Onsala Proposal

Andre   0108.F-9315

Filaments, cores and star formation in Orion B

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

Abstract

Submillimeter imaging surveys of Galactic molecular clouds with Herschel show that molecular filaments play a crucial role in the early phases of star formation. They support a two-stage paradigm for low-mass star formation: first, ~0.1 pc-wide filaments form in the diffuse ISM, probably as a result of large-scale turbulent compression; then, prestellar cores arise from gravitational fragmentation of the densest filaments.

With its moderate angular resolution (25" at 350 microns), however, Herschel can only marginally resolve the transverse size and internal structure of molecular filaments in the nearest giant molecular clouds (GMCs), like Orion at d ~ 400 pc. Here, we propose to use ArTeMiS on APEX to obtain dust continuum images at 350 and 450 microns of the densest parts of the Orion-B GMC, at a factor of 3.5 higher resolution than Herschel/SPIRE, in order to investigate in great detail the connection between filamentary structures and pre-/proto-stellar cores, as well as the pre-/proto-stellar core mass/luminosity functions, in this nearby complex of intermediate- to high-mass star formation.

Applicants

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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	ARTEMIS (350/450 micron)	14h (14h)		0.5-1 mm	02-09	

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
NGC 2024	05:41:42.99	-01:50:30.0	J2000	0.0	420	A	(+ 420 in P102)
NGC 2071	05:47:09.84	+00:18:00.0	J2000	0.0	420	A	(+ 420 in P102)

Scientific Rationale

Understanding the life cycle of the interstellar medium (ISM) from diffuse gas to molecular complexes and dense cores where (proto)stars form is a fundamental open problem in modern astrophysics. Our global understanding of star formation (SF) in the Galaxy has made significant progress in recent years, in large part thanks to extensive imaging surveys with *Spitzer* and *Herschel*. In particular, the results of *Herschel* surveys emphasize the role of molecular filaments in the earliest stages of SF. Nevertheless, the basic question of what regulates star formation remains remains mostly unanswered.

A filament paradigm for solar-type star formation

The results from the *Herschel* Gould Belt survey (HGBS) have highlighted the omnipresence of filaments in nearby (d $<$ 500 pc) molecular clouds, and suggested an intimate connection between the filamentary structure of the cold ISM and the formation process of pre-stellar cores (André+2010, 2014). In any given cloud, *Herschel* imaging reveals a whole network of filaments (see also Molinari et al. 2010). In nearby clouds, a detailed analysis of the radial column density profiles shows that these filaments are characterized by a narrow distribution of central widths, with a typical FWHM value $\sim$0.1 pc (Arzoumanian+2011, 2019; Koch & Rosolowsky 2015). The origin of this common inner width of filaments in nearby clouds is not yet well understood, even though several possible interpretations have been proposed (e.g. Fischera & Martin 2012; Hennebelle & André 2013; Federrath 2016).

The interplay between cores and filaments

Another major result from *Herschel* surveys of nearby clouds is that most (>75%) pre-stellar cores and protostars are found in dense, supercritical filaments, for which the mass per unit length exceeds the critical line mass of isothermal, long cylinders (e.g. Inutsuka & Miyama 1997), $\mathrm{M}_{\mathrm{line;crit}} = 2c_s^2/G \approx 16\ \mathrm{M}_\odot/\mathrm{pc}$, where $c_s \approx 0.2$ km/s is the isothermal sound speed for molecular gas at T$\sim$10 K (e.g. André+2010; Könyves+2015; Marsh+2016).

The *Herschel* observations also confirm the existence of a close relationship between the prestellar core mass function (CMF) and the stellar initial mass function (IMF) in the regime of solar-type stars (~ 0.1–$5\,M_\odot$ – Könyves+2015). The pre-stellar CMF exhibits a peak at $\sim$0.6 $\mathrm{M}_\odot$, which corresponds to the Jeans mass within marginally critical filaments with $M_{\mathrm{line}} \approx M_{\mathrm{line,crit}} \sim 16\,M_\odot$/pc.

