



Enlightening the Chemistry of Infalling Envelopes and Accretion Disks Around Sun-Like Protostars: The ALMA FAUST Project

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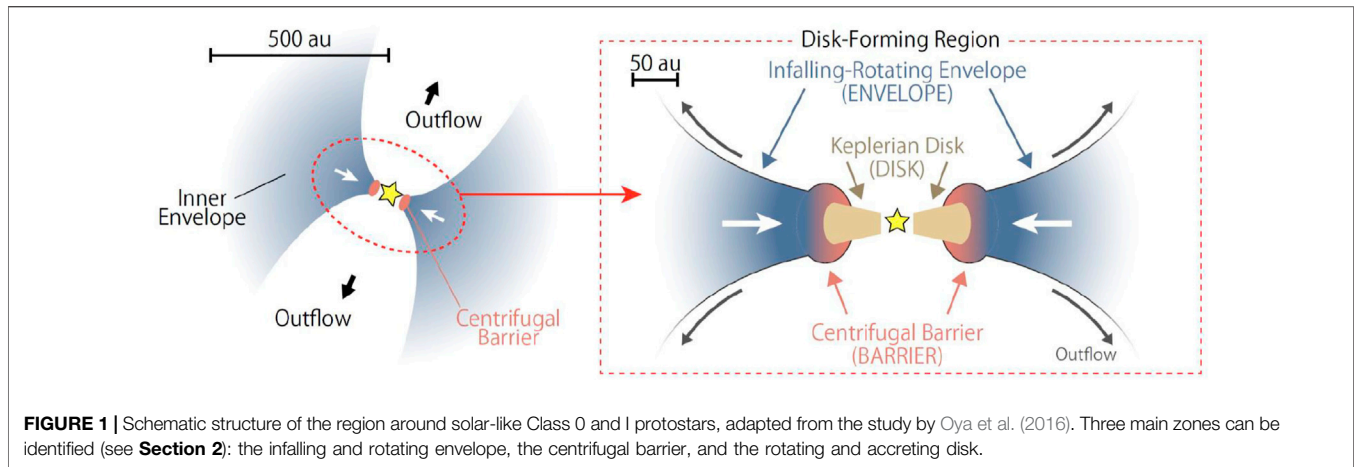
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The huge variety of planetary systems discovered in recent decades likely depends on the early history of their formation. In this contribution, we introduce the FAUST Large Program which focuses specifically on the early history of solar-like protostars and their chemical diversity at scales of ~ 50 au, where planets are expected to form. In particular, the goal of the project is to reveal and quantify the variety of chemical composition of the envelope/disk system at scales of 50 au in a sample of Class 0 and I protostars representative of the chemical diversity observed at larger scales. For each source, we propose a set of molecules able to (1) disentangle the components of the 50–2000 au envelope/disk system, (2) characterize the organic complexity in each of them, (3) probe their ionization structure, and (4) measure their molecular deuteration. The output will be a homogeneous database of thousands of images from different lines and species, i.e., an unprecedented source survey of the chemical diversity of solar-like protostars. FAUST will provide the community with a legacy dataset that will be a milestone for astrochemistry and star formation studies.

Keywords: astrochemistry, stars: formation, interstellar medium: molecules, interstellar medium: abundances, protostars

1 INTRODUCTION: THE ROOTS OF FAUST

Planets are a common product of the star formation process, and there is an incredible variety of planetary systems in the Galaxy (e.g., <http://exoplanet.eu/>), very different from the Solar System. The origin of such diversity, both in physics and chemistry, probably resides in the earliest history of the system formation, namely, what happens during the protostellar phases. The low-mass star formation is the complex process transforming a diffuse atomic cloud into, first, a dense molecular cloud and eventually into a Sun-like star surrounded by its planetary system. Meanwhile, the chemical composition of the gas involved in this process increases its complexity, from mostly atomic clouds to the so-called interstellar complex organic molecules (iCOMs), i.e., species with at least six atoms (e.g., methanol, CH₃OH), which can be considered as a brick to build pre-biotic chemistry (see e.g. Ceccarelli et al., 2007; Herbst and van Dishoeck, 2009; Caselli and Ceccarelli, 2012; Jørgensen et al., 2020, and references therein). Nowadays, evidence is mounting that the first steps of the process, namely, when the protostar is in the so-called Class 0 ($\sim 10^4$ yr) and I ($\sim 10^5$ yr) source phases (e.g., André et al., 2014, and references therein), are crucial for the future of the nascent planetary system.



