High resolution CO observations towards the Bright Eastern Knot of the SNR Puppis A

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ABSTRACT

Aims. This paper reports molecular observations towards the Bright Eastern Knot (BEK) in the SNR Puppis A, a feature where radio and X-ray studies suggest that the shock front is interacting with a dense molecular clump.

Methods. We performed high-resolution millimetric observations towards the BEK of Puppis A using the SEST telescope in the ^{12}CO J=1–0 and 2–1 lines (beams of 45″ and 23″ respectively). More extended, lower angular resolution ^{12}CO J=1–0 observations taken from NANTEN archival data were also analyzed to obtain a complete picture.

Results. In the velocity range near 16 km s^{-1}, the Puppis A systemic velocity, our study revealed two important properties: (i) no dense molecular gas is detected immediately adjacent to the eastern border of the BEK and (ii) the molecular clump detected very close to the radiocontinuum maximum is probably located in the foreground along the line of sight and has not yet been reached by the SNR shock front. We propose two possible scenarios to explain the absence of molecular emission eastwards of the BEK border of Puppis A. Either the shock front has completely engulfed and destroyed a molecular clump or the shock front is interacting with part of a larger cloud and we do not detect CO emission immediately beyond it because the molecules have been dissociated by photodissociation and by reactions with photoionized material due to the radiative precursor.

Key words. ISM: molecules — ISM: clouds — ISM: supernova remnants — ISM: individual objects: Puppis A

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1. Introduction

Shock waves generated by supernova remnants (SNRs) can accelerate, compress, heat, fragment or even destroy surrounding interstellar clouds. Strong shock-cloud interactions can enhance or reduce abundances of different molecular species with respect to quiescent cloud conditions. Observations of molecular gas associated with SNRs provide information essential to understand the physics and chemistry involved in these processes.

Puppis A is a Galactic SNR that has been extensively studied in the whole electromagnetic spectrum. In radio continuum, Puppis A appears as an asymmetric clumpy shell with the brightest section along the eastern border (Figure 1a) (Castelletti et al. 2006 and references therein) presenting a good correlation with soft X-ray emission (Petre et al. 1982; Aschenbach 1988). The X-ray emission includes both extended features and compact knots, the most conspicuous of which is the bright eastern knot (BEK; Petre et al. 1982) that coincides with an indentation in the shock front of the SNR as seen in radio. Such morphology suggests an interaction between the SNR and a dense interstellar clump. Hwang et al. (2005) presented ACIS *Chandra* X-ray images and spectral data of the region around the BEK. They conclude that a cloud-shock interaction in a relatively late phase of evolution is taking place near the BEK, while closer to the forward shock in the BEK region, the SNR has recently interacted with a more dense and extended obstacle.

CO studies of the interstellar medium surrounding Puppis A performed by Dubner & Arnal (1988) with angular resolution of $8'.7$, revealed the existence of a chain of molecular clouds concentrated along the E and NE periphery of the remnant. Studies in infrared wavelengths of Puppis A also suggest the existence of interstellar clouds along the eastern border of the SNR (Arendt et al. 1991). From the atomic and molecular studies (Dubner & Arnal 1988; Reynoso et al. 1995), a systemic velocity of $v_{LSR} \sim +16$ km s^{-1} and a kinematical distance of 2.2 ± 0.3 kpc were derived for Puppis A, a distance later confirmed by Reynoso et al. (2003) based on interferometric, high resolution HI data in the direction of the associated radio quiet neutron star RX J0822-4300 located within the remnant.

In this work, we present high resolution SEST observations performed in the ^{12}CO J=1–0 and J=2–1 lines towards the BEK region, complemented with lower resolution molecular mapping of a larger region including the BEK based on archival data of the NANTEN telescope. The posibility of interaction between the SNR shock front and the surrounding gas is locally investigated in an attempt to understand the origin of the enhancement observed both in X-ray and radio continuum emissions.

