Nobeyama 45-m mapping observations toward nearby molecular clouds, Orion A, Aquila Rift, and M17: Project overview

Fumitaka Nakamura1,2,3, Shun Ishii1,4, Kazuhito Dobashi5, Tomomi Shimoikura5, Yoshito Shimajiri6, Ryohei Kawabe1,2,3, Yoshihiro Tanabe7, Asha Hirose5, Shuri Oyamada1,8, Yumiko Urasawa9, Hideaki Takemura1,2, Takashi Tsukagoshi1, Munetake Momose7, Koji Sugitani10, Ryoichi Nishi9, Sachiko Okumura8, Patricio Sanhueza1, Quang Nygen-Luong1, Takayoshi Kusune1

1National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan
2The Graduate University for Advanced Studies (SOKENDAI), 2-21-1 Osawa, Mitaka, Tokyo 181-0015, Japan
3Department of Astronomy, The University of Tokyo, Hongo, Tokyo 113-0033, Japan
4Joint ALMA Observatory, Alonso de Córdova 3107 Vitacura, Santiago, Chile
5Department of Astronomy and Earth Sciences, Tokyo Gakugei University, 4-1-1 Nukuikitamachi, Koganei, Tokyo 184-8501, Japan

6Laboratoire AIM, CEA/DSM-CNRS-Université Paris Diderot, IRFU/Service d’Astrophysique, CEA Saclay, F-91191 Gif-sur-Yvette, France

7College of Science, Ibaraki University, 2-1-1 Bunkyo, Mito, Ibaraki 310-8512, Japan
8Faculty of Science, Department of Mathematical and Physical Sciences, Japan Womens University, 2-8-1 Mejirodai, Bunkyo-ku, Tokyo 112-8681, Japan

9Department of Physics, Niigata University, 8050 Ikarashi-2, Niigata 950-2181, Japan

10Graduate School of Natural Sciences, Nagoya City University, Mizuho-ku, Nagoya, Aichi
Abstract

We carried out mapping observations toward three nearby molecular clouds, Orion A, Aquila Rift, and M17, using a new 100 GHz receiver, FOREST, on the Nobeyama 45-m telescope. In the present paper, we describe the details of the data obtained such as intensity calibration, data sensitivity, angular resolution, and velocity resolution. Each target contains at least one high-mass star-forming region. The target molecular lines were $^{12}$CO ($J = 1 - 0$), $^{13}$CO ($J = 1 - 0$), C$^{18}$O ($J = 1 - 0$), N$_2$H$^+$ ($J = 1 - 0$), and CCS ($J_N = 8_7 - 7_6$), with which we covered the density range of $10^2$ cm$^{-3}$ to $10^6$ cm$^{-3}$ with an angular resolution of $\sim 20''$ and a velocity resolution of $\sim 0.1$ km s$^{-1}$. Assuming the representative distances of 414 pc, 436 pc, and 2.1 kpc, the maps of Orion A, Aquila Rift, and M17 cover most of the densest parts with areas of about 7 pc $\times$ 15 pc, 7 pc $\times$ 7 pc, and 36 pc $\times$ 18 pc, respectively. On the basis of the $^{13}$CO column density distribution, the total molecular masses are derived to be $3.86 \times 10^4 M_\odot$, $2.67 \times 10^4 M_\odot$, and $8.1 \times 10^5 M_\odot$ for Orion A, Aquila Rift, and M17, respectively. For all the clouds, the H$_2$ column density exceeds the theoretical threshold for high-mass star formation of $\gtrsim 1$ g cm$^{-2}$, only toward the regions which contain current high-mass star-forming sites. For other areas, further mass accretion or dynamical compression would be necessary for future high-mass star formation. This is consistent with the current star formation activity. Using the $^{12}$CO data, we demonstrate that our data have enough capability to identify molecular outflows, and for Aquila Rift, we identify 4 new outflow candidates. The scientific results will be discussed in details in separate papers.

Key words: ISM: clouds — ISM: kinematics and dynamics — ISM: molecules — ISM: structure — stars: formation

1 Introduction

Star formation not only determines the observed properties of galaxies, but also significantly influences galaxy evolution (MacLow & Klessen 2004; McKee & Ostriker 2007). What drives and regulates star formation in galaxies? There is little consensus to this apparently simple and fundamental
question. Theoretical studies have demonstrated that once self-gravitating objects (cloud cores) form, their gravitational collapses lead to star formation at high rates (Klessen et al. 1998). However, star formation is known to occur in a very low rate in galaxies (Zuckerman & Evans 1974). For example, the total molecular gas mass in our Galaxy is estimated to be $10^9 \, M_\odot$ from the CO observations. If all the molecular clouds are converted to stars within a cloud free-fall time which is a few Myr at the typical cloud density of a few thousand cm$^{-3}$, the free fall rate of star formation is calculated to be about $10^3 \, M_\odot \, yr^{-1}$, which is about $10^3$ times larger than the observed star formation rate (McKee & Williams 1997; Murray & Rahman 2010; Robitaille & Witney 2010). More accurate estimations of star formation rates toward individual molecular clouds are basically consistent with the above rough calculation (Krumholz & Tan 2007). The small Galactic star formation rate thus implies that some physical processes make star formation slow and inefficient.

However, it remains uncertain what processes make star formation slow and inefficient. There are several processes discussed to slow down and regulate star formation, e.g., stellar feedback, magnetic field, and cloud turbulence (Shu et al. 1987; McKee & Ostriker 2007; Krumholz et al. 2014). It is thus crucial to characterize internal cloud structure and physical properties of nearby molecular clouds to understand the roles of the processes in star formation. In our project, we carried out mapping observations toward three nearby molecular clouds using the Nobeyama 45-m telescope, and attempt to address the issues of the inefficient star formation.

Processes of star formation are often influenced by large-scale events. Protostellar jets and outflows are often extended to 0.1–10 pc-scale (Bally 2016). Expanding bubbles with 1–10 pc generated by stellar winds from intermediate-mass and high-mass stars are discovered in nearby clouds (Arce et al. 2011; Feddersen et al. 2018; Pabst et al. 2019). FUV radiation from high-mass stars sometimes affects the parent clouds in 10 pc scale (Shimajiri et al. 2011; Ishii et al. 2019). Much larger bubbles created by supernovae interact with entire molecular clouds (Frisch et al. 2015). Galactic spiral density waves influence molecular cloud formation and subsequent star formation (Elmegreen 1979). One of the immediate objectives of the present project is to reveal clouds structure and dynamics of target clouds and attempt to elucidate how these events influence structure and dynamics of the target clouds. In summary, wide-field mapping observations are important to understand the effects of stellar feedback and external events like large-scale shocks because they potentially affect cloud properties and structures in a cloud scale, 1−10 pc. For comparison, we summarize several recent wide-field survey toward our target clouds in table 1. For Orion A, there are many molecular-line mapping surveys done so far, but many of these surveys were observed only in the northern parts including OMC-1. As Aquila Rift, many molecular-line mapping surveys are just focusing on the two prominent star-forming regions, W40 and Serpens South. As for M17, only a few wide-field surveys
that cover at least about 1 square degree areas have been done so far.

The main objectives of the present paper are to show the project overview and to describe the details of the observations and calibration of the obtained data. In section 2, we describe how we select our target clouds and lines. The details of the observations are described in section 3. In section 4, we describe how to produce final data cubes. Then, we summarize the quality of our maps such as sensitivity, angular resolution, and velocity resolution. In sections 5, we present the spatial distributions of the molecular line emission obtained and in section 6 we derive the spatial distribution of the $^{13}$CO and $^{18}$O abundances toward Orion A. We briefly discuss the global molecular gas distributions of the target clouds mainly using $^{12}$CO and its isotopologues. In section 7, we show the preliminary results of CO outflow survey toward L1641N in Orion A and Serpens South in Aquila Rift, demonstrating that our data can be used to detect outflows. Finally, we summarize the main results of the present paper in section 8.

The detailed analysis will be presented in separate papers. For example, Tanabe et al. (2019), Ishii et al. (2019), and Nakamura et al. (2019) describe the results of the outflow survey, cloud structure analysis, and multi-line observations of the OMC-2 FIR 4 region for Orion A, respectively. Shimoikura et al. (2019) and Kusune et al. (2019) present the detailed cloud kinematic structure and the relationship between filamentary structure and magnetic field, respectively, toward Aquila Rift. For M17, Nguyen Luong et al. (2019), Shimoikura et al. (2019), and Sugitani et al. (2019) will report the global cloud kinematics, dense core survey, and relationship between cloud structure and magnetic field, respectively. In addition to the three main regions, a few other star forming regions such as Northern Coal Sack (Dobashi et al. 2019) and DR 21 (Dobashi et al. 2019b) were studied during our project. These data are obtained for intensity calibration of the CO lines taken with a new 100 GHz receiver, FOREST.

2 Project Overview

2.1 Molecular line data with a $10^{-2}$ pc resolution within distances of a few kpc

In 2011, the state-of-art facility, ALMA, started science operations. Since then, we can easily conduct observations with much higher sensitivity and higher angular resolution than ever done before. In the ALMA era, one of the important objectives of our project is to make useful datasets to compare with ALMA maps of distant molecular clouds. Even using one of the largest millimeter telescopes, the Nobeyama 45-m telescope, the achieved beam size at 115 GHz is at most $\sim 15''$. On the other hand, we can easily achieve $\sim 1''$ resolution using ALMA. To overcome the disadvantage of the coarse angular resolution, we choose nearby molecular clouds as our targets of the Nobeyama 45-m
telescope. Large-scale ALMA mapping observations toward nearby molecular clouds are still limited and are impossible to do because of its small field of view and extremely-long observation time. On the other hand, the coarse beams of the single-dish telescopes allow us to conduct wide-field mapping observations. In this sense, our Nobeyama mapping project is complementary to the ALMA observations toward distant molecular clouds.

Previous observational studies are often influenced by the effects of different spatial resolutions when cloud structure and physical properties of molecular clouds are compared. We would like to minimize the effects of the different spatial resolution to better understand the cloud structure and the environmental effects. In our project, we therefore aim to obtain maps that can be compared directly with those obtained with ALMA in almost the same spatial resolution.

The number of pointings of the ALMA mosaic observations is limited below 150 for the 12-m Array, which can cover the area with $\sim 5\arcmin \times 5\arcmin$ with an angular resolution of 1″ at the ALMA band-3 ($\sim 100$ GHz). Assuming that we map about 1 square degree area with an angular resolution of 20″ toward the regions whose distances are 20 times closer than the areas observed by ALMA with 1″ resolution, both maps obtained have comparable spatial coverage and spatial resolution. As described below, we thus chose Orion A, Aquila Rift, and M17 as our targets of the Nobeyama 45-m mapping observations. In table 2, we compare the achieved spatial resolutions of several molecular clouds, mainly including our target regions. In our previous Nobeyama 45-m observations, we have mapped nearest molecular clouds ($\sim 140$ pc) such as L1551 (Yoshida et al. 2010; Lin et al. 2017) and $\rho$ Ophiuchus cloud (Maruta et al. 2010; Nakamura et al. 2011) using the Nobeyama 45-m telescope. These maps have a spatial resolution of about 2000 – 3000 au, which is comparable to those of the maps of Orion A (414 pc) combined with the CARMA data (Kong et al. 2018). For more distant clouds with distances of a few kpc, ALMA observations can achieve the spatial resolution of a few thousand au at an angular resolution of $\sim 1″$. Thus, our Nobeyama maps of nearby clouds can be directly compared with the maps of the molecular clouds within a few kpc in a comparable spatial resolution of a few thousand au.

We opened all the mapping data we took in this project to the public. The data are available through the Japanese Virtual Observatory (JVO) archival system.\(^1\)

2.2 Target Lines

We chose the following five molecular lines: $^{12}$CO ($J = 1 - 0$), $^{13}$CO ($J = 1 - 0$), C$^{18}$O ($J = 1 - 0$), N$_2$H$^+$ ($J = 1 - 0$), and CCS ($J_N = 8_7 - 7_6$). The $^{12}$CO molecule is the second most abundant

\(^{1}\) http://jvo.nao.ac.jp/index-e.html
after the hydrogen molecule in molecular clouds, and therefore it can trace the basic cloud structure reasonably well. Rarer isotopologues of $^{12}$CO such as $^{13}$CO and $^{18}$O can trace relatively denser gas with densities of $10^3 - 10^4 \text{ cm}^{-3}$. $\mathrm{N}_2\mathrm{H}^+$ has a critical density of $\sim 10^5 \text{ cm}^{-3}$ and traces cold dense gas, particularly in prestellar phase, very well (Caselli et al. 2002; Punanova et al. 2016). Thus, we can cover the densities from $10^2 \text{ cm}^{-3}$ to $10^6 \text{ cm}^{-3}$ using these 4 lines. The main reason why we choose CCS is that CCS can be obtained simultaneously with $^{13}$CO ($J = 1 - 0$), $^{18}$O ($J = 1 - 0$), and $\mathrm{N}_2\mathrm{H}^+$ ($J = 1 - 0$) as we mention below. CCS is abundant in early prestellar phase and traces a similar density range to $\mathrm{N}_2\mathrm{H}^+$. Thus, CCS can provide additional information of chemical evolution of prestellar dense gas (Suzuki et al. 1992; Marka et al. 2012; Loison et al. 2014).

