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Far-Infrared Line Images of Dwarf Galaxies

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Irregular dwarf galaxies are about ten times more widespread in the universe than regular spiral galaxies. They are characterized by a relatively low metallicity, i.e. lower abundance of the heavier elements (metals) with respect to hydrogen than in the solar neighborhood. These heavier elements in the form of molecules, atoms, or ions, which have radiative transitions in the infrared, play a decisive role in the energy balance of the ISM and thereby for the formation of stars. Dwarf galaxies are thus model cases for the physical conditions in the early phase of the universe.

Large Magellanic Cloud: 30 Doradus. The two nearest dwarf galaxies are the Magellanic clouds at a distance ~ 50 kpc. The LMC contains 30 Dor, a region with young, extremely massive stars which strongly interact with the surrounding ISM on account of their stellar winds and intense UV radiation. 30 Dor is the brightest object in the LMC at almost all wavelengths.

During two flight series on the Kuiper Airborne Observatory in March 1991 and March 1992 we mapped a 7'×6' area in the 158 μm [CII] line and in the 145 μm [OI] line. The [CII] line emission is shown in Fig. 1 , overlaid with the CO ($1 \rightarrow 0$) contour lines (Johannson *et al.* 1992). We find excellent spatial correlation between the two maps. [CII] radiation arises from photodissociation regions (PDRs), i.e. from the interface regions between fully ionized and molecular gas (Tielens and Hollenbach 1985). The [CII] line is bright (peak intensity 10^{-3} erg $s^{-1}cm^{-2}sr^{-1}$ (Poglitsch *et al.* 1992), and the [CII]/CO line intensity ratio is about ten times greater than in Galactic star formation regions (Stacey *et al* 1991). On the other hand, we find a [OI] to [CII] ratio ~ 1/20 which suggests temperatures and densities comparable to that in Galactic PDRs. The enhanced [CII]/CO ratio can be understood by the effect of the low abundance of heavy elements: A low dust to gas ratio and reduced CO self-shielding lead to an increased penetration depth of UV photons into the molecular gas. A much greater fraction of the CO is dissociated which leads to a decreased filling factor of the CO line emitting regions. The C^+ column density will not be affected much since the lower carbon abundance is compensated by the greater depth of the photodissociated layer (Maloney and Black 1988). Therefore, in an ensemble of low metallicity clouds, one would expect an enhanced [CII] to CO ($1 \rightarrow 0$) line intensity ratio. We estimate that in the 30 Dor region more than half of the interstellar gas must be contained in PDRs compared to about 10% in molecular clouds in our Galaxy.

IC 10 is also a relatively nearby (1.3 Mpc) dwarf galaxy. Its metallicity of about 1/6 the solar value is even smaller than that of the LMC. As common with dwarf galaxies, this galaxy lacks a nucleus as generally thought of in spiral galaxies, but active star formation is concentrated in the central parts of the system. With our imaging far-infrared spectrometer FIFI we have mapped a $9' \times 5'$ area around the center of IC 10 in the [CII] fine structure line (Madden *et al* 1992). We find a [CII] peak intensity 8×10^{-5} erg $s^{-1}cm^{-2}sr^{-1}$ at the site of maximum HI (Shostak and Skillman 1989), CO (Becker 1990), and radio continuum emission. The [CII]/CO line intensity ratio (~ 15000) is not as extreme as in 30 Dor, but still 2.5 times greater than in Galactic star formation regions. Again we can conclude that a large fraction of the ISM (at least 1/4) is contained in photodissociation regions. Toward the local HI maximum west of the center where no CO emission has been detected we find [CII] emission. The line intensity is much greater than expected from standard atomic clouds. It is likely that a substantial fraction of the observed [CII] emission arises from molecular hydrogen gas not traced by CO emission. The low metallicity medium in IC 10 may allow molecular hydrogen clouds of substantial column density to exist which have no detectable CO.

HE2-10 is a more distant (5 to 10 Mpc) dwarf galaxy we have recently observed in [CII] and CO ($1 \rightarrow 0$). It is a blue compact dwarf (BCD) galaxy undergoing a recent burst of starformation, possibly triggered by the collision of 2 merging dwarf galaxies. Its high gas content and metallicity value 1/2 that of solar, higher than that of IC10 and 30 Dor, make it an interesting subject to add to the study of the effects of metallicity on star formation traced through [CII], CO and FIR. The [CII] intensity is estimated to be $7 \pm 2 \times 10^{-4}$ erg s^{-1} cm^{-2} sr^{-1} assuming a central 13" source. The ratio of I[CII] to I(CO) is ~ 5×10^3, on the order of that seen in Galactic star formation regions, and a factor of 3 less than that in the lower metallicity dwarf IC10.

