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Book of Abstracts

Unifying Galactic and Extragalactic Views of Star Formation
Spectroscopic Studies & Data Science

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Z

Application of scattering transforms to the separation of ISM phases

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Abstract

Scattering transform statistics have enabled recent breakthroughs in modeling and separating complex physical processes. Inspired by neural networks yet requiring no training, these statistics provide a robust framework for quantitative analysis and modelling of complex non-Gaussian processes, even with limited data. In this talk, I will introduce these models and demonstrate their potential as building blocs for solving inverse problems and component separation. I will highlight their application to diverse datasets from the interstellar medium (ISM), showcasing their efficiency and versatility.

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*Speaker

Understanding the dynamical state of star-forming filaments through magnetic field morphology: First results from the B-FUN project with NIKA2-POL

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Abstract

Far-infrared and submillimeter imaging with Herschel and Planck have revolutionized our understanding of the link between the structure of the cold ISM and the star formation process, supporting a paradigm in which magnetized filaments play a central role. The dynamical state of molecular filaments and the detailed role of magnetic fields in the formation and fragmentation of filamentary structures remain poorly understood, however. Many star-forming filaments have thermally supercritical masses per unit length and this poses a problem since such filaments would naively be expected to undergo rapid radial contraction with time. Investigating how thermally supercritical filaments can maintain a typical inner width _˜ 0.1 pc and fragment into prestellar cores instead of collapsing radially to spindles is crucial to understanding star formation. In an effort to shed some light on this issue, I will present new 1.2mm dust continuum polarization observations obtained with NIKA2-Pol on the IRAM 30m telescope as part of the B-FUN large program on filaments. Based on initial results from B-FUN, I will discuss how a combination of magnetic support and accretion-driven turbulence may allow thermally supercritical filaments to form stars.

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Gas-phase Elemental abundances in Molecular CloudS (GEMS): Understanding the diversity of starless cores.

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Abstract

Gas chemistry has a key role in the star formation process by determining aspects such as the gas cooling and the ionization degree. Molecular filaments can fragment to prestellar cores to a large extent because molecules cool the gas, thus diminishing the thermal support relative to self-gravity. The ionization fraction controls the coupling of magnetic fields with the gas, driving the dissipation of turbulence and angular momentum transfer, and therefore, it plays a crucial role in the cloud collapse (isolated vs. clustered star formation) and the dynamics of accretion discs. In the absence of other ionization agents (X-rays, UV photons, J-type shocks), the ionization fraction is proportional to the square of the cosmic-ray ionization rate for molecular hydrogen, which becomes the key parameter in the dynamical and chemical cloud evolution. In addition, there is increasing evidence that the chemical composition of the parent cloud is to a large extent preserved during the star formation process, and some complex molecules detected in protoplanetary disks might be formed in the prestellar core phase. Addressing the chemistry of starless cores is therefore of paramount importance to understand both the dynamical and chemical evolution of the matter during the formation of stars and planets.
Starless cores have been a priority target of astrochemical studies over the past decade, during which deep molecular surveys have been carried out toward a limited number of objects. Among them, the starless core TMC-1 (CP) has emerged as the archetype of cold core chemistry, with hundreds of molecular species detected. However, until recently there has been a lack of sufficiently complete chemical survey, covering a large enough number of species to constrain physical and chemical parameters, across a statistically significant sample of starless cores spanning different environments and physical conditions. This limitation has hindered the development of a more general picture of the prestellar phase of star formation.

The IRAM 30 m Large Program Gas-phase Elemental Abundances in Molecular Clouds observed 31 starless cores in more than 15 molecular species and their isotopologues. In this work, we focus primarily on the carbon chemistry revealed by this survey, while also examining its implications for the sulfur and oxygen budgets through molecular abundance ratios. Our results reveal significant variations in the carbon budget among starless cores in Taurus, Perseus, and Orion, challenging the notion of a single chemical prototype for starless

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cores. Instead, these differences point to a diversity of initial conditions that may ultimately influence the chemical and physical evolution of forming stars and planetary systems.

Several tools are being developed to interpret the large chemical abundances database derived from the GEMS project. In particular, we have developed a neural emulator of the chemical code Nautilus to make a thorough exploration of the parameter space feasible. We used this emulator to identify the combinations of species that most effectively constrain key parameters such as gas density, temperature, and elemental depletion through a bayesian network analyses. This approach demonstrates that selected molecular abundance ratios, including those involving sulfur and oxygen, provide powerful probes of the starless cores with different uncertainties depending on the specific parameter.

Bayesian modeling of the multiphase ISM of a star-forming region in the LMC

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Abstract

The Large Magellanic Cloud (LMC) provides a unique laboratory to understand the interaction between the interstellar medium (ISM) and massive star formation, in a galaxy with a low metallicity, a milestone to understand interstellar media at an earlier evolutionary stage than the Milky Way. The LMC's proximity to our Galaxy permits observation of its dusty and gaseous infrared emission at a parsec-scale resolution, thereby enabling study of interstellar properties at the scale of a molecular cloud. The SOFIA Legacy Program (LMC+) (1) has observed the (CII) λ158 μm and (OIII) λ88 μm lines in the southern molecular ridge at a resolution of 2.5 pc. These new observations provide access to the dominant cooling lines in the neutral and ionised ISM, enabling investigation of the major heating and cooling mechanisms in the three massive star-forming regions, N158, N159 and N160. In neutral regions, the main mechanism responsible for the gas heating is the photoelectric effect. This process consists in the ejection of an electron from a dust grain after the absorption of a UV photon.