More specifically, a breakthrough result has been provided by the ALMA (Atacama Large Millimeter/submillimeter Array) interferometer, which provided images of rings and gaps (see e.g., Sheehan and Eisner, 2017; Andrews et al., 2018; Fedele et al., 2018) in the dust distribution around objects with an age less than 1 Myr. This supports that planet formation starts earlier than the classical protoplanetary stage (Class II; $\sim 10^6$ yr). These findings then support the importance of investigating the chemical complexity associated with protostars younger than 1 Myr.

In a nutshell, a Sun-like protostar is accreting its mass through a disk rotating along the equatorial plane. The disk, expected with a radius less than 100 au, is perpendicular to fast ($\sim 100 \text{ km s}^{-1}$) jets removing the angular momentum excess (see e.g., Frank et al., 2014; Lee et al., 2017a). In turn, the disk is fed by a large-scale ($\geq 1,000$ au) rotating and infalling molecular envelope. The chemical composition of the envelopes surrounding solar-like Class 0 and I protostars on large scales (100–2000 au) can be very different. Two distinct classes have been discovered (1) the hot corinos (Ceccarelli et al., 2007) and the WCCC (warm carbon chain chemistry) sources (Sakai and Yamamoto, 2013). Hot corinos (as e.g., IRAS16293-2422) are compact (≥ 100 au) and dense ($\geq 10^7 \text{ cm}^{-3}$) regions, where the temperature is warm enough (≥ 100 K) to thermally evaporate the frozen dust mantles. As a consequence, the gas phase is chemically enriched in iCOMs due to either direct release from dust mantles or formed in the gas phase using simpler molecules from the mantles. On the other hand, WCCC sources (as e.g., L1527) are deprived of such iCOMs and enriched with unsaturated carbon-chain species, such as HC_{2n+1}N , C_nH , and C_nH_2 (Higuchi et al., 2018, and references therein).

In this context, breakthrough open questions are (i) whether such diversity is also present in the inner envelope/disk system (~ 50 au) and (ii) what molecules are passed from the large-scale envelope (~ 2000 au) to the disk in which planets, comets, and asteroids form. Yet, this is crucial to know because very likely the chemical composition and fate of the future planetary systems depend on the chemical class to which the original protostar belonged. The aim of this study is to introduce the ALMA (Atacama Large Millimeter/submillimeter Array) Large Program (LP) FAUST (Fifty AU Study of the chemistry in the disk/envelope system of Solar-

like protostars; <http://faust-alma.riken.jp>), focused on astrochemistry of Class 0/I sources imaged at the Solar System spatial scale.

2 THE FAUST PROJECT

2.1 Context and Main Goals

The goal of FAUST is to characterize the gas chemical composition of the protostellar system, associated with several physical components at work to build a Sun-like star from a rotating and infalling envelope. FAUST builds up on previous surveys of the chemical composition of the Sun-like youngest protostars at larger spatial scales, such as ASAI (<https://www.oan.es/asai/>), and SOLIS (<https://solis.osug.fr/>), which covered the large envelopes at ≤ 5000 au and the transition between the large-scale envelope and the circumstellar disk at ≥ 5000 au and ≤ 100 au, respectively. The FAUST approach is to identify three zones (see Figure 1), as learnt from previous ALMA studies (e.g., Sakai et al., 2014a, 2017):

- **ENVELOPE:** Here, we mean the infalling–rotating envelope on scales of a few 100 au. The gas chemical composition evolves from that at large (~ 2000 au) scales because of the heating from the central object, which sublimates the grain mantles (Ceccarelli et al., 1996). Besides, the gas close to the outflow cavity wall might also be exposed to the UV and X-ray photons from the central object or be affected by mild transverse shocks (Stäuber et al., 2005), with a consequent chemical enrichment of the gas.
- **BARRIER:** The gas transits a centrifugal barrier, on scales of about 50 au, before entering the disk. The gas chemical composition may be drastically affected by the low velocity ($\sim 1 \text{ km s}^{-1}$) shock at the centrifugal barrier as grain mantles may be at least partially liberated into the gas phase and the gas heated and compressed (Sakai et al., 2014b,a; Oya et al., 2016). As a matter of fact, the IRAS 04 386 + 2557 protostar, in the L1527 Taurus core, can be considered the archetypal edge-on disk where Sakai et al. (2014b, 2017) revealed, for the first time, an increase of SO abundance at the radius of the centrifugal barrier.

