# ARO Proposal Cover Sheet

Arizona Radio Observatory

☐ 12m ■ SMT

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Date:
Proposal Number:

**Title**

Studying the Properties and Kinematics in the Nearest Massive Hub-Filament Region

**Abstract**

We propose a 8'x12' mapping observation of N2H+ 3-2, 13CS 6-5, HCO+ 3-2, and HCN 3-2 toward the Orion Molecular Cloud 1. The proposed SMT observation can be served as the short-spacing information for our SMA data to trace the physical conditions and gas kinematics inside and outside the hub-filament structure. Our previous CSO data in N2H+ 3-2 show a spatially extended feature which has a higher velocity than that of the filaments. However, this feature was not observed in N2H+ 1-0. We would like to examine whether the feature really exists using the new, independent data acquired from the SMT. This information is crucial for understanding the environment of star formation in massive hub-filament regions.



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| | | | | ☐ |



**List permanent IP addresses for remote login**: 140.109.177.14 & 140.109.177.32

**Receivers:** ☐ 3mm (12m) ■ 1mm (SMT) ☐ 0.8mm (SMT) ☐ 0.7mm (SMT) ☐ 0.4mm (SMT)

**Total Numbers of Hours Requested** *(LST Intervals* x *Repeats add up to this number)***:** 12

| LST Interval* | Repeats* | Telescope / Line / Frequency [GHz]* | Avoidance Dates* |
|---|---|---|---|
| 2.5h - 8.5h | 2 | SMT N2H+(3-2) 279.512 | |
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***** Please list the LST interval blocks you want scheduled (i.e. "22h – 7h" means to schedule a block starting at 22h LST and ending at 7h LST; please list only one LST block per row) and the number of times each block should be repeated (i.e. if 22h – 7h should be repeated 3 times, then enter "3" in the Repeats column). If you are proposing to use both the 12m and SMT, please list separate LST intervals for each telescope on different rows**. In the 'Telescope/Line/Frequency" column, please indicate 12m or SMT** and list the *primary* spectral line and tuning frequency in GHz (i.e. "12m 12CO(1-0) 115.2712081", or for a spectral survey "SMT 215.1-280.0"). It is the observer's responsibility to check that their sources are outside sun avoidance (10 deg @ 12m, 44 deg @ SMT). List dates in "Avoidance Dates" column for which that LST block should be ***avoided*** in scheduling (i.e. "Nov 25 – Jan 12").

**Special Requirements (dates cannot observe, special equipment, etc.):**

Cannot observe in Oct 25 - Nov 9, Dec 25 - Jan 11, and Feb 1-15.

# Studying the Properties and Kinematics in the Nearest Massive Hub-Filament Region

PI: Yu-Hsuan Teng and Naomi Hirano

## I. Scientific Justification

### A. Introduction

Filamentary structure has been commonly observed in star-forming clouds from parsec scale to sub-parsec scale. The prevalence of filamentary structure may indicate its persistance for a large fraction of the lifetime of a star-forming cloud. Therefore, it is believed that such structure may play an important role in star formation process, and may provide clues about the origin of star-forming regions. In addition, by examining the low-mass star-forming clouds within 300 pc, Myers (2009) found that all young stellar groups are associated with "hub-filament structure (HFS)", where the "hub" is a high column density region harboring young stellar groups, and the "filaments" are elongated structures with lower column density radiating from the hub. It is known that such HFS also exists in some distant regions that form high-mass stars, although the incidence of HFS in massive star-forming regions is still unclear (Myers 2009).

The Orion A molecular cloud is the nearest high-mass star-forming region at a distance of 414 pc (Menten et al. 2007). The Orion Molecular Cloud 1 (OMC1), which resides at the center of the Orion A, is the most active star-forming region in the cloud. Previous VLA observation in $NH_3$ (Fig.1a; Wiseman and Ho 1998) revealed a typical HFS in OMC1, in which several filamentary structures radiate from the Orion KL. Recent high-resolution observation with ALMA in $N_2H^+$ J=1-0 (Fig.1b; Hacar et al. 2018) resolved a total of 28 filaments with a FWHM of $\sim$0.02-0.05 pc in OMC1. These filaments appear to be hierarchical: clumpy cores were observed even inside the filaments with sub-parsec scales. This may indicate that the smaller filaments in OMC1 are possible sites for low-mass star formation. Therefore, studying the physical conditions and gas motions in OMC1 is likely the key to understand the evolution of HFS and its relation with star formation.