The objective of this work is to combine data acquired by the SAGE (2) survey with Spitzer (3.6 to 70 microns), the HERITAGE (3) survey with Herschel (100 to 250 microns), and new data from SOFIA, with the aim of creating maps of dust properties and constraining the efficiency of the photoelectric heating of the gas in this region. To that end, we have homogenized our multi-wavelength maps to an optimal, common resolution and pixel grid. We took particular care in the estimate of the non-Gaussianity of our uncertainties and their correlations. The spatially-resolved spectral energy distribution of each pixel was then fitted with the hierarchical Bayesian code, HerBIE (4), using the THEMIS dust model (5,6). Two original aspects are presented in our work. The first one is that the modeling we perform allows us to compare the efficiency of the photoelectric heating to the actual mass of its carriers, and not only to their luminosity. The second one, is that, using ancillary data, we provide a phase decomposition of the (CII) luminosity. Doing so, the efficiency we estimate is less biased by the (CII) linked to other heating mechanism. Our results confirm that the photoelectric heating is dominated by the smallest grains. In addition, the overall efficiency of the heating appears reduced, because of the lower abundance of these grains, relative to

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[*]Speaker

the gas, in the LMC. These results therefore provide an empirical prescription to account for gas heating at early evolutionary stages of the interstellar medium. I will conclude the talk by discussing the challenges of running a hierarchical Bayesian code over such a large data set, and what this method
brings to the robustness of our analysis.

From Diffuse Gas to Star-Forming Filaments: Mapping the Magnetic and Ionization Landscape of Orion B

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Abstract

A delicate balance between gravity, stellar feedback, and magnetic pressure governs the stability of molecular clouds. However, the influence of the magnetic field (B) is strictly limited by the ionization fraction (fe), which regulates the ion-neutral coupling. In this talk, we present a joint analysis of SOFIA/HAWC+ polarization data and IRAM 30-m molecular line observations (12CN, HCO+, N2H+, etc.) across the Orion B complex. We report on the discovery of an ordered magnetic field in NGC 2024 (30–80 micro G) that follows the morphology of expanding H II shells but shows evidence of subcriticality in dense filaments. Crucially, we supplement this physical mapping with a new analytical method for deriving fe across large areas using 3–4 mm line ratios. Our results show that fe scales with volume density (n) as: from n^{-0.2} to n^{-0.3} and is highly sensitive to the FUV radiation field (G0). These findings provide a quantitative basis for the coupling required to support the observed magnetic morphologies, offering a roadmap for future wide-field studies of cloud evolution.

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*Speaker

Direct Detection of Cosmic-Ray-Excited H in Interstellar Space

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Abstract

Stars and planets form within cold, dark molecular clouds, where cosmic rays (CRs) dominate the ionization, drive chemistry, set the gas temperature, and regulate gravitational collapse. Yet despite decades of theoretical work, we have never directly measured the CR ionization rate. Instead, we have relied on indirect chemical tracers and uncertain modeling assumptions, leaving a critical gap in our understanding of star formation physics. How do cosmic rays actually shape the environments where stars are born, and can we ever observe their effects in situ? I will present our recent breakthrough, now published in *Nature Astronomy* (2026), reporting the first direct detection of CR-excited vibrational H emission. Using James Webb Space Telescope observations of the starless core Barnard 68, we detect an emission pattern that matches theoretical predictions for CR excitation with remarkable precision, confirming a decades-old proposal long considered beyond observational reach. This detection effectively turns molecular clouds into natural, light-year-scale CR detectors, enabling direct measurement of the ionization rate and opening a transformative new window into CR origin, propagation, and their role in star formation and galaxy evolution.

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*Speaker

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Resolved CO Isotopologues and Dust Emission in Giant Molecular Clouds of the Andromeda Galaxy

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Abstract

To unify Milky Way and extragalactic star formation studies, we require resolved observations of individual giant molecular clouds (GMCs) across diverse galactic environments. Such measurements are difficult to obtain in the Milky Way due to distance uncertainties and line-of-sight confusion. The Andromeda galaxy (M31) therefore provides a unique external laboratory to study GMCs across an entire galaxy disc.

Our recent Submillimeter Array (SMA) survey of M31 resulted in the first detections of resolved dust continuum emission from individual GMCs in an external spiral galaxy. I present results from the completed survey targeting 80 Herschel-identified giant molecular associations in M31. The observations simultaneously probe the J=2–1 transitions of ^{12}CO, ^{13}CO, and C^{1}O, together with 230 GHz dust continuum emission at _˜15 pc resolution. Dust continuum emission is detected in 71 cloud cores, 26 of which are spatially resolved, enabling direct comparison between dust and CO emission on identical spatial scales.

We directly measure the dust mass-to-light ratios α^{12}CO and α^{13}CO and perform a virial analysis of the resolved sources. We find that the majority (80%) of dust-traced GMC regions are gravitationally bound and close to virial equilibrium, consistent with previous results showing that while M31 GMCs are largely unbound, dense gas resides within bound structures within bound GMCs. By combining these measurements with optical spectroscopy of associated H II regions, we test the metallicity dependence of αCO across the M31 disc. Despite significant metallicity variation, αCO remains approximately constant within uncertainties, challenging theoretical predictions if a constant gas-to-dust ratio is assumed. Altogether, these results position M31 as a key bridge between Galactic and extragalactic studies of molecular cloud structure and star formation.

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Neural network-based emulation of ISM models : the case of the Meudon PDR code

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Abstract

Detailed numerical models of the physics and chemistry of interstellar medium (ISM) environments enable us to link local physical conditions to observable emission lines. However, their computational cost often makes them impractical for use in Bayesian inference frameworks, where repeated model evaluations are required for MCMC sampling. Approximation methods must therefore be used, most commonly interpolation over grids of pre-computed models.

In this presentation, I will first introduce the Meudon PDR code, a state-of-the-art model of UV-irradiated neutral ISM environments. This code self-consistently solves the radiative transfer through a gas slab, along with its chemistry, thermal balance, and the quantum level populations of numerous species. Its computation time (multiple hours) makes it impractical for direct use in MCMC-based inference.

