UNVEILING ALMA BAND 2

Workshop, Bologna (Italy),
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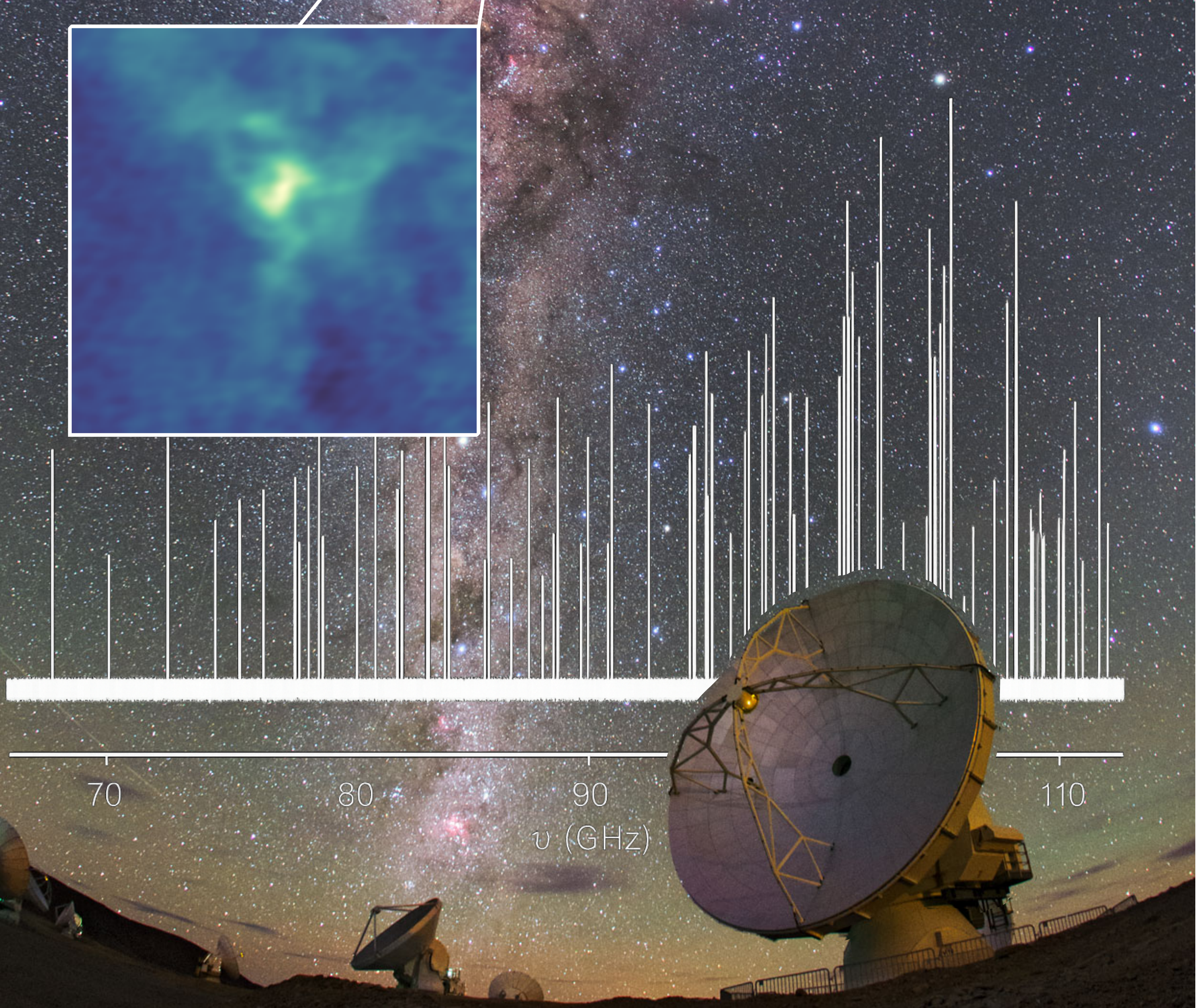
Abstract booklet



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1. Tuesday, February 24$^{\text{th}}$

Overview of ALMA Band 2 (invited)

Neil Phillips
ESO

The unboxing of the band 2 receivers (invited)

Fabrizio Villa
INAF OAS Bologna

The Band 2 is the first ALMA receiver fully compatible with the ALMA Wideband Sensitivity Upgrade (WSU). In this talk, we take a closer look inside the receiver, illustrating its internal architecture, the key components, and the choices made by the Band 2 collaboration. We describe the design and implementation strategies that enable state-of-the-art performance in terms of noise temperature and bandwidth, making the ALMA Band 2 the most advanced receiver to date.

Testing and characterization of Low-Noise Amplifier Chains for ALMA Band 2

Anna Elisa Camisasca
University of Bologna

The ALMA Band 2 project aims to extend the capabilities of the Atacama Large Millimeter/submillimeter Array (ALMA) to the 67–116 GHz frequency range, improving both sensitivity and spectral coverage for the study of low-excitation astrophysical phenomena and key molecular lines. A critical component of the receiver is the low-noise amplification chain, which has a strong impact on the overall system performance. Following a long development process, European industries, in collaboration with ESO, have developed innovative cryogenic Low-Noise Amplifiers that can be coupled to meet the strong ALMA Band 2 requirements. The coupling and testing of these components is done under ESO responsibility in collaboration with the ECOGAL ERC Synergy project.

This talk presents the methods used for testing, calibration, and characterization of the amplifier chains developed for Band 2, with particular emphasis on measurements of noise temperature, gain, and compression with different source temperatures. Practical aspects of prototype integration and comparison are also discussed, as well as strategies adopted to ensure performance reproducibility and stability in compliance with ALMA requirements. The experimental results contribute to defining the final receiver chain design for the Band 2 production phase.

ALMA band 2 as a powerful redshift machine (invited)

Carlos De Breuck
ESO

ALMA has been used to determine redshifts of sub/mm selected sources since Cycle 0. These projects make use of the regular spacing of the CO lines, which redshifts into the Band 2 frequency range where those sources are most frequent. Up to now, only the 84-116 GHz range could be covered with Band 3 in a rather inefficient setup of 5 spectral tunings. Band 2 will provide two very significant improvements: (1) the extended frequency range from 67 to 116 GHz will allow to remove more ambiguous redshifts, and (2) the 2-18 GHz with flexible placement of the spectral windows provides contiguous frequency coverage, even before the WSU. This combination will turn ALMA Band 2 into a powerful redshift machine, (partially) taking over the role where optical spectroscopy had a monopoly for more than half a century.

