ATOMIC CARBON IN STARBURST GALAXIES: MISSING CI (J=1−0) EMISSION IN THE CENTRE OF M82

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Abstract

CI is an important coolant in the ISM and is an excellent diagnostic of photodissociation regions associated with star formation. We discuss evidence that the CI $J = 2-1$ line is possibly much stronger than the J=1−0 line, indicating a need for high frequency observations of the nuclear regions of starburst galaxies if we wish to understand the thermal processes of the molecular gas in starbursts.

Key words: Galaxies: M82 – Galaxies: M83 – Missions: FIRST

1. Introduction

It is believed that gravity cannot be solely responsible for the collapse of molecular clouds to form stars. Molecular and atomic line emission is expected to play an important role in determining the thermal balance of interstellar molecular clouds. In particular, CO and CI are believed to be the dominant cooling species in the ISM (Goldsmith & Langer 1978).

In order to measure the relative contributions to cooling by line emission, we would need to map entire molecular clouds at all important frequencies. The large angular size of galactic molecular clouds makes this a daunting task. We can bypass this problem by studying extragalactic star forming regions. The analysis of spectral line ratios rather than individual line strengths will minimize the effect of the low filling factor of extragalactic molecular clouds. Understanding the emission characteristics of CI in other more active galaxies than the Milky Way is crucial to our understanding of its role in thermal balance of starburst environments. This paper presents a comparison of previously published data for M82 and M83. Details of the data reduction and calibration are available in Petitpas & Wilson (1998), Petitpas & Wilson (2000) and White *et al.* (1994).

2. CO and CI Emission in M83

Figure 1 (see last page) shows the integrated intensity maps of M83. The top panel is ^{12}CO J=3−2, the middle panel is ^{12}CO J=4−3, and the bottom panel is CI (J=1−0). The maps are oriented such that the bar runs horizontally along the x-axis. While there are differences in the morphologies, all maps exhibit the 'twin peak' structure often associated with gas collection along the leading edge of the bar at the inner Lindblad resonance.

The ^{12}CO J=4−3 and CI maps both show the northern peak brighter than the southern peak, while in the ^{12}CO J=3−2 map, both peaks are much closer in brightness. In addition, Figure 2 shows the CI/^{12}CO J=4−3 line ratios which indicates that the ^{12}CO J=4−3 emission is originating in the same hot photon-dominated regions as the CI emission. The peak brightness and integrated intensities of the CI spectral lines are much lower than those of ^{12}CO lines at the same position (even at the same beam size), suggesting that there is much more flux lost by CO emission than by CI.

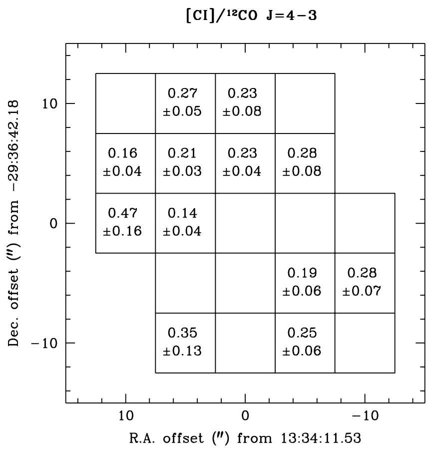

Figure 2. The integrated intensity CI/^{12}CO J=4−3 line ratios for M83. The orientation is the same as Figure 1. The line ratios are uniform at the 2σ level, which indicates that the ^{12}CO J=4−3 emission is originating in the same hot photon-dominated regions as the CI emission.

3. CO and CI Emission in M82

Figure 3 (see last page) shows the integrated intensity maps for ^{12}CO J=3−2(top), ^{13}CO J=3−2(middle), and CI J=1−0 (bottom) for the edge on starburst galaxy M82. All maps exhibit a double peaked morphology, despite evidence that the higher J transitions are optically thick. This suggests that the double peaked structure is not the

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result of an edge-on torus of molecular gas as is commonly assumed (Neininger *et al.* 1998; Petitpas & Wilson 2000).

