MOLECULAR AND IONIZED GAS IN CIRCUMNUCLEAR STARBURST GALAXIES

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ABSTRACT

The present project intends to explore the causal physical connections between (a) the presence of high molecular gas surface densities in the nuclear and circumnuclear regions of galaxies, (b) the existence of a high star formation efficiency, i.e. presence of associated HII regions, and (c) the formation of an AGN, i.e. a central massive black hole, as the final product of this evolutionary path.

With regard to points (a) and (b), our results (Table 1) show that the amount of molecular gas in these galaxies is a factor of 10 smaller than in luminous IRAS galaxies. However, the global molecular gas surface brightness, $\Sigma(H_2)$, and the star formation efficiency (SFE), as measured by the usual L_{FIR}/M_{H_2} ratio, follows the correlation found for luminous IRAS galaxies extrapolated to lower surface brightness (Table 1).

If we calculate the same parameters locally, we find regions with a high (low) molecular gas surface brightness but a low (high) star formation efficiency. Examples of these situations are regions R2 and R4 (Fig. 1a) in NGC3351, and the 1480 km s^{-1} CO component in NGC3504 (Fig. 3b). It is not clear yet whether this result is a consequence of regions being in a different evolutionary phase.

In relation to points (b) and (c), we detect a galaxy, NGC3504, that could be an example of a galaxy in a starburst–AGN transient phase. This galaxy has a similar CO total mass and surface density as that observed in other Seyfert 1 galaxies for which high resolution CO maps have been obtained. It also shows a bright central radio, IR and [OIII] emission peak together with a more extended and diffuse structure. These characteristics are also similar to those of other Seyfert 1 galaxies like NGC3227 and NGC7469.

1. NGC 3351

The circumnuclear molecular gas distribution in this galaxy shows two almost equally bright emission peaks separated by about 10$''$ (i.e. 500 parsecs) in the NNE–SSW direction, as illustrated in our CO(2→1) map (see Fig. 1b). These two CO peaks are also well separated in velocity by 140 km s^{-1}. The NNE peak has a velocity of V_{LSR}= 710 km s^{-1} while the SSW peak has a centroid velocity of V_{LSR}= 850 km s^{-1}.

The total amount of molecular gas has been calculated assuming a mean CO(2→1) to CO(1→0) ratio of 0.8 and the standard CO(1→0) to M_{H_2} conversion according to the expression $N_{H_2}[cm^{-2}] = 2.8 \times 10^{20}\ I_{CO}\ [K\ km\ s^{-1}]$. The total mass of molecular gas within a region of 24$''$ by 24$''$ in size, corresponds to $M_{H_2} = 3.8 \times 10^8\ M_\odot$. The two CO peaks with comparable masses lay close to large complexes of HII regions.

The Hα map (Fig. 1a) shows a ring-like gas distribution where two of the brightest HII regions (R1 and R3 in Fig. 1a) seem to be spatially associated with the CO emission peaks. This hypothesis is also supported by the fact that the CO(2→1) over CO(1→0) ratio shows a positive gradient towards region R3 where a maximum value of 1.2 is measured. According to detailed radiative transfer models, this value indicates a fraction of the gas being optically thin, and, possibly, a high excitation temperature. These characteristics are found in M82 and may be common in starburst regions.

2. NGC 2903

This galaxy shows an elongated molecular gas distribution along the North-South direction (Fig. 2b). This elongation matches the morphology of the bright circumnuclear HII regions, as indicated by the Hα gas distribution (Fig. 2a). The total H_2 mass in a region of 24$''$ × 24$''$ is $1.9 \times 10^8\ M_\odot$.

The overall CO distribution is resolved in a 13$''$ beam, but our observations do not show individual peaks, either spatially or kinematically resolved, in spite of the several HII regions detected in an 8$''$ × 6$''$ area (Fig. 2a).

3. NGC 3504

This galaxy shows a molecular gas distribution more compact than in the previous two galaxies (see Fig. 3b). This is in good agreement with the structure detected in our Hα image (Fig. 3a) where the HII regions are distributed in a circumnuclear ring-like structure 4$''$ (i.e. 400 parsecs) in diameter.

The total molecular gas content over a size of 24$''$ by 24$''$ corresponds to $M_{H_2} \approx 2.3 \times 10^9\ M_\odot$ where it appears equally distributed in two emission peaks. The H_2 surface density quoted in Table 1 refers to the gas being uniformly distributed in a 24$''$ × 24$''$ area. If the deconvolved size of the two peaks is considered, the surface density increases by a factor of 3-4. The same applies to the molecular gas distribution in NGC 3351.

