MOLECULES IN THE NEARBY STARBURST GALAXY, IC 342

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Abstract

We present high resolution ($\sim 5''$) images in the emission lines of several important molecules in the nearby starburst galaxy, IC 342. The data was taken with the OVRO millimeter array. The morphology of the species vary strongly across the nucleus, indicating widespread chemical differentiation or strong variations in the excitation of their dense gas components across the starburst region. Peak molecular abundances are similar to those found in the envelope of SgrB2. The carbon chain molecules are confined to the central starburst region, with HC_3N tracing the densest gas associated with the star formation, and C_2H lining the inner "ring" of molecular gas presumably associated with the cloud PDR surfaces. Widespread, bright emission in CH_3OH and HNCO demonstrate that gas-grain chemistry is important across the nucleus. Surprisingly, the dense, quiescent gas tracer, N_2H^+ is ubiquitous.

Key words: galaxies: individual(IC 342) – ISM: molecules

1. Introduction

For external galaxies, the large distances prohibit resolving the inner workings of GMCs, but observations of trace molecules may afford the opportunity to investigate the structure and physical conditions on GMC sizescale. External galaxies provide three principle benefits for studying the large-scale chemical structure of the ISM, (i) the overall geometry of a star-forming region is often easier to understand than in our Galaxy, (ii) one can simultaneously study many GMCs in one observation, and (iii) external galaxies can have more extreme conditions than found anywhere in the Galaxy. These combine to make external galaxies potentially powerful complimentary tools for studying the global interplay between astrochemistry and star formation or dynamics.

2. Observations and Results

We surveyed, at resolutions high enough to resolve individual GMCs, the molecules (HNC, HC_3N, C_2H, $C^{34}S$, HNCO, CH_3OH, N_2H^+ and SO) in the nearby starburst nucleus, IC 342, with the OVRO array. IC 342 is the nearest (D $\sim$ 2 Mpc), gas-rich spiral with active star formation. It is nearly face-on with widespread molecular gas in both dense GMCs (about the mass of SgrB2) and a diffuse medium (comparable to the Galaxy's "central molecular zone"). A multitude of CO isotopomers have been observed providing a detailed knowledge of the distribution of H_2 column density, temperature, and density (eg. Meier, Turner & Hurt 2000; Meier & Turner 2001). Molecular gas is distributed along x_1 and x_2 bar orbitals, in response to a small central bar of recently formed stars ($\sim 10^7$yrs). Inflow along the arms are driving two younger, optically obscured starbursts ($\sim$1000 O7 stars) at the orbit intersections (GMC B and C; Böker, Forster-Schrieber & Genzel 1997; Meier & Turner 2001).

2.1. Dense, Quiescent Gas

Dense gas is confined largely to the leading edges of the arms and to the central ring, and is collected into five major GMCs (see Figure 1) with similar HCN(1-0) and HNC(1-0) intensities (I(HNC)/I(HCN) $\sim$ 0.5). HC_3N has the largest dipole moment and E_u of any observed transition, an its emission is confined to the two young starbursts seen in 3 mm continuum (Meier & Turner 2001). Considering that N_2H^+ avoids active regions, and in general traces dense quiescent gas in the Galaxy (eg. Womack, Ziurys & Wyckoff 1992), it is surprising N_2H^+ is ubiquitous ($N_2H^+/H_2 \sim 3 \times 10^{-10}$; assuming $T_r = 10$ K and H_2 column densities estimated from $C^{18}O$) and follows the CH_3OH morphology closely.

These observations show that most of the dense gas is confined to the GMCs along the central molecular ring, with the warmest, densest gas occuring at the starbursts. However, the fact that N_2H^+ also peaks here suggests

