

DISCOVERY OF CO EMISSION FROM NGC 1275

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ABSTRACT

We report the discovery of CO radio emission in both the $J = 1-0$ and $J = 2-1$ rotational lines from the elliptical galaxy at the center of the Perseus cluster, NGC 1275, an object which is thought to be accumulating mass in a cooling flow. We estimate $\sim 6 \times 10^9 M_\odot$ of cold interstellar matter in this galaxy, consistent with estimates from the *IRAS* 100 μm flux. This molecular material is probably forming new stars.

The CO, which probably condenses from the cooling flow, has such a small velocity dispersion that it is likely that it collapses into stars before it virializes in the gravitational potential of this galaxy which would require $< 3 \times 10^7$ yr. This time scale implies a star formation rate $> 200 M_\odot \text{ yr}^{-1}$ which is close to the value of $\sim 100\text{--}300 M_\odot \text{ yr}^{-1}$ derived from modeling the X-ray emission as a cooling flow. If the star formation rate is in fact this high, then the initial mass function is weighted toward low-mass stars.

Subject headings: galaxies: general — interstellar: molecules — stars: formation

I. INTRODUCTION

The traditional view of elliptical galaxies is that they are essentially devoid of interstellar matter. However, as technology has advanced, it has become well established that more than half of all ellipticals contain detectable amounts of interstellar matter (Schweizer 1987). Unlike spirals where most of the interstellar matter is cool ($T < 100$ K), within ellipticals, X-ray data show that most of the interstellar matter is hot ($T > 10^7$ K). Nevertheless, appreciable ($> 10^7 M_\odot$) amounts of cold interstellar matter are frequently detected within ellipticals (Jura *et al.* 1987).

NGC 1275 is a giant elliptical galaxy at the center of the Perseus cluster (Kent and Sargent 1979; Hu *et al.* 1983; Wirth, Kenyon, and Hunter 1983). This galaxy is a bright X-ray source, and the X-ray data are interpreted as the emission from a cooling flow such that $\sim 100\text{--}300 M_\odot \text{ yr}^{-1}$ (scaled to $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$) is flowing into this galaxy (Cowie and Binney 1977; Fabian *et al.* 1981; Sarazin 1986; Silk *et al.* 1986). It is not clear what happens to all this infalling matter.

A strong candidate for the ultimate fate of this material that flows into ellipticals is star formation (Cowie and Binney 1977; Fabian, Nulsen, and Canizares 1982; Johnstone, Fabian, and Nulsen 1987; Jura 1977; Sarazin and O'Connell 1983; White and Sarazin 1987a, b, c; Silk *et al.* 1986). In NGC 1275, there is "excess" blue light which can be understood if there are appreciable numbers of young stars (Wirth, Kenyon, and Hunter 1983; Romanishin 1987). If star formation is proceeding, then by analogy to the Milky Way, there should be cold, molecular material present in this galaxy. H_2 has been detected in emission from this object (Fischer *et al.* 1987), but it is probably shock-excited with $T > 1000$ K, and it is very difficult to estimate the total amount of molecular material. Previous searches for CO and cold molecular material from which stars can form have been unsuccessful (Bieging *et al.* 1981; Jaffe 1987). Here, we report the detection of CO radio emission from NGC 1275. This result is consistent with the view that large amounts

of cold molecular material are present in this galaxy and that substantial star formation activity is proceeding.

II. OBSERVATIONS

We obtained our data at the 30 m IRAM telescope during 1988 March 8–11. The system temperature outside the atmosphere was 800–900 K (115 GHz), and around 1000 K (230 GHz). The spectra are expressed as main-beam brightness temperatures using beam efficiencies of 0.56 (115 GHz) and 0.45 (230 GHz). Besides the central position, two other points were observed, based on the $\text{H}\alpha$ emission maps of Hu *et al.* (1983).

The spectra for the $J = 1-0$ and $J = 2-1$ rotational lines are shown in Figure 1. Table 1 lists several parameters of interest.