These *Herschel* results support a paradigm for solar-type star formation in two main steps (e.g. André+2014): first, the dissipation of kinetic energy in large-scale magneto-hydrodynamic (MHD) flows generates a quasi-universal web-like filamentary structure in the ISM; second, the densest filaments fragment into pre-stellar cores and ultimately protostars by gravitational instability. However, the moderate angular resolution of *Herschel* (25–36$''$ at 350–500 μm, or 0.05–0.07 pc at a distance of 400 pc) only allows to marginally resolve the inner width of the filaments seen in the Orion molecular complex. Observations at higher resolution are crucially needed to resolve substructures within the filaments, and to probe fragmentation into individual ($\sim 0.01 - 0.1$ pc) pre-/proto-stellar cores.

Constraining the early stages of intermediate- to high-mass star formation

Given the key role of filaments for the formation of low-mass stars, the question naturally arises whether a similar scenario could describe the earliest phases of intermediate and high-mass star formation. Since molecular filaments are also known to be present in other galaxies (e.g. Fukui+2015), this picture may have broader implications for our understanding of star formation on galaxy-wide scales. Assuming that all filaments have similar inner widths, it has been argued that the filamentary structure may help to regulate the star formation (SF) efficiency in dense molecular gas (André+2014), and may be responsible for a quasi-universal SF law in the dense ISM of galaxies (Lada+2012, Shimajiri+2017).

To make further progress on this topic, it is of prime importance to image the dusty molecular filaments detected with *Herschel* at higher resolution using ArTéMiS in a number of massive giant molecular clouds (GMCs), more representative of star formation in the Galaxy than the nearest clouds of the Gould Belt (e.g. Taurus). We already used the ArTéMiS camera to conduct such observations towards several regions of high-mass star formation, including NGC 6334 (André+2016) and the Orion A GMC/integral-shaped filament (Schuller+2021; see Fig. 1). We here propose to extend these detailed studies to the Orion B GMC, by completing the preliminary observations already taken in project 0102.F-9310 (see Fig. 3).

Immediate objectives

We propose to map the densest parts of the Orion B GMC, a region of intermediate- to high-mass star formation at a distance of only ∼400 pc. We propose to focus on the regions with $N_{H_2} > 1.0 \times 10^{22}$ cm^{-2}, equivalent to $A_V > 10$ mag, where most core/star formation is observed to take place in nearby clouds (e.g. André+2010; Lada+2012). Using a standard dust opacity (e.g. Hildebrand 1983) and assuming a temperature of 15–18 K, a column density of 1.0×10^{22} cm^{-2} corresponds to a flux density of ∼0.3–0.6 Jy/8″-beam at 350 μm. Therefore, we need to reach an r.m.s. of 0.3 Jy to detect at 3–5 σ the gas above 3.0×10^{22} cm^{-2}. These data will allow us to:

- study the detailed radial density structure of dense *Herschel* filaments. The 8″ resolution of ArTéMiS translates to 0.015 pc at the distance to Orion B, allowing us to precisely measure the width of such filaments (cf. André+2016, Schuller+2021), and to investigate their fragmentation into cores.
- extract individual dense cores down to masses of ∼0.15–0.3 $M_\odot$. We will make use of source extraction algorithms developed for Herschel data analysis (e.g. *getsources*, Men'shchikov+2012) to extract compact cores from the maps. We will then study the pre-/proto-stellar core mass/luminosity functions in Orion B down to masses well below 1 $M_\odot$.
- investigate the detailed connection between filaments and pre-/proto-stellar cores.

By combining ArTéMiS and *Herschel* data, we will be able to recover structures over a wide range of spatial scales, from the 8″ resolution of ArTéMiS at 350 μm up to the degree scale probed by the *Herschel* data. As part of project 098.F-9304 on Orion A, **we have developed a multi-resolution technique enabling us to generate robust column density maps at 8″ resolution and dust temperature maps at 18″ resolution from the combined ArTéMiS +*Herschel* data (see Fig. 1 and Schuller+2021)**. We intend to apply the same technique to the Orion B data. The results will be unique to explore the interplay between the large scale structures of the cold ISM, dense filaments, and star-forming clumps, in one of the nearest massive GMCs.

