CO J = 2-1 observations of the central region of NGC 3628

Israel, F.P.; Maloney, P.R.; Baas, F.

Citation

Israel, F. P., Maloney, P. R., & Baas, F. (1990). CO J = 2-1 observations of the central region of NGC 3628. *Astronomy And Astrophysics*, *237*, 17-20. Retrieved from https://hdl.handle.net/1887/7223

Astron. Astrophys. 237, 17–20 (1990)

ASTRONOMY
AND
ASTROPHYSICS

CO $J=2-1$ observations of the central region of NGC 3628

F.P. Israel[1], **F. Baas**[2,3], **and P.R. Maloney**[1]

[1] Sterrewacht Leiden, Huygens Laboratorium, Postbus 9513, NL-2300 RA Leiden, The Netherlands
[2] Laboratory Astrophysics, Huygens Laboratorium, Postbus 9513, NL-2300 RA Leiden, The Netherlands
[3] Joint Astronomy Centre, 665 Komohana Street, Hilo, HI 96720, USA

Received February 9, accepted March 21, 1990

Abstract. We present a fully sampled map at 21″″ resolution of the $J=2-1$ CO emission from the center of the interacting galaxy NGC 3628 in the Leo triplet. We confirm earlier conclusions that the center contains a strong CO concentration of major axis diameter 14″ (450 pc at 6.7 Mpc distance). The mass of this concentration, estimated from ^{13}CO observations, is of order $3\ 10^7\ M_\odot$, or 5% of the total mass of stars and gas in the center. The molecular concentration is probably coincident with the rotating disk seen in H I absorption. The H_2 to CO conversion factor of the NGC 3628 core appears to be lower than that of the disk of our Galaxy by a factor of about 5, suggesting that the CO in the core of NGC 3628 is rather warm. The core of NGC 3628 does not appear to be the site of a starburst.

Key words: galaxies – CO emission – nuclear disks

1. Introduction

NGC 3628 is an Sbc galaxy, seen edge-on. It is part of the Leo triplet (Arp 217) which also contains NGC 3623 (M 65) and NGC 3627 (M 66, Arp 17). In the literature, distance estimates are found ranging from 6.7 to 24 Mpc. For the sake of consistency with previous discussions, we adopt $D=6.7$ Mpc (De Vaucouleurs, 1975). For the orientation of the major axis of NGC 3628, we adopt PA = 104°. H I observations (Rots, 1978; Haynes et al., 1979) and optical observations (Burkhead and Hutter, 1981) indicate strong tidal interaction between NGC 3628 and NGC 3627 which has been modelled by Rots (1978) and Boisse et al. (1987). NGC 3628 contains a central continuum radio source of 5″ × 1″ size (Van der Hulst et al., 1981; Condon et al., 1980), corresponding to 160 × 35 pc. The central region has been detected in the far-infrared (Rickard and Harvey, 1984; Rice et al., 1988). Against the central continuum radio source, several species, such as H I, OH and H_2CO have been seen in absorption (Dickey, 1982; Schmelz et al., 1987; Rickard et al., 1982; Baan et al., 1986).

The central region was detected in the $J=1-0$ CO transition by Rickard et al. (1985; HPBW = 65″), Young et al. (1983; HPBW = 50″) and Boisse et al. (1987; HPBW = 22″; hereafter BCC). The latter authors show the presence of a marginally resolved central CO component. We have included NGC 3628 in our survey of the central CO emission in galaxies bright at infrared wavelengths. Here we report on the result of our $J=2-1$ CO observations.

2. Observations

The Observations were obtained in February 1989 with the JCMT on Mauna Kea, Hawaii. At the observing frequency, the JCMT has a beamwidth of 21″, very nearly equal to that of the IRAM 30 m telescope at the frequency of the $J=1-0$ CO transition. We used the common-user receiver A, with an overall single sideband system temperature (including the sky) of about 1000 K, together with the 500 MHz acousto-optical backend AOSC. The observations were made in a position-switching mode, with integration times of 20 s. Integration times per position were generally of order 5–10 min on-source; the central position was reobserved several times for a total of about 30 min on-source. The reference position was offset by 10′ in azimuth, well-clear from the galaxy. The temperature scale used is T_R^*, assuming $\eta_{\rm fss}=0.7$; on this scale Orion A and IRC + 10216 have $T_R^*(J=2-1\ ^{12}{\rm CO})=150$ K and 36 K and $T_R^*(J=2-1\ ^{13}{\rm CO})=50$ K and 4.5 K respectively. Pointing was frequently checked on the planets Mars and Jupiter, and on IRC + 10216. The pointing of the observations presented here is accurate to about 3″ rms. A total of 30 positions was observed, in a grid oriented along the major axis of NGC 3628, with a spacing of 10″. We also observed the central position in the $J=2-1\ ^{13}$CO transition.

