Optical and X-ray emission from PSR 0540-69.3 and its pulsar-wind nebula

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Abstract

HST/WFPC2 has been used to observe PSR 0540 69.3 and its pulsar-wind nebula (PWN) on several occasions. The most recent data are, however, contaminated by Charge Transfer Efficiency (CTE) problems, which can lead to high uncertainties in flux and proper motion estimates. We have used a wavelet filtering analysis of the images to reconstruct the structure of the PWN. This reveals that the structure shows remarkable time variability. The same is seen in X-rays after correction for the data pile-up effect. Different physical scenarios to explain these results are discussed.

An overview image of PSR 0540-69.3

PSR 0540-69.3 (further simply 0540) and its PWN are remnants of a powerful explosion that occurred roughly 1000 years ago in the Large Magelanic Clouds (LMC). The pulsar is often called the Crab twin. However, there are some differences between them.

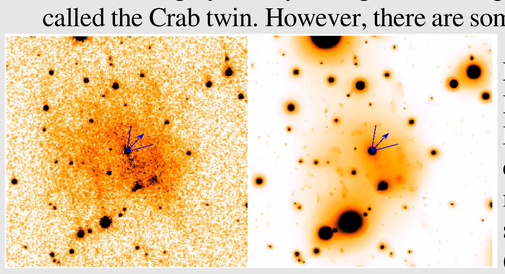

Fig. 1. Observations. An image of the field around PSR 0540-69.3 obtained in the F555W band with HST/WFPC2 on November 2005. The pulsar was exposed on the PC chip and its proper motion is marked by an arrow. The diffuse emission surrounding the pulsar is the pulsar wind nebula (PWN). (*left*) Original image where only basic data reduction has been applied. Note that the CTE problem can be seen clearly. (*right*) Wavelet filtered image of PSR 0540-69.3 using an algorithm developed by Jean-Luc Starck and his team (for more details, see Starck & Murtagh 2006).

