FOC OBSERVATIONS OF SN 1987A [1]

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ABSTRACT. We present and discuss the first images of SN 1987A obtained on day 1278 with the *FOC* on board the *Hubble Space Telescope*. The supernova is well detected and resolved spatially in the four observed bands. The UV luminosity of SN 1987A is found to be comparable to that emitted in the visible and infrared spectrum. Narrow-band [OIII] imaging reveals that the circumstellar nebula surrounding SN 1987A has the shape of a perfectly elliptical ring, implying an inclination of $43° \pm 3°$. A comparison of the ring angular size with its absolute size derived from an analysis of the light curves of narrow UV lines measured with *IUE*, gives an accurate determination of the distance to SN 1987A, *i.e.* $d(1987A) = 51.2 \pm 3.1$ *kpc*. Allowing for the relative position of SN 1987A within the LMC, the distance to the *center* of the LMC turns out to be 50.1 ± 3.1 *kpc*. This value agrees very well with the determinations obtained from light curve analyses of variable stars.

1. Observations

SN 1987A and its immediate surroundings were observed with the f/96 camera of the *FOC* on 1990 August 23-24 UT (JD 2448127.6; Day 1277.8). Three exposures were obtained in the broad-band UV filters, F175W (1676 s), F275W (838 s) and F346M (575 s), and one 1660 s exposure in the narrow-band F501N [OIII] 5007 Å filter. A 512×512, $0.022'' \times 0.022''$ pixel detector format was used, providing a field of view of $11'' \times 11''$ (Jakobsen *et al.* 1991).

In all four bands the supernova was well detected and resolved spatially (see *e.g.* Fig. 1). The F501N exposure also shows the circumstellar ring known to surround SN 1987A (Crotts, Kunkel and McCarthy 1989, Wampler *et al.* 1990). The F346M and F175W exposures are very similar in appearance to the F275W image and show little, if any, trace of the ring.

2. Supernova Angular Size

A comparison between the images of star 4 and SN 1987A reveals that the supernova is clearly extended, with an average angular diameter of $\theta \simeq 170 \pm 30$ *mas* (Jakobsen *et al.* 1991). Adopting a distance of 51 *kpc* (see Section 7) it corresponds to a linear radius of $R \simeq 2.1 \times 10^{-2}$ *pc* and an expansion velocity of $v \simeq 6000$ *km* s^{-1}. This average velocity is

[1] Based on observations with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by AURA, Inc., under NASA contract NAS 5-26555.

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J. Bergeron (ed.), Highlights of Astronomy, Vol. 9, 471–474.

well within the 2,000-30,000 $km\ s^{-1}$ range of velocities seen in the spectrum of SN 1987A (Cassatella 1987, Kirshner *et al.* 1987, Phillips *et al.* 1988).

3. Flux Measurements

Absolute, broad-band fluxes were also determined for SN 1987A by carrying out digital aperture photometry on the images. The luminosity of SN 1987A in the ultraviolet, $L \simeq 2 \times 10^{36}\ erg\ s^{-1}$, is comparable to that emitted in the visible through infrared portion of the spectrum. Moreover, the derived brightness temperature of $\sim 2500\ K$ agrees quite well with direct measurements of the gas temperature at late epochs (*e.g.* Spyromilio, Stathakis and Cannon 1991).

4. HST Observation in the [OIII] 5007Å Line

The circumstellar ring seen in the F501N image appears as a near perfect ellipse centered on SN 1987A. The measured major and minor semi-axes of the ring are $830 \pm 15\ mas$ and $605 \pm 15\ mas$, respectively. The relative darkness of the interior of the ring with respect to the exterior, indicates that the object is indeed a circular annulus and not a limb-brightened shell. In this case, the inclination angle is $\alpha = 43° \pm 3°$. The angular width is estimated to be less than 4 pixels, or 88 *mas*. Factor of 4-5 intensity fluctuations are seen along the ellipse suggesting the effect of some instability during the process of formation of the ring.

5. Nature of the Ring

The ring is a relic of CNO processed stellar envelope (Fransson *et al.* 1989) that was ejected in the form of a stellar wind by the progenitor, when it was in the phase of red supergiant. The diffuse gas was later compressed by a fast wind from the star when it had evolved back to a blue supergiant state, about ten thousand years before the explosion occurred. The image suggests that the fast stellar wind was more efficient at compressing the gas along an equatorial plane, to create the observed ring-like structure, that constitutes a sort of a thick belt around the "waist" of a larger bubble (Luo and McCray 1991).