ALMA Band 2: A New Window to the Core of High-Redshift Radio-Quiet Quasars

Abhijeet Pramod Borkar
Astronomical Institute of the Czech Academy of Sciences

Active galactic nuclei (AGNs) emit across the electromagnetic spectrum, with their radio and X-ray properties extensively studied. However, our understanding of the nuclear submillimeter (submm) continuum emission—particularly in radio-quiet AGNs—remains limited due to past constraints in angular resolution and sensitivity. The nature of this submm emission and its link to the coronal X-ray emission is a key unresolved question. Recent works suggest that the submm continuum could arise from the same population of electrons responsible for the X-ray production.

To fully test this hypothesis and constrain the underlying physics, it is crucial to study this correlation not just in nearby sources, but also its evolution at high redshift. Probing the rest-frame 100 GHz (230 GHz) emission in sources beyond $z \approx 0.2$ ($z \approx 1.7$)

requires moving beyond the standard ALMA Band 3. The newly available ALMA Band 2 offers the deep sensitivity and frequency coverage necessary to detect submm emission from a large sample of radio-quiet sources at high redshift.

In this presentation, I will detail our analysis of the submillimeter-to-X-ray correlation using a sample of SDSS-selected quasars. I will discuss the current limitations inherent in existing datasets and highlight how targeted observations utilizing ALMA Band 2 will provide a transformative leap forward, enabling us to trace the co-evolution of accretion disk-corona system.

Probing the Sizes of AGN Coronae with ALMA-B2

Santiago del Palacio
Chalmers University of Technology

Recent advances in millimetre observations have opened new windows into the study of active galactic nuclei (AGN). In particular, self-consistent spectral energy distribution models suggest that the mm emission originates from the compact, hot corona. However, strong degeneracies remain in the inferred coronal size, mainly due to the lack of high-resolution observations below 85 GHz. We show that ALMA Band 2 observations will be crucial to breaking these degeneracies and constraining key coronal properties — including size, non-thermal electron fraction, and magnetic field strength. The wide frequency coverage of Band 2 will also enable efficient monitoring of short-term variability, allowing us to trace the dynamical evolution of the corona on timescales of days.

Probing the Regulation of Star Formation at Cosmic Noon with ALMA Band 2 (invited)

Annagrazia Puglisi
University of Southampton

Star formation is regulated by the interplay between gas accretion, its conversion into stars, and feedback. These processes were at their most efficient at $z \sim 1$–3, when galaxies rapidly assembled their stellar mass and central black holes. Recent JWST observations have highlighted the structural diversity of star-forming galaxies at these epochs, underscoring the need for spatially resolved studies of the interstellar medium to understand how gas is redistributed, how star formation is regulated, and how bulges, spiral arms, and bars emerge and evolve.

A major limitation in current studies is sensitivity, particularly at high spatial resolution. Mapping molecular gas and dust in typical star-forming galaxies requires long integration times, which at the $\simeq$0.1" resolutions needed to connect the interstellar medium to the structures revealed by JWST can extend to several tens of hours even in the brightest systems. As a result, current samples are biased toward the most massive and actively star-forming galaxies and toward inner, highly excited regions, leaving more typical star-forming galaxies and diffuse, low-surface-brightness components largely unexplored.

In this talk, I will review the current observational limitations and discuss how the enhanced sensitivity of the new ALMA Band 2 receivers enables efficient, spatially resolved observations of low-excitation, low-surface-brightness molecular gas and dust continuum at cosmic noon, opening new opportunities to investigate the physical mechanisms regulating star formation, structure build-up, and gas redistribution during the peak epoch of galaxy growth.

Free-jet rotational spectra of urea analogues: laboratory data for future ALMA Band 2 searches (poster)

Filippo Baroncelli
University of Bologna

Urea (NH_2CONH_2) is a molecule of high astrobiological relevance due to its central biological role on Earth, where it participates in nitrogen metabolism and contributes to peptide stabilization. Its detection in the interstellar medium (ISM) is therefore significant for understanding how prebiotic molecules can form and persist in space. According to the CDMS, urea has been detected towards the high-mass star-forming region Sgr B2(N) using the Atacama Large Millimeter/submillimeter Array (ALMA) (Belloche et al. A&A 628 (2019) A10) and towards the quiescent giant molecular cloud G+0.693-0.027 using IRAM-30m single dish (Jiménez-Serra et al. Astrobiology 20 (2020) 1048). These discoveries demonstrate that complex nitrogen-oxygen compounds can form under a wide range of interstellar conditions, supporting the idea that some biologically relevant species may already exist before planets are formed.

Building on these findings, we investigated the rotational spectra of two urea derivatives, N-methylurea and N,N-dimethylurea, which could also be present in the ISM. High-resolution measurements were conducted under supersonic expansion conditions across the 2-8 GHz and 60-74 GHz frequency regions revealed complex features arising from the internal rotation of methyl groups, particularly pronounced in N,N-dimethylurea, leading to intricate hyperfine structures. Detailed characterization and assignment of these patterns are crucial for generating accurate spectral predictions, thereby facilitating future astronomical searches. The data presented here provide a precise and comprehensive reference within the frequency coverage of the new ALMA Band 2 receivers, offering a valuable resource for the potential detection of these molecules in the ISM.

A radio-submm continuum investigation of dust-obscured nuclei in local IR-bright galaxies (poster)

Yiqing Song
ESO-Chile/MPIfR

Local gas-rich galaxy mergers provide the ideal nearby laboratories for investigating the co-evolution between supermassive blackholes and their host galaxies during a key phase of rapid transformation. High-resolution interferometric observations of the radio/sub-mm continuum offer an excellent extinction-free tool for investigating the nature of the compact dust-obscured nuclei in these systems. Here I present results from a multi-frequency radio continuum survey with the Very Large Array at 3, 15 and 33 GHz of 68 local IR-luminous mergers from the Great Observatories All-sky LIRG Survey, which has uncovered prevalent compact nuclear star-forming clumps on 100pc-scale that are forming stars more than 10 times faster compared to regions in nearby normal star-forming galaxies. Some nuclei exhibit extreme radio luminosity surface densities at 33 GHz that exceed the model prediction for star formation, suggesting contributions from growing SMBHs (i.e. AGN). These nuclear regions also have a wide range of radio spectral indices measured between 15 - 33 GHz, potentially reflecting diverse dominant mechanisms related to extreme star formation and/or hidden AGN (e.g., thermal free-free, synchrotron emission, anomalous microwave emission, self-absorbed synchrotron emission). A pilot study of seven nuclei from the sample is currently underway with ALMA Cycle 12 observations to construct the 15 - 800 GHz SED for identifying the dominant mechanisms powering their radio/sub-mm emission, supplemented by archival observations of the molecular gas at matched spatial scales. The most powerful constraints will come from future long-baseline Band 2 observations at 67 - 116 GHz that probe the critical regime where these various forms of plasma and dust emission intersect. Combined with multi-phase diagnostics of the circumnuclear ISM from JWST, these ALMA observations will shed new light on the interplay between nuclear starburst and SMBH growth in dusty gas-rich environments.