I will then present our recent efforts to develop emulators of the Meudon PDR code for Bayesian inference applications using artificial neural networks (ANNs). We explore several strategies to optimize the network architecture and compare ANN-based emulators with alternative approaches based on interpolation over pre-computed model grids. We show that the resulting ANN emulators are faster, more memory-efficient, and more accurate than interpolation methods.

This approach, implemented in the public Python package NNBMA, significantly accelerates and simplifies the application of Bayesian inference to complex ISM models, enabling robust estimation of physical conditions from observations.

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*Speaker

Deep learning for source/line detection in hyperspectral data

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Abstract

Modern radio-interferometric surveys produce large imaging datasets in which reliable identification of galaxies is a key limiting factor for scientific exploitation. Astronomical sources span a wide range of scales, morphologies, and signal-to-noise ratios, which can impair classical detection pipelines that often rely on simple rules and require extensive post-processing to improve the quality of the produced catalogs.

In this talk, I will present recent work on deep-learning approaches for automatic galaxy detection and characterization in radio data. I will introduce YOLO-CIANNA (Cornu et al. 2024), a regression-based deep learning detection method inspired by the well-known YOLO general-purpose object detector, generalized for 3D hyperspectral data and fully reworked and re-implemented with astronomical data in mind. I will describe its application to simulated HI emission cubes from the second edition of the SKAO Science Data Challenges, and discuss the design choices that enable it to rank first in this challenge (Hartley et al. 2023, Cornu et al. 2026), while remaining computationally efficient and scalable. I will then present ongoing work generalizing this approach to radio surveys from SKA precursors (e.g., LUDMA with MeerKAT) and discuss the challenge of building realistic and properly labeled training samples from real observations.

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*Speaker

Automated line attribution in line surveys

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Abstract

With the advent of wide-band, high-sensitivity spectroscopic surveys, the identification of spectral lines and their assignment to molecular transitions has become increasingly challenging. In particular, hot molecular cores and their low-mass counterparts, hot corinos, host a rich inventory of complex organic molecules that exhibit transitions spanning a wide range of frequencies and upper-level energies. Identifying the emitting species requires detailed radiative transfer modeling, however, this task is complicated by line blending and often spatially unresolved, complex source structure. To address these challenges, we have developed a data-driven model based on convolutional neural networks that enables a quick assessment of the molecular content of observed spectra. We present the development of this approach and demonstrate the applicability of CNNs to the analysis of complex millimeter spectra. These developments open promising perspectives for future applications, including preparation for next-generation datasets such as ALMA WSU.

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*Speaker

Identifying the Stellar Populations "behind" interstellar clouds for Ice Mapping the distribution of solid material in star-forming regions

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Abstract

Molecular clouds are the nurseries of stars; their chemical composition and evolution are key to understanding the processes dominating star formation, and the materials incorporated into associated (exo)planets. The majority of the molecular reservoirs in these cold, dense environments are in the form of ice molecules in the solid state. Consequently, ices can only be detected in observations through their characteristic broad IR (infrared) absorption features, requiring that the cloud is probed on a line of sight (LOS) towards a brighter source, such as a background star or an embedded source. With the advanced sensitivity and multiplexing ability of the James Webb Space Telescope (JWST), we are now able to detect hundreds if not thousands more background stars than before. Each background star provides a LOS through which we can probe the chemical composition across a molecular cloud, and with wide field slitless spectroscopy (WFSS) we can observe ice spectra in each LOS concurrently. This technique not only enables us to "map" ice distributions in star-forming clouds, but also to trace the solid state astrochemistry of star-forming regions on spatial scales and in regions of the cloud that were previously entirely inaccessible.
The analysis of observed ice spectra intrinsically requires us to accurately characterise the source against which observations were made, to disentangle ice features from the observed stellar continuum and photospheric lines. A good knowledge of the background sources is required, and in the case of JWST NIRCAM data, the vast majority of the stars observed are uncatalogued, and therefore previously unknown.

I have developed a novel pipeline to simulate JWST ice-mapping observations and characterise the stellar continuum against which ice spectra are detected, through parametrisation of source SED (spectral energy distribution), extinction, distance and instrumental effects. Computation time is reduced without sacrificing accuracy, via exploration of the model parameter space, to pre-select appropriate priors and limits. I will show my early results, demonstrating that the pipeline effectively reproduces the baseline in observations towards two LOS ice observations in the Cha I molecular cloud complex, and that it aids in the removal of contaminating stellar photospheric lines. From these results, I will demonstrate an improvement on historical methods and illustrates the benefits accurate continuum modelling can have on the detection of minor ice species and analysis of ice spectra.
I'll consider how my method can be quickly and reliably applied to 1000's of spectra concurrently. I'll briefly show how my work to date has constrained the priors for the next step

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*Speaker

in my research, namely emulating the stellar SEDs using a combination of PCA (principal component analysis) to find the eigen-spectra of a grid template SEDs (with effective temperature, surface gravity and metallicity as parameters), combined with a GPR (gaussian process regression) to evaluate the weights eigenvalues and interpolate between grid points. This renders the SED parameter-space continuous, necessary for efficient fitting algorithms and accurately determining the stellar parameters of 1000's of previously uncatalogued stars.

Quantifying the information content of spectral tracers for interstellar medium studies

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Abstract

Wide-field multiline observations encode rich information on the physics and chemistry of the interstellar medium (ISM), but it remains difficult to quantify how much a given line, or a combination of lines, actually constrains physical conditions. In practice, observing strategies are therefore often driven by availability or tradition rather than by a quantitative estimate of information content. We present an information-theory-based framework to measure the constraining power of spectral tracers with respect to astrophysical parameters. The method models line intensities and physical conditions as jointly distributed random variables and uses conditional entropy and mutual information to quantify the expected information gain brought by one line or by a set of lines. Because it does not rely on a specific regression or inference algorithm, it provides a common language for astronomers interested in tracer selection and for data scientists interested in feature selection under noise.