### B. Preparatory Work and Proposed Observation

The rotational transitions of $N_2H^+$ are known to be the good tracers of dense and quiescent gas. $N_2H^+$ is less affected by depletion even in the dense and cold environments. In addition, this molecule is also less affected by the violent phenomena such as outflows and expanding HII regions.

We have observed the OMC1 region in $N_2H^+$ 3-2 using the Submillimeter Array (SMA). The SMA image reveals that OMC1 consists of filamentary structures having a typical width of $\sim$0.025 pc. Although the interferometer data reveal the filamentary structure clearly, short spacing information is necessary in order to estimate the physical condition of filaments. We have obtained the short spacing data using the Caltech Submillimeter Observatory (CSO) and combined them with the SMA data. We found that the combined SMA and CSO data in $N_2H^+$ 3-2 (Fig.2a) reveals more extended emissions than the combined ALMA and IRAM 30m data in $N_2H^+$ 1-0. Furthermore, the moment 1 of the SMA + CSO data (Fig.2b) show a velocity difference of $\sim$ 1 km/s between the filaments and extended components in the northern part of OMC1. By comparing Fig.2b with the moment 1 observed with SMA (Fig.2c), it is clear that most high velocity components in the combined map are originated from the CSO data.

However, we doubt the authenticity of the extended features with higher velocities because there is no such extended emission in the $N_2H^+$ 1-0 image although it is also combined with the short spacing data. Furthermore, we found that there is a velocity difference between the SMA and CSO data. As shown in Fig.3, we plot the stacked spectrum of the northern region observed with (a) ALMA + IRAM (1-0), (b) SMA (3-2), and (c) CSO (3-2). On the basis of the hyperfine structure fitting, both SMA and ALMA + IRAM data show a velocity centroid of $\sim$9.8 km/s (Fig.3a & b), while the CSO data show a higher velocity centroid of ∼10.6 km/s (Fig.3c). We carefully checked the observed information in the CSO data but could not find anything wrong that could cause such a velocity offset.

Unfortunately, the CSO has already been decommisioned, so we have no chance to comfirm this issue. Therefore, we plan to obtain the independent data using the SMT, and examine whether the spatially extended feature having a higher velocity than filaments really exists in the $N_2H^+$ 3-2. If these features are real, it would be interesting to compare different physical conditions and kinematics between the "filament" and "non-filament" regions. But if the proposed observation turns out to have different conditions from those in the CSO data, we will combine the SMT and SMA data for future analysis. We would like to emphasize that confirming the presence/absence of the higher velocity feature in the non-filament region is crucial in publishing our results.

To cover the whole region of our SMA data, we propose to map the 8'×12' area of OMC1 in $N_2H^+$ 3-2. First, the velocity of the SMT data will be compared with those observed with the CSO and SMA. If the velocity of the SMT data is consistent with that of the CSO, we will be able to confirm the presence of the spatially extended feature with higher velocity. If the SMT data show the same velocity as the SMA data, we can conclude that there is no such feature. In such case, the newly obtained SMT data will be combined with the SMA data.

We will use the ALMA + IRAM archival data cube of $N_2H^+$ 1-0 from Hacar et al. (2018) to obtain the $N_2H^+$ 3-2 / 1-0 intensity ratio. By comparing with non-LTE spectra models, we will derive the density and kinetic temperature of the traced gas components. Direct measurement of the gas properties using the same molecular species can avoid the bias caused by chemical differentiation. In addition, the 4 IF mode of the SMT allows us to observe the $HCO^+$ 3-2, HCN 3-2 and $^{13}$CS 6-5 together with the $N_2H^+$ 3-2. Since we also obtained the $HCO^+$, HCN and $^{13}$CS data with the SMA, the SMT data can also be used to add the short spacing information of these molecular lines.

## II. Technical Justification

We propose to simultaneously observe the $N_2H^+$ 3-2 (279.512 GHz), $^{13}$CS 6-5 (277.45 GHz), $HCO^+$ 3-2 (267.558 GHz), and HCN 3-2 (265.886 GHz) using the SMT 1.3 mm ALMA band 6 receiver with On-The-Flying mapping. We will use the 4 IF mode with a bandwidth of 128 MHz and a resolution of 250 kHz (∼0.27 km/s). The four observed lines can be fit appropriately in the 4 IF mode if the LO is set around 272.5 GHz.

