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POSTER PAPER

SNR Puppis A: molecular gas possibly associated with the brightest X-ray feature

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Abstract. We analyze the ^{12}CO emission towards the brightest X-ray knot in the supernova remnant (SNR) Puppis A. The observations were performed with the SEST telescope in the ^{12}CO J=1–0 and 2–1 lines (beams of 45″ and 23″ respectively). We discovered a compact molecular clump near the radio and X-ray maxima and calculated its physical parameters. From the comparison with *Chandra* X-ray data we conclude that this molecular clump lies in front of Puppis A along the line of sight. The possibilities of a recent interaction between the SNR and the molecular gas are analyzed.

Resumen. Se analiza la emisión del ^{12}CO en la región más brillante de emisión de rayos X del remanente de supernova (RSN) Puppis A. Las observaciones fueron realizadas en las transiciones J=1–0 y 2–1 con el telescopio sueco SEST con resoluciones angulares de 45″ y 23″ respectivamente para ambas líneas. Se descubrió la presencia de un grumo molecular compacto cerca del máximo en radio y en rayos X. Se calculan los parámetros físicos de dicha componente molecular. De la comparación con datos en rayos X del satélite *Chandra* se concluye que dicho grumo molecular se encuentra por delante del RSN Puppis A a lo largo de la visual. Se analiza la posibilidad de una reciente interacción entre el frente de choque del RSN y el gas molecular.

1. Introduction

The galactic SNR Puppis A has been extensively studied in the whole electromagnetic spectrum. In the radio continuum emission, this SNR presents an asymmetric clumpy shell morphology with the brightest section along the eastern border (Castelletti et al. 2006, and references therein). The radio continuum has a good correlation with soft X-ray emission (Petre et al. 1982), which shows extended features and compact knots. The most conspicuous X-ray structure is the bright eastern knot (BEK; Petre et al. 1982) that coincides with an indentation in the shock front of Puppis A as seen in radio continuum, suggestive of an interaction between the SNR and a dense interstellar cloud. Hwang et al. (2005) presented ACIS *Chandra* X-ray images and spectral data of the region around the BEK. They conclude that a cloud disruption process in a relatively late phase of evolution is taking place near the BEK, while closer to the for-

ward shock in the BEK boundary, the SNR has recently interacted with a dense obstacle that extends eastwards.
In this work we present high resolution observations performed in the ^{12}CO J=1–0 and J=2–1 lines towards the BEK region. We report on the presence of a compact molecular clump located slightly to the south of the compact X-ray–bright region and to the east of the X-ray "bar" structure discovered by Hwang et al. (2005). We study the possibilities of interaction between the SNR shock front and the molecular clump.

2. Observations

The ^{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 and spectral resolutions were 45″ and 23″ and 0.108 km s^{-1} and 0.054 km s^{-1} for the J=1–0 and 2–1 transitions, respectively. A square of approximately $3'.35 \times 3'.35$ centered at RA = $8^{\rm h}\ 24^{\rm m}\ 8.5^{\rm s}$, dec = $-42°\ 59'\ 00''$ (J2000), around the BEK of Puppis A, was observed through 81 pointings with a grid spacing of 23″.

3. Results

Figure 1 shows a ^{12}CO J=1–0 spectrum 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 3 km s^{-1} component corresponds to foreground gas associated with the Gum Nebula (Yamaguchi et al. 1999). We are interested in the component near 16 km s^{-1}, the systemic velocity attributed to Puppis A (Reynoso et al. 2003).

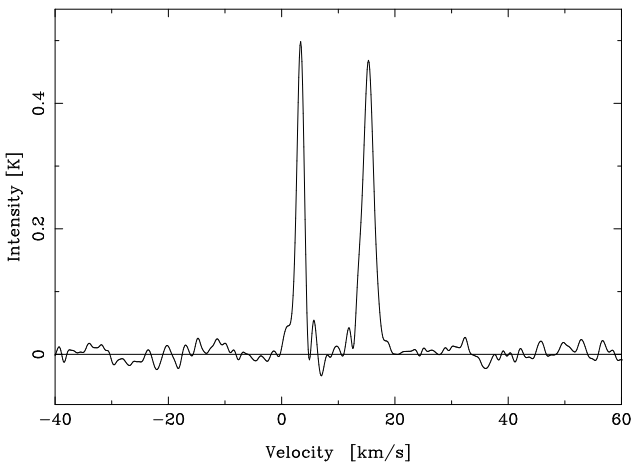

Figure 1. ^{12}CO J=1–0 average profile from the 81 observed spectra towards the BEK of Puppis A.