The difference in the integrated intensity maps translates into a variation in the integrated intensity CO line ratios across the disk of M82. LVG analysis suggests that the variation in line ratios can be explained if the west lobe of M82 is hotter and less dense than the easter lobe (Petitpas & Wilson 2000). This may be the result of an interaction with M81 which triggered enhanced star formation in the west lobe which both heats and depletes the molecular gas.

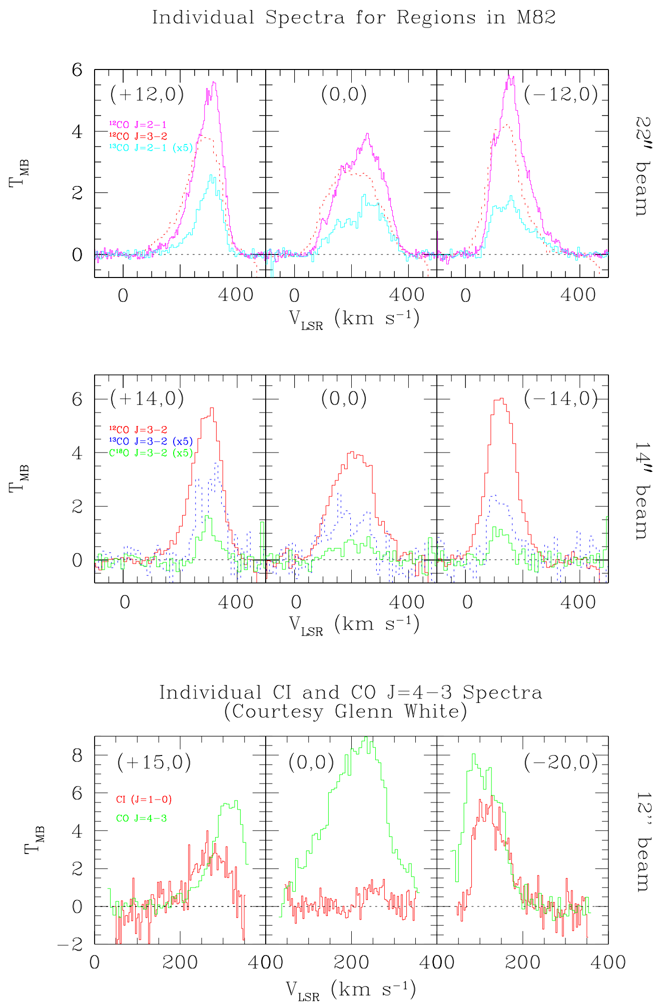

Figure 4. Individual spectra for the three main lobes of M82. Note how the ^{12}CO J=4−3 emission peaks in the central region, while the CI (J=1−0) emission seems depleted. Recall that the CI/^{12}CO J=4−3 ratio was constant in M83.

The strongest CI J=1−0 emission in M82 occurs in the western lobe, providing independent confirmation that there may be more vigorous star formation in the western lobe. CI emission is expected to dominate in PDRs, which are likely present in (or perhaps the cause of) the hotter, lower density regions of M82.

4. Missing CI (J=1−0) in the nucleus of M82

In the outer lobes of M82, the CI J=1−0 and ^{12}CO J=4−3 emission show similar line profiles and relative intensities. However, in the nucleus of M82 the ^{12}CO J=4−3 emission is strongest, while the lower J emission tends to have a double peaked appearance, with decreased emission from the nucleus. This agrees with the findings of Gerin & Phillips (2000) who find that CI (J=1−0) emission is depleted in the nuclei relative to the disk of nearby galaxies. The depletion in M82 is *much* stronger than any of the galaxies in their study. The bright ^{12}CO J=4−3 emission (which was *not* used in the LVG models) suggests that there is a region of very hot gas in the centre of M82, which is not evident in the analysis of CO emission of $J < 3$. The depletion of CI J=1−0 may be the result of the increased temperatures (indicated by the enhanced ^{12}CO J=4−3 emission) forcing the CI into the higher J=2−1 state, leaving the lower level depleted.

