Preface

In our quest to elucidate the origin of the universe and the formation of galaxies, particularly that of the Milky Way in which we live, astounding progress has been made in recent years through observational and theoretical studies. Not only have gigantic surveys covering a large fraction of the sky brought statistics enlightening evolutionary paths of galaxies, but powerful instruments, such as radio interferometers and ground- and space-based optical/infrared telescopes, have been able to map individual objects with high sensitivity and spatial resolution. Yet we do not fully understand the physics behind the observational results, and a number of unsolved problems need to be discussed, such as: What is the origin of disks and spheroids and which form first? What determines the global star formation rate in galaxies? How influential are the environment and interactions for nearby galaxies? What causes starburst and AGN activity in galaxies?

In order to discuss and make progress on these important questions, aided by recent observational and theoretical work, we organized a symposium entitled "Mapping the Galaxy and Nearby Galaxies", on 26 June - 30 June, 2006, at Ishigaki island. Ishigaki is a tropical resort island located about 1000 km south-west from the main island of Japan and surrounded by a coral reef and beautiful white sand beaches. Ishigaki is also the site of one of the 20 m radio telescopes in the VLBI Exploration of Radio Astrometry (VERA) network, which is operated by National Astronomical Observatory of Japan.

The symposium was also planned in celebration of Professor Yoshiaki Sofue's 63rd birthday and his retirement from the University of Tokyo. Although Prof. Sofue has worked mainly in the domain of radio astronomy, he has been active over the past four decades in a large number of different fields in galactic and extra-galactic astronomy. The wide range of topics discussed in this symposium were all related to some of his numerous works.

After very long flights (even for most Japanese attendees!), and a friendly welcome at the airport from the local authorities, a total of 160 people participated to the symposium, about half from outside Japan. During the week, 24 invited talks, 28 contributed talks, and 94 poster papers were presented in four sessions: (1) Basic Components of the Galaxy and Spiral Galaxies, (2) The Galactic Center and Central Region of Galaxies, (3) Nearby Galaxies, and (4) Galactic Evolution and Environment.

In Session I, the discussion focused on results on stellar and interstellar matter in spiral galaxies from recent observational surveys at optical through radio wavelengths, such as those carried out with NANTEN, Spitzer, or maser techniques. Theoretical studies on the evolution of barred spiral galaxies and the Milky Way halo were also presented. The structure of galactic magnetic fields was discussed from both an observational point of view and that of three-dimensional magneto-hydrodynamic simulations.

In Session II, observational results were presented on the central region of our Galaxy and active galactic nuclei from the X-ray satellite SUZAKU, as well as from optical, infrared, and radio studies. CO line surveys of nearby spiral galaxies obtained by NMA, the NRO45 m, the IRAM30m and the IRAM interferometer were discussed, along with 3D kinematics of the central parts of nearby spiral galaxies. Initial results of ASTE were also presented in talks and poster papers. The strong influence of barred potentials on the gas dynamics was discussed from a theoretical point of view.

Session III continued with invited talks and contributions on observational studies of nearby galaxies, or the outer part of spiral galaxies and extragalactic magnetic field.

Galactic evolution and environment were discussed in Session IV. Environmental effects in clusters of galaxies and local groups, results from the COSMOS survey, and observations of rotation curves in $z \sim 2$ spiral galaxies from the VLT were presented, as well as recent theoretical studies on the co-evolution of supermassive black holes and bulges.

During a free afternoon, participants visited the VERA observatory and took a tour of the 20 m telescope with its unique dual-beam system. In the observatory, the 4D2U (Four-dimensional Digital Universe) project of NAOJ presented 3-D movies of numerical simulations and a virtual trip from the solar system to the horizon of the universe. Astronomers also enjoyed beautiful tropical beaches and another "universe" with colorful fish and many kinds of coral from glass-bottom boats, at the emerald blue Kabira bay. They had also the opportunity to visit the nearby island Taketomi, and some of them made a complete bicycle tour of the island, famous for its ancient typical houses decorated with "Seasers" (talismanic lions).