Radio Astronomy in Madagascar with MeerKAT/SKA and ALMA Synergy (poster)

Solohery Randriamampandry
University of Antananarivo

This poster presents recent developments in radio astronomy at the University of Antananarivo (UoA-Astro) Madagascar, with a focus on galaxy evolution and cosmology. Our research combines observational data, theoretical modeling, and numerical simulations to study galaxies and large-scale structures across cosmic time. We highlight results from MeerKAT and SKA precursor surveys, and explore how these complement upcoming ALMA Band 2 capabilities, particularly in probing cold gas and star formation in dense environments.

We also discuss UoA-Astro's growing role in African astronomy, including capacity-building efforts, student training, and international collaborations. These initiatives aim to strengthen regional expertise in radio interferometry and prepare for the SKA era, while fostering synergies with ALMA science in the 67–116 GHz range.

Probing the Physical Conditions of Cold Molecular Gas with ALMA Band 2

Francesco Salvestrini
INAF - Astronomical Observatory of Trieste

Millimetre observations are essential for tracing the cold molecular gas that fuels both star formation and supermassive black hole (SMBH) accretion throughout cosmic history. Full frequency coverage across 40–230 GHz is critical to continuously sample key cold-gas tracers—particularly the low-J CO transitions—from the nearby Universe to the peak epoch of galaxy and SMBH growth.

The new ALMA Band 2 (67–116 GHz) will open an unexplored window to continuously probe low-J CO emission in galaxies up to the end of the Cosmic Noon. This is crucial to track any evolution of the physical mechanisms regulating the cold-gas cycle. Furthermore, by analyzing the excitation of the CO spectral line energy distribution (CO SLED), we can disentangle the relative contributions of photon-dominated regions (PDRs) and X-ray–dominated regions (XDRs) in galaxies hosting active SMBHs, providing new insight into the impact of SMBH feedback on the interstellar medium.

In this context, I will present results from a physically motivated model, galaxySLED (Esposito et al. 2024), which reproduces the CO SLEDs of active and inactive galaxies across different cosmic epochs. I will show how the inclusion of low-J CO transitions significantly improves our ability to disentangle the roles of SMBH accretion and star formation, and to obtain more accurate estimates of CO-to-H2 conversion factors.

Molecular deep field observations with ALMA band 2

Roberto Decarli
INAF OAS Bologna

The cosmic history of star formation shows a slow increase from early ages up to cosmic noon (redshift z=1-3), followed by a decline by about an order of magnitude down to present age. Understanding what drives such an evolution is a key problem in galaxy evolution studies. Molecular scans, i.e., sensitive interferometric observations at mm-wavelengths of extragalactic fields, provide us with an effective way to sample the amount of molecular gas stored in galaxies in different cosmic epochs. ALMA band 2 provides an extraordinary opportunity to push molecular gas observations: We can now target the low-J CO transitions in key redshift ranges (e.g., CO(2-1) all the way up to z=2.44). Leveraging on the full band 2+3 coverage provides a virtually continuous CO redshift coverage at any z (with only a gap at z=0.75-1.0), and coverage of two or more CO transitions in a wide range of redshifts, thus alleviating any uncertainty in the line identification. In the light of the forthcoming WSU upgrade, the advent of band 2 at ALMA is going to mark a transformational leap forward (both in survey speed and effectiveness: multi-line and redshift coverage) toward a quantitative assessment of the role of molecular gas reservoirs in shaping the cosmic history of star formation.

Binary nature of supernovae type Ic revealed by molecular gas observations

Michał Michałowski
Adam Mickiewicz University

Supernova (SN) explosions are important for galaxy evolution because they enrich the interstellar medium with heavy elements and provide feedback which can halt further star formation. These effects depend on what stellar progenitors explode as a given SN type. Type Ic SNe (without hydrogen or helium lines in their spectra) can be explosions of either 10 solar mass stars in binary systems or very massive (>30 Msun) stars. These models involve very different lifetimes of the SN progenitors, so predict very different states of molecular gas around the explosion. Exploiting this, I will show that millimetre carbon monoxide observations of galaxies hosting SNe provide evidence for the binary model of type Ic SNe. This is an important distinction from the point of view of stellar evolution as well as galaxy's future star formation. This finding can be implemented in sub-grid prescriptions in numerical cosmological simulations to improve the feedback and chemical mixing. I will discuss how ALMA band 2 observations can enable further research in this direction including more distant supernovae.

2. Wednesday, February 25th

Science opportunities for studies of nearby galaxies using the new ALMA Band 2 receiver (invited)

Eva Schinnerer
MPIA

ALMA Band 2 perspective in the observation of starforming galaxies

Rosita Paladino
ESO - INAF IRA

ALMA Band 2 will provide useful tools to study star formation in the local Universe. It will extend the observations of tracers such CO(1-0) and HCN(1-0) to star-forming galaxies at intermediate redshifts. Furthermore, it will open access to a frequency range where no interferometric capabilities currently exist. Within this band, the fundamental transitions of molecules such as DCN, DCO^+, and N_2D^+ become observable. These species are particularly valuable probes in very dense star-forming regions, where CO is expected to be depleted onto dust grains, a nd deuterated molecules dominate the chemistry. Theoretical studies predict that such species should be detectable in a variety of extragalactic star-forming environments. With its exceptional sensitivity, angular resolution, and unprecedented observing speed, ALMA will provide the first opportunity to detect and spatially resolve these transitions in nearby galaxies.

Extragalactic carbon chemistry in external galaxies

Mathilde Bouvier
Leiden Observatory, Leiden University

Carbon-chain molecules are abundant in the interstellar medium and represent ~40% of all detected species. In addition, carbon chain molecules play a major role in the formation of more complex chemistry and could be linked to polycyclic aromatic hydrocarbons (PAHs; e.g. Allamandola et al. 1989, Guzman-Ramirez et al. 2011, Guzman et al. 2014), key elements of the evolution of the ISM and of star-formation in galaxies. While in our galaxy, carbon chain molecules (including cyanopolyynes; e.g. C4H, HC3N, HC5N, c-C3H2) are routinely observed in a wide range of various environments (from dark clouds to star-forming regions and comets), their detection in external galaxies is more challenging due the large distances involved. Carbon chain molecules have been detected in a few extragalactic sources (e.g. NGC 253, NGC 4418, Arp 220, NGC 1068, PKS 1830-211; Costagliola & Aalto 2010, Martin et al. 2011, Muller et al. 2011, Costagliola et al. 2015, Martin et al. 2021) but their study remains very limited. The upcoming Band 2 covering the frequency range between 67 and 116 GHz, in synergy with Band 1 (35 - 50 GHz), will be ideal to study carbon chains as their peak of emission lies across these two bands. The arrival of band 2 will thus initiate a new era in the study of carbon chemistry in external galaxies.

