STUDIES OF INTERSTELLAR VIBRATIONALLY-EXCITED MOLECULES

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Several molecules thus far have been detected in the ISM in vibrationally-excited states, including H_2, SiO, HC_3N, and CH_3CN (e.g. Goldsmith, et al. 1985). In order for vibrational-excitation to occur, these species must be present in unusually hot and dense gas and/or where strong infrared radiation is present. Vibrationally-excited molecules thus serve as useful probes of the physical conditions near star-forming regions and in the circumstellar envelopes of late-type stars. They also trace material where "shock" or "high temperature" chemistry may be occurring (i.e., gas that is sufficiently hot such that activation energy barriers in chemical reactions are overcome, allowing otherwise inaccessible reaction pathways to take place). Even more fundamentally, molecules in an excited vibrational state are subject to a different reaction potential surface than in the ground state, and unique reaction pathways may become available as vibrational-excitation occurs.

Unfortunately, past studies of vibrationally-excited molecules in the ISM have been somewhat incomplete. Either they have involved measurements of rotation vibration transitions, done in the IR where sensitivity is limited; else, they have been concerned with microwave/mm-wave observations of rotational lines of relatively low-excitation bending modes of large polyatomic molecules such as CH_3CN. Such molecules are not very abundant and thus lines originining in excited states are weak and difficult to study.

In order to do a more thorough investigation of vibrational excitation in the ISM, we have done studies of several mm-wave transitions originating in excited vibrational modes of HCN, an abundant interstellar molecule. Vibrationally-excited HCN was recently detected toward Orion-KL and IRC+10216, using the NRAO 12 meter antenna (Ziurys and Turner 1986). The J=3-2 rotational transitions were detected in the molecule's lowest vibrational state, the bending mode, which is split into two separate levels, $(0,1^{1c},0)$ and $(0,1^{1d},0)$ states, due to ℓ-type doubling. This bending mode lies 1025K above ground state, with an Einstein A coefficient of 3.6 s^{-1}. The J=3-2 line of $(0,2^0,0)$ mode of HCN, which lies 2050K above ground state, was also observed toward IRC+10216, and subsequently in Orion-KL (Turner and Ziurys, private communication). Toward KL, these initial measurements suggested that vibrationally-excited HCN arises from the "hot core", being excited by 14 μm IR flux from IRc2 with a vibrational temperature of $T_{vib} \sim 150$-200K. In addition, these observations implied that the column density of HCN in this region was $>10^{18}$ cm^{-2}, thus making the abundance of HCN greatest in the "hot core" as compared with all other gas components in KL. Analysis of the vibrationally-excited HCN lines toward IRC+10216 indicated an r^{-2} spatial dependence of this species' abundance in the envelope, inconsistent with the "freeze-out" model of circumstellar chemistry.

Further measurements of vibrationally-excited HCN have been done using the FCRAO 14 meter telescope, which include the observations of the (0,1,0) and (0,2,0) modes towards Orion-KL, via their J=3-2 transitions at 265-267 GHz (Ziurys, Snell, and Erickson 1986). The spectrum of the J=3-2 line in Orion of the $(0,1^{1d},0)$ mode of HCN, taken with the FCRAO telescope, is shown in Figure 1. A map was subsequently made of this line, shown in Figure 2, which indicates that emission from vibrationally-excited HCN arises from a region probably smaller than the FCRAO telescope's 20 arcsec beam. Such a distribution is consistent with the species' emission arising from the "hot core". As the figure shows, however, there might be some E-W elongation of vibrationally-excited HCN. A map of the ground state J=3-2 HCN line was done as well with the FCRAO 14 meter, and is also shown in Figure 2. As evident from the map, the ground state line shows a completely different spatial distribution from that of the vibrationally-excited emission, being far more extended and showing pronounced N-S elongation along the Orion ridge. Analysis of the two excited modes of HCN, along with the ground state $HC^{15}N$ line (Johansson, et al. 1984), indicates a vibrational temperature of 290 K for HCN; this value is close to that derived for vibrationally-excited HC_3N from Hat Creek interferometer measurements by Plambeck (1986), who found $T_{vib} = 265 \pm 35$ K. Such a vibrational temperature is consistent with infrared excitation of the vibrational modes of HCN by 7 an 14 μm radiation from IRc2.