6. Narrow Emission Lines

The presence of narrow emission lines of highly ionized species has been detected in the short wavelength IUE spectrum since late May 1987 (Wamsteker *et al.* 1987) revealing that the progenitor had been a red supergiant before becoming the blue supergiant that made the explosion (Fransson *et al.* 1989).

After reaching a maximum around day 410, the line intensities have been decreasing for about 300 days, to then stabilize to a roughly constant value or a decline at a much slower rate (Sonneborn *et al.* 1990). The most obvious interpretation of the observed light curves for all lines is in terms of light travel effects combined with intrinsic decay of the emission.

7. Distance to SN 1987A and the LMC

As expected with a tilted ring geometry, the intensity is zero for an initial period of time $t_o = [R_{ring}/c] \times [1 - sin(i)]$ where i is the inclination of the ring. Then the intensity rises until it reaches a maximum at $t_{max} = [R_{ring}/c] \times [1 + sin(i)]$ and starts declining afterwards (Panagia *et al.* 1991a).

The emission lines evolution with time has been modeled by Panagia *et al.* (1991a) and

https://doi.org/10.1017/S1539299600009576 Published online by Cambridge University Press

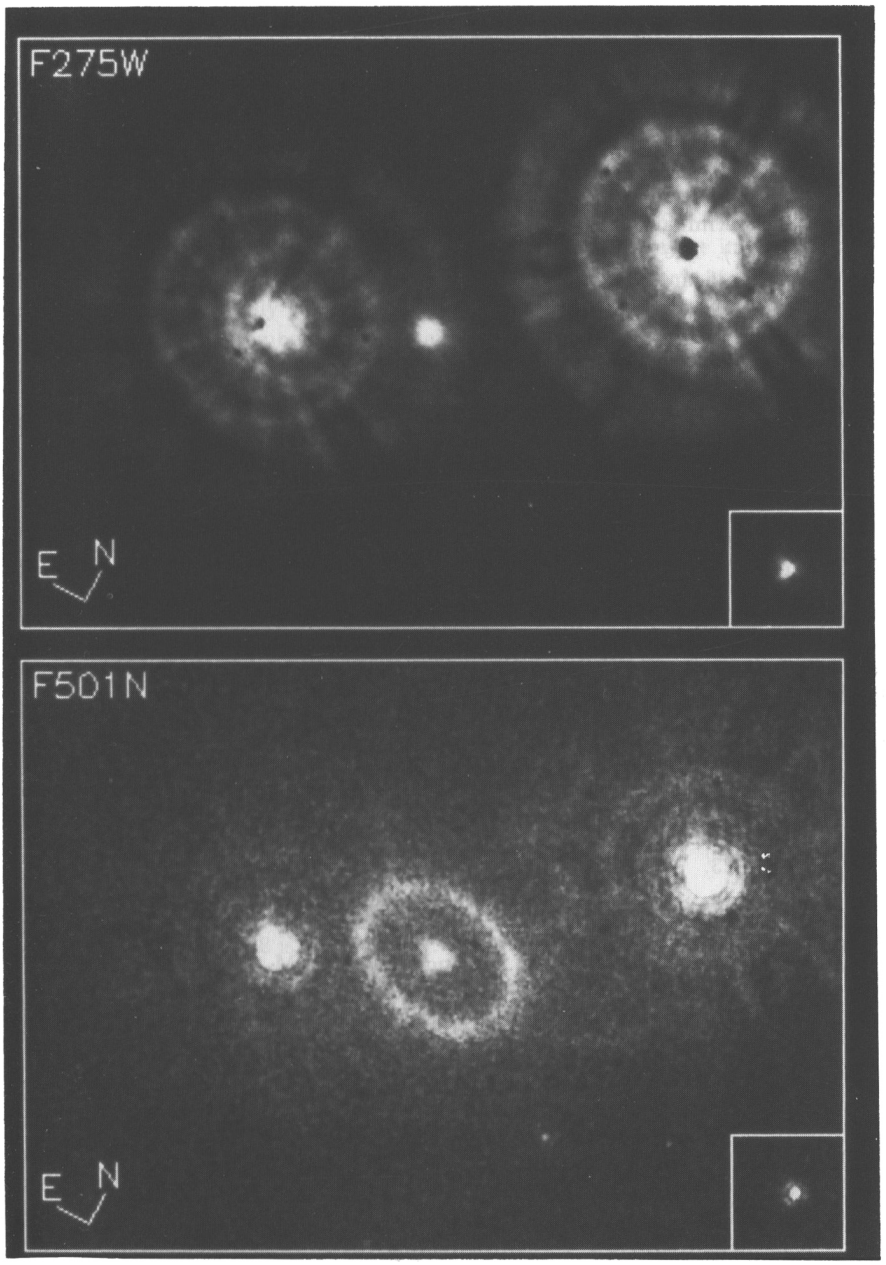

Fig. 1 8.4″ × 5.9″ segments of the F275W exposure (upper frame) and F501N exposure flower frame) showing SN 1987A and its two companion stars numbers 2 and 3. The images from the same exposures of the $V = 18.24$ reference star number 4 located 5.5″ west of SN 1987A are shown as inserts.

https://doi.org/10.1017/S1539299600009576 Published online by Cambridge University Press

Panagia and Gilmozzi (1991) to derive the time of the maximum, $t_{max} = 413 \pm 24$ *days*, and the absolute diameter of the ring: $2R = (1.27 \pm 0.07) \times 10^{18}$ *cm*

Once *both* the ring absolute diameter and its angular diameter are known one can derive the *distance* to SN 1987A: $d(1987A) = 51.2 \pm 3.1$ *kpc* (Panagia *et al.* 1991).

