SNR0540-69 -the Crab twin- revisited: Chandra vs. HST

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Abstract

High resolution images of the Crab-like SNR SN0540-69 have been recently obtained by the HRC, on board the Chandra X-ray Observatory, and by the FORS1 instrument, attached to ESO/VLT1. A detailed comparison of these images with an archival Planetary Camera one will be presented.

1 Introduction

The study of extended objects relies heavily on multiwavelength imaging. Irrespective of the astrophysical classification of the actual target, its multiwavelength phenomenology provide precious insights on the physical processes at work as well as on the source geometry. However, comparing images taken at different wavelengths is not a trivial task. The job is made difficult by the instruments different performances, in particular by their different resolution. Although it will always be possible to superimpose a low resolution image on a high resolution one, the most astrophysically compelling comparisons will come from instruments with similar resolutions. The sharpness of view of HST, while perfectly suited to map extended sources, sets a very demanding standard for multiwavelength comparison. So far, only radio VLA/VLBI images could compete with HST, as shown, e.g. by Macchetto (1996) 2.

Unfortunately, the same was not true for X-ray astronomy where the HST performances were, so far, unmatched. The High Resolution Camera, on board Chandra Observatory (Weisskopf, O’Dell and van Speybroek 1996 9), is the first X-ray instrument capable of sub arcsec angular resolution, making it possible, for the first time, detailed X-to-optical comparisons.

Among the first objects observed by Chandra HRC, during the initial calibration phase, one finds, apart for the Crab, the most Crab-like among the SNRs, SN0540-69, the Crab twin in the LMC.

Since HST did observe the object with the Planetary Camera, it is now possible to compare in detail the X and optical images of this plerion. Moreover, SN 0540-69 has been observed in polarization mode during the commissioning of the FORS1 instrument, now operational at VLT1 (Antu). Owing to the synchrotron emission mechanism generally thought to be at work in a plerion, polarization plays a key role in the objects phenomenology, thus making it desirable to add the polarization information into the multiwavelength study. 0540-69 is a challenging plerion since its LMC location implies very reduced angular dimensions, thus it stands out as a very interesting test case for our multiwavelength approach. Here we shall report on the first detailed superposition of these three data sets: HST, Chandra and polarimetry from the ground.

2 Data Analysis

2.1 HST

SNR B0540-69.3 was observed with the PC chip (45 mas/px) of the WFPC2 on October 19th 1995. Two 300 s exposures were obtained through the F555W filter (5442 Å, 1220 ÅFWHM). The data have been recalibrated by the ST-ECF pipeline using the most recent reference files and have been combined to reject cosmic ray hits. In order to better study finer details of the remnant structure, fore/background stars spatially coincident with the remnant have been removed by subtracting a model PSF computed from more than 40 suitable field stars. The resulting image is shown in Fig. 1a, after having being filtered with an adaptive smoothing algorithm with
a 4σ significance threshold. The pulsar (V=22.5) is clearly visible at the center of the plerion. The plerion morphology appears dominated by an elongated structure, on which a secondary emission maximum can be recognized southwest of the pulsar.

### 2.2 Chandra

The Chandra X-ray Observatory pointed the supernova remnant SNR B0540-69.3 during the calibration phase of the High Resolution Camera (HRC; Murray et al. 1997) on 1999/08/31 for 20 ksec. The data, available in the Chandra public Archive (Obs.Id 132), have been used by Gotthelf & Wang (2000) for a morphological study of the remnant. This made it possible to resolve three different emission components: (i) a point-like source, identified with the pulsar PSRB0540-69, (ii) an elongated toroidal structure around the pulsar and (iii) a jet like feature apparently protruding from the pulsar. As remarked by Gotthelf & Wang (2000), when the different distance factor is taken into account, this structure is surprisingly similar to the ones observed by Chandra around the Crab pulsar.

The HRC data were retrieved from the Chandra Public Archive and reanalyzed using the CIAO software. The image, integrated over the whole HRC energy range (0.08-10 keV) and with the full resolution aspect solution (0.13 arcsec/px), is shown in Fig.1b, where the three different emission components described above are indicated.

### 2.3 VLT

Polarimetric observations of SNR 0540-69 were taken on April 12th 1999 during the commissioning of FORS1 on the VLT/UT1. The instrument was operated in the low-resolution mode, with a corresponding pixel size of 0.2 arcsec. Several images with different polarization angles have been obtained under average seeing conditions of 1.2 arcsec and combined as described in Wagner & Seifert (2000). The processed image, showing the degree of polarization of the optical flux in a gray-scale representation, is shown in Fig. 1c. The optical emission from the plerion turns out to be significantly polarized, as expected from synchrotron radiation and the polarization maps seem to follow a toroidal morphology. Moreover, a clear polarization maximum is also detected around the pulsar position.