Another reason why we mainly chose the CO lines is that the main beam efficiencies of the 45-m telescope at 100 GHz band ($\lesssim 0.5$) is not so superb as those of other telescopes such as the IRAM 30-m and LMT telescopes (see table 3) and thus observations in strong emission lines such as $^{12}$CO and its isotopologues can be done more efficiently within limited observation time. Although $\mathrm{N}_2\mathrm{H}^+$ is not so strong as $^{12}$CO, $^{13}$CO, and $^{18}$O, a new multi-beam SIS receiver, FOREST, allows us to observe $\mathrm{N}_2\mathrm{H}^+$ line simultaneously with $^{13}$CO and $^{18}$O. In addition, CCS ($J_N = 8_7 - 7_6$) can also be obtained simultaneously with $\mathrm{N}_2\mathrm{H}^+$, $^{13}$CO and $^{18}$O using a spectral window mode which has become available since the 2016-2017 season.

We also adopted a velocity resolution of $\sim 0.1 \text{ km s}^{-1}$, so that we can reasonably identify dense cores with typical internal velocity dispersion of a few tenths km s$^{-1}$. Our observed emission lines are summarized in table 3.

2.3 Target Clouds

We chose the target clouds taking into account the following conditions:

(1) The main part of the target cloud can be covered by one square degree with a few hundred hours using the new 100 GHz 4-beam SIS receiver FOREST, including overhead such as pointing observations and flux calibration.
(2) The target clouds are relatively well studied, and additional datasets are available.
(3) A target cloud contains regions of ongoing high-mass star formation.
(4) The spatial resolution of the Nobeyama 45-m data can be comparable to or smaller than the typical size of dense cores ($\sim 0.1 \text{ pc}$).

Taking the above conditions into account, we chose the following three regions as our targets: (1) Orion A ($d \sim 414 \text{ pc}$, Menten et al. (2007); Kim et al. (2008)), (2) Aquila Rift ($d \sim 436 \text{ pc}$, Ortiz-León et al. (2017b)), and (3) M17 ($d \sim 2000 \text{ pc}$, Xu et al. (2011)).
In this survey, we chose nearby clouds which contains the formation sites of O-type and early B-type stars. There are not so many such regions within \( \sim 1 \text{ kpc} \) (e.g., Orion A, Aquila Rift, California, Mon R2, and Orion B). Among them, Orion A and Aquila Rift may be the nearest. The evolutionary stages of the star-forming regions appear to be different in Aquila Rift and Orion A. For example, star formation lasts at least a few Myr in OMC-1 (Da Rio et al. 2016). On the other hand, in the Serpens South cluster in Aquila Rift, a fraction of the Class O/I protostars is extremely high, suggesting the age within 0.5 Myr. In other words, Orion A contains more evolved star-forming regions than Aquila Rift. The distances of Orion A and Aquila Rift are similar (\( \sim 400 \) pc), and thus it is easy to directly compare the cloud structures with the same spatial resolutions for molecular clouds in different evolutionary stages. These are the main reason why we chose these two clouds. The star formation efficiencies of Orion A and Aquila Rift appear to be similar at a few % to each other (Evans 2009; Maury et al. 2011), which is typical of nearby star-forming regions (Krumholz & Tan 2007). Thus, we believe that the two regions are representative of nearby star-forming molecular clouds.

The beam size of the Nobeyama 45-m telescope at 100 GHz is \( \sim 15'' \), corresponding to \( \sim 6200 \) au and \( 30000 \) au at the distances of 414 pc and 2000 pc, respectively. The spatial resolution of M17 is not satisfied with the last condition, but we chose it by the following two reasons. (1) the densest part of an infrared dark cloud in M17, M17 SWex, was observed by ALMA and the \( \text{N}_2\text{H}^+ \) data are available (see e.g., Ohashi et al. (2016); Chen et al. (2019)), and we can combine the 45-m data with the ALMA data to fill the zero spacing so that we can make maps whose spatial resolution is comparable to those of the maps of other two targets obtained with the Nobeyama 45-m telescope (\( \sim 8000 \) au). (2) Star formation activity in M17 appears to be triggered by a Galactic spiral wave passage (Elmegreen 1979) and thus the M17 data are expected to provide us a clue to better understand the Galactic star formation process. In addition, M17 is the nearest high-mass star forming region located to the Sagittarius arm. The stellar density at NGC 6811 is highest at \( > 10^3 \) star pc\(^{-2} \) after the Carina cluster among the regions in the MYStIX survey of massive star forming regions in X-Ray (Kuhn et al. 2015). M17 is closer to us than the Carina region. Povich et al. (2010) proposed that high mass star formation may be delayed at the IRDC region and the mass function of young stars in IRDC appears to be different from the Salpeter initial mass function. M17 is expected to provide us key information to understand how high-mass stars form. Therefore, we chose the distant high-mass star-forming region M17.

As for Orion A, we combine our Nobeyama 45-m data with the CARMA interferometric data to obtain maps with \( \sim 8'' \) resolution. The combined maps have spatial resolution comparable to those of the Taurus and \( \rho \) Ophiuchus molecular clouds previously obtained with the Nobeyama 45-m telescope, with a spatial resolution of about 3000 au (\( \sim 20'' \)) at a distance of 140 pc. Thus, using the
Nobeyama data and ALMA data, we can directly compare internal structure and physical properties of several clouds located at the different distances in the range from 140 pc to a few kpc with the same spatial resolutions (see table 2). We expect that our maps obtained are useful as templates of nearby molecular clouds which can be compared with maps toward more distant molecular clouds, which can be obtained with ALMA, e.g., Infrared Dark Clouds at a few kpc such as the Nessie nebula and G11.11-0.12 (Snake).

We determine the mapping areas by reference to the 2MASS $A_V$ maps (Dobashi et al. 2005; Dobashi 2011), Herschel column density maps, and Spitzer images. Taking the observation time into account, we planned to map the target areas with $A_V \gtrsim$ a few corresponding to a few tenth g cm$^{-2}$, so that we can detect almost all the self-gravitating cores in our target clouds (see the $A_V$ threshold derived by Andrè et al. (2010)).

Figures 1, 2, and 3 present the mapping areas of Orion A, Aquila Rift, and M17, respectively, overlaid on the Herschel or Spitzer images.

3 Observations

As described in the next section, we used the molecular line data taken with BEARS for intensity calibration. In this section, we first describe the details of the FOREST observations, and then describe the details of the BEARS observations. BEARS is the SIS 25-element focal plane receiver with the frequency coverage of 82 – 116 GHz, and has been used for many mapping observations since 2000. Therefore, the intensity calibration scheme is well established compared to the new receiver, FOREST, which was also demounted for repair after the first season and re-installed in the second season. In addition, the surface accuracy of the telescope dish was significantly improved for the first two seasons by applying the holograph to the dish surface. A careful data reduction of the obtained data is crucial to verify the absolute intensity scale of the FOREST data. Thus, we used the data taken with BEARS for the intensity calibration. For both observations, we adopted the OTF mapping mode with a position switching method using the emission-free positions areas summarized in table 6.

For FOREST, we adopted two frequency set to observe the target lines. Set 1 is for $^{12}$CO and $^{13}$CO. Set 2 is for C$^{18}$O, N$_2$H$^+$, $^{13}$CO and CCS with a spectral window mode. For BEARS, we observed only single line for the individual observations.

3.1 FOREST

FOREST is a 4-beam dual-polarization sideband-separating SIS receiver (Minamidani et al. 2016) and has 16 intermediate frequency (IF) outputs in total, then 8 IFs in the upper-sideband and other
8 IFs in the lower-sideband were used for the molecular line observations. As backends, we used a
digital spectrometer based on an FX-type correlator, SAM45, that is 16 sets of 4096 channel array.
We divided the mapping area into smaller sub-areas whose sizes are summarized in table 4. Then,
we carried out the OTF observations toward each sub-area. The parameters of the OTF observations
are summarized in table 5. Scans of the OTF observation are separated in the interval of 5′′17. Thus,
individual scans by 4 beams of FOREST are overlapped. The positions of the emission-free areas
used for the observations are summarized in table 6. We note that the coordinates of the emission-free
areas are the ones for the first beam of FOREST.

Calibration of the observations was done by the chopper wheel technique to convert the output
signal into the antenna temperature $T^*_A$, corrected for the atmospheric attenuation. Some details of
the observations are also summarized in table 7. The telescope pointing was checked every 1 hour by
observing the SiO maser lines from the objects presented in table 6. The pointing accuracy was better
than $\sim 3''$ throughout the entire observation.

In order to minimize the scanning effects, the data with orthogonal scanning directions along
the R.A. and decl. axes were combined into a single map. We adopted the same gridding convolution
function (spheroidal function) as the BEARS data to calculate the intensity at each grid point of the
final cube data with a spatial grid size of 7′′5.

The FOREST receiver and telescope conditions have not been stable for the first two seasons.
For example, the receiver was demounted on June, 2016 (right after the first season) to improve several
internal components. Second, the surface accuracy of the 45-m dish was significantly improved for the
first two seasons by applying the holograph to the dish surface. Therefore, the observation conditions
were different from season to season. To minimize the effects of these factors in determining the
intensity scale of observed lines, we scaled the data obtained with FOREST by those of BEARS whose
intensity calibration method is well established. The detail of the flux calibration of the FOREST data
is described in the next section.

In the last season (2016-2017), a new observational capability called a spectral window mode
was available, which allows us to obtain more lines simultaneously. We therefore observed $^{13}$CO
($J = 1 - 0$), C$^{18}$O ($J = 1 - 0$), N$_2$H$^+$ ($J = 1 - 0$), and CCS ($J_N = 7_6 - 6_5$) simultaneously. In the
spectral window mode, we equally divided the whole bandwidth into two, so that the bandwidth and
frequency resolution of the spectrometer arrays were set to 31.25 MHz and 15.26 kHz, respectively.
3.2 BEARS

The procedure of the BEARS observations is basically similar to that of FOREST. The details of the BEARS observations are summarized in table 8. Some of the results of the BEARS observations are described in the references listed in the last column of table 8. In brief, we divided the mapping area into many $15' \times 15'$ or $20' \times 20'$ rectangle sub-areas. The sizes of these sub-areas are determined so as to complete an OTF scan within 1 or 1.5 hours. We carried out mapping observations toward each sub-region in an OTF mode (Sawada et al. 2008) using BEARS and 25 sets of 1024 channel Auto Correlators (ACs) which have the bandwidth of 32 MHz and the frequency resolution of 37.8 kHz. The velocity resolutions of the observations for individual lines are listed in table 8.

Calibration of the observations was done by the chopper wheel technique to convert the output signal into the antenna temperature $T_A^*$, corrected for the atmospheric attenuation. At 110 GHz, the half-power beam width was about $15''$, which corresponds to about 0.03 pc at a distance of 414 pc. The main beam efficiency ($\eta_{45m}$) was about 0.5 at 110 GHz for the corresponding observation season. The telescope pointing was checked every 1 or 1.5 hours by observing SiO maser sources, Orion KL and IRC+00363 for the Orion A and Serpens South observations, respectively, and was better than $3''$ during the whole observing period.

We obtained a map by combining scans along the two axes that run at right angles to each other. We adopted a convolutional scheme with a spheroidal function to calculate the intensity at each grid point of the final cube data with a grid size of 7.5''. This convolutional scheme is the same as that of the FOREST data. The spheroidal function is given in Sawada et al. (2008). The resultant effective resolution was about $21''$ at 110 GHz. Finally, we converted the intensities in the antenna temperature scale ($T_A^*$) into those in the brightness temperature scale ($T_{mb}$) by dividing with the main beam efficiencies ($\eta$), $T_{mb} = T_A^* / \eta$. The typical rms noise levels of the final maps are listed in table 8. We note that for Orion A, the coverages of the $^{12}$CO and $^{13}$CO maps taken with BEARS are from Decl. $\sim -5^\circ 20'$ to $\sim -6^\circ 30'$, which is slightly smaller than the actual mapping area of the FOREST observations. The coverage of the C$^{18}$O map were much smaller than those of $^{12}$CO and $^{13}$CO. For the other lines ($N_2H^+$ and CCS), no OTF data are available. The typical noise level achieved for the BEARS observations were $\sim 0.4$ K and 0.7 K at 0.1 km s$^{-1}$ for $^{12}$CO and $^{13}$CO, respectively.

4 Flux Calibration

The procedure of the flux calibration is complicated as we describe in this section. First, we briefly summarize our flux calibration procedure, and then we describe the details of the procedure in the subsequent subsections.
0. All the data were converted the intensity data in $T_A^*$ using the standard NRO data reduction tool, NOSTAR.