Studying feedback in galaxies with ALMA Band 2 (invited)

Claudia Cicone
Institute of Theoretical Astrophysics, University of Oslo

Feedback processes supposedly play a crucial role in regulating star formation across cosmic times and in preventing galaxies from overgrowing, yet observational constraints on these mechanisms remain elusive. Galactic outflows are multi-phase, including molecular gas, atomic gas, ionised gas, and dust. The cold molecular gas component of such outflows, which is uniquely quantifiable using mm and sub-mm observations, appears to carry a significant fraction of their mass. Even though several new tracers are being explored, low-J CO transitions are still the most reliable lines to measure the outflow mass loading factors and momentum rates. The latter are necessary constraints for theoretical models. The new ALMA Band 2 receiver, providing simultaneous coverage of the 67 GHz to 116 GHz bands, offers a unique opportunity to measure the mass of molecular outflows for the first time in a consistent and homogeneous way up to z 2.4, hence from the local Universe to Cosmic noon. In synergy with ALMA Band 1, the CO(1-0) & CO(2-1) coverage extends up to z=5.5. Crucially, at these low frequencies, thanks to the larger synthesised beam size and field of view, ALMA provides its best performance in terms of brightness sensitivity to extended structures, which is essential for mapping molecular outflows that can extend by tens of kpc, potentially up to the edge of the circumgalactic medium. At the same time, the much higher spatial resolution compared to other interferometers covering the same frequencies allow us to spatially resolve the outflows on kpc scales and so better disentangle them from the disk. In addition, the new ALMA Band 2, thanks to its great flexibility in spectral setup, will enable simultaneous observations of multiple high density tracers in the outflows of galaxies well beyond the local Universe. High density tracers such as HCN and CN have shown in a few local galaxies a puzzling enhancement in the outflow compared to the disk, which points to either a peculiar outflow chemistry or to an unexpected abundance of very high density gas entrained in high-velocity winds.

Carbonaceous chemistry with ALMA Band 2 (invited)

José Cernicharo
IFF-CSIC

In this talk I will present the possible studies that could be carried out with ALMA using the new band 2 receivers in the context of the study of carbon chemistry in space. In this context, I will analyse the results obtained in the last years using broad-band spectroscopy in the 30-50 GHz domain. I will focus on the results related to the starless cold core TMC-1 and the C-rich evolved star IRC+10216. Band 2 will permit a comparative systematic study of the chemistry in both type of objects. In particular, the detection of small PAHs in TMC-1, and the non-detection of the same molecules in IRC+10216 where they were expected to be present, is a challenge for astrochemistry. To solve the problem of where and how PAHs are formed, sensitive observations at all frequencies are required. Low frequencies are very well adapted to the search and study of large molecules, while high frequencies are extremely adequate to the study of very small species. However, medium size carbon-chain molecules will have their emission peak in band 2. A complete census of the molecular content (stable species, radicals, anions and cations) in these objects is needed to progress in our understanding of carbon-chemistry in interstellar and circumstellar clouds.

Is there a dry gap? Looking for the 67.8 GHz water maser

Anita Richards
JBO, University of Manchester

Water masers are uniquely suited to exploring the physical conditions (temperature, number density, water abundance etc.) in circumstellar envelopes, on scales an order of magnitude finer than is possible using thermal molecular lines. This is thanks to about 100 predicted lines (Gray+ 2016), (about 25 detected), sampling energy states from 200 to over 6000 K, occurring in regions from the stellar radio atmosphere out to many hundreds R* (Baudry+ 2023). This reveals a mixture of conditions due to clumping in winds, asymmetric mass loss etc. At high resolution, maser beaming characteristics provide a diagnostic for shocks, also highlighting protostellar jets and cloud collisions in star forming regions.

The largest fractional frequency gap between detected water masers is from 22 to 96 GHz, which could be filled by the 67.8 GHz line. Its energy levels ($\sim$2620 K) are close to those of the known 262 and 658 GHz masers, but it is predicted to be excited at high number densities over a wider temperature range. The inner few R*, where the dust-driven wind is initiated, are pulsation-dominated. The morphology of shock-excited masers may show additional, discrete ejecta (Humphreys R. et al. 2024). A few previous 67.8 GHz observations give a tentative upper limit of a few Jy in a small sample. Full ALMA will reach orders of magnitude greater sensitivity, but the main limitation is likely to be the need for self-calibration, at about 0.5 Jy (still requiring brightness temperatures high enough to confirm masing).

We will explore the potential of 67.8 GHz masers (and multi-line projects) for understanding turbulent, uneven processes and shocks in mass loss from evolved stars and in star-forming regions, and discuss the practicalities and technique development involved in exploring challenging spectral regions.

Exploring the mid-IR properties of single high-mass YSOs

Carlotta Sanna
Univerisà degli Studi di Cagliari, INAF-OAC

Although massive stars play a crucial role in the evolution of their host galaxies, the processes that lead to their formation remain not completely understood. One of the biggest uncertainties arises from the lack of a solid diagnostic tool to classify massive young stellar objects (MYSOs) according to their evolutionary stage. The commonly used indicator, the bolometric luminosity-to-envelope mass ratio (L/M), is based on a theoretical scheme inherited from low-mass star formation models and is limited by extreme extinction and by mid-infrared observations that typically probe entire proto-clusters rather than individual sources.

My PhD project explores a new approach to probe the mid-IR properties of single MYSOs within proto-clusters indirectly using roto-vibrationally excited lines at millimeter wavelengths. These transitions are pumped exclusively by the mid-infrared radiation of single MYSOs, so their intensities closely reflect the local mid-IR conditions. I present ALMA Band 7 observations of methanol roto-vibrationally excited lines in a sample of massive proto-clusters at different evolutionary stages. Preliminary analysis shows that the line intensities are not only sensitive but strongly dependent on the mid-IR radiation of MYSOs, suggesting that they can be a promising diagnostic of MYSO luminosities at specific mid-IR wavelengths.

Since methanol transitions cover a broad spectral range accessible with ALMA, it is essential to extend this approach to ALMA Band 2, where many of these transitions occur. The synergy with ALMA capabilities opens new opportunities to explore the potential of roto-vibrational lines as diagnostic tools for probing the mid-IR radiation field of single MYSOs, while simultaneously testing the reliability and scalability of the proposed method.