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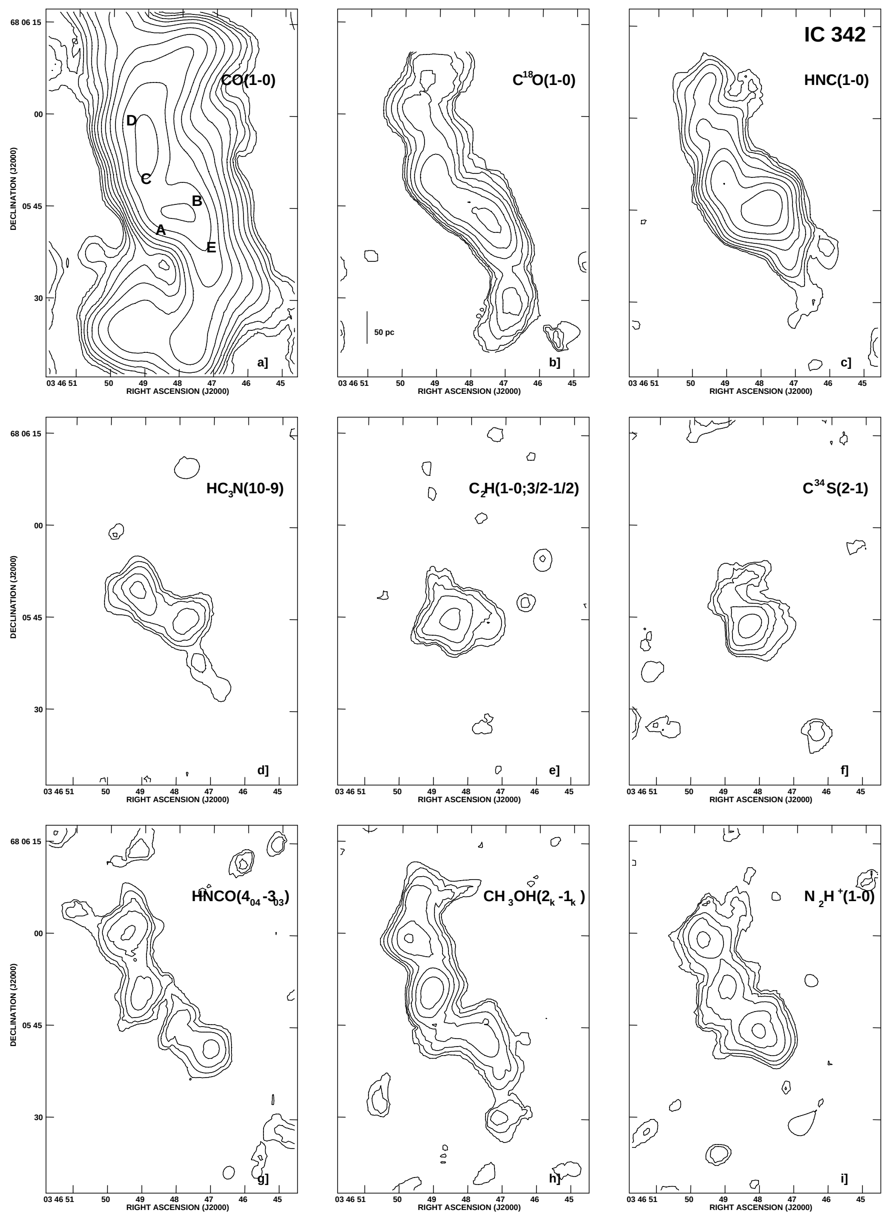

Figure 1. The integrated intensities of nine tracer molecules observed towards the nucleus of IC 342. Each map is contoured at $2^{i/2}$, i = 0,1,2,... times the 2σ times the RMS intensity in each map, except for ^{12}CO(1-0). (a) The ^{12}CO(1-0) transition contoured in steps of 7.7 K km s^{-1} for 6.″5 × 5.″5 resolution. Locations of the five major GMCs based on HCN are labeled A-E (Downes et al. 1992). (b) The $C^{18}O$(1-0) transition contoured in steps of 1.4 K km s^{-1} for 6.″0 resolution, (c) the HNC(1-0) transition in steps of 2.0 K km s^{-1} for 5.″9 × 5.″1 resolution, (d) the HC_3N(10-9) transition in steps of 2.0 K km s^{-1} for 5.″9 × 5.″1 resolution, (e) the C_2H N(J,F)= 1($\frac{3}{2}$,2)-0($\frac{1}{2}$,1) transition in steps of 3.6 K km s^{-1} for 5.″5 × 4.″9 resolution, (f) the $C^{34}S$(2-1) transition in steps of 2.5 K km s^{-1} for 6.″6 × 5.″6 resolution, (g) the HNCO($4_{04} - 3_{03}$) transition in steps of 2.4 K km s^{-1} for 5.″9 × 5.″1 resolution, (h) the CH_3OH($2_k - 1_k$) transition in steps of 2.0 K km s^{-1} for 6.″0 × 4.″8 resolution, and (i) the N_2H^+(1-0) transition in steps of 1.8 K km s^{-1} for 6.″2 × 5.″1 resolution. SO($2_3 - 1_2$) was observed but not detected at a 2σ RMS equal to that of $C^{18}O$(1-0) transition.

