JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
31: 95 ~ 99, 1998

CO OBSERVATIONS OF OPTICALLY SELECTED BARRED GALAXIES

LEE, HYUNG MOK[1], KIM HYORYOUNG[2] AND ANN HONGBAE[1]
[1]Department of Earth Sciences, Pusan National University, Pusan 609-735, Korea
[2]Taeduck Radio Astronomy Observatory, Daejeon 305-348

(Received Aug. 20, 1998; Accepted Sep. 15, 1998)

ABSTRACT

We report preliminary results of an on-going survey of optically selected barred galaxies with ^{12}CO(J=1-0) line. The entire sample is composed of about 100 bright barred galaxies ($B_T \leq 13$) with small inclination angle. Most of the galaxies are relatively nearby with receding speed less than 10,000 km/sec. In the first observing run, we have observed central parts of 18 galaxies and detected CO emissions from 5 galaxies (NGC521, 2525, 4262, 4900, and 7479). Most of these galaxies are not observed with CO previously, except for NGC7479 which has been studied at various wavelengths. The peak antenna temperature of detected galaxies ranges from about 30 to 300 mK.

Key Words : celestial mechanics – stellar dynamics – globular clusters : general

I. INTRODUCTION

Barred galaxies are known to comprise nearly 50% of all spiral galaxies. The mechanism for the formation of stellar bar is not very well understood, but the effects of the bar on the galactic evolution have been extensively studied. The stellar bar is considered to be a long lived phenomena. The rotation of the bar produces fluctuating potential and the motion of stars and the interstellar clouds should be greatly influenced by the presence of the bar. In general, non-circular velocity component develops among interstellar clouds and stars (e.g., Binney et al. 1991). The clouds then could experience collisions that take away orbital energy. The clouds would spiral into the central parts where more frequent collisions are expected. It has been known for a long time that the star formation activity in barred galaxies is relatively strong (e.g., Soifer, Houck & Neugebauer 1987).

According to recent numerical simulations, the shape of the central bulge could evolve due to mass inflow in barred galaxies. The tri-axial bulges preferentially found from the barred galaxies (Kormendy 1982, Ann 1995) could be a result of the secular evolution driven by the bar. The complex structures such as dust lanes, nuclear rings, and nuclear spiral arms found from high resolution CCD data are believed to be related to the bar. Our galaxy is also known to have a bar from various studies. For example, the kinematic structure of the galactic center molecular clouds revealed by various molecular lines (e.g., CO by Bitran [1987], CS by Bally *et al.* [1988], and HCN by Lee [1996], among others) strongly suggests the presence of a bar.

The bar affects stars and clouds in the same manner, but they act differently. It is hard to produce complex morphology in stellar distribution because stars are 'collisionless' particles that move along orbits determined by smooth potential of the galaxy. The clouds, on the other hand, are affected by hydrodynamical collisions which significantly modify the kinematics of the clouds. The stars and clouds acquire non-circular velocity components and the clouds can collide rather frequently because of their large cross sections. Shocks resulting from cloud collisions produce rather sharp edges and orbital energy can be dissipated as a result of the collisions (e.g., Lee et al. 1998). The hydrodynamic collisions obviously are much more frequent in barred galaxies than in normal spirals. Therefore, we expect rather complex shape in the distribution of interstellar clouds compared to that of stars.

The distribution of interstellar clouds can be best studied by mapping galaxies with molecular lines such as ^{12}CO(J=1-0) line. Unfortunately, the angular resolution of single dish radio observation is inadequate to study the detailed distribution of clouds. One can use millimeter array to obtain angular resolution comparable to optical observation, but it requires much longer integration than single dish observations. Also only strong sources can be reliably mapped with arrays.

The selection of strong CO galaxies should be done using single dish telescopes. There have been many CO surveys of external galaxies (e.g., Young & Scoville 1990, Young et al. 1995, Elfhag et al. 1996). A large number of galaxies have been detected with CO up to now. Most of these galaxies are normal spirals. Most of the surveys are done for galaxy samples with rather strong IR emission. The CO luminosity is found to be more tightly correlated with the IR luminosity than optical.

No systematic studies have been done for barred galaxies, although there are some barred galaxies in the previously observed samples. The purpose of the present study is to observe barred galaxies with CO lines in order to select CO bright galaxies which can be studied with high resolution instruments. In this paper, we report the result of the first survey that has been carried out at Taeduck Radio Astronomy Observatory (TRAO).

