PRE-SUPERNOVA RING AROUND PSR0540-69.

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ABSTRACT. SNR0540-69 is a supernova remnant in the LMC, harbouring a young (\(\tau \sim 1600 \text{ yrs}\)) radio/optical/X-ray pulsar (P=50 ms). Ground based H\(\alpha\) imaging of the region has shown a unique spiral-like structure centered around the pulsar. In narrow band HST imaging, the feature seems resolved in a ring-like structure, probably ejected by the progenitor star in a pre-supernova phase (\(\geq 10^4 \text{ yrs}\) ago).

1. Introduction.

SNR0540-69 is the remnant of the last supernova explosion occurred in the Large Magellanic Cloud before SN1987A (Kirshner et al, 1989). High resolution H\(\alpha\) images of the remnant unveiled a spiral-like feature, centered on the pulsar optical counterpart, and definitely not present in other wide (B and V) or narrow-band filter (OIII and SII) images (Caraveo et al, 1992). The spiral-like feature was later confirmed by a deeper H\(\alpha\) exposure, taken with sub-arcsec seeing conditions. The resulting image is shown in Figure 1.

To investigate the nature of the H\(\alpha\) structure, we have pursued both spectroscopy and high resolution, narrow band imaging.

2. The data.

2.1. Spectroscopy.

Spectroscopy of SNR0540-69 was performed on 1995 January, at ESO (La Silla) using EMMI (ESO Multi Mode Instrument) at the 3.5m NTT. Two 50-minute spectra were obtained with a 1.5” slit centered at the pulsar position and the long axis oriented North-South and East-West, as shown in Fig.1.

Globally, our results are in excellent agreement with the comprehensive work of Kirshner et al (1989) but for the region around H\(\alpha\). The identification of the feature observed at \(\sim 6580 \text{ \AA}\) is not straightforward. It was first attributed to [NII] (6584 \text{ \AA}) by Mathewson et al (1980), then to CaI (6572.8 \text{ \AA}) by Dopita & Tuohy (1984) and, finally, to H\(\alpha\) (6562.8 \text{ \AA}) by Kirshner et al (1989). However, the width of the feature
Fig. 1. 30 min $H\alpha$ exposure of SNR0540-69 taken in Jan 1994 with the SUperb Seeing Imager (SUSI) of the ESO/NTT and a $\sim 0.6''$ seeing. North to the top, East to the left. The spiral-like feature is $\sim 4''$ in size. The two stripes show the slit orientations.

($\sim 3500 \pm 50$ km/s as opposed to the values of $\sim 1800 - 2000$ km/s measured for single unblended lines) is far too large to allow the identification with a single line. In order to better assess the structure of the of the 6580Å region we can exploit the excellent quality of our 2-D spectra. Figs.2a and b show a blow-up of the NS and EW 2-D spectra in the region 6500-7000 Å including both the SII doublet and the 6580Å region. While the SII lines are blended and significantly redshifted (to wit their origin in a young SNR which is both expanding at $v \sim 1200$ km/s and receding at $v \sim 600$ km/s), the 6580Å complex is composed of three lines which appear both narrower and less (if at all) redshifted. As in the Crab Nebula (e.g. Nasuti et al. 1996), we identify the lines as an $H\alpha$, unrecoverably polluted by LMC emission, in the middle of a better defined NII doublet (6548, 6584Å). The three lines appear unblended and the troughs, although partially filled by the synchrotron continuum of the plerion, are deeper than expected if the lines were affected by the same velocity dispersion as the SII. Moreover, looking at the brighter 6584Å component of the NII doublet, we see that, while its appearance is markedly different in the two spectra, its centroid is not significantly redshifted w.r.t. the LMC lines. However, the structure of the 6584Å line points towards a non-spherical emitting region which is not expanding at the rate measured for SNR0540-69 neither is it receding at the same speed.
Fig. 2. Blow-up of the 2-D spectra, showing the Hα complex and the SII doublet, for the N-S (a) and E-W (b) orientations of the slit. x-axis: wavelengths, increasing from left to right (1 pixel = 1.2 Å); y-axis: spatial coordinate along the slit (1 pixel=0.27") (a) North at top, South at bottom (b) East at top, West at bottom. The passbands of the HST filters 656N (λ = 6562 Å; ∆λ = 22 Å) and 658N (λ = 6590 Å; ∆λ = 28.5 Å) are also shown together with the ESO/NTT Hα (λ = 6552 Å; ∆λ = 60 Å).

2.2. Imaging.

New imaging of SNR0540-69 was performed in October 1995 with the HST/WFPC2. To image the different components of the λ = 6580 Å feature, clearly blended in the wider ESO Hα filter (see the passband schematically shown in Fig. 2a), we have used the WFPC2 "Hα" (656N) and “N[II]” (658N) filters. The resulting images are shown as contour plots in Fig.3 a,b where all field stars, falling within or close the remnant, were removed. The difference in the remnant brightness between the two filters confirms our spectroscopy, where the NII [6584 Å] line appeared most prominent than the Hα one. The most notable feature in Fig. 3a,b is a bright emission knot ~ 1” south of the pulsar position, clearly visible also in the Hα NTT image (Fig.1). Since the knot does not appear in our reference HST V-band image, we attribute it to the remnant structure rather than to a fore/background object. Although the S/N is too low to claim
any definite association, a physical link between this knot and PSR0540-69 seems to be present in the 656N image (Fig.3a). The interaction of PSR0540-69 with the surrounding medium is clearly shown in the 658N image (Fig.3b) where a conical structure is seen to originate from the pulsar and to connect it with an arc-shaped feature ~1" to the NW. A similar, albeit fainter, arc is visible on the East side of the pulsar and the combination of the two yields a ring-like structure (~3" in diameter and ~0.2" thick) centered roughly on PSR0540-69. An additional, faint North-South, bar-like, emission is seen to go through, or originate from, the pulsar. Although definitely brighter in the "[NII] filter", a ring-like structure of similar dimensions can be inferred in the noisy 656N image (Fig. 3a).

