Onsala Proposal

Perotti 0108.F-9300

Unveiling the evolving chemistry of Herbig-Haro objects: the giant HH175

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

Abstract

Herbig-Haro objects are omnipresent in star-forming regions, resulting from the launch of protostellar jets. These are highly energetic phenomena that may alter the morphology and kinematics of the neighboring gas. Although they are ubiquitous in regions where stars form, it is still not clear how exactly they are tied into the global star-formation process.

The aim of this proposal is to shed light on the activity of HH objects. To accomplish this goal, we propose to perform a chemical survey of the giant HH175, an ideal laboratory to study the effects of HH objects due to its relatively simple structure. The proposed observations will provide a chemical inventory of HH175, and hence quantitative constraints into its physical and chemical nature. The observations will supply unique insights on the dependencies of gas-to-ice relationships on the physical conditions of star-forming regions. This study will also serve as a pathfinder for JWST NIRSpec observations of HH175 and thus to make a first, but necessary step towards unveiling the role of Herbig-Haro objects in star-forming regions.

Applicants

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Is this a long term proposal: No

Overall scheduling requirements

No

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	APEX	nFLASH230 (200-270 GHz)	18h (18h)	241.791	1-2 mm		We will perform a mosaic on the Herbig-Haro Object 175 to cover its apex and clumps. We will include two CO isotopologue lines at 219.560 GHz (C18O) and 220.398 GHz (13CO).

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
HH175	05:44:48.30	+09:10:14.9	J2000	12.42	1080	A	

Scientific Rationale

Herbig-Haro objects (HHs) are ubiquitous in star-forming regions but nevertheless they are wrapped in a veil of mystery. They are often associated to a single young stellar object (YSO), being protagonists of the earliest phases of star-formation. Herbig-Haro objects are believed to form when high-velocity protostellar jets collide with the surrounding molecular cloud, inducing shocks. Such shocks compress and heat the gas, generating UV radiation (Neufeld & Dalgarno 1989). Their activity can dramatically change the chemical composition of the gas around Herbig-Haro objects, mutating the chemistry of the region (e.g., enhancing gas-phase reactions, ejecting ice molecules from dust grains; Neufeld & Dalgarno 1989, Hollenbach & McKee 1989).

Among the 1000+ Herbig-Haro flows detected so far, only a few dozen have parsec-scale dimensions (Reipurth et al. 2001). One of these giant flows, HH 175, is located in the B35A cloud (Fig. 1), in the λ Orionis cluster (410 $\pm$ 20 pc; Zucker et al. 2019). HH 175 is an intriguing object because it is aligned with the bipolar outflow associated with the multiple protostellar system IRAS 05417+0907 (Myers et al. 1988; Connelley et al. 2008, Craigon 2015). Its apex is characterized by three main clumps, HH 175 A, B and C (Reipurth & Friberg, 2021) which are transient, as the jet will reach them within a timescale of the order of 10^4 yr or less (Raga & Williams, 2000). *Further observations are required to fully understand the multiple effects of HH 175 on the physical structure and chemistry of B35A.* These observations will shed light on the role of HHs in star-forming regions, providing better constrains on the nature of solid and gaseous molecules and their interplay during the earliest phases of star-formation.

