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THE PROGENITOR OF SN 1987A

G. Sonneborn

Astronomy Programs, Computer Sciences Corporation,
and IUE Observatory, Goddard Space Flight Center

ABSTRACT

Spatially resolved IUE spectra (1150 - 2000 Å) taken at the position of SN 1987A in March 1987 show that the 12th mag B3 I star Sk -69° 202 has disappeared. Only the two fainter companion stars (Star 2 and Star 3) are now present near the site of the supernova Sk -69° 202 is the star which exploded to produce SN 1987A. The known characteristics of Sk -69° 202 are consistent with the interpretation that the progenitor was a relatively compact star, having a high-velocity low-density stellar wind prior to the outburst. Recent IUE spectra of SN 1987A (May 1988) show no evidence that Sk -69° 202 still exists inside the expanding ejecta

Keywords: Supernovae, ultraviolet spectra

I. INTRODUCTION

It came as a surprise to those following the early observations of SN 1987A that the definitive identification of the progenitor would be made in the ultraviolet. However, the discovery that the supernova's far ultraviolet flux faded by three orders of magnitude in the first four days of the outburst (Ref. 1), revealing a constant, stellar background flux, presented us with an unexpected opportunity to examine the supernova's immediate surroundings for the survivors. By 27 February 1987 the far UV flux had dropped to a level where a constant, stellar background was detected shortward of 1500 Å .

Analysis of preoutburst plates revealed an excellent positional coincidence between the supernova and the 12th mag B3 I star Sk -69° 202 (Ref. 2) and the presence of a second star 3 arc sec to the NW (Ref. 3). Similarities between the IUE spectrum of the UV source at the position of the supernova and that of a luminous early-type star seemed to imply (Ref. 4) that Sk -69° 202 might have survived the explosion.

It was soon discovered that IUE spectra of SN 1987A were broadened perpendicular to the dispersion shortward of λ 1500, indicating the presence of more than one source in the 10" x 20" aperture during the supernova exposures (Ref. 5). The detection of two early-type UV stellar spectra at *the site of the fading supernova and the identification of two* blue stars in the Sk -69° 202 system seemed to imply that the spectra came from the two stars: Sk -69° 202 (Star 1) and Star 2.

Subsequently, high-precision measurements and image syntheses of the Sk -69° 202 field (Ref. 6) demonstrated the reality of a *third* star and provided accurate relative positions for the three members of the Sk -69° 202 system. Star 3 was about two magnitudes brighter than previously thought (m_v = 15.5), about 1.6 arc sec SE of Star 1, and also blue in color. This review summarizes the work (Refs. 7 and 8) which demonstrates that the objects detected near the supernova in IUE spectra are Stars 2 and 3 and that Sk -69° 202 is no longer present.

II. OBSERVATIONS AND DATA ANALYSIS

The identity and characteristics of the stars within several arc seconds of the supernova, and detected in IUE spectra, are determined by analysis of SWP low-dispersion spectra taken after 1 March 1987. During this period the far UV flux of the supernova was much weaker than the other sources in the aperture and the projected separation of Stars 2 and 3 was sufficiently large to allow deconvolution of their spectra. The analysis described below makes use of IUE spatially-resolved low-dispersion spectra, the so-called Extended Line-By-Line (ELBL) spectra (see Refs. 9 and 10).

The relative positions of Stars 1, 2, and 3 from Ref. 6 were adopted for comparison with the IUE data. The orientation of the three stars and the large aperture are shown to scale in Figure 1. The aperture orientation on the sky is determined by the satellite's solar array orientation. Because the Large Magellanic Cloud is located near the south ecliptic pole, IUE's array orientation changes about one degree per day. It was completely fortuitous that the stars within a few arc seconds of SN 1987A were in near-optimal alignment with the spectrograph's spatial direction at the time when the supernova's UV flux faded.

