MOLECULAR LINE OBSERVATIONS OF GALAXIES IN JAPAN

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ABSTRACT. A short report about molecular line observations of galaxies in Japan is shown. Out of them only 6 topics are shown in this paper; they are (1) bar potential and gas inflow of the central regions, (2) high velocity components of a peculiar galaxy NGC4258, (3) CO bar in our Galaxy, (4) vertical and off-plane structure of the CO disk in a galaxy NGC891, (5) the CO Tully-Fisher relation, and (6) CO emission from a proto-galaxy candidate IRAS F10214+4724.

1. Introduction

In Japan using the 45-m telescope at Nobeyama Radio Observatory (NRO) and the Nobeyama Millimeter Array (NMA) many millimeter-wave observations of extra-galaxies are done. They are ranged from nearby galaxies to cosmological objects. In this paper six topics are reported out of them.

2. Bar potential and gas inflow

Due to recent improvement in angular resolution of millimeter wave astronomy, observational investigations about gas response to bar potential can be done. M83 is the best sample because it is one of the nearest galaxy with a pronounced bar structure (distance=3.7 Mpc). Handa et al. (1990) observed it with the 45-m telescope in CO(J=1-0) and found concentration of the CO emission to the dust lanes along the bar and non-circular rotation. In order to improve the spatial

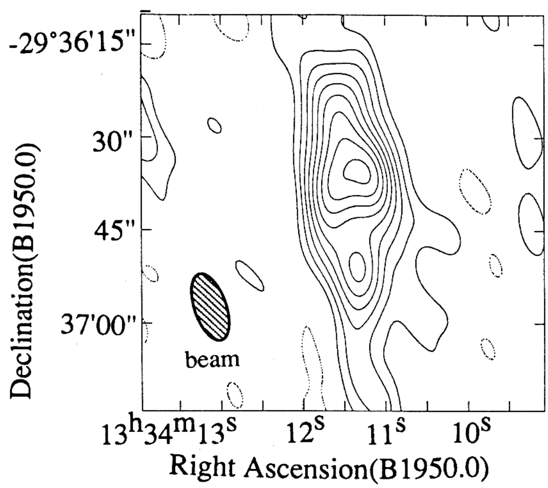

Figure 1: Integrated intensity map of the nucleus of M83. The position angle of the large-scale molecular bar (45 degrees) are different from that of the inner bar.

resolution we observe the central region using the NMA (Handa et al. 1993).

Figure 1 shows an integrated intensity map. Most of the CO emission is confined in the narrow ridge. This ridge connects two major dust lanes on the bar. It is significant that the position angle of the central ridge is different from the large-scale "molecular bar" (Handa et al. 1990).

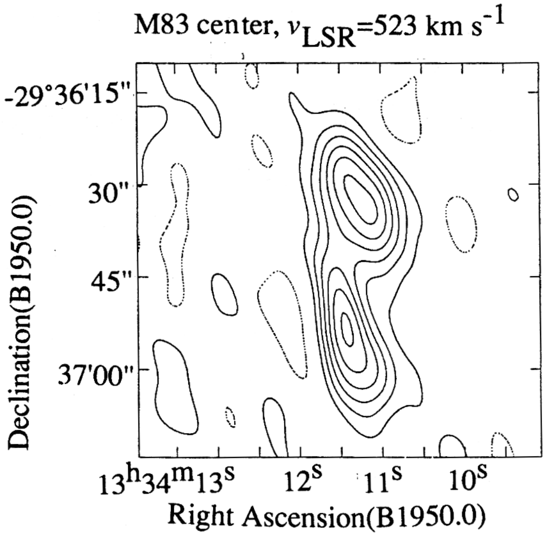

Figure 2: A channel map at v_{LSR}=523 km s^{-1}. The central gap corresponds to the nuclear HII complex.

In order to investigate kinematics we made channel maps with 20 km s^{-1} step. The narrow ridge is composed from the features which roughly follow the galactic rotation. At the systemic velocity the CO ridge has a gap (Figure 2). A radio continuum map (Cowan & Branch 1985) shows that a nuclear star formation complex is located just at the gap. The configuration suggests the inflow gas activates the nuclear star burst activity, as shown in our Galaxy (Oka et al. 1992). There are also some features out of the main ridge. They do not follow the simple rotation kinematics. We call it "out-of-rotation" features.