3. Discussion.

Since the passbands of the 656N and 658N filters encompass respectively the Hα and [NII] line, we can directly compare the spectra, shown in Fig.2 a,b, with the HST images, shown in Fig. 3 a,b, once the different pixel sizes of the two instruments are properly accounted for. Since the NTT/EMMI spatial resolution (y-axis on Fig 2) is 0.27" per pixel and the PC pixel size is 0.045", the 1.5" slit covers ~33 PC pixels. In the N-S spectrum, shown in Fig.2a, the [NII] line has a spatial extent identical to the ring diameter and its brightest part corresponds to the southern knot. Going from North to South, the average velocity of the line shifts redward continuously for a total displacement of 3-4 EMMI pixels, corresponding to ≤ 5 Å. In the E-W spectrum, the [NII] line is dominated by the emission of the knot, now appearing in the upper part of Fig.2b, owing to the
rotation of the CCD. The less intense (and slightly bluer) part of the line is due to the SW part of the arc-shaped feature, which we have tentatively interpreted as a ring around the pulsar.

All in all, the velocity of the [NII] feature differs very little from the LMC one and the overall shear along the N-S diameter can be quantified to be $\leq 100 \text{ km/s}$. However, a ring expanding $\leq 50 \text{ km/s}$ could not have been formed at the time of the SN explosion. To account for the ring dimensions, an expansion velocity of $\sim 200 \text{ km/s}$ would be needed and our data do not support a velocity shear of $\sim 20\degree$, corresponding to 16 EMMI pixels. Moreover, the [NII] line emission originated from the ring is not affected by the overall SNR0540-69 recession speed. Therefore this ”ring” must have formed before the event responsible for such a recession, i.e. before the SN event itself.

Our slowly expanding ring would thus trace a pre-supernova stage of the progenitor star like, probably, for the rings around SN1987A (e.g. Plait et al, 1995, Panagia et al, 1996) and for the hourglass nebula around the blue supergiant (BSG) Sher 25 (Brandner et al, 1997a and b). SNR0540-69 would thus be the second example, after SN1987A, of a supernova remnant retaining memory of a pre-supernova mass ejection similar to that undergone by the BSG Sher25 $\sim 6,600$ year ago (Brandner et al, 1997b). Indeed, both the dimensions and the slow expansion rate of the SNR0540-69 ring are reminiscent of the inner ring of SN1987A as well as of that around Sher 25.

If we now concentrate on the comparison between SNR0540-69 and SN1987A, we find that their many similarities in dimensions, composition and velocity point towards similar progenitors for these two supernovae which happen to be in the same star forming region in the LMC (Kirshner et al, 1989). Assuming that the progenitor of the $\sim 1600 \text{ yrs}$ old SNR0540-69 experienced mass ejection $\geq 10^4 \text{ yrs}$ before the supernova explosion and using the distance value of 50.9 kpc, as inferred by Panagia et al (1997) for SN1987A, the measured angular size of the ring ($\sim 3\"$) implies a velocity $\sim 30 - 40 \text{ km/s}$. This is larger to the expansion velocity measured for the inner ring of SN1987A ($\sim 11 \text{ km/s}$, Panagia et al, 1996) but similar to the value of $\sim 30 \text{ km/s}$ found for the $\sim 6,600 \text{ yrs}$ old ring around Sher25 (Brandner et al, 1997b).

4. Conclusions

Coupling high resolution imaging with spectroscopy, we have shown that the ring-like structure around PSR0540-69 was formed during the pre-supernova phase and survived to the present day. We can exclude that the ring be simply due to SN ejecta since this would imply an expansion velocity too high to be consistent with our spectral data but far too low to be consistent with the average expansion rate measured for the SNR. Moreover, the absence of any significant redshift for the NII line argues strongly in favor of a pre-supernova origin. In the assumption that the receding speed of SNR0540-69 was acquired during the supernova explosion, the ”ring” must have originated before such explosion, during the pre supernova phase of the progenitor as it is believed to be the case for the rings around SN1987A.

However, considering also the case of the ring detected around the BSG Sher 25, we can study such structures well before the SN explosion, and follow them when they are lighted first by the SN flash and than by the interaction with the SN ejecta and, possibly,
with the pulsar relativistic wind. Indeed, at variance with the case of SN1987A, where, as expected (Luo et al 1994), the inner ring is now being reached by the supernova ejecta (NASA PR 98-24), the ring of SNR0540-69 has been swept over by the ejecta long ago and it is now shining after $\sim 1,600$ yrs from the SN explosion most probably owing to shock heating. On the other hand, the presence of PSR0540-69, i.e. a young energetic ($\dot{E} \sim 1.5 \times 10^{36}$ erg/s) pulsar powering the surrounding plerion, could also play an active role.

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