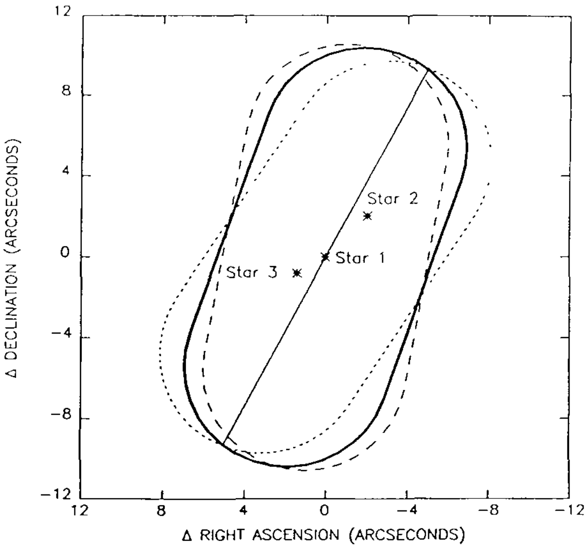

Figure 1 Changing IUE aperture orientation with respect to the SN 1987A field The astrometric positions (Ref 6) of Stars 2 and 3 are shown relative to Star 1 The outline of the aperture is shown for three dates 27 February, 13 and 22 March 1987 The straight line is the direction perpendicular to the dispersion for the 13 March date (solid line) (From Ref. 8)

The 1250 – 1600 Å ELBL data from 13 March (SWP 30512) are compared in Figure 2 with similar data for a single point source. The spectral data have been averaged in 50 Å intervals; no binning or smoothing has been applied in the spatial direction. The presence of two sources in the aperture during the supernova exposure is apparent. The FWHM of the IUE point-spread function (PSF) in SWP spectra varies between 4.6 arc sec at 1350 Å to 6.0 arc sec at 1900 Å (Ref. 11). A good photographic representation of the spatially-resolved spectra of Stars 2 and 3 is shown in Ref. 7.

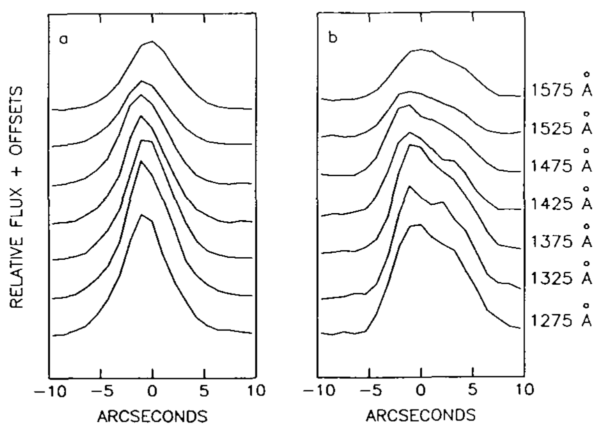

Figure 2 Low-dispersion SWP spatially-resolved spectra a) The ELBL data for a single point source is shown at 50 Å intervals from 1275 to 1575 Å . b) The ELBL data for one of the supernova images (SWP 30512, 13 March) shows the presence of two sources close to the position of SN 1987A . (From Ref. 8)

Numerical procedures were developed to analyze overlapping spectra in IUE low-dispersion images (Ref. 12). Multiple PSFs are fit to the spatial profile of the ELBL data with a multi-variable least squares fitting technique, adopting the skewed-gaussian form of the IUE PSF (Ref. 11). Figure 3 compares the variation in the mean separation between two PFSs with that expected for Stars 1 and 2 and for Stars 2 and 3. A more detailed discussion of the fitting procedure is given in Ref. 8. The variation depicted in Figure 3 is the result of changing IUE aperture orientation due to solar array constraints.