III. INTERPRETATION

We adopt $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and scale all quantities accordingly. The distance to NGC 1275 is 69 Mpc, and the beam angular diameter (21" for the 1–0 transition) corresponds to 7 kpc. We estimate the amount of mass in molecular material from the formula given by Sanders *et al.* (1986) (see also Dickman, Snell, and Schloerb 1986):

$$M_T(\text{H}_2) = 5.82[(\pi/4)d_b^2 I_{\text{CO}}],$$

where I_{CO} is the total $J = 1-0$ CO line integrated intensity (K km s^{-1}), and d_b (pc) is the telescope beam diameter at the distance of the source. With $I_{\text{CO}} = 25 \text{ K km s}^{-1}$, then $M_T(\text{H}_2) = 6 \times 10^9 M_\odot$. Using the same Hubble constant, Jura *et al.* would have estimated from the *IRAS* 100 μm flux a mass of $6 \times 10^9 M_\odot$ of cold interstellar matter, so the results are consistent with each other.

The good agreement between our measured velocity of 5230 km s^{-1} and the optical velocity of 5216 km s^{-1} (Sandage and Tammann 1981) indicates that the molecular material is dynamically part of NGC 1275. This naturally occurs in models where the CO condenses out of hot gas flowing into the center of NGC 1275, but it is not easily understood if we are

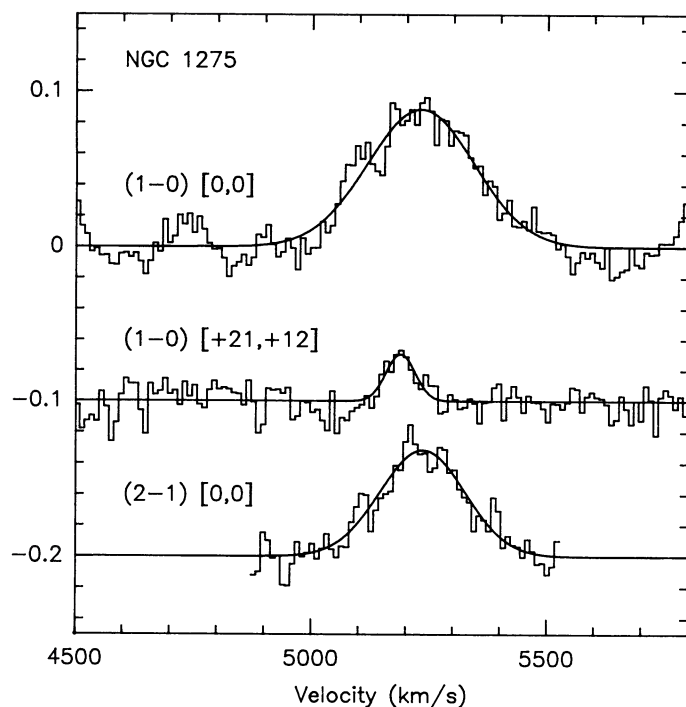


FIG. 1.—Spectra of CO (1–0) and (2–1) observed in NGC 1275. Offsets are indicated in square brackets. The spectra have been smoothed to 4 MHz for the (1–0) line and 8 MHz for the (2–1) line, corresponding to 10.6 km s^{-1} in the source rest frame. Linear baselines were used; Gaussian fits to the data are shown.

witnessing the collision between a gas-rich companion to a giant elliptical (Hu *et al.* 1983).

It appears that the molecular gas is associated with the ionized gas observed in the H α filaments. We have reconstructed from the color-coded maps of Hu *et al.* (1983) the H α spectrum that would have been observed in beams identical to our radio beam at the two positions where we detect CO emission. The results are summarized in Table 2. The line parameters are not expected to be identical, but the changes of central velocity, line width, and integrated intensity between the two positions are similar in CO and H α , and strongly suggest that the CO- and H α -emitting regions are associated. In the rest of the discussion, we assume that the CO gas has a spatial distribution similar to that of the H α -emitting gas, and that the bulk of the emission originates within $10''$ (3.5 kpc) of the center of NGC 1275.

