Onsala Proposal

Tan 0115.F-9302

Measuring the Background Temperature of Orion Nebula Cluster Disks

Semester: feb2025 **Science Cat.: ISM and star formation**

Abstract

We propose to map the central 3'x3' region of the Orion Nebula Cluster (ONC) with APEX. These observations will probe extended molecular cloud structures in the region, which can influence the morphologies of gaseous circumstellar disks observed with ALMA. In young clusters like the ONC, we expect significant extended emission. We will utilize one SEPIA345 setup to observe transitions of CO, HCO+, and HCN with a sensitivity of ~0.15 K and spectral resolution of 0.25 km/s. These lines have been utilized in recent ALMA surveys of the ONC, which detected several-dozen gas disks not only in emission but also in absorption against the bright background cloud. Our APEX observations will complement the ALMA surveys and yield precise measurements of the cloud intensity towards the position of ALMA-detected disks. With these measurements, we will a) extract cloud-corrected measurements of disk molecular line emission, and thus, b) more-accurately constrain disk properties. This program will unlock the full potential of existing ALMA datasets, and play a vital role in the design of future ALMA surveys.

Applicants

Name	Affiliation	Email	Country		Potential observer
Dr. Ryan Boyden	Chalmers University of Technology (Space, Earth and Environment)	xhs4wj@virginia.edu	Sweden		Yes
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		Remarks	New affiliation is: University of Virginia, USA

Is this a long term proposal: No

No overall scheduling requirements

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	APEX	SEPIA345 (277-371 GHz)	7h (7h)	343 GHz and 332 GHz	0.5-1 mm	02 -07	We we will use two different spectral setups to cover all lines of interest. OTF mapping of a 3.0' x 3.0' region. Aug 8 to 12 run is preferred due to the LST range of our source.

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
ONC	05:35:19.90	-05:23:23.5	J2000	5.0	390	A	

Scientific Rationale

The stellar cluster environment is thought to play a critical role in circumstellar disk evolution. While recent ALMA surveys have begun mapping disk properties over a variety of nearby clusters (e.g., Eisner et al. 2018), the majority of these studies focused on measuring dust emission. **Gas-disk properties in clustered environments remain poorly characterized observationally**, and this is in strong contrast with gas disks found in nearby, low-density star-forming regions, such as Taurus and Lupus (e.g., Öberg et al. 2021).

A unique characteristic of young clusters is that they are often embedded in giant molecular clouds, which can emit significant large-scale emission over the same molecular transitions used to probe compact disks. Previous ALMA surveys of the Orion Nebula Cluster (ONC), the densest and most extremely-irradiated cluster of Orion, have employed extended array configurations to search for molecular line emission from compact disks while spatially filtering large-scale emission from the surrounding molecular cloud (e.g., Bally et al. 2015, Boyden & Eisner 2020). These surveys detected a number of gas disks using bright, optically thick tracers such as CO and HCO^+; and remarkably, many of the detections were seen in *absorption* against the warm background, meaning that the ALMA-detected emission is *negative* (see Figures $1-3$).

The prevalence of ONC disks seen in CO and/or HCO^+ absorption indicates that absorption detections are common in young stellar clusters, i.e., the most common sites of star formation (Lada & Lada 2003). **Therefore, it is essential that we understand the properties of gas disks seen in absorption; *and that we correctly interpret the negative emission observed with ALMA*.**

In Figure 1, we show simulated ALMA observations of a compact disk positioned in front of a bright molecular cloud, generated using CASA's `simobserve` task. We design the synthetic observations to be representative of previous ONC surveys, adopting an observing frequency of 345 GHz and employing an array configuration that yields an angular resolution of $\sim 0\farcs08$ and maximum recoverable scale of $\sim 1''$. With this setup, we find that the background cloud is mostly resolved out by the interferometer, but along the positions where the cloud is behind the compact disk, the simulated emission is *negative*.

We have found that the simulated emission observed towards the disk is equivalent to the difference between the intensities of the compact disk emission and spatially filtered cloud emission via the equation:

$$I_{obs} = I_d - I_c(1 - e^{-\tau_d}), \tag{1}$$

where I_{obs} denotes the observed emission, I_d denotes the disk intensity, I_c denotes the cloud intensity, and τ_d denotes the disk optical depth (Boyden & Eisner 2023). If the disk is intrinsically brighter than the cloud, then we recover positive emission in the synthetic ALMA observations. Otherwise, the observed emission is negative.