Disappearing cores and early fragmentation in massive clumps: insights from synthetic ALMA Band 2 observations

Alice Nucara
INAF-IAPS

ALMA surveys have shown that fragmentation in massive clumps is a complex, multi-scale process (Vázquez-Semadeni+19, Liu+23, Traficante+23, Yang+23, Coletta+25). Unexpectedly, ALMAGAL Band 6 continuum observations have also revealed the presence of a population of "disappearing cores" (Mininni+ in prep.), i.e. cores detected at 5000AU scales that lack a counterpart at 2000AU scales. At the same time, with the Rosetta Stone project we have post-processed Band 6 continuum maps from numerical simulations (Lebreuilly+25) to investigate fragmentation at 5000AU and below (Nucara+25, Nucara+ in prep.), and to follow how the number and properties of cores evolve with clump evolution. In these synthetic observations, particularly in the earliest stages, we have identified 5000AU cores that do not match with the position of sink particles and are either collapsing or transient. We have also identified sink particles without a corresponding core, pointing to a scenario of complex early fragmentation. In this framework, observations in Band 2 will be crucial: by detecting deuterated species tracing the young star-formation phases, they will allow us to distinguish whether disappearing cores will form stars or are simply transient structures. Building on this, we are now developing synthetic ALMA Band 2 observations based on advanced simulations including tracer particles and chemical networks (Lebreuilly+ in prep., Mininni+ in prep.). We will test whether pristine gas reservoirs are detectable in deuterated species, in contrast to transients and to cores already associated with one or multiple sink particles. Eventually, this work will demonstrate how Band 2 molecular-line observations (both synthetic and real) will play a key role in understanding the star-formation process, linking chemistry and early fragmentation in massive star-forming regions.

Tracing the impact of the environment on the continuous process of fragmentation with ALMA Band 2

Chiara Mininni
INAF-IAPS

The advent of ALMA has opened a new era in various fields of astrophysics thanks to its unprecedented resolution and sensitivity in the millimetric and sub-millimetric domain. In the field of star-formation it has allowed study down to the resolution of protoplanetary disks, and the ability to carry out large statistical survey at the scale of cores, such as ASHES, ALMA-IMF, and ALMAGAL, that would have not been feasible in reasonable time with other facilities. From the results of two of the largest surveys performed in the last years, ALMA-IMF and ALMAGAL, it is clear that the fragmentation of a clump to form cores is not an event that happen once at a specific point in time, but the number of cores in a clump keeps increasing with the evolution (Coletta et al.2025), with evolved regions still showing a population of pre-stellar cores (Nony et al.2023). Moreover, also after the formation of an UC HII regions and subsequent HII region expansion, a new wave of star formation could be triggered as predicted by models, and observed in different studies (e.g. Liu et al.2015, Mininni et al. in prep).

The ALMA Band 2 will open a new window to study further these processes. The frequency range of new Band 2 encompass the emission of the (1-0) transitions of deuterated species such as DCO^+ and N_2D^+, together with HCO^+ and N_2H^+ (and isotopologues). Moreover, it will allow to observe lower J transitions of cyanopolyynes, HC3N, HC5N, and HC7N, that have been found to be good chemical clock at later stages for cores. The presence of all these species will allow a proper identification of the age of the different cores in a clump, sorting them from the more pristine to the more evolved, with a better detection rate than higher J transitions at higher frequencies. Moreover, we will be able to derive the physical properties of the cores. This will open a new window to precisely investigate the impact of the evolution of the region on the continuous waves of new formed cores.

Deuterium chemistry in the ISM, and how ALMA Band 2 will enhance our knowledge of it (invited)

Olli Sipilä
Max-Planck-Institute for Extraterrestrial Physics

Deuterated molecules are precious tracers of physical conditions in the interstellar medium, especially in cold and dense clouds where the freeze-out of CO onto dust grain surfaces boosts the reactivity of the trihydrogen cation H3+ (normally destroyed by CO) with HD, initiating efficient deuteration. Furthermore, deuterated molecules formed in cold clouds, especially on the surfaces of grains, can survive into the protostellar stage; by observing deuteration in clouds and disks, one can obtain information on the inheritance of material across the star formation process.

In this talk, I will review our current state of knowledge regarding deuterium chemistry in clouds and disks, from the point of view of observations as well as theoretical models. In particular, I will connect the current status of our knowledge of deuterium chemistry to those molecules and transitions that will be observable with ALMA Band 2, anticipating the kind of improvements we may expect from observations carried out in Band 2 in comparison to what is currently achievable using other telescopes.

Broadband observations at 3mm: The Power of Astrochemistry to study the role of the environment on star- and disk-formation

Jaime Pineda
Max-Planck-Institut für Extraterrestrische Physik

The star- and disk-formation process results from the complex interplay between gravity, turbulence, and magnetic fields. While gravity drives collapse, turbulence and magnetic fields act to counter it. High-angular-resolution interferometric observations have revealed much about disk properties, yet the influence of the environment—the surrounding cloud, filaments, and magnetic field structure—on disk formation and evolution remains poorly understood.

I present NOEMA 3 mm observations obtained with the PolyFix correlator, which provides a 16 GHz instantaneous bandwidth. This allows simultaneous measurement of continuum and multiple molecular lines, enabling us to probe both disk kinematics and the large-scale environment. These data offer a comprehensive view of the link between the small-scale disk and its parental cloud, highlighting the importance of environmental feedback on disk evolution.

This work also serves as a pathfinder for studies with the upcoming ALMA Band 2 (67–116 GHz). The frequency overlap between NOEMA and ALMA Band 2 will allow direct comparison and combination of datasets, providing access to low-J transitions of key molecules (e.g., CO, HCN, HCO+, DCO+) and cold dust continuum emission. The broader primary beam and enhanced sensitivity of ALMA Band 2 will enable mapping of extended structures while maintaining sub-arcsecond resolution in the densest regions.

By connecting NOEMA's 3 mm capabilities with the forthcoming ALMA Band 2, we demonstrate how multi-instrument synergy will advance our understanding of how disks assemble within their natal environments—from cloud to core to disk—under realistic physical conditions.

Laboratory Spectroscopy for the Detection of Complex Organic Molecules with ALMA Band 2

Mattia Melosso
University of Bologna

The forthcoming availability of ALMA Band 2 opens a unique window for astrochemical exploration, particularly in the study of complex organic molecules (COMs) in the interstellar medium. This frequency range bridges a crucial gap between existing observational windows, encompassing numerous low-energy rotational transitions that are essential for accurate molecular identification and excitation analysis. However, the full scientific potential of ALMA Band 2 can only be realized through the support of high-precision laboratory rotational spectroscopy.