1. For the $^{12}$CO and $^{13}$CO of Orion A, the intensities of each emission line and each sub-box were multiplied by the scaling factor $SF_{i, l}^{\text{BEARS}}$, where the scaling factor $SF_{i, l}^{\text{BEARS}}$ is the ratio of the integrated intensity of the FOREST observations and that obtained with BEARS for the corresponding sub-box $i$ and the superscript $l$ indicates the corresponding line ($^{12}$CO or $^{13}$CO). For the sub-boxes where BEARS data were not available, the average scaling factor of the corresponding season is adopted. Note that the BEARS data are in the $T_{mb}$ scale.

2. For the other data (in $T_A^*$), the intensities corrected for the daily variation were obtained by multiplying the intensity data of the corresponding sub-box by the scaling factor of the daily variation $SF_{\text{ref}}$, where the scaling factor $SF_{\text{ref}}$ is the ratio of the sum of the integrated intensity of the reference area obtained at the the corresponding observation session ($S_{\text{ref}} = \sum_i I_{i, \text{ref}}$) and that obtained at the reference date ($S_{\text{ref}}^* = \sum_i I_{i, \text{ref}}^*$), $SF_{\text{ref}} = S_{\text{ref}}^*/S_{\text{ref}}$). Note that we observed a small reference area at least once during each observation session.

3. Then, the intensities corrected for the daily variation were divided by the beam efficiency at the corresponding frequency and converted the intensities in the $T_{mb}$ scale.

We describe the details of the procedure below.

4.1 Orion A

4.1.1 $^{12}$CO and $^{13}$CO

The $^{12}$CO and $^{13}$CO maps obtained with BEARS cover the northern part of the FOREST observation areas shown in figure 1. The intensity scales of the $^{12}$CO and $^{13}$CO data were thus calibrated by comparing with the previous survey data taken by the BEARS receiver (Shimajiri et al. 2011; Nakamura et al. 2012; Shimajiri et al. 2014), which were already corrected into the main beam temperature ($T_{mb}$) scale. We obtained the intensities by dividing the FOREST intensities obtained in $T_A^*$ by the scaling factor $SF_i$ determined in each box. We determined a scale factor for the data of each observation sub-box and each line using the following equation,

$$SF_{i, l}^{\text{BEARS}} = \frac{\sum_{k=1}^{N_i} W_{k, \text{BEARS}, l}/W_{k, \text{FOREST}, l}}{N_i}$$

where $W_{k, \text{FOREST}, l}$ is the integrated intensity of a given box in the antenna temperature scale at the $k$-th grid, and $W_{k, \text{BEARS}, l}$ is the integrated intensity of the same box in the brightness temperature scale at the $k$-th grid. $l$ is the corresponding line, and $N_i$ is the number of grids in the $i$-th box. We measure the intensity ratio at every grid and took an average in each sub-box. For almost all the boxes, the
dispersions of the scaling factors were within $3 \sigma$ of the mean value of each observation season. For the boxes where the SF values are larger than $3 \sigma$ of the mean value or the boxes where the emission is too weak to measure the SF value, we adopted the value of SF measured immediately before or after the corresponding observation. However, we note that such sub-boxes with large dispersions were rare. The scaling factors so derived are consistent with the results of the measurements of the telescope main beam efficiencies. For example, in the 2015-2016 season, the mean value of the scaling factor was measured to about 2.1, which corresponds to the main beam efficiency of 0.48 at 115 GHz. The actual main beam efficiency of the telescope was measured to be about 0.45.

Finally, we combined the FOREST $^{12}$CO and $^{13}$CO data with the BEARS data to reduce the noise levels. The data combination enable us to typically reduce the noise levels by a factor of 1.5–2, which was crucial for making the CARMA and NRO combined Orion images, so that the noise levels in the uv space were well matched.

4.1.2 C$^{18}$O, CCS, and N$_2$H$^+$

Since the map coverage of the C$^{18}$O data obtained with BEARS is not so large and we do not have the corresponding N$_2$H$^+$ and CCS data, we applied a different intensity calibration procedure. For the C$^{18}$O and N$_2$H$^+$ data, we derived the daily scaling factors or daily intensity variations by observing a small area containing FIR 4, which was observed at every observation session once or twice. To determine the daily scaling factors, we observed a small area which contains FIR 3/4/5 at the date when the wind speed at the telescope site was almost zero and $T_{\text{sys}}$ was close to the lowest value, and we adopted the integrated intensity of the FIR 3/4/5 area at that date as a reference. Immediately after this measurement, we also observed a small area of B213 in Taurus to compare the data with those obtained with the IRAM 30-m telescope (Tafalla & Hacar 2015) to check the intensity accuracy. To compare the intensities taken with different telescopes, we smoothed the Nobeyama data to match the map effective angular resolution. The details of the FIR 3/4/5 area are given in Nakamura et al. (2019). For C$^{18}$O, we also checked the absolute intensity by using the C$^{18}$O map obtained with BEARS toward the northern part of Orion A (Shimajiri et al. 2014, 2015a) and we confirmed that our FOREST C$^{18}$O intensities agree with the BEARS data within an error less than 10%. For N$_2$H$^+$, we checked the absolute intensity by using the N$_2$H$^+ (J = 1 – 0)$ fits data obtained with the IRAM 30-m telescope toward B213 in Taurus (Tafalla & Hacar 2015). We confirmed that the intensity of N$_2$H$^+ (J = 1 – 0)$ in B213 obtained with FOREST was only about 5% larger than that of the IRAM value, where we divided the intensity in the antenna temperature scale by the main beam efficiency at 94 GHz. Thus, we consider that the intensity scale of the N$_2$H$^+$ data is reasonably accurate.

For CCS, we simply divided the intensities in $T_A^*$ by the main beam efficiency. The CCS
emission is extremely weak for all the targets.

4.2 Aquila Rift and M17

The BEARS maps of Aquila Rift were only toward the Serpens South region and the map coverages are very small compared to the FOREST mapping areas. Therefore, we did not combine the BEARS and FOREST data. Thus, we applied the same procedure as the Orion A C$^{18}$O data calibration to make the $^{12}$CO, $^{13}$CO, C$^{18}$O, and N$_2$H$^+$ data of Aquila Rift. After correcting the daily intensity variations of the FOREST data, we compared the FOREST intensities to the BEARS intensities toward Serpens South to determine the scaling factors. The scaling factors computed agreed with those determined with the main beam efficiencies within an error of $\sim 5 - 10\%$. For M17, we mapped small areas to measure the daily intensity variations and followed the same procedure as that for Aquila Rift.

4.3 Main Beam Efficiencies of the Nobeyama 45-m telescope

The Nobeyama Radio Observatory measures the main beam efficiencies of the telescope at several frequencies every season, except the 2016-2017 season that was our last (third) season. The planets such as Mars and Jupiter are often used for the measurements. See the web page of the observatory for details of the measurements. Here, we obtain the main beam efficiencies of the observed lines by fitting the values measured with several receivers on the 45-m telescope.

In figure 4, we show the telescope main beam efficiency measured in the 2015-2016 season. We plotted all the values of the main beam efficiencies measured with available receivers installed on the 45-m telescope. By fitting the data points with the following function,

$$\eta_A = \eta_{A0} \times \exp \left\{ - \left( \frac{4\pi \varepsilon}{\lambda} \right)^2 \right\},$$

we derive the main beam efficiencies at the frequencies of our target molecular lines using the least-square fit, and we obtain $\eta_{A0} = 0.539$ and the accuracy of the parabola surface is given as $\varepsilon = 0.151$ mm. The derived main beam efficiencies are summarized in the last column of table 3. This procedure is basically the same as the recommended one by the observatory.

We use the obtained main beam efficiencies to convert the intensities measured in the antenna temperature scale into those in the brightness temperature scale except for $^{12}$CO and $^{13}$CO of Orion A.
5 Global Molecular Gas Distribution

In this section, we present the global molecular gas distribution toward the three target clouds. The detailed characteristics, particularly the velocity structures, of the individual clouds will be described in separate papers.

5.1 Average spectra of the three clouds

In figure 5, we present the average spectra of the CO lines for the three clouds. For Orion A, the average spectrum of the $^{12}$CO emission line has a single peak. There are three peaks or shoulders in $^{13}$CO and C$^{18}$O at around 7 km s$^{-1}$, 9 km s$^{-1}$, and 11 km s$^{-1}$. The Orion A filament has a large velocity gradient toward the northern part, and these components are affected by the global velocity gradient along the filament. However, roughly speaking, the 11 km s$^{-1}$ component is dominant toward the northern part, while the 7 km s$^{-1}$ component appears in the southern part. The 9 km s$^{-1}$ component is strong in the main filamentary structure.

For the other two regions, the spectra have multiple peaks. For Aquila Rift and M17, $^{12}$CO has at least three major peaks. For Aquila Rift, the C$^{18}$O has a single peak at 7.3 km s$^{-1}$ and thus the dips seen in $^{12}$CO and $^{13}$CO are expected to be due to the self-absorption (Shimoikura et al. 2018). The weak but distinct component at around 40 km s$^{-1}$ may be the molecular gas influenced by a supperbubble created by star formation in Scorpius-Centaurus Association (Breitschwerdt et al. 1996; Frisch et al. 2015). This component is seen in $^{13}$CO but it is difficult to be recognized in C$^{18}$O. The $^{12}$CO profile has a tail between 10 km s$^{-1}$ to 35 km s$^{-1}$. This comes from several different components which reside in this region. These components are more prominent in the average spectra of smaller areas and we will discuss them later in a separate paper. These complicated molecular gas distribution may be due to the interaction of molecular clouds with superbubbles (Frisch 1998; Frisch et al. 2015; Nakamura et al. 2017).

For M17, the three components of $\sim$ 20 km s$^{-1}$, $\sim$ 40 km s$^{-1}$, and $\sim$ 55 km s$^{-1}$ are the molecular gas components which belong to the Sagittarius, Scutum, and Norma arms, respectively, (Zucker et al. 2015) as discussed in Nguyen Luong et al. (2019), and the main component is the one with 20 km s$^{-1}$ where NGC 6811 and M17 SWex are located.

5.2 Orion A

Figures 6, 7, 8, 9, and 10 show the integrated intensity maps of Orion A for $^{12}$CO ($J = 1 - 0$), $^{13}$CO ($J = 1 - 0$), C$^{18}$O ($J = 1 - 0$), N$_2$H$^+$ ($J = 1 - 0$), and CCS ($J = 8_7 - 7_6$), respectively. For comparison, we overlaid the contours of the Herschel H$_2$ column density map on the integrated intensity image.
in the right panel of each figure. Each map except N\textsubscript{2}H\textsuperscript{+} is integrated from 2 km s\textsuperscript{-1} to 20 km s\textsuperscript{-1}. For N\textsubscript{2}H\textsuperscript{+}, we integrated the emission from 0 km s\textsuperscript{-1} to 22 km s\textsuperscript{-1} so that all seven hyperfine components are summed up. Our maps cover a region from OMC-3 to NGC1999, spanning about 2 degrees in declination. The results of protostellar outflow survey and cloud structure analysis are given in separate papers (Tanabe et al. 2019; Ishii et al. 2019; Takemura et al. 2019).

Figures 6, 7, 8 show that the 12\textsuperscript{CO}, 13\textsuperscript{CO}, and C\textsuperscript{18}O emission trace the areas with the column density higher than \(\sim 0.5 \times 10^{22} \text{ cm}^{-2}\), \(\sim 0.75 \times 10^{22} \text{ cm}^{-2}\), and \(\sim 2.5 \times 10^{22} \text{ cm}^{-2}\), respectively. N\textsubscript{2}H\textsuperscript{+} emission comes from the area with the column density larger than \(\sim 5 \times 10^{22} \text{ cm}^{-2}\) (see figure 9).

In figure 10, we show the integrated intensity map of CCS, where the image was smoothed with an effective angular resolution of 32′′ to improve the signal to noise ratios. The CCS emission is significantly detected only in the OMC-1 region where the strong C\textsuperscript{18}O and N\textsubscript{2}H\textsuperscript{+} emission is detected. Our CCS map is the first unbiased CCS map of Orion A with the \(J_{N} = 8_{7} - 7_{6}\) line. Previous wide-field maps were taken only toward the main filament with other transition lines (\(J_{N} = 4_{3} - 3_{2}\) at 45 GHz and \(J_{N} = 7_{6} - 6_{5}\) at 81.5 GHz) by Tatematsu et al. (2008, 2014). CCS is known to trace the dense gas with densities of \(10^{4} \text{ cm}^{-3}\), but the abundance of CCS decreases very rapidly due to the destruction. In Orion A, the CCS emission is very weak. Only toward the OMC-1 region, we detect the emission with a signal-to-noise ratio of 5 \(\sigma\). Weaker emission is sometimes seen along the ridge. This weak CCS emission implies that Orion A is relatively evolved molecular cloud. We note that CCS is detected in the OMC-2 FIR 4 region for much higher sensitivity observations (Nakamura et al. 2019). The OMC-1 region may be relatively chemically-young compared to other parts in Orion A. Recently, Hacar et al. (2018) proposed that the OMC-1 region is gravitationally contracting along the main filament. Such a global infall motion can be recognized in our 13\textsuperscript{CO} data (Ishii et al. 2019). If OMC-1 is indeed infalling toward the center, the gas is continuously fed along the main filament in OMC-1. Thus, the significant CCS emission in OMC-1 may come from the material newly fed from outside by the gravitational contraction.

