# THE PHYSICAL AND CHEMICAL STRUCTURE OF WARM, DENSE REGIONS : IC 63 AND IC 443

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## 1. Introduction

Elevated temperatures in molecular clouds can result either from heating by ultraviolet photons or from the passage of shock waves. The effect that these processes have on the chemical abundances is not well established observationally, but is of great importance for the interpretation of molecular line observations not only in our own Galaxy, but also in external galaxies. We present here initial results from our study of two "template" regions: the photon–dominated region IC 63 and the shocked region IC 443.

In order to derive molecular abundances, it is necessary to have accurate constraints on the temperature and density in the sources. These have been obtained from observations of (sub)millimeter lines of CO (2→1, 3→2), HCN, $HCO^+$ (1→0, 3→2, 4→3), CS (2→1, 5→4, 7→6) and $H_2CO$ (various lines), combined with detailed statistical equilibrium calculations.

## 2. Photon–dominated region : IC 63

IC 63 is a reflection nebula located close to the star $\gamma$ Cas (type B0.5 IV, $D \approx 200$ pc), in which fluorescent ultraviolet $H_2$ emission has been detected (Witt *et al.* 1989). The cloud is exposed to several hundred times the general Galactic UV background radiation. Our CO 2→1 observations show a small ($1' \times 2' \approx 0.05 \times 0.1$ pc), isolated molecular cloud coincident with the brightest nebulosity. The line widths are of order 2 km $s^{-1}$, so that there cannot be an important shocked component. From the relative strengths of the CO, CS, $HCO^+$ and HCN lines, we find $T \approx 35$ K and $n \approx 3 \times 10^4$ $cm^{-3}$. The derived abundances at this temperature and density are listed in Table 1.

## 3. Shocked region : IC 443

IC 443 is a well–known supernova remnant, which has been studied before by White *et al.* (1987) and Ziurys *et al.* (1989). Its interaction with the molecular cloud shows up as strong and broad ($\Delta V \gtrsim 20$ km $s^{-1}$) molecular lines in small clumps. Observations of shocked $H_2$ reveal a ring–like structure (Burton *et al.* 1988). Comparison of CO 1→0, 2→1 and 3→2 line strengths along the ring shows that the low–$J$ CO lines are optically thin. We have concentrated our searches for other molecules on three positions: one in clump B, and two in clump G (nomenclature from Huang *et al.* 1986).

From the modeling of the relative strengths of the CS, HCN, $HCO^+$ and $H_2CO$ lines (see Figure 1), we find temperatures of about 100 K and densities around $5 \times 10^5$ $cm^{-3}$, with little variation between the clumps. Our column densities for CS, HCN and $HCO^+$ (see Table 1) agree with those of Ziurys *et al.* within a factor 2 at the same positions.

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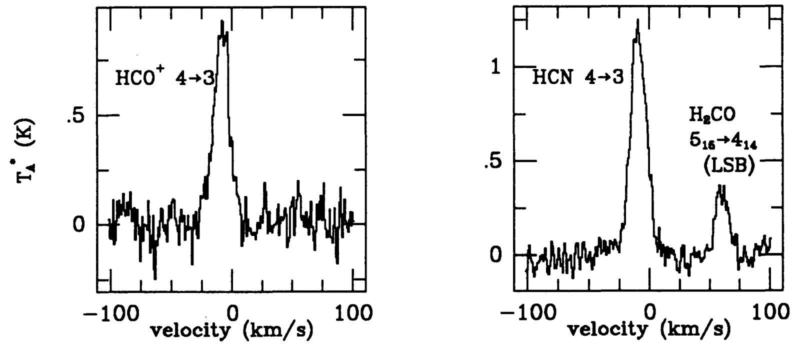

*Fig. 1. Spectra of IC 443 G obtained at the Caltech Submillimeter Observatory*

## 4. Conclusions

The preliminary results presented in Table 1 show that within factors of a few, there are no significant differences between the abundances in IC 63 and IC 443, and dark clouds like L134N and TMC–1, for the molecules studied in this work. In IC 63, the abundances may be slightly lower due to the enhanced photodissociation rates. In IC 443, the shock has clearly compressed and heated the surrounding molecular cloud, but has hardly affected the chemistry. In particular, the $HCO^+$ abundance is not significantly enhanced, contrary to earlier speculations. Volatile molecules such as $CH_3OH$, and sulfur–bearing molecules such as SO and $SO_2$ have low abundances in both clouds.

**Table 1.** Column densities $N$ (in $cm^{-2}$) and relative abundances $X$ (CO / $H_2$ = $1 \times 10^{-4}$).

| | IC 63 | | IC 443 B | | IC 443 G | | L134N | TMC-1 |
|---|---|---|---|---|---|---|---|---|
| | $N$ | $X$ | $N$ | $X$ | $N$ | $X$ | $X$ | $X$ |
| $H_2$ | 3 (21) | 1.0 | 5 (21) | 1.0 | 7 (21) | 1.0 | 1.0 | 1.0 |
| CO | 3 (17) | 1 (-4) | 5 (17) | 1 (-4) | 7 (17) | 1 (-4) | 1 (-4) | 1 (-4) |
| $^{13}CO$ | 2 (15) | 7 (-7) | 8 (15) | 2 (-6) | 2 (16) | 3 (-6) | 4 (-6) | 4 (-6) |
| CS | 1 (13) | 3 (-9) | 5 (13) | 1 (-8) | 3 (13) | 4 (-9) | 7 (-10) | 1 (-8) |
| HCN | 4 (12) | 2 (-9) | 4 (13) | 8 (-9) | 1 (14) | 1 (-8) | 3 (-9) | 2 (-8) |
| $HCO^+$ | 5 (12) | 2 (-9) | 4 (13) | 8 (-9) | 8 (13) | 1 (-8) | 6 (-9) | 3 (-9) |
| $H_2CO$ | 8 (12) | 3 (-9) | 3 (13) | 6 (-9) | 6 (13) | 9 (-9) | 2 (-8) | 2 (-8) |
| CN | 3 (13) | 1 (-8) | ... | ... | <3 (13) | <4 (-9) | <3 (-9) | 3 (-8) |
| SO | <1 (12) | <3 (-10) | ... | ... | ... | ... | 5 (-9) | 5 (-9) |
| $SO_2$ | <1 (13) | <3 (-9) | ... | ... | <1 (13) | <1 (-9) | 1 (-9) | <1 (-9) |
| $CH_3OH$ | <4 (12) | <2 (-9) | ... | ... | ... | ... | 2 (-9) | 2 (-9) |

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