NANTEN2 Sub-mm Observatory

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Abstract

NANTEN2 is a wide field sub-mm/mm observatory equipped with heterodyne receivers at four frequency bands at 100, 200, 500 and 800 GHz. The observatory is locate at 4865m above the sea level in Atacama, Chile and has been in astronomical use since 2005. I summarize the highlights of the recent astronomical results and present on-going project with an emphasis on a study of CMB by a super CO survey NASCO as a collaborative effort with Planck.

1. Introduction

Stars are the basic constituent in the Universe and are continuously being formed from molecular gas in galaxies. It is important to understand the physical properties of the molecular gas in order to obtain deeper insights into the star formation and sub-mm studies offer a unique tool to estimate density and temperature for this aim. The atmospheric transparency generally becomes large with increasing frequency and we need to install the sub-mm observing facility at a high-altitude dry site where observing conditions are reasonably good even for the sub-mm band. We have developed NANTEN2 4 m telescope (figure 1) in order to make large scale sub-mm and mm observations of the molecular gas in the Galaxy and others in the Local group. I shall present some of the recent results obtained with NANTEN2 and an on-going new project NASCO.

Figure 1 NANTEN2 telescope located in Atacama, Chile.

2. Highlights of the Recent Results

NANTEN2 has been used to observe high mass star forming regions, the Galactic Center, and the Magellanic Clouds in the J=7–6, 4–3 and 2–1 transitions of CO as well as the C_I transitions [1-7].

Figure 2 shows the sub-mm and mm CO molecular distributions toward the most active star forming region N159 in the Large Magellanic Cloud (LMC). This galaxy is the nearest one to our own and provides an excellent laboratory to study evolution of giant molecular clouds (GMC) and star formation therein. The data in this figure indicates that a massive cloud core in a GMC is actively forming massive star clusters. This offers a unique opportunity to reveal earliest stage of a rich cluster formation.

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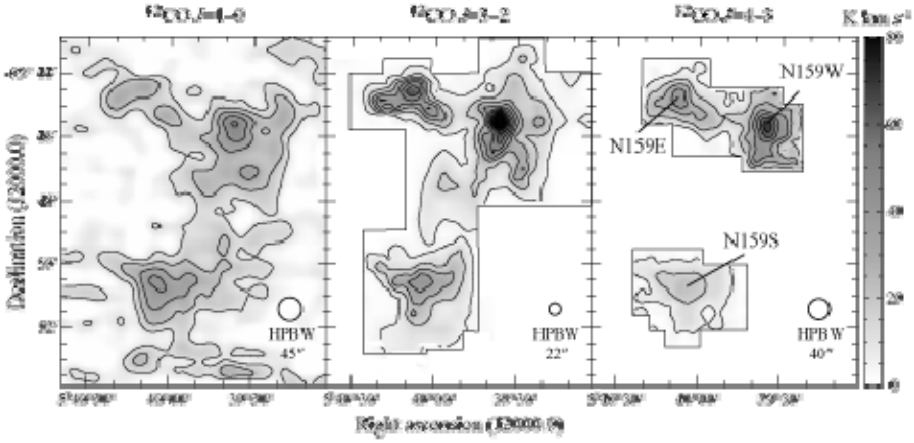

Figure 2: LMC N159 region in the Large Magellanic Cloud.

Figure 3 shows a multi-line study of a strongly shocked gas in the Galactic Center. NANTEN mm observations revealed molecular loops which are created by the Parker instability to lift up the gas with the magnetic field lines [8]. This instability forms accumulated molecular gas in their foot points and sub-mm studies shown here demonstrate high temperatures of the gas caused by the strong shock in the foot points.

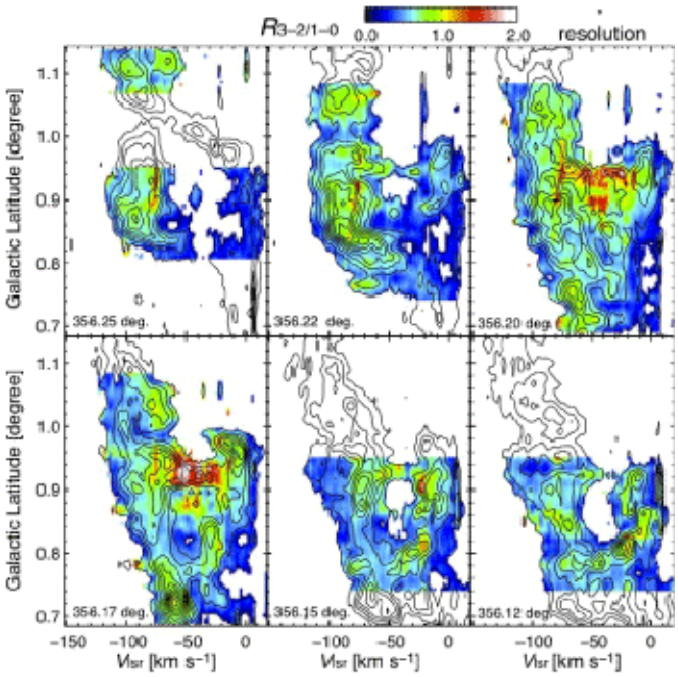

Figure 3: Observations of the foot point of loops 1 and 2 created by the Parker instability in the Galactic center.