The beam size of the SMT is estimated to be 27" at a frequency of $N_2H^+$ 3-2. The proposed mapping area is 8'×12', and the spectral resolution is 250 kHz. Thus, the observing time can be calculated by the radiometer equation

$$t = \frac{1}{\Delta f} \times \left(\frac{T_{sys}}{T_{rms}}\right)^2 \times K^2 \times \left(\frac{\text{survey area}}{\text{beam area}}\right)$$

where the factor K = 2 if position-switching is assumed (Mangum et al. 2007).

Our SMA data cube has a RMS noise level of ∼0.35 K for a ∼0.22 km/s velocity channel. Since the proposed observation will be combined with the SMA data cube, we request a RMS noise level of 0.2 K in the $T_A^*$ unit, which is similar to that of the SMA data after correcting the beam efficiency (70%) of the SMT. Assuming a $T_{sys}$ of 350 K and an additionally 30% of overhead time for setup and pointing, it takes ∼10.7 hours of total observing time to acheive a $T_{rms}$ of 0.2 K. Also, our target is observable with elevation $> 30°$ in the hour angle range of ± 3 hours. Therefore, we request two nights of observation from 2.5h LST to 8.5h LST.

## References


Hacar et al., 2018, A&A, 610, A77

Mangum et al., 2007, A&A, 474, 679

Menten et al., 2007, A&A, 474, 515

Myers, 2009, ApJ, 700, 1609

Wiseman and Ho, 1998, ApJ, 502, 676

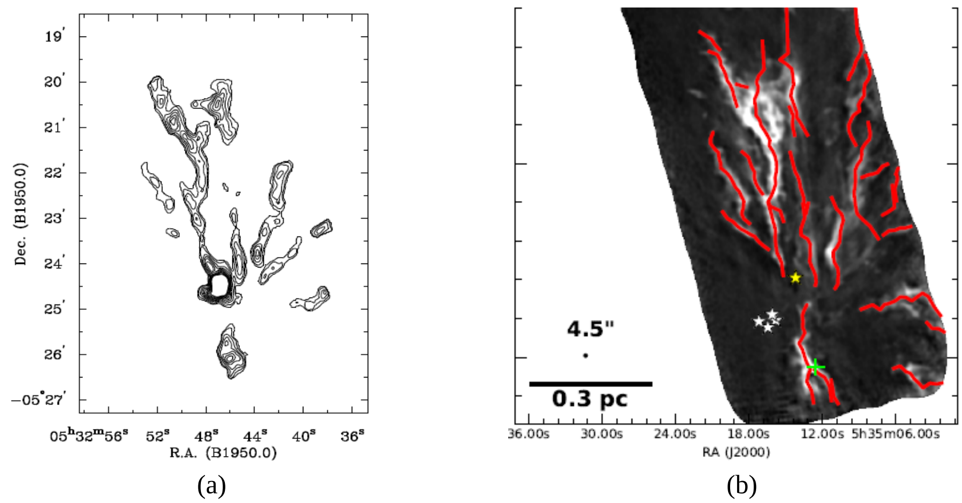


Fig. 1. The filamentary OMC1 region. (a) $NH_3$ (1,1) observation with VLA from Wiseman and Ho (1998). (b) $N_2H^+$ 1-0 observation with ALMA + IRAM 30m and the filaments identified from Hacar et al. (2018).

