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Further observations of the light echoes from SN 1987 A *

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Abstract. We report here on further direct observations of the light echoes from SN 1987A as obtained on 12 November 1988 with the 3.6 m telescope + EFOSC at the European Southern Observatory. In agreement with predictions made from earlier observations, the radii of the two light rings are measured to be 43″.3 and 72″.5. However, we report a noticeable displacement of the center of the outer ring by 2″.6 to the north-east from the supernova position. Application of the model of planar-like sheets of material located between the supernova and the observer leads to the following improved results: the inner light echo originates in a plane of interstellar matter, approximately perpendicular to the line-of-sight, at a distance $b \simeq 117$ pc (382 l.y.) from the supernova whereas the outer light echo arises in a plane at a distance $b \simeq 325$ pc (1062 l.y.) which seems to be pointing towards the Tarantula giant H II region.

Key words: Supernova 1987A – interstellar medium – light echoes – galaxies: Magellanic clouds

1. Introduction

Following the discovery of the two light echoes from SN 1987A (Crotts, 1988; Rosa et al., 1988), several independent studies dealing with the origin and evolution of this phenomenon have been reported. In the framework of the standard model developed by Couderc (1939), both Gouiffes et al. (1988) and Suntzeff et al. (1988) have shown that the inner and outer circular arcs around SN 1987A may be described as due to the scattering of the supernova light near maximum in two planar-like sheets of interstellar material located approximately perpendicular to the line-of-sight at distances $b_1 = 122$ and $b_2 = 316$ pc, and $b_1 = 115$ and $b_2 = 305$ pc, respectively, from the supernova. If we extrapolate to the date of our observations (12 November 1988) the angular radius versus time relations derived by Gouiffes et al. (1988), one finds values of 42″.9 and 72″.8 for the two rings. Measurements of our CCD frames lead to the results of 43″.3 and 72″.5, in excellent agreement with the above predictions. We describe hereafter these observations in more detail, reporting principally on the measurement of a decentring of the outer light echo with respect to the supernova position.

2. Observations and data reduction

We have obtained on 12 November 1988 four CCD frames of SN 1987A using the ESO faint object spectrograph and camera (EFOSC, see Dekker and D'Odorico, 1985) at the f/8 Cassegrain focus of the ESO 3.6 m telescope. The CCD frames were taken in the coronographic mode during 1 min and 10 min exposures, each through the Bessel R and Gunn I filters. These data were reduced with the MIDAS application programs available at ESO (La Silla) following a standard procedure which consists of cleaning, flat fielding and dark subtraction. We have also obtained R and I exposures of the standard star E3e (Graham, 1982) in order to calibrate the fluxes. Figure 1 illustrates the light echoes from SN 1987A as seen on the 10 min R CCD exposure.

3. Description of the light echoes

Fitting at best the observed light echoes with adequate ring models (cf. Fig. 2), we find on both sets of R and I frames that the measured radial intensity profile peaks at maximum values for angular radii of 43″.3 and 72″.5 (cf. Fig. 3) and that the shape of the former ones scarcely departs from circularity. Furthermore, whereas the center of the inner ring is found to coincide very well, within the measurement uncertainties, with the position of SN 1987A, that of the outer ring is seen on the four individual frames to be displaced towards north and east by 1″.2 ± 0″.2 and

