Onsala Proposal

Gorai 0108.F-9318

High frequency astrochemical survey toward massive protostars

Semester: may2021 **Science Cat.: ISM and star formation**

Abstract

Massive protostars are unique laboratories for understanding the interstellar synthesis of various simple and complex organic molecules, including important prebiotic species. The chemistry in these regions is very rich, and numerous interstellar molecules have been identified in such regions. Here, we propose to use APEX 12m's unique capabilities to conduct a continuous line survey in the high-frequency range 680 to 712 GHz of the target sources. However, no high-frequency data are available for the proposed targets. At these frequencies, we have access to the fundamental transitions of light molecules and high excitation transitions of complex organic molecules (COMs), which will greatly complement existing lower frequency data. With this project, we will be able to: (i) explore the general landscape of chemical complexity, physical and excitation conditions in a variety of massive star-forming regions; (ii) investigate kinematics, such as infall, rotation and outflows, close to the protostars by observing high excitation simple molecular species, such as CO, CS; (iii) chemical content and their sensitivity to the physical conditions by employing astrochemical models.

Applicants

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Is this a long term proposal: No

Overall scheduling requirements

We request to observe our target sources during July-August 2021. The sources will be above elevation 40 deg at the Apex site and with 5 hrs useful per night from July to August 2021.

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	APEX	SEPIA660 (581-727 GHz)	3h (3h)	706	< 0.5mm	16-22	We propose to set two tuning frequencies one at 698 GHz and another at 706 GHz for these, we will have two signal bands and two image bands and each with bandwidth 7.9 GHz (see Table 1). A continuous 32 GHz spectral coverage will be performed by using a pair of spectral setups and offsetting their tuning frequencies by 8 GHz. We will use a double sideband configuration in dual polarisation mode. No scheduling constraints for the proposed target.
B	APEX	SEPIA660 (581-727 GHz)	2h (2h)	698	< 0.5mm	16-22	

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
G031.28+0.06	18:48:11.82	-01:26:31.0	J2000	108.0	300	A B	
G045.12+0.13	19:13:27.96	+10:53:35.6	J2000	55.0	300	A B	
G045.47+0.05	19:14:25.74	+11:09:25.9	J2000	60.0	300	A B	

Scientific Rationale

Introduction

How do massive stars (M>8M$_\odot$) form? Several theories have been proposed such as Core Accretion (McKee and Tan 2003), Competitive Accretion (Bonnell et al. 2001), the Inertial-Flow model (Padoan et al. 2020), and Protostellar Collisions (Bonnell et al. 1998). All these models imply different physical conditions and evolutionary paths for the forming massive stars. The chemical conditions of these sources locally depend on such properties (density, temperature etc.). Hence, the different massive star formation models are expected to leave different imprints on the chemical content and complexity of massive protostars. Moreover, many complex physical processes, such as infall, rotation, outflows, and shocks are present in high-mass protostellar objects (HMPOs) and that also affect their chemistry. It is thus possible to use various simple and complex molecules as diagnostic of the physical and chemical processes occurring in massive protostars. The abundances of these species are time-dependent and highly sensitive to the collapse and growth times of HMPOs, which are quite uncertain. *Therefore, comparing observed molecular abundances with those predicted by time-dependent chemical models is a useful method for constraining the physical conditions and evolutionary histories of HMPOs and ultimately their formation mechanism.* This can be achieved by performing unbiased chemical line surveys toward massive star-forming regions. These surveys are crucial for understanding the chemical content and excitation conditions of the observed regions.

We propose to perform a line surveys around 680-712 GHz toward a sample of 3 protostellar sources, known to be at different stages of evolution. With this work, we will be able to investigate chemical complexity and physical conditions of the source and will use these results to better constrain their formation mechanisms. **We now propose to study the chemical diversity in different evolutionary sequences and physical environments of massive stars.** We aim to extend our understanding of chemical properties and excitation conditions in these regions and test the role of physical conditions such as density, temperature, and radiation field on the chemical complexity and diversity.