3. Analysis

3.1. Observational results

Figure 1 contains the individual observed profiles binned to a resolution of 13.0 km s^{-1}, obtained after fitting linear baselines (in some cases also second-order polynomials) to the observed profiles. The rms noise in these spectra is $T_R^*=70$ mK, except for the central position which has an rms noise of 30 mK. The positional grid is oriented along the major and minor axes respectively. There is a relatively strong ($T_R^*=0.67\pm0.03$ K) signal with a broad velocity distribution (FWHM 215 km s^{-1}) at the map center, quickly disappearing along the minor axis. Along the major axis, the peak signal drops to about 60% of the central peak signal, then stays constant. The velocity width decreases to

---

Send offprint requests to: F.P. Israel

1990A&A...237..171I

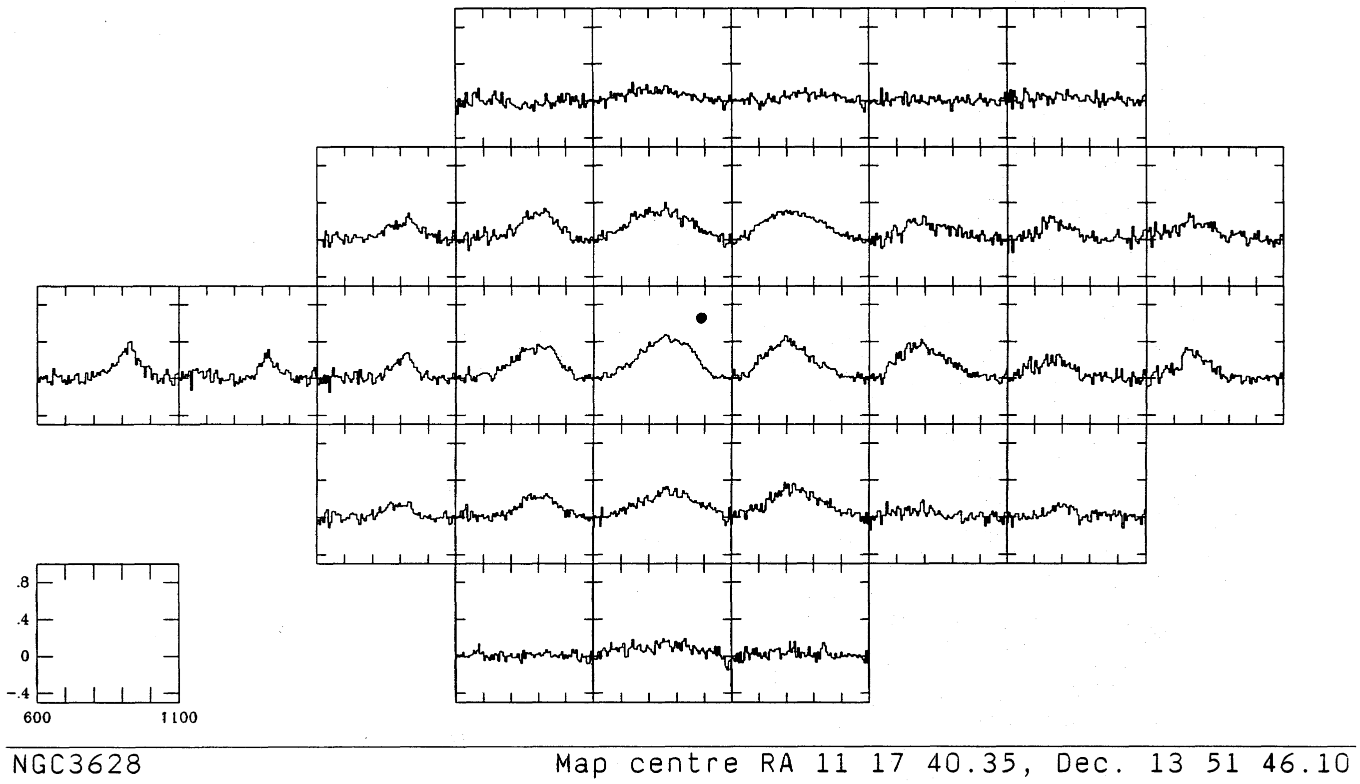

Fig. 1. Observed profiles of $J=2-1$ ^{12}CO emission from NGC 3628, shown in a rectangular grid along major/minor axis. Frame separation is 10″; velocity resolution 13.0 km s^{-1}. Intensities in $T_A^* = 0.7\,T_R^*$. Frame containing central profile is marked by a dot in the upper right corner