Figure 9 shows the N\textsubscript{2}H\textsuperscript{+} map of the Orion A molecular cloud. The map is consistent with the image taken by Tatematsu et al. (2008), who mapped the Orion A filament in a position-switch mode with full-beam sampling, using the receiver BEARS. Our mapping area is much wider than theirs. Also, since we mapped the Orion A in the OTF mode, the angular resolution is somewhat better than that of Tatematsu et al. (2008). The N\textsubscript{2}H\textsuperscript{+} emission is stronger in the northern part (OMC-1, OMC-2, and OMC-3) and traces the main filamentary structure running in the north-south direction. Our N\textsubscript{2}H\textsuperscript{+} map shows that many faint N\textsubscript{2}H\textsuperscript{+} cores are distributed outside the main filament as well.
5.3 Aquila Rift

Figure 11, 12, 13, 14, and 15 show the integrated intensity maps of Aquila Rift for $^{12}$CO ($J = 1 - 0$), $^{13}$CO ($J = 1 - 0$), C$^{18}$O ($J = 1 - 0$), N$_2$H$^+$ ($J = 1 - 0$), and CCS ($J = 7_{\text{a}} - 6_{\text{a}}$), respectively. Each map except N$_2$H$^+$ is integrated from $-10$ km s$^{-1}$ to 45 km s$^{-1}$. For N$_2$H$^+$, we integrated all seven hyperfine components to produce the intensity map.

The $^{12}$CO emission is strongest toward the W40 region and the Serpens South cluster. The $^{13}$CO emission traces an arc-like structure in the W40 region. However, the filamentary structures particularly toward the Serpens South region are difficult to be recognized in the $^{12}$CO and $^{13}$CO images. From the C$^{18}$O image, we can vaguely find the filamentary structures in Serpens South. The filamentary structures detected by the Herschel map are prominent toward Serpens South in N$_2$H$^+$.

A prominent linear structure is seen in the north east part of the observed area from W40 in $^{13}$CO map. This $^{13}$CO structure is less prominent in the Herschel column density map. This structure may be created by the interaction of the molecular cloud and the W40 HII region. Similar linear structures are seen in C$^{18}$O at different parts of the mapped area. In figure 16, we compare the 250$\mu$m Herschel image (gray scale) with the $^{13}$CO image velocity-integrated from 5.0 km s$^{-1}$ to 6.6 km s$^{-1}$ (contours). Weak 250$\mu$m emission appears to trace the $^{13}$CO linear structure. See Shimoikura et al. (2019) for the details of the cloud structure and properties of the Aquila Rift. The $^{12}$CO integrated intensity map indicates the presence of protostellar outflows particularly in the Serpens South protocluster region [see also Nakamura et al. (2011); Shimoikura et al. (2015)]. In Section 7, we present the results of outflow survey toward the Serpens South region. The CCS emission is weak but significant emission comes along the Serpens South filament. This indicates that the Serpens South filaments are relatively chemically-young.

5.3.1 M17

Figure 17, 18, 19, and 20 show the integrated intensity maps of M17 for $^{12}$CO ($J = 1 - 0$), $^{13}$CO ($J = 1 - 0$), C$^{18}$O ($J = 1 - 0$), and N$_2$H$^+$ ($J = 1 - 0$), respectively. Each map except N$_2$H$^+$ is integrated from $-10$ to 60 km s$^{-1}$. We could not detect the significant CCS emission, and thus we do not show the CCS integrated intensity map. For N$_2$H$^+$, we integrated all seven hyperfine components to make an integrated intensity map.

The $^{12}$CO and $^{13}$CO emission is strongest toward the M17 HII region. The emission lines are spatially extended toward the M17 SWex region whose dense parts are detected in C$^{18}$O. The N$_2$H$^+$ emission is spatially localized and seen as blobs. The detailed cloud structure and kinematics will be discussed in separate papers (e.g., Shimoikura et al. 2019).
6 Spatial Variation of the fractional abundances of $^{13}\text{CO}$ and $^{18}\text{C}$ O

Here, using $^{12}\text{CO}$, $^{13}\text{CO}$, and $^{18}\text{C}$ O, we derive the physical quantities such as the excitation temperature, fractional abundances and optical depth toward Orion A. The detailed analysis is presented in Ishii et al. (2018). See separate papers for the results of the other regions.

6.1 Derivation of Excitation Temperature, Optical Depth, and column density of CO

Here, we derive excitation temperature, optical depth, and $^{13}\text{CO}$ and $^{18}\text{C}$ O column densities toward Orion A. First, we describe how we derive the physical quantities from our data, and then briefly present the spatial distributions of the physical quantities for Orion A.

Assuming that the $^{12}\text{CO}$ ($J = 1-0$) line is optically thick, we derive the excitation temperature $T_{\text{ex}}$ using the following equation (see e.g., Pineda et al. (2008), Shimajiri et al. (2011), and Ishii et al. (2019)),

$$T_{\text{ex}} = \frac{5.53}{\ln\{1 + 5.53/(T_{\text{peak}} + 0.819)\}} \text{ K}$$

(3)

where $T_{\text{peak}}$ is the maximum intensity along the line-of-sight. We also assumed that the excitation temperatures of $^{13}\text{CO}$ and $^{18}\text{C}$ O are the same as $T_{\text{ex}}$ calculated with the above equation. We note that the excitation temperature of $^{12}\text{CO}$, which is likely to be close to LTE, can be used as a good measure of the gas temperature.

The optical depths and column densities at each channel are derived with the following formula,

$$\tau_{^{13}\text{CO}} = -\ln\left[1 - \frac{T_{^{13}\text{CO}}}{5.29(J(T_{\text{ex}}) - 0.164)}\right]$$

(4)

$$N_{^{13}\text{CO}} = 2.42 \times 10^{14} \left[\frac{\tau_{^{13}\text{CO}} T_{\text{ex}} \Delta V}{1 - \exp(-5.29/T_{\text{ex}})}\right] \text{ cm}^{-2}$$

(5)

$$\tau_{^{18}\text{C}O} = -\ln\left[1 - \frac{T_{^{18}\text{C}O}}{5.27(J(T_{\text{ex}}) - 0.164)}\right]$$

(6)

and

$$N_{^{18}\text{C}O} = 2.42 \times 10^{14} \left[\frac{\tau_{^{18}\text{C}O} T_{\text{ex}} \Delta V}{1 - \exp(-5.27/T_{\text{ex}})}\right] \text{ cm}^{-2}$$

(7)

where we assumed that the rotational transition is in the LTE. Here, $\Delta V$ is the velocity resolution. The beam filling factors of $^{13}\text{CO}$ and $^{18}\text{C}O$ are set to unity. The function $J_X(T)$ is given by $[\exp(5.29/T) - 1]^{-1}$ and $[\exp(5.27/T) - 1]^{-1}$ for $^{13}\text{CO}$ and $^{18}\text{C}O$, respectively. To derive the opacity-corrected total column densities (Pineda et al. 2008), we sum up the column density at each channel along the line of sight and multiplied the column densities by the correction factor of $\tau_i/[1 - \exp(-\tau_i)]$, where $i$ is either for $^{13}\text{CO}$ or $^{18}\text{C}O$. The opacity-corrected total $\text{H}_2$ column density is then derived from the
$^{13}\text{CO}$ integrated intensity assuming the constant abundance of $2 \times 10^{-6}$ (Dickman 1978). We also derived the $^{13}\text{CO}$ and $^{18}\text{C}$ fractional abundances relative to $\text{H}_2$ by dividing the column densities by the $\text{Herschel} \ \text{H}_2$ column density. See also Ishii et al. (2019) for these derivations for Orion A.

We summarize the molecular gas mass derived from $^{13}\text{CO}$ in table 9. The total masses of the observed areas are estimated to be $2.67 \times 10^4 M_\odot$, $3.86 \times 10^4 M_\odot$, and $8.1 \times 10^5 M_\odot$ for Orion A, Aquila Rift, and M17, respectively.

6.1.1 Orion A

In figure 21, we present the excitation temperature map of Orion A determined by the $^{12}\text{CO}$ peak intensity. The excitation temperature ranges from $\sim 8 \text{ K}$ to $\sim 100 \text{ K}$, and takes its maximum near Orion KL. The main filament has somewhat higher temperatures at $\sim 50 \text{ K}$ in the northern region. The southern part including L1641N and NGC 1999 has somewhat lower temperature at $10-20 \text{ K}$. This temperature distribution is consistent with that of Kong et al. (2018) with a finer angular resolution.

The excitation temperature derived from $^{12}\text{CO}$ tends to be somewhat higher than the dust temperature derived from the Spectral Energy Distribution (SED) of the Herschel data. In figure 22, we show the ratio of the excitation temperature derived from $^{12}\text{CO}$ to the dust temperature. Here, we smoothed the excitation temperature map with an effective angular resolution of 36" to match the effective resolution of the dust temperature map. The ratio stays at around 2 along the main filament, except in OMC-1 where the ratio is about 5.

Figures 23, 24, and 25 show the spatial distributions of the opacity-corrected $^{13}\text{CO}$ column density, the fractional abundances relative to $\text{H}_2$ and the optical depth for $^{13}\text{CO}$ ($J = 1 - 0$) and $^{18}\text{C}$O ($J = 1 - 0$), respectively. The optical depth of $^{13}\text{CO}$ ranges from a few to unity. It is about unity along the filament. Several compact regions such as L1641N has larger optical depth at $\sim 3$. On the other hand, the optical depth of $^{18}\text{C}$O is less than unity for almost all areas. Thus, the $^{18}\text{C}$O emission is reasonably optically-thin for the entire cloud.

The fractional abundance of $^{13}\text{CO}$ ranges from a few $\times 10^{-7}$ to a few $\times 10^{-6}$. It tends to be small at being $5 \times 10^{-7}$ toward some dense areas such as the main filament of OMC-1/2/3 and L1641N. Outside the dense areas, the abundance goes up to a few $\times 10^{-6}$. For $^{18}\text{C}$O, the fractional abundance ranges from $1 \times 10^{-8}$ to $1.5 \times 10^{-7}$. Similar to the $^{13}\text{CO}$ abundance, it is small at some dense areas such as OMC-1/2/3 and L1641N.

Our map indicates that the fractional abundance varies from region to region within a factor of $\sim 10$ (see figure 26). Toward the dense regions, the ratio seems to approach to $\sim 5$, close to the standard interstellar value. This variation may be related partly to the selective dissociation due to the FUV radiation discussed by Shimajiri et al. (2011) and Ishii et al. (2019). See Ishii et al. (2018) for
more details of the analysis.

In figure 27a, we present the cumulative $^{13}$CO mass distributions of Orion A. We divide the cloud into three areas: North (Dec. $\geq -05:32:56.0$), OMC-1 ($-05:30:26.0 \leq$ Dec. $\leq -05:16:03.5$), and South (Dec $\leq -05:32:56.0$), where North area includes OMC-1. This indicates that the OMC-1 area contains a fraction of molecular gas with column density higher than $\sim 1$ g cm$^{-2}$, the threshold for high mass star formation proposed by Krumholz & McKee (2008), beyond which further fragmentation of clouds can be avoided to form lower-mass cores, where $\sim 1$ g cm$^{-2}$ corresponds to the $^{13}$CO column density of $\sim 5 \times 10^{17}$ cm$^{-2}$, assuming the $^{13}$CO fractional abundance of $2 \times 10^{-6}$ (Dickman 1978). In contrast, in the South, the molecular gas with column densities higher than the threshold is deficient. The total $^{13}$CO mass is estimated to be $3.9 \times 10^4 M_\odot$ with $7.4 \times 10^3 M_\odot$, $1.6 \times 10^4 M_\odot$, and $2.3 \times 10^4 M_\odot$ for OMC-1, North, and South, respectively.

Below, we repeat the same analysis shown above to the other two regions.

6.1.2 Aquila Rift

Figure 28 shows the spatial distribution of the CO excitation temperature. The excitation temperature is high toward the W40 HII region. Serpens South has a relatively high excitation temperature of 25 K, but in other parts around Serpens South it is very low at $\sim 10$ K, indicating that the star formation may not be active. In figure 29, we show the ratio of the excitation temperature derived from $^{12}$CO to the dust temperature. Here, we smoothed the excitation temperature map with an effective angular resolution of 36$''$ to match the effective resolution of the dust temperature map. The excitation temperature is nearly the same as the dust temperature in Aquila Rift except in W40 HII region where the excitation temperature goes up to about 2.