Estimating the relative position of SN 1987A within the LMC with a discussion of radial velocity data of the supernova, the neutral H gas and of other discrete sources in the 30 Dor region, Panagia *et al.* (1991a) have concluded that the distance to the *center* of the LMC is 50.1 ± 3.1 *kpc* or, conversely, its distance modulus is 18.50 ± 0.13. This value agrees very well with the determinations obtained from light curve analyses of variable stars (*cf.* Feast and Walker 1987). The apparent discrepancy with lower estimates obtained from HR diagram fits is not significant because they are affected by larger uncertainties (Feast and Walker 1987).

8. References

Cassatella, A. 1987, in *ESO Workshop on SN 1987A*, ed. I. J. Danziger (Garching: ESO), p.101.

Crotts, A. P. S., Kunkel, W. E., and McCarthy, P. J. 1989, *Ap. J. (Letters)*, **347**, L61.

Fransson, C., Cassatella, A., Gilmozzi, R., Kirshner, R.P., Panagia, N., Sonneborn, G., and Wamsteker, W., 1989, *Ap. J.*, **336**, 429.

Jakobsen, *et al.*, 1991, *Ap. J. (Letters)*, **369**, L63.

Kirshner, R. P., Sonneborn, G., Crenshaaw, D. M., and Nassiopoulos, G. E. 1987, *Ap. J.*, **320**, 602.

Luo, D., and McCray, R., 1991, *Ap. J.*, in press.

Panagia, N., and Gilmozzi, R., 1991, preprint.

Panagia, N., Gilmozzi, R., Macchetto, F., Adorf, H-M., and Kirshner, R.P, 1991a, *Ap. J. (Letters)*, **380**, L23.

Panagia, N., *et al.*, 1991b, in preparation.

Phillips, M. M., Heathcote, S. R., Hamuy, M., and Navarrete, M. 1988, *A. J.*, **95**, 1087.

Sonneborn, G., Cassatella, A., Fransson, C., Gilmozzi, R., Kirshner, R.P., Panagia, N., and Wamsteker, W., 1990, *IUE Toulouse Symposium*, ed. E. Rolfe, ESA SP-310,

Spyromilio, J., Stathakis,, R.A., and Cannon, R.D., 1991, *ESO/EIPC Workshop on "SN 1987A and other Supernovae"*, *ESO WCP No. 37*, ed.I.J. Danziger and K. Kiăr, p. 225.

Wampler, E.J., Wang, L., Baade, D., Banse, K., D'Odorico, S., Gouiffes, C., and Tarenghi, M., 1990, *Ap. J. (Letters)*, **362**, L13.

Wamsteker, W., Gilmozzi, R., Cassatella, A., and Panagia, N., 1987, *I.A.U. Circ* No. 4410.