Onsala Proposal

Tan **0115.F-9304**

SOMA-ArTeMiS: Resolving Massive Protostar SEDs to Test Formation Theories

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

Abstract

We propose to observe 350 and 450 micron continuum emission from 14 regions of massive star formation selected from the SOMA survey with APEX-ArTeMiS. This will yield highest possible resolution (i.e., 8 and 10 arcsec) single dish mapping of more than 50 protostars at these wavelengths, i.e., three times better than achieved by the Herschel space telescope. From the resulting maps and ancillary data already in hand from Spitzer-IRAC, SOFIA-FORCAST and JCMT-POL2, we will be able to measure MIR to FIR spectral energy distributions, which then allows inference of mass surface densities, temperatures, spectral indices of dust emissivity (constraining grain growth), and bolometric luminosities, which are crucial parameters needed to help characterize the protostars and test theoretical models of massive star formation.

Applicants

Name	Affiliation	Email	Country		Potential observer
Mr. Chi Yan Law	Chalmers University of Technology (Space, Earth and Environment)	cylaw.astro@gmail.com	Sweden		Yes
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Is this a long term proposal: No

Overall scheduling requirements

All sources are observable in the August window

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	APEX	LASMA (268-375 GHz)	14h (14h)		0.5-1 mm	03-10, 16-20	We are proposing for ArTeMiS, but since the online form does not have such choice, so we randomly select one but we make explicitly here we are requesting for ArteMiS Bolometric observations All sources are needed to be observed in the August run Note that this proposal proposes for ArTeMiS Bolometer

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
G028.20-00.05	18:42:58.00	-04:14:05.0	J2000	95.0	51	A	Aug
G040.62-00.14	19:06:02.00	+06:46:37.0	J2000	32.0	51	A	Aug
G035.03+00.35	18:54:00.00	+02:01:18.0	J2000	53.0	51	A	Aug
G028.37+0.07	18:42:53.20	-04:00:08.0	J2000	79.0	51	A	Aug
G45.12+00.13	19:13:27.96	+10:53:35.7	J2000	60.0	51	A	Aug
G19.75-00.13	18:27:31.60	-11:45:54.7	J2000	121.0	51	A	Aug
G058.77+00.65	19:38:49.00	+23:08:40.0	J2000	32.0	51	A	Aug
G030.76+00.20	18:46:45.00	-01:50:29.0	J2000	98.0	51	A	Aug
G23.96+00.15	18:34:25.20	-07:54:45.8	J2000	79.0	51	A	Aug
G018.67+00.03	18:24:53.00	-12:39:20.0	J2000	49.0	51	A	Aug
G25.40-00.14	18:38:08.27	-06:45:58.2	J2000	95.0	51	A	Aug
G45.47+00.05	19:14:25.74	+11:09:25.9	J2000	62.0	51	A	Aug
G032.03+00.05	18:49:37.00	-00:46:50.0	J2000	99.0	51	A	Aug

Abstract: We propose to observe 350 and 450 micron continuum emission of the remaining 14 regions of massive star formation selected from the SOMA survey with APEX-ArTeMiS. This will yield highest possible resolution (i.e., 8 and 10 arcsec) single dish mapping of more than 50 protostars at these wavelengths, i.e., three times better than achieved by the Herschel space telescope. From the resulting maps and ancillary data already in hand from Spitzer-IRAC, SOFIA-FORCAST and JCMT-POL2, we will be able to measure MIR to FIR spectral energy distributions, which then allows inference of mass surface densities, temperatures, spectral indices of dust emissivity (constraining grain growth), and bolometric luminosities, which are crucial parameters needed to help characterize the protostars and test theoretical models of massive star formation.

1. Scientific background: Massive stars are important throughout the Universe, but the mechanism of their formation remains debated (e.g., Tan et al. 2014; Rosen et al. 2020). Mid- to far-infrared (MIR-FIR) spectral energy distributions (SEDs) are important to measure the properties of embedded massive protostars and test theoretical models of their formation. For instance, by fitting the protostellar SED models of Zhang & Tan (2018) based on the model of Turbulent Core Accretion (McKee & Tan 2003), one constrains the initial mass of the core (M_c), the mass surface density of the clump environment ($\Sigma_{\rm cl}$), and the evolutionary stage as parameterized via the current protostellar mass (m_*). The accretion rate and bolometric luminosity of the system are directly related to these parameters and so are also constrained. Furthermore, it is possible to infer the viewing angle to the outflow axis ($\theta_{\rm view}$) and the level of foreground extinction (A_V).