Figures 30, 31 and 32 show the spatial distribution of the $^{13}$CO column density, the fractional abundances relative to H$_2$ and the optical depth for $^{13}$CO ($J=1-0$) and $^{18}$O ($J=1-0$), respectively. The optical depth of $^{13}$CO tends to be higher than Orion A, and sometimes larger than 2–3 toward the Serpens South region. The fractional abundances of $^{13}$CO and $^{18}$O seem to be low in the filamentary structures seen in the Herschel map. This may indicate that CO molecules are depleted in the cold dense gas in Serpens South. The ratio of $^{13}$CO and $^{18}$O abundances stays at around 0.1 (see figure 33).

In figure 27b, we present the cumulative $^{13}$CO mass distributions of Aquila Rift. We divide the cloud into two areas: East (Dec. $\geq 18:30:39.6$) and West (Dec $\leq 18:30:39.6$). This indicates that the Eastern area contains a fraction of molecular gas with column density higher than $\sim 1$ g cm$^{-2}$, the threshold for high mass star formation proposed by Krumholz & McKee (2008). In contrast, in the Western area which contains Serpens South, the molecular gas with column densities higher than
the threshold is deficient. The total $^{13}$CO mass is estimated to be $3.9 \times 10^4 M_\odot$ with $7.4 \times 10^3 M_\odot$, $1.6 \times 10^4 M_\odot$, and $2.3 \times 10^4 M_\odot$ for OMC-1, North, and South, respectively.

6.2 M17

Figure 34 shows the spatial distribution of the CO excitation temperature. The excitation temperature is high toward the M17 HII region. In contrast, in the infrared dark cloud, the excitation temperature stays at $30 - 40$ K. The excitation temperatures are not so low as those of Serpens South region. Figures 35 and 36 show the spatial distribution of the column density and the optical depth for $^{13}$CO ($J = 1 - 0$) and C$^{18}$O ($J = 1 - 0$), respectively. The optical depths of $^{13}$CO and C$^{18}$O tend to be higher toward the M17 SWex. See Nuygen Luong et al. (2019) for the details of the global molecular gas distributions.

In figure 27c, we present the cumulative $^{13}$CO mass distributions of M17. We divide the region into two areas: M17 HII area ($l \geq 14.9$) and M17 SWex ($l \leq 14.9$). This indicates that the M17 HII contains a fraction of molecular gas with column density higher than $\sim 1$ g cm$^{-2}$, the threshold for high mass star formation proposed by Krumholz & McKee (2008). In contrast, in the M17 SWex, the molecular gas with column densities higher than the threshold is deficient. This may be a reason why the high-mass star formation is not active in M17 SWex (Povich et al. 2016). The total $^{13}$CO mass is estimated to be $3.6 \times 10^5 M_\odot$ and $4.5 \times 10^5 M_\odot$, for M17 HII and M17 SWex, respectively. M17 SWex area contains about two time more massive molecular gas than M17 HII.

7 Molecular Outflows

Molecular outflow feedback is one of the important stellar feedback mechanisms. Molecular outflows can inject significant energy and momentum in molecular clouds. Our $^{12}$CO data are useful to identify the outflows and gauge how much energy and momentum are injected into the clouds. Molecular outflow survey is one of the main sciences we will conduct. Here we briefly present the result of the molecular outflow survey toward small areas in Orion A (L1641N) and Aquila Rift (Serpens South). See Tanabe et al. (2018) for the results of comprehensive outflow surveys toward Orion A.

7.1 Orion A (L1641N)

In figure 38, we present the three-color image of the L1641N region. The red, blue and green images show the $^{12}$CO intensity image integrated from 11 km s$^{-1}$ to 15 km s$^{-1}$ (redshifted component), $^{12}$CO intensity image integrated from -20 km s$^{-1}$ to 0 km s$^{-1}$ (blueshifted components), and Herschel column density image, respectively. In this region, Stanke & Williams (2007) and Nakamura et al.
identified molecular outflows in $^{12}$CO ($J = 2 - 1$) and $^{12}$CO($J = 1 - 0$), respectively. The high-velocity components they previously identified are recognized in our image. For example, there are several dust cores in this region which are seen in green. The redshifted collimated flow running from north to south blows out from the brightest dust core located at the position of (R.A., Dec.)=(5:36:19, −6:22:29).

The result of accurate outflow identification is presented in Tanabe et al. (2018), who found 44 CO outflows in Orion A, 17 out of which are new detections. Based on the identified outflow physical parameters, they estimated the momentum injection rates due to the molecular outflows and found that the total momentum injection rate due to the outflows and the expanding shells identified in the $^{13}$CO data by Feddersen et al. (2018) is larger than the turbulence dissipation rate in Orion A. Thus, the stellar feedback such as the molecular outflows and expanding shells driven by stellar winds is an important mechanism to replenish the internal cloud turbulence.

7.2 Aquila Rift (Serpens South)

In figure 39, we present the three-color image of the Serpens South region. Nakamura et al. (2011) conducted the molecular outflow survey toward the Serpens South cluster in $^{12}$CO ($J = 3 - 2$). The present paper is the first outflow survey using $^{12}$CO ($J = 1 - 0$). The coverage of the image shown in figure 39 is wider than that of Nakamura et al. (2011). The red, blue and green images indicate the $^{12}$CO intensity image integrated from 11 km s$^{-1}$ to 15 km s$^{-1}$ (redshifted component), $^{12}$CO intensity image integrated from -20 km s$^{-1}$ to 0 km s$^{-1}$ (blueshifted components), and Herschel column density image, respectively. The distribution of the high velocity components basically similar to that of $^{12}$CO ($J = 3 - 2$).

By visual inspection, we attempt to identify the high-velocity components which are likely to originate from the molecular outflows toward Herschel protostellar cores in this region. The result of the identification is summarized in table 10. We detected in the $^{12}$CO ($J = 1 - 0$) emission almost all the outflow lobes identified by Nakamura et al. (2011). In total, we identified 13 outflow driving sources including the 3 tentative detections. From this survey, we identified 4 new outflow sources, all of which are located outside the map of Nakamura et al. (2011).

As discussed by Shimoikura et al. (2015), the Aquila Rift region contains several cloud components with different line-of-sight velocities. The existence of such multiple components sometimes precludes clear identification of high-velocity components since high-velocity components tend to overlap with different cloud components along the line of sight. More careful inspection of the data cube is needed to fully identify the molecular outflows. We expect that more outflows exist even in
the area presented here. We will present a complete outflow survey toward Aquila Rift in a separate paper.

The scientific results will be reported in more details in separate papers

8 Summary

In the present paper, we described the project overview of Nobeyama mapping project toward the three nearby molecular clouds, Orion A, Aquila Rift, and M17. The main purpose of the present paper is to summarize complicated observational procedures and flux calibration methods. We summarize the main results of the present paper as follows.

1. We conducted wide-field mapping observations toward three nearby molecular clouds, Orion A, Aquila Rift, and M17, in $^{12}$CO ($J = 1 - 0$), $^{13}$CO ($J = 1 - 0$), C$^{18}$O ($J = 1 - 0$), N$_2$H$^+$ ($J = 1 - 0$), and CCS ($J_N = 8_7 - 7_6$) using the Nobeyama 45-m telescope.
2. The map coverage is over $1^\circ \times 1^\circ$. We cover most of the molecular clouds seen in dust emission.
3. We checked the absolute intensities obtained with the new 4-beam receiver, FOREST, by comparing the intensities obtained with the previous receiver, BEARS toward the same areas for $^{12}$CO, $^{13}$CO, and C$^{18}$O.
4. For N$_2$H$^+$, we compared the intensities of the Taurus molecular cloud obtained with the IRAM 30-m telescope, and the fluxes taken with FOREST coincide with those obtained with the IRAM 30-m telescope within an error of 5%.
5. We obtained the column densities of $^{13}$CO ($J = 1 - 0$) and C$^{18}$O ($J = 1 - 0$) and derived their fractional abundances toward Orion A. Our maps indicate that the fractional abundances depends on the cloud environments, and varies from region to region by a factor of $\sim 10$.
6. The cumulative column density distributions clearly show that only a fraction of the molecular gas has column densities high enough to create high-mass stars for individual clouds.
7. Our maps have sufficient sensitivities to identify the molecular outflows. In particular, in our $^{12}$CO ($J = 1 - 0$) data, we confirmed all the outflows previously detected in $^{12}$CO ($J = 3 - 2$) toward Serpens South, and identified 4 new outflows in the adjacent region. Using the catalog of the protostars, we identified the driving sources of these CO outflows.
8. Finally we briefly describe results from our project published in separate papers. We revealed hierarchical structure of Orion A, applying SCIMES and Dendrogram to $^{13}$CO cube data. In total, we identified about 80 clouds in Orion A. The abundance ratio of $^{13}$CO to C$^{18}$O varies from region to region, affected by the far-UV radiation (Ishii et al. 2019). We identified 44 outflows in Orion A. 15 out of 44 are the new detections (Tanabe et al. 2019). We estimated a momentum injection rate
of the identified outflows and found that they have significant injection momentum rate in the surroundings. Using the data of the OMC-2 FIR 4 region, we characterize the spatial variation of the abundance ratios of several molecules and discussed the possible outflow-triggered star formation Nakamura et al. (2019). The data was taken for the flux calibration of Orion A data. For Aquila, Shimoikura et al. (2019) reveal evidence of the interaction of molecular cloud with the expanding H\textsc{ii} region. Kusune et al. (2019) and Sugitani et al. (2019) carried out the near-infrared polarization observations toward Aquila and M17, respectively, and revealed that the global magnetic field tend to be perpendicular to the elongation of the molecular clouds. Nguyen Luong et al. (2019) revealed the global molecular gas distribution in M17, and found that in the IRDC region, the column densities are not dense enough to create high-mass stars, but ongoing cloud-cloud collisions are likely to be forming higher density regions. Thus, future high-mass star formation is expected.

Acknowledgments

This work was financially supported by JSPS KAKENHI Grant Numbers JP17H02863, JP17H01118, JP26287030, and JP17K00963. This work was supported by NAOJ ALMA Scientific Research Grant Numbers 2017-04A. This work was carried out as one of the large projects of the Nobeyama Radio Observatory (NRO), which is a branch of the National Astronomical Observatory of Japan, National Institute of Natural Sciences. We thank the NRO staff for both operating the 45 m and helping us with the data reduction.

