THE COLLIDING WIND-FORMED STRUCTURES OF SUPERNOVA PRECURSORS

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Abstract. The wind interaction processes in supernova precursors can be responsible for the formation of regular structures of the circumstellar matter not only at the distances of 10^{18} cm (SN1987A), but also at those of less than 10^{16} cm.

1. Introduction

Having impressive evidence (radio, X-ray, optical) of the mass loss processes in supernova (SN) precursors, we are still far from understanding the main properties of the media ejected prior to the SN explosion event. Chugai & Danziger (1994) have shown the possibility of a two (rarefied and dense) component wind for the case of SN 1988Z, but the roles of clumping and equatorial wind are still under discussion.

Dopita *et al.* (1984) discovered a so-called "superwind", which had been ejected with the extremely high velocity of 3000 km/s immediately prior to the SN event. The fascinating change of the velocity shifts in SNe 1983K (Niemela *et al.* 1985) and 1990M (Polcaro & Viotti 1991) witness to the existence of complicated, but rather regular structures in the wind on the scales of less than 10^{16} cm. This paper is an attempt to unite these observational facts in a common dynamical model.

2. SN 1987A nebula

At the present time the only well-known result of a wind interaction process in a SN precursor is the "Napoleon's Hat" around SN1987A (Wang & Mazzali 1992), formed by the slow dense wind (with an asymmetry) and the following fast one. The well-known axially symmetric nebula is quite similar to planetary nebulae and nebulae surrounding Luminous Blue Variables (in shape and even in size = 10^{18} cm) and can be related to such structures around Wolf-Rayet stars. Unfortunately, this is the only example available in a direct image. The other wind-formed structures have been revealed just in the SN spectra.

3. Type II SN 1983K

The wind being highly variable, the pronounced colliding wind-formed structures can occur close to the SN progenitor. The system of interacting wind layers with different deviations from symmetry and increasing velocities are presented schematically in Fig. 1. This way the distinct prolate ellipsoidal

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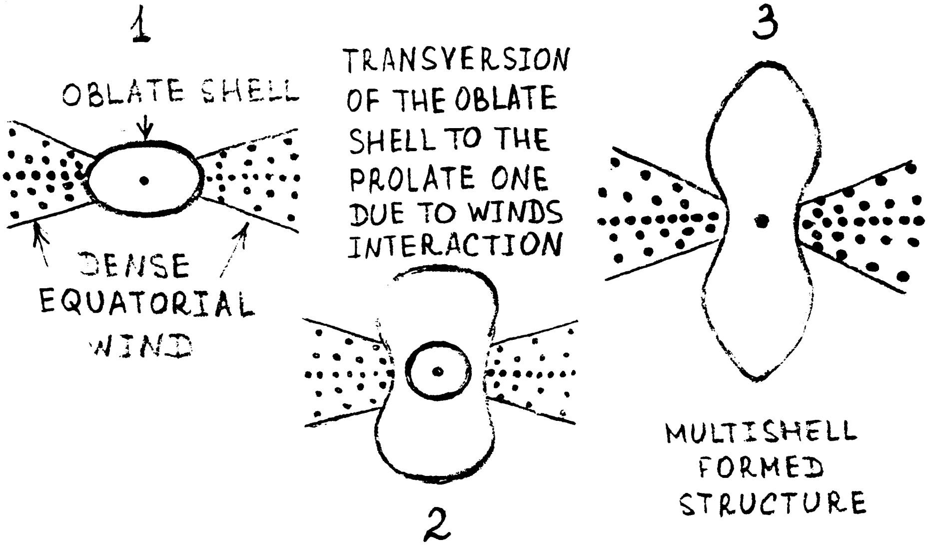

Fig. 1. The formation of the wind multi-shell structure.

shell can be formed by the supernova progenitor just before the explosion. The presence of such a shell can explain the narrow Hα absorption lines observed in the spectra of SN 1983K (Tsiopa 1993). The lines form in the parts of the shell closest to the expanding SN envelope, where hydrogen is excited up to the second level, with previous regions being already swept by the SN envelope. Naturally, the velocity shift had been increasing during the period of observation (two months) with the acceleration of 40 km/s per day due to the velocity distribution in the ellipsoidal wind-formed shell.