In order to derive values for selected parameters of the potential well of NGC 1275, we have modeled its mass dis-

TABLE 2
PROPERTIES OF H α EMISSION INSIDE THE CO BEAMS

Offset (α , δ)	Line Area (arbitrary units)	Velocity (km s^{-1})	FWHM (km s^{-1})
0', 0'	5.8	5250 (30)	370
+21, +12	1.6	5130 (30)	170

tribution as:

$$\rho = \rho_0 [1 + (r/r_0)^2]^{-1.375}$$

with $\rho_0 = 8.9 \times 10^{-22} \text{ g cm}^{-3} = 1.3 \times 10^{10} M_{\odot} \text{ kpc}^{-3}$ and $r_0 = 1 \text{ kpc}$. These parameters are essentially taken from White and Sarazin (1988) with the assumption that $M/L = 6$ in solar units. From this density distribution, we derive the following values for parameters of interest: (1) stellar mass interior to 7 kpc, two beam radii, $= 3.3 \times 10^{11} M_{\odot}$; (2) a time for a cloud initially at rest at 7 kpc from the center of the galaxy to accelerate to 400 km s^{-1} of $\sim 2 \times 10^7 \text{ yr}$; and (3) a stellar velocity dispersion of $\sigma_* = 290 \text{ km s}^{-1}$.

To derive the stellar velocity dispersion, σ_* , we assume it is everywhere isotropic and compute the “pressure,” $p = \rho \sigma_*^2$, by integrating the equation of stellar hydrodynamics:

$$dp/dr = -\rho g.$$

The measured velocity dispersion of the CO can be used to infer the kinematics of the material. The stellar velocity dispersion σ_* corresponds to a FWHM profile width:

$$W_{\text{FWHM}} = 2^{3/2} (\ln 2)^{1/2} \sigma_* = 2.35 \sigma_*.$$

If the FWHM of the CO were the same as that of the stars, this would imply a stellar velocity dispersion of 113 km s^{-1} . This is markedly lower than the typical value for giant elliptical of 300 km s^{-1} (Whitmore, McElroy, and Tonry 1985) and much smaller than predicted by the density distribution given above. Also, the observed FWHM of the H α emission filaments of 350 km s^{-1} (Kent and Sargent 1979) is considerably less than would be expected from a giant elliptical galaxy. Therefore, although because the optical spectra are complex and the stellar radial velocity dispersion has not been accurately measured for NGC 1275, it seems that the gas displays a significantly smaller velocity dispersion than do the stars.

In the usual models for cooling flows, the matter accretes subsonically into the galaxy. Therefore, if the CO condenses out of the infall, it should be moving initially nearly at rest relative to the center of mass of the system. However, once the gas is no longer supported by the high pressure of the hot, X-ray-emitting gas, we anticipate that it will accelerate within

TABLE 1
SUMMARY OF CO OBSERVATIONS

Offsets (α , δ) (1)	Transition (2)	Integration Time (minutes) (3)	Line Area* (K km s^{-1}) (4)	Velocity* (km s^{-1}) (5)	FWHM* (km s^{-1}) (6)
0'', 0''	(1–0)	165	25 (0.8)	5230 (4)	266 (10)
+21, +12	(1–0)	149	2.4 (0.4)	5188 (6)	73 (14)
0, 0	(2–1)	97	15 (0.7)	5233 (5)	208 (10)

* Parameters derived from Gaussian fits, with formal errors in parentheses. The radial velocities are heliocentric. All the uncertainties may be underestimates because we quote only formal statistical errors, and there may be additional systematic errors such as baseline curvature.

the gravitational potential of the galaxy. Therefore, eventually, the gas should virialize in the system. Because we observe the gas to have a much smaller velocity dispersion than we imagine the stars to have, it seems that the gas does not exist in molecular form long enough to achieve complete virialization. In this case, the lifetime of the molecular clouds must be less than a crossing time. The very small velocity dispersion of 70 km s^{-1} of the CO gas found away from the center of NGC 1275 is consistent with this interpretation.