These results are essential in answering key open questions: e.g., are special environmental conditions needed for massive star formation? Krumholz & McKee (2008) proposed than a minimum clump environmental mass surface density of about $1\ {\rm g\,cm^{-2}}$ is needed to form high-mass stars. However, this condition has been called into question by Fedriani et al. (2023) based on SED fitting derived properties of m_* and $\Sigma_{\rm cl}$. However, the uncertainties in the SED-derived parameters are typically limited by the low resolution of the Herschel images defining the FIR part of the SED. At 350 μm, Herschel had a resolution of about $30''$. For typical distances to sources of 2 kpc, this corresponds to 0.29 pc, which is several times larger than expected core sizes. For example, a fiducial 60 $M_\odot$ core in a $\Sigma_{\rm cl} = 1\ {\rm g\,cm^{-2}}$ clump environment has a diameter of 0.11 pc (McKee & Tan 2003). *Thus the 3.4 times better angular resolution of APEX-ArTeMiS compared to Herschel-SPIRE will allow typical massive protostellar cores to be resolved in a wider range of environments, crucial for testing theoretical models.*

2. Target selection and planned analyses: The sources selected for this proposal are from the SOFIA Massive (SOMA) Star Formation Survey (PI: Tan), which aims to test theoretical models of massive star formation by characterizing a sample of ~ 100 high- and intermediate-mass protostars spanning a range of environments and evolutionary stages. These objects have been observed with the *SOFIA*-Faint Object infraRed CAmera for the *SOFIA* Telescope (FORCAST) instrument from ~ 10 to $40\,\mu$m. Most of the sources have also been observed as part of the SOMA follow-up (SOMA+) project with JCMT-POL2 (PI: Pattle; Co-PI: Law) at 450 and 850 microns. In addition, most of the sources have been observed in the near-IR with either HST, LBT or VLT (PI: Fedriani). While Herschel PACS and SPIRE data also exist for most of the sources, as noted the SPIRE data have relatively poor angular resolution. With the much-improved resolution of APEX-ArTeMiS compared to Herschel-SPIRE, estimates of protostellar properties will be greatly improved for each SOMA target. This is especially the case in regions of clustered massive star formation (Telkamp et al., 2025, see Figure 1), which are selected for inclusion here with highest priority.

With the obtained APEX-ArTeMiS images we will refit the MIR to FIR SEDs of the sources with the standard SED fitting methods developed for the SOMA survey (Fedriani et al. 2023). As described above, this will allow the measurement of crucial intrinsic properties of the sources. We will then study the potential dependence of the massive star formation process on environmental conditions, helping to resolve a key open question in the field. Figure 2 presents the ArTeMiS-SPIRE combined column density map of AFGL 5180 based on APEX-ArTeMiS data taken in August 2024. Based on the successful observations of the two regions in 2024, we intend to continue the observations to complete the remaining 14 fields.

3. Technical justification: We propose APEX observations toward 14 SOMA regions with the ArTeMiS bolometer to observe continuum intensity simultaneously at 350 μm and 450 μm. All sources are above 40 deg in August 2025 observation windows of the current call with at least 2 available hours per night. To estimate the APEX time required per source, we define a constant map size of $4.7' \times 4.7'$ based on the JCMT-POL2 Stokes I images at 450 μm. We define the required sensitivity at 350 μm based on the *Herschel*-SPIRE images after beam conversion. A uniform sensitivity of 500 mJy/bm will ensure at least SNR$\geq$ 3 toward the main structures for all sources (and with most having significantly higher SNR values up to $\sim$ 15). From the sensitivity calculator, assuming a PWV of 0.7, this requires 0.85 hrs (including overhead) to achieve the desired sensitivity per source. Hence, we request 14 hrs to observe all targeted sources.

References: • Tan, J. C., Beltrán, M. T., Caselli, P. et al. 2014, Protostars & Planets VI, 149. • Rosen, A. L., Offner, S. R., Sadavoy, S. I. et al. 2020, Space Science Rev., 216, 62. • Zhang, Y. & Tan, J. C. 2018, ApJ, 853, 18. • McKee, C. F. & Tan, J. C. 2003, ApJ, 585, 850M. •Mattern et al. 2024, A&A, 688, A163. • Fedriani, et al., 2023, ApJ 942 7. Telkamp et al. 2025., accepted to ApJ.