Taking into account that the ^{12}CO J=2–1 line is optically thinner and surveys denser gas than the J=1–0 line (e.g. Sakamoto et al. 1994), we will use it to

compare with the radio continuum and X-ray emissions. Figure 2 displays, the ^{12}CO J=2–1 emission integrated between 13.5 and 17.5 km s^{-1} superimposed over the radio continuum emission (*left*) and over the X-ray emission (*right*).

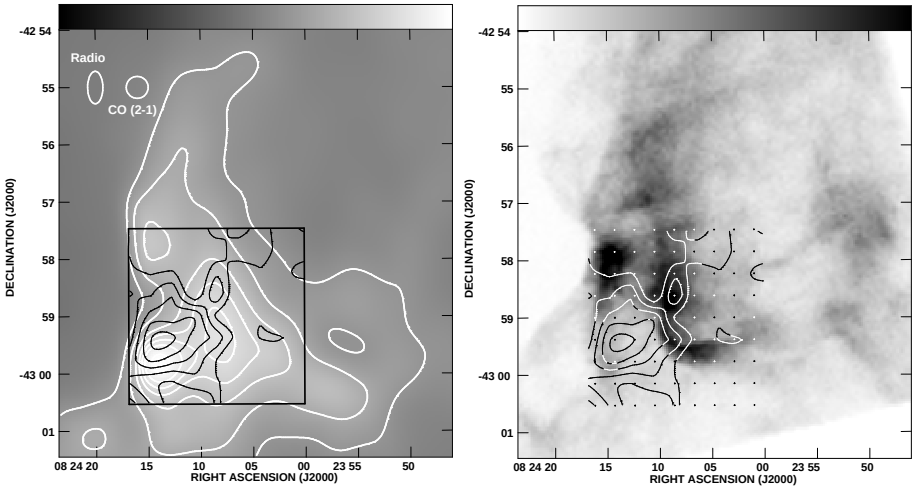

Figure 2. The ^{12}CO J=2–1 emission integrated between 13.5 and 17.5 km s^{-1} is presented in black contours with levels: 1.2, 2, 2.5, 3, 3.5, 4 K km s^{-1}. They are superimposed over the radio continuum emission (*left*, obtained from Castelletti et al. 2006) and over the X-ray emission (*right*, obtained from the *Chandra* SNR Catalog). The points in the right image represent the pointings for the molecular observations. The beams of the radio continuum and the ^{12}CO J=2–1 emissions are shown at the left image. The angular resolution of the *Chandra* X-ray image is $0''.5$.

Figure 2 shows that the maximum of the molecular clump lies spatially very close to the maximum of the radio continuum, but it does not overlap it. The angular separation between them is $\sim 25''$. On the other hand, the anticorrelation with the X-ray emission is remarkable.
Assuming for Puppis A a distance of 2.2 kpc (Reynoso et al. 2003), the linear diameter of the molecular clump is 0.3 pc, the mass M $\simeq$ 9.5 M$_\odot$ and its volume density $n \simeq 1.7 \times 10^4$ cm^{-3}.

4. Discussion

In the velocity range around 16 km s^{-1} we observe a conspicuous molecular clump lying very close to but not exactly coincident with the maximum of the radio continuum emission of the BEK. We used the ratio between the integrated lines ($R_{2-1/1-0} = \int T_{\rm CO2-1}\, dv \,/ \int T_{\rm CO1-0}\, dv$) to trace shocked gas. Large values in $R_{2-1/1-0}$ are expected to be found in shocked molecular clouds, as observed in the clouds related with the SNRs G349.7+0.2 ($R_{2-1/1-0} \sim 1.5$; Dubner et al. 2004), W44 ($R_{2-1/1-0} \sim 1.3$), IC443 ($R_{2-1/1-0} \sim 1.3{-}4$) and HB 21 ($R_{2-1/1-0} \sim 1.6{-}2.3$) (Seta et al. 1996, Koo et al. 2001). We calculated this ratio in the velocity range from 13.5 to 17.5 km s^{-1}, obtaining $R_{2-1/1-0} \sim 0.6$.

Such a low value suggests that we are observing quiescent rather than shocked gas.
Figure 2 (*right*) shows that the molecular clump is surrounded by regions of enhanced X-ray emission. This anticorrelation can be interpreted in a scenario where the cold molecular clump is in front of the SNR along the line of sight absorbing the X-ray emission, as observed, for example, in the SNR CTB 109 (Sasaki et al. 2006). Probably the SNR shock front is recently reaching the clump.

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