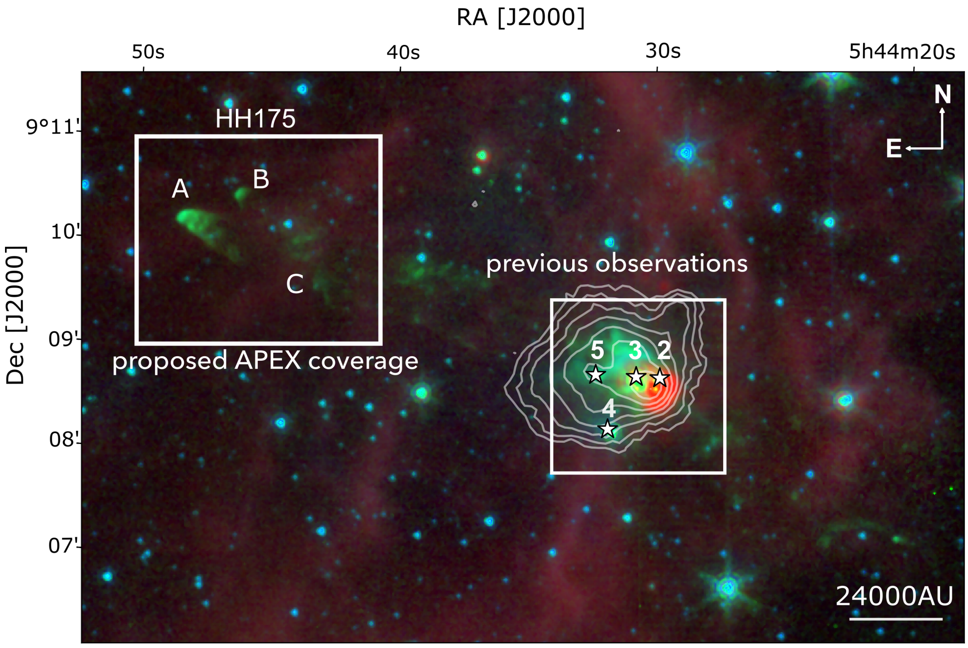

Figure 1: **The molecular outflow driven by IRAS 05417+0907 (Object 3) and terminating in HH175.** The upper left square indicates the proposed APEX coverage, a total map size of $125'' \times 120''$, centered in the region where the tip of HH175 (HH175 A) and its two clumps (HH175 B and HH175 C) are located. The same coverage has been requested for SMA observations. The right white square marks the region previously mapped with APEX and SMA and displayed in Figures 2 and 3 (APEX ID: O-102.F-9304A-2018; Perotti et al. 2021).

Linking ice and gas in Orion B35A.

B35A is a unique case of an environment affected by a giant Herbig-Haro objects with a relatively simple structure, and thus is an ideal laboratory to study the effects of HHs on ice and gas chemistry. Submillimeter (APEX, SMA) and infrared (AKARI) observations of B35A have been combined to produce gas-ice maps, and hence to study the gas-ice interplay towards the protostars emanating HH 175 (Figures 2–3; O-102.F-9304A-2018, Perotti et al. 2021).

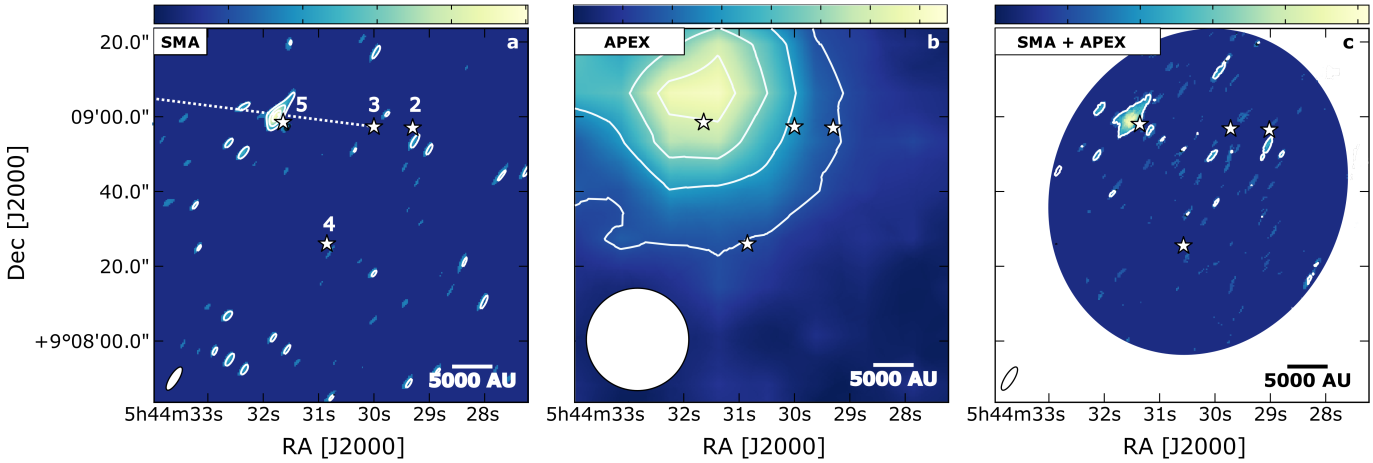

Figure 2: **SMA+APEX moment zero maps of CH_3OH 5_0–4_0 towards the protostellar system in B35A.** The methanol CH_3OH peaks in the direction of HH175 and of the outflow associated to the multiple protostellar system IRAS 05417+0907 (Object 3). APEX ID: O-102.F-9304A-2018. Figure from Perotti et al. 2021.