TABLE 1 | List of the frequency windows and of the species covered by the selected backends, divided in four groups (see **Section 2.2**).

| Setup | Frequency (GHz) | Zones | Molecular complexity | Gas ionization | Molecular deuteration |
|-------|----------------------------|---|---|---------------------------------|---|
| 1 | 214.0–219.0 229.0–234.0 | c-C ₃ H ₂ , CH ₃ OH, SO SiO, H ₂ CO, C ¹⁸ O | CH ₃ OH, NH ₂ CHO CH ₃ CHO, HCOOCH ₃ | DCO ⁺ | N ₂ D ⁺ , D ₂ CO |
| 2 | 242.5–247.5 257.5–262.5 | c-C ₃ H ₂ , CS CH ₃ OH, SO | CH ₃ OH, NH ₂ CHO CH ₃ CHO, HCOOCH ₃ CH ₃ OCH ₃ | H ¹³ CO ⁺ | HDCO, CH ₂ DOH |
| 3 | 85.0–89.0 97.0–101.0 | CH ₃ OH, HC ₃ N | CH ₃ OH, ¹³ CH ₃ OH | N ₂ H ⁺ | c-C ₃ HD |

Another enlightening case is represented by the HH212 pristine jet/disk system, located in Orion B. The disk, edge-on also in this case, shows iCOM-rich rotating rings, possibly associated with the centrifugal barrier with a radius of about 40 au (Lee et al., 2017b, 2019).

- **DISK:** At scales smaller than about 50 au, the gas settles in the rotationally supported disk, where the gas chemical composition is expected to be stratified (e.g., Aikawa and Herbst, 1999; Walsh et al., 2015) and affected by the dynamics and dust coagulation (e.g., Zhao et al., 2016; Ilee et al., 2017). Indeed, very recently, Podio et al., (2020) observed with ALMA the evolved Class I source IRAS 04 302 + 2247, where the bulk of the envelope has been dispersed; the molecular (CO, CS, and H₂CO) emission is vertically stratified on a scale of 50–60 au (see also van't Hoff et al., 2020). A breakthrough result would be to reveal a chemical stratification in early protostellar disks still fully embedded in the envelope. Furthermore, the observations of protostellar disks are also challenged by the presence of jets and disk winds, which are powered at similar scales (e.g., Lee et al., 2017a; Tabone et al., 2017). For a proper study of disks, it is mandatory to reveal also the fast jet flowing perpendicular to the disk equatorial plane using e.g., a standard tracer as SiO (see e.g., Codella et al., 2019). Finally, at these small scales, dust opacity increases, which strongly affects the emission spectrum from the gas (see below).

Therefore, the three zones are expected to possess distinct physical and chemical properties, likely varying from source to source and/or depending on the star-forming regions. The goal of FAUST is to disentangle the three zones with the help of their kinematic signatures and ALMA line images at 50 au spatial resolution. Our pioneering studies showing the proof of concept have already been conducted for a few sources and a few molecules (e.g., Ceccarelli et al., 2010; Oya et al., 2016; Codella et al., 2017): time is now ripe for a systematic study of many more sources and many more species, *via* an ALMA LP. In summary, the aim of FAUST is to reveal and quantify the variety of the chemical composition of the envelope/disk system of solar-like Class 0 and I protostars. Such chemical varieties will add a new dimension to the diversity of planetary systems, and we expect that it will have a substantial impact on studies of planet formation and the origin of the Solar System.

2.2 Sources and Molecular Lines

From a kinematical point of view, the envelope/disk system can be divided into three different zones. Although they could, in principle, be studied kinematically by observing CO and its isotopologue lines, but as a matter of fact, only rarer species provide a much more powerful diagnostic tool because they are differentially enhanced in the three zones, thanks to chemical composition changes (e.g., Sakai et al., 2014b, 2017; Oya et al., 2016). FAUST will simultaneously use kinematics and chemistry to fully resolve the complexity of the envelope/disk system. Four groups of species have been selected to probe different topics:

1. **ZONE PROBES:** c-C₃H₂, CS, CH₃OH, SO, SiO, H₂CO, C¹⁸O, and HC₃N. We select the following species to disentangle each zone: Envelope: c-C₃H₂ and CS. These species are present in the infalling–rotating envelope, with different abundances for different sources, but their abundance significantly drops in the other two zones so that they are specific in probing the ENVELOPE zone in different sources. Barrier: CH₃OH, SO, and SiO. Their abundance is enhanced in the weak shocks at the centrifugal barrier. Narrow (~ 1 km s⁻¹) SiO lines could trace the release of Si from dust mantles (Guillet et al., 2011; Lesaffre et al., 2013) at the centrifugal barrier, whereas broad (≥ 10 km s⁻¹) SiO emission is expected to trace fast jets (associated with high-velocity shocks) perpendicular to the disk. Disk: H₂CO, C¹⁸O, and HC₃N. Given their relatively large abundance in the warm layers of the disks, lines from these species can probe the inner disk, *via* their high-velocity components.
2. **MOLECULAR COMPLEXITY PROBES:** CH₃OH, NH₂CHO, CH₃CHO, CH₃OCH₃, and HCOOCH₃. A major goal of FAUST is measuring the organic complexity in the disk/envelope system as it might be inherited at later stages by the nascent planetary system (Zhao et al., 2016). Based on previous studies, five species are particularly important to identify the organic diversity: methanol (CH₃OH), formamide (NH₂CHO), acetaldehyde (CH₃CHO), dimethyl ether (CH₃OCH₃), and methyl formate (HCOOCH₃). They are predicted to have a different chemical origin, with methanol a grain-surface product and formamide likely a gas-phase product (Codella et al., 2017; Skouteris et al.,

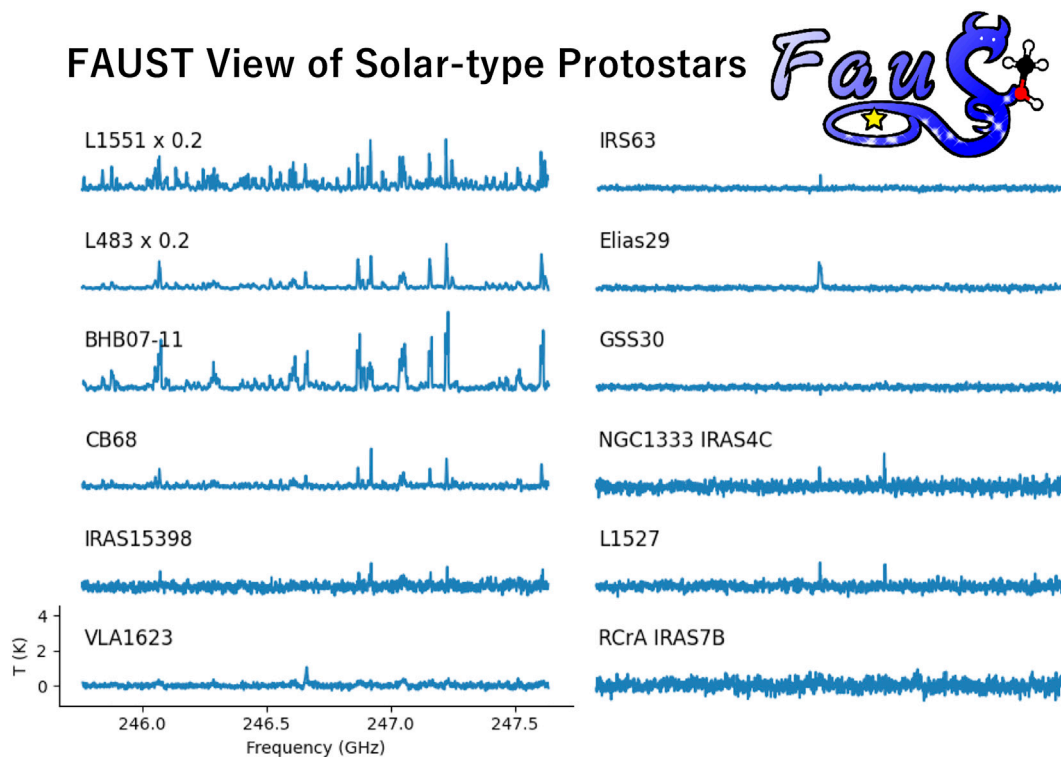


FIGURE 2 | Zoo of preliminary spectra observed towards FAUST sources (see black labels) in a portion of 2 GHz (245.7–247.7 GHz) of the frequency Setup2 (See **Table 1**). The FAUST logo is also reported. The intensity scale is in brightness temperature (K). The spectra have been obtained merging ACA data with those at high-spatial resolution. The identification of the lines is out of the focus of the present study. The goal of the sketch is to enlighten the observed chemical differentiation, with some sources characterized by a rich spectra associated with iCOM emission.

