

THE SERPENS STAR-FORMING REGION IN HCO^+ , HCN , AND N_2H^+

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ABSTRACT

This poster presents single-dish and aperture-synthesis observations of the $J=1-0$ ($\lambda \approx 3$ mm) transitions of HCO^+ , HCN , and N_2H^+ towards the Serpens star-forming region. Jets driven by young stars affect the structure and the chemistry of their surrounding cloud, and this work aims to assess the extent to which the emission of these three molecular lines is dominated by such processes. In Serpens I find that N_2H^+ 1–0 traces the total amount of material, except in two regions slightly ahead of shocks. In contrast, the HCO^+ and, especially, HCN emission is dominated by regions impacted by outflows. One previously unknown, strongly shocked region is located ~ 0.1 pc northwest of the young stellar object SMM 4. There is a marked spatial offset between the peaks in the HCN and the N_2H^+ emission associated with shocked regions. I construct a simple, qualitative chemical model where the N_2H^+ emission increases in the magnetic precursor of a C-type shock, while N_2H^+ is destroyed deeper in the shock as the neutrals heat up and species like HCN and water are released from icy grain mantles. I conclude that N_2H^+ is a reliable tracer of cloud material, and that unresolved observations of HCO^+ and HCN will be dominated by material impacted by outflows.

Key words: ISM: molecules – ISM: clouds – ISM: jets and outflows – stars: formation

1. INTRODUCTION

The formation of stars is accompanied by energetic activity such as jets and outflows. This can affect the structure and the chemical composition of the surrounding cloud, possibly influencing its continued star formation. A relevant question therefore is, to what the extent the emission of commonly used tracers of dense gas reflects the energetics of star formation rather than the underlying structure of the cloud. This is especially interesting for

unresolved observations of clouds and cloud complexes, at large distances in our Galaxy or in other galaxies (e.g., Aalto et al. 1995; Helfer & Blitz 1997; Wild & Eckart 2000; Kuno et al. 2002). This poster contribution investigates the emission lines of three molecules (HCO^+ , HCN , and N_2H^+) in the Serpens star-forming region, with the specific question in mind of the relation between the emission and activity of young stars.

The Serpens star-forming region is ideally suited for the stated aim. It is relatively nearby at $\sim 310 \pm 40$ pc (de Lara et al. 1991) and harbors several deeply embedded protostars as well as apparently starless dust condensations (Casali et al. 1993; Davis et al. 1999). The molecular cloud consists of two subcondensations, northeast (NE) and southwest (SW), each of which are broken up into numerous subclumps and filaments. Many outflows emanate from the Serpens region (Davis et al. 1999), apparently driven by the embedded protostars. The high density of young stellar objects (YSOs) and the complex structure of the region precludes identification of the driving sources of many of these flows. It is likely that the course of some of the flows are altered by collisions with dense cloud material, further confusing the picture.

2. SINGLE-DISH OBSERVATIONS

In this poster I present single-dish observations of the $J=1-0$ lines of HCO^+ , HCN , and N_2H^+ obtained with the Kitt Peak 12-meter (KP12m) telescope¹; aperture-synthesis observations are discussed in § 3. The KP12m maps cover a $420'' \times 420''$ area encompassing the NE and SW condensations (Fig. 1). The beam size of the telescope is $60''$. The N_2H^+ emission traces the NE and SW condensations equally, resembling the SCUBA 850 μm emission that traces cold dust (Davis et al. 1999). The HCN and HCO^+ emission is dominated by the SE con-

¹ The 12m Telescope is a facility of the National Science Foundation currently operated by the University of Arizona Steward Observatory under a loan agreement with the National Radio Astronomy Observatory.