The simulated observations shown in Figure 1 demonstrate that while extended ALMA configurations are capable of filtering out large-scale cloud emission, the cloud can still influence the ALMA-observed line intensity towards compact disk. The subset of ONC disks seen in CO and/or HCO^+ absorption represent clear examples of the background cloud influencing the intensity of the ALMA-observed emission. However, it is also possible that disks seen in emission are influenced by the cloud, as illustrated in Equation 1. **To overcome the effects of the background cloud and more-accurately measure the line fluxes of the ONC's circumstellar disks, we must constrain the intensity of the background molecular cloud over the same molecular transitions used to probe the disks.**

Planned Observations

We propose to map the central $3' \times 3'$ region of the ONC with APEX. This region includes ~ 250 cluster members for which near-IR/sub-mm photometry and/or HST imaging indicate the presence of circumstellar disks (Hillenbrand & Carpenter 2000; Ricci et al. 2008; Eisner et al. 2018). Our program will cover a similar area of the ONC that was observed in earlier ALMA programs that targeted the 0.87 mm continuum and CO J $= 3-2$ and HCO^+ J $= 4-3$ lines (Mann et al. 2014, Eisner et al. 2018, see Figure 2). With the excellent short-spacing coverage available with APEX ($\geq 20''$ at 350 GHz), we can probe extended cloud structures in the ONC and measure the localized background cloud intensity towards the positions of ALMA-detected ONC disks.

Our observations will utilize one spectral setup to target the same molecular lines covered in previous ALMA programs—the CO J $= 3-2$ and HCO^+ J $= 4-3$ lines—as well as the bright, optically thick HCN J $= 4-3$ line that is commonly employed in disk surveys (see Table 1, Figure 4). With a sensitivity of ~ 0.1 K and spectral resolution of ~ 0.25 km s^{-1}, we expect to map large scale cloud emission emission at high S/N, rendering high-precision measurements of the background temperature as a function of position and velocity.

Immediate Objectives

With direct measurements of CO J $= 3-2$ and HCO^+ J $= 4-3$ background cloud intensity, we will be able to extract cloud-corrected measurements of disk molecular line emission from ALMA observations covering the ONC, enabling us to unlock the full potential of existing ALMA datasets. Figure 3 depicts our method for decomposing the ALMA observations. Using the thermochemical code RAC-2D (Du & Bergin 2014), we intend to generate synthetic CO J $= 3-2$ and HCO^+ J $= 4-3$ channel map observations of disks as a function of disk, stellar, and environmental parameters. We will then use the proposed background cloud intensity measurements to convert the synthetic channel maps into *simulated interferometric observations* of a disk that is located at the position of an ALMA-detected ONC disk, via Equation 1. By fitting these simulated interferometric observations to the ALMA observations, we can constrain disk properties for all the ONC disks whose line emission is influenced by the background cloud.

Previous modeling led by the PI has demonstrated the effectiveness of our methodology for constraining the gas-to-dust ratios of ONC disks detected in CO absorption (see Fig. 3). However, we are currently unable to model detections in HCO^+ absorption, as there is no available dataset probing extended HCO^+ emission in the ONC. Moreover, in previous work, we used the CARMA-NRO Orion survey of CO J $= 1-0$ (Kong et al. 2018) to extrapolate the CO J $= 3-2$ cloud intensity. *Our proposed APEX maps will provide the first high-dynamic-range view of extended HCO^+ emission in the ONC, which will enable us to constrain disk properties from ALMA observations of HCO^+ absorption. These maps will also directly measure the CO J $= 3-2$ cloud intensity with the same resolution as the CARMA-NRO Orion survey*, which is essential for obtaining accurate local background temperatures towards individual disks.

Technical Justification

Time Estimate: We propose to observe during the August 8 to 12 run with SEPIA345 using the OTF observing mode to cover a field of view of 9.0 arcmin^2. Our target has an R.A. of $\sim$5 hr, hence the August 8 to 12 run will provide the most optimal observing conditions for our science. For an elevation of 30 degrees, observing frequency of 345 GHz and spectral resolution of 0.25 km/s, the time estimator tells us that we will need a telescope time of 6.5 hr to reach a sensitivity of $\sim$ 150 mK with good conditions (1.0 mm of pwv, Tsys $\sim$400 K).