In this contribution, we emphasize the crucial role of laboratory spectroscopy in providing the rest frequencies, transition strengths, and partition functions necessary to interpret astronomical spectra. The accurate characterization of molecular spectra in the 67-116 GHz range is vital to disentangle line confusion and improve our comprehension of interstellar chemistry. We present recent advances in laboratory measurements of astrophysically relevant species and discuss how these data integrate with ALMA Band 2 capabilities to enhance line identification and modeling efforts.

By combining laboratory precision with ALMA's unprecedented sensitivity and spatial resolution, Band 2 will enable the detection of new molecular species, trace chemical evolution across diverse environments, and refine our understanding of the molecular complexity emerging in the interstellar medium.

ALMA Observations of G351.77: Probing Outflow–Filament Alignment in a Star-Forming Ridge

Silvia Leurini
INAF-OACa

In this talk, I will present recent ALMA band 3 observations of the ridge G351.77 in the shock tracer SiO. The data reveal a population of outflows from low-mass young stellar objects spread all along the filamentary cloud. G351.77 is an ideal target for investigating whether evolution and feedback from star formation influence the relative orientation of outflows with respect to the axis of the hosting filament since it hosts different evolutionary phases. Our data reveal that the orientation of the outflows in respect to the filament orientation is well represented by a mixed population with a majority of perpendicular outflows and 10%–20% of parallel outflows. Indeed, our study seems to suggest that the most quiescent region is where outflows are predominantly perpendicular to filament while in more active regions dynamic interactions may have dissipated this alignment. We will also discuss the impact of the new ALMA band 2 receiver for studies of filamentary clouds, since its much broader bandwidth will allow simultaneous observations of tracers of both dense gas and shocks for a more complete view of the hosting filament.

Feedback from Supernova Remnants in Molecular Clouds: How Shocks May Trigger Star Formation

Giuliana Cosentino
IRAM ARC Node

Supernova remnants (SNRs) drive large-scale shocks that enhance the density of the surrounding Interstellar Medium (ISM) . They also inject vast amounts of energy and momentum that perturb and disperse the ISM. The interplay between these effects may be paramount in regulating star formation in molecular clouds. However, how molecular clouds physical and chemical properties are affected by SNR-driven shocks is not well constrained observationally. In this talk, I will present our work aimed to address this questions. I will present our study of the large scale shock triggered by the SNR W44 on the molecular cloud G034.77-00.55. I will show how the shock, probed by Silicon Monoxide (SiO) and observed with ALMA, enhances the density of the processed gas to values compatible with those required by massive star formation. As revealed by N_2H^+(1-0) ALMA observations, at the shock interface, the dense, post-shocked material is organised into core-like structures that have mass, density, size and viral state similar to those reported for cold cores in other star-forming regions. Furthermore, the post-shocked gas exhibits high levels of deuterium fractionation (up to 0.1) measured from N_2H^+ and N_2D^+ single-pointing observations, and comparable to those typically measured in starless and pre-stellar cores. Follow-up NOEMA maps of the N_2H^+ and N_2D^+(1-0) emission across the shock front confirm the presence of these cores in both tracers and their high-level of deuteration. Our work therefore indicates that, at least locally, SNR-driven shocks may play a role in the regulating star formation in molecular cloud. Moreover, the N_2D^+(1-0) frequency of $\sim$77 GHz will soon be offered by ALMA in Band 2. Hence, the NOEMA maps in hand offer a unique window into the scientific outcome expected in the ALMA Band 2 era.

3. Thursday, February 26th

Unveiling prebiotic molecules in the interstellar medium with ALMA Band 2 (invited)

Víctor M. Rivilla
Centro de Astrobiología, CAB, CSIC-INTA

The emergence of prebiotic molecules in molecules clouds and star-forming regions is a crucial step in understanding the chemical origins of life. ALMA Band 2 (67–116 GHz) offers a uniquely powerful frequency range for investigating this topic, providing an optimal balance of line intensities, reduced line blending and lower dust opacity, which hinders the detection of more complex species at higher frequencies. In this talk, I will present recent results on the analysis of prebiotic molecules using ALMA observations, focusing on the key role of Band 2 in detecting new molecular species and constraining their formation pathways. I will discuss how Band 2 observations will enable reliable molecular identification, accurate determination of column densities, and improved insight into the available chemical inventory at the earliest stages of star formation. Finally, I will discuss the prospects for the future of the Band 2 Wide Sensitivity Upgrade (WSU) in furthering our understanding of astrochemical complexity and the formation of prebiotic molecules in space.

Novel mapping of complex molecules toward low-mass stellar nurseries with ALMA

Samantha Scibelli
NRAO

Nearby ($<$ 400pc) molecular clouds contain starless and dynamically collapsing prestellar cores that are the fundamental singular "units" of low-mass (M $<$ a few Msun) star and planet formation. Within the past decade, single-dish sub-millimeter observations have revealed the prevalence of "complex" molecules, defined here as those known to be precursors to biologically relevant species here on Earth, toward a large number of cold ($\sim$10 K) starless and prestellar cores, challenging our understanding of their gas-phase chemical pathways and formation mechanisms. Unfortunately, it is still largely unknown the spatial distribution of complex molecules toward these cores to high sensitivity because of the large amount of time it would take large single-dish telescopes to map these lines, due to poor atmospheric opacity and low efficiency in moving large single-dish telescopes. Still, obtaining the radial dependence of complex molecules is crucial for comparing to chemical models that put quantitative constraints on the processes regulating organic chemistry in this earliest stage of star formation. In this talk, I will showcase preliminary maps from three new ALMA Band 1 Cycle 11 and 12 programs that targeted complex molecules towards three different starless and prestellar cores located in three different molecular clouds. I highlight that only ALMA Band 1, and the upcoming Band 2 upgrade, can uniquely map "bright lines" (that is, low energy transitions) of complex molecules at the appropriate spatial resolution (5-10 arcsec) in a reasonable amount of time toward nearby starless and prestellar cores.

2'-Hydroxyacetophenone: Lab data and ALMA archive screening

Assimo Maris
University of Bologna

According to the Cologne Database for Molecular Spectroscopy, as of September 2025, thirteen benzene derivatives have been detected toward TMC-1 from the QUIJOTE and GOTHAM line surveys, using the 40m-Yebes and 100m-GBT dishes observations, respectively. These species include benzene molecules with side chains, such as benzonitrile and ethynylbenzene, as well as polycyclic aromatic hydrocarbons (PAHs) like indene and phenalene. Additionally, PAHs functionalized with cyano groups, which enhance their dipole moments, have been detected: 2-cyanoindene; 1- and 2-cyanonaphtalene; 1- and 5-cyanoacenaphtalene; 1-, 2- and 4-cyanopyrene and cyanocoronene. Besides aromatic species, several organic molecules bearing two oxygenated functional groups have been observed in different sources using both single dish and array radiotelescopes: 3-hydroxypropenal, hydroxypropanone, methoxymethanol, methoxyethanol, methyl acetate, ethyl formate, and ethylene glycol.