that despite the strong star formation, either significant amounts of sterile, quiescent gas must be present, or that N_2H^+ is not exclusively a tracer of quiescent gas.

2.2. PDRs

The radical C_2H is observed exclusively towards the central star formation complex, peaking towards GMC A and inside the central ring, with fractional abundances of $C_2H/H_2 \sim 5 \times 10^{-8}$. $C^{34}S$ is the only other species as confined as C_2H, also peaking at GMC A.

From the gas-phase chemistry, C_2H is expected to be abundant where high abundances of C^+ and FUV photons are present, namely PDRs (eg. Sternberg 1999). Likewise, the enhancements of CS (23 x $C^{34}S$) likely arise from the commensurate increase in S^+ in the PDR (eg. Jansen et al. 1995). N(SO)/N(CS) as low as <0.05 also favor early-time C-rich conditions. These results provide excellent confirmation that the gas physical conditions of the central ring are strongly influenced by PDRs. C_2H and $C^{34}S$ also demonstrates that GMC A has different physical and chemical conditions from the other GMCs.

2.3. Grain Chemistry

CH_3OH is widespread and bright, and traces the leading edges of the molecular bar arms and the cusps in the x_1 orbits (GMC D). It has a high fractional abundance, $CH_3OH/H_2 \sim 2 \times 10^{-8}$. An additional peak in methanol is seen towards GMC C, one of the locations of obscured massive star formation. HNCO emission displays a qualitatively similar behavior, being especially strong towards GMC D. A similar enhancement of HNCO near the bar ends is seen in two other nearby barred galaxies, Maffei 2 and NGC 6946 (Meier et al. in prep.).

The high abundance of CH_3OH seen in IC 342 probably requires liberation of grain mantles to explain the observed abundances (eg. Millar, Herbst & Charnley 1991), suggesting that grain processing is important on nucleus-wide scales. Moreover, the fact that HNCO (and CH_3OH) exhibit enhancements at the sites of dynamical resonances, leads to the speculation that on large scales (coherent enhancements over at least 50 pc), disruption of grain mantles is through cloud-cloud collisions induced by non-circular motions present in barred galaxies. Future studies of more galaxies may reveal the exciting prospect that chemistry can even be used to understand galaxy dynamics. The CH_3OH peak towards GMC C is most likely due to mantle evaporation due to the massive star formation there. This GMC, which is bright in species like HCN, HNC, HC_3N, HNCO, CH_3OH and NH_3 (Ho et al. 1990), is an excellent extragalactic analogue of a hot core like Sgr B2.

3. The Chemical Structure of IC 342

A significant numbers of molecules are detected in IC 342, opening up the possibility of studying the localized effects of star formation and dynamical shocks on gas chemistry. Morphological variations are more dramatic than seen in the CO isotopomers, suggesting that the dense gas component of starbursts exhibit either significant variations in gas excitation or that there is widespread chemical differentation across the nucleus. We see for the first time, gas with M 82-like chemistries *and* NGC 253-like chemistries (eg. Mauersberger & Henkel 1993) in the same galaxy. Based on the location for each in IC 342, it is tempting to conclude that the ISM in M 82 is dominated by GMC A-like chemistries, or PDR molecular gas, while NGC 253 is dominated by gas-grain chemistries caused by grain mantles liberated in bar driven shocks. These observations suggest that the prospects for high resolution extragalactic astrochemistry with future arrays, such as CARMA and ALMA are excellent.

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