EVIDENCE FOR ASYMMETRIES IN SN1987A

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ABSTRACT. Results of observations carried out during the past year and a half after the explosion of SN1987A (February 23 1987), show strong evidence for asymmetry in the expanding shell. The departure from spherical symmetry in SN1987A has important implications for further detailed modeling of supernovae explosions, light curves and spectra.

INTRODUCTION

The supernova SN1987A in the LMC provides an exceptional opportunity to observationally test the assumption of spherical symmetry which has been widely used in the theoretical models of the supernova explosions. The assumption of spherical symmetry has also been made in attempts to use supernovae as cosmological distance indicators (Baade method). If the supernovae are not spherically symmetric, the distances estimated will be too high. We present here the evidence for asymmetries in SN1987A obtained using spectroscopic, polarimetric and speckle interferometric observational techniques.

OBSERVATIONAL RESULTS

I. *SPECTROSCOPY*

Early spectroscopic observations of the SN1987A (March, 1987) obtained by Hanuschik and Dachs (1987) revealed the presence of a double-peaked feature in the Hα region. A bump appeared first in the transition region between the Hα absorption trough and the maximum emission about 20 days after the explosion. An equally displaced component from the rest wavelength of the Hα in the LMC was observed a few days later. A similar double-peaked structure was also observed in several H I lines in the optical and the infrared (Phillips, 1987; Danziger et al, 1987) between the 20th and

D. McNally (ed.), Highlights of Astronomy, Vol. 8, 193–198.

https://doi.org/10.1017/S1539299600007760 Published online by Cambridge University Press

the 80th day after the explosion. The origin of this spectral feature is probably related to some departure from spherical symmetry of the supernova shell, but the presence of two equally displaced components indicates that the source must have some global symmetry (Lucy, 1987).

Infrared spectra obtained 120 to 250 days after core collapse by Danziger et al (1987) show a redshift bias for the emission components of strong P Cygni lines in the velocity range of 500-1400 Km/s. A similar effect has been observed by Terndrup et al (1988) in the optical and the infrared for the peaks of the H I, Ca II and [Fe II] emission lines: the peaks are redshifted by 500-700 Km/s in the rest system of SN1987A. A possible interpretation of the observed effect is that it arises from a geometrical asymmetry of the line-forming region.

The peaks of the [O II] $\lambda\lambda$ 6300Å, 6363Å forbidden emission lines which became visible in the supernova spectrum around 130 days after the explosion did not show any redshift bias (Terndrup, 1988). On the other hand, the high-dispersion spectra of the top of the [O II] doublet obtained at the Anglo-Australian Observatory (April 1988, AAO Newsletter #45) show the presence of small fluctuations which occur at the same line-of-sight velocities for the two lines. These observations may indicate that several clumps are present in the expanding envelope, or alternatively, that there are radial 'fingers' of material with a higher velocity of expansion.

II. *POLARIMETRY*

Shapiro and Sutherland (1982) proposed an observational test of the spherical symmetry of the supernovae based on the fact that the light of an unresolved, aspherical supernova atmosphere (scattering dominated) is linearly polarized. This test was performed on SN1987A, and the results of several polarimetric and spectropolarimetric observations obtained at different epochs after the explosion indicate that this supernova is not spherically symmetric.

Some of the earliest polarimetric observations of the SN1987A (10-11 days after the explosion) were carried out by Schwarz and Mundt (1987). The results of the narrow band polarimetry obtained in the peaks and the troughs of several spectral lines (Hα, Hβ, Hγ, Na D) show variation in polarization across line profiles. Jeffery (1987) interpreted the observed polarization structure as arising from an asymmetric, expanding, scattering atmosphere. He has carried out Sobolev-Method radiative transfer calculations with an ellipsoidal model for the SN1987A photosphere and shell in order to fit the polarimetric data. The best fits to the data were obtained for an axis ratio of the shell (minor axis over major axis) between 0.6 and 0.8.

Multicolor linear polarimetric observations of SN1987A (U,B,V,R, and I filters) have been obtained between February 28 and April 29, 1987 by Méndez et al (1988). The measurements made during the first month after the explosion show polarization of 0.1-0.5 % at position angle of about 25° (or at 205° since there is a 180° ambiguity). After the first month, the position angle remained almost unchanged in U and B filters, but an additional component became visible in V, R, and I filters. The wavelength dependence of the polarization measured during the first 30 days indicates that the scattering is dominated by Thompson scattering. The appearance of the second component after 30 days has been interpreted as due to the change of absorption in the total opacity, although the possibility that it arises from a completely different polarizing mechanism has not been excluded. In order to interpret the measurements obtained during the first month, Méndez et al (1988) propose a model which is based on the assumption that the outer layers of the supernova shell are ellipsoidal. Results obtained imply that the axis ratio of the shell is between 0.8 and 0.9.

Results from the spectropolarimetric measurements obtained by Cropper et al (1988) between February and July 1987, also suggest that the SN1987A is asymmetric. The polarization has been measured in the spectral range between 350 nm and 900 nm including the regions around Hα and Ca II lines. The measurements indicate that the position angle of the principal scattering axis is wavelength dependant. For example, the principal scattering axes for the Hα and the Ca II triplet appear to be perpendicular. These results have been interpreted using two different supernova polarization models, one proposed by Shapiro and Sutherland (1982) and the other by McCall (1984). Assuming that the scattering atmosphere has a shape of an oblate or prolate spheroid, the best fit to the data has been obtained for the axial ratio of 0.7 to 0.9.