References

André, P. et al. 2010, A&A, 518, L102
Arce, H. G. et al. 2011, ApJ, 742, 105
Aso, Y., Tatematsu, K., Sekimoto, Y. et al. 2000, ApJS, 131, 465
Berné, O., Marcelino, N., & Cernicharo, J. 2014, ApJ, 795, 13
Bally, J. 2016, ARA&A, 54, 491
Breitschwerdt, D., Egger, R., Freyberg, M. J., Frisch, P. C., Vallerga, J. V. 1996, Space Science Reviews, 78, 183
Buckle, J. V., Davis, C. J., di Francesco, J., et al. 2012, MNRAS, 422, 521
Caselli, P., Benson, P. J., Myers, P. C., & Tafalla, M., 2002, ApJ, 572, 238
Chauhan, N., Pandey, A. K., Ogura, K. et al. 2009, MNRAS, 396, 964
Chen, H.-R., V. et al. 2019, ApJ, in press (arXiv:1903.04376)
Chini, R., Reipurth, B., Sievers, A. et al. 1997, A&A, 325, 542
Dame, T. M., Hartmann, D., & Thaddeus, P. 2001, ApJ, 547, 792
Da Rio, N., Tan, J. C., Covey, K. R., et al. 2016, ApJ, 818, 59
Dickman, R. L., 1978, ApJS, 37, 407
Dobashi, K., Uehara, H., Kandori, R., Sakurai, T., Kaiden, M., Umemoto, T., Sato, F., 2005, PASJ, 57, 417
Dobashi, K. 2011, PASJ, 63, 1
Dobashi, K. et al., 2019a, PASJ, in press (arXiv:1905.07395D)
Dobashi, K. et al., 2019b, PASJ, in press
Elmegreen, B. G. & Lada, C. J. 1977, ApJ, 214, 725
Elmegreen, B. G. 1979, ApJ, 232, 729
Emerson, D. T. & Graeve, R. 1988, A&A, 190, 353
Evans, N. J. II et al., ApJS, 181, 321
Feddesen, J. R., Arce, H. G., Kong, S. et al. 2018, ApJ, 862, 121
Frisch, P. C. 1998, in IAU Coll. 166, The Local Bubble and Beyond, ed. D. Breitschwerdt, M. Freyberg, & J. Truemper (Berlin: Springer), 269
Frisch, P. C. et al., 2015, in Journal of Physics: Conference Series, 577, 012010
Furlan, E., Megeath, S. T., Osorio, M., et al. 2014, ApJ, 786, 26
Goicoechea, J. R. et al., 2018, A&A, in press
Goldsmith, P.F., Langer, W.D., Ellder, J., Irvine W., & Kollberg E. 1981, ApJ, 249, 524
González-Garcia, B., Manoj, P., Watson, D., M., et al. 2016, A&A, 596, 26
Gutermuth, R. A., et al. 2008, ApJ, 673, L151
Hacar, A., Tafalla, M., Forbrich, J. et al. 2018, A&A, 610, 77
Hacar, A., Alves, J., Tafalla, M., & Goicoechea, J. R., 2018, A&A, 602, 2
Hirota, T., Yamamoto, S., Mikami, H., Oishi, M. 1998, ApJ, 503, 717
Hirota, T., Ikeda, M., Yamamoto, S. 2001, ApJ, 547, 814
Ikeda, N., Sunada, K., & Kitamura, Y. 2007, ApJ, 665, 1194
Ishii, S., et al. 2016, PASJ, 68, 10
Ishii, S., et al. 2019, PASJ, in press
Kainulainen, J., Stutz, A. M., Stanke, T. et al. 2017, A&A, 600, 141
Kama, M., López-Sepulcre, A., Dominik, C., et al. 2013, A&A, 556, 57
Kama, M., Caux, E., López-Sepulcre, A., et al. 2015, A&A, 574, 107
Kim, M. K., Hirota, T., Honma, M. et al. 2008, PASJ, 60, 991
Kirk, H., et al. 2013, ApJ, 766, 115
Klessen, R. S., Burkert, A., & Bate, M. R. 1998, ApJ, 501, L205
Kong, S, Arce, H. G., Feddersen, J. R. et al. 2018, ApJS, 236, 25
Konyves, V., André, P., Menshchikov, A. et al. 2015, A&A, 584, 91
Krumholz, M., R., Bate, M. R., et al. 2015, A&A, 574, 107
Krumholz, M. R., & McKee, C. F. 2008, Nature, 451, 1082
Krumholz, M. R., & Tan, J. C. 2007, ApJ, 654, 304
Kusune, T., et al., 2019, PASJ, in press
Lin, S.-J., Shimajiri, Y., Hara, C. et al. 2016, ApJ, 826, 193
Loinard, L., Torres, R. M., Mioduszewski, A. J. et al. (2007), ApJ, 671, 546
Loison, J.-C., Wakelam, V., Hickson, K. M., 2014, MNRAS, 443, 398
Lombardi, M., Bouy, H., Alves, J., & Lada, C. J., 2014, A&A, 568, 1
López-Sepulcre, A., Taquet, V., Sánchez-Monge, ., et al. 2013, A&A, 556, 62
Megeath, S. T., Gutermuth, R., Muzerolle, J., et al. 2012, AJ, 144, 192
Meingast, S., Alves, J., Mardones, D., et al. 2016, A&A, 587, A153
Mac Low, M.-M., & Klessen, R. S. 2004, RvMP, 76, 125
Marka, C., Schreyer, K., Launhardt, R., Semenov, D. A., Henning, Th. 2012, A&A, 537, 4
Maruta, H., Nakamura, F., Nishi, R., et al. 2010, ApJ, 714, 680
Maury, A. J. et al. 2011, A&A, 535, 77
McKee, C. F. 1989, ApJ, 345, 782
McKee, C. F., & Williams, J. P. 1997, ApJ, 476, 144
McKee, C. F., & Ostriker, E. C., 2007, ARA&A, 45, 56
Menten, K. M., Reid, M. J., Forbrich, J., Brunthaler, A., 2007, A&A, 474, 515
Minamidani et al. 2016, Proc. SPIE, 9914, 99141Z
Myers, P. C. 2009, ApJ, 700, 1609
Murray, N. W., & Rahman, M. 2010, ApJ, 709, 424
Nakamura, F., & Li, Z.-Y., 2007, ApJ, 662, 395
Nakamura, F., Kamada, Y., Kamazaki, T., et al., 2011, ApJ, 726, 46
Nakamura, F., et al., 2011b, ApJ, 737, 56
Nakamura, F., Miura, T., Kitamura, Y., et al., 2012, ApJ, 746, 25
Nakamura, F., et al., 2014, ApJL, 791, L23
Nakamura, F., Dobashi, K., Shimoikura, T., Tanaka, T., & Onishi, T. 2017, ApJ, 837, 154
Nakamura, F., Oyamada, S., Okumura, S. et al. 2019, PASJ, in press (arXiv:1906.11454)
Nishimura, A. et al. 2015, ApJS, 216, 18
Nishimura, A. et al. 2018, PASJ, 70, 42
Nguyen Luong, Q. et al. 2019, submitted to PASJ
Ohashi, S., Sanhuesa, P., Chen, H.-R., et al., 2016, ApJ, 833, 209
Ortiz-León, G. N., Loinard, L., Kounkel, M. A. et al. 2017a, ApJ, 834, 141
Ortiz-León, G. N., Dzib, S. A., Kounkel, M., A., et al., 2017b, ApJ, 834, 143
Osorio, M., Diaz-Rodriguez, A. K., Anglada, G., et al. 2017, ApJ, 840, 36
Pagani, L., Daniel, F., & Dubernet, M.-L. 2009, A&A, 494, 719
Pabst, R. et al. 2019, Nature, 565, 618
Pineda, J. E., Caselli, P., & Goodman, A. A. 2008, ApJ, 679, 481
Povich, M. S., et al. 2006, ApJ, 696, 1278
Povich, M. S., & Whitney, B. A. ApJ, 714, L285
Povich, M. S., Townsley, L. K., Robitaille, T. P., et al. ApJ, 825, 125
Punanova, A., Caselli, P., Pon, A., et al. A&A, 587, 118
Reipurth, B., Rodriguez, L., & Chini, R. AJ, 118, 983
Ripple, F., Heyer, M. H., Gutermuth, R., Snell, R. L., & Brunt, C. M. 2013, MNRAS, 431, 1296
Robitaille, T., & Whitney, B. A. 2010, ApJ, 710, 11
Rumble, D. et al., 2016, MNRAS, 460, 4150 MNRAS, 431, 1296
Sandell, G., Knee, L. B. G. 2001, ApJ, 546, 49
Sawada, T., Ikeda, N., Sunada, K., et al. 2008, PASJ, 60, 445
Shu, F. H., Adams, F. C., & Lizano, S. 1987, ARA&A, 25, 23
Shimajiri, Y., Takahashi, S., Takakuwa, S., et al. 2008, ApJ, 683, 255
Shimajiri, Y., Kawabe, R., Takakuwa, S., et al. 2011, PASJ, 63, 105
Shimajiri, Y., Kitamura, Y., Saito, M., et al. 2014, A&A, 564, A68
Shimajiri, Y., Kitamura, Y., Nakamura, F., et al. 2015, ApJS, 217, 7
Shimajiri, Y., Sakai, T., Kitamura, Y. et al. 2015, ApJS, 221, 31
Shimajiri, Y., et al. 2017, A&A, 604, 74
Shimoikura, T., Dobashi, K., Nakamura, F., et al. 2015, ApJ, 806, 201
Shimoikura, T., Dobashi, K., Nakamura, F., Matsumoto, T., Hirotta, T. 2018, ApJ, 855, 45
Shimoikura, T., Dobashi, K., Nakamura, F., Shimajiri, Y., Sugitani, K. 2019, PASJ, in press (arXiv:1809.09855)
Stanke, T., & Williams, J. P. 2007, AJ, 133, 1307
Sugitani, K. & Ogura, K. 1994, ApJS, 92, 163
Sugitani, K., Nakamura, F., Shimoikura, T., Dobashi, K., Nguyen-Luong, Q., & Kusume, T., PASJ, in press
Suzuki, H., Yamamoto, S., Ohishi, M. et al. 1992, ApJ, 392, 551
Tafalla, M. & Hacar, A., 2015, A&A, 574, 104
Takahashi, S., Saito, M, Ohashi, N., et al. 2008, ApJ, 688, 344
Tanaka, T., Nakamura, F., Awazu, Y., et al. 2013, ApJ, 778, 34
Tanabe, Y., et al. 2019, submitted to PASJ
Tatematsu, K., Kandori, R., Umemoto, T., Murata, Y., Sekimoto, Y. 2008, PASJ, 60, 407

26
Tatematsu, K., Ohashi, S., Umemoto, T. et al. 2014, PASJ, 66, 16
Tennekes, P. P., Harju, J., Juvela, M., Tóth, L. V., 2006, A&A, 456, 1037
Torres, R. M., Loinard, L., Mioduszewski, A. J., & Rodríguez, L. F., 2007, ApJ, 671, 1813
Yokogawa, S., Kitamura, Y., Momose, M., & Kawabe, R. 2003, ApJ, 595, 266
Yoshida, A., Kitamura, Y., Shimajiri, Y., & Kawabe, R., 2010, ApJ, 718, 1019
Wang, P., Li, Z.-Y., Abel, T., & Nakamura, F. 2010, ApJ, 709, 27
Wilson, B. A., Dame, T. M., Masheder, M. R. W., & Thaddeus, P. 2005, A&A, 430, 523
Xu, Y., Moscadelli, L., Reid, M. J. et al. 2011, ApJ, 733, 25
Zucker et al. 2015, ApJ, 815, 23
Zuckerman, B. & Evans, N. J., II, 1974, ApJ, 192, 149
| Telescope/Survey         | Line/continuum | Resolution (arcsec/arcmin) | cloud/Key Reference |
|--------------------------|----------------|----------------------------|---------------------|
| Osaka Pref. 1.85-m       | $^{12}\text{CO}/^{13}\text{CO}/^{18}\text{O}$ $J=2-1$ | 2.7                  | Orion A/Nishimura et al. (2015) |
| Tsukuba 30-cm            | $^{12}\text{CO}$ $J=4-3$ | 9.4                  | Orion A/Ishii et al. (2016) |
| Harvard-CfA 1.2 m        | $^{12}\text{CO}$ $J=1-0$ | 8.4                  | Orion A/Wilson et al. (2005) |
| ASTE, NRO 45-m           | 1.1$m^{12}\text{CO}$ $J=1-0$ | 36″/21″              | Orion A/Shimajiri et al. (2011) |
| JCMT/GBS                 | $^{13}\text{CO}/^{18}\text{O}$ $J=3-2$ | 17″                  | Orion A/Buckle et al. (2012) |
| FCRAO 14-m               | $^{12}\text{CO}/^{13}\text{CO}$ $J=1-0$ | 46″                 | Orion A/Ripple et al. (2013) |
| IRAM 30-m                | $^{12}\text{CO}/^{13}\text{CO}$ $J=2-1$ | 11″                 | Orion A/Berné et al. (2014) |
| ASTE 10-m                | $^{12}\text{CO}$ $J=3-2$ | 30″                 | Orion A/Takahashi et al. (2008) |
| Herschel/HIFI IRAM 30-m  | $\text{CH}^+/$$^{12}\text{CO}$ ($J = 10 – 9$)/$\text{HCN}/^{13}\text{CO}$ ($J = 6 – 5$),… | 4″–27″              | Orion A (OMC-1)/Goicoechea et al. (2018) |
| Herschel-Planck          | dust continuum | 36″                  | Orion A/Lombardi et al. (2014) |
| Spitzer                  | MIR 3–24 μ m  | 2″–5″               | Orion A/Megeath et al. (2012) |
| VISTA/VISION             | NIR 0.85–2.4μ m | 0.85″              | Orion A/Meingast et al. (2016) |
| IN-SYNC                  | NIR 1.5–1.6 μ m | 1.6″                | Orion A/Da Rio et al. (2016) |
| NRO 45-m                 | $\text{N}_2\text{H}^+$ $J=1-0$ | 21″                | Orion A/Tatematsu et al. (2008) |
| NRO 45-m                 | $^{13}\text{CO}$ $J=1-0$ | 21″                | Orion A/Ikedaa et al. (2007) |
| CARMA+NRO 45 m/CARMA-NRO Orion | $^{12}\text{CO}/^{13}\text{CO}/^{18}\text{O}$ $J=1-0$ | 8″               | Orion A/Kong et al. (2018) |
| NRO 45-m                 | $^{12}\text{CO}/^{13}\text{CO}/^{18}\text{O}/\text{N}_2\text{H}^+$ $J=1-0$ / CCS $J_N = 7_6 - 6_5$ | 21″–24″          | Orion A/this paper |
| Harvard-CfA 1.2 m        | $^{12}\text{CO}$ $J=1-0$ | 8.4                | Aquila/Dame et al. (2001) |
| Osaka Pref. 1.85-m       | $^{12}\text{CO}/^{13}\text{CO}/^{18}\text{O}$ $J=2-1$ | 2.7                | Aquila/ Nakamura et al. (2017) |
| Herschel                 | dust          | 36″                | Aquila/André et al. (2010) |
| IRAM 30-m/MAMBO          | 1.2mm        | 11″               | Aquila/Maury et al. (2011) |
| IRAM 30-m                | HCN/$^{13}\text{CN}/^{13}\text{CO}$+$/^{13}\text{CO}$+$ $J=1-0$ | 40″               | Aquila/Shimajiri et al. (2017) |
| JCMT/GBS                 | 850μ m $^{12}\text{CO}$ $J=3-2$ | 15″/22″           | Aquila (W40)/Rumble et al. (2016) |
| ASTE 10-m                | $^{12}\text{CO}$ $J = 3 – 2 / \text{HCO}^+$ $J=4-3$ | 31″             | Aquila (W40)/Shimoikura et al. (2015) |
| ASTE 10-m                | $^{12}\text{CO}$ $J=3-2 / \text{HCO}^+ + J=4 – 3$ | 24″             | Aquila (Serpens South)/Nakamura et al. (2011b) |
| Spitzer                  | IRAC          | 2″                | Aquila (Serpens South)/Gutermuth et al. (2008) |
| NRO 45-m                 | $\text{N}_2\text{H}^+$ $J=1-0$ | 24″            | Aquila (Serpens South)/Tanaka et al. (2013) |
| MOPRA                    | $\text{N}_2\text{H}^+$/H$^3\text{CN}$/HCN/HNC/$^{13}\text{CO}$+$ $J=1-0$ | 40″            | Aquila (Serpens South)/Kirk et al. (2013) |
| NRO 45-m                 | CCS $J_N = 4_3 – 3_2$/HC$_3$N $J = 5 – 4$ | 37″          | Aquila (Serpens South)/Nakamura et al. (2014) |
| NRO 45-m                 | $^{12}\text{CO}/^{13}\text{CO}/^{18}\text{O}/\text{N}_2\text{H}^+$ $J=1-0$ / CCS $J_N = 7_6 - 6_5$ | 21″–24″       | Aquila/this paper |
| Spitzer                  | MIR           | 2″                | M17/Povich et al. (2010, 2016) |
| HHT 10-m                 | $^{12}\text{CO}/^{13}\text{CO}$ $J=2-1$ | 32″            | M17/Povich et al. (2009) |
| NRO 45-m                 | $^{12}\text{CO}/^{13}\text{CO}/^{18}\text{O}$ $J=1-0$ | 20″            | M17/Nishimura et al. (2018) |
| NRO 45-m                 | $^{12}\text{CO}/^{13}\text{CO}/^{18}\text{O}/\text{N}_2\text{H}^+$ $J=1-0$ / CCS $J_N = 7_6 - 6_5$ | 21″–24″       | M17/this paper |