Observing Requirements

The total area that we propose to map covers ∼500 arcmin^2, encompassing the contour shown in Fig. 2. We have divided the regions to be mapped into smaller on-the-fly maps (e.g. Fig. 3), in order to cover only the densest parts of this complex. According to the online time estimator, a total of ∼14 to ∼31 to hours of observing time (including overheads) is needed to map ∼500 arcmin^2 down to an r.m.s. of 0.3 Jy/beam, depending on the exact PWV ∼0.6 mm and source elevation (from ∼40° to 55°). Good data (∼ 14 hr) were already taken in project 0102.F-9310 (see Fig. 3), but sometimes at rather low elevation ($\lesssim 40°$), and we need to improve the S/N of the maps to reach our science goals. We thus **request another 14 hr of telescope time** with PWV<0.7 mm between Jul. and Dec.

References

• André, Ph.+2010, A&A, 518, L102 • André, Ph.+2014, in Protostars and Planets VI, p. 27 • André, Ph.+2016, A&A, 592, A54 • Arzoumanian, D.+2011, A&A, 529, L6 • Arzoumanian, D.+2019, A&A, 621, A42 • Federrath, C. 2016, MNRAS, 457, 375 • Fischera, J., & Martin, P.G. 2012, A&A, 542, A77 • Fukui, Y.+2015, ApJ, 807, L4 • Hennebelle, P., & André, Ph. 2013, A&A, 560, A68 • Hildebrand, R. H. 1983, QJRAS, 24, 267 • Inutsuka, S-I, & Miyama, S.M. 1997, ApJ, 480, 681 • Koch, E.W., & Rosolowsky, E.W. 2015, MNRAS, 452, 3435 • Könyves, V.+2015, A&A, 584, A91 • Könyves, V.+2020, A&A, 635, A34 • Lada, C.J.+2012, ApJ, 745, 190 • Marsh, K.A.+2016, MNRAS, 459, 342 • Men'shchikov+2012, A&A, 542, A81 • Molinari, S.+2010, A&A, 518, L100 • Schuller, F., André, Ph., Shimajiri, Y.+2021, A&A, in press (arXiv:2104.03717) • Shimajiri, Y., André, Ph., Braine, J.+2017, A&A, 604, A74