We illustrate the approach with simulations of photodissociation regions representative of the Horsehead Nebula, combined with realistic IRAM 30m observing conditions. In that setting, we show that the most informative tracers depend strongly on both the physical regime and the achieved signal-to-noise ratio. We also show that the best multiline subsets are not, in general, obtained by simply combining the individually best lines. Low-J CO isotopologues already carry substantial information on column density over a broad range of conditions, whereas constraining the UV radiation field requires surface tracers such as (CI) and (CII).

Beyond observation planning, the same statistical viewpoint connects naturally to other ORION-B developments, including fast emulation of ISM models, inverse modelling of physical conditions, and dimension-reduction methods for denoising or clustering hyperspectral cubes. More broadly, we argue that information theory provides a useful bridge between astrophysical interpretation and modern data-analysis strategies for large spectroscopic surveys.

References:

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*Speaker

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- Einig et al. 2024, A&A, 691, A109
- Einig et al. 2023, A&A, 677, A158
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Exploring the circumstellar environment by direct imaging at high contrast with data-driven approaches

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Abstract

The detection of exoplanets, the characterization of their atmospheres, and the study of exoplanet formation mechanisms are major current challenges in astrophysics. High-contrast direct imaging (HCI) is one of the observational techniques of choice to address these questions. However, such observations are particularly demanding due to the extreme contrast levels and angular resolution required. In addition to the use of extreme adaptive optics and coronagraphs, advances in data science have become critical for analyzing these observations and disentangling the signals of interest (exoplanets and circumstellar disks) from the strong nuisance component (speckles and noise) that corrupts the data.
In this context, I will present some of our recent developments in statistical and deep learning applied to HCI, aimed at the optimal and reliable extraction of astrophysical information from multivariate observations (including spatial, temporal, spectral, and multi-epoch diversity). These approaches are based on a fine modeling of the different components contributing to the total signal and incorporate domain knowledge as prior information. Emphasis will be placed on (i) combining deep learning models with statistical modeling of the nuisance, (ii) leveraging large archival datasets as a valuable source of diversity for tackling the unmixing task, and (iii) jointly exploiting the spectral diversity of observations.

The methods are tailored to the specific challenges of high-contrast imaging: (i) very low signal-to-noise ratios and non-stationary noise, (ii) detection of rare events, and (iii) absence of ground truth. Applied on real data from the VLT/SPHERE instrument these approaches enable fine modeling and effective removal of the nuisance component, leading to reliable and nearly optimal estimates of the astrophysical quantities of interest. This results in significantly improved detection sensitivity and more accurate astro-photometric characterization.

Looking ahead, instruments on the next generation of thirty-meter-class telescopes will enable the exploration of the innermost environments of Sun-like stars at unprecedented contrast

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*Speaker

levels. Achieving the associated scientific goals will require addressing several data science challenges: (i) approaching the ultimate performance limits of the instruments through optimal signal extraction, (ii) capturing complex, spatially structured nuisance exhibiting strong variability, and (iii) building robust nuisance models that go beyond the limitations of angular differential imaging, particularly in the vicinity of the host star. We will discuss these challenges in light of the methodological developments presented.

Chemical complexity in outer Galaxy star-forming regions

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Abstract

Molecules can form in space on dust grain surfaces or in the gas phase through several chemical processes. Some of these molecules could be the seeds of biogenic compounds which, delivered to planets, may favour the emergence of life on them. Therefore, understanding how molecules form where stars and planets are born is a key astrophysical question. So far, the answer has been mostly searched for in regions close to the Solar System, in the middle of the Milky Way. The portion of the Galaxy beyond the solar circle, called outer Galaxy (OG), presents physical, chemical, and structural differences with resepct to the local and inner Galaxy. In particular, in the OG metallicity is sub-Solar and decreases with the Galactocentric distance. With fewer metals and dust grains, and less shielding from UV radiation that can destroy fragile molecules, the expected scenario would be that in the OG the formation and survival of molecules is less efficient than in regions located in the local and inner Galaxy. However, this scenario is challenged by recent observational results. First, the molecular abundances in low-metallicity environments do not simply scale with metallicity. Second, complex organic molecules (COMs), namely organic species with 6 or more atoms, are more abundant than expected in low-metallicity galaxies.

I will review the results of the project 'CHEMical complexity in star-forming regions of the OUTer Galaxy' (CHEMOUT), which aims to unveil the molecular composition of 35 star-forming regions at different Galactocentric distance (in the range 9-24 kpc) through observations obtained mainly with the IRAM-30m telescope. Several organic molecules were detected, including the COMs CH3CCH and CH3OH, as well as oxygen-, nitrogen-, and sulphur-bearing species. The results of the project are important to evaluate the role of metallicity in shaping the molecular composition of Galactic star-forming regions. Based on the results of CHEMOUT and of similar projects, it appears increasingly clear that the efficiency of the interstellar medium in forming organic and pre-biotic molecules is ubiquitous.

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*Speaker

Flow Matching for Robust Simulation-Based Inference under Model Misspecification

Florence Forbes*[1,2]

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Abstract

Simulation-based inference (SBI) is transforming experimental sciences by enabling parameter estimation in complex non-linear models from simulated data. A persistent challenge, however, is model misspecification: simulators are only approximations of reality, and mismatches between simulated and real data can yield biased or overconfident posteriors. We address this issue by introducing Flow Matching Corrected Posterior Estimation (FMCPE), a framework that leverages the flow matching paradigm to refine simulation-trained posterior estimators using a small set of real calibration samples. Our approach proceeds in two stages: first, a posterior approximator is trained on abundant simulated data; second, flow matching transports its predictions toward the true posterior supported by real observations, without requiring explicit knowledge of the misspecification. This design enables FMCPE to combine the scalability of SBI with robustness to distributional shift. Across synthetic benchmarks and real-world datasets, we show that our proposal consistently mitigates the effects of misspecification, delivering improved inference accuracy and uncertainty calibration compared to standard SBI baselines, while remaining computationally efficient.