We present the laboratory spectroscopic data for a new candidate molecule for interstellar detection: 2′-hydroxyacetophenone, a benzene compound featuring two oxygenated substituents, the hydroxyl and acetyl groups. Due to the strong hydrogen bond between the OH and the CO, the molecule predominantly exists in a single conformer at room temperature, characterized by a relatively high electric dipole moment along the b-axis (≈3 D), making it a promising target for radioastronomical searches. We provide spectral predictions up to ALMA Band 4 based on experimental measurements and discuss preliminary results from a screening of the ALMA Science Archive limited to datasets with CARTA (Cube Analysis and Rendering Tool for Astronomy) coverage, aimed at identifying potential signatures of 2′-hydroxyacetophenone in the interstellar medium. Its detection would help clarify the role of oxygenated aromatics in prebiotic chemistry.

Dust evolution and planet formation in disks: the potential of ALMA Band 2 (invited)

Greta Guidi
IPAG Grenoble

In the past decade ALMA has revolutionised our view on protoplanetary disks. Its exquisite sensitivity and angular resolution unveiled a large diversity of structures in the dust and gas distribution, such as concentric rings, spirals, lopsided patterns. Multiple mechanisms have been invoked to explain these features, such as vortices forming after the development of dynamical instabilities, presence of embedded planets, chemical effects at the locations of snowlines. More recently, the possibility to detect kinematic perturbations induced by protoplanets, and even to trace the material accumulating in their circumplanetary disks, has opened a new window in planet formation studies.

Recovering the mass of young disks through ALMA Band 2 continuum: mock-surveys of Class0/I YSOs from 1mm to 7mm

Gabriele Columba
UniBo - DIFA

Constraining the mass budget of young stellar objects (YSOs) from mm-continuum observations, typically in Band 6 or 7, has proven to be challenging, especially for Class 0/I disks, which are still embedded within their envelopes. We explored the potential of using mm-wavelengths (1, 3, and 7mm, i.e. ALMA Bands 1, 2, and 7) to overcome the dust optical thickness and recover reliable YSO disk masses, using detailed numerical simulations of disk formation as ground truth. The sample of synthetic targets, generated from magneto-hydrodynamic simulations, was post-processed with radiative transfer (using the RADMC-3D package). Then, we simulated ALMA observations with CASA and analysed them as if they were real observational data, fitting commonly adopted models for both disks and envelopes.

We finally compared the results of this analysis with the ground truths to assess our ability to use observations to derive the YSOs physical parameters.

In this talk I will demonstrate that, contrary to Band 7, Band 2 is the ideal frequency band to derive accurate disk bulk parameters (radii and, especially, masses), and show how to actually recover the disk mass. Moreover, I will discuss the differences between results in Band 1, 2 and 7, and the key caveats that can significantly affect the inferred YSO properties. Our results can be used to design ALMA Band 2 surveys aimed at obtaining accurate estimates of young disk properties, which are essential to constrain the initial conditions for planet formation.

THE SEARCH FOR CHEMICAL COMPLEXITY IN PROTOPLANETARY DISKS: ALMA Wideband Preview of HL Tauri

Davide Napolitano
INAF IRA

In preparation for the WSU, ALMA has acquired, with R. Loomis as P.I., a large demonstration dataset: 32 separate observations of the HL Tau disk in Band 3, with high angular (0".15) and spectral (0.18 km/s) resolution. This dataset is meant to be representative of a single observation with ALMA Band 2 once the WSU is fully implemented. It was acquired to test the data handling capabilities required for the typical WSU dataset, and to demonstrate the potential for the instantaneous scientific content of a dataset. This work is limited by the demonstrative nature of the dataset, not ideal to study the thermal line emission in disks: the surface brightness sensitivity is too low to detect the less abundant molecules, and the long baselines used imply a filtering of the large spatial scales traced by the most abundant species. Nevertheless, we demonstrate that the WSU datasets can be effectively used to derive intraband continuum spectral indices with snapshot observations. After the WSU, such derivation will be possible with a single observation. We also provide an inventory of molecular line absorption from the envelope of HL Tau, and we use the detection of a low excitation SO line to place constraints on the temperature and abundance of the shocked gas at the interface between accretion streamer and disk, confirming the assumptions of Garufi et al. (2022) regarding the origin of SO as mechanically desorbed by slow accretion shocks. As for the efforts for ever more complete detection of COMs in disks, we note that the high angular resolution of this preview dataset is not compatible with the sensitivity required for the detection of weak COM lines. With the WSU and Band 2, a large-bandwidth observation of HL Tau can be repeated with higher sensitivity, likely to surpass the limitations of this work and give a more complete survey of the chemical budget of HL Tau. Still, compromises on the angular resolution might still be necessary for the detection of COMs.

ALMA Band 2 and the initial condition for planet formation

Leonardo Testi
Università di Bologna

ALMA has transformed the field of protoplanetary disks and planet formation by discovering substructures in disks around pre-main sequence stars and obtaining for the first time population measuments of their bulk properties, like mass, size and molecular gas content. Yet one of the key discovery that all this has enabled is that these are most likely planet-hosting, rather than proto-planetary disks. In recent years the focus has shifted progressively towards the study of younger protostellar disks and their formation, in order to unveil the initial conditions and the first steps of planet formation. Within the ECOGAL project, one of our main goals has always been to derive the importance of f the physical conditions during the cloud collapse to determine the initial conditions of planet formation. Three key ingredients, based on numerical simulations, are the level of magnetization and the effect on the collapse, the evolution of the dust properties from envelopes to disks and the mass loading of the disk. All these can be probed at millimeter wavelengths, but only combining polarization, long wavelength and high sensitivity observations at scales from the envelope scale ($\sim$1000AU) to the disk scale ($\sim$10AU). For this purpose we contributed to the development of the polarization capabilities of NOEMA, leading to the Anygma Large Programme, and the contribution to the ALMA Band 2, leading to the first ever ALMA Guaranteed Time Project. In this talk, I will review the results of Enygma, tracing the 3mm polarization, dust properties and the kinematics of the gas from 1000AU to 100AU scale. I will show the evidence of the connection between inner envelope kinematics and magnetic field, and how we can trace the dust properties. I will also present the plans for the ALMA Band 2 GTO programme to link the inner envelope to the disk scale and provide direct constraint on the initial conditions for planet formation.