This is not a complete list of the recent wide-field survey. See also table 1 of Kong et al. (2018) for Orion A.
Table 2. Spatial resolutions achieved for the Nobeyama 45-m, CARMA, and ALMA observations

| telescopes                  | angular resolution nearest regions | intermediate regions | distant regions |
|-----------------------------|-----------------------------------|----------------------|-----------------|
| NRO 45-m only              | ∼ 20"                             | 2800 au (0.014 pc)   | 40000 au (0.2 pc) |
| CARMA+NRO 45-m             | ∼ 8"                              | –                    | –               |
| ALMA                        | ∼ 1"                               | 140 au               | 3000 au         |

The distances are adopted from the following references: nearest regions, Taurus (137 pc, Torres et al. (2007) and Loinard et al. (2007)), ρ Oph (137 pc, Ortiz-León et al. (2017a)), intermediate regions, Orion A (414 pc, Menten et al. (2007); Kim et al. (2008)), Aquila Rift (436 pc, Ortiz-León et al. (2017b)), and distant regions, M17 (2.0 kpc, Xu et al. (2011)). We note that for the M17 region, several clouds with different distances seem to be overlapped along the line of sight (Povich et al. 2016). Here we refer to the ALMA observations just for comparison of the spatial resolutions achieved. In the present paper, we present the data obtained with the Nobeyama 45-m telescope. The detail of the CARMA+Nobeyama combined data is presented in Kong et al. (2018).

Table 3. Observed lines

| Molecule | Transition | Rest Frequency (GHz) | Beam Size (arcmin) | ΔV (km s⁻¹) | Main Beam Efficiency (η) |
|----------|------------|----------------------|--------------------|-------------|--------------------------|
| 12CO     | J=1–0     | 115.271204           | 14.3 ± 0.4         | 0.1         | 0.416 ± 3%               |
| 13CO     | J=1–0     | 110.201354           | 14.9 ± 0.4         | 0.1         | 0.435 ± 3%               |
| C₁₈O     | J=1–0     | 109.782176           | 14.9 ± 0.4         | 0.1         | 0.437 ± 3%               |
| N₂H⁺     | J=1–0     | 93.1737637           | 17 ± 0.5           | 0.1         | 0.500 ± 5%               |
| CCS      | N₇=8–7     | 93.870098            | 17 ± 0.5           | 0.1         | 0.497 ± 5%               |

The rest frequency of the main hyperfine component of N₂H⁺ is adopted from Pagani et al. (2009). The beam size and main beam efficiencies listed are those measured with FOREST. The errors of the efficiencies are mainly due to the uncertainty of brightness temperature of the planets used for the measurements. See the NRO web page for more details.

Table 4. Sizes of Observation Boxes for the FOREST observations

| lines | scan | ¹²CO/¹³CO | C¹⁸O/N₂H⁺ | ¹³CO/C¹⁸O/N₂H⁺/CCS |
|-------|------|-----------|----------|-------------------|
| season |      | 2014-2015/2015-2016/2016-2017 | 2015-2016 | 2016-2017         |
| Orion A | x    | 10′ × 5′  | 20′ × 5′  | 20′ × 5′          |
| Orion A | y    | 5′ × 10′  | 5′ × 10′  | 5′ × 10′          |
| Aquila Rift | x    | 20′ × 10′ | –         | 20′ × 10′         |
| Aquila Rift | y    | 10′ × 20′ | –         | –                 |
| M17 | x    | 20′ × 10′  | 20′ × 10′  | 20′ × 10′         |
| M17 | y    | 10′ × 20′  | 10′ × 20′  | 10′ × 20′         |

Taking into account the observation schedule of each season, we changed the observation box sizes. For Aquila Rift, we could not obtain y-scan data of C¹⁸O, N₂H⁺, and CCS. In addition, for M17, we significantly reduced the observation area for the C¹⁸O, N₂H⁺, and CCS observations. These incomplete observations are mainly due to the malfunction of the master collimator driving system happened in the 2016-2017 season.
Table 5. Parameters of Observations with FOREST

| Box size         | 10' × 5' | 20' × 5' | 20' × 10' |
|------------------|----------|----------|-----------|
| Time for scan (s) | 15       | 30       | 26        |
| Number of ONs per OFF | 4        | 2        | 3         |
| Separation between scans | 5''.17   | 5''.17   | 5''.17    |
| Frequency resolution (kHz) | 15.26   | 15.26   | 15.26     |

For all observations, scans of the OTF observations are separated in the interval of 5''.17. Thus, individual scans by 4 beams of FOREST are completely overlapped. This minimizes the effort of flux calibration greatly.

Table 6. Map coverage and positions of emission-free areas used for the observations and SiO maser objects used for the pointing observations

| Regions        | Map coverage | Emission-free areas R.A. (J2000.0) Dec.(J2000.0) | Pointing Objects R.A. (J2000.0) Dec.(J2000.0) | (SiO maser line) |
|----------------|--------------|-----------------------------------------------|-----------------------------------------------|------------------|
| Orion A        | 0.7° × 2°    | 05h29m00s0 05h35m14s16 05h22m21s5          | -05°25'30''0  -05°22'17''5                      | Orion KL         |
| Aquila Rift    | 1° × 1°      | 18h41m19s09 18h37m19s26 18h37m19s26        | +04°12'00''0  +10°25'42''0                      | V1111-Oph        |
| M17            | 2° × 0.5°    | 18h37m19s26 18h37m19s26 18h37m19s26        | +10°25'42''2  +10°25'42''2                      | V1111-Oph        |

These areas and objects were used for both the BEARS and FOREST observations.

Table 7. Summary of the FOREST observations

| Lines | Period          | Observation Time | T_{sys} | vel. res. | noise level |
|-------|-----------------|------------------|---------|-----------|-------------|
| Orion A | 12CO 2014 Dec — 2016 Dec | 150 hrs | 350 ~ 400 K | 0.1 km s^{-1} | 0.50 ~ 1.5 K |
|        | 13CO 2014 Dec — 2017 March | 150 hrs | 150 ~ 200 K | 0.1 km s^{-1} | 0.20 ~ 0.30 K |
|        | C^{18}O 2017 Jan — 2017 March | 150 hrs | 150 ~ 200 K | 0.1 km s^{-1} | 0.26 ~ 0.30 K |
|        | CCS 2017 Jan — 2017 March | 150 hrs | 150 ~ 200 K | 0.1 km s^{-1} | 0.30 ~ 0.49 K |
|        | N_2H^+ 2017 Jan — 2017 March | 150 hrs | 150 ~ 200 K | 0.1 km s^{-1} | 0.26 ~ 0.30 K |
| Aquila Rift | 12CO 2015 March — 2017 March | 50 hrs | 300 ~ 500 K | 0.1 km s^{-1} | 0.38 ~ 0.50 K |
|        | 13CO 2015 March — 2017 March | 150 hrs | 150 ~ 200 K | 0.1 km s^{-1} | 0.38 ~ 0.50 K |
|        | C^{18}O 2016 March — 2017 March | 120 hrs | 150 ~ 200 K | 0.1 km s^{-1} | 0.20 ~ 0.30 K |
|        | CCS 2016 March — 2017 March | 120 hrs | 150 ~ 200 K | 0.1 km s^{-1} | 0.17 ~ 0.20 K |
|        | N_2H^+ 2016 March — 2017 March | 120 hrs | 150 ~ 200 K | 0.1 km s^{-1} | 0.18 ~ 0.22 K |
| M17    | 12CO 2015 March — 2017 March | 25 hrs | 300 ~ 500 K | 0.1 km s^{-1} | 0.48 ~ 1.7 K |
|        | 13CO 2015 March — 2017 March | 150 hrs | 150 ~ 200 K | 0.1 km s^{-1} | 0.16 ~ 0.80 K |
|        | C^{18}O 2016 March — 2017 March | 65 hrs | 150 ~ 200 K | 0.1 km s^{-1} | 0.17 ~ 0.34 K |
|        | CCS 2016 March — 2017 March | 65 hrs | 150 ~ 200 K | 0.1 km s^{-1} | 0.20 ~ 0.27 K |
|        | N_2H^+ 2016 March — 2017 March | 65 hrs | 150 ~ 200 K | 0.1 km s^{-1} | 0.15 ~ 0.27 K |

The values of T_{sys} are given in the single side band.
### Table 8. Summary of the BEARS observations

| Lines         | Period          | Observation Time | $T_{\text{sys}}$ | vel. res. | noise level | obs mode | reference |
|---------------|-----------------|------------------|------------------|-----------|-------------|----------|-----------|
| 12CO (north)  | 2007 Dec – 2008 May | ∼ 40 hrs         | 250 – 500 K      | 0.2 km s$^{-1}$ | 0.4 K       | OTF      | 1         |
| 12CO (south)  | 2009 Dec – 2010 Jan | ∼ 20 hrs         | 300 – 600 K      | 0.5 km s$^{-1}$ | 0.52 K      | OTF      | 2         |
| 13CO (north)  | 2013 May         | ∼ 50 hrs         | 270 – 470 K      | 0.3 km s$^{-1}$ | 0.7 K       | OTF      | 3         |
| 13CO (south)  | 2012 Apr – 2013 March | ∼ 60 hrs        | 210 – 400 K      | 0.1 km s$^{-1}$ | 1.96 K      | OTF      | this paper|
| C$^{18}$O (north) | 2010 March – 2013 May | ∼ 100 hrs       | 270 – 470 K      | 0.1 km s$^{-1}$ | 0.3 K       | OTF      | 3         |
| Aquila Rift (Serpens South) |           |                  |                  |           |             |          |           |
| 12CO         | 2011 Apr – 2011 May | ∼ 15 hrs         | 250 – 500 K      | 0.5 km s$^{-1}$ | 1.3 K       | OTF      | this paper|
| 13CO         | 2011 Apr – 2011 May | ∼ 30 hrs         | 210 – 400 K      | 0.5 km s$^{-1}$ | 0.88 K      | OTF      | this paper|
| C$^{18}$O    | 2011 Apr – 2014 Apr | ∼ 30 hrs         | 200 – 400 K      | 0.1 km s$^{-1}$ | 0.9 K       | OTF      | this paper|

The values of $T_{\text{sys}}$ are given in the double side band. References — 1: Shimajiri et al. (2011), 2: Nakamura et al. (2012), 3: Shimajiri et al. (2014)