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*Speaker

Assisting sampling with generative models

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Abstract

Deep generative models parametrize very flexible families of distributions able to fit complicated datasets of images or text. These models provide independent samples from complex high-distributions at negligible costs. On the other hand, sampling exactly a target distribution, such as a Bayesian posterior or the Boltzmann distribution of a physical system, is typically challenging: either because of dimensionality, multi-modality, ill-conditioning or a combination of the previous. In this talk, I will discuss a recent line of work using generative models to accelerate sampling.

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*Speaker

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Hierarchical Bayesian modeling of the spatially-resolved ISM in the nearby galaxy M99

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Abstract

Contemporary dust models are solely developed by using constraints from the Galaxy. Yet, dust evolves, locally within the ISM, but also, cosmically from one galaxy to another. This double evolution can be studied by scrutinizing the variations of the measured grain properties (abundance, size distribution, etc.) with tracers of the environmental conditions (gas density, radiation field, metallicity, etc.). This type of study however requires particular care as dust models present numerous degeneracies and non-linearities. This is amplified by the fact that multi-wavelength Spectral Energy Distribution (SED) modeling of regions that are spatially-resolved usually present different layers of foreground and background contaminations, and that their uncertainties are non-trivially correlated. I will present the results from a recent study of the nearby galaxy M99. I will discuss the data curation we performed, homogenizing our multi-wavelength photometry, subtracting foregrounds and backgrounds, and propagating the different sources of uncertainties. We have modeled the near-IR-to-radio SED of this galaxy at an angular scale of 25" (1.75 kpc), including observations with the IRAM-30m/NIKA2 camera. We have used our in-house hierarchical Bayesian code HerBIE. The analysis of our results allow us to quantify several evolution processes: (1) The millimeter-wavelength dust opacity clearly changes with the density of ISM, likely under the effect of mantle growth and grain-grain coagulation; (2) The fraction of small grains presents also clear local variations, mainly controlled by the intensity of the radiation field, probably because of photosublimation; (3) Besides, the dust, the synchrotron continuum index variations are consistent with cosmic-ray electron ageing.

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*Speaker

A hierarchical likelihood model for non-linear inverse problems under additive and multiplicative noises

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Abstract

Solving ill-posed inverse problems in astronomy presents many challenges related to the complexity of the
physical models considered and the acquisition device. Due to calibration errors and the sensitivity of the acquisition
equipment, it is natural to consider additive and multiplicative noise sources together with lower censorship. This becomes
essential when the forward model is highly non-linear, with a dynamic range spanning several orders of magnitude. In
addition, the forward model represents a physical system that is costly and complex to evaluate. It is encoded by a simplified
black-box model that is easier to evaluate (5), but remains highly non-linear. Finally, the quantification of uncertainties is
crucial for scientific applications that aim to arbitrate between several hypotheses or models when interpreting images or
inferred parameters. In astronomy, for example, the absence of ground truth makes it impossible to calibrate the acquisition
equipment. The frequent use of surrogate models (5) further motivates uncertainty quantification. In this case, inference
approaches such as Markov chain Monte Carlo algorithms (7) provide both estimates and uncertainty quantification regarding
the multiple constraints mentioned above.

The presence of two noise sources leads to a non-standard likelihood distribution, which makes the whole posterior
difficult to sample efficiently using off-the-shelf algorithms. In practice, several studies propose neglecting one of the noise
sources (1 , 3). Other approaches consider both sources of noise (2, 4, 6) to accurately model the underlying physical process.

The approaches (2, 4) are however restricted to linear forward models, making them unsuitable for applications such as
astronomy. The approach proposed in (6) allows all the challenges induced by the model above to be taken into account
while still considering both noise sources. In this approach, a smooth interpolation between

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[*] Speaker

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two likelihood approximations is considered. In the low amplitude regime, where the additive noise dominates, a purely additive approximation is used while in the high amplitude regime a purely multiplicative approximation is used since the multiplicative noise dominates. The transition in between these two extreme regimes is guided by some weight function. However, this interpolation introduces multiple hyperparameters that are difficult and costly to calibrate.

We propose an alternative to (6), based on a hierarchical likelihood model. This approach does not require hyperparameter calibration, which makes it easier for practitioners to use and adaptable to a wide range of problems. The associated posterior distribution can be sampled efficiently using kernels inspired by (6). Furthermore, the two-level likelihood makes it possible to separate the forward model from the combination of two noise sources, thereby simplifying the sampling algorithm.

Results on synthetic data show similar performance to (6) in terms of the reconstruction and uncertainty quantification metrics of the parameters of interest for a comparable computation time. This hierarchical approach has proved to be able to accurately infer the specified model while solving bottlenecks of previous methods. References

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Multi-species non-LTE modelling of Galactic massive star forming regions

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Abstract

The formation of massive stars drives the chemical enrichment, energetics, and dynamical evolution of the interstellar medium in galaxies. Massive star-forming regions therefore provide an essential laboratory for linking the small-scale physics of star formation in the Milky Way to the unresolved starburst environments observed in external galaxies. I will present a multi-line non-LTE study of the prominent Galactic high-mass star-forming complexes W43 and W49A, two luminous regions whose extreme gas conditions make them valuable templates for connecting Galactic and extragalactic star formation.

The analysis is based on data from the IRAM LEGO survey, probing scales from individual parsec-sized structures to the molecular cloud complex as a whole. These data are complemented by APEX observations targeting higher-frequency transitions (e.g. J = 3–2 and 4–3), thereby extending the excitation coverage and improving constraints on the underlying physical conditions.