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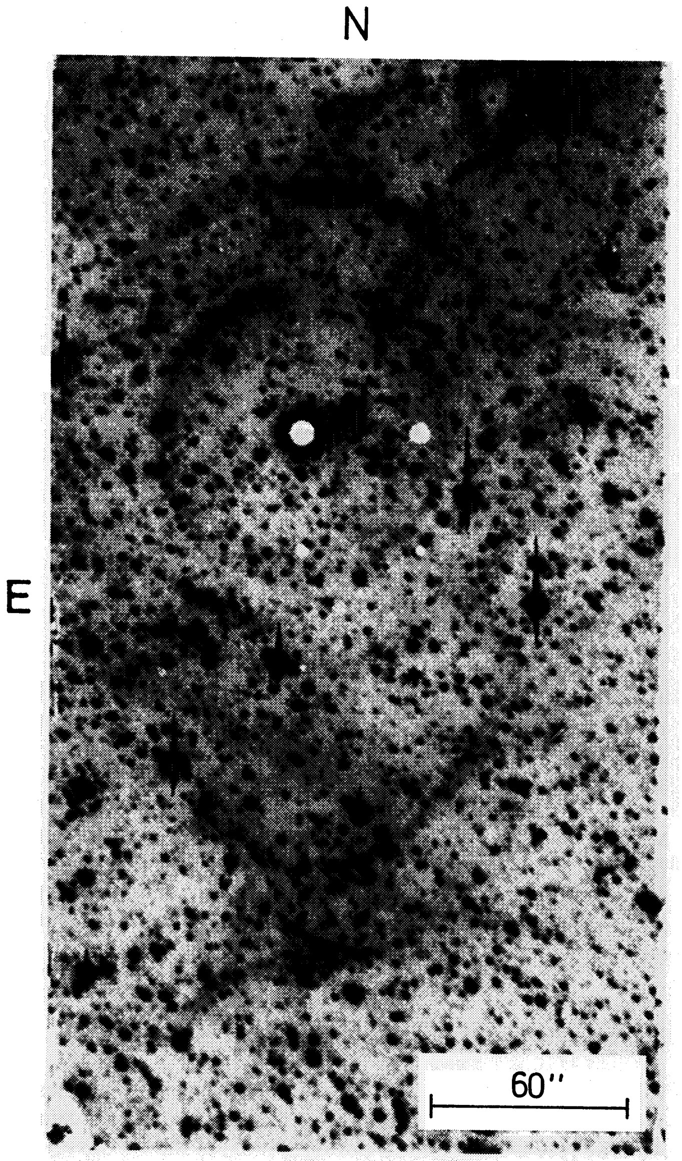

Fig. 1. CCD frame of the light echoes around SN 1987A obtained with EFOSC in the coronographic mode during a 10 min exposure through a Bessel R filter on 12 November 1988. North is up and East to the left

2″3 ± 0″4, respectively. In the framework of the model developed by Couderc (1939) and referring to the plane of sky along the position angle 62° ± 6°, such a displacement of the light echo's center is directly accounted for by a 53° ± 6° inclination of the plane of interstellar material giving rise to the outer light echo. Since the position angle of 62° counted from the location of SN 1987A corresponds admirably well with the direction of the Tarantula (30 Doradus) H II region, it is very likely that the relevant plane of scattering material is associated with the latter one and that the supernova is located ≃ 700 pc deeper in the LMC than is 30 Doradus. Such a possible geometry has first been qualitatively suggested by Suntzeff et al. (1988) and it is therefore very likely that some of the highly redshifted interstellar lines recorded in the spectrum of SN 1987A arise in that complex H II region (cf. Gouiffes et al., 1988). Whereas the radial intensity profile of both light echoes looks somewhat triangular (cf. Fig. 3), the estimated FWHM and FWZI of the inner and outer rings are typically found to be 6″ ± 1″, 15″ ± 2″ and 6″ ± 1″, 13″ ± 2″, respectively. If we interpret these angular widths as being due to the time spread of the initial pulse giving rise to the observed light echoes (cf. Couderc, 1939), one finds FWHMs ≃ 154 and 94 days for the inner and outer rings, respectively. These values should be compared with the FWHM of 71 days for the light curve of the supernova near maximum (see Suntzeff et al., 1988). For the particular case of the inner light echo, we conclude that the associated planar sheet of interstellar matter scattering the supernova light cannot have a negligible thickness. Nevertheless, application of the theory of Couderc (1939) allows one to set in this case an upper limit of 81 pc.