Binney et al. (1991) gave a physical explanation to gas response to bar potential which has been calculated (e.g. Sørensen et al. 1976, Roberts et al. 1976). According their results most gas is accumulated in the shocked region on the "cusped orbit". A weaker gas concentration is also seen at the other side on the same orbit. It is called as "run-over" gas. Considering the geometrical parameters of M83 overall kinematics in the central region can be understand very well using the bar potential model; the "invert S-shape" ridge corresponds to the shocked region and the "out-of-rotation" features corresponds to the "run-over" gas.

Similar distribution of molecular gas was found in the central region of another galaxy NGC 2782 using the NMA (Ishizuki 1993a, Ishizuki 1993b). The CO emitting reason is elongated almost perpendicular to the large-scale bar and connects two ends of the dust lanes. Their channel maps clearly show no emission at the nucleus. All these features are quite similar to those of M83.

NGC 3504 is another type. The CO map obtained with NMA shows a single central peak (Ishizuki 1993a, Ishizuki 1993b). It is detached from the dust lanes on the stellar bar. The CO peak is just located at the nuclear star forming region.

Some barred spiral galaxies show the "twin-peak structure" in CO line (Kenney et al. 1992). The "twin-peaks" are located just at the tangential points of the nuclear star forming ring and dust lane of the bar, which correspond to the inner Lindblad resonance.

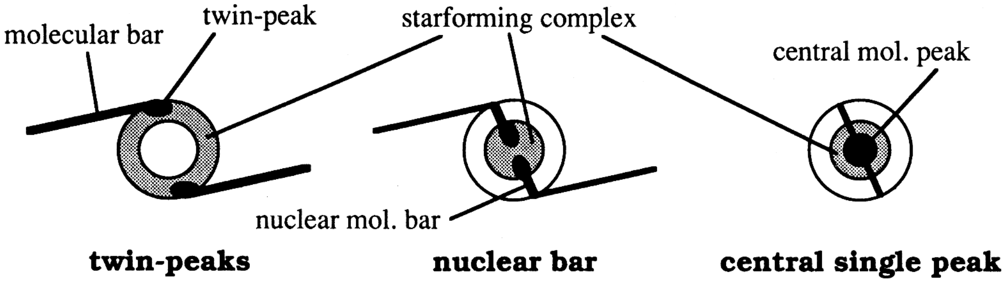

Figure 3: A morphological sequence of barred spiral galaxies in CO emission; outer twin-peak, nuclear bar, and central single peak.

Our results of two galaxies, M83 and NGC 2782, are different from their twin peaks. Our samples show an inset of twin peak structure.

Summarizing these results we propose the morphological sequence of barred spirals with 3 categories; outer twin peaks, nuclear bar and central single peak. At present we have no answer what this sequence means; it should mean the sequence of evolution or dynamical parameters. More observations are required in order to improve the statistics, and qualitative comparison between observations and numerical calculations is required.

3. High velocity components from active galactic nuclei

Nakai et al. (1993) observed toward the nucleus of a peculiar galaxy NGC 4258 in H_2O maser line using the Nobeyama 45-m telescope. They found high velocity features. If they are due to Doppler shift, then they show violent motion near the nucleus. Another possibility is due to frequency modulation with Ramman scattering by dense plasma (Deguchi et al. 1993).

4. The CO bar in our Galaxy

Recent investigations show that our Galaxy has a bar in the center (e.g. Manabe & Miyamoto 1975; Blitz & Spergel 1991; Nakada et al. 1991; Weinberg 1992). The unique "radial" distribution of molecular clouds in our Galaxy may be due to the the non-axisymmetric distribution caused by the bar potential.

Nakai (1992) compared the azimuthally averaged CO distributions of nearby barred spirals and our Galaxy. From similarity of their "radial" distributions he concludes that our Galaxy has a central bar. An *l-v* diagram from a large scale survey of our Galaxy is consistent with the bar.

5. Vertical structure of the galactic disk

Most of observational researches have focused on the two-dimensional distributions so far. In order to investigate vertical structure of the galactic disk and the disk-halo interaction we need high-resolution observations of edge-on galaxies. So we observed the nearest edge-on galaxy, NGC 891 using the NMA with a 4.5" × 4.4" beam (Handa et al. 1992). The field center is 90"-offset from the center of the galaxy.