2017), while for acetaldehyde, dimethyl ether, and methyl formate, the chemical synthesis route is largely debated (e.g., Garrod et al., 2008; Balucani et al., 2015).

3. **GAS IONIZATION PROBES:** H^{13}CO^+ , DCO^+ , and N_2H^+ . The degree of ionization in the inner 100 au envelope is a very important parameter for any theory of planet formation (e.g., Balbus and Hawley, 1998). Yet, this quantity is very poorly known at these scales. Several processes can affect it, from an inner source of energetic particles and/or X-rays (Stäuber et al., 2005) to the growth of dust grains (Zhao et al., 2016). Here, we propose to use molecular ions, following a previously used methodology, to estimate the gas ionization, such as the $\text{H}^{13}\text{CO}^+/\text{DCO}^+$ and $\text{H}^{13}\text{CO}^+/\text{N}_2\text{H}^+$ abundance ratios. The first ratio measures the ionization in cold (smaller than ~ 30 K) and dense ($\geq 10^4 \text{ cm}^{-3}$) gas (e.g., Caselli et al., 2008), while the second one in warm (≥ 40 K) and, again, quite dense (up to $\sim 10^7 \text{ cm}^{-3}$) gas (e.g., Ceccarelli et al., 2014b).
4. **DEUTERIUM-BEARING SPECIES:** $c\text{-C}_3\text{HD}$, N_2D^+ , HDCO , D_2CO , and CH_2DOH D-bearing species are powerful diagnostic tools to study the physical conditions at present and in the past (Ceccarelli et al., 2014a). Specifically, species like $c\text{-C}_3\text{H}_2$ (one of the infalling–rotating envelope probe) and N_2D^+ are present-day products, whereas H_2CO and CH_3OH ,

being major components of the grain mantles, were mostly formed during the pre-stellar phase and introduced in the present-day gas by the presence of the accreting inner object. The respective deuterated counterparts provide, therefore, a precious tool to understand the physical conditions when these species are/were deuterated. In addition, molecular deuteration provides a sort of Ariadne’s thread that links the ISM to the Solar System history (Ceccarelli et al., 2014a).

We selected a representative sample of sources that is known to exhibit a wide chemical composition diversity, based on the available large-scale observations. The following two criteria have been adopted: (1) Chemical diversity: Since, so far, the major chemical diversity is represented by WCCC and hot corino sources, we select sources that represent a continuous variation of the abundance ratio of species characteristics of these two classes. Specifically, (i) CH_3OH can be regarded as a proxy of the hot corino species because it is a crucial organic molecule, considered a parent species of larger iCOMs; (ii) small hydrocarbons such as C_2H or $c\text{-C}_3\text{H}_2$ are characteristics of WCCC sources. The selected sources are, therefore, associated with measured abundance ratios of these species varying by two orders of magnitude, covering the two extremes of hot corino and WCCC sources (Higuchi et al., 2018). (2) Distance and previously