Previous studies

The sources are selected from the SOFIA Massive (SOMA) star formation survey (De Buizer et al. 2017, Liu et al. 2019, 2020), which used SOFIA-FORCAST to measure their 8 to 40 μm emission. The SOMA sources have well-measured IR spectral energy distributions (SEDs), thus allowing detailed constraints on the physical properties of the sources. Our three target sources belong to three different groups: **Type I: "MIR sources in IRDCs" - relatively isolated sources in Infrared Dark Clouds; Type II:"Hypercompact"- often jet-like, radio sources, where the MIR emission extends beyond the observed radio emission; Type III: "Ultra-compact" - radio sources where the radio emission is more extended than the MIR emission.** The luminosity of all these sources is lies within $10^4 - 10^5$L$_\odot$ and their distance ranges between 4.9 to 6 kpc. We have one source of each type (see Table 1).

G31.28+0.06 (type I) is actually a shell source (see Figure 1) with the continuum emission from one part of the shell dominating the emission from the rest of the shell, which was studied at centimeter (cm) and mm wavebands (Fey et al. 1992, Mateen et al. 2006). Massive stars generate strong radiation feedback, which plays a key role in the evolution of molecular clouds. The discovery of a photoionized bipolar outflow was reported by Zhang et al. 2019 toward the massive protostar **G45.47+0.05 (type II)** using high-resolution observations at 1.3 mm with the ALMA and at 7 mm with the Karl G. Jansky Very Large Array (VLA). The coexistence of a jet and a massive photoevaporation outflow in this source suggests that accretion is on-going, in spite of strong photoionization feedback. Multi-wavelength study of a molecular core containing the ultracompact (UC) HII region **G45.12+0.13 (type III)** reveals bipolar outflow by observing CO (Hunter et al. 1997), and multi transitions ^{13}CO and CS were observed in this source (Churchell et al. 1992). ALMA band 6 data is available in the archive for all the targets (ALMAGAL: ALMA Evolutionary study of High Mass Protocluster Formation in the Galaxy). For the proposed targets, we have accepted proposal of IRAM 30m in the 3mm window. However, so far high frequency data is not available for these sources, which will provide a complimentary benefit to the available low frequency data to investigate these massive protostars' chemical and physical properties. High-frequency observations are sensitive to various important transitions of many small molecules and high excitation lines of simple and COMs, which can provide robust constraints on the excitation conditions and chemistry within a source. Therefore, a spectral line survey at high frequencies using the APEX telescope will help to better understand the chemical content and excitation conditions in high-mass star-forming regions. Here, we request to observe a continuous frequency range of 32 GHz from 680-712 GHz.

We propose to use APEX 12m antenna to perform this line survey and use the obtained data to understand: (i) chemical complexity and associated kinematics in these sources in the context of massive star formation by observing various high excitation lines of simple (e.g., CO, CS, SiO, $H^{13}CO^+$) and high excitation lines of COMs (e.g., CH_3OH, CH_3CN); (ii) major sources of sulfur to study the sulfur depletion problem (various S-bearing species, e.g., SO, SO_2, H_2S, show strong transitions in this regime); (iii) N-bearing molecules and prebiotic chemistry (e.g., HCN, CH_3CN); (iv) isotopic fractionation of various species, specifically D-fractionation as deuterated species (e.g., HDO, DCN) also show strong transitions in this frequency range. Moreover, this proposed observation will provide crucial insights into the chemical history and physical properties of different environments and evolutionary states of massive protostars.

Facilities Requested

We request to use the SEPIA660 instrument of the APEX 12m telescope to perform a high-frequency line survey toward three massive protostars. The capabilities of the SEPIA660 receiver and the FFTS backends are unique for our scientific purposes.