We conclude, at this stage in our study of low metallicity objects, that photodissociation regions consitute a larger fraction of the mass of these galaxies, as seen in the enhanced [CII] to CO ratio in the nearby galaxies IC10 and 30 Dor, compared to ratios observed in star formation regions in our Galaxy. In extreme cases with complete photodissociation of CO as possibly found in IC10 one could severely underestimate the amount of molecular gas when using CO as a tracer. The [CII] to CO ratio observed in more distant sources, such as HE2-10, is additionally affected by beam dillution. The PDR emission in the beam is then not dominated by the more prominent Orion-like sources (O-stars). Instead, we are likely seeing the affect of beam-averaging of the more common PDRs associated with B stars in the beam toward more distant sources, thereby reducing the effect of enhanced [CII] to CO ratio due to low metallicity.

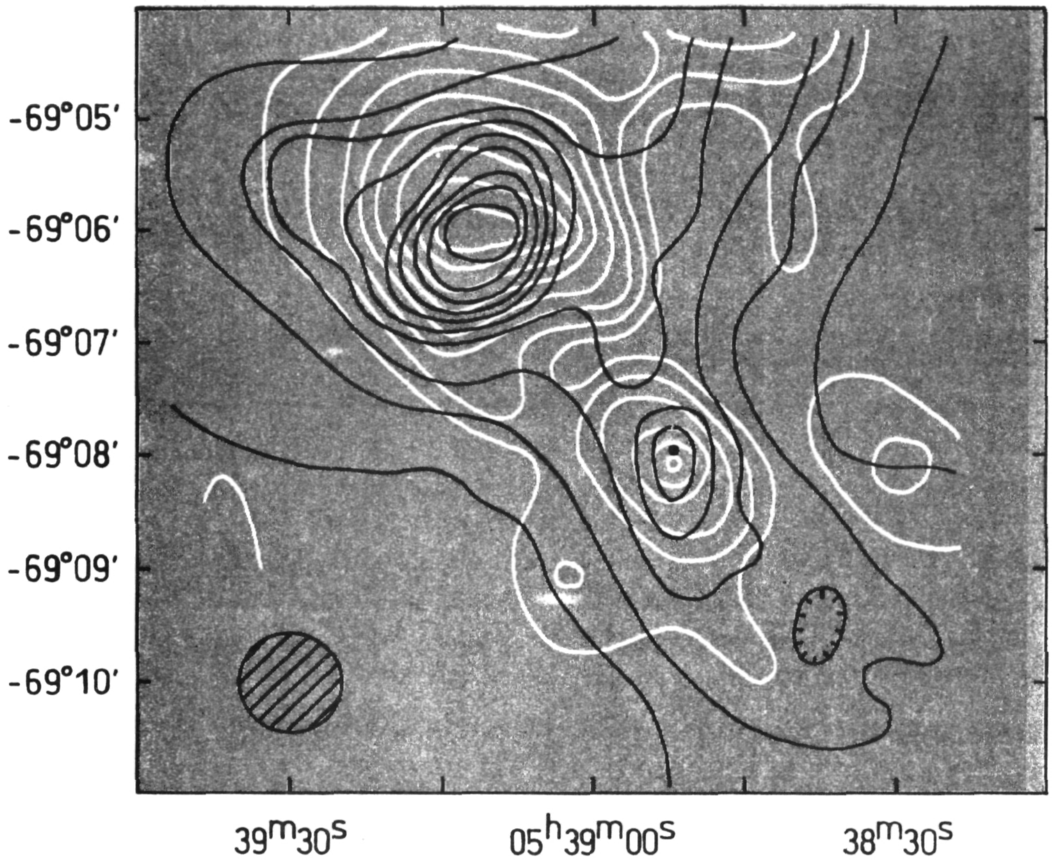

Fig 1.[CII] 158 μm emission (black) and CO (J=1-0) (white) in 30 Doradus.

References

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