The dust that assembles the youngest protoplanetary disks

Luca Cacciapuoti
European Southern Observatory

The importance of the early stages of star and planet formation is becoming more and more evident thanks to efforts such as the recent ALMA programs "FAUST" and "eDisk", in which the properties of the youngest protostellar systems are investigated in detail. During these phases, an infalling envelope shapes up into a keplerian disk at the innermost scales due to conservation of angular momentum.

The dust properties of such envelopes have been at the centre of a debate that has not yet found answer: "are dust grains growing in protostellar envelopes to pebble sizes?" (Kwon et al. 2009, Miotello et al. 2014, Galametz et al. 2019). The main difficulties to answer such a question come from the lower sensitivity, the limited bandwidth, and the inability to trace simultaneously small and large scales of ALMA's predecessors. I will present the latest multi-scale, multi-wavelength approaches to measure dust emission spectral indices across the envelopes of Class

0/I young stellar objects, and show its results when applied to the ALMA "FAUST" Large Program (Cacciapuoti et al., 2023, 2025).

Two remaining limitations of these studies are the still: (i) a debated role of optical depth in the inner envelopes, which could bias spectral indices to low values, then mistaken for a sign of grain growth; and (ii) the inaccurate knowledge of the contribution from free-free emission at long wavelengths, which contaminates the studied dust thermal emission. The large fractional bandwidth of ALMA Band 2 will allow precise (2x better than Band 3) intra-band measurements of spectral indices at long wavelengths, much needed to solve the optical depth uncertainty, and can be combined with ALMA Band 1 and VLA to smoothly model the SED with both dust properties and contaminating free-free emission.

Inside the gap: star-wind disk or dust emission within transitional disks' cavities

Mélanie Armante
INAF-OOA

Among the variety of structures that can be observed within disks, some present an inner cavity depleted from gas and dust. Such disks are called transitional disks (TDs). Cavities, are generally attributed to the formation and evolution of giant planet(s) severing the connection between the outer and inner disks, which is then rapidly depleted by accretion onto the star. At the same time, these planets are modifying the disk gas pressure profile leading to the creation of a pressure trap and, consequently, a ring-like structure in the dust distribution. This scenario implies that the planets inside the ring greatly stops the exchange of pebbles between the outer and the inner part of the disk, and that the only material that can be accreted is the one passing through the planet(s), resulting in a low stellar mass accretion for stars in TDs. In these conditions, in this cavity no significant dust emission at (sub-)millimeter wavelengths should be observed. On the contrary, a compact millimeter emission is observed for about 50% of TDs by ALMA, as it is the case for the TD surrounding CQ Tau, a nearby, intermediate mass pre-main sequence star. As of today, it is not clear if such compact emission is due to the presence of pebbles or whether it is due to non-thermal emission related, e.g., an ionized wind. To quantify this possibility, we performed a detailed multi-wavelength analysis to study the emission in CQ Tau's inner disk, combining a large set of sensitive and high angular resolution continuum observations from ALMA and VLA, from 0.87 mm to 6 cm. We present the results of a detailed spectral index analysis to extrapolate the free-free emission present and then separate between this emission and dust thermal one. Especially, we present unexpected results for which higher angular resolution ALMA observations at higher wavelength could greatly help with the interpretation. Finally, we present first attempts to extend these results to a broader sample of TDs.

Unveiling the ENYGMA of magnetic braking in protostars: a study on the inner envelope kinematics in Class 0/I YSOs

Alessandro Soave
Università di Bologna

During the earliest evolutionary stage of a Young Stellar Object (Class 0 YSO), when the protostar is still deeply embedded in its natal envelope, magnetic fields play a key role in removing angular momentum from the infalling gas through magnetic braking — a resistive process where field lines counteract the torsional motion of the collapsing, rotating envelope. Thus, magnetic braking has been proposed as a solution to the "angular momentum problem": if all the angular momentum were conserved, the protostar would be disrupted by centrifugal forces. However, simulations show that overly efficient magnetic braking, unless mitigated by non-ideal MHD effects or field–rotation misalignment, can suppress the formation of even small ($<$10 au) disks.

ENYGMA, a NOEMA large program surveying 50 Class 0/I YSOs at 3 mm in full polarization mode, offers a unique opportunity to jointly characterize the envelope kinematics and the magnetic field properties across a statistically significant sample. I will present our first kinematic analysis using the C17O (J=1–0) transition, an excellent tracer of the dense gaseous inner envelope between 100 and 300 au, where magnetic braking is expected to be strongest due to the pinched field lines. Velocity maps derived via hyperfine structure fitting reveal a diverse variety of velocity gradients, which we compare with the magnetic field topology from the polarization maps. For most sources, a velocity gradient perpendicular to the outflow, likely tracing envelope rotation, is found. By constructing position–velocity diagrams along these gradients, I could derive specific angular momentum profiles down to <1000 au and compare them with the magnetic field strength and the polarization fraction. Finally, I will outline our plans to follow up key ENYGMA targets with ALMA Band 2 Guaranteed Time Observations to probe the transition from envelope (100–300 au) to disk scales (10–30 au).

Postprocessing of numerical simulations: from RAMSES to polarization maps for ALMA Band 2

Sacha Gavino
Università di Bologna

The polarization state in star forming regions is partly shaped by dust grain properties. The observation of the magnetic field in these regions can therefore directly provide precious hints on the grain properties and evolution during star and planet formation. We will present a new postprocessing pipeline that aims to bridge star formation simulations to dust properties. Starting from RAMSES simulation outputs, we perform radiative transfer postprocessing to generate synthetic maps of polarized dust emission, that can later be compared to observations. This framework allows us to explore how different dust grain properties—such as size distribution and composition—affect the polarization state and, consequently, the magnetic field morphology.

This work is carried out in the context of ENYGMA, a NOEMA large program within ECOGAL, which aims to map at 3mm magnetic fields and characterize dust properties in $\sim$50 Class 0 protostars. By interpreting the observed magnetic fields in light of our synthetic polarization maps, we can constrain the role of dust evolution in shaping magnetic structures during the early phases of star formation.

Finally, I will discuss how the upcoming ALMA Band 2 can contribute to provide a critical missing link between dust growth and magnetic field tracing. Its sensitivity to larger grains will offer new insights into the transition from dense cores to planet formation.

Images in the Abstract book are, in order of appearance the following. Page of Contents: Bologna, strada Maggiore. Tuesday: the cold cartidge assembly in the ALMA Cryostat taken from `https://zenodo.org/records/13681547`, and elaborated by Fabrizio Villa. Wednesday: ALMA antennas, photo credit Iztok Bončina/ALMA (ESO/NAOJ/NRAO) .Thursday: ALMA antennas, photo credit ESO/José Francisco Salgado.

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