo. Estos datos se comparan con las estructuras de super-viento observadas en SNe de tipo II. A juzgar por la velocidad de expansión, las estructuras de viento que estamos considerando, están situadas a una distancia de $10^{14} - 10^{15}$ cm del centro de la explosión. El tiempo de eyección puede estimarse, para SN 1990M, en 5×10^7 s antes del evento explosivo. Distancias relativamente tan pequeñas y tiempos tan cortos para la formación de estructuras regulares, implican la presencia de altos gradientes iniciales de densidad y velocidad en la materia del viento. Por lo tanto, puede sospecharse una extraordinaria actividad de la estrella precursora. Se discuten los posibles mecanismos de eyecciones recurrentes de materia en sistemas binarios en la fase de pre-supernova.

ABSTRACT

The pre-supernova winds of type I SN are very difficult to detect: they are of low mass, rather slow (hundreds of km s^{-1}) and almost immediately swept by the SN envelope expanding at very high speed. No Type Ia supernova has ever been observed in radio. Nevertheless the SNe 1981B and 1990M give evidence of the existence of a circumstellar shell, which is revealed by hydrogen lines in the pre-maximum spectra. Those are compared with the superwind structures observed in type II SNe. Judging from the expansion velocity of the SN envelope, the wind formed structures under consideration are situated at a radius from the explosion centre of $10^{14} - 10^{15}$ cm . The time of ejection prior to the explosion event can be estimated as 5×10^7 s for SN 1990M. Such rather small distances and short periods of time for the formation of the regular structures imply the presence of high initial gradients of density and velocity in the wind matter. Thus an extraordinary activity of the precursor can be suspected. The possible mechanisms of recurrent ejections of matter in pre-supernovae binary systems are discussed.

Key words: **STARS: MASS LOSS — SUPERNOVAE: GENERAL**

1. INTRODUCTION

An impressive amount of observations of Supernovae (SNe) (in radio, X-ray, optical) show evidence of stellar matter ejected before the SN explosion. The optical and UV spectral features formed by the stellar wind matter are very complicated, inhomogeneous and highly variable. The time of detection of the details originated in the wind can differ from near the maximum light to years after the explosion.

Prior to the explosion the SN progenitor was ejecting matter. Thus, at the moment of the explosion the progenitor was already surrounded by an envelope. The SNe are observed after the explosion only when the wind matter is interacting with the emission of the explosion itself. The stellar wind can be affected by the following interactions: 1) UV pulse of radiation due to outcoming shock wave; 2) emission of the expanding supernova envelope; 3) fast particles; 4) direct collision of the SN envelope with the stellar wind matter.

The variability of the winds of antique SNe precursors, was proved by the radio observations of SNe at both long (1979C) and short (1993J) time scales. Unfortunately, spectral observations of the SNe have not been systematic. Hence, we do not have a complete dynamic picture of the evolution of the spectral features. The most important observational results are the following:

- Dopita et al. (1984) discovered the so called "superwind", ejected with extremely high velocity (3000 km s^{-1}), immediately prior to the SN event.
- The fascinating change in the velocity shifts in SN 1983K (Niemela et al. 1985) witnesses the existence of complicated, but quite regular structures in the wind at the scales of less than 10^{16} cm.
- The famous result of the interaction process in a SN and the wind of its precursor is the "Napoleon's Hat" around 1987A (Wang & Mazzali 1992). This well-known axially symmetric nebula is quite similar to those surrounding Luminous Blue Variables (in shape and even in size $= 10^{18}$ cm) and can be related to structures around Wolf-Rayet stars. Unfortunately, this is the only example of a direct image available. Other wind formed structures were revealed just in the SN spectra.

2. THE WINDS OF SUPERNOVAE TYPE II

Though the velocities of the envelopes in SNe type II are less than in SNe type I, the winds of their progenitors are extremely fast (up to 2000–4000 km s^{-1}). The wind being highly variable and dense, pronounced colliding wind-formed structures can occur close to the SN progenitor. A system of interacting wind layers with different deviations of symmetry and increasing velocities can result in the formation of the distinct prolate ellipsoidal shell around the SN precursor just before the explosion (Tsiopa 1995). The presence of such shell can explain the narrow Hα absorption line, observed in the spectra of SN 1983K. The line is formed in the parts of the shell closest to the expanding SN envelope, where hydrogen is excited to the second level, with previous regions being already swept by the SN envelope. Naturally, the velocity shift increased during the period of observation (two months) with the acceleration of 40 km s^{-1} per day due to the velocity distribution in the ellipsoidal wind formed shell.

3. THE WINDS OF SUPERNOVAE TYPE IA

No type Ia SN has ever been observed in radio. Apparently, less massive progenitors cannot provide an extended dense circumstellar shell. The pre-supernova winds of SNe type Ia are very difficult to detect: they are less massive, slower (not more than hundreds of km s^{-1}) and are almost immediately swept by the SN envelope expanding with very high speed.