Figures

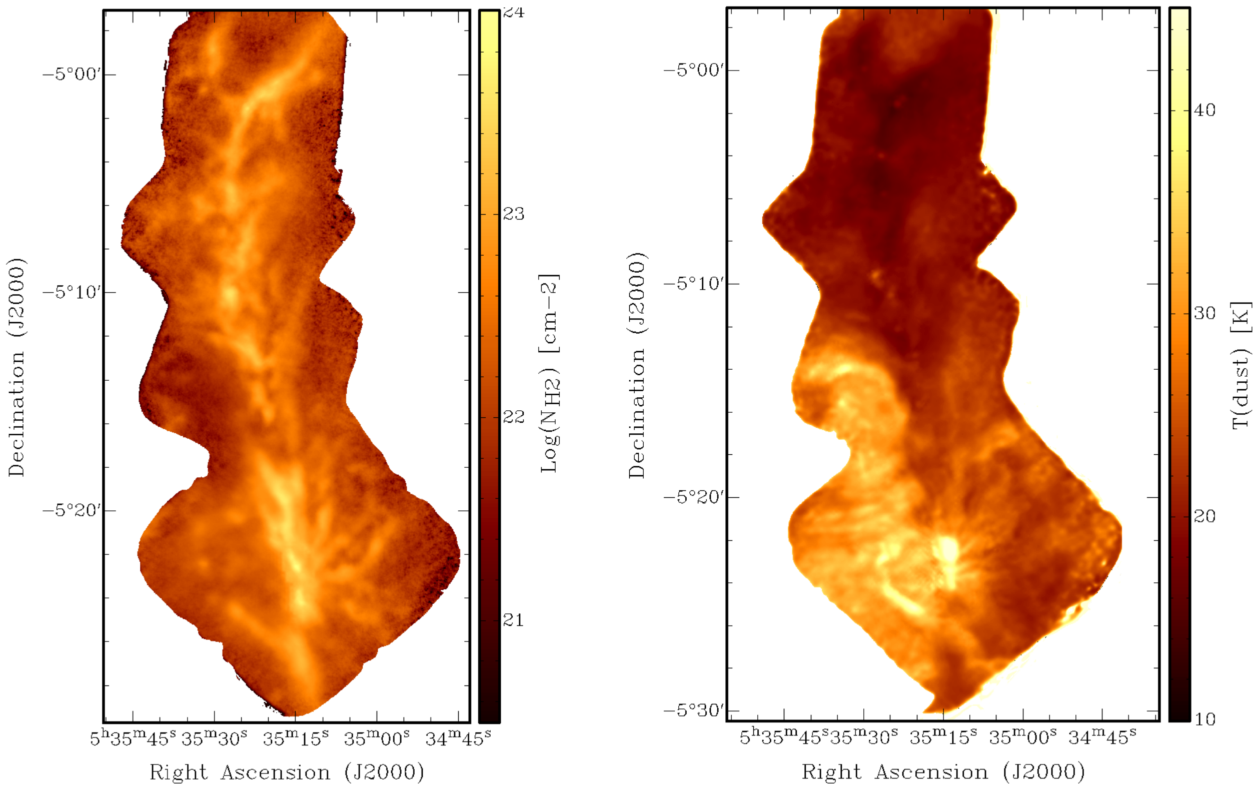

Figure 1: High-resolution ($\sim 8''$ and $\sim 18''$) column density (left) and dust temperature (right) maps of the Orion A integral-shaped filament region obtained by combining ArTéMiS 350 μm & 450 μm data (project 098.F-9304) with *Herschel* data from the *Herschel* Gould Belt survey (see http://gouldbelt-herschel.cea.fr/archives). (From Schuller, André, Shimajiri et al. 2021, A&A – arXiv:2104.03717).