Approximately 20 molecular species are analysed, including tracers of bulk molecular gas, dense gas, shocks, and cold quiescent material. The observed line intensities are modelled using the non-LTE radiative transfer code RADEX. Physical parameters are constrained through both χ^2 minimisation and Bayesian inference, allowing exploration of parameter degeneracies and the identification of distinct gas components contributing to the emission. This study aims to characterise the different gas phases present in W43 and W49A and to assess which molecular tracers are particularly sensitive to energetic processes such as shocks and outflows. By establishing how these tracers respond to local excitation conditions on parsec and cloud scales, this work provides a physically motivated framework for interpreting molecular line emission in extragalactic star-forming environments, where similar processes occur but remain spatially unresolved.

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*Speaker

Filaments and fibers in the Gould Belt molecular clouds

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Abstract

Filaments dominate the internal structure of molecular clouds, regulate star formation within them, and play a central role in their chemical evolution. Over the past decade, extensive observational efforts have focused on identifying and characterizing filament populations in nearby star-forming regions across the Gould Belt. Owing to their proximity, large-scale continuum surveys conducted with Herschel have enabled systematic measurements of key filament properties, including their radial density profiles and mass per unit length.

Complementary molecular line studies have revealed the complex internal gas kinematics within these regions. When examined at high spatial and spectral resolution, filaments that appear monolithic in continuum maps instead fragment into a rich, hierarchical network of velocity-coherent substructures known as fibers. These fibers likely represent the first subsonic structures emerging from the turbulent cascade in molecular clouds, and they provide the immediate environment for gravitational fragmentation and core formation.

In this invited talk, I will discuss the role of fibers in our current understanding of the star formation process in molecular clouds, as well as the observational and analytical techniques used to identify and characterize them.

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*Speaker

High-angular resolution, wide-field observations of the Milky Way Central Molecular Zone

Jonathan Henshaw*[1]

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Abstract

The Central Molecular Zone (CMZ) is a ring-like accumulation of molecular gas in the innermost few hundred parsecs of the Milky Way, generated by the inward transport of matter driven by the Galactic bar. The CMZ is the most extreme star-forming environment in the Galaxy. The unique combination of large-scale dynamics and extreme interstellar medium conditions, characterized by high densities, temperatures, pressures, turbulent motions, and strong magnetic fields, make the CMZ an ideal region for testing current star and planet formation theories. In this talk, I will review the recent observational and theoretical advances in the field, highlighting new observations from the ALMA CMZ Exploration Survey (ACES). I will also discuss the new challenges that we face when dealing with high-angular resolution, wide-field observations of one of the most complex environments in the Galaxy.

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*Speaker

LEGO: A Comprehensive Imaging Line Survey of Galactic Molecular Clouds

Jens Kauffmann*[1]

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Abstract

The LEGO (Line Emission in Galaxy Observations) Large Program on the IRAM 30m-telescope executed the most comprehensive imaging line survey of molecular clouds in the Milky Way to date. It covered 25 targets with bandwidths of 30 GHz and more in the 70–115 GHz range, resulting in data cubes for up to 30 transitions per region. Several studies appearing in 2026 use LEGO data to solidify connections between galactic and extragalactic star formation research (Neumann et al., in prep., Stelter et al., in prep.) and to investigate the impact of magnetic fields on accretion motions in star-forming molecular clouds (Imming et al., in prep.). This presentation provides an overview of the survey design, the data pipeline, and the data products now becoming publicly available for the general user community. It illustrates the value of the data products by showcasing results from studies now processing for publication.
LEGO's primary motivation is to "calibrate" the line emission properties of molecules used to characterize gas densities and temperatures in spatially unresolved observations of galaxies. Initial work by LEGO in particular demonstrated that NH is a more direct tracer of dense gas than HCN (Kauffmann et al, 2017; Barnes et al. 2020). LEGO work elsewhere presented at this meeting (Neumann et al., in prep., Stelter et al., in prep.) adds more nuance to this picture by studying cloud-scale emission trends in very luminous galactic star-forming sites. Here I outline future work of this flavor enabled by LEGO data becoming available now. I describe how the full LEGO sample probes a broad range of galactic environments, including clouds of lower luminosity and metallicity, thus enabling a major leap forward in our ability to "calibrate" emission line properties as a tool for the study of galaxy evolution.

LEGO data also provide critical constraints on the evolution of individual star-forming sites. I will present how gas motions sensed in doppler-shifted molecular emission lines constrain accretion motions in a magnetized molecular cloud (Imming et al., in prep.). The data are consistent with a model where magnetic fields are too weak to prevent collapse, but are strong enough to influence cloud evolution. I will illustrate how the LEGO data becoming available now generally enable research into the dynamics of the star formation process across a wide range of cloud properties and galactic environments.

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*Speaker

Tracing Variations of Dust Emissivity Spectral Index Associated with Interstellar Shocks

Wonju Kim*[1], Alvaro Sanchez-Monge[2], Gary Fuller[3], Friedrich Wyrowski[1], and Amélie Saintonge[1]

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[3]The University of Manchester – United Kingdom

Abstract

Dust grains play a crucial role in the interstellar medium (ISM), acting as coolants and enabling the formation of molecular hydrogen (H), which drives star formation. In addition, other molecular species form on grains, and grains can also store different molecules on their surfaces. As products of star formation, dust grains are continually reshaped and redistributed within the molecular clouds where stars form. However, the links between dust-grain properties and interstellar molecules are still poorly constrained. To address this, we investigate the relationship between dust properties and molecular gas in a star-forming molecular cloud using new IRAM 30m NIKA2 1 and 2 mm dust continuum data together with SiO, HNCO, and HCN multi-transition spectral line mapping observations with IRAM 30m and Yebes 40m telescopes. Our analysis reveals that the dust emissivity spectral index (β), derived from the NIKA2 data, varies significantly with SiO abundance: β becomes steeper (> 1.5) in regions with high SiO abundances (> 5–6×10). In contrast, regions with low β values (flatter slopes) show no significant SiO emission or very low SiO abundances, X(SiO) a few $\times$ 10^1. We find similar, though weaker, trends with HNCO, and a less pronounced correlation with HCN. These results suggest that molecular species associated with dust-grain formation processing are highly sensitive to dust-grain properties and their variations within the same environment. I will present these initial results on the dust emissivity spectral index and discuss their implications in the context of shock tracers and dust–gas coupling in star-forming regions. In addition, I will present newly obtained NIKA2 continuum data toward the outer Galactic molecular clouds and associations between molecular gas and dust emissivity spectral index in lower-metallicity environments.

