THE HYPERFINE STRUCTURES OF HCN J = 1–0 AND THE IMPLIED PHYSICAL INFORMATIONS: I. S140

(Letter to the Editor)

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Abstract. The hyperfine structures of HCN J = 1–0 are observed toward S140 with a high-resolution spectroscope. The measured ratios $R_{02} = T^*$($F = 0–1)/T^*$($F = 2–1)$ and $R_{12} = T^*$($F = 1–1)/T^*$($F = 2–1)$ are $0.29 \pm 0.03$ and $0.43 \pm 0.03$ separately. A large velocity gradient model, the escape probability method and spherical approximation are adopted to calculate the radiative transfer. The correlations between the ratios of the hyperfine satellites and density (or optical depth) have been studied. To fit the measured ratios, a density of $(0.9 \pm 0.1) \times 10^6$ cm$^{-3}$ is obtained toward S140 center. According to the differences between the calculated excitation temperatures of the hyperfine satellites, one finds that the so-called hyperfine anomalies is caused by the unrealistic LTE assumption.

1. Introduction

The process from molecular cloud to pre-Main-Sequence star is a process to higher densities. The dense cores of clouds with OB-star formation have the densities of $10^6$ cm$^{-3}$. Evans II et al. (1987) find that S140 shows no clear evidence for densities greater than $10^6$ cm$^{-3}$ basing their submillimeter spectral line observations. They also pointed that a full multitransition analysis is hard to do toward HCN since some transitions (e.g., $J = 2–1$ and $J = 5–4$) are at frequencies where the atmospheric opacity is large. However, it is usually overlooked that the observations of hyperfine structure could provide invaluable informations on the densities. The goals of the present study are probing the density by observing the hyperfine structures of HCN J = 1–0 (88.63 GHz) and interpreting the cause of the so-called hyperfine anomalies in S140.

2. Observations

The observations were carried out in November 1989 with the 4 m radiotelescope of Nagoya University. The half-power beamwidth was 2.7' at 110 GHz. The front-end was a low-noise SIS mixer which provided a system temperature of about 250 K (DSB). An AOS served as the back-end, which had frequency resolution of 40 kHz, correspondence to a velocity resolution of 0.14 km s$^{-1}$ at 88.6 GHz. The chopper wheel method
was used to calibrate the antenna temperature. Each point is observed in the frequency-switching mode and integrated to 8–10 min to achieve a satisfying signal-to-noise ratio.

3. Model and Calculation

According to the observed infrared spectrum of S140 IR (Harvey et al., 1978) we assume there is a black body with an angular diameter of 0'03 at the center. The radiation field of a black body is described by a radiation temperature $T_{\text{rad}} = 600$ K and a dilution factor $f = 10^{-5}$ at $1.5 \times 10^{17}$ cm. The outer region is a homogeneous dust shell which absorbs the energy radiated by the inner region and re-radiates. As a result, there is a dust field of dust temperature 63 K with $\lambda^{-0.75}$ emissivity and $\tau_{100\mu} = 0.33$. The HCN molecules are exposed to the 600 K black-body, dust, and cosmic background radiation fields.

A large velocity gradient model (Goldreich and Kwan, 1974), the escape probability method and spherical approximation are adopted to calculate the radiative transfer. The statistical calculation covers 28 energy levels. The Einstein radiative transition probabilities, the energy levels and the collision transition probabilities are calculated by Cao (1990). The method of calculating the collision transition probabilities between hyperfine levels published by Varshalovich and Khersonsky (1977) is adopted. In our calculation the kinetic temperature is 35 K determined from the observations on CO, the velocity gradient is 4.0 km s$^{-1}$ pc$^{-1}$ determined from the observations on HCO$^+$ (Wooten et al., 1980) and the fractional abundance of HCN is $1.3 \times 10^{-9}$ derived by Blair et al. (1978).