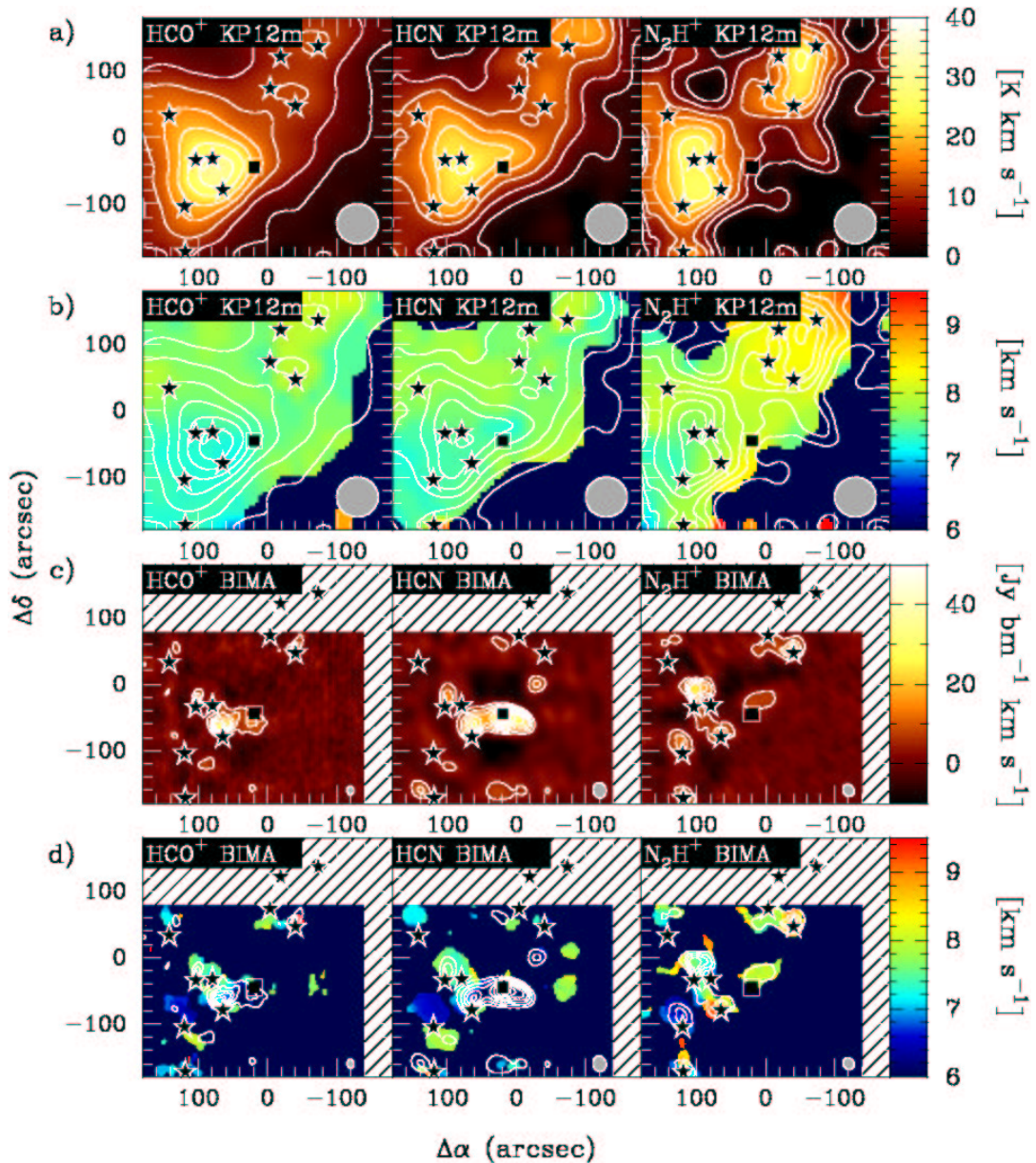


Figure 1. (a) KP12m maps of integrated intensity. (b) KP12m maps of the velocity centroid, with contours of integrated intensity superposed. (c) BIMA maps of integrated intensity. (d) BIMA maps of velocity centroid, with contours of integrated intensity superposed. The star symbols mark the locations of the YSOs; the square marks the location of the ‘shock front’. The beam sizes are represented by the grey ellipses in the lower right-hand corner of each panel. The BIMA maps only cover the SE region.

densation, where most of the YSOs are located and where most of the outflows originate. This indicates that N_2H^+ reliably reflects the distribution of the cloud material, while HCO^+ and HCN emission is enhanced near outflows. The velocity centroids of the emission lines show an east–west gradient of 2.5 km s^{-1} , most clearly seen in

N_2H^+ , indicating solid-body rotation of the entire cloud, as reported by Olmi & Testi (2002).