The conference banquet close to the sea was the climax of the meeting. After a beautiful sunset tinted the beach, participants enjoyed local cuisine and magnificent performances of traditional dancing and music by students of Yaeyama Shoko High School.

In the next decade, further progress will be possible with new-generation instruments, such as ALMA, JWST, ELTs, Herschel, SPICA, and SKA. With these telescopes, complete multi-wavelength data at high resolution will become available on structures in our Galaxy, nearby galaxies and the more distant universe. The present symposium was a good opportunity to have a comprehensive discussion on what has been learned so far, what are the major outstanding problems, and how we can physically tackle them. We were impressed by recent progress in numerical modeling of galaxies, which will be an essential tool in understanding and testing physical interpretations of "mapping observations" at high resolution.

We wish to express our thanks to the members of the scientific organizing committee for their valuable advice. On behalf of the SOC, we would like to thank Mareki Honma and his team for their collaborative and assiduous effort for almost two years to organize this successful symposium. We are also grateful to Ishigaki City and NPO Yaeyama Hoshino-kai (Star Watching Club) for their warm hospitality and help in various aspects not only during the conference but also in the phases of preparation. We also thank the 4D2U project (Eiichiro Kokubo, Takaaki Takeda, and Sorahiko Nukatani) for their impressive demonstration in VERA observatory. We should also thank Shioko Izumi, Toshiko Tachibana, Tomoka Tosakaki, Haruhiko Takahashi, Takeshi Hashiguchi, and Mayumi Handa for the help they provided to the LOC.

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Keiichi Wada (*National Astronomical Observatory of Japan*)
and Françoise Combes (*Observatoire de Paris*)

Prof. Yoshiaki Sofue, Hiromi Sofue, and Françoise Combes

Yoshiaki Sofue, Mareki Honma, Masaki Morimoto, Naomasa Nakai, Keiichi Wada, Nick Scoville, Nagateru Ohama (City Mayor), Françoise Combes, Reinhard Genzel

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Nobuo **Arimoto** (NAOJ)
Françoise **Combes** (Paris observatory, France)
Reinhard **Genzel** (MPE, Germany)
Naomasa **Nakai** (Tsukuba, Japan)
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Takayuki **Saitoh** (NAOJ)
Sachiko **Onodera** (University of Tokyo)

NAOJ: National Astronomical Observatory of Japan

Reinhard Genzel gives a speech for a warm welcome by Ishigaki-City at the airport.

2

New Views of Molecular Gas Distribution and Star Formation of the Southern Sky with NANTEN

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1 Introduction

Star formation is a fundamental process that dominates the cycling of various matters in galaxies. Stars are formed in molecular clouds, and the formed stars often affect the parent body of the molecular gas strongly via their UV photons, stellar winds, and supernova explosions. It is therefore of vital importance to reveal the distribution of molecular gas in a galaxy in order to investigate the galaxy history. Recent progress in developing (sub-)millimeter wave receiver systems has enabled us to rapidly increase our knowledge on molecular clouds. The "NANTEN" telescope has an angular resolution of $2.'6$ at 115 GHz and has rapidly revealed the molecular view of the Galaxy, LMC, and SMC with its relatively high spatial resolution. The spatial coverage of the NANTEN is comparable or larger than that by CfA 1.2m telescopes[1] in the southern sky. In this presentaion, I shall introduce some of the results obtained from the NANTEN CO surveys in the Galaxy. I will also mention the "NANTEN2" project, which is an upgrade of NANTEN to achieve an extensive survey in sub-mm wavelength at Atacama.