3. On-Going Project: a Study of the Foreground Components of CMB as a Collaborative Effort with Planck

Support for the formation of the Universe via the Big Bang 13.7 Gyrs ago is found through an enormous diversity of data. The recession of galaxies (the Hubble law), abundance of light elements, and the cosmic microwave background (CMB) radiation all offer firm observational evidence for the Big Bang. It is now imperative to experimentally test and explore the physics of inflation, the most dramatic rapid expansion of the Universe over 30 orders of magnitude, immediately following the Big Bang. Gravitational waves associated with the inflation have left an imprint on the polarization of the CMB, the so-called B-mode signal, and the detection of the B-mode polarization in the CMB holds the most potential for observational exploration of the inflation epoch.

Crucial for elucidating the B-mode polarization is a complete understanding of foreground emission. As the B-mode signal is so much weaker than the foreground Galactic polarized emission, it is immediately overwhelmed by continuum emission from dust in the Interstellar medium (ISM), at frequencies of 100 GHz and higher and which must be removed using alternative techniques, such as that described in this proposal.

The detection of the B-mode signal has become the most crucial for modern cosmology. The majority of ongoing cosmological experiments, including the Planck project, are focused towards achieving this goal. Realizing this objective is entirely contingent upon accurate estimates of the foreground polarized emission, originating primarily from dust oriented along the magnetic field lines at a frequency of 100 GHz or higher as discussed by the Task Force on Cosmic Microwave Background Research, July 11, 2005 (http://www.nsf.gov/mps/ast/tfcr_final_report.pdf). The reliable detection of the B-mode polarization will have far-reaching impacts on a number of fundamental physical sciences including cosmology, astronomy, and particle physics.

The primary goal for the proposed research is the detection of B-mode polarization across larger angular scales than the Planck CMB data. Complimented with additional ground-based, experiments to provide small-scale component, these data will be absolutely key in an observational test of the inflation Universe. Essential to this goal is an understanding of the foreground polarization generated by the Galactic aligned dust in the ISM, which otherwise completely obscures the background B-mode polarization signal. These data are to be obtained from the successful Planck mission, launched in 2009. Polarization of the foreground Galactic dust is generated by interaction of elongated dust with large and small-scale magnetic fields, which are themselves strongly coupled with the dense and diffuse ISM. As the densest phase of the ISM has been shown to correlate very well with molecular emission, a complete knowledge of the morphological structure of the densest phase of molecular gas throughout the entire of the Galaxy is necessary for the success of this B-mode project.

Presently, no suitable whole-sky survey of the Galactic molecular emission exists: the largest and most complete survey in existence is the NANTEN Galactic plane CO survey (NGPS ver.1; 110 Million points) which consists of under-sampled CO data at 4′–8′ grid, with a 2.6′ beam.
We intend to undertake a "super CO survey", consisting of 20 million observed points as an extension to the NGPS, with the NANTEN2 4m telescope. The superb condition of the site will allow rapid on-the-fly (OTF) sky survey of complete sampling in 2–3 yrs covering 70 % of the sky in the J=1–0 transitions of ^{12}CO, ^{13}CO and C^{18}O molecules in a range of 109–115 GHz, best probes of the dense ISM. This survey, named NASCO [NANTEN Super CO Survey as Legacy], will provide, first and foremost, the most comprehensive and detailed dataset of the morphology and velocity distribution of the dense ISM within the Galaxy.

The foreground Galactic polarization can be derived from dust and ISM magneto-hydrodynamic models developed by the Planck consortium. The resulting Galactic polarization model will be compared with the Planck polarization data, and the modeling parameters will be iterated until a satisfactory match between model and data is achieved. This process will produce the most accurate description of the polarized CMB emission, will reveal the morphological structure of the B-mode polarization, and answer the fundamental cosmological question on the occurrence and rate of the inflation of the very early Universe.

An important and useful byproduct of this process is the high-resolution and high-accuracy sampling of the Galactic magnetic field, which will make far-reaching contributions to this field of study. NASCO will have further-reaching application when combined with ancillary datasets that trace additional phases of the ISM. Such data will become available from international and in-development facilities: the higher resolution H_I datasets (SKA), the low-frequency recombination lines and the early-epoch H_I Universe (LOFAR) etc. When combined with these and other datasets, NASCO will be integrated into a full description of the multi-phase gas component and with the dust component of the near and far Universe. We therefore expect that the proposed research will bring about a number of important breakthroughs in the ISM physics of our Galaxy and Universe, across both large and small scales, and will form a precious Legacy for the world-wide astronomical community.

We here note that the Planck specification indicates CO J=1–0 line contamination in the 100 GHz band covering 82–118 GHz and also in two more bands covering the J=2–1 and 3–2 CO lines. This possible contamination should be carefully verified by the CO data and strengthen the importance of the proposed NASCO CO data.

4. Acknowledgments

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