about a third of the central value; thus integrated CO strengths drop to 20% of the peak before reaching constancy.

In Fig. 2 we compare the ^{12}CO and ^{13}CO profiles of the central position. Because of its low signal to noise ratio, the latter was binned to a resolution of 42 km s^{-1}. Because of its weakness and the limited velocity range covered, the error in the ^{13}CO strength is mostly due to baseline uncertainty. In order to determine the magnitude of this uncertainty, we have fitted several baselines to the observed profile. The best result is $T_R^* = 0.10 \pm 0.02$ K, and $\int T_R^*\,dV = 12 \pm 3$ K km s^{-1}. Thus, the $J=2-1$ ^{12}CO/^{13}CO ratio is 6.7 ± 1.2 for the peak signal; for the integrated signal, the ratio is 11 ± 2.5. The ^{13}CO emission appears narrower in velocity than the ^{12}CO emission by about 60%. Although we would like to base our conclusion on ^{13}CO data with a better S/N ratio, this may indicate a lower ^{12}CO optical depth for fast-rotating material, i.e. for molecular material relatively close to the nucleus.

Figure 3 is a map of total $J=2-1$ ^{12}CO emission integrated over the velocity interval of 500 to 1200 km s^{-1} (LSR). Again, the orientation of the map is along the major and minor axes of NGC 3628. There is a clear concentration of molecular material in the galaxy center, superposed on relatively weak disk emission, thus confirming the result obtained by BCC. The map peak is within a few arcsec from our (0,0) position ($\alpha = 11$:17:40.35, $\delta = +13$:51:46.1), coincident with the radio nucleus (Van der Hulst et al., 1981; Condon et al., 1982). This position is, within the errors, the same as found in $J=1-0$ ^{12}CO by BCC. As pointed out by the latter, it does not coincide with the position of either the optical nucleus or that of the far-IR IRAS source associated with NGC 3628. We note that the optical "nucleus" is located at the edge of the molecular core, indicating that the true nucleus is completely obscured. With respect to the infrared data, we note that at 12 μm the IRAS emission appears, in fact, centered on the radio/molecular nucleus and that the IRAS source is virtually pointlike, especially at 12 and 25 μm (cf. Rice et al., 1988). At 60 and 100 μm, the IRAS source shows a southward extension at a few % of the peak brightness, and at the same position and angle as the southward H I extension seen by Haynes et al. (1979).

The FWHM dimensions of the molecular core (Fig. 3) are 35″ × 29″, in very good agreement with the $J=1-0$ CO result obtained by BCC (1987). However, the emission at the center is enhanced by the underlying, more broadly distributed but unrelated CO emission from the disk of NGC 3628. Subtracting this emission from the map we find FWHM diameters of 25″ × 23″. After correction for the finite beamsize, this indicates an intrinsic molecular core size of 14″ × 9″ (or 450 × 290 pc at $D = 6.7$ Mpc). As in particular the minor-axis diameter is near the JCMT resolution limit, the error in its value is relatively large. However, the CO major axis diameter agrees very well with the diameter of 410 pc found by Schmelz et al. (1987) for the H I core of NGC 3628.