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*Speaker

Beyond Moment 0: Deep Learning the Spectral Kinematics of High-z Star Formation?

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[5]University of Connecticut [Storrs] – United States

Abstract

Accurate **Star Formation Rate (SFR)** estimation at high redshift (z∼5) is fundamental to our understanding of the feedback mechanisms governing early (beyond cosmic noon) massive galaxy assembly. Traditional Star Formation Rate (SFR) estimates have long relied on empirical power-law scaling relations, primarily linking integrated emission line luminosities (Moment 0) to star-forming activity. However, these approaches may ignore the rich physical information encoded in the spectral and spatial dimensions of **Integral Field Unit (IFU)** data, potentially masking the complex, multi-phase nature of the interstellar medium during the epoch of peak galaxy assembly.

This talk presents a novel framework for SFR estimation that moves beyond 1D scaling laws by utilizing **synthetic IFU cubes** from the **FIRE (Feedback In Realistic Environments)** simulations through which we obtain physically-motivated complex data as well as ground truth targets, ideal for supervised machine learning, with the final goal of generalisation to observations. Focusing on massive galaxies at high redshifts (z _˜ 5), we analyze both **Far-Infrared (FIR)** and **optical** emission lines across multiple galactic inclinations. Our first approach extracts per-spatial pixel (spaxel) multidimensional features - including the integrated luminosity, velocity centroids, dispersion, skewness, and kurtosis - to train machine learning models capable of **capturing non-linear correlations between luminosity surface density, spectral kinematics, and SFR surface density**. We also aim to transcend ”per-spaxel” feature analysis by developing models to exploit the spatial and velocity-space correlations inherent in IFU data. By mapping the full Position-Position-Velocity (PPV) cubes of distinct emission lines directly to high-resolution SFR surface density maps, we **investigate whether the spatial morphology, spectral ”shape”, and turbulent velocity structure provide a more robust proxy for star formation than luminosity alone**. We aim to perform feature importance analysis as well to **identify the strongest observational tracers and spatial-spectral regions that drive accurate SFR inference**. This work aims to uncover the hidden role of the velocity dimension in SFR physics, if any, and provide a sophisticated machine-learning pipeline for interpreting

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[*] Speaker

upcoming high-resolution PPV data from facilities like JWST and ALMA.

This talk also involves a brief overview of a **deep and sparse denoising** benchmarking framework for PPV data cubes, as at high redshift, faint galactic emissions are observed amid overwhelming interferometric noise from instruments such as ALMA, making one of the key methodologies for proceeding with accurate scientific analyses to be - denoising and flux/spectral restoration - for which we have developed **sparsity-based iterative wavelet transform** approaches, **deep learning**, along with traditional techniques (PCA, ICA), and performed a benchmarking study with multi-tiered data sets: theoretically generated **physically motivated mock PPV cubes of rotating disk galaxies**, state-of-the-art **synthetic data cubes from zoom-in cosmological simulations**, and observations from **ALMA**. We explore the methodologies over a wide parameter space and obtain reliable data-driven inferences on the use of the most powerful methods - unsupervised wavelet-based, and supervised deep learning based approaches for spectral cubes.

Topological models to recover intrinsic variations of physical conditions in galaxies

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Abstract

Our ability to answer fundamental questions pertaining to galaxy evolution largely rely on underlying models or simulations. Integrated spectra of galaxies (JWST or ALMA high-z spectra but also nearby dwarf galaxies observed in the far-infrared) are often interpreted using single 1D models (or empirical relationships themselves calibrated on such models). Topological models - which consist of statistical distributions of 1D models - aim to better reflect the complexity of the interstellar medium (ISM) and of the energetic sources at play. We present the association of the statistical inference code MULTIGRIS (Lebouteiller & Ramambason 2022) with several 1D model databases from Cloudy (Ferland et al. 2017) in order to revisit several topology-dependent questions: the escape fraction of ionizing photons (Ramambason et al. 2022), the fraction of molecular gas (Ramambason et al. 2024), and the predominant ISM heating mechanisms as a function of the galaxy metallicity (Varese et al. 2025). Finally, topological models may be able to recover the intrinsic variations of physical parameters within galaxies even from spatially-unresolved spectra. One potential application is to derive robust metallicity measurements in galaxies and infer the mass-metallicity relationship over a wide metallicity range (Lebouteiller et al. 2025).

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*Speaker

The cosmic-ray ionization rate in nearby cold clumps

Gan Luo*[1], Marco Padovani , Daniele Galli , Arshia M. Jacob , Thomas Bisbas , Brandt Gaches , and Di Li

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Abstract

The cosmic-ray ionization rate (CRIR) is a fundamental parameter in star formation: it initiates the ion–molecule networks that produce key ions (H3+, HCO+) and governs the coupling between magnetic fields and dense gas. Although recent studies indicate that the CRIR depends on local environment and star-formation activity, substantial uncertainties remain due to methodological differences and poorly constrained cloud physical conditions. Atomic hydrogen residing within molecular gas can serve as a robust tracer of the CRIR because its formation depends on the dissociation of H2 by low-energy cosmic rays. In our recent works, we use measurements of HI narrow self-absorption (HINSA) to infer the CRIR in cold clumps within nearby star-forming clouds. In the Perseus complex, we measure markedly different CRIRs in two adjacent regions: the region with a higher star-formation rate exhibits a much lower CRIR, in agreement with diffuse γ-ray constraints. These results suggest that the CRIR enhancement associated with star formation should be significantly attenuated before it can contribute to the large-scale Galactic cosmic-ray background. By combining HINSA with observations of simple hydrides (CH), we further constrain the abundances of C+ and O in the cold clumps, and find no evidence for strong atomic-oxygen depletion in our sample.