Table 1: Our proposed APEX-ArTeMiS observations

Field	R.A. (J2000)	Dec. (J2000)	Average mJy/beam	SOMA paper/ ref	month
AFGL5180	06:08:53.00	+21:38:30.00	4833	V	**Done**
IRAS07299-1651	07:32:10	−16:58:14	2031	I	**Done**
G035.03+00.35	18:54:00	+02:01:18	4519	V	Aug
G030.76+00.20	18:46:45	−01:50:29	2814	V	Aug
G028.37+0.07	18:42:53.2	−04:00:08.00	3120	V	Aug
G018.67+00.03	18:24:53	−12:39:20	1694	V	Aug
G058.77+00.65	19:38:49	+23:08:40	1553	V	Aug
G19.75-00.13	18:27:31.60	−11:45:54.72	1553	V	Aug
G23.96+00.15	18:34:25.20	−07:54:45.83	2152	V	Aug
G028.20-00.05	18:42:58	−04:14:05	7654	Law et al. 2022	Aug
G032.03+00.05	18:49:37	−00:46:50	5265	IV	Aug
G040.62-00.14	19:06:02	+06:46:37	2427	IV	Aug
G45.47+00.05	19:14:25.74	+11:09:25.90	6397	I	Aug
G25.40-00.14	18:38:08.27	-06:45:58.16	3801	IV	Aug
G45.12+00.13	19:13:27.96	+10:53:35.69	7076	II	Aug
IRAS18264-1152	18:29:14.68	-11:50:23.96	7488	III	Aug