The nucleus of M82 has been observed in CI J=2−1 by Stutzki *et al.* (1997). They find the CI J=2−1/J=1−0 $\approx$ 1 in the nucleus of M82, but it should be noted that the CI J=1−0 beam was larger than the J=2−1, suggesting that the reported spectral line ratio may be artificially lowered due to the J=1−0 beam partially overlapped the two bright lobes of M82.

5. Summary

In the barred starburst galaxy M83, the CI/^{12}CO J=4−3 line ratios are similar indicating that the relative cooling rates are similar all over the nucleus and 'twin-peaks' of this galaxy.

In the barred starburst galaxy M82, the CI J=1−0 emission is similar to the ^{12}CO J=4−3 emission in the 'twin-peaks', but is remarkably different in the nucleus. The ^{12}CO J=4−3 reaches maximum intensity, while the CI J=1−0 emission appears depleted. This suggests that the nucleus of M82 is extremely hot, bumping CO and CI into higher J excitation states, resulting in strong emission from the higher J transitions of CO (and perhaps CI) and leaving the lower J transitions depleted.

We need observations at higher frequencies in order to determine the total cooling contributions by CO and CI.

Acknowledgements

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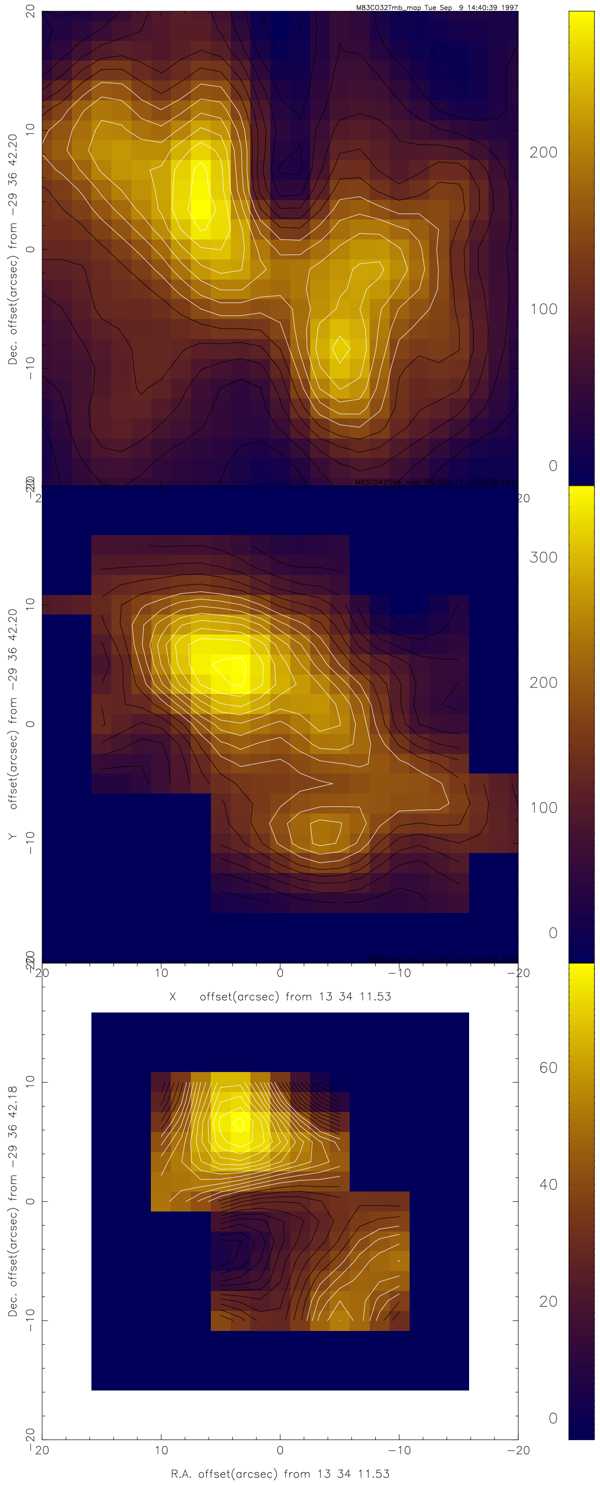

