Onsala Proposal

Tan 0115.F-9305

Tracing atomic outflows from massive protostars

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

Abstract

Carbon can exist in different phases either ionized (CII), atomic (CI) or molecular form (e.g., CO) from the diffuse medium to dense molecular gas. Carbon gas fraction is not well understood towards the young stellar objects (YSOs). We aim to study CI, which is a major component of the atomic outflows, toward 10 massive young stellar objects (MSYOs) with a unique capability of APEX 12m telescope using nFLASH460 band receiver. Together with atomic outflow, our spectral setup cover molecular outflow tracer, CS, and several simple and complex molecules, which will further provide the chemical properties and excitation conditions of the different sources. These proposed observations will prove better insights into the atomic outflows, carbon gas fractions, and kinematics of MSYOs.

Applicants

Name	Affiliation	Email	Country		Potential observer
Dr. Prasanta Gorai	Chalmers University of Technology (Space, Earth and Environment)	prasanta.astro@gmail.com	Sweden		Yes
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Viviana Rosero	NRAO	vrosero@nrao.edu	United States		
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Remarks	My Current affiliation is the University of Oslo. I can not change it in the system.

Is this a long term proposal: No

Overall scheduling requirements

We request that our target sources be observed from July to August 2025. The sources will be above elevation 40 degrees at the Apex site and will be useful for 5 hours per night from July to August 2025.

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	APEX	nFLASH460 (385-500 GHz)	1h (1h)	491	< 0.5mm		We are proposing one tuning frequency at 491 GHz (USB) for the single pointing observations.

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
AFGL_51	06:08:53.40	+21:38:29.0	J2000	10.0	384	A	
IRAS072	07:32:09.70	-16:58:11.0	J2000	18.2	384	A	
G045_47	19:14:25.60	+11:09:25.0	J2000	60.0	384	A	
AFGL_40	03:01:31.20	+60:29:12.0	J2000	-40.0	384	A	
W3IRS_5	02:25:40.50	+62:05:51.0	J2000	-39.0	384	A	
NGC_753	23:14:01.70	+61:27:19.0	J2000	-57.0	384	A	
Cep_A	22:56:17.90	+62:01:49.0	J2000	-10.0	384	A	
IRAS_22	22:21:26.60	+63:51:38.0	J2000	-11.3	384	A	
AFGL_43	03:07:24.50	+58:30:52.0	J2000	-49.0	384	A	
G040_62	19:06:01.60	+06:46:36.0	J2000	31.0	384	A	

Scientific Rationale

Introduction

High-mass stars play a crucial role in regulating the dynamics of the interstellar medium (ISM)-their strong UV radiation ionizes and heats the surrounding medium, creating HII regions that expands at supersonic velocities relative to the sound speed of the neutral medium producing photodissociation regions (PDRs) and ionization/shock fronts (e.g., Bisbas et al. 2015). 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 of massive stars. Apex offers the ability to analyze the spectra of various lines, from simple atomic elements to complex molecules, and thus study the stratification of chemical species, which in turn provides us with important information regarding the kinematics, density and excitation condition.

The atomic component of the jet, tracing the PDR, is expected to be present due to the strong radiative feedback and it is likely located at the interface of the ionized and molecular outflowing material. Photodissociation regions define the transition between hot ionized and cold dark molecular regions. They consist of neutral gas interacting with far-ultraviolet radiation and are characterized by strong infrared emission. We have observed data for 10 different sources of high-J CO, [OI] and [OIII] using SOFIA/FIFI-LS and will serve as complementary data for this project.

Atomic carbon line: The fine-structure transition of atomic carbon, [CI] 1-0 with a rest frequency of 492.16 GHz is optically thin ($\tau < 1$) and easily excited in typical molecular gas conditions critical density of 500 cm^3, upper state energy (E_{up}) =23.6 K. CI is currently used to trace the properties and the kinematics of ISM gas. Indeed, atomic carbon surveys of molecular clouds in our Galaxy (e.g., Ikeda et al., 2002) show a remarkable spatial and kinematical similarity in the CI and CO emission. This has been confirmed with 3D photodissociation region simulations (Offner et al., 2013; 2014) suggesting that CI is not just present in a thin CII/CI/CO transition layer of PDRs. Recently, CI has been clearly detected in 98 sources out of ATLASGAL-selected 100 massive clumps with APEX and reported strong correlation between CI and ^{13}CO (2-1) (Lee et al. 2022).