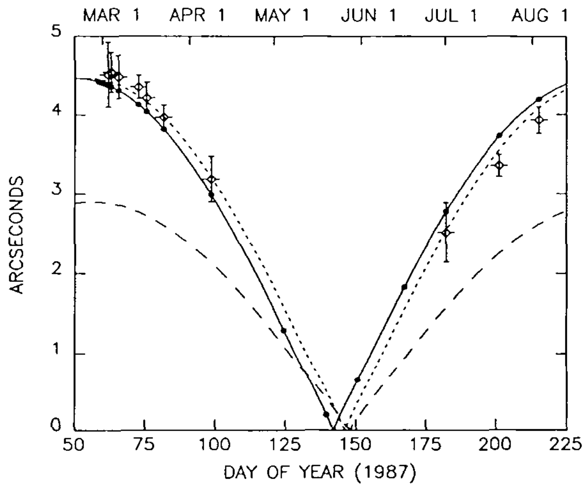

Figure 3 The measured (diamonds) and predicted (solid dots and line) separation between Stars 2 and 3 as a function of time The expected separation between Stars 1 and 2 is also shown (large dashed line). The small dashed line represents a 4° change in the Star 2-3 position angle to 133.°7 (From Ref 8)

III. RESULTS

The measured separations between the two spectra are in very good agreement with the astrometry of Walborn *et al.* (Ref. 6) only if the observed stars are Stars 2 and 3 The results are not consistent with the expected separation between Stars 1 and 2. The error in the component separations, which includes the estimated uncertainty in the IUE spatial scale and the rms error in the least-squares fits to each 25 Å section of the spatial profile, are small, generally less than 5% of the gaussian FWHM. We do not know the relative contributions to the small systematic differences between measured and predicted separations from measurement error in the astrometric positions and in the IUE analysis and spatial scale. However, these differences can be accounted for by a 4° rotation of the Star 2 – Star 3 position angle, as shown in Figure 3.

Two point sources produce an excellent fit to the ELBL data ($\lambda < 1500$) taken after about 1 March, with flux residuals ($data - computed\ fit$) of several percent of the height of the gaussian PSF (Fig. 4a). However, there was a period of a day or two at the end of February when Stars 2 and 3 and SN 1987A had comparable UV flux levels below 1500 Å . A two component fit to these data yields large flux residuals of 25 – 30% (Fig. 4b) When three point sources are fit to the same data an excellent result is obtained, with flux residuals again close to several percent (Fig. 4c). The third point source is located between Stars 2 and 3, 2.9±0.3 arc sec from Star 2, in good agreement with the position of Sk -69° 202 / SN 1987A with respect to Stars 2 and 3.

The gaussian fitting procedure also determines the relative contribution of Stars 2 and 3 to the total flux for the entire SWP wavelength range. The deconvolved spectra of stars 2 and 3 are shown in Figure 5. They have the appearance of early-B spectral types. The strength of the numerous interstellar lines in both spectra is consistent with IUE low-dispersion spectra of other LMC early-type stars. Both Stars 2 and 3 must be located in the LMC, and are not foreground objects.

Dereddened fluxes for Stars 2 and 3 have been determined by comparing their deconvolved spectra with the Kurucz (Ref. 13 and unpublished) model atmosphere grid. The reddening was estimated from the colors of Sk -69° 202 (Ref. 14) and recent work on intrinsic colors of LMC supergiants (Ref. 15). A two component extinction has been adopted: $E(B-V)_{GAL} = 0.08$ from the Galaxy (Ref. 16) and $E(B-V)_{LMC} = 0.10$ from the LMC (30 Doradus curve from Ref. 17), for a total $E(B-V)$ of 0.18. The one-third solar abundance Kurucz models which give the best fit to the continuum slopes are: T_{eff} = 20000K and 25000K (± 2000K) and log g = 3.0 and 4.5 (± 0.5) for Stars 2 and 3, respectively. This suggests that Star 2 might be slightly evolved (luminosity class IV or III). However, the deconvolved spectra are noisy and not of high enough quality to reliably assign spectral types and luminosity classes.