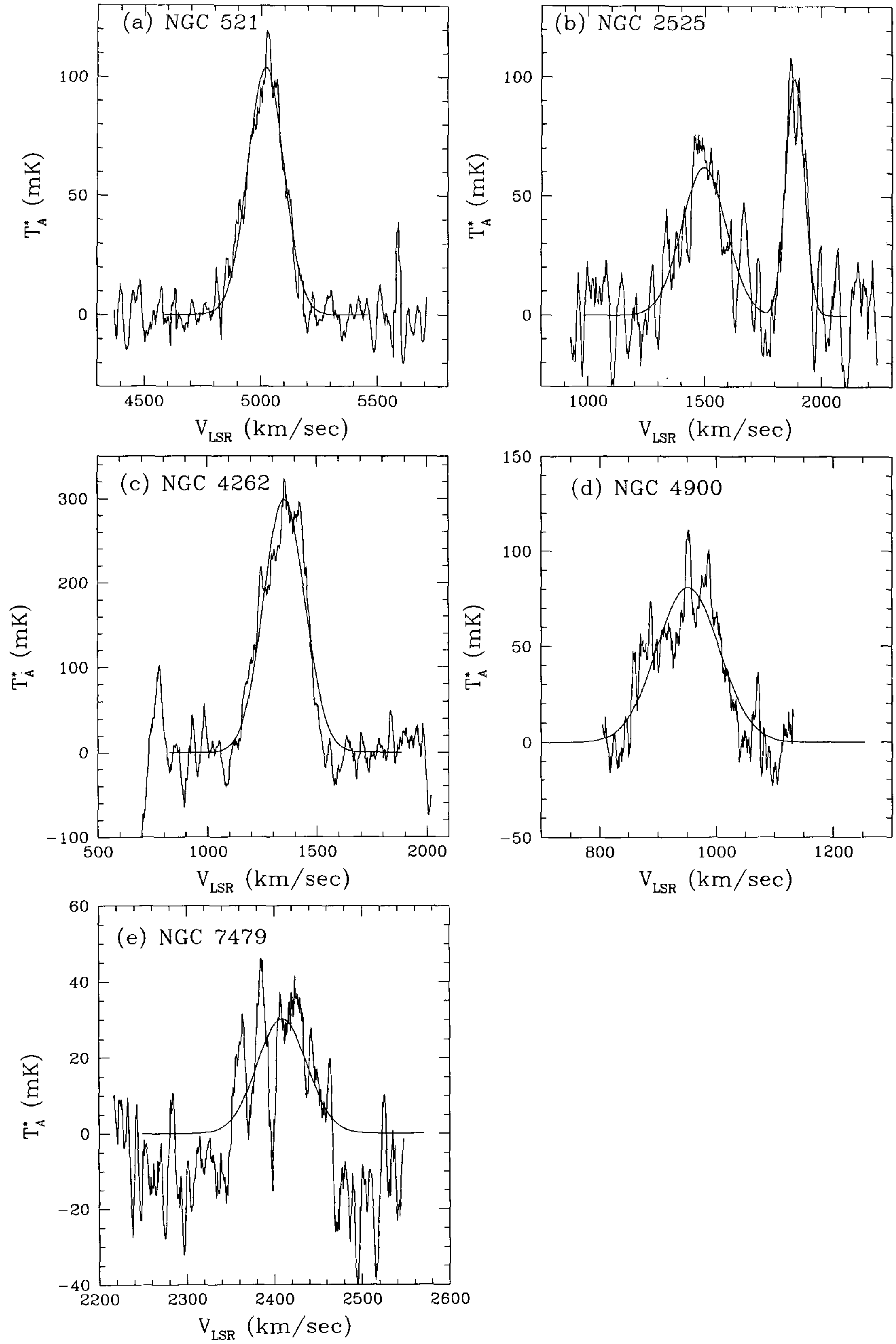

Fig. 1.— Line profiles of CO emission for (a) NGC 521, (b) NGC2525), (c) NGC 4262, (d) NGC 4900, and (e) NGC 7479

II. THE SURVEY

(a) Sample

We have selected our sample from Revised Shapley-Ames Catalogue satisfying following criteria: (1) small inclination angle with respect to the line-of-sight (i.e., nearly face-on), (2) optically bright ($B_T < 13$) galaxies, and (3) those with $\delta > -5°$. We have selected nearly face-on galaxies because we are interested in examining the detailed morphological aspects using optical image and high resolution interferometric data when it becomes available. The total number of galaxies satisfying the above criteria was about 100. About 10% of our sample have been detected with CO previously. The entire sample will be surveyed using single dish telescope.