Taking into account that even the identification of lines originated in the SN envelope is often problematic in spectra of type Ia SNe, it is not surprising, that the detection of hydrogen lines attributed to the circumstellar shell is considered quite improbable (Della Valle et al. 1996). Though the existence of the circumstellar matter in precursors of SNe type Ia has been the matter of recurrent debates for some time, it should be noted that there are some arguments not taken into consideration by the authors of this recent paper. Polcaro & Viotti (1991) have reported the discovery of circumstellar hydrogen close to the SN 1990M. They published two spectra obtained in 1990, June 16.9 and June 20.1. The second one is of lower quality, but there is no doubt that the hydrogen absorption changed between the observational sets (it was shifted and saturated). That is why it seems rather difficult to attribute the Balmer line under discussion to the host galaxy (Della Valle et al. 1996).

We must mention that the spectra of type Ia SNe 1995ak, 1995am, 1995bd and 1996C were reported to exhibit hydrogen lines in emission from the host galaxies (Capellaro & Turatto 1995; Garnavich et al. 1995, 1996). But even in these cases we cannot be absolutely sure about the origin of the Balmer lines.

In the case of 1981B, a week after maximum, a narrow Hα was detected in emission at the rest wavelength, and no trace of this line was found 5 days later (Branch et al. 1983). Since the spectrum with the Balmer line was of higher resolution than the others, it is difficult to consider this observational fact to be a mistake.

A possible explanation of such cases can be given by the model of non-spherical wind-formed shell around the SN precursor (Tsiopa 1995). The circumstellar line profile is determined by the orientation of the shell axis and time of observation, as the shell is being swept by the expanding SN envelope.

For the case of 1990M, the model implies an existence of a shell formed by matter with a maximum velocity of 1200 km s^{-1} and a minimum of 600 km s^{-1}, and an inclination to the line-of-sight of 40 degrees.

The hydrogen emission line observed by Branch et al. (1983) can also find its place within the framework of the same model. A small narrow feature was observed at the rest wavelength of $H\alpha$. Pure emission with zero velocity shift implies a wind ellipsoid with an axis perpendicular to the line-of-sight, and with most of it already swept by the SN envelope. Such spectral line is supposed to disappear in a very short time, and in fact 5 days later the feature was not detected.

Anyway, the problem of the identification of the cicumstellar lines remains very complicated. That is why early spectral observations of SNe with high resolution and careful analysis (cf., Cumming 1996) are quite promising. It is very important to take a series of spectra for each SN.

4. DISCUSSION.

Judging from the SN envelope expansion velocity, the pre-SN stellar wind formed structures under consideration are located at distances from the explosion centre of $10^{14} - 10^{15}$ cm for SN 1983K, and $3 - 6 \times 10^{15}$ cm for SN 1990M. For the maximum light date proposed for SN 1990M by Della Valle et al. (1996), the size of the wind-formed structure is twice larger. The time of shell ejection can be estimated as 6×10^6 s for SN 1983K, and 5×10^7 s for SN 1990M (10^8 s for SN 1990M if the revised maximum light date is assumed). Such rather small distances and short periods of formation of regular structures imply the presence of high initial gradients of density and velocity in the wind matter. Thus, an extraordinary activity of the SN precursor can be suspected even for a single star. During the periods of interior reconstruction, preceding the type II SN event, for example, even the outer parts of the star are likely to be unstable. Strong pulsation with different modes, such as several-mode resonant coupling, probably determine the mass-loss rates in critical periods of stellar evolution. While expanding, the star throws away the very outer part of its envelope (or, in other words, the stellar wind increases dramatically) and a flying away shell is formed. In this case the SN precursor would be surrounded by a system of interacting shells (Tsiopa 1990). One type of steady stellar wind flow is changed to another one, with different wind velocity and density, in a non-smooth way. During the period of reconstruction the star produces a strongly inhomogeneous wind.

It should be noted that the majority of the pulsating stars are located in the same place in the Hertzsprung-Russell diagram as type II SN precursors are thought to be. The modern SN theory does not provide any indications about the resonance nature of the explosion, as deflagration regimes of the thermonuclear explosion of a degenerate core can provide only very short period pulsation (10 seconds). These cannot correlate with the envelope motions. However, there are some possible additional energy sources which can function in phase correlation with proper pulsation of the star at the last stages of its evolution. First of all, it can be the flaring up of the nuclear shell source, for example He; then the process of the neutronization can split into stages, and finally for non-Fe core (O-C, for example) the outer parts of the core can also flare up. It is possible that the SN explosion itself is stimulated by the resonance pulsation.

For binary precursors of SNe type Ia some other mechanisms are certainly to be considered. However, the close pre-SNe systems buried in a common envelope, or one compact object inside the extended atmosphere of the other component, are in some sense undistinguishable from a star which is rotating and pulsating. Perhaps, the eccentricity of the orbit in a binary system can be treated as a trigger in generating instabilities and resonance effects, which may generate a circumstellar shell.

In a close binary supernova precursor the shell ejections can be more readily connected with the mass losing component, a red giant in its final period of evolution, for example, than with the mass accreting white dwarf. The strongly variable accretion rate might promote the degenerate object to approach the Chandrasekhar limit.

The recurrent ejections of matter with different velocities can result in formation of axial colliding wind formed structures. A very energetic individual pulsation of supernova precursor just before the explosion event produces a shell, perhaps like that discovered in the early spectra of SN 1984E.

The only way to find a supernova progenitor in the Galaxy —before the explosion— is to understand the structure of its wind and to compare it with the known peculiar wind producing stars.

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