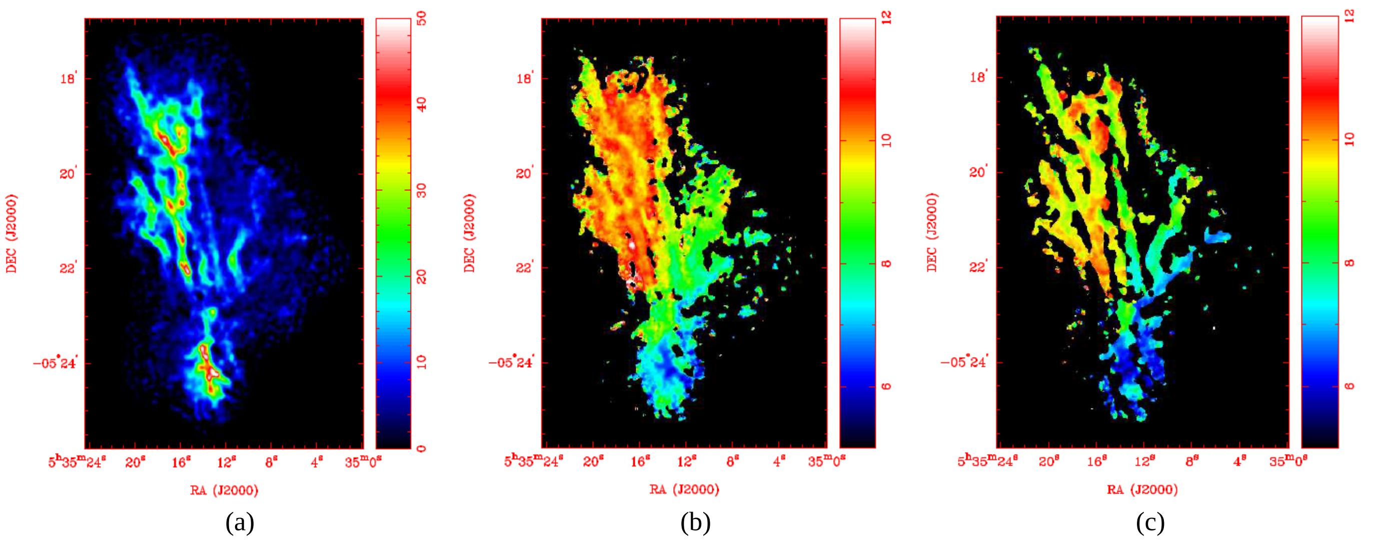


Fig. 2. (a) Moment 0 (unit: K·km/s) and (b) moment 1 (unit: km/s) of the combined SMA + CSO data in $N_2H^+$ 3-2. (c) Moment 1 (unit: km/s) of the SMA data in $N_2H^+$ 3-2.

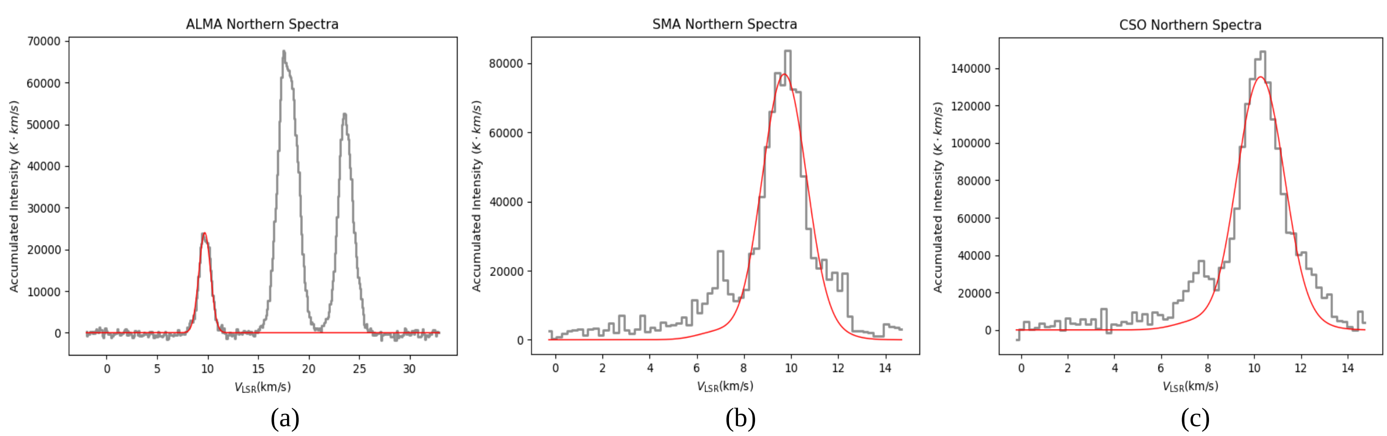


Fig. 3. Stacked spectrum and the hyperfine fitting of the OMC1 northern region observed with (a) ALMA + IRAM in $N_2H^+$ 1-0, (b) SMA in $N_2H^+$ 3-2, and (c) CSO in $N_2H^+$ 3-2.