The observations obtained by Cropper et al (1987) yield another important result. When all polarimetric measurements are plotted in the Stokes-parameter *QU* plane, the locus defines a band, the axis of symmetry of which is at a position angle of about 200°. This axis is nearly aligned with the direction (P.A.=194° ± 2°) of the bright companion to the SN1987A observed in March and April 1987 by Nisenson et al (1987) and Matcher et al (1987) using speckle interferometry techniques. Also, the position angle of this axis is almost identical with the position angle of the major axis of the elongation in the supernova images (P.A.= 200° ± 5°) obtained between June (1987) and April (1988) using speckle imaging techniques (Karovska et al, 1988a).

The spectra of the polarized radiation recorded between 140 and 360 days after the explosion, using spectropolarimetry at AAO show broad redshifted features corresponding to the emission lines (Bailey, 1988). The

https://doi.org/10.1017/S1539299600007760 Published online by Cambridge University Press

observed polarization structure has been interpreted in terms of electron scattering in an asymmetric, expanding atmosphere. The polarization position angle measured since July 1987 was about 110° (in the red wing of Hα,after correcting for the effects of interstellar polarization). This is shifted by 90° from the measurements of the first few months after the explosion. The position angle of the electron scattering axis seems to be aligned with the minor axis of the elongation in the supernova speckle images (P.A.=110° ± 5°).

III. *SPECKLE INTERFEROMETRY*

High angular resolution speckle interferometry observations of SN1987A obtained on March 25 and April 2, 1987 revealed a bright source separated from the supernova by approximately 60 mas (Nisenson et al, 1987). Data were recorded with the two-dimensional photon counting detector (PAPA) on the Cerro Tololo Interamerican Observatory (CTIO) 4 m telescope using several narrow bandpass (10 nm) filters. The supernova 'companion' was observed at the position angle of 194° in Hα, at 533 nm, and at 450 nm with the magnitude differences of 2.7, 3, and 3.5-4 respectively. no companion was seen in the data recorded on the comparison stars (unresolved by the telescope).

This bright source was observed again 12 days later (Meikle et al 1987) at AAO 4 m telescope at the same position angle and at nearly the same distance from the supernova. A magnitude difference of 3 has been measured at 658.5 nm. Successive speckle observations, starting with June 1987, did not yield new detection of this source for a magnitude difference smaller than 4 (a magnitude difference of 4 was the upper limit for certain detection). This indicates that the source had faded faster then the supernova itself. Attempts to interpret the speckle data have not resulted in a definitive explanation of the nature of this bright source. However, there is additional evidence that the supernova companion source may well have been physically associated with the supernova itself. The source lies on an axis almost aligned with the principal symmetry axis of the supernova envelope as defined from the early polarization observations, and also by the elongation in speckle images of the SN1987A observed between June 1987 and April 1988.

Speckle interferometric observations from March-April, 1987 did not show any convincing evidence of an asymmetry in the supernova shell. However, spectroscopic and polarimetric observations show evidence that the supernova shell was asymmetric at this early epoch after the explosion. The asymmetry was not detected by speckle interferometry because of the small size of the supernova at that epoch (≤ 12 mas, Karovska et al 1988b), and because of the relatively low signal-to-noise in the data.

Successive speckle interferometry observations made at CTIO 4 m telescope between 95 and 411 days after the explosion showed unambiguously that the supernova is asymmetric (Karovska et al, 1988a). The asymmetry was observed at four epochs (day 95-98, 265-267, 370-373, and 409-411) at several different wavelengths between 450 nm and 850 nm including Hα line and Ca II triplet. The position angle of the major axis of the elongation in the images was 200° ± 5°. The images appeared to be somewhat brignter in the south-west direction. The variation of the position angle as a function of wavelength was less than 10°.

Measurements of the minor and the major axis of the elongated images obtained at several different wavelengths show that the supernova size increased substantially since June 1987. The largest change was detected in the images obtained from the data recorded near the Hα maximum emission. The minor axis increased from 6 mas in June 1987 to 20 mas in April 1988. During the same epoch the major axis increased from 10 mas to 30 mas. The ratio between the minor and the major axes of the elongated images is between 0.6 and 0.9, depending on the wavelength of observation. The ratio between the axes has not diminished since June 1987.

CONCLUSION

A number of spectroscopic, polarimetric and speckle interferometric observations of the SN1987A show that this supernova is not spherically symmetric. The asymmetry is not negligible and should be included in theoretical models. This can be crucial for the interpretation of other observational results, for example the early emergence of the X-rays and gamma rays and the evolution of their spectra as a function of time (Grebenev and Sunyaev, 1987).

Current observational results do not give definitive answers to the questions: When did the asymmetry appear? What caused it? Although some of the observations showed evidence for an asymmetry as early as few days after the explosion, it is unclear whether the SN1987A was initially asymmetric or the departure from the spherical symmetry appeared after the explosion. Rotational effects, presence of strong magnetic fields, and appearance of nonspherical instabilities during the core collapse are some of the potential sources for an initial departure from spherical symmetry. The departure from the spherical symmetry in the SN1987A envelope can be also caused by an initial asymmetry in the progenitor envelope. The progenitor envelope could have been rotationally flattened due to angular momentum transfer from a binary companion during the stellar evolution (Chevallier and Soker, 1988). Another possibility is that the asymmetry appeared after the collapse due to the growth of nonspherical instabilities in the expanding envelope.

Further observations of SN1987A may provide more information and help us to determine the cause of the asymmetry. If the source of the asymmetry is not peculiar to SN1987A, a major revision of the supernova models and an assessment of the reliability of the distances derived using Baade method would be necessary.

This work has been partially supported under grant AFOSR-86-0103 and the Smithsonian Institution Scholarly Studies and Research Opportunities grant programs.

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