(b) Observations

We have observed 18 galaxies in January 1998 using 14 m radio telescope at TRAO. Since the external galaxies are rather weak molecular line sources, we need rather long integration. The noise level for the observations with bandwidth of $\Delta\nu$ per channel and integration of Δt can be expressed as

$$\Delta T_A = \frac{cT_{sys}}{\sqrt{\Delta\nu\Delta t}}, \tag{1}$$

where T_A is the antenna temperature, T_{sys} is the system temperature, and c is the backend constant which is 1.8 for TRAO system. The system temperature ranges from 800 to 1500 K depending on the ambient temperature and the weather condition. Our observations are done with the 512 channel 1MHz filter bank which gives velocity resolution of 2.60 km/sec and total velocity coverage of 1331 km/sec for 115 GHz CO line. If we require the observation limit of $T_A \geq 50$ mK at $S/N \approx 5$, the noise in antenna temperature should be kept around 10 mK. Therefore the total integration time per galaxy should be 6 hours or less. Actual integration time was adjusted while carrying out the observations. Stronger sources could be reliably observed with only about 30 minutes of integration.

In order to determine the baseline of the spectra, we have used the position switching method. The baseline was eventually determined by fitting the data outside of the profiles to a first or second order polynomials depending. We have observed only one point per galaxy because we are interested in selecting galaxies with strong CO emission. The beam size of the telescope was 48″.

III. RESULTS

Out of 18 program galaxies in the present observing run, we have detected CO emission from 5 galaxies. The observational characteristics of these galaxies are summarized in Table 1. The line profiles are fitted to Gaussian function and the results are summarized in the fifth and sixth columns of Table 1 where we have listed the peak antenna temperature ($T_{A,max}$) and FWHM velocity (V_{FWHM}). The profiles are fitted to a single Gaussian except for NGC2525 which has two distinct profiles.

Except for NGC 7479, these galaxies have not been observed with CO before. The peak antenna temperature ranges from around 30 to 300 mK and the line width ranges from 62 to 220 km/sec. The line profiles of detected galaxies are shown in Fig. 1a-1e, together with the best fitting Gaussian profiles. Since the original data are very noisy, we have taken average of 8 nearby channels to obtain smooth profiles.

(a) Statistical Properties

Since our sample is very small, it is difficult to draw any statistical conclusions. Furthermore, the amount of molecular gas cannot be estimated from single point observations because the angular sizes of the galaxies are larger than the beam size. More detailed statistical analysis will be done after observing the entire sample and to larger extent. Here we give only very sketchy discussion.

The correlation between CO and IRAS luminosities exists in external galaxies (see Young & Scoville 1991 for summary), but the scatter is very large. Our sample is simply too small to see if there is a correlation. Furthermore, we need to observe the entire galaxy in order to derive the CO luminosity. We just point out that 13 galaxies are identified in the Point Source Catalogue (PSC) of IRAS out of 18 program galaxies, and that only one galaxy (NGC 4262) among the detected five galaxies does not appear in the PSC.

The spiral galaxies are divided into three varieties according to the shape of spiral arms: ring shaped (s), *s*-shaped (s), and (rs). In our sample, there were 6 (r)'s, 6 (s)'s and 4 (rs)'s. Among five detected galaxies 1 was (r), 3 were (s) and 1 was (rs). Therefore, (r) galaxies have less probability of CO emission.

(b) Individual Galaxies

We now describe briefly the galaxies that are detected in the present observations.

NGC 521 is an SB(r)bc galaxy with very small, bright nucleus and a narrow bar (0.55′ × 0.06′). There is a non-interacting nearby galaxy NGC533 at the distance of 13.5′. This galaxy has rather strong emission lines from the central part. Ho, Filippenko & Sargent (1997) classified this as a "transition object" which means that the properties lie between HII nucleus and LINERs (low-ionization nuclear emission-line regions: Beckman 1980). The CO line profile can be approximated by a Gaussian with peak intensity of 104 mk and velocity width (FWHM) of 182 km/sec.

NGC 2525 is an SB(s)c galaxy with extremely small, bright nucleus and a rectangular shaped short bar (0.55′ × 0.15′). There appears a pseudo ring whose

Table 1. Galaxy Sample and Observed Result

Name	Classification	α [^{h} ^{m} ^{s}] (1950)	δ [$^\circ$ $'$ $''$] (1950)	$T_{A,max}$	V_{FWHM} (km/sec)
NGC 521	SB(r)bc	01 22 00	01 28 12	103.8	182.3
NGC 1353	SB(rs)b	03 29 49	-20 59 18	–	–
NGC 1637	SB(s)c	04 38 58	-02 57 11	–	–
NGC 1744	SB(s)d	04 57 56	-26 05 48	–	–
NGC 1832	SB(r)bc	05 09 48	-15 44 48	–	–
NGC 2525	SB(s)c	08 03 15	-11 17 06	62.4	220.5
				99.4	92.3
NGC 2950	SB(r)0/a	09 38 59	59 04 51	–	–
NGC 3145	SB(rs)bc	10 07 43	-12 11 18	–	–
NGC 3412	SB(s)0	10 48 15	13 40 41	–	–
NGC 3992	SB(rs)bc	11 55 01	53 39 18	–	–
NGC 4123	SB(r)c	12 05 38	03 09 18	–	–
NGC 4262	SB(s)0	12 16 59	15 09 18	298.6	220.8
NGC 4608	SB(r)0	12 38 42	10 25 42	–	–
NGC 4900	SB(rs)c	12 58 06	02 46 06	80.9	125.7
NGC 5850	SB(r)b	15 04 36	01 44 17	–	–
NGC 7479	SB(s)c	23 02 26	12 03 11	30.2	66.9
NGC 7741	SB(s)cd	23 41 24	25 47 54	–	–
NGC 7743	SB(s)0	23 44 22	09 56 04	–	–