### 3 The image superposition

We have used the X-ray/optical data to perform a comparative analysis of the remnant morphology. Of course, given the small spatial extent of the plerion (5 arcsec), such an analysis must rely on a very accurate image superposition. Since the optical and X-ray images are not directly comparable, a frame registration procedure as the one described in De Luca et al. (these proceedings) can not be applied. We have thus performed an absolute frame registration using the astrometric information attached to the image headers and the ratio between the image pixel sizes as their relative scale factor. Unfortunately, such an image superposition yielded residuals of more than 1 arcsec per coordinate, far too large for the study of a 5 arcsec object. This poor accuracy is obviously traceable to the limited positional accuracy of the reference stars used to define the absolute coordinates of the three data sets. In the case of the HST, the absolute astrometric accuracy of the Guide Star Catalog (GSC) ranges typically from 0.2” to 0.8” per coordinate (Russell et al. 1990). Similar values apply for the USNO-A02 catalog, which was used as reference for the VLT observations (Monet et al. 1998a,b), while the accuracy of the Chandra HRC aspect solution, depending both on the absolute reference grid and on possible errors in the processing of the event files, is expected to be of about 1 arcsec. A better superposition of the images can be obtained by registering the coordinates of the common sources in a relative reference frame. To this aim it is necessary:

1. to select the reference image;
2. to compute source centroids with a sufficient accuracy.

Of course, owing to its excellent angular resolution (pixel size 0.045”, FWHM of point sources of order 0.1”), the HST image was obviously chosen as reference and the centroids of possible reference stars were computed with an accuracy of 2-4 mas.

#### 3.1 Chandra vs. HST

The only source present in the Chandra image is the plerion itself. However, although unresolved in the Chandra image (HRC pixel size 0.132”, FWHM 0.5”), the pulsar is bright enough to stand well above the mean count
Figure 1: a) HST/WFPC2 image of SNR0540-69 obtained through the 555W filter. The image is the result of the combination of two 300s exposures. Point sources (other than the pulsar) has been removed by PSF subtraction; b) Chandra X-ray observation of the plerion SNR0540-69. The image, integrated over the energy range 0.08-10 keV, has been obtained with the High Resolution Camera (HRC); c) Polarization map of the plerion. The image, obtained by processing several VLT/FORS1 observations in polarimetric mode, shows the degree of polarization of the optical flux emitted by SNR0540-69. The pulsar is not visible in this map. North to the top, East to the left.

Figure 2: Superposition of the Chandra/HRC(left) and VLT/FORS1 (right) contour plots over the HST/WFPC2 image.

rate from the plerion (the peak flux is $3.75 \times 10^{-3}$ counts pixel$^{-1}$s$^{-1}$, to be compared with a mean flux of $(0.6 \pm 0.2) \times 10^{-3}$ counts pixel$^{-1}$s$^{-1}$ in an annulus centered on the maximum of emission with inner radius 0.6” and width 1”). This allows the determination of the pulsar centroid through 2-D gaussian fitting of its intensity profile, yielding a conservative uncertainty of 1 pixel. We then registered the two images by superposing the pulsar centroids in the HST PC reference frame. We used as plate scale the ratio between the pixel sizes, the possible error on this value being not significant when propagated over the 2.5” radius of the plerion. To account for image rotation, we used the roll angles of the telescopes, whose known accuracies (0.04 deg for HST (FGS instrument handbook) and 0.3 deg for Chandra (McDowell 2000[3]) are vastly sufficient not to introduce significant errors, at least in the small region we are studying. The result is shown in Fig 2a where we have superimposed the X-ray isophotes to the HST star-free image.

3.2 VLT vs. HST

Since the VLT polarization image contains no resolved point sources, we computed the superposition parameters using a total flux image, pertaining to the same set of FORS1 observations in polarimetric mode (see Wagner & Seifert, 2000[3]), with the same pointing, orientation and plate scale. In this complementary image we could identify 11 reference stars in common with HST image. We then applied the standard astrometric procedure using the centroids of the stars to compute the 4 parameters (i.e. X and Y shifts, plate scale and rotation angle) needed to overlay the frames. The mean residuals on the reference stars positions turned out to be of order 50 mas, a value mainly driven by the poor seeing of the VLT image, however largely sufficient for our
purposes. This transformation was then applied to our degree-of-polarization FORS image and Fig 2b gives the polarization isophotes superimposed the HST images. The registration of the 3 images in a common (the HST PC one) reference frame with an accuracy better than 0.2" allows now a careful analysis of the morphological correlations.

4 The Results

The HST and Chandra data outline a very similar elongated pattern featuring a shallow maximum in the SW. Also the faint jet, marginally visible in the Chandra image, does have an optical counterpart. The polarization image, on the contrary, has a structure of its own, clearly connected with the edges of the elongated disk-like plerion, where the maximum of the polarization is detected. A secondary maximum in the polarization contours is seen near the pulsar but it does not coincide with it. This is a good example of the importance of accurate image superposition in the understanding of extended objects. Proving or disproving correlations at subarcsec level between different wavelength images is a challenge that can be met.

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