Evolution of PWN emission

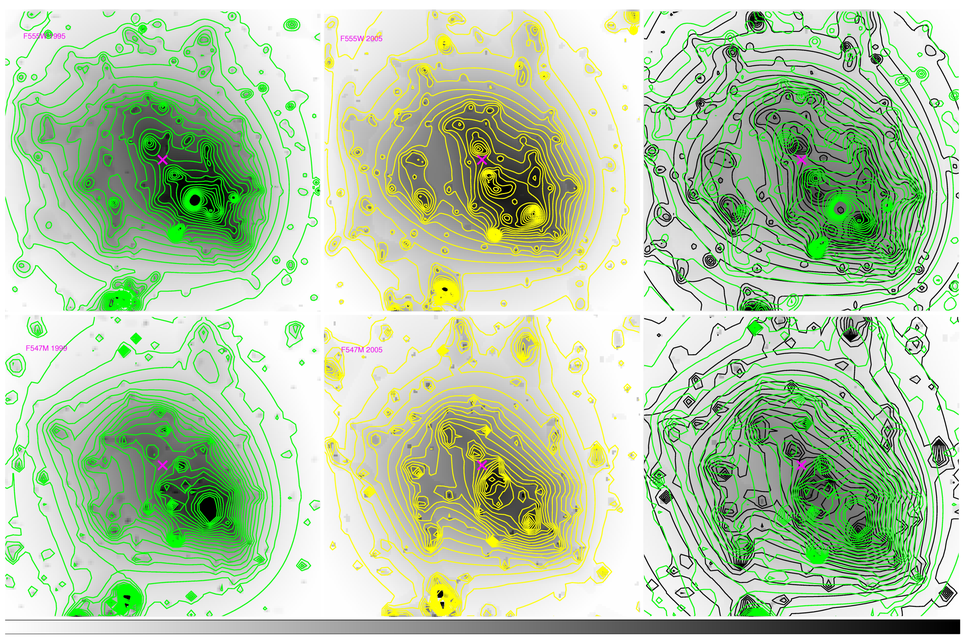

Fig. 2. Wavelet filtered images of the field around PSR 0540-69.3 obtained with HST/WFPC2. The pulsar and other stars were subtracted off to better show the PWN. All images were aligned to the 2005 epoch (North is up and East is to the left). The pulsar position is marked by a green cross. (*Upper left:*) Image obtained in the F555W band in 1995. The green contours show the flux levels. (*Upper middle:*) The image obtained in the F555W band in 2005. The yellow contours show flux levels. (*Upper right:*) Image obtained in the F555W band in 2005. The green contours show the flux levels for the 1995 epoch, while the black contours represent the flux levels for the 2005 epoch. (*Lower left:*) Image obtained in the F547M band in 1999. The green contours show the flux levels. (*Lower middle:*) Image obtained in the F547M band in 2005. The yellow contours show the flux levels. (Lower right:) Image obtained in the F547M band in 2005. The green contours show the flux levels for the 1995 epoch, while black contours represent the isophotal flux levels for the 2005 epoch. Note that the bright area to the right of the pulsar position shows different behaviour compared to for the wider F555W filter.

Crab and PSR 0540-69.3

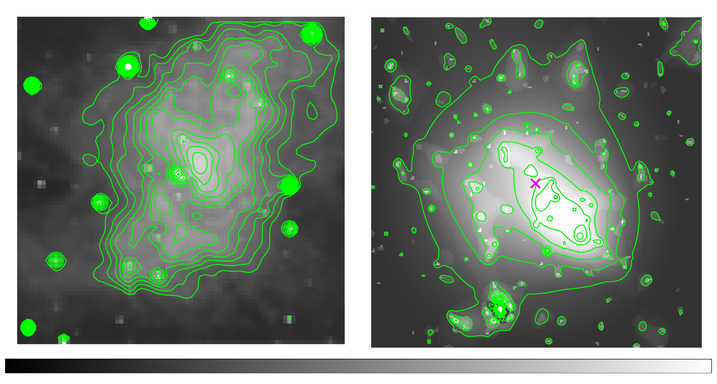

Fig. 3. (*Left:*) An image simulating a Crab system distance of 51 kpc. The original image of the Crab pulsar and its PWN obtained with VLT/FORS1 in the B band. (*Right:*) A wavelet filtered image of the field around PSR 0540-69.3 obtained with HST/WFPC2/F547M. The pulsar and other stars were subtracted off to better show the PWN. All images have North up and East to the left. The pulsar position is marked by a pink cross.

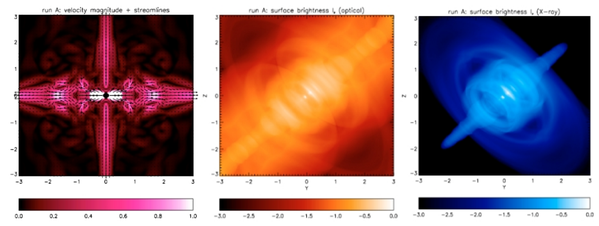

Fig. 4: Models by Del Zanna et al. (2006): *Left:* velocity maps (in units of *c*) and streamlines. *Middle:* optical (5364 Å) surface brightness I_ν, in logarithmic scale and normalized to the maximum value. *Right:* same as middle but for X-rays at 1 keV. The PWN axis of symmetry is 48 degrees with respect to North. Distances from the central pulsar are shown on the axes, and expressed in light years (ly). For a distance of d=2 kpc (i.e., the distance to the Crab), 1 ly=32´´.