In the integrated intensity map a narrow CO emission ridge is seen (Figure 4). It is edge-on view of molecular gas disk of the galaxy. The confinement of the CO emission in the thin disk suggests that most of the molecular gas is belonging to the population I objects like in our Galaxy. The apparent thickness of the ridge is about 7", which means that the deconvolved width is about 6" or 270 pc (FWHM). We believe that it means the intrinsic thickness because of no systematic velocity gradient along the minor axis. This width is broader than that of our Galaxy by factor 2. The geometrically thick CO disk of NGC 891 may be due to active star formation in the disk.

We found a prominent spur at v_{LSR}=407 km s^{-1}. We call it as a "molecular spur" of NGC 891. The height of the spur is 520 pc above the disk. Using the HI rotation curve of the galaxy, it is located at 5.5 kpc from the galactic center. The mass of the spur is estimated to be 3×10^7 $M_\odot$, which is about a half

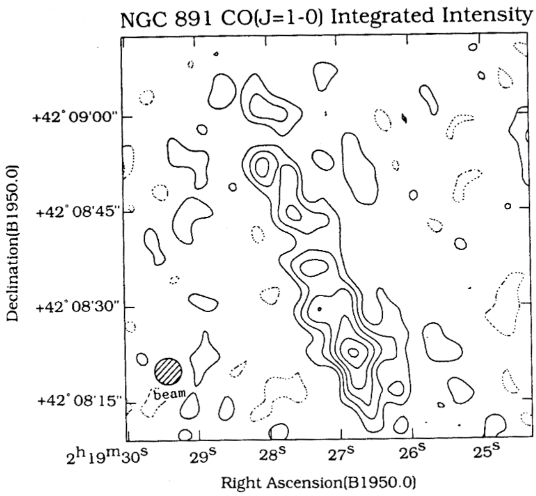

Figure 4: Integrated intensity of NGC 891. The field center is 90" offset from the center of the galaxy.

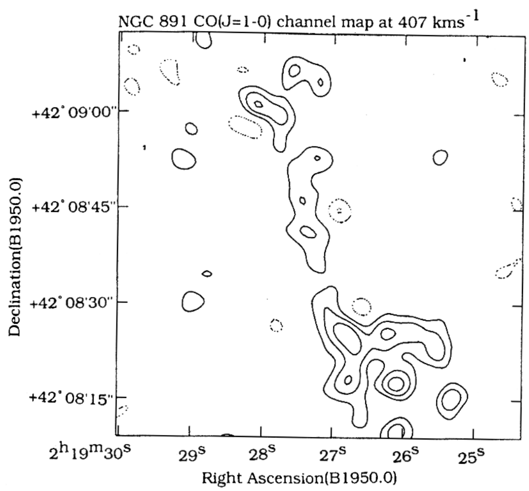

Figure 5: The molecular spur of NGC 891, which is 520 pc above the galactic disk.

mass of 30 Doradus molecular cloud complex.

We consider possible explanations about the origin of the molecular spur. The galaxy-galaxy interaction is not, because NGC 891 has no companion and shows no warping in the outer HI disk. A falling cloud elongated by tidal force is not, because gravitation above a uniform flat does not generate tidal elongation. Therefore we think the spur was made by internal activity of the galaxy as discussing some off-plane features in our Galaxy (e.g. Sofue 1973, Sofue & Tosa 1974, Shapiro & Field 1976). The potential energy of the spur is estimated 3×10^{52} erg using mass model of the galactic disk. The chimney model predicts a similar structure but predicted kinetic energy by superbubble is shortage about factor of 10 (Norman & Ikeuchi 1989). Halo gas gathering due to the Parker instability is another possibility (Shibata & Matsumoto 1991). If it is, then quick gas conversion from HI to H_2 should be needed.

6. The CO Tully-Fisher relation

The Tully-Fisher relation is a powerful tool to estimate a distance to a spiral galaxy (Tully & Fisher 1977). It is, however, less powerful beyond 100 Mpc because it is difficult to get good HI profiles enough to measure the HI line width.