Sensitivity: To extract reliable measurements of disk emission from ALMA observations of disk + cloud emission, we need to measure the cloud emission at high precision. The CARMA-NRO Orion survey of CO J $= 1-0$ achieved an RMS of $\sim$ 250 mK in 0.25 km/s channels, and this proved sufficient for constraining disk properties for the ONC disks detected in CO absorption (Boyden & Eisner 2023). We request a factor of $\sim$2 deeper to ensure we will obtain high-precision background temperatures measurements.

Figures and Tables

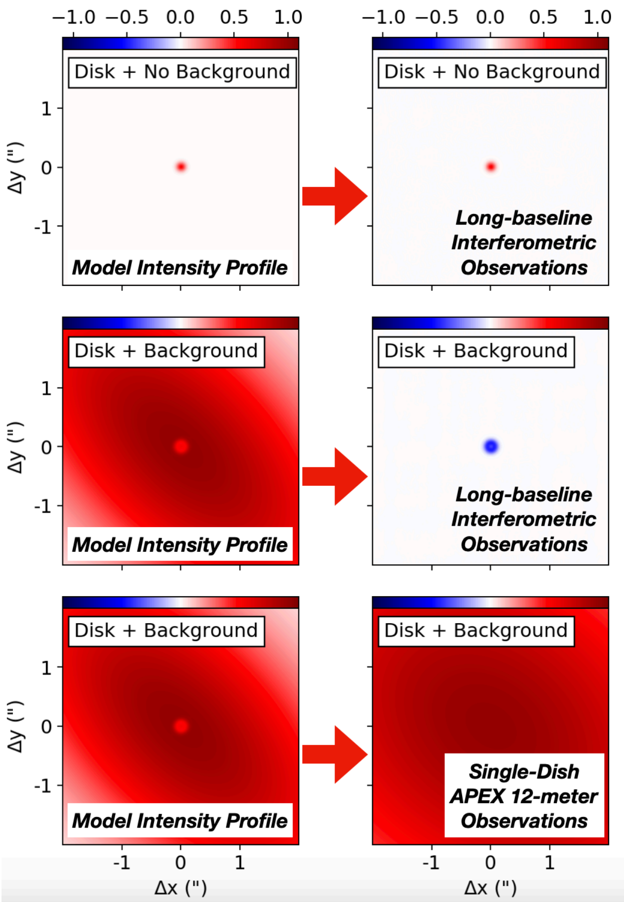

Figure 1: *Demonstration of the effects of spatial filtering on interferometric molecular line observations of protoplanetary disks. The left column shows normalized model intensity profiles of a compact, optically thick disk positioned in front of no background (top) or in front of an extended bright background cloud (middle, bottom). The right column shows simulated images that are obtained when the model profiles are observed with long-baseline interferometers (top, middle) or with single dish telescopes (bottom). The simulated images are generated using CASA's* `simobserve` *task. For the top-right and middle-right panels, we use an extended ALMA configuration similar to those used in previous surveys of the ONC. For the bottom-right panel, we use a single dish telescope comparable to the APEX 12-meter. In this figure, the disk is modeled as a Gaussian with a full-width-at-half maximum of* $0''.1$*, and the background cloud is modeled as a Gaussian with major and minor axes of* $8''$ *and* $4''$*, respectively.*

Table 1: *Key molecular transitions covered with our observations. All lines of interest can be covered with one SEPIA345 setup.*

Molecule	Transition	Frequency (GHz)	Label in Fig. 4	Notes
CO	$J = 3 - 2$	345.796	L1	Covered in previous ONC ALMA programs
HCO^+	$J = 4 - 3$	356.734	L2	Covered in previous ONC ALMA programs
HCN	$J = 4 - 3$	354.505	L3	Bright molecule in disks