We propose to observe CI line at $\sim$ 492 GHz toward 10 massive protostars. We do expect a strong emission of this transition in the proposed objects for three main reasons. First, we have evidence of atomic outflow using OI emission from FIFI-LS SOFIA project of the targeted sources. The second is because of the UV radiation that photodissociates CO (van Dishoeck & Black 1988), increasing both CI and CII abundances, and ALMA Band 6 observations show the emission of the ^{12}CO(2-1) transition for most of the sources, and thus CI is expected. The third is due to a newly discovered effect of the destruction of CO due to cosmic rays that are expected to be high in the outflow due to the frozen magnetic field lines along which charged particles move (Bisbas et al. 2015). The UV radiation and outflows driven by massive star formation produce photodissociation regions (PDRs) and shocks around the forming massive protostars, resulting in rich spectra of atomic and molecular emission.

Source Selection The sources are selected from the SOFIA Massive (SOMA) star formation survey (De Buizer et al. 2017, Liu et al. 2019, 2020, Fedriani et al. 2023, Telkamp et al. 2025), 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. Recently, the approved SOFIA FIFI-LS program of SOMA targets (Project ID: 09-0169, PI: Yao-Lun Yang) aims to observe atomic outflow via OI 63 μm emission, further motivating us to observe these sources with APEX to observe CI outflow with its unique capability of nFLASH receiver.

Description of observations: The aim of this proposal is to observe atomic carbon (CI) to trace the atomic component of the outflow. We will obtain simultaneously several simple (e.g., CS, C_3H_2, H_2CCO) and complex organic molecules (CH_3CHO, C_2H_3CN) with the same setup. The data will be sensitive to CI (1-0) emission that is able to trace the poorly studied atomic component of the outflow including CS (10-9) which is also a very good tracer of molecular outflow and several hot core lines that probe source's chemical properties. The prime focus of our observation is the [CI] line at 492 GHz, probing atomic outflows and warm molecular gas. For instance, atomic outflow has already been detected via [OI] 63 μm emission in IRAS 07299-1651 (see Fig. 1, one of our proposed targets). For all the proposed targets, we have observed data in far-IR emission of high-J CO, [OI] and [OIII] using SOFIA/FIFI-LS and will serve as complementary data for this project to investigate the relation between atomic and molecular outflow.

Facilities Requested

We request to use the nFLASH460 instrument of the APEX 12m telescope to perform single pointing observations. The capabilities of the nFLASH460 receiver and the FFTS backends are unique for our scientific purposes.

Observing Requirements

We propose to use APEX 12m telescope to observe 10 targets with single pointing centered at their RA and DEC positions during the July-December season. For this observation, the nFLASH460 receiver will be used. We propose to observe 10 target sources in the position switching mode with tuning frequency at 491.0 GHz at USB, where we expect the achievable angular resolution $\sim 12.7''$ at 491 GHz. Recently, Law et al. 2022 has observed CI 492 GHz line toward 98 massive clumps and achieved maximum sensitivity 100 mK with median line width 5 km S^{-1}. Here, we propose a sensitivity of 40 mK and a velocity resolution 1.0 km/s, which is enough to detect all target lines. We have used the ON-OFF observing time calculator at APEX V7.3 to estimate the total time needed to achieve our goal. Using FLASH460 tuned to 491 GHz in the USB, selecting a spectral resolution of 1.0 km/s and assuming a typical source elevation of 45 deg and a typical PWV of 0.5 mm, we could get down to a noise of 40 mK[Ta*] in 37.3 minutes (including telescope and calibration overheads). **Thus, in total for ten sources, we need 6 hours of APEX time including telescope and calibration overheads.**

Observing Plan

We request normal observational and calibration procedures.

Reference:

• Bonnell, I. A., et al. 2001, MNRAS, 324, 573; • Beuther, H., et al. 2014, A&A, 571, A53; • Bonnell, I. A., et al. 1998, MNRAS, 298, 93, 102; • Bisbas, T. G., et al. 2015, ApJ, 803, 37; • De Buizer, J. M., Liu, M., Tan, J. C., et al. 2017, ApJ, 843, 33; • Fedriani, R., et al. 2023, ApJ, 942, 7; • Ikeda, M., et al. 2002, ApJS, 139, 467; • Liu, M., Tan, J. C., De Buizer, J. M., et al., 2019, ApJ, 874, 16; • Liu, M., Tan, J. C., De Buizer, J. M., et al., 2020, ApJ 904 75; • Lee et al. 2022, A&A, A80, 2022; • McKee, C. F. and Tan, J. C. 2003, ApJ, 585, 850M; • Offner, S. S. R., et al. 2013, ApJ, 770, 49; • Offner, S. S. R., et al. 2014, MNRAS, 440, L81; • Padoan, P., et al. 2020, ApJ, 900, 82; • Telkamp, Z., et al. 2025, ApJ, in press; • Zhang et al. 2019, Nature Ast., 3, 517; • van Dishoeck, E. F., & Black, J. H. 1988, ApJ, 334, 771;