References:
Goldsmith, P.F., Krotkov, R., and Snell, R.L. 1985, Ap.J., 299, 405.
Johansson, et al. 1984, Astr. Ap., 130, 227.
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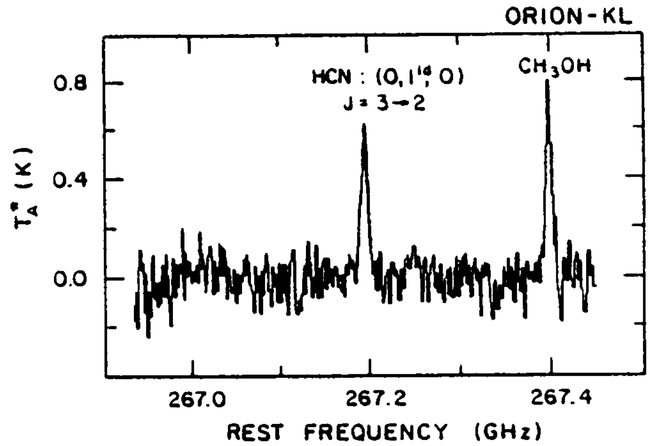

Figure 1: The J=3-2 transition of the $(0,1^{1d},0)$ bending mode of vibrationally-excited HCN, observed towards Orion-KL with the FCRAO 14 meter telescope at 267 GHz.

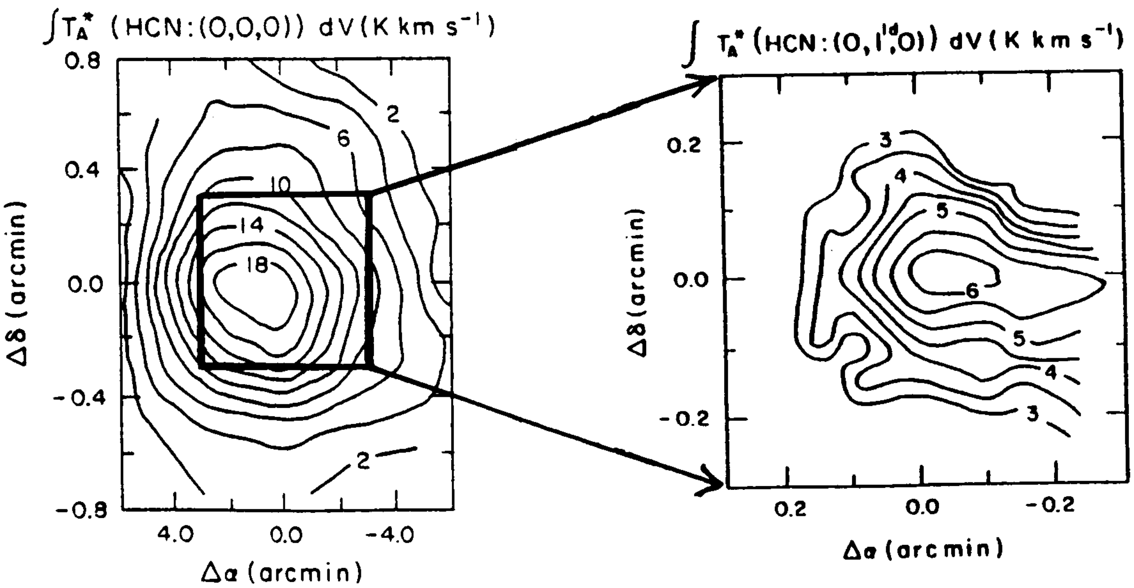

Figure 2: Maps of the integrated intensity of the J=3-2 lines of ground state and vibrationally-excited HCN, showing that they have different spatial distributions. The excited state emission probably arises from a source $\lesssim 20''$ in size.