4. Type Ia SNe 1990M and 1981B

The discovery of Hα absorption in the early spectra of the Type Ia SN 1990M by Polcaro rises the question of resemblance of different types of SN environment. The SN 1990M exploded in the edge-on galaxy NGC 5493 far from the centre. That is why we must take into consideration the velocity of galaxy rotation to find out the proper velocity of SN. The problem is that the direction of rotation is not yet settled. If the SN is situated in the appoaching part of the galaxy, the observed Hα absorption must indicate matter moving towards the SN. Taking into account the large distance from the centre of the explosion (otherwise the matter would be swept away by the SN envelope expanding with very high speed), the supposition of an accretion process does not seem well grounded. Therefore let us consider the SN 1990M to be situated in the receeding edge of the galaxy. Then, to find out the proper velocity of the SN we are to add the rotation velocity of

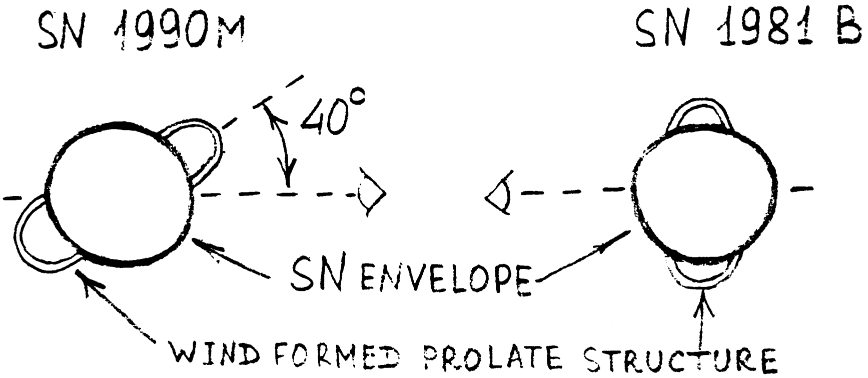

Fig. 2. The formation of the wind-originated hydrogen SNe lines in SN 1990M (absorption) and SN 1981b (emission)

the galaxy (v_{rot} = 260 km/s, Wardle 1986) to its proper velocity.

Within the framework of this hypothesis, the development of the absorption is quite consistent with the picture of an ellipsoidal shell formed by the matter with a maximum velocity of 1200 km/s and a minimum one of 600 km/s and inclination to the line of sight of 40 degrees.

The hydrogen line emission observed by Branch *et al.* (1983) can also find its place within the framework of the proposed hypothesis. The small narrow feature was located at the rest wavelength of Hα. Pure emission with zero velocity shift implies the wind ellipsoid axis is perpendicular to the line of sight with most of it already swept by the SN envelope. Such a spectral line is supposed to disappear in a very short time — 5 days later the feature was not detected.

5. Discussion

Judging from the SN envelope expansion velocity, the wind-formed structures under consideration are situated at radii from the explosion centres of $10^{14} - 10^{15}$ cm for SN 1983K and $3 - 6 \times 10^{15}$ cm for SN 1990M. The time of shell ejection can be estimated as 6×10^6 sec for SN 1983K and 5×10^7 sec for SN 1990M. Such rather small distances and short periods of the regular structure formation imply the presence of high initial gradients of density and velocity in the wind matter.

Extraordinary activity of the precursor can be suspected even for a single star. During the periods of interior reconstruction (preceding the SN Type II event, for example) even the outer parts of the star are likely to be in an unstable state. Strong pulsation with different modes can be evoked. Such processes as several-mode resonant coupling are probable to determine the mass-loss rates in critical periods of stellar evolution. So, one type of steady stellar wind flow is changed to another one (with different wind velocity and density) not in a smooth way. During the period of reconstruction, the star produces a strongly inhomogeneous wind. In other words, the stellar wind is thrown away as a system of interacting shells (Tsiopa 1990)

As for SN Type Ia precursors, some other mechanisms are certainly involved. However the close systems buried in a common envelope (or one compact object inside the extended atmosphere of the other component) are in some sense indistinguishable from the rotating pulsating star. The forming circumstellar environments may occur rather similarly. Perhaps, the eccentricity of the orbit in binary system can be treated as a trigger in generating instabilities and resonance effects.

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

Acknowledgements

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DISCUSSION:

van Kerkwijk: Would you expect to see sometimes a decrease in velocity of the low-velocity component? Has this been observed?

Tsiopa: No, it has not been observed. It is possible only in presence of several shells, because the matter ejected with lower velocity is swept first by the expanding SN envelope.

Langer: Can one estimate the amount of mass contained in the shells around the supernovae from observations?

Tsiopa: It was made by Polcaro and Viotti (1991) and Niemela et al. (1985). But the problem is rather complicated, because we do not know what part of the hydrogen is excited and observations cover only piece of circumstellar structure. In any case it is not less than 10^{-7} $M_{\odot}$. I hope to get a more precise answer in future when more statistical material is gained; the special observational long-term program is started this year.