Such gas-ice maps are essential to link small-scale variations traced by ice mapping with large-scale astrophysical phenomena probed by gas-mapping. Our gas-ice maps show that the methanol (CH_3OH) emission detected by APEX and SMA is tracing the outflow terminating in HH 175 (Fig. 3; Perotti et al., 2021). This finding allowed us to conclude that desorption of ice molecules is occurring in B35A due to the presence of HH 175. In fact, where the CH_3OH emission is stronger (e.g., Object 5) – and hence the outflow activity is at work – the water ice abundances relative to H_2 are the lowest in the region (Fig. 3). This is due to the ejection of water molecules from the dust grains in the outflow shocks. In contrast, where the CH_3OH emission is weaker (e.g. Object 4) – further away from the outflow trajectory – the water ice abundances are the highest in the region. Which other molecules are affected by HH 175?

We now know that this vast outflow is shaping the physical structure and chemistry where HH 175 is originated, but to what extent compared to where the HH 175 terminates? *We hereby propose to perform a chemical survey directly at the HH 175 apex (Fig. 1), to make a first, but necessary step towards unveiling the role of Herbig-Haro objects in star-forming regions.*

With the proposed observations we seek to test:

- **What is the chemical inventory at the apex of HH 175 and towards its clumps?** To which degree the UV irradiation from the HH apex enhances the emission of gas-phase molecules compared to the region where the HH is emanated? Our previous observations of B35A show CH_3OH emission extending in the direction of the apex of HH 175 (Fig. 2). The proposed observations will confirm or not this hypothesis.

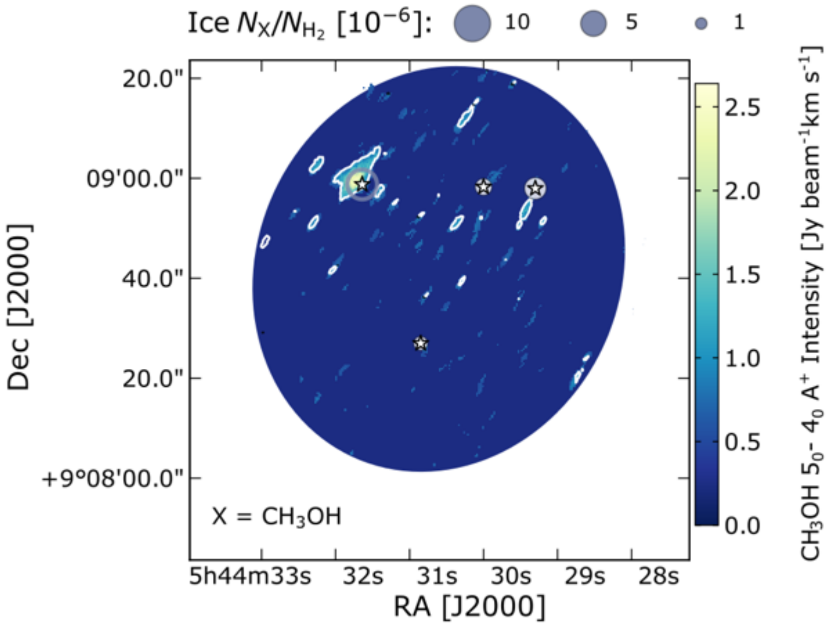

Figure 3: **Gas-ice maps of the multiple protostellar system in B35A.** The colour scale shows CH_3OH gas integrated intensity from SMA+APEX data, whereas grey circles indicate H_2O ice abundances relative to H_2 from AKARI observations. The H_2O ice abundances are lower in correspondence of the CH_3OH emission tracing the outflow. *We here propose to perform the same type of gas-ice comparative study for the apex of HH175.* Figure from Perotti et al. 2021.

- **What are the gas-to-ice ratios toward HH 175?** With the planned observations, the column densities of gaseous species (e.g., CO, CH_3OH) will be derived using the population diagram method. Simultaneously, the column densities of the ice molecules in the same region will be inferred from ancillary *James Webb Space Telescope* NIRSpec observations. Finally, gas-to-ice ratios will be measured. Are they comparable to the values suggested by laboratory experiments, simulations and observations (Öberg et al. 2009a; Bertin et al. 2016; Perotti et al. 2020, 2021)? The measurements of the absolute values of the gas-to-ice ratios will validate or not the proposed numbers.