Figure 4 contains the position-velocity distribution of CO along the major axis. Note that the latter is offset from the dark band by about 10″. The diagram shows the usual rotational "flipover" of velocities around the (0,0) velocity of $V_{\rm LSR} = 860$ km s^{-1}. The general appearance of Fig. 4 is similar to the major-axis position velocity diagram in the $J=1-0$ transition (BCC), with a few differences. There is no sign of the secondary maximum shown at −30″ in Fig. 3 from BCC (which should show up at −40″ in our Fig. 4), whereas we find peak and centroid velocities about 40 km s^{-1} less positive at the other end of the diagram (+30″ in Fig. 4). At present, we have no explanation for

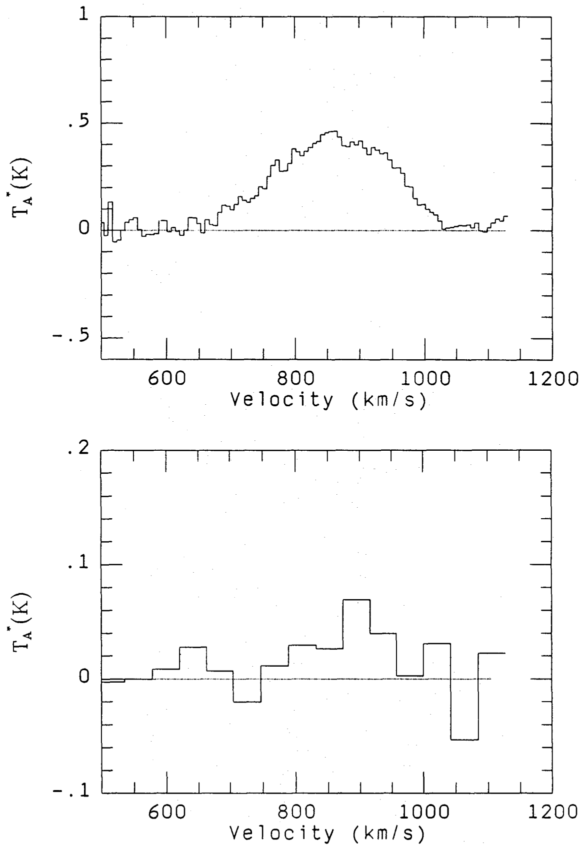

Fig. 2. Central $J=2-1$ ^{12}CO profile, with a velocity resolution of 6.4 km s^{-1} (top), and corresponding $J=2-1$ ^{13}CO profile with a velocity resolution of 41.6 km s^{-1}. Intensities in $T_A^* = 0.7\, T_R^*$

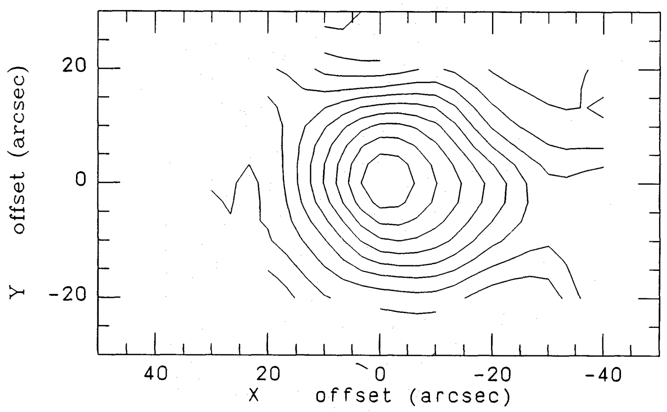

Fig. 3. Map of $J=2-1$ ^{12}CO emission integrated over V(LSR) = 600–1100 km s^{-1}. Contour values are from 14.3 K km s^{-1} to 130 K km s^{-1} in steps of 14.3 K km s^{-1}. Central peak has $T_R^* = 141$ K km s^{-1}. Positions sampled are every 10″

these differences, but we note that both positions are at the edge of our position-velocity map.

3.2. *Total mass of the central core*

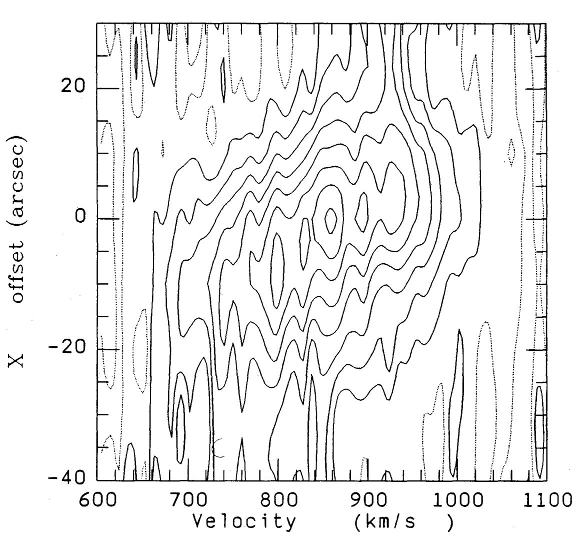

Fig. 4. Position-velocity map of CO emission along the major axis of NGC 3628. Contour values range from 0.07 K to 0.57 K in steps of 0.07 K. Dashed contour is $T_R^* = -0.07$ K