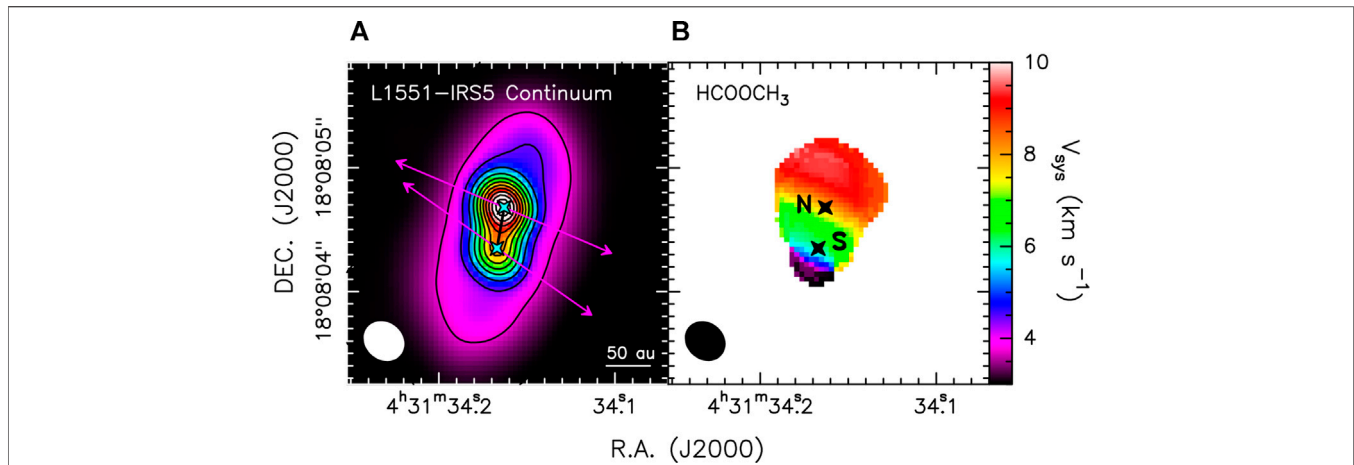


FIGURE 3 | L1551 IRS5 binary source, in Taurus. **(A)**: 1.3 mm dust continuum emission in color scale and black contours (Bianchi et al., 2020): the N and S protostars are revealed. **(B)**: Gas enriched in iCOMs around the IRS5 binary system, imaged on the 50 au scale. More specifically, the intensity-weighted velocity (also called moment 1) map of the $\text{HCOOCH}_3(18_{4,14}-17_{4,13})\text{A}$ is shown, revealing a velocity gradient perpendicular to the axes of the protostellar jets (see the arrows in the **(A)**) driven by N and S. The systemic velocities are $+4.5 \text{ km s}^{-1}$ (S object) and $+7.5 \text{ km s}^{-1}$ (N). The chemical enrichment occurs in rotating hot corinos around the protostars and/or in the rotating circumbinary disk.

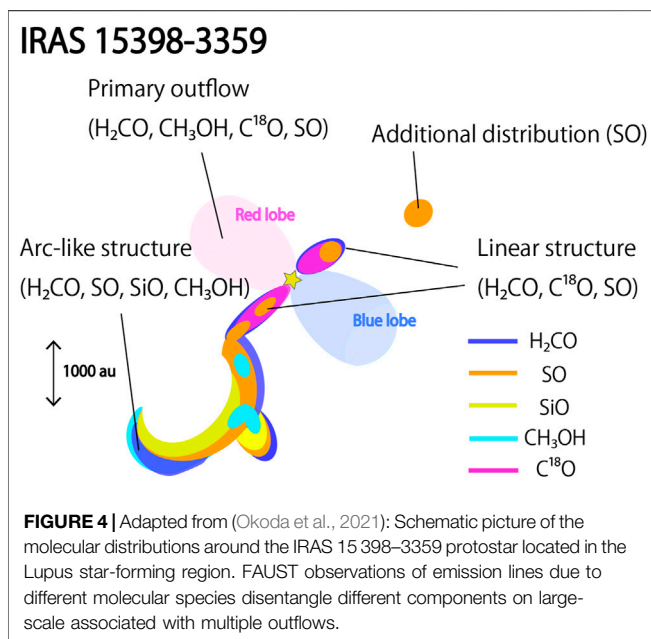


FIGURE 4 | Adapted from (Okoda et al., 2021): Schematic picture of the molecular distributions around the IRAS 15398-3359 protostar located in the Lupus star-forming region. FAUST observations of emission lines due to different molecular species disentangle different components on large-scale associated with multiple outflows.

studied sources: We select nearby Class 0 and I sources with distance $\leq 250 \text{ pc}$ and a bolometric luminosity $\leq 25 L_{\odot}$.

The final list contains 13 sources located in different star-forming regions: L1527 and L1551 IRS5 (the Taurus region), IRAS 15398-3359 (Lupus), L483 (Aquila), Elias 29, VLA1623A, IRS63, and GSS30 (Ophiucus), NGC1333 IRAS4A, and IRAS4C (Perseus), BHB07-11 (Pipe), RCrA IRS17A (Cr A), and CB68 (the isolated source). We will observe the three frequency settings in **Table 1**. They target lines from the four groups of molecules described above. We require a uniform linear resolution of 50 au