Finally, the average surface brightness of the two light echoes is found to be very similar, in both the Bessel R and Gunn I passbands: $B_r \simeq B_I \simeq 23.7 \pm 0.5$ mag/arcsec^2. Of course, local fluctuations of the surface brightness exceeding 1 mag are observed; these are probably due to large density variations in the interstellar medium.

4. Discussion

Because the surface brightness of the two light echoes around SN 1987A should decrease as the inverse of the time interval $(t - t_0)$ elapsed since the epoch (t_0) of light maximum and since the two rings progress at the NE towards denser regions of the interstellar medium located near 30 Doradus, we may conceive that distinct parts of the luminous rings will remain visible during several decades.

Table 1. Compilation of the angular radius of the light echoes reported in the literature up to day

Date	t (in days)	Angular radius in arcsec		Remarks	References
		Inner echo	Outer echo		
23.4/2/87	0			Neutrino pulse from SN 1987A	Hirata et al. (1987)
17/5/87	83			Supernova light maximum	Gouiffes et al. (1988)
16/8/87	174		32.8		Gouiffes et al. (1988)
13/2/88	355	32	52		Gouiffes et al. (1988)
16/3/88	386	32.9	55.7		Gouiffes et al. (1988)
20/3/88	390	32.8	54		Suntzeff et al. (1988)
12/11/88	627	43.3	72.5	Outer ring off-centre	Present paper