4. Results and Discussions

Figure 1 is the observed $J = 1-0$ HCN spectrum at the center of S140. The hyperfine satellites of $J = 1-0$ are well resolved. The measured ratios $R_{02} = T_a^* (F = 0-1)/T_a^* (F = 2-1)$ and $R_{12} = T_a^* (F = 1-1)/T_a^* (F = 2-1)$ are listed in Table I. Comparing with the others, our results accord with Baudry et al. (1980) well. Figure 2 shows the calculated correlation between density ($n$) and the ratios $R_{02}$ and $R_{12}$, where the other physical parameters are as mentioned above. According to the measured ratios ($R_{02} = 0.29 \pm 0.03$ and $R_{12} = 0.43 \pm 0.03$) a density of $(0.9 \pm 0.1) \times 10^6$ cm$^{-3}$ is obtained. Table II lists the densities of S140 center probed.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>The measured ratios $R_{02}$ and $R_{12}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{02}$</td>
<td>$R_{12}$</td>
</tr>
<tr>
<td>0.29 ± 0.03</td>
<td>0.43 ± 0.03</td>
</tr>
<tr>
<td>0.25 ± 0.02</td>
<td>0.44 ± 0.04</td>
</tr>
<tr>
<td>0.37 ± 0.06</td>
<td>0.54 ± 0.06</td>
</tr>
</tbody>
</table>
THE HYPERFINE STRUCTURES OF HCN $J = 1-0$

Fig. 1. The observed $J = 1-0$ HCN spectrum at $\alpha(1950) \ 22^h17^m41^s$, $\delta(1950) \ 63^\circ3'48''$.8.

Fig. 2. The correlation between density $n$ and the ratios $R_{02}$ and $R_{12}$. The other physical parameters are described in the text.
TABLE II
The densities probed by various molecular lines

<table>
<thead>
<tr>
<th>Species</th>
<th>Transition</th>
<th>Density (in 10 cm(^{-3}))</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS</td>
<td>(J = 7-6) and (2-1)</td>
<td>(5.7 \pm 0.2)</td>
<td>Evans (\text{II et al. (1987)})</td>
</tr>
<tr>
<td>CS</td>
<td>Multiple</td>
<td>(5.9 \pm 0.1)</td>
<td>Evans (\text{II et al. (1987)})</td>
</tr>
<tr>
<td>CS</td>
<td>Multiple</td>
<td>(5.9 \pm 0.1)</td>
<td>Snell (\text{et al. (1984)})</td>
</tr>
<tr>
<td>(\text{H}_2\text{CO})</td>
<td>Multiple</td>
<td>(5.9 \pm 0.1)</td>
<td>Mundy (\text{et al. (1986)})</td>
</tr>
<tr>
<td>HCN</td>
<td>(J = 1-0)</td>
<td>(5.9 \pm 0.1)</td>
<td>This paper</td>
</tr>
<tr>
<td></td>
<td>((F = 1-1, 2-1, 0-1))</td>
<td>(5.9 \pm 0.1)</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3. The correlation between optical depth \(\tau\) and the ratios \(R_{02}\) and \(R_{12}\). The other physical parameters are described in the text.

by various molecular lines. Figure 3 shows the calculated correlation between optical depth \(\tau\) and the ratios \(R_{02}\) and \(R_{12}\). If one simply assumes that the excitation temperatures of the hyperfine satellites are identical (LTE), the limit values of \(R_{02}\) and \(R_{12}\) are 0.2 and 0.6 separately when \(\tau \ll 1\) and are identically when \(\tau \gg 1\). However, our calculating results in Figure 2 and Figure 3 show that when the density (or optical depth) increases \(R_{02}\) and \(R_{12}\) do not increase monotonously. At certain \(n\) (or \(\tau\)) \(R_{02}\) and \(R_{12}\) might be higher than LTE optical thick limit value 1. \(R_{12}\) also might be lower than LTE optical thin limit 0.6. S140 center of density \((0.9 \pm 0.1) \times 10^6\) cm\(^{-3}\) is an example where the measured \(R_{12}\) is 0.43 \pm 0.03 lower than LTE optical thin limit. It were the so-called hyperfine anomalies. In fact, our calculation results show that the excitation tempera-
tures of the hyperfine satellites are not identical. In case of \( n = 0.9 \times 10^6 \text{ cm}^{-3} \), the excitation temperatures are 22 K \((F = 1-1)\), 47 K \((F = 2-1)\), and 18 K \((F = 0-1)\). Therefore, the simple LTE assumption is unrealistic in S140 which causes the so-called anomalies. On the contrary, the ratios of hyperfine satellites do normally offer us the informations in S140. Since the size of source at half maximum level is roughly the same as the beam size, the probed density is an averaged value of HCN cloud in S140.

References

Cao, Y. Q.: 1990, unpublished.