to identify the centrifugal barrier and to disentangle the disk from the envelope, namely, an angular resolution of 250–350 mas, depending on the distance of the source, and almost uniform brightness sensitivity. The high-angular scale of 50 au will be reached using the 12-m antenna ALMA array in different configurations. Furthermore, given the goal to also sample the molecular envelope, Atacama Compact Array (ACA/Morita Array) observations of 7-m antennas will be also performed. By combining all the visibility data obtained using both the 12-m and the 7-m antenna array, FAUST will be able to follow the physical and chemical changes from the large-scale envelope ($\sim 2000 \text{ au}$) to the inner disk/jet system. For each frequency setting, we allocate one continuum setting to measure the dust spectral energy distribution (SED) from 3 to 1 mm. The frequency resolution is set to 0.2 km s^{-1} , i.e., the sound speed at 10 K.

2.3 Data Exploitation

We will use a two-step modeling procedure to extract the information from the data, as follows: (1) Kinematics and radiative transfer models: The three zones are disentangled by comparing the velocity structure observed in the various molecular lines with kinematic models (Oya et al., 2016). The gas temperature and density structure, as well as the species column density, will be extracted from a multiline non-LTE (when possible) analysis using 1 and 3D codes (Bisbas et al., 2015; Zhao et al., 2016), taking into account the dust optical depth. The analysis of the continuum will provide the distribution of the H_2 column density. (2) Astrochemical models: The derived molecular abundances will be compared with our astrochemical models (Ceccarelli et al., 2018; Wiström and Charnley, 2018), where the physical structure will be incorporated. From this analysis, we will extract valuable constraints on the reactions involved in the formation and destruction of the observed iCOMs. FAUST members with specific expertise will contribute to the project with laboratory experiments and

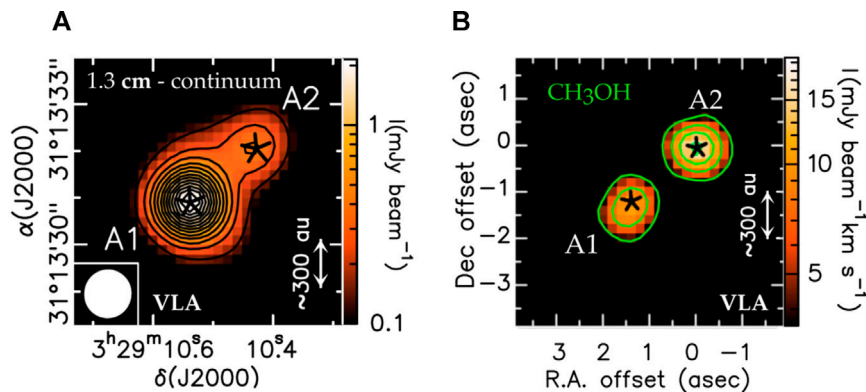


FIGURE 5 | (A): NGC1333 IRAS 4A continuum emission map at 25 GHz as imaged using VLA (Adapted from De Simone et al. (2020)). Two protostars A1 and A2 are observed. **(B):** CH₃OH(6_{2,4}-6_{1,5}) velocity-integrated maps in the color scale, revealing for the first time the hot-corino associated with A1, missed by sub-millimeter surveys due to dust opacity effects.

theoretical quantum chemistry calculations (Watanabe et al., 2010; Dulieu et al., 2013; Skouteris et al., 2017). In summary, we will determine (i) the extent to which the large-scale envelope diversity is conserved in the disk/envelope system and (ii) what molecules are passed from the large-scale envelope to the disk. In this way, the goal of the FAUST project will, therefore, be achieved.

3 FIRST FAUST RESULTS AND PERSPECTIVES

The analysis of the FAUST data is in progress. However, some instructive results have been already obtained. The data were reduced by using a modified version of the ALMA calibration pipeline and an additional in-house calibration routine (Okoda et al., 2021) to correct the system temperature and spectral line data normalization. Figure 2 reports an example of the zoo of FAUST spectra observed in a portion of the frequency Setup 2 (see Table 1) toward the protostellar coordinates. The spectra have been obtained merging ACA data with those at high-spatial resolution. The line identification and the discussion of the chemical content are out of focus of the present study; the goal of the spectra sketched in Figure 2 is to enlight a chemical differentiation, indicating the source sample is not biased by some selection criterium. More precisely, four (query) sources (L1551, L483, CB68, BHB07-11, and CB68) are characterized by iCOM emission, revealing hot corino activity. The next step is a careful investigation of weaker lines and the inspection of the images obtained using each array configuration, in order to provide a complete characterization of the molecular complexity in each source.