- **What are the gas and ice variations towards HH 175?** Gas-ice maps of HH 175 will be constructed and compared to gas-ice maps of the Serpens SVS4 and B35A (Perotti et al. 2020, 2021). The comparison will allow to better constrain how universal are the trends for gaseous and solid molecules observed in SVS4 and B35A compared to this shocked region.

Observing Requirements

With this proposal, we request to observe two molecular outflow tracers (CO and CH_3OH) towards the apex of the shocked region in the B35A cloud. Observing these transitions will provide unique constraints on the physical structure and the chemistry of shocked regions and, by inference, on the unclear role of HH objects in star-forming regions.

Imaging

In order to complement the SMA data with APEX short-spacing we here propose to map the apex of HH 175 (HH 175 A) and its clumps (HH 175 B and HH 175 C) at 26″ resolution. We request to make a total map size of 125″ × 120″, to fully cover the entire shock front and the SMA coverage (Fig. 1). APEX data are crucial to assess the spatially filtered flux by the SMA. With these data it will be possible to directly account and compensate for the missing flux. Additionally, we will accompany the proposed observations with JWST NIRSpec data to access the ice composition towards the shocked region. This will allow us to investigate the ice chemistry of HH 175, and to compare it with its gas chemistry, addressed in this APEX proposal.

Integration times

The methanol rotational bands at 241.791 GHz are the most challenging to detect. The weakest methanol peak intensities are of the order of 0.025 K in the region of B35A previously mapped with the APEX beam (Fig. 1), we therefore expect comparable or higher intensities. We aim at detecting the weakest methanol transitions at a peak S/N of 5, i.e. 0.005 K in 1 km s^{-1} bins. According to the OTF time estimator v8.1.2, with a dump time of 1 sec under 2 mm PWV, we will map the methanol emission towards HH 175 with the requested rms in 18 hrs of telescope time.

Frequency setup

We seek to probe the spatially extended lower-excited 5_K–4_K methanol emission at 241.791 GHz, which we expect to be bright in this dense cluster. The spectral setting has been chosen to observe a suite of methanol transitions with E_u values ranging from 34 to 73 K. In addition, ^{13}CO (220.398 GHz) and $C^{18}O$ (219.560 GHz) J = 2-1 will be targeted, allowing us to compare the methanol emission with the emission of its precursors.

Planned analysis

The PI is currently a Ph.D. student supervised by Jes Jørgensen and Lars Kristensen. The team has extensive experience of APEX data reduction and analysis. The PI will lead the data analysis and the resulting publication. Helen Fraser (JWST PI), Hugh Dickinson and Zak Smith will provide key expertise in interpreting the ice data, Per Bjerkeli will support with the gas-phase analysis, and Bo Reipurth will supply his vast knowledge on the target of these observations, HH 175.

References

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Students involved

Student	Level	Applicant	Supervisor	Applicant	Expected completion date	Data required
Giulia Perotti	Master	Yes	Jes Jørgensen	Yes	2021/06	No

Linked proposal submitted to this TAC: Yes

This a resubmission of APEX ID 0107.F-9304, which was accepted in P107. The PI was advised to resubmit in this call to perform and complete all the observations in P108.

The complementary accepted proposal APEX ID: 0107.F-9305 will map the spatial distribution of cold gas tracers in B35A.

Linked proposal submitted to other TACs: Yes

We have asked for Submillimeter Array (SMA) observations to investigate this particular region at an angular resolution of ~4" to combine with the proposed APEX data.

Relevant previous Allocations: Yes

We obtained APEX time to pursue three projects which targeted:
A. the Serpens SVS4 cluster, the APEX observations were also combined with SMA observations (APEX ID: O-099.F-9316A-2017, 4.2hrs), Perotti et al. 2020.
B. The Lamda Orionis B35A cloud, and in particular the multi-protostellar system IRAS 05417+0907, emanating the HH175 (APEX ID: O-102.F-9304A-2018, 11.2 hrs); Perotti et al., 2021. These observations did not target the apex of HH175.
C. The IRS7 region in Corona Australis (APEX ID: O-105.F-9300A-2019, 21.5 hrs); Perotti et al. in prep.

Additional remarks

ESO=gperotti

Observing run info :

Run: A backup strategy: This proposal does not require particular weather constraints