size is 2.1′ × 1.4′. There are line profiles peaked at 1495 km/sec and at 1885 km/sec. The first component coincides with the galaxy redshift measured by HI observations. The second component is closer to the redshift obtained from optical absorption lines (Humason, Mayall & Sandage 1956). These two components are separated by about 400 km/s which is somewhat large difference for the components residing in the same galaxy. There may be a background galaxy which lies just behind this galaxy. More detailed studies in radio and optical wavelengths is desirable for this galaxy.

NGC 4262 is a compact (about 1.9′ × 1.7′) SB0 galaxy, but has the strongest CO emission ($T_{A,max} \approx$ 300 mK) among our sample. This galaxy has a small nucleus in a short, stubby bar in a bright diffuse lens. There is probably a nuclear bar that appeared in J-band photometry (Shaw et al. 1995). This galaxy is somewhat exceptional one because it is very early type galaxy which normally contains small amount of cold interstellar medium. It does not appear in PSC.

NGC 4900 is classified as an Sc in RSA, and as SB(rs)c in RC3. This galaxy has HII nucleus as observed by Ho, Filippenko & Sargent (1997) using H_α filter. The peak CO intensity is around 81 mK and the velocity width (FWHM) is 125.7 km/s.

NGC7479 is a Seyfert galaxy with strong IR radiation and balmer lines. The CO was detected by Solomon & Sage (1988), Young et al. (1989), Tinney et al. (1990) and Elfhag et al. (1996). However, the CO intensity is only around 30 mK, which is the weakest among our detected galaxies.

IV. SUMMARY

This paper reports the preliminary results of the CO survey of barred galaxies. We have observed subsample of 18 galaxies out of the entire sample of ~100 galaxies that are optically selected, using TRAO 14 m radio telescope. Each galaxy is observed toward the central part and Five galaxies are detected with about T_A = 50 mK threshold. Only one galaxy (NGC 7479) has been previously observed and remaining four detections are new. The line profiles are fitted to Gaussian profiles and the resulting peak antenna temperature ranges from about 30 to 300 mK. We will observe the entire sample in the near future and the results of these observations will serve as a fundamental database for further high resolution observations with array.

This research was supported in part by Korea Research Foundation non-directed research grant No. 1997-001-D00163.

REFERENCES

Ann, H. B., 1995, JKAS, 28, 209

Bally, J., Stark, A. A., Wilson, R. W., & Henkel, C. 1988, ApJ, 324, 223

Beckman, T. M., 1980, A&A, 87, 152.

Binney, J., Gerhard, O.E., Stark, A.A., Bally, J., & Uchida K.I. 1991, MNRAS, 252, 210

Bitran, M. E., 1987, Ph. D. thesis, Univ. of Florida.

Elfhag, T., Booth, R. S., Höglund, B., Johansson, L. E. B., & Sandqvist, Aa., 1996, A&AS, 115, 439.

Ho, L. C., Filippenko, A. V., & Sargent, L. W., 1997, ApJS, 112, 315.

Humason, M. L., Mayall, N. U., & Sandage, A. R., 1956, AJ, 61, 97

Kormendy, J., 1982, ApJ, 257, 75

Lee, C. W., 1996, ApJS, 105, 129

Lee, C. W., Lee, H. M., Ann, H. B., & Kwon, K. H., 1998, ApJ, submitted

Shaw, M., Axon, D., Probst, R., & Gatley, I., 1995, MNRAS, 274, 369.

Soifer, B. T., Houck, J. R., & Neugebauer, G., 1987, ARAA, 25, 287

Solomon, P. M., & Sage, L. J., 1988, ApJ, 334, 613.

Tinney, C. G., Scoville, N. Z., Sanders, D. B., & Soifer, B. T., 1990, ApJ, 362, 473

Young, J. S., Xie, S., Kenney, J. D. P., Rice, W. L., 1989, ApJ, 70, 699

Young, J. S., Xie, S., Tacconi, L., et al. 1995, ApJS, 98, 219

Young, J. S., & Scoville, N. Z., 1991, ARAA, 29, 581