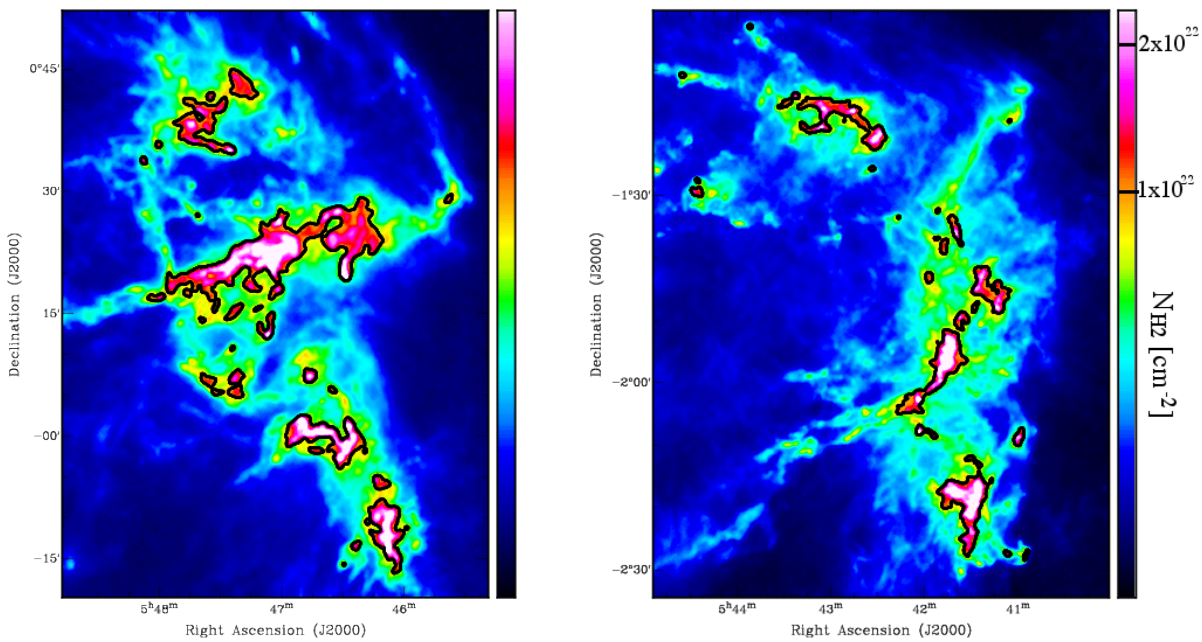

Figure 2: H_2 column density maps derived from *Herschel* Gould Belt survey data of the Orion B North region (around NGC 2068/2071, left) and Orion B South region (around NGC 2023/2024, right). (From Könyves+2020 and http://gouldbelt-herschel.cea.fr/archives). The black contour corresponds to $N_{H_2} = 1.0 \times 10^{22}$ cm^{-2}.

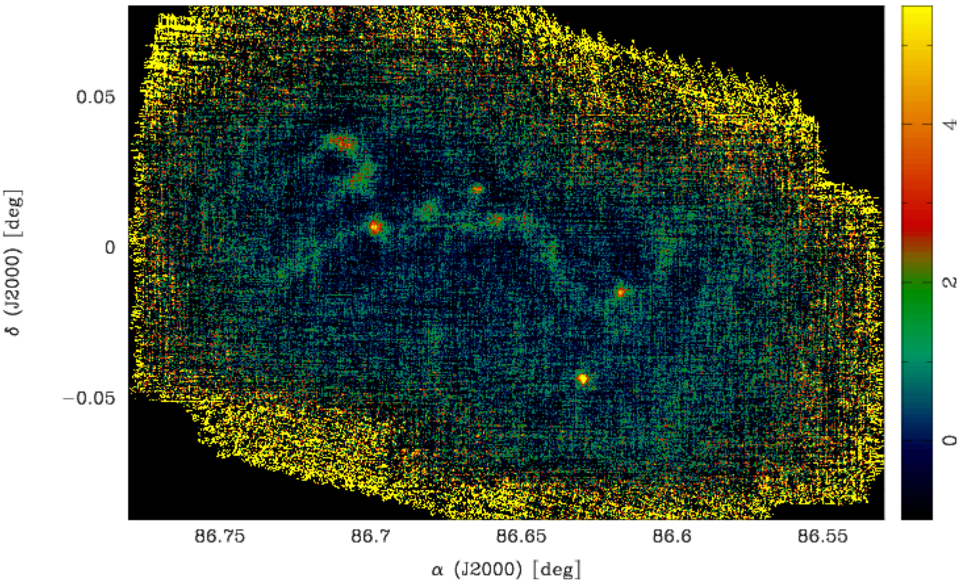

Figure 3: Preliminary ArTéMiS 350 μm image of the NGC 2068 sub-region in the Orion B cloud obtained as part of project 0102.F-9310. The color bar is in Jy/8″-beam. **The immediate objective of the present proposal is to improve the S/N in the preliminary ArTéMiS maps of 0102.F-9310, in order to produce high-resolution column density and dust temperature maps of dense gas structures in Orion B, of quality comparable to the maps recently published for Orion A (Schuller+2021 – see Fig. 1).**

No PhD Students involved

Linked proposal submitted to this TAC: No

Linked proposal submitted to other TACs: No

Relevant previous Allocations: Yes

098.F-9304 on Orion A, 16 hr, results shown in Fig. 1
(see Schuller+2021, A&A, in press arXiv:2104.03717).

0102.F-9310 on Orion B, 14 hr, preliminary results illustrated in Fig. 3.
More observing time is required to improve S/N (this proposal).

Additional remarks

ArTéMiS GTO proposal
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Observing run info :