Observing Requirements

We propose to use 15 hours of the APEX 12m telescope observing time during the July-December season to observe a continuous frequency of 32 GHz, in the frequency range 680-712 GHz. For this observation, the SEPIA660 receiver will be used, which covers the window 597-725 GHz. The SEPIA receiver has dual polarisation 2SB and capability of wide bandwidth coverage (7.9 GHz + 7.9 GHz) which enables it to cover a bandwidth of 15.8 GHz with a single tuning frequency, which is very useful for a line survey at high frequency. A continuous 32 GHz spectral coverage will be performed by using a pair of spectral setups and offsetting their tuning frequencies by 8 GHz. We propose to set two tuning frequencies one at 698 GHz and another at 706 GHz for these, we will have two signal bands and two image bands and each with bandwidth 7.9 GHz (see Table 1). We propose to observe three target sources in position switching mode, OTC (on/off), where we expect the achievable angular resolution $\sim$ $7''$-$9''$ at 680-712 GHz. If rms noise is 20 mk, we expect a large number of lines with intensity $\geq$100 mk (see Figure 2), which gives signal to noise ratio is >5. We have used the ON-OFF observing time calculator at APEX V7.3 to estimate the total time needed to achieve our goal. Using SEPIA660 tuned to 706 GHz in the USB, selecting a spectral resolution of 0.5 km/s and assuming a typical source elevation of 45 deg and a typical PWV of 0.4 mm, we could get down to a noise of 20 mK[Ta*] in 3.1 hours for one source. For similar setup with other tuning frequency at 698 in the USB we need 1.9 hours. Thus, in total we need 15 hours time for three sources including telescope and calibration overheads.

Observing Plan

We request normal observational and calibration procedures.

Reference:

• McKee, C. F. and Tan, J. C. 2003, ApJ, 585, 850M; • Churchwell et al. 1992, A&A, 253, 541; • Bonnell, I. A., et al. 2001, MNRAS, 324, 573; • Padoan, P., et al. 2020, ApJ, 900, 82; • Bonnell, I. A., et al. 1998, MNRAS, 298, 93, 102; • Cesaroni, R., et al. 2010, A&A, 509, 50; • De Buizer, J. M., Liu, M., Tan, J. C., et al. 2017, ApJ, 843,33 • Fey, A. L., Claussen, M. J., Gaume, R. A., 1992, AJ, 103, • Hunter, T. R., et al. 1997, ApJ, 478 283; • Haufner, P., Peterson, S., Cesaroni, R., ApJ, 514, 899; • Liu, M., Tan, J. C., De Buizer, J. M., et al., 2020, ApJ 904 75; • Liu, M., Tan, J. C., De Buizer, J. M., et al., 2019, ApJ, 874, 16; • Mateen, M., Hofner, P., & Araya, E. 2006, ApJS, 167, 239; • Zhang, Y., Tanka, K.E.I., Rosero, V. et al. 2019, ApJL, 886, L4

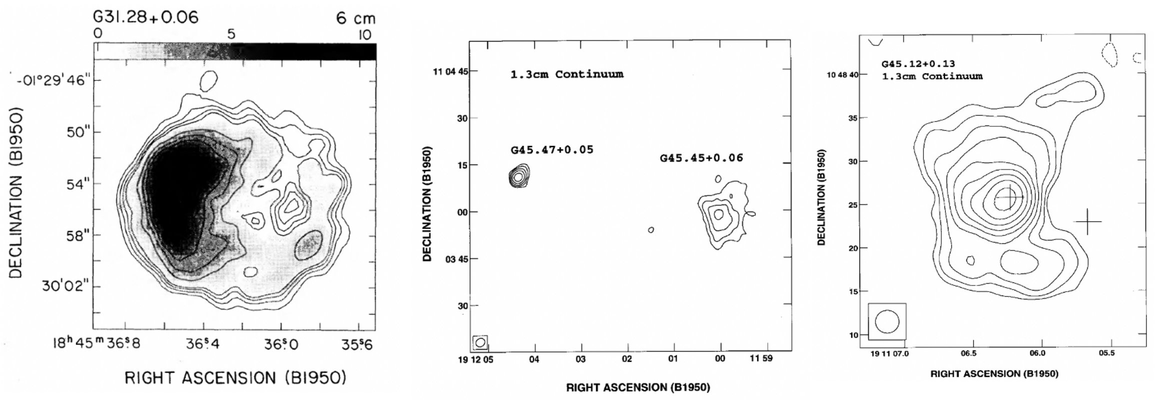

Figure 1: Left panel: 6 cm continuum of G31.28+0.06 (Fey et al. 1992); middle panel: 1.3 cm continuum toward the HII region G45.47+0.05 (Hofner et al. 1999); right panel: 1.3 cm continuum toward the UC HII region G45.12+0.13 (Hofner et al. 1999).

Table 1: List of the target sources and their types.

Source	RA	DEC	Types
G031.28+0.06	18:48:11.82	-01:26:31.01	I
G045.47+0.05	19:14:25.74	+11:09:25.90	II
G045.12+0.13	19:13:27.96	+10:53:35.69	III

Table 2: List of the 2 spectral setups proposed for the survey, including the local oscillator frequencies as well as the frequency coverages. All frequencies are in GHz.