2. Observations

The high-resolution ^{12}CO data were acquired during March 9 to 11, 2000 with the 15 m Swedish-ESO Submillimetre Telescope (SEST) that operated in La Silla (Chile). The angular resolutions of this telescope were $45''$ and $23''$ for the ^{12}CO J=1–0 and J=2–1 transitions respectively. An Acousto-Optical spectrometer was used as back end, consisting of a narrow band high-resolution (HRS) spectrometer with 1000 channels, bandwidth 80 MHz, and channel separation 41.7 kHz (corresponding to 0.108 km s^{-1} for the ^{12}CO J=1–0 and 0.054 km s^{-1} for the ^{12}CO J=2–1). The observed velocity ranges were [−40 km

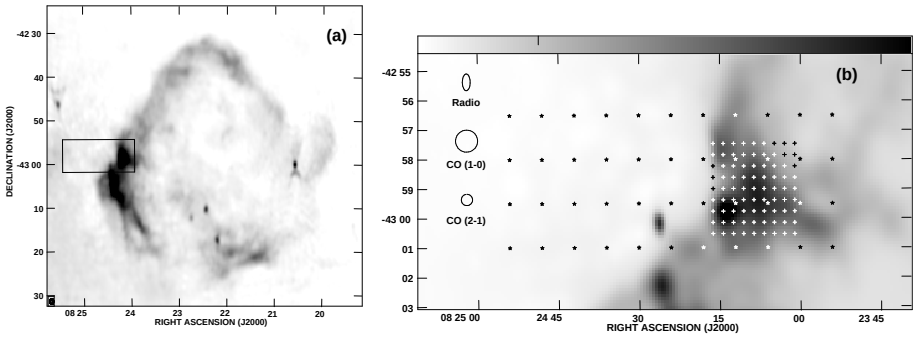

Fig. 1. (a) Radio continuum image of Puppis A at 1425 MHz (from Castelletti et al. 2006). The rectangle shows the region surveyed with SEST in the ^{12}CO J=1–0 and J=2–1 lines. **(b)** Observed region in detail. The pointings are indicated with crosses and stars. The respective beams are shown to the left.

s^{-1},+60 km s^{-1}] and [−10 km s^{-1},+40 km s^{-1}] for the ^{12}CO J=1–0 and J=2–1 transitions respectively.

Figure 1a displays the SNR Puppis A as observed in radio continuum at 1420 MHz. The rectangle shows the region surveyed with the SEST telescope. In this region the ^{12}CO J=1–0 and 2–1 transitions were observed in 81 pointings with a grid spacing of 23″. The pointings are shown as crosses in the enlargement included in Figure 1b. This region covers a square of approximately 3′.35 × 3′.35 centered at RA = $8^{\rm h}24^{\rm m}8.5^{\rm s}$, dec = −42°59′00″ (J2000). The whole field was observed twice with an integration time of 105 sec per position each time. Beyond this square, 44 additional pointings, also shown in Figure 1b as stars, were observed in both CO lines with a grid spacing of 90″, except for one pointing (at RA = $8^{\rm h}23^{\rm m}54^{\rm s}$ and dec = −43°01′00″) that was observed only at the ^{12}CO J=1–0 transition.

All spectra were Hanning smoothed to improve the signal-to-noise ratio. The rms noises in main-beam brightness temperature are $\sigma_{1-0} \sim 0.15$ K and $\sigma_{2-1} \sim 0.30$ K for the 81 pointings observed over the BEK and $\sigma_{1-0} \sim 0.20$ K and $\sigma_{2-1} \sim 0.15$ K for the 44 additional pointings for the ^{12}CO J=1–0 and 2–1 transitions respectively. The spectra were processed using the XSpec software package developed at the Onsala Space Observatory. Images were produced using the AIPS package.

Additionally we used ^{12}CO J=1–0 data acquired with the 4 m radiotelescope NANTEN that operated in Las Campanas Observatory (Chile), to explore a more extended region along the eastern border of Puppis A. These data are part of the the study in the direction of the Gum Nebula carried out by Yamaguchi et al. (1999). The angular resolution of the telescope is 2′.6 and the grid sampling is 8′ in l and b. The total bandwidth and the effective spectral resolution were 40 MHz and 35 kHz respectively, corresponding to a velocity coverage of 100 km s^{-1} and a velocity resolution of ∼ 0.1 km s^{-1}. At this velocity resolution the typical rms noise was ∼ 0.7 K (Yamaguchi et al. 1999).

3. Results

Figure 2 shows ^{12}CO J=1–0 and J=2–1 spectra in the whole observed velocity range obtained from the average of the 81 pointings towards the BEK of Puppis A. Two velocity components are present, near 3 and 16 km s^{-1}. The narrow 3 km s^{-1} component probably