2 NANTEN Telescope

The 4-m radio telescope of Nagoya University equipped with the highest sensitivity SIS receiver at 115 GHz allowed us to cover a large area within a reasonable time at an angular resolution high enough to resolve dense cores in nearby (within 1 kpc) dark clouds and also to resolve distant (up to 30kpc from the sun) giant molecular clouds. In 1996, the 4-m telescope "NANTEN" was installed at Las Campanas observatory in Chile under mutual collaboration with the Carnegie Institution of Washington, and we started a CO survey toward the southern sky. Two major works with the NANTEN telescope were the Galactic plane CO survey and the Magellanic Clouds molecular cloud survey (see Kawamura et al. in this conference). The other projects are to observe various objects including high mass star forming regions (Carina, Centaurus, Orion, Bright-Rimmed Clouds), SNRs/Supershells (Vela SNR, Gum Nebula, Carina Flare), Galactic center, Low-mass star forming regions (Ophuichus, Lupus, Chamaeleon, Pipe nebula), Galactic high-latitude molecular clouds (Aquila, infrared-excess clouds), and so on. Many of the results are presented in two special issues of **PASJ 1999 vol. 51 No. 6 and 2001 vol. 53 No. 6**.

3 Results from Surveys by NANTEN

3.1 Galactic Plane Survey

Figure 1 shows the CO total intensity map of a part of the southern Galactic plane obtained with the NANTEN telescope. This map consists of more than 1,100,000 spectra. The observing grid spacings are 4′ between 5 degrees from the galactic plane and 8′ for the area above 5 degrees in the galactic latitude with a 2.′6 beam. In the longitudinal direction almost 200 degrees, i.e., L=220° to 60° have been covered. The velocity resolution and coverage are 0.65 km s^{-1} and ∼500 km s^{-1}, respectively. Typical rms noise fluctuations are ∼0.4 K at a velocity resolution of 0.65 km s^{-1}. We are trying to re-identify Giant Molecular Clouds in the Galaxy by using this new data set. One of the notable features seen especially in this survey is the existence of a number of vertical features perpendicular to the galactic plane. I will focus here on two of such features, CO supershells and high galactic latitude clouds.

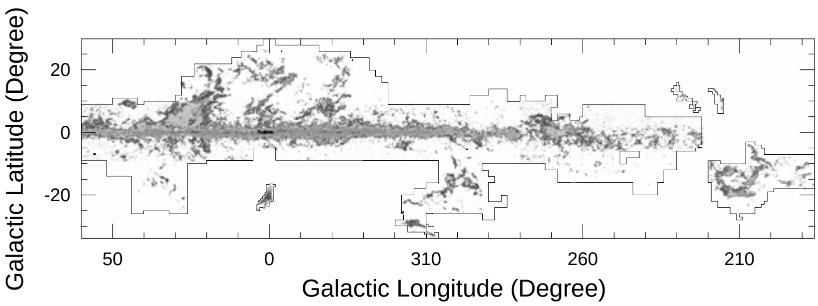

Fig. 1. A grayscale map of the ^{12}CO (J =1–0) velocity integrated intensity shown in galactic coordinate for the galactic plane survey with NANTEN.

3.2 Molecular Supershells

Supershells are large cavities created by multiple supernovae, having a size greater than $\sim$ 100 pc in the interstellar space mostly identified in the HI emission in the past. Some of the supershells exhibit expansion at a velocity greater than 10 km s^{-1}, and their kinetic energies are more than 10^{52} erg. So far, more than a few hundred HI shells including galactic worms have been identified in the galaxy (e.g., [5, 6]). On the other hand, the number of CO supershells, large shell structure identified in CO emission, are quite few because of the lack of systematic CO searches out of the plane to date.

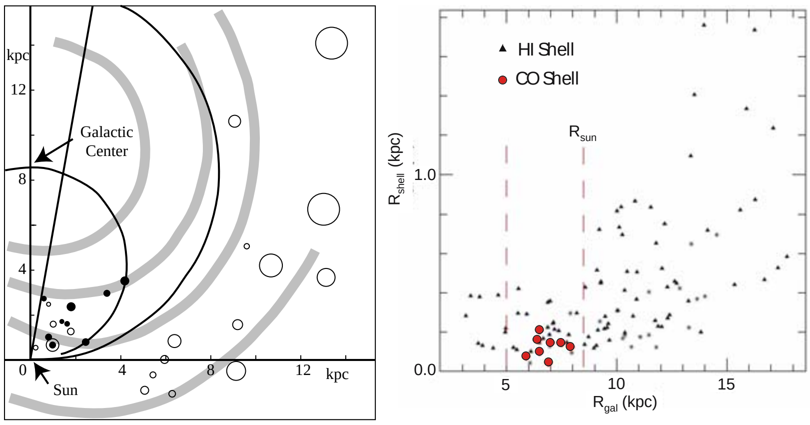

Fig. 2. (Left) Distribution of the CO shells (filled circles, [9]) and the HI shells (open circles, [10]) in the 4th quadrant. The gray thick lines indicate the location of spiral arms. (Right) Galacto-centric radius vs. size distribution of the CO and HI shells.