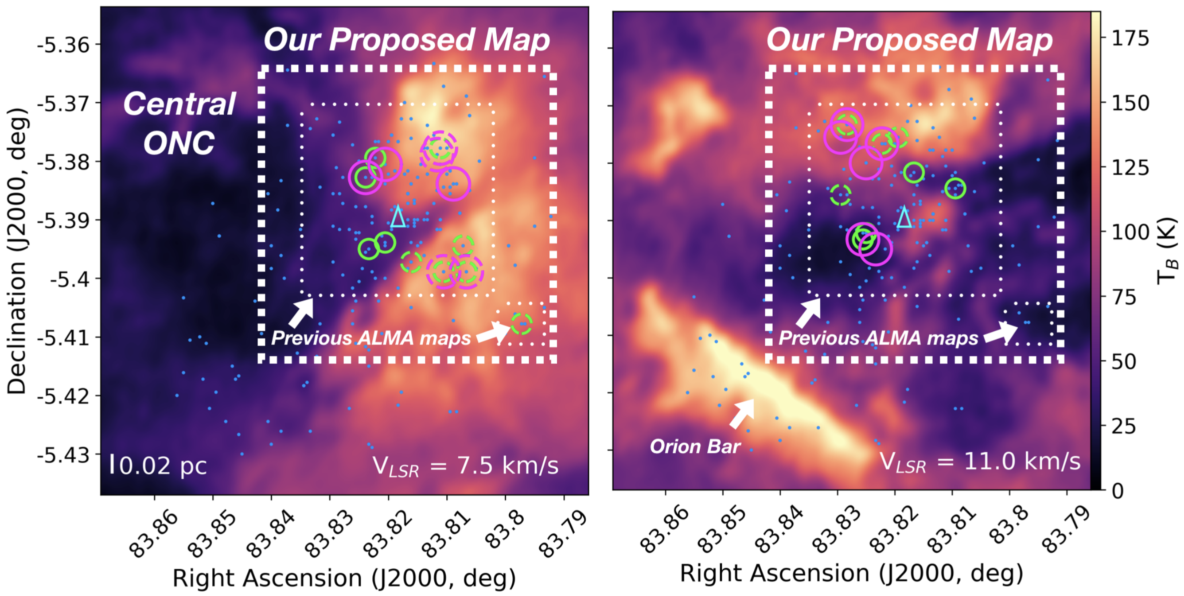

Figure 2: *Large-scale CO $J = 1-0$ emission seen towards the ONC at ~ 7.5 km s^{-1} (left) and ~ 11 km s^{-1} (right). The data are taken from Kong et al. (2021) and have an angular resolution of 8$''$, which is similar to the resolution of our proposed APEX observations. Blue dots indicate the positions of disks identified with sub-mm photometry and/or HST imaging. Circles indicate the positions of disks that are also detected in CO $J = 3-2$ (green) and/or HCO$^+$ $J = 4-3$ (purple) with ALMA by Bally et al. (2015) and Boyden & Eisner (2020). Solid circles correspond to detections in emission, whereas the dashed circles denote detections in absorption. Sources with peak signals near ~ 7.5 km s^{-1} are plotted in the left panel, while sources with peak signals closer to ~ 11 km s^{-1} are plotted in the right panel. The cyan triangle indicates the position of the massive O-star θ^1 Ori C. Finally, dashed squares indicate the regions covered with previous ALMA surveys (thinner lines) and with our proposed APEX observations (thicker lines).*