PSR 0540-69.3 and its PWN in optic and X-rays

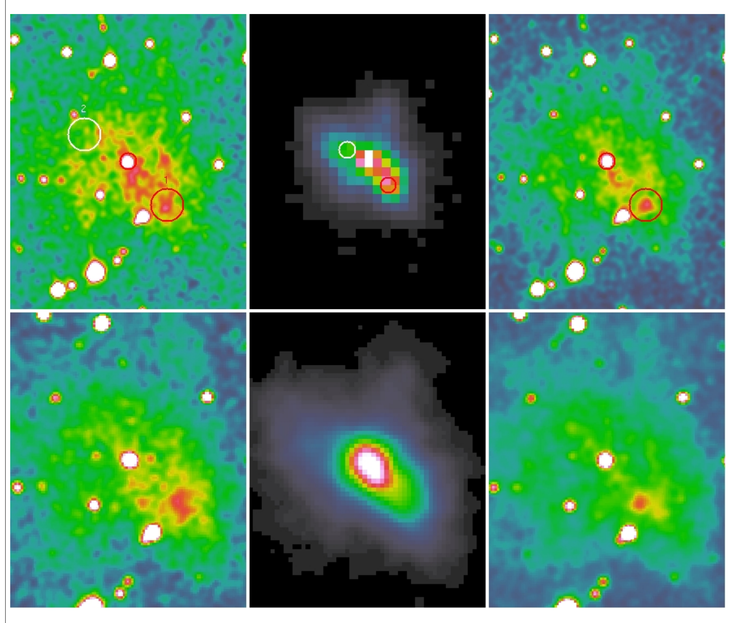

Fig. 5. PSR0540-69.3 and its PWN in the optical and X-rays. ***(Upper left):*** HST/WFPC2 image in combination with the F547M filter obtained on November 2005. The red circle of smaller aperture marks the 0540 pulsar, while the red circle of larger aperture, 0.5", marks the position of the bright blob, the nature of which we try to establish. The white circle includes an area area of the same size as the blob, but is placed on the opposite side of the pulsar. ***(Upper middle):*** An X-ray image of 0540 obtained with Chandra/ACIS-S in the range 0.5 – 8 keV on February 2006. The white and red circles correspond the same areas and positions as above. ***(Upper right):*** HST/WFPC2 image in combination with the F555W filter obtained on November 2005. ***(Lower left):*** HST/WFPC2/F547M image obtained on October 1999 (Morse et al. 2003). ***(Lower middle):*** An X-ray image of 0540 obtained with Chandra/HRC-I in the range 0.1 – 10 keV on August 1999. ***(Lower right):*** HST/WFPC2/F555W image obtained on October 1995 (Caraveo et al. 2000). Note that the blob is present on all the images.

Multiwavelength spectra of the selected areas

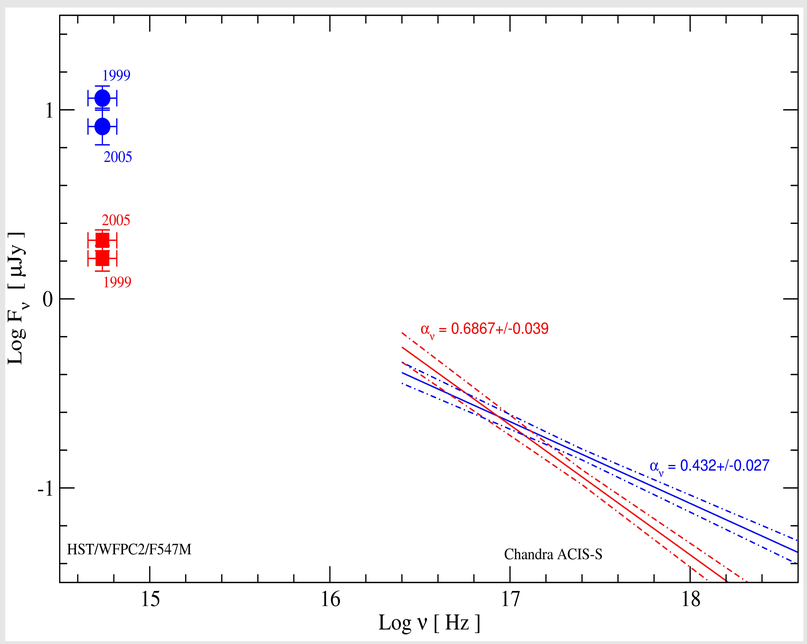

Fig. 6: Multiwavelength spectra of the blob or "Area 1" (blue lines and symbols) and "Area 2" (red lines and symbols). (For the notations and positions see the Fig. 5 upper left panel.) Note that the X-ray spectra are non-thermal and that a multiple power laws are needed if one tries to connect the optical and X-ray spectral regions.

The Crab PSR/PWN and PSR 0540-69.3 with its PWN show many similarities:

- Both have jets and and a torus
- Both show streaming motions in the plane of the torus. Most clearly seen for the PWN of PSR 0540-69.3 in Fig. 3 and Fig. 5.
- The pulsars have similar spin down ages (roughly 1,000 years).

However, some important differences:

- The PSR 0540-69.3 PWN is strong in X-rays and weak in optical with respect to the Crab PWN.
- The PWN of PSR 0540-69.3 shows an asymmetrical flux distribution even in the torus plane. We have selected "Area 1" which appears to have a shift in position compared to the pulsar position, which requires motion with half the speed of light.
- "Area 1" has some flux variations in the optical and has a non-thermal spectrum in X-rays.

We are currently working on a multiwavelength comparison of the 0540 and Crab systems in terms of the evolution of their PWNe.

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