We discovered a CO supershell in the Carina region, named "Carina flare", from sensitive observations with NANTEN [2], demonstrating that there actually exist molecular clouds associated with supershells. More detailed analysis is carrying out by using high resolution HI data toward the Carina flare (Dawson et al. in preparation). Subsequently, we started a systematic search for CO supershells with NANTEN. [9] completed the search for CO supershells in the 4th galactic quadrant between 300° and 350° in the galactic longitude. Eight CO supershell candidates have been additionally identified by them. In Figure 2a, we show the face-on view of the distribution of CO [9] and HI [10] supershells. It is notable that the coincidence between the CO and HI shells is fairly poor. Only one shell is detected in both CO and HI.

We summarize the characteristics of CO shells along with a comparison with those of HI shells: (1) CO shells are located along the galactic arms, but many HI shells are located in the inter-arm regions (see Figure 2a). (2) CO shells are smaller in size than most of the HI shells (see Figure 2b). (3) The dynamical timescales (=$R_{\rm shell}$ / $V_{\rm exp}$) of CO shells ($(0.2 - 1) \times 10^7$ yr) are smaller than those of HI shells ($(0.5 - 3) \times 10^7$ yr). These three characteristics are interpreted in terms of the evolution of supershells as follows. It is likely that a supershell is formed in an OB association that is located in the spiral arm. In the spiral arm, the shell accumulates the ambient gas as it expands, and molecular clouds are formed in the shell. In this phase, the supershell tends to be observable as a CO shell rather than a HI shell because the cavity of the shell is embedded in and contaminated by the HI gas. After a typical crossing time, a few $\times\ 10^7$ yr, the shell should gradually move to the inter-arm region due to the galactic rotation, and the galactic shear may distort the shell. Then the expanding shell cannot collect the ambient gas efficiently any longer. Separation between the CO clouds in the shell becomes sparse, and the CO clouds themselves may dissipate due to the expansion or by forming stars. Thus, the shell-like feature of CO clouds is not significant in this phase. In the inter-arm region, the HI contamination becomes less significant, and the shell becomes more obvious in HI than in CO. In this scenario, the HI and CO shell corresponds to different evolutionary stages of a single shell, and this may explain the cause for the poor coincidence between the CO and HI shells.

3.3 High Latitude Clouds

We have carried out high galactic latitude molecular clouds observations with the NANTEN telescope in order to reveal the molecular gas distribution around the solar system and the physical properties of low-density molecular clouds. Three types of observations have been made at the region.

A survey for high galactic latitude molecular clouds was carried out toward the 68 of far-infrared excess clouds of [12] by using ^{12}CO (J=1–0) line [11]. The CO emissions were detected in the 32 infrared excess clouds, corresponding to the detection rate of 47%. The CO detection rates for the cold and warm infrared excess clouds whose dust temperature are lower and higher than 17 K are 72% and 33%, respectively. This indicates that the cold clouds are well shielded from external UV radiation, resulting in a high CO abundance and a low temperature of the clouds. The infrared-excess clouds with no CO emission are most likely to be molecular hydrogen clouds because the temperature is similar to, or lower than, that of the surrounding H I gas. Even in far-infrared excess clouds with CO emission, molecular gas without CO emission seems to occupy more than 90% of the area of the clouds.