3. INTERFEROMETER OBSERVATIONS

To investigate if the close match between N_2H^+ and dust continuum, and the association of HCN and HCO^+ with

outflows holds on smaller scales, aperture-synthesis images are shown in Fig. 1. These interferometer observations were obtained at the BIMA² millimeter array, at resolutions of 12''–21''. Mosaics of 13 array pointings cover a 320'' × 260'' region around the SE condensation; the NW condensation has already been studied at high angular resolution by Williams & Myers (2000).

There exists an almost one-to-one correspondence between the peaks in the N₂H⁺ BIMA map and the 850 μm emission. The only exceptions are two N₂H⁺ peaks, one north of SMM 3 and one ~ 60'' northeast of SMM 4. As discussed below, both locations probably are shocks. The association of HCO⁺ and HCN with outflows become very clear at the small scales traced by BIMA. Emission is found north of SMM 3 and SMM 4, along the directions of the jets of these sources. An emission peak, especially prominent in HCN, is located ~ 60'' northwest of SMM 4. The velocity-centroid of the emission around this peak stands out as extremely blue, at > 2 km s⁻¹ from systemic. The likely interpretation of this peak is a ‘shock front’ of a jet impacting a cloud fragment, although no obvious driving source is present. Possible candidates are a jet from (the vicinity of) SMM 1 or from (the vicinity of) SMM 4. In the latter case it may be argued that at the ‘shock front’ this jet deflects off a cloud condensation and later connects up with the outflow lobe marked ‘Wr’ in the CO map of Davis et al. (1999).

Interferometers are only sensitive to small-scale emission, and filter out emission on spatial frequencies below the smallest antenna separation. Compared to the KP12m data that do cover these scales, the BIMA data contain ~ 30% of the flux. While this is only a small fraction of the emission, the similarity in distribution of the emission in the KP12m and BIMA maps suggests that outflows contribute significantly to the total emission of HCO⁺ and HCN. Hogerheijde (in prep.) analyses the emission and the abundances quantitatively.

4. A SHOCK MODEL FOR HCN AND N₂H⁺

Close inspection of the HCN and N₂H⁺ BIMA maps near the tip of SMM 3’s jet and near the ‘shock front’ reveals that N₂H⁺ peaks ~ 20'' ahead of HCN. The structure of C-type shocks (Draine & McKee 1993) may offer an explanation for this offset. C-type shocks have a magnetic precursor where charged particles accelerate and warm up ahead of neutral particles, enhancing the inten-

sity of N₂H⁺ emission lines. Deeper into the shock the neutrals accelerate and warm up. If the pre-shock density is sufficiently high, dust grains will be predominately neutral, and it is in this region that they will release the contents of their ice mantles. These include HCN, as seen toward other outflow (Lahuis & van Dishoeck 2000; Hogerheijde 2001), water, and CO. The latter two effectively destroy N₂H⁺ through chemical reactions, causing the N₂H⁺ emission to disappear where the HCN peaks. A quantitative model has to include time scales, length scales, and an adequate chemical network, and is discussed in Hogerheijde (in prep.). High-angular resolution observations with, e.g., the Smithsonian Millimeter Array, can help test this model.

5. CONCLUSIONS

Aperture-synthesis and single-dish maps of the Serpens star-forming region show that N₂H⁺ accurately traces the distribution of the cloud material, while HCO⁺ and especially HCN probe material that is shocked by outflows. Unresolved observations of the latter two species therefore would reflect star-forming activity rather than cloud column density. A difference map of N₂H⁺ and HCN may be a useful tool to identify regions in cloud complexes that are actively star forming, as opposed to dense but quiescent. On small scales, however, N₂H⁺ emission may be enhanced in magnetic precursors of C-type shocks, but appears effectively destroyed in the warmest regions of shocks where HCN peaks.

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² The BIMA array is operated by the Universities of California (Berkeley), Illinois, and Maryland, with support from the National Science Foundation.