Line ID	f_{sky}[GHz]/SB	Signal Band	f_{LO}	Image Band
700	698 USB	696-704	692	680-688
702	706 USB	704-712	700	688-696

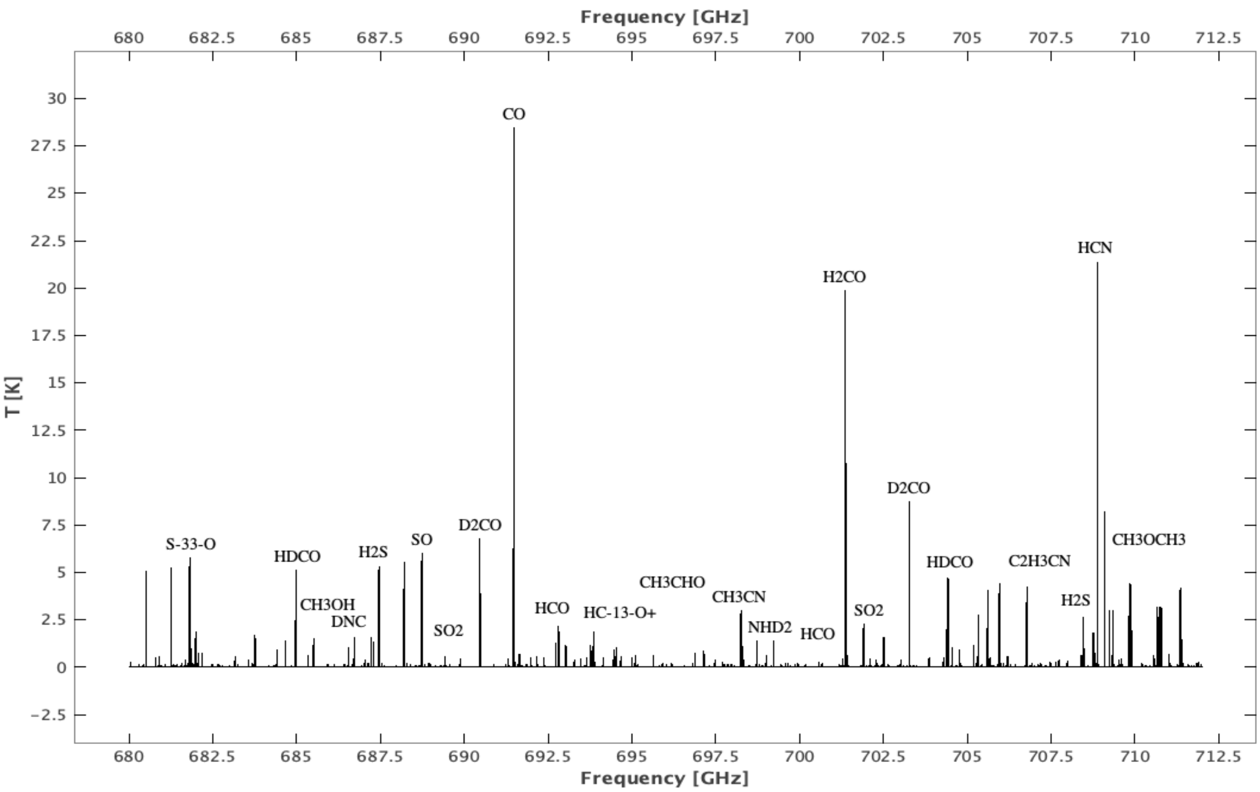

Figure 2: LTE model spectrum of expected lines towards massive protostars. Here we have various abundant simple species (e.g., CO, SO_2, HCN) and high excitation lines of COMs (CH_3OH, E_{up}=501 K; CH_3OCH_3, E_{up}=696 K).

Students involved

Student	Level	Applicant	Supervisor	Applicant	Expected completion date	Data required
Mr. Chi Yan Law	Doctor	Yes	Prof Jonathan Tan	Yes	2023/12	No

Linked proposal submitted to this TAC: No

Linked proposal submitted to other TACs: No

Relevant previous Allocations: No

No additional remarks

Observing run info :