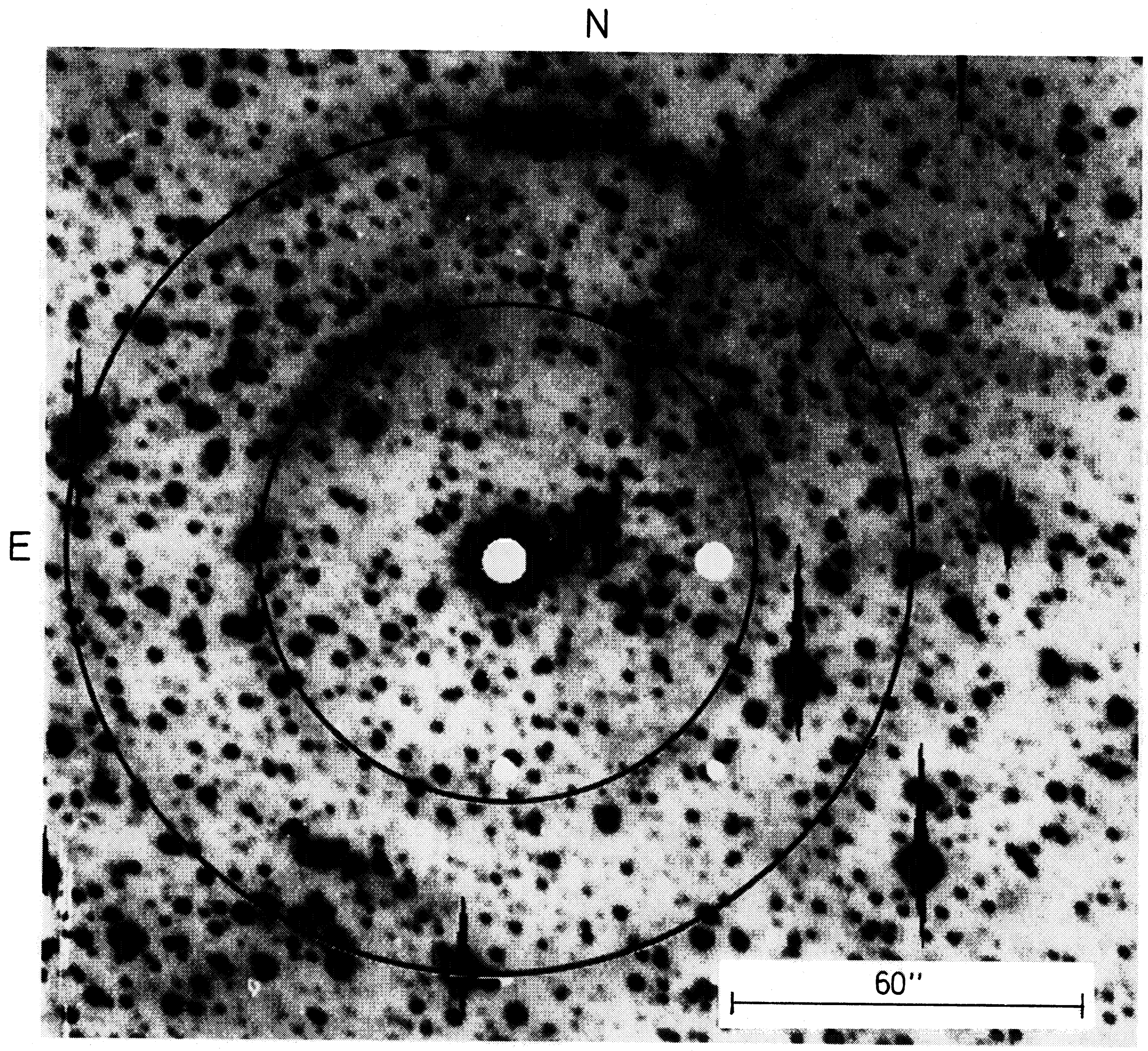

Fig. 2. Enlarged view of the CCD frame described in Fig. 1 showing in the overlay the best fitted circles to the light echoes. The center of the outer ring is somewhat displaced to the north-east by 2″.6 with respect to the central position of SN 1987A

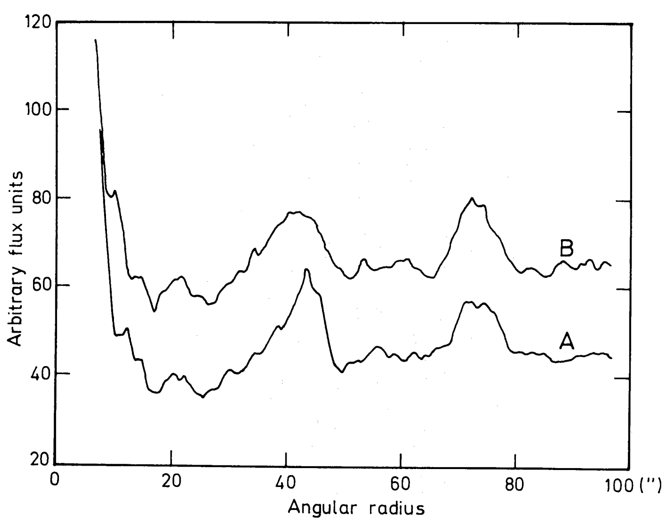

Fig. 3. This diagram illustrates the radial surface brightness profiles of the light echoes with respect to their best fitted centers (see Fig. 2) located (A) at the supernova position, (B) 2″.6 NE from it at p.a. = 62°. Curve B has been displaced vertically by 20 units with respect to curve A

Given all previous measurements of the echoes angular radii (see Table 1) and by means of Couderc's Eq. (V), where the distance to SN 1987A is taken to be 50 kpc, we find new estimates for the distances b_1 and b_2 between the supernova and the planar sheets of scattering material and the epoch to be: (inner echo) $b_1 = 117\,\mathrm{pc} \pm 15$, (outer echo) $b_2 = 325\,\mathrm{pc} \pm 15$ and $t_0 = 64\,\mathrm{d} \pm 15$, i.e. around 28 April 1987.

Because the expected image of the third ring detected by Bond et al. (1989) at 9."5 from the supernova position falls in the bright outer profile of the image of SN 1987A and because the use of a coronograph prevents us from modelling the exact shape of such a profile, we are not able to confirm or dismiss the presence of the third ring from our observations, not even to provide a realistic constrain on its surface brightness.

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