### Table 9. Molecular Gas Mass Estimated from 13CO toward Orion A, Aquila Rift, and M17

| Name          | Region                  | Mass          |
|---------------|-------------------------|---------------|
| Orion A       | total                   | $3.86 \times 10^4$ |
| Orion A North | Dec. ≥ −05:30:26.0      | $1.56 \times 10^4$ |
| Orion A South | Dec. ≤ −0.5:16:03.5     | $2.30 \times 10^4$ |
| Orion A OMC-1 | −05:30:26.0 ≤ Dec. ≤ −0.5:16:03.5 | $7.4 \times 10^3$ |
| Aquila Rift   | total                   | $2.67 \times 10^3$ |
| Aquila East (W40) | R.A. ≤ 18:30:39.6     | $1.30 \times 10^4$ |
| Aquila West (Serpens South) | R.A. ≥ 18:30:39.6 | $1.37 \times 10^4$ |
| M17           | total                   | $8.1 \times 10^5$ |
| M17           | $l \geq 14:26:22.5$    | $3.6 \times 10^5$ |
| M17 SWex      | $l \leq 14:26:22.5$    | $4.5 \times 10^5$ |

OMC-1 is a part of the north area of Orion A. The distances of 414 pc, 436 pc, and 2.0 kpc are adopted for Orion A, Aquila Rift, and M17, respectively. The excitation temperature of 13CO is estimated from the peak intensity of 12CO at each pixel.
Table 10. Molecular Outflow Candidates in Serpens South

| No. | R.A. (J2000) | Dec. (J2000) | Outflows classification | Nakamura et al. (2011) |
|-----|--------------|--------------|-------------------------|------------------------|
| 135 | 18:28:48.09  | -01:38:11.6  | N                       |                        |
| 147 | 18:29:00.01  | -01:42:42.8  | N                       |                        |
| 151 | 18:29:03.62  | -01:39:03.0  | BR C                    | B12, R7                |
| 155 | 18:29:05.52  | -01:41:53.6  | R C                     | B11, R6                |
| 163 | 18:29:08.34  | -01:30:46.8  | N                       |                        |
| 171 | 18:29:12.68  | -01:46:18.4  | R M new                 |                        |
| 174 | 18:29:13.10  | -02:03:51.2  | N                       |                        |
| 196 | 18:29:21.13  | -01:37:12.8  | N                       |                        |
| 202 | 18:29:23.69  | -01:38:54.0  | R C                     | B10, R5                |
| 209 | 18:29:25.54  | -01:47:31.5  | N                       |                        |
| 250 | 18:29:43.44  | -01:56:49.9  | N                       |                        |
| 251 | 18:29:43.84  | -02:12:56.0  | N                       |                        |
| 271 | 18:29:53.06  | -01:58:04.5  | N                       |                        |
| 285 | 18:29:59.67  | -02:00:58.7  | R C R2                  |                        |
| 289 | 18:30:00.85  | -02:06:57.3  | N                       |                        |
| 290 | 18:30:01.20  | -02:06:09.8  | N                       |                        |
| 292 | 18:30:01.50  | -02:10:25.5  | BR C                    | B15, R8                |
| 297 | 18:30:03.68  | -01:36:29.4  | R C new                 |                        |
| 299 | 18:30:04.19  | -02:03:05.5  | BR C                    | B1,B2, B3,B6, R1, R3, R4? |
| 315 | 18:30:12.44  | -02:06:53.6  | B C                     | B7                     |
| 321 | 18:30:14.93  | -01:33:34.9  | BR M new                |                        |
| 323 | 18:30:16.22  | -02:07:16.3  | N                       |                        |
| 326 | 18:30:17.64  | -02:09:59.3  | B C                     | B14                    |
| 342 | 18:30:26.03  | -02:10:41.2  |                         |                        |
| 347 | 18:30:27.97  | -02:10:59.0  |                         |                        |
| 349 | 18:30:28.98  | -01:56:03.2  | R Y R9                  |                        |
| 351 | 18:30:29.28  | -01:56:50.6  | R M new                 |                        |
| 362 | 18:30:37.53  | -02:08:56.3  | N N                     |                        |

1st column: the number of *Herschel* protostellar core catalog by Konyves et al. (2015). 4th column: B = blueshifted component, R = redshifted component. 5th column: C = clear, M = marginal. 6th column: comparison with the identification by Nakamura et al. (2011), new = new detection (this paper). In the densest part of the Serpens South cluster, outflow components from several different are observed. We assigned all such lobes to No. 299.
Fig. 1. Observation areas overlaid on the H$_2$ column density maps of Orion A. The solid and dashed lines indicate the observation boxes for $^{12}$CO+$^{13}$CO set and C$^{18}$O+N$_2$H$^+$+CCS set, respectively. The H$_2$ column density map has about an effective angular resolution of $\sim 36''$ (see Lombardi et al. 2016).
Fig. 2. Same as figure 1 but for Aquila Rift. The color image shows the H$_2$ column density map whose fits data were downloaded via the *Herschel* Gould Belt Survey Archive system. The solid and dashed lines are the same as those in figure 1.
Fig. 3. Observation areas overlaid on the Spitzer 8µm image of M17. The color image shows the Spitzer 8µm image of M17 downloaded from the Glimpse Archival system. The solid and dashed lines are the same as those in figure 1.
Fig. 4. Main beam efficiency of the Nobeyama 45-m telescope as a function of frequency. The crosses indicate the efficiencies measured with the receivers installed on the 45-m telescope. The red line shows the line fitted with Equation [2].

Fig. 5. Average Spectra of $^{12}$CO, $^{13}$CO, and C$^{18}$O toward (a) Orion A, (b) Aquila Rift, and (c) M17. The blue, red, and black lines indicate the $^{12}$CO, $^{13}$CO, and C$^{18}$O spectra, respectively.
Fig. 6. (a) $^{12}$CO ($J = 1 - 0$) moment-0 map of Orion A, velocity-integrated from 2 km s$^{-1}$ to 20 km s$^{-1}$. (b) Same as panel (a) but the contours of the H$_2$ column density are overlaid on the image. The contour levels are drawn at $2.5 \times 10^{21}$ cm$^{-2}$, $5.0 \times 10^{21}$ cm$^{-2}$, $7.5 \times 10^{21}$ cm$^{-2}$, $2.5 \times 10^{22}$ cm$^{-2}$, $5.0 \times 10^{22}$ cm$^{-2}$, $7.5 \times 10^{22}$ cm$^{-2}$, ···. The effective angular resolution of the $^{12}$CO map is 21".7.
Fig. 7. (a) $^{13}$CO ($J = 1 - 0$) moment-0 map of Orion A, velocity-integrated from 2 km s$^{-1}$ to 20 km s$^{-1}$. (b) Same as panel (a) but the contours of the H$_2$ column density are overlaid on the image. The contour levels are the same as those of figure 6. The effective angular resolution of the $^{13}$CO map is 22".1.
Fig. 8. (a) C$^{18}$O ($J = 1 – 0$) moment-0 map of Orion A, velocity-integrated from 2 km s$^{-1}$ to 20 km s$^{-1}$. (b) Same as panel (a) but the contours of the H$_2$ column density are overlaid on the image. The contour levels are the same as those of figure 6. The effective angular resolution of the C$^{18}$O map is 22".1.

Fig. 9. (a) N$_2$H$^+$ ($J = 1 – 0$) velocity integrated map of Orion A. The integration range is from 0 km s$^{-1}$ to 20 km s$^{-1}$. (b) Same as panel (a) but the contours of the H$_2$ column density are overlaid on the image. The contour levels are the same as those of figure 6. The effective angular resolution of the N$_2$H$^+$ map is 24".1.
Fig. 10. CCS integrated intensity map of Orion A. We smoothed the CCS image with an effective angular resolution of 32". The contour levels are the same as those of figure 6. The effective angular resolution of the CCS map is 24".0.

Fig. 11. $^{12}$CO ($J = 1 - 0$) integrated intensity map of Aquila Rift. In the panel (b), the contour levels are drawn at $1.0 \times 10^{22} \text{ cm}^{-2}$, $2.5 \times 10^{22} \text{ cm}^{-2}$, $5.0 \times 10^{22} \text{ cm}^{-2}$, $7.5 \times 10^{22} \text{ cm}^{-2}$, $1.0 \times 10^{23} \text{ cm}^{-2}$, $1.5 \times 10^{23} \text{ cm}^{-2}$. The effective angular resolution of the $^{12}$CO map is 21".7.
Fig. 12. $^{13}$CO ($J = 1 - 0$) integrated intensity map of Aquila Rift. The contour levels are the same as those of figure 11. The effective angular resolution of the $^{13}$CO map is 22\".1.

Fig. 13. C$^{18}$O ($J = 1 - 0$) integrated intensity map of Aquila Rift. The contour levels are the same as those of figure 11. The effective angular resolution of the C$^{18}$O map is 22\".1.

Fig. 14. $N_2H^+$ ($J = 1 - 0$) integrated intensity map of Aquila Rift. The contour levels are the same as those of figure 11. The effective angular resolution of the $N_2H^+$ map is 24\".1.

Fig. 15. CCS ($J = 8_7 - 7_6$) integrated intensity map of Aquila Rift. The contour levels are the same as those of figure 11. The effective angular resolution of the CCS map is 24\".0.
Fig. 16. The $^{13}$CO intensity map overlaid on the Herschel 250 $\mu$m image. The integration range of the $^{13}$CO is from 5.0 km s$^{-1}$ to 6.6 km s$^{-1}$. The contours start at 4.0 K km s$^{-1}$ with an interval of 4.0 K km s$^{-1}$.

Fig. 17. $^{12}$CO ($J = 1 - 0$) integrated intensity map of M17. The effective angular resolution of the $^{12}$CO map is 21$''$.7.
Fig. 18. $^{13}$CO ($J = 1 - 0$) integrated intensity map of M17. The effective angular resolution of the $^{13}$CO map is 22\".1.

Fig. 19. C$^{18}$O ($J = 1 - 0$) integrated intensity map of M17. The effective angular resolution of the C$^{18}$O map is 22\".1.
Fig. 20. $N_2H^+ (J = 1 - 0)$ integrated intensity map of M17. The effective angular resolution of the $N_2H^+$ map is $24''.1$.

Fig. 21. The excitation temperature map of Orion A.
Fig. 22. The ratio of the excitation temperature derived from $^{12}$CO to the dust temperature derived from the Herschel data. The ratio is around 1 – 2 along the main ridge of Orion A, except in OMC-1.

Fig. 23. The opacity-corrected $^{13}$CO column density map of Orion A.
Fig. 24. (a) The $^{13}$CO fractional abundance and (b) its optical depth maps of Orion A.

Fig. 25. (a) The C$^{18}$O fractional abundance and (b) its optical depth maps of Orion A.
Fig. 26. The $^{13}$CO-to-$^{18}$O fractional abundance ratio of Orion A.
Fig. 27. The cumulative column density distributions in (a) Orion A, (b) Aquila Rift, and (c) M17. In Orion A, the area is divided into two (North and South) at Dec. $\leq -05:32:56.0$. OMC-1 is a part of North and within $-05:30:26.0 \leq \text{Dec} \leq -05:16:03.5$. In Aquila Rift, the area is divided into two (West and East) at R.A. $= 18:30:39.6$. In M17, the area is divided into two (HII and SWex) at $l = 14:26:22.5$.

Fig. 28. The excitation temperature map of Aquila Rift.
**Fig. 29.** The ratio of the excitation temperature derived from $^{12}$CO to the dust temperature derived from the Herschel data. The ratio stays at around unity in the molecular clouds. In W40, it goes up to $\sim 2$.

**Fig. 30.** The opacity-corrected $^{13}$CO column density map of Aquila Rift.
Fig. 31. (a) The $^{13}$CO fractional abundance and (b) its optical depth maps of Aquila Rift.

Fig. 32. (a) The C$^{18}$O fractional abundance and (b) its optical depth maps of Aquila Rift.
Fig. 33. The $^{15}$O-to-$^{13}$CO fractional abundance ratio of Aquila Rift.

Fig. 34. The excitation temperature map of M17.

Fig. 35. (a) The $^{13}$CO fractional abundance and (b) its optical depth maps of M17.
Fig. 36. (a) The $^{18}$O fractional abundance and (b) its optical depth maps of M17.

Fig. 37. The $^{18}$O-to-$^{13}$CO fractional abundance ratio of M17.
Fig. 38. Three color image of the L1641N cluster-forming region with $^{12}$CO ($J = 1 - 0$) intensity integrated from 10 km s$^{-1}$ to 16 km s$^{-1}$ (red), $^{12}$CO ($J = 1 - 0$) intensity integrated from 0 km s$^{-1}$ to 5 km s$^{-1}$ (blue), and Herschel column density (green).

Fig. 39. Three color image of the Serpens South region with $^{12}$CO ($J = 1 - 0$) intensity integrated from 11 km s$^{-1}$ to 15 km s$^{-1}$ (red), $^{12}$CO ($J = 1 - 0$) intensity integrated from -20 km s$^{-1}$ to 0 km s$^{-1}$ (blue), and Herschel column density (green). The squares and circles indicate protostellar core candidates with and without molecular outflows, respectively. The size of the circle is the same as the FWHM beam size of 21.7″.