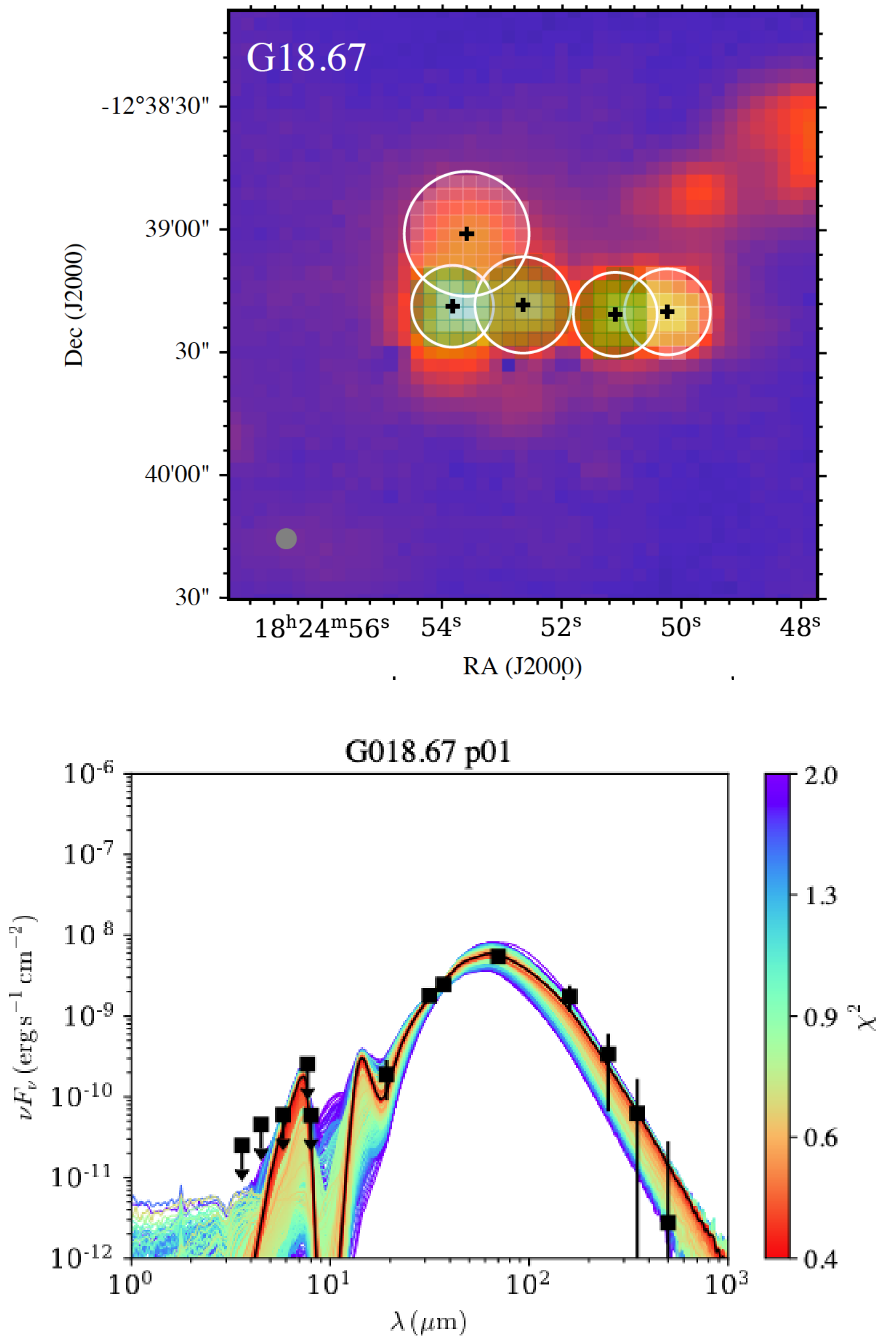

Figure 1: **(a) Top:** Herschel 70 μm images of an example SOMA V (Telkamp et al., 2025) region G18.67. The white circles denote the apertures used for the fiducial photometry, centered on the black crosses that are the source positions found by an automated search algorithm. Pixels are shaded to show which source each is assigned to. Gray circle in the lower left shows the beam of about 6 arcsec FWHM. APEX-ArTeMiS resolution at 350 μm will be similar at 8 arcsec. One sees that such a resolution is needed to more clearly separate out sources in crowded, clustered regions. **(b) Bottom:** Protostar model (Zhang & Tan 2018) fitting to the SED of the brightest source shown in (a). The best fitting protostar model is shown with a black line, while all other "good" model fits are shown with colored lines (red to blue with increasing χ^2). Note, the error bars become very large at long wavelengths due to systematic uncertainties associated with the difficulty of resolving the sources. The APEX-ArTeMiS observations will allow much more accurate SED determination and thus much tighter constraints on protostellar properties.

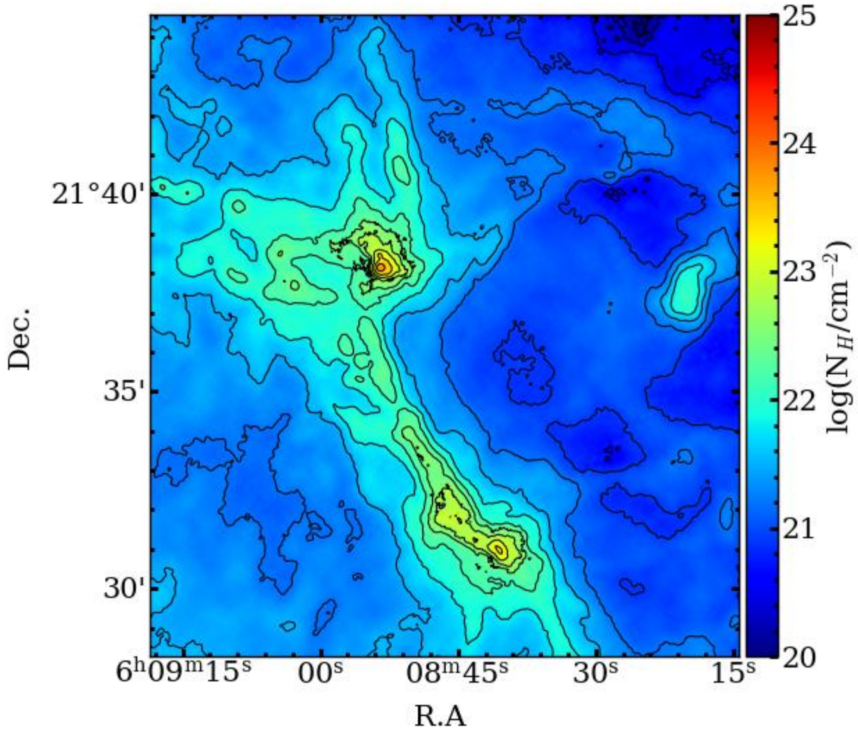

Figure 2: ArTeMiS-SPIRE combined column density map of AFGL 5180 based on APEX-ArTeMiS data taken in August 2024. This column density map has a resolution of 8 arcsec, i.e., a factor of > 4 better than standard Herschel column density maps (36 arcsec). It was obtained using a method described in detail in Mattern et al. (2024).

No PhD Students involved

Linked proposal submitted to this TAC: No

Linked proposal submitted to other TACs: No

Relevant previous Allocations: No

Additional remarks

This proposal is to propose observation of ArTeMiS with instrument PI Phillips Andre as Co-I of the proposal

Observing run info :

Run: A backup strategy: The time estimation is based on the poorest weather ArteMiS can operate (Phillipe Andre, private discussion), which better weather will lead to shorter integration time.