It is not out of the question that we are observing emission from a face-on flat disk of CO rather than blobs that have condensed out of a cooling flow. However, the good correspondence between the CO and H α kinematics and the lack of any rotation pattern in the well-studied H α emission (Rubin *et al.* 1978; Hu *et al.* 1983) argues against the picture that the CO emission originates in an otherwise ordinary disk.

Conservatively, if the matter originates at 7 kpc from the center of NGC 1275 and is moving at 100 km s^{-1} , the time to accelerate to this speed is appreciably less than $3 \times 10^7 \text{ yr}$. This implies that the lifetime of the clouds is $< 3 \times 10^7 \text{ yr}$. With $6 \times 10^9 M_{\odot}$ of material, this implies a star formation rate $> 200 M_{\odot} \text{ yr}^{-1}$, a value fully consistent with that derived from the cooling flows and the usual Jeans estimates for the gravitational collapse of molecular clouds (Spitzer 1978).

On the other hand, if the cooling flow has been proceeding steadily over a time on the order of 10 Gyr, it should have accumulated $2 \times 10^{12} M_{\odot}$. If we assume that star formation is confined to the region of H α and CO emission, this mass is incompatible with the inferred mass of NGC 1275 within the same radius.

Currently, there are a wide range in the estimates of the star formation rate in NGC 1275 (Fischer *et al.* 1987; Johnstone, Fabian, and Nulsen 1987; Romanishin 1987; Silk *et al.* 1986; Wirth, Kenyon and Hunter 1983) using standard initial mass functions similar to those in the local Milky Way. On the basis of the amount of "excess" blue light and the intensity of the H α or Br γ emission, star formation rates of between 1 and $30 M_{\odot} \text{ yr}^{-1}$ are estimated. Part of this range can be explained in terms of using different Hubble constants, different aperture

observations from which the data are analyzed, and different models to extrapolate to the total star formation rate (Gehrz, Sramek, and Weedman 1983; Hunter, Gallagher, and Rautenkranz 1982; Johnston, Fabian, and Nulsen 1987). If the star formation rate is close to the value of $200 M_{\odot} \text{ yr}^{-1}$ that is derived from analysis of both the X-ray and molecular data, then the new stars are preferentially of lower mass (see, for example, Jura 1977). If low-mass stars are preferentially formed in cooling flows, this may have profound consequences for our understanding of the mass-to-light ratios in galaxies.

Our results support the high rate of star formation deduced from the modeling of the cooling flow, but suggest that we may be witnessing a transient phenomenon.

IV. SUMMARY

1. We have detected CO emission from NGC 1275. The inferred mass of molecular material is $\sim 6 \times 10^9 M_{\odot}$. The presence of molecular material is consistent with the view that active star formation is occurring within this galaxy.

2. Because the velocity of the CO is very close to that of the stars, the most natural explanation for the origin of this material is that it condenses out of the cooling flow of ~ 100 – $300 M_{\odot} \text{ yr}^{-1}$ that this galaxy is accreting.

3. Since the velocity dispersion of this gas is much smaller than what we believe to be the velocity dispersion of the stars, it seems that the molecular material does not have time to be virialized in the gravitational field of the galaxy. This implies a lifetime of the clouds of $< 3 \times 10^7 \text{ yr}$ and thus a star formation rate of $> 200 M_{\odot} \text{ yr}^{-1}$, consistent with the inferred inflow rate. If the star formation rate is in fact this high, the initial mass function in NGC 1275 is weighted more toward low-mass stars than the initial mass function in the solar neighborhood.

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