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Observations of the CO J=6-5 Transition in Starburst Galaxies

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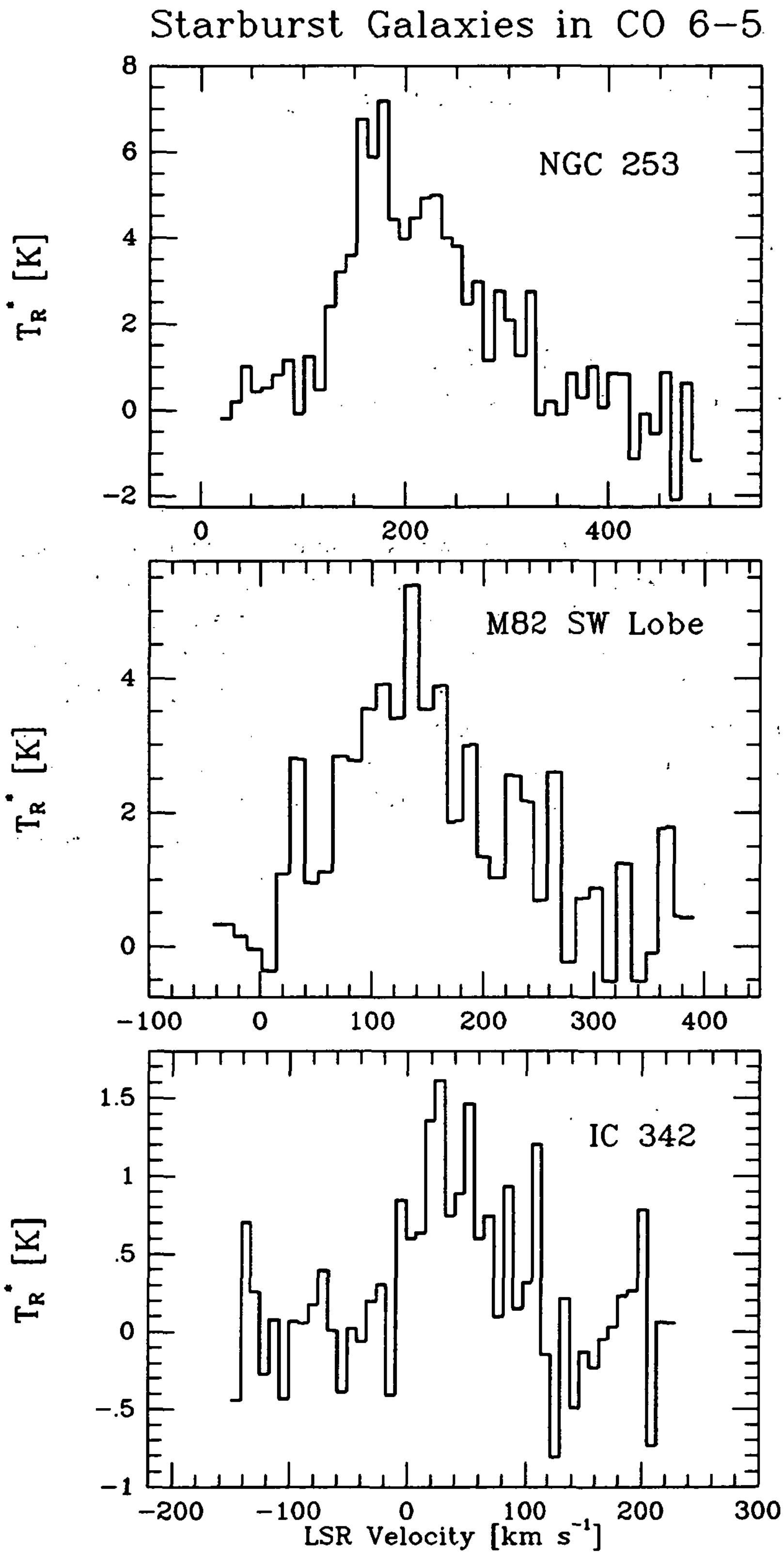
Over the past several years, short-submillimeter observations of carbon monoxide's (CO) mid-J rotational levels have revealed the presence of a large amount of excited molecular gas in luminous giant molecular clouds in our Galaxy. Submillimeter lines are specific probes of excited material: collisional excitation of the J=6 level requires gas temperatures approximately equal to the level energy of 116 K above ground, and the 6-5 transition's critical density is approximately 10^6 cm^{-3} in optically thin gas. Radiative trapping effects reduce the excitation requirements to some extent, but detection of the CO J=6-5 line is nearly indisputable proof of the existence of gas that is both warm and dense. The excitation conditions also imply that cool ($T < 20$ K) molecular clouds within the beam neither emit nor absorb in the short-submillimeter lines; in our Galaxy, clouds with active massive star formation emit the strongest short-submillimeter CO rotational lines.

We used these properties to explore the distribution of excited molecular material and physical conditions within the star formation regions of several classical starburst nuclei: NGC253, M82, and IC342. We have used the 6-5 transition as a thermometer of warm molecular gas in starburst nuclei, unambiguously finding that the nuclear molecular gas in starburst galaxies is substantially warmer than in typical disk clouds.

A number of recent observations make it very plausible that the gas in the nuclei of galaxies is on average more excited than the gas in the disks. Low-J lines from CO and molecules with large dipole moments that trace density, radio and dust continuum, and far-IR line emission all tend to peak strongly toward nuclei. Detection of the CO 6-5 line toward relatively compact nuclear regions is in general agreement with this trend. The present data are consistent with either moderately excited widespread nuclear gas or highly excited gas in small regions. However many possible physical components the nuclear regions may have, detection of the 6-5 line is unambiguous evidence for molecular gas with temperatures of tens to hundreds of kelvins widely distributed in galactic nuclei, gas on average warmer than in typical disk clouds. Nuclear gas heating could be either large scale, for example turbulent motions or cloud-cloud collisions in noncircular bar orbits, more local effects of radiation from high mass star formation and supernovae, or some combination. High CO excitation temperatures can affect galactic nuclear mass estimates and consequently star formation efficiencies deduced from lower-J CO lines.

The first description of these results has been published in the Astrophysical Journal (Letters) 382, L75. We are presently mapping the extended 6-5 and lower-J lines in the nuclei of NGC253 and M82.


Starburst Galaxies in CO 6−5
NGC 253
M82 SW Lobe
IC 342
T_R^* [K]
LSR Velocity [km s^{-1}]