With the information now available, we can estimate the mass of the central regions of NGC 3628. The kinematics implied by Fig. 4 yield both upper and lower limits to the *total* mass of the central region. Emission due to the molecular core spans a range of about 280 km s^{-1}. The *highest* velocities must occur at *less* than the molecular core radius. Thus, by assuming circular velocities we find an upper limit for the total mass within $R = 225$ pc of $M(\text{tot}) < 10\ 10^8\, M_\odot$. A lower limit is obtained by taking the rotational velocities at $\Delta R = \pm 20''$. These represent material that *cannot be closer* to the nucleus than 325 pc (i.e. 10″). We find $M(\text{tot}) > 3\ 10^8\, M_\odot$. Another estimate for the total mass is obtained from the H I absorption results. From Dickey (1986), we find for a core radius of 200 pc a mass of order $M(\text{tot}) = 2\ 10^8\, M_\odot$, whereas Schmelz et al. (1987) estimate $M(\text{tot}) = 6$–$10\ 10^8\, M_\odot$, consistent with our result. Thus, the best estimate for the total mass with 200 pc from the nucleus is $M(\text{tot}) = 7 \pm 3\ 10^8\, M_\odot$ ($D = 6.7$ Mpc).

The (optical) center of NGC 3628 was observed between 50 and 160 μm with a 40″ aperture by Rickard and Harvey (1984). They found a total FIR luminosity of 3.5 $10^9\, L_\odot$ (scaled to $D = 6.7$ Mpc). The IRAS luminosity of the whole galaxy, again scaled to 6.7 Mpc, is $L(\text{FIR}) = 4.3\ 10^9\, L_\odot$. A luminosity of 3.5 $10^9\, L_\odot$ in a 40″ aperture corresponds to a total stellar mass within 650 pc from the *optical* nucleus of $M(\text{stellar}) = 5\ 10^6\, M_\odot$ if the infrared emission is dominated by young luminous stars (starburst), and to about $M(\text{stellar}) = 7\ 10^8\, M_\odot$ if it is dominated by evolved stars. The above results therefore suggest that the core of NGC 3628 does not contain a dominant presence of luminous young stars.

3.3. *Molecular core mass and H_2/CO conversion*

From the observed ^{12}CO and ^{13}CO emission we obtain, by assuming $N(H_2) = 5\ 10^5\, N(^{13}\text{CO})$, $T_{\text{ex}} = 10$–15 K and a beam filling factor of about 5–15, a mass $M(H_2) = 1$–$3\ 10^7\, M_\odot$. By taking into account the uncertainties in the ^{13}CO profile, this could be increased by at most a factor of two. Thus, the molecular mass is roughly of order 5% of the total central mass.

A rather different result is obtained by using Galactic standard conversions such as $N(H_2) = 2.3\ 10^{20}\, T_R^*\, dV$ (Bloemen et al., 1986) which yields $M(H_2) = 2\ 10^8\, M_\odot$, implying that about 30% of the total mass is in molecular form. If about 20% of the central integrated emission is due to unrelated disk emission (Sect. 3.1), this value could be lowered to about 1.5 $10^8 M_\odot$. It thus appears that the standard conversion overestimates the H_2 mass present by typically a factor of five. In the Galactic Center region, a similar effect has been noted by Blitz et al. (1985). In NGC 3628, it cannot be explained by abundances different from solar, as these would affect the mass estimates in roughly the same way. More probably, the degree of excitation of the central CO in NGC 3628 is higher than normally found in the disk of our Galaxy.

The appearance of NGC 3628 in the two lower CO transitions is very similar (this paper, BCC). This is significant, as the beamsizes used in the two sets of observations are virtually the same. Whether or not this similarity has anything more than incidental meaning can only be determined by further observations of other galaxy nuclei and disks. Assuming proper calibration for both data sets, the ratio of the CO strengths in the $J=2-1$ to that of the $J=1-0$ transitions is 1.0 ± 0.1, which merely indicates $T_{\rm ex} > 20$ K, because of the poor sensitivity of the $J=2-1/J=1-0$ ratio to higher temperatures. However, the calibrator spectra published by Mauersberger et al. (1989) for the IRAM 30 m telescope, and the calibrator strengths given in Sect. 2 suggest a calibration discrepancy between the IRAM and the JCMT telescopes, which would lead to a ratio of 0.8 ± 0.1 instead, corresponding to $T_{\rm ex} = 10\,(-3, +10)$ K. In this light, observation of the NGC 3628 core in higher CO transitions such as $J=3-2$ is highly desirable.