Using large millimeter telescopes we can detect good CO profiles of farther galaxies beyond this limit, because their smaller beam gives less dilution. If there is a tight correlation between HI and CO line widths, then we can use the "CO Tully-Fisher relation" for farther galaxies. Using the IRAM 30-m telescope Dickey & Kazès (1992) show a correlation between HI and CO line widths. Sofue & Shöninger (1993) show that total profiles made by spatial integration from high resolution data of edge-on galaxies are almost the same in HI and in CO. It is because flat rotation of galaxies smooths out the difference between distributions of HI and CO and produces similar line profiles. It means that the "CO Tully-Fisher relation" is useful. Of cause we need to confirm it and to improve statistics.

7. IRAS F10214+4724 - a proto-galaxy?

IRAS F10214+4724 is a faint IRAS object but is at cosmological distance; its redshift is z=2.286 (Rowan-Robinson et al. 1991). So it is focused as a proto-galaxy. From this object redshifted CO(J=3-2) emission was detected using the NRAO 12-m telescope (Brown et al. 1992). Using the Nobeyama 45-m telescope Tsuboi & Nakai (1992) detect in CO(J=3-2) line and marginally in CO(J=1-0). But there is some discrepancy between Nobeyama's result and NRAO's result in CO flux. This may be due to some extension of CO emitting region, because NRAO's result is obtained with a larger beam. Using NMA Kawabe et al. (1992) observe the galaxy. They cannot detect any extended emission from the galaxy. It is, therefore, difficult to solve the discrepancy using all present data. In 1993 observations with the NRO 45-m telescope around the peak will provide a conclusion for this question.

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QUESTIONS and ANSWERS

Talk Title : Molecular Line Observations of Galaxies in Japan

Speaker : Handa, T.

Lee,Youngung : Molecular hump at 4 kpc in our Galaxy has been explained as molecular ring. Another molecular ring was also found in M31. Could you tell us any better supporting evidence for the molecular bar than ring model?

Handa, T. : There are many observational evidences of existence of the stellar bar in our Galaxy. Theoretical models and observational results of extra galaxies show that gas distribution in bar potential is non-axisymmetric. Therefore non-axisymmetric distribution in out Galaxy is very reasonable. The molecular gas distribution in M31 is a clear ring. But M31 has no central component which is seen the "radial" distribution in out Galaxy. I believe that M31 is very different from our Galaxy in interstellar gas. It should belong to another category.

Hong, S. S. : (1) Regarding the PARKER instability as a cause for the off-plane molecular structure, you mentioned a problem of conversion time scale from HI to H2. Please elaborate a little list more on your appointment related to the time scale problem. (2) Please give me information about the density contrast between the outermost contour and the finer most one of the off-plane CO structure.

Handa, T. : (1) I have not quantitatively compared out results to theoretical models. According to the model the gas in the spur region moves from the inter-spur region highly above the plane. So we think that the gas should convert quickly from HI to H_2. (2) We cannot detect any emission in the halo besides of the spur. So we only mention about its lower limit. The dynamic range between the peak and the lowest contour, which id 1.4 sigma, is about 3.

Koo, Bon-Chul : For the molecular spur in NGC 891, you mentioned that if it is due to a superbubble, the needed energy is $3x10^{52}$ erg where as the supplied energy is $3x10^{51}$ erg. Could you explain how you derived those parameters?

Handa, T. : The needed energy I derived is gravitational potential energy which moves whole molecular gas in the spur from the midplane of the disk to the present position. The supplied energy is just refer the kinetic energy supplied by a superbubble derived by Norman & Iueuchi(1989). The latter is not derived from any observational evidences.

Kim, K.-T. : Regarding Tully-Fisher relation, What say good with CO observation. than the traditional HI observation. Suppose you have both HI of CO radio telescope, which one fit t-f relations you would go for first?

Handa, T. : At present status it is difficult to say which is the better. The advantage of CO line width is the higher angular resolution using conventional large telescopes. After improving receivers in millimeter wave will provide the better S/N for compact objects, say distant galaxies. For example the 100-m telescope gives 9' beam in 21cm HI line, and the 45-m telescope gives 15" beam in 2.6 mm CO line. The difference of dilution factor is 10^3 for smaller objects than 15". At present the application of Tully-Fisher relation is mainly limited to 100 Mpc by the sensitivity of the HI detectability. We can go beyond the limit by using CO Tully-Fisher relation. But before doing it we should confirm this relation by more observations to improve statistics. For nearby galaxies we should use the HI line. For faraway galaxies we should use the CO line after establishing the CO Tully-Fisher relation.