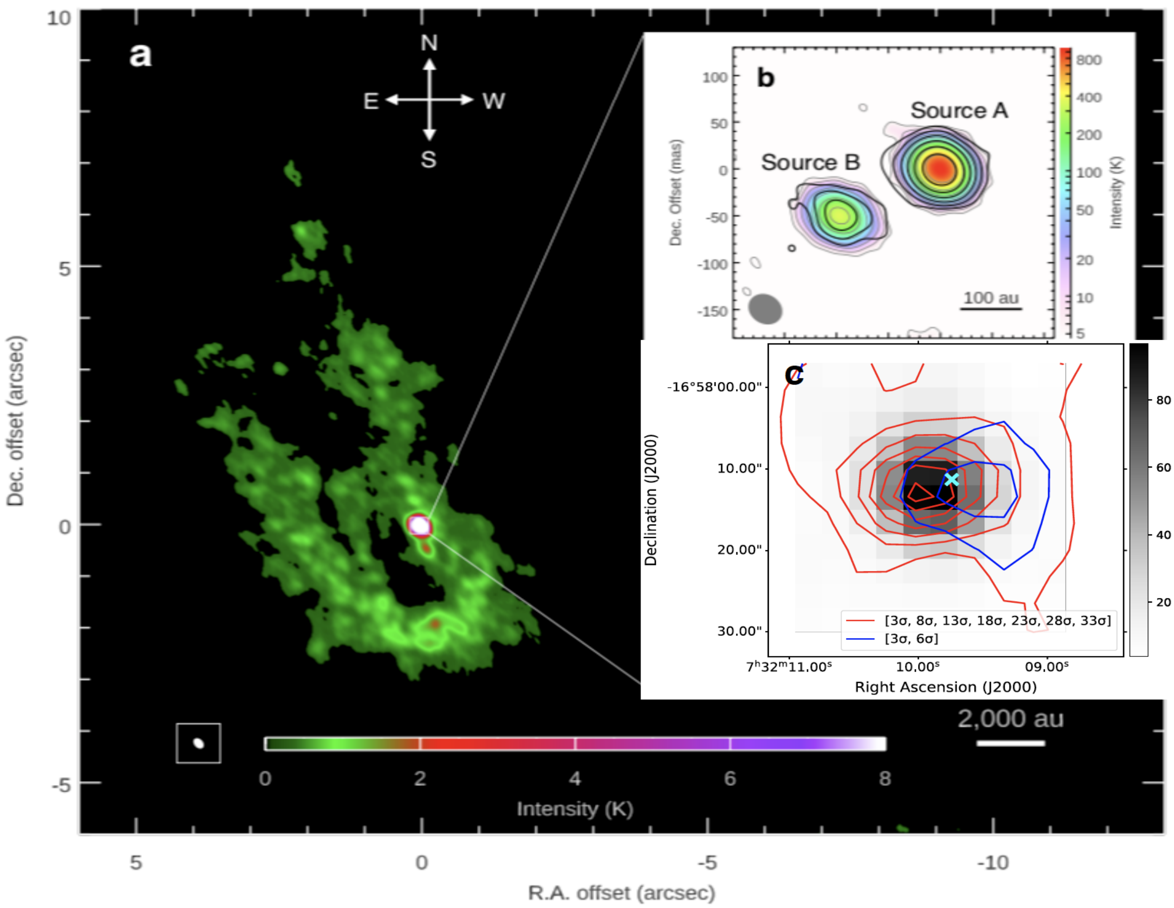

Figure 1: (From Zhang et al. 2019, Nature Ast., 3, 517) Maps of the 1.3 mm continuum and H30α line emissions for IRAS 07299-1651. (a) The 1.3 mm continuum map is in color scale in the background image, for which the synthesized beam (see box in lower-left corner) is $0.22'' \times 0.15''$. Structures here are consistent with being infall streamers that feed a circumbinary disk. (b) Zoom-in high-resolution 1.3 mm continuum map (color scale and grey contours) and the H30α line emission (black contours). The synthesized beam (see bottom-left corner) is 35 mas$\times$ 29 mas. (c) (Private comm.) SOFIA-FIFI-LS observation of OI 63 μm emission tracing blue and redshifted atomic outflows from the region (1σ = 4.5 Jy/[$3'' \times 3''$ pixel]). They will also be sensitive to [CI] emission from atomic outflows.

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 :