An example of what FAUST is able to provide when studying the inner 50 au around protostars is reported by Bianchi et al. (2020), who imaged the Class I L1551-IRS5 binary system in several species, namely, methanol (including ¹³CH₃OH and CH₂DOH), methyl formate (HCOOCH₃), and ethanol

(CH₃CH₂OH). Figure 3A shows the dust continuum 1.3 mm emission revealing the binary components, namely, the N (northern) and S (southern) objects. The two sources are surrounded by a circumbinary disk, clearly traced by Cruz-Sáenz de Miera et al. (2019). The 50 au resolution reveals an iCOM-rich hot corino toward the N component (see the HCOOCH₃ map in Figure 3B) and, in addition, a possible second hot corino around the S object. The number of hot corinos imaged around Class I sources is, so far, limited to a handful number (e.g., De Simone et al., 2017; Yang et al., 2021). The discovery of iCOM emission in L1551-IRS5 is, thus, instructive in the effort of tracking how the chemical richness around Class 0 objects is inherited by later Class I protostars: as a matter of fact, it looks that chemistry does not dramatically change. Projects on this topic based on statistically reliable samples will be hopefully performed soon. Figure 3B shows the map of the velocity peak of the HCOOCH₃(18_{4,14}-17_{4,13}A) line profile. A clear velocity gradient is revealed perpendicular to the axes of the protostellar jets (see the arrows in the Left panel) driven by N and S. In conclusion, the chemical enrichment occurs in rotating hot corinos around the protostars and/or in the rotating circumbinary disk.

Moving to larger spatial scales (from 50 au to 1800 au), FAUST recently published a review of the molecular emission in the Class 0 IRAS15398-3359 star-forming region in Lupus (Okoda et al., 2021). The FAUST multi-species approach (CO, C¹⁸O, SO, H₂CO, CH₃OH, and SiO) allows Okoda et al. (2021) to well trace the dense and/or shocked material around the protostellar object. Besides the already known main outflow located along the NE-SW direction, a narrow (~ 1 km s⁻¹) line emission of shock tracers such as SiO and CH₃OH reveals (i) a secondary outflow with an axis normal to the main flow, and (ii) an arc-like structure related with the secondary outflow (see the schematic picture in Figure 4). Which is the origin of the secondary outflow? Are the outflows driven by different protostars? As a matter of fact, there is no evidence (neither in the FAUST continuum maps) of a companion (neither of the Class 0 IRAS15398-3359 protostar. An alternative solution proposed by Okoda et al. (2021) is that the

secondary outflow is a relic of a past reorientation of the outflow launched from a single protostar and that the arc-like structure has dissipated the turbulence of the old shocked material. In principle, a dramatic change in the direction of the outflow axis could be possible if the molecular core hosting the protostar is associated with a non-uniform internal angular momentum, transferred onto the central region *via* episodic accretion.

Finally, the FAUST synergy is at work also to prepare complementary observations to those collected with the ALMA Large Program. More specifically, we started pilot projects in the cm-spectral window using the very large array (VLA) interferometer. Given the dust opacity at cm-wavelengths is negligible (e.g., Testi et al., 2014, and references therein), the main goal is to evaluate the effects of dust emission on Solar System scales, associated with both high volume and column densities (e.g., Miotello et al., 2014; Galván-Madrid et al., 2018; Galametz et al., 2019) on the collected iCOM images (and derived abundances) at (sub-) mm-wavelengths. An instructive example is provided by De Simone et al. (2020), who imaged at 1.3 cm at VLA in the FAUST context, the NGC1333-IRAS4A binary system. One of the two components 4A1 lacks iCOM emission when observed at millimeter wavelengths (see **Figure 5**), while the other component 4A2 is very rich in iCOMs. De Simone et al. (2020) found that, once imaged at 1.3 cm, methanol lines are similarly bright toward 4A1 and 4A2, proving that both are hot corinos and not only 4A2. Complementing the ALMA observations with centimeter images can be then considered the future step which the FAUST synergy will perform. The VLA-ALMA combination will allow us to perform steps ahead in the study of the protostellar environments and to understand the ultimate molecular complexity in regions with a high column density of the material and consequently high dust opacity.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Materials, further inquiries can be directed to the corresponding author.

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