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HIGH RESOLUTION OBSERVATIONS OF MOLECULAR GAS DISTRIBUTION IN GALAXIES

MIN S. YUN
National Radio Astronomy Observatory, P.O. Box 0, Socorro, NM 87801, USA

ABSTRACT

Recent high resolution CO observations of normal and starburst galaxies at Owens Valley Millimeter Array are summarized. While normal disk galaxies generally show exponential distribution which follows the optical blue light, starburst galaxies are often characterized by a compact (~1 kpc) nuclear complex whose surface gas mass density is strongly correlated with the observed large infrared luminosity and thus the ongoing massive star formation.

Key Words : molecular gas, star formation

I. INTRODUCTION

The millimeter array telescopes in operation today are capable of mapping the rotational transitions of CO and other molecular species at 1-2″ resolution, sufficient to resolve giant molecular clouds (GMC's) in galaxies as far away as Virgo cluster and to study detailed distribution of molecular gas at kpc scale out to about 100 Mpc in distance. Molecular gas is often the dominant component of the ISM in the inner disk of galaxies and the sites of current active star formation. Mapping their distribution can help probe the status of the ISM and its evolution. In this paper, I present the highlights of the recent high resolution observations of molecular gas in both normal and starburst galaxies at the Owens Valley Millimeter array and suggest possible explanations to interesting trends observed.

II. MOLECULAR GAS DISTRIBUTION IN NORMAL AND STARBURST GALAXIES

The early single dish observations of nearby spiral galaxies (Young & Scoville 1982, Scoville & Young 1983) have shown that the molecular gas distribution in normal disk galaxies can be described as exponential distribution with scale lengths of 2-4 kpc, closely following the distribution of blue light. Interferometric observations of CO emission in eight Virgo spirals by Canzian (1990) have found a similar exponential distribution with a rather massive ($1\text{-}3\times10^8 M_\odot$) central concentration centered on the nucleus. Spiral arms and other sites of young stars are often associated with prominent CO features.

The IRAS detected IR luminous starburst galaxies are by far the best studied galaxies with millimeter interferometers because of their bright CO emission. In the two nearby prototypical starburst systems M82 (Shen & Lo 1995) and NGC 253 (Canzian et al. 1988, Yun et al., in preparation), a compact nuclear molecular gas complex of about 1 kpc in diameter is found fueling the formation of young massive stars as traced in infrared with total infrared luminosity of $3 \times 10^{10} L_\odot$. Much more spectacular starburst systems known as ultraluminous infrared galaxies (ULIRGs; $L_{IR} > 10^{12} L_\odot$) such as Arp 220 or Mrk 231 host even more surprising nuclear molecular complex – over $10^{10} M_\odot$ of molecular gas concentrated in an area smaller than 1 kpc in diameter, with a resulting surface H_2 mass density $\Sigma_{H_2} > 10^4 M_\odot$ pc^{-2} (Scoville et al. 1996, Bryant & Scoville 1996) In comparison, typical surface gas mass density in spiral arms is less than 100 $M_\odot$ pc^{-2}. Most of these IR luminous galaxies are either strongly interacting or merging galaxies. A few gas rich but less luminous merging systems are found with a more extended molecular gas distribution (e.g., VV 114), and they are interpreted as dynamically young mergers and transitional objects on their way to become ULIRGs (Yun et al. 1994, Yun & Scoville 1995). Some optically selected merging galaxies ("Toomre Sequence") are also studied in CO in order to study their relationship to the IR luminous mergers, and equally compact but less massive nuclear gas concentrations are found, fueling moderate starbursts (L_{IR} = [3-10]$\times10^{10} L_\odot$; Yun & Hibbard 1996). These observational results of merger systems generally support the merger induced starburst scenario of Barnes & Hernquist (1991).

III. CENTRAL GAS DENSITY AND NUCLEAR STARBURST

Naively one would expect the total IR luminosity would correlate with the total molecular gas content, but there is a considerable scatter in this relation because of a large spread in the "star formation efficiency" (L_{IR}/M_{H_2}) among different galaxies. It was suggested previously that this star formation efficiency (L_{IR}/M_{H_2}) would be well correlated with Σ_{H_2} from the star formation consideration (e.g., Scoville et al. 1991), and this trend is indeed seen. Nevertheless, a much more striking correlation is observed between the total IR luminosity (L_{IR}) and the mean gas surface density (Σ_{H_2}).

The most straightforward explanation for the observed L_{IR}-Σ_{H_2} correlation is a simple star formation law. The slope of the correlation is near unity on the low luminosity end, and this is equivalent to a Schmidt law ($R \propto \rho^n$, Schmidt 1959) with n=1 if the observed IR luminosity is interpreted as a measure of current nuclear star formation rate. A similar linear density dependence on star formation rate has been inferred in the nearby spiral disks from the similarity in distribution between CO and optical star formation tracers (e.g., Young & Scoville 1984, Canzian 1990). On the higher luminosity end, the slope of the correlation approaches 2, and such a star formation relation with $n > 1$ is expected in the induced star formation scenario. In particular, a $\Sigma_{H_2}^2$ dependence is predicted for star formation induced by cloud-cloud collisions (Larson & Tinsley 1978). Therefore, among the galaxies with the highest mean gas density, induced star formation processes such as cloud-cloud collision may dominate the star formation process, resulting in extremely high "star formation efficiency" (L_{IR}/M_{H_2}). An alternative explanation for the steepening of the slope at high luminosity end is the contribution from the putative hidden active nucleus (e.g., Sanders et al. 1988).

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