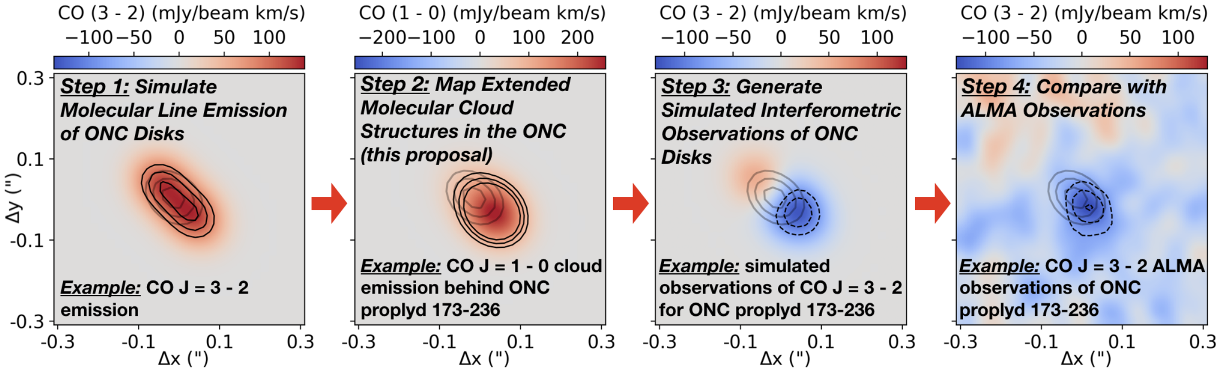

Figure 3: *Illustration of our model pipeline. Far left: simulated CO $J = 3-2$ emission of a compact disk, generated with the code* RAC-2D *(Du & Bergin 2014). Grey contours show ALMA-detected dust emission of the ONC proplyd 173-236. Center left: spectrally-integrated CO J $= 1-0$ background cloud emission towards the position of 173-236, taken from the CARMA-NRO Orion survey (Kong et al. 2021). Center Right: simulated interferometric CO $J = 3-2$ observations of ONC proplyd 173-236, obtained by subtracting the localized CO $J = 1-0$ cloud intensity measurements from the synthetic CO $J = 3-2$ channel map emission, via Equation 1. Because the cloud is brighter along certain velocity channels, the combined disk + background emission profile appears in emission in some channels and in absorption in other channels. Far right: ALMA CO $J = 3-2$ observations of 173-236. Black contours show -3, -4, and -5σ absorption. For all ALMA-detected gas disks in our field, we will fit suites of simulated interferometric observations to the ALMA channel map observations via a χ^2 minimization procedure, and constrain disk properties.*

References

Ansdell, M., et al. 2017, AJ, 153, 240 • Bally, J., et al. 2015, ApJ, 808, 69 • Boyden, R., et al. 2020, ApJ, 894, 74 • Boyden, R., et al. 2023, ApJ, 947, 7 • Cleeves, L., et al. 2014, ApJ, 794, 123 • Du, F., & Bergin, E. 2014, ApJ, 792, 2 • Eisner, J., et al. 2018, ApJ, 860, 77 • Goicoechea, J., et al. 2020, A&A, 639, A1 • Hillenbrand, L. A., & Carpenter, J. M. 2000, ApJ, 540, 236 • Kong, S., et al. 2018, ApJS, 236, 25 • Kong, S., et al. 2021, RNASS, 5, 3 • Lada, C., & Lada, E. 2003, ARA&A, 41, 57 • Öberg, K., et al. 2021, ApJS, 257, 1 • Ricci, L., et al. 2018, AJ, 136, 2136 • van der Tak, F. F. S., et al. 2007, A&A, 468, 627 • van Terwisga, S., et al. 2020, A&A, 640, 27 • Williams, J., et al. 2014, ApJ, 796, 120

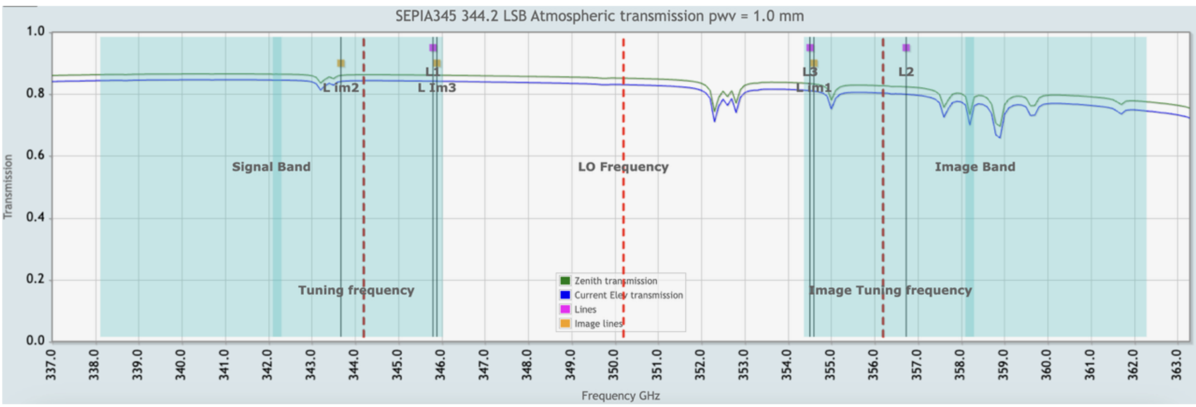

Figure 4: *Spectral Setup of our Proposed SEPIA345 APEX observations, which will cover the CO* $J = 3-2$ *(L1), HCO*$^+$ $J = 4-3$ *(L2), and HCN* $J = 4-3$ *(L3) lines.*

No PhD Students involved

Linked proposal submitted to this TAC: No

Linked proposal submitted to other TACs: No

Relevant previous Allocations: No

No additional remarks

Observing run info :

Run: A backup strategy: If weather is poor, we will spectrally average our data cubes down to lower spectral resolution to improve S/N.