We then carried out a CO survey of high galactic latitude molecular clouds toward an H I filament including MBM 53, 54, and 55 [13]. We covered the whole area of the H I filament in ^{12}CO (J=1–0) with a $4'$ grid spacing (Figure 3a). Many clumpy molecular clouds are found to form the filament. We identified 110 ^{12}CO clouds and the total mass is estimated to be $\sim 1200 M_\odot$. ^{13}CO (J=1–0) observations were carried out toward the region of strong ^{12}CO intensities in order to measure the optical depth of molecular gas. There is no detection in $C^{18}O$ (J=1–0) line in the observed region. This indicates that there are no clouds dense enough to have star formation in the near future. These observations spatially resolved the entire gas distribution of MBM 53, 54, and 55 for the first time, and we have found a massive cloud, HLCG 92−35 whose mass is ∼330 $M_\odot$, corresponding to 1/4 of the total mass. This CO cloud occupies the galactic western half of a circular H I cloud toward (L, B) ∼ (92°, −35°), and the H I to CO mass ratio is estimated to be the largest in the observed region. Far-infrared excess clouds toward HLCG 92−35 are the largest in the observed region. The ratio of the luminosity of the infrared excess to CO mass is also significantly larger than those of the other clouds, by a factor of ∼5. These facts indicate that HLCG 92−35 is a CO-forming molecular cloud, which is younger than the MBM clouds in terms of molecular cloud formation. A past explosive event has been suggested by [3] toward the H I filament. Toward HLCG 92−35, molecular gas is distributed along the western edge of the H I cloud, which implies that the molecular gas may be formed by a compression of expanding H I shell.

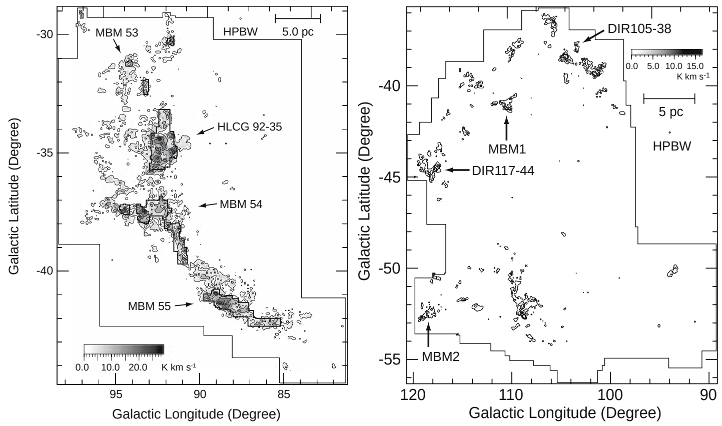

Fig. 3. (Left) a: Total velocity integrated intensity map of ^{12}CO (J = 1–0) toward MBM53, 54, and 55 region in the galactic coordinate[13]. The lowest contour is 1.50 K km s^{-1}, and the separation between the contours is 6.0 K km s^{-1}. The observed area of ^{12}CO is denoted by a thin solid line and the one of ^{13}CO is denoted by thick solid lines. (Right) b: Total velocity integrated intensity map of ^{12}CO (J = 1–0) shown in the galactic coordinate[14]. The lowest contour and the separation between contours are 0.77 and 3.08 K km s^{-1}, respectively. The solid line represents the observed area. The locations of DIR clouds in [12] and MBM clouds in [8] are shown in the figure.

