Kodaikanal Obs. Bull. (1988) 10, 55-58

SPECKLE INTERFEROMETRY OF SN1987A AND THE "MYSTERY SPOT"

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SUMMARY

Two groups have independently studied SN1987A by the technique of optical speckle interferometry in the visible region of wavelengths about a month after the explosion. Both detect a secondary source a factor of ten fainter than the primary, at a position angle of 15° and a separation of 60 milliarcseconds, in a 100Å wide band including Hα. Among the possible explanations suggested for this remarkable source are (i) A relativistic jet breaking out from a weak spot in the supernova shell (ii) Relativistic ejection along the axis of rotation during the collapse (iii) Ionisation of a nearby gas cloud by a flash of hard radiation emitted at a very early stage, followed by recombination.

The secondary source has now disappeared, leaving us to decide between these different possibilities.

BRIEF DESCRIPTION OF THE OBSERVATIONS

About thirty days after the explosion of SN1987A, a team from the Harvard-Smithsonian Centre for Astrophysics (CFA) observed the supernova by speckle interferometry at 6560, 5300, and 4500Å and reported the detection of a remarkable secondary source in a 100Å wide band at the Hα wavelength of 6563Å (Nisenson et al. 1987). The estimated separation was 60 milliarcseconds, the position angle 14° and the flux about 2.7 magnitudes fainter than the primary. The data were consistent with both primary and secondary being point sources. The familiar pictures, which suggest a large source and a small spot result from the style of plotting! One can debate the wisdom of a multicolour image when the real information consists of three numbers plus the overall flux. Since an attempt to detect the same source two or more months later failed, it is fortunate that an independent detection was made by the Imperial College group 50 days after the explosion. Their magnitude difference was, within the errors, consistent with that measured by the CFA group and the separation marginally greater at 74 milliarcseconds. The wavelength used was Hα and the position angle could have been 16° or 196°, the signal to noise ratio being inadequate for resolving the ambiguity (Marcher et al. 1987).

REMARKS ON THE SPECKLE TECHNIQUE

Speckle data can be processed to give the autocorrelation function of the object. Essentially, this means that one accummulates a histogram of the number of pairs of photons in a given frame as a function of the vector separation of the pair. The histogram would have a broad background of the size of the seeing disc. Then there would be a peak at the origin (essentially a pair of photons from the same component of the object arriving in the same speckle). The information about the structure of the object is contained in pairs which arrive from <u>different</u> parts of the object but in the same speckle. Their separation is clearly a property of the object (for a binary star, the angular distance between the two components). Since we have to associate two vector separations $\underline{r}_1 - \underline{r}_2$ and $\underline{r}_2 - \underline{r}_1$ with a pair of photons, the histogram is symmetric about the origin. For a binary star, we have a pair of peaks at the binary separation $\underline{b}$. This gives rise to a 180° ambiguity in the position angle. One method of removing this ambiguity is called the Knox-Thompson algorithm. This is usually formulated in terms of the Fourier transform of the speckle image. Karbelkar (to be published) has developed an alternative image-plane description which in my view is more convenient both for physical understanding and for technical purposes (e.g. signal-to-noise ratio estimates). Consider the simple case of an asymmetric binary. The idea is that one records not only the separation but also the centroid of each pair of photons in a given frame. Correlated pairs which make up the second peak in the autocorrelation will have a centroid displaced by b/2 from the centroid of the stronger source, in the direction of the second source (assumed much weaker and at a separation b). In this way, the parity information about the binary can be recovered from the speckle image, provided the signal-to-noise ratio is high enough to detect this centroid shift.

Coming back to SN1987A, it constitutes a good example where the ability to form an image and not just an autocorrelation makes a significant difference. In models involving jets or ejection along the rotation axis (see below) a pair of sources on opposite sides is entirely possible and it is hence important to distinguish this observationally from a single secondary source. For these two possibilities, the autocorrelation is almost the same since correlated pairs of photons from the two weak sources contribute a much weaker peak to the autocorrelation.

MODELS

It was pointed out by the observers that no object of comparable strength existed in the LMC before the explosion and it was therefore natural to associate the secondary source with the supernova phenomenon. The angular separation implied a minimum distance of 15 light days after a month - i.e., relativistic velocity for the influence which caused the source. (The increase in separation between days 30 and 50 again implied a minimum transverse velocity of 0.3c but was of marginal statistical significance.) Another significant constraint could be placed on models involving interception of some energy from the supernova. Since the intensity of the secondary source is only one order of magnitude down from what we receive from the primary, one needs to postulate

i) An energy reserve greater than what we see and/or

ii) Directed energy flow and/or

iii) A large solid angle subtended by the intercepting object.

The first two points remind us of the long standing problem of extragalactic radio sources. It is hence natural both that a model involving a relativistic jet from the central object would be proposed and that the proposer should be none other than Martin Rees (1987). The idea is that a central rapidly rotating pulsar is filling the supernova cavity with relativistic particles/electromagnetic fields. This energy input would normally just push the shell (optically thick at this stage). However, a "weak spot", perhaps due to a companion star, develops in the shell and releases a beam which travels relativistically and manifests itself where it interacts with the surrounding medium as a secondary source. However, it is now more than a year after the explosion, the shell is optically thinner and the supernova fainter. No evidence for a fast energetic pulsar has emerged.

Another idea (Piran and Nakamura 1987) is that in the collapse of a rotating star with a large magnetic field, one can have ejection of matter along the axis. This was originally suggested from numerical simulations by Le Blanc and Wilson (1970). The ejected fragments can interact with the surroundings. One would presumably have to postulate some asymmetry, either in the ejection or in the surrounding medium. The turnoff of the source could be because of the ejecta crossing the region of high density ballistically. However, it is not clear that the interaction releases much energy in this case. If the ejecta are slowed significantly then the velocity may be too slow to turn off within a few months.

I find the recent proposal by Hillebrandt and coworkers (1987) very interesting. An X-ray and/or ultraviolet flash is believed to be emitted when the supernova shell is at its hottest, smallest, and densest phase which lasts a few hours (the time taken for the outer layers of the star to double their radius). The total energy emitted in this flash is estimated at more than 10^{48} ergs, which in principle could power a 10^{41} erg s^{-1} source for a few months. The idea is that a significant fraction of this energy must be intercepted by a nearby (3.10^{17} cm) dense (10^{6} cm^{-3}) hydrogen cloud and converted to ionisation energy. The ionisation front is shown to move essentially at the speed of light under these conditions, followed by a recombination region which emits the actual photons observed from the secondary source. It is intriguing that some otherwise unexplained Hα features appeared in the spectrum of SN1987A at about the time the spot appeared (N.K. Rao, these proceedings). Although some fairly extreme parameters are required for the flash and the cloud, this model is appealing in that its consequences are more calculable than the previous two mentioned. It does raise many interesting questions, like the formation and survival of such a cloud near a massive star. In some ways, the work of Hillebrandt et al. reminds one strongly of the light echo model for supernovae explored by Morrison and Sartori (1969).

The only sure conclusion seems to be that the secondary source detected near SN1987A has joined the list of astrophysical enigmas.

ACKNOWLEDGEMENTS:

I would like to thank the organisers for a stimulating workshop and D. Bhattacharya in particular for many discussions.

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