Figure 1. Integrated intensity maps of the barred starburst galaxy M83. In these figures the bar runs horizontally. The top panel is ^{12}CO J=3−2, the middle panel is ^{12}CO J=4−3, and the bottom panel is CI (J=1−0). The color scale is given in K-km s^{-1} in the $T_{\rm MB}$ temperature scale.

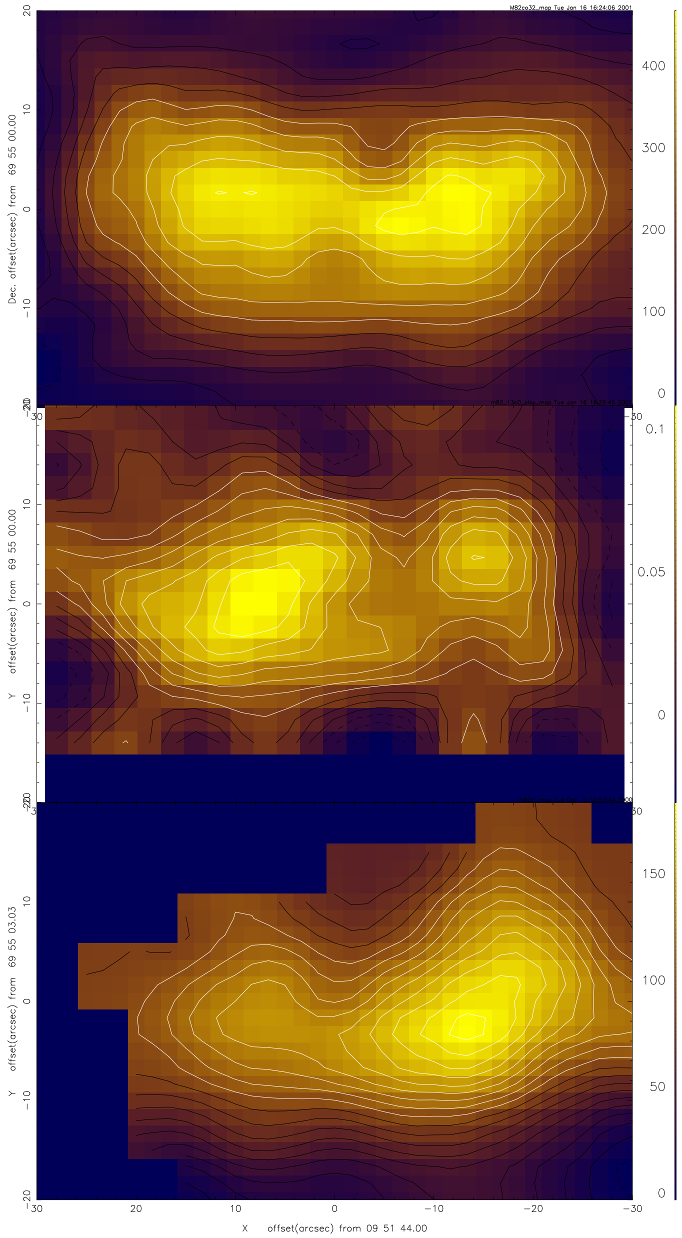

Figure 3. Integrated intensity maps of the barred starburst galaxy M82. In these figures the bar runs horizontally. The top panel is ^{12}CO J=3−2, the middle panel is ^{13}CO J=3−2, and the bottom panel is CI (J=1−0). The color scale is given in K-km s^{-1} in the $T_{\rm MB}$ temperature scale.