3.4. Circumnuclear disk in NGC 3628

High resolution (VLA – 1″) H I absorption measurements of the center of NGC 3628 led Schmelz et al. (1986) to propose the existence of rapidly rotating central gas disk. For the outer radius of this disk they found 205 pc, while the thickness is much less. The disk is, at least in H I, rather clumpy. The radio continuum also has a disk-like morphology, but is smaller; it appears to be embedded in the H I disk. It is tempting to identify the central molecular concentration in NGC 3628 with the H I disk, especially in view of the very similar extent. In the above, we have estimated the total mass of gas and stars within the boundaries of the disk at about 7 $10^8 M_\odot$ (if $D = 6.7$ Mpc). The total molecular mass is of order 3 $10^7 M_\odot$ (5%), while the H I mass can be estimated from the published data to be very roughly of order 5 $10^6 M_\odot$ (about one %). The mass and size of the central molecular disk in NGC 3628 are very similar to those of the corresponding disk in NGC 5128 (Cen A) as derived by Israel et al. (1990). The present data do not allow to determine further physical constraints. In this respect, aperture synthesis CO observations, $J=3-2$ CO observations, and near-IR H_2 observations, particularly of the extent of H_2 emission would be extremely useful.

Acknowledgements. It is a pleasure to thank the staff of the JCMT for their efforts in obtaining the data contained in this paper under sometimes difficult conditions. The referee, F. Casoli, made useful comments leading to an improvement of the paper.

References

Baan, W.A., Gusten, R., Haschick, A.D.: 1986, *Astrophys. J.* **305**, 830

Blitz, L., Bloemen, J.G.B.M., Hermsen, W., Bania, T.M.: 1985, *Astron. Astrophys.* **143**, 267

Bloemen, J.B.G.M. and 9 other authors: 1986, *Astron. Astrophys.* **154**, 25

Boisse, P., Casoli, F., Combes, F.: 1987, *Astron. Astrophys.* **173**, 229

Burkhead, M.S., Hutter, D.J.: 1981, *Astron. J.* **86**, 523

Condon, J.J., Condon, M.A., Gisler, G., Puschell, J.J.: 1982, *Astrophys. J.* **252**, 102

De Vaucouleurs, G.: 1975, *Stars and Stellar Systems* **9**, 309

Dickey, J.M.: 1982, *Astrophys. J.* **263**, 87

Dickey, J.M.: 1986, *Astrophys. J.* **300**, 190

Haynes, M.P., Giovanelli, R., Roberts, M.S.: 1979, *Astrophys. J.* **229**, 83

Israel, F.P., Van Dishoeck, E.F., Baas, F., Koornneef, J., Black, J.H., De Graauw, Th.: 1990, *Astron. Astrophys.* **227**, 342

Mauersberger, R., Guelin, M., Martin-Pintado, J., Thum, C., Cernicharo, J., Hein, H., Navarro, S.: 1989, *Astron. Astrophys. Suppl.* **79**, 217

Rice, W., Lonsdale, C.J., Soifer, B.T., Heugebauer, G., Kopan, E.L., Lloyd, L.A., De Jong, T., Habing, H.J.: 1988, *Astrophys. J. Suppl.* **68**, 91

Rickard, L.J., Bania, T.M., Turner, B.E.: 1982, *Astrophys. J.* **252**, 147

Rickard, L.J., Harvey, P.M.: 1984, *Astron. J.* **89**, 1520

Rickard, L.J., Turner, B.E., Palmer, P.: 1985, *Astron. J.* **90**, 117

Rots, A.H.: 1978, *Astron. J.* **83**, 219

Schmelz, J.T., Baan, W.A., Haschick, A.D.: 1987, *Astrophys. J.* **315**, 492

Van der Hulst, J.M., Crane, P.C., Keel, W.C.: 1981, *Astron. J.* **86**, 1175

Young, J.S., Tacconi, L.J., Scoville, N.Z.: 1983, *Astrophys. J.* **269**, 136