In summary, only two of the original three stars comprising the Sk -69° 202 system are detected in spatially-resolved UV spectra taken at the position of SN 1987A. The temporal variation of the spectral separation is in good agreement with that expected for the positions of Stars 2 and 3 measured on preoutburst plates. Furthermore, in late February 1987 the location of the supernova spectrum shortward of 1500 Å , relative to Stars 2 and 3, was in excellent agreement with the expected position of Star 1. Sk -69° 202 is absent from the field and was therefore the progenitor of SN 1987A. The known characteristics of Sk -69° 202 are consistent with the interpretation that the progenitor was a relatively compact star (Ref. 18), having a high-velocity low-density stellar wind prior to the outburst (Ref. 19). Recent IUE spectra of SN 1987A (May 1988) show no evidence that Sk -69° 202 still exists inside the expanding ejecta.

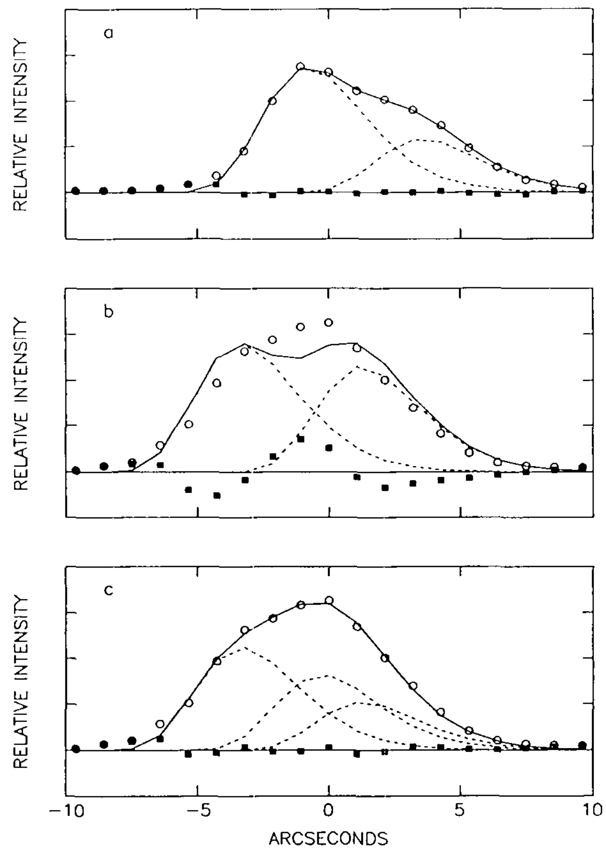

Figure 4 Least-square fits of IUE PSFs to spatial profiles of the 1350 – 1375 Å region of ELBL data a) Two components are fit to SWP 30512 The computed fit (solid line), observations (open circles), individual PSFs (dashed lines), and residuals (solid squares) are shown The left- and right-hand components correspond to Stars 2 and 3, respectively b) A two-component fit to SWP 30408 (27 Feb 1987), where SN 1987A and Stars 2 and 3 had similar flux levels The component separation is 4 50 arc sec c) A three-component fit to the same data as in Fig 4b is in excellent agreement with the observations The center component corresponds to SN 1987A (From Ref 8)

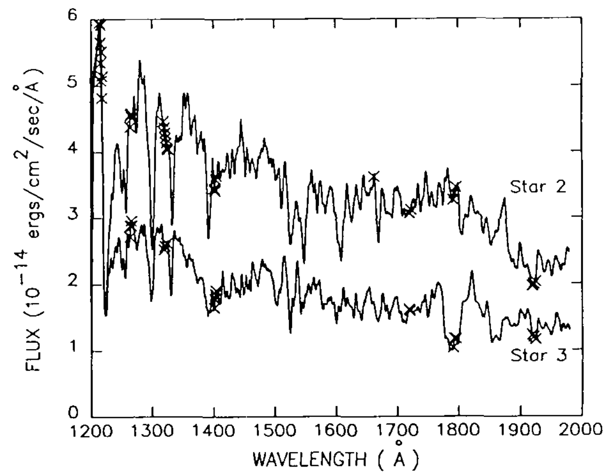

Figure 5 The deconvolved spectra of Stars 2 and 3 Strong interstellar absorption lines between 1250 and 1500 Å are evident, even in low dispersion, implying both stars are in the LMC The xs mark portions of the spectrum effected by camera reseaux

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