The two peaks are spatially separated by about 4$''$ almost along the EW direction, and also kinematically separated by about 120 km s^{-1}. This velocity difference is consistent with the two [OIII]5007 velocity components detected within the first 4$''$ around the nucleus. This

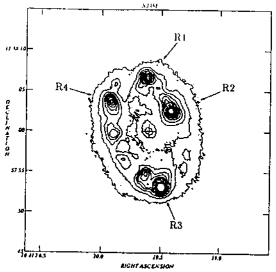
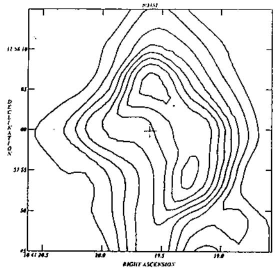


Figure 1(a): Hα image of NGC3351 obtained with the Nordic Telescope at La Palma Observatory. The pixel size corresponds to 0.196″ and the effective resolution is about 0.8″ in FWHM. The central cross indicates the emission peak in the broad R band filter. Labeled regions [indicate circumnuclear] HII complexes. The



Levels = 16, 24, 32, ..., 72 K km/s
CO 2-1 integrated line intensity, measured with the IRAM-30m telescope.
Angular resolution was 13″. Units are in Tmb.

Figure 1(b)

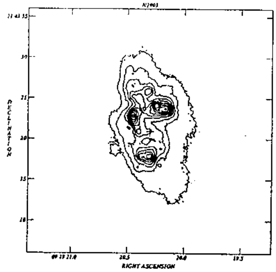
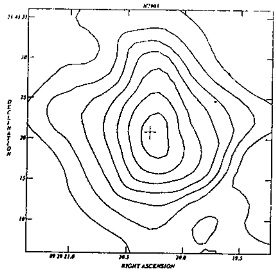


Figure 2(a): As figure 1(a) but for NGC2903. The linear scale corresponds to 36 pc arcsec^{-1}.



Levels = 20, 30, ..., 80 K km/s
CO 2-1 integrated line intensity, measured with the IRAM-30m telescope.
Angular resolution was 13″. Units are in Tmb.

Figure 2(b)

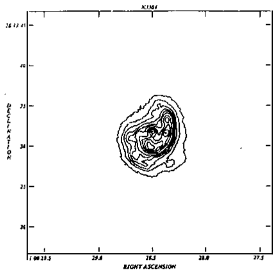
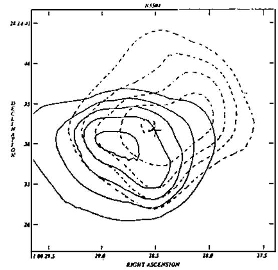


Figure 3(a): As figure 1(a) but for NGC3504. The linear scale corresponds to 100 pc arcsec^{-1}.



Levels = 24, 36, ..., 72 K km/s
CO 2-1 integrated line intensity, measured with the IRAM-30m telescope.
Full line for the 1480 km/s component; dashed line for the 1600 km/s component.
Angular resolution was 13″. Units are in Tmb.

Figure 3(b)

suggests that the motion of the cold molecular gas is also shared by the warm ionized gas. Consequently, it indicates a direct physical connection between the molecular clouds and the circumnuclear star forming regions.

Table 1: Properties of Circumnuclear Starburst Galaxies

Galaxy NGC#	$\alpha(1950)$ hh:mm:ss	$\delta(1950)$ ° ′ ″	$V_{LSR}^{(4)}$ km s^{-1}	P.A. °	i °	$D^{(5)}$ Mpc	L_{FIR} $10^9 L_\odot$	$M_{H_2}^{(6)}$ $10^8 M_\odot$	$\Sigma_{H_2}^{(7)}$ $M_\odot$ pc^{-2}	SFE $L_\odot$ $M_\odot^{-1}$
2903	09:29:20.3	21:43:21	543	17(1)	60(2)	7.2	3.6	1.9	140	19
3351	10:41:19.6	11:58:00	780	11(3)	46(3)	10.4	3.0	3.8	180	8
3504	11:00:28.5	28:14:32	1543	149(3)	22(3)	20.6	14.0	23.	380	6

REFERENCES

(1) de Vaucouleurs et al. 1991, Third Reference Catalog.
(2) Jackson, J.M. et al. 1989, Astrophys. J. **337**, 680.
(3) Grosbol, P., 1985, Astron. Astrophys. Suppl. **60**, 261.
(4) centroid of the CO emission.
(5) derived from the measured V_{LSR}, and assuming H_0=75 km s^{-1}.
(6) in a 24″ × 24″ region.
(7) H_2 mass assumed to be uniformly distributed in a 24″ × 24″ area.