Finally, we carried out large scale CO observations toward a loop-like structure in far infrared whose angular extent is about 20×20 degrees around (L, B) ∼ (109°, −45°) in Pegasus whose diameter corresponds to ∼26 pc assuming a distance of 100 pc, which is a distance of a star HD886 (B2IV) at the center of the loop. We covered the loop-like structure in the ^{12}CO (J=1–0) emission at 4′–8′ grid spacing and in the ^{13}CO (J=1–0) emission at 2′ grid spacing for the ^{12}CO emitting regions [14]. The ^{12}CO distribution is found to consist of 78 small clumpy clouds whose mass ranges from 0.04 $M_{\odot}$ to 11 $M_{\odot}$. Interestingly, about 83% of the ^{12}CO clouds have very small masses of less than 1.0 $M_{\odot}$. ^{13}CO observations revealed that 19 of the 78 ^{12}CO clouds show significant ^{13}CO emission. ^{13}CO emission was detected the region where the molecular column density of ^{12}CO clouds is greater than 5×10^{20} cm^{-2}, corresponding to Av of $\sim$1 mag. We find no indication of star formation in these clouds in IRAS Point Source Catalog and 2MASS Point Source Catalog. The very low mass clouds identified are unusual in the sense that they have very weak ^{12}CO $T_{\rm peak}$ of 0.5 K–2.7 K and that they aggregate in a region of a few pc with no main massive clouds; contrarily to this, similar low mass clouds less than 1 $M_{\odot}$ previously observed in the other regions including at high galactic latitude region are all associated with more massive main clouds of $\gtrsim$100 $M_{\odot}$. A comparison with a theoretical work on molecular cloud formation [7] suggests that such small clouds may have been formed in the shocked layer through the thermal instability. The star HD886 (B2IV) at the center of the shell may be the source of the mechanical luminosity via stellar winds to create shocks, forming the loop-like structure with very small clouds delineated.

4 NANTEN2 Projects

The "NANTEN2" is an upgrade of the 4-m mm telescope, NANTEN, which was operated at Las Campanas Observatory, Chile. The upgrade started by moving NANTEN from Las Campanas to Atacama in Northern Chile at an altitude of 4,800m in 2004 to realize a large-scale survey at sub-mm wavelengths. In this new project, we will make large-scale surveys toward the Galaxy and the nearby galaxies including the Magellanic Clouds. We will reveal the physical and chemical states of interstellar gas in various density regions with the highly excited CO (carbon-monoxide) and CI (neutral carbon) spectra in the millimeter to sub-millimeter wavelength (86–810 GHz). With thorough extensive surveys, we will make studies of star formation process in the Local Group and investigate the dynamical effects of energetic explosive events like supernovae and supershells on the interstellar matter.

We installed a new main dish to achieve the sub-mm observations for NANTEN2. It consists of 33 aluminum panels that are adjustable with actuators (3 for each panel), and a light-weight carbon fiber back structure. After adjustment of the main reflector using photogarmmetry and holography, the expected surface accuracy is 15 micron rms. The new telescope is enclosed in a dome with a shiftable GoreTex membrane to prevent perturbations such as strong wind and sunlight. The installation started at the beginning of 2004. The highest observing frequencies will be covered by KOSMA SMART

(Sub-Millimeter Array Receivers for Two frequencies) receiver [4], a new multi-beam receiver capable of observing both 490 GHz and 810 GHz radiation simultaneously and effectively.

Fig. 4. NANTEN2 telescope

NANTEN2 is equipped with such low-noise superconducting receivers and the field of view of NANTEN2 is larger than those of ASTE, APEX, and ALMA. NANTEN2 will be suitable to cover a large sky area within a short observation time while the resolution is coarser than those of ASTE, APEX, and ALMA. In this sense NANTEN2 and other telescopes in Atacama are complementary relationship. The NANTEN2 observations provide a large database of interstellar matter in the Galaxy and the Magellanic Clouds. This database must be a useful guide for the future science with ALMA.

NANTEN2 Project is a collaboration between universities in Japan (Nagoya University and Osaka Prefecture University), in Germany (University of Cologne and University of Bonn), in South Korea (Seoul National University), and in Chile (University of Chile). Two groups are joining, University of New South Wales (Australia) and ETH Zurich (Switzerland), making a NANTEN2 Consortium with 8 Universities.

5 Summary

The NANTEN CO survey has provided a new view of the molecular distribution in the southern sky, from the galactic center to the outer edge of the galaxy. Its larger coverage in the galactic latitude than the previous surveys and high sensitivity have allowed us to identify previously unknown weak features such as CO supershells. Detailed searches for weak CO emission toward the galactic center and the warp regions have revealed physical properties of CO clouds in peculiar environments in the galaxy. NANTEN telescope was moved to Atacama area in 2004 with an upgraded main reflector having three times better surface accuracy. This project, NANTEN2, is motivated to explore the large-scale molecular distribution for the first time in the sub-mm region.

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