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*Speaker

Revisiting the role of the HCN(1-0) line as a tracer of the dense gas reservoir for star formation.

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Abstract

Massive stars form within dense clumps inside giant molecular clouds (GMCs). Finding appropriate chemical tracers of the dense gas (n(H2) $>$ several 1e4 cm-3 or Av $>$ 8 mag) and linking their line luminosity with the star formation rate is of critical importance. In the context of the ORION-B large program we investigate the origin and physical conditions of the HCN-emitting gas and study its relation to other molecular tracers. We find that about 70% of the total HCN J = 1-0 luminosity, (L' = 110 K km s-1 pc2) arises from translucent gas with n(H2) $<$ 1e4 cm-3, and even lower-density gas if the ionization fraction is Xe $>=$ 1e-5 and electron excitation dominates. The widely used HCN/CO J=1-0 line intensity ratio shows a bimodal behavior, with an inflection point at Av $<$ 3 mag typical of translucent gas and illuminated cloud edges. These results challenge the prevailing view of HCN J = 1-0 emission as a tracer of dense gas. Its use therefore requires careful interpretation, taking into account excitation conditions, chemistry, and environmental effects.

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*Speaker

Fusion of JWST data - Demonstrating practical feasibility

Landry Marquis*[1,2,3]

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[2]Signal et Communications – Institut de recherche en informatique de toulouse – France
[3]Institut Supérieur de l'Aéronautique et de l'Espace – Université de Toulouse – France

Abstract

The computational technique of data fusion, widely established in Earth observation for producing high-resolution hyperspectral cubes, merges information from instruments with complementary resolutions: low spatial/high spectral versus high spatial/low spectral. As astronomical observations increasingly employ such complementary instrument configurations, data fusion emerges as a compelling enhancement strategy, though previous astronomical applications have proven unsuccessful. Here we achieve the first successful astronomical data fusion by integrating JWST observations from NIRSpec integral field spectrograph and NIRCam imager. Our methodology, validated on the d203-506 protoplanetary disk in Orion and on Titan, generates fused data products combining NIRCam's superior spatial resolution with NIRSpec's spectral resolution. These results pave the way for extracting the physical properties from JWST data with unprecedented spatial resolution and showcase the transformative potential of data fusion in astronomy.

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*Speaker

High-Resolution Absorption Imaging of Infrared-Dark Filaments with JWST

Michael Mattern*[1] and Ph. André[1]

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Abstract

Dense molecular filaments are believed to be representative of the initial conditions of star formation in interstellar clouds. Characterizing their physical properties such as their transverse size is therefore paramount. The results of Herschel Gould Belt survey observations suggest that nearby molecular filaments have a narrow distribution of inner widths with a typical FWHM of ∼0.1 pc and a dispersion of a factor of ∼2.
However, filamentary structures have also been found on larger and shorter interstellar scales, e.g., giant molecular filaments, fibers, and streamers. This raises the questions of whether the _˜0.1 pc width of Herschel filaments represents a significant departure from a purely self-similar, hierarchical ISM and whether the 0.1 pc scale truly matters for the star formation process and the IMF.

Answering these questions requires the combination of high dynamic range mapping observations covering a broad range of scales, densities and Galactic environments. Observations of molecular lines provide good probes of the chemical composition and dynamics of the gas, but are typically limited to specific ranges of densities and thus scales due to the necessary excitation conditions of the various transitions. Therefore, additional dust continuum observations in both emission or absorption are essential to understand the role of filaments across scales.
Our approach has been to combine Herschel, APEX/ArTéMiS, and JWST/MIRI data to construct high-resolution and high dynamic range column density maps of star-forming clouds across the Milky Way. This allows us to cover a dynamic range of four order orders of magnitude in spatial scales and to resolve the fine structure of the dense/cold ISM down to angular scales of 0.26". In this talk, we will present the results of our pilot JWST/MIRI study on six infrared-dark filaments, including NGC6334M (André et al. 2025). While there is evidence of a Kolmogorov-like spectrum of small-scale fluctuations down the resolution of the data, we identify a break in the power spectrum of column density fluctuations at a size scale of _˜0.1-0.2 pc comparable to the width of nearby Herschel filaments. We conclude that the latter reflects the presence of a genuine common scale in the structure of the cold ISM.

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*Speaker

Magnetic field and star formation

Anaëlle Maury*[1], Patrick Hennebelle , and Josep M. Girart[2,3]

[1]ICE/CSIC CEA/AIM – Spain
[2]Institut de Ciencies de lÉspai [Barcelona] – Spain
[3]Institut dÉstudis Espacials de Catalunya – Spain

Abstract

In this review, I will aim at providing a global outlook on the progresses made in the recent years to characterize the role of magnetic fields during the embedded phases of the star formation process. Thanks to the development of observational capabilities and the parallel progress in numerical models, capturing most of the important physics at work during star formation; it has recently become possible to confront detailed predictions of magnetized models to observational properties of the youngest protostars. I will start presenting the most important consequences when adding magnetic fields to state-of-the-art models of protostellar formation, emphasizing their role to shape the resulting star(s) and their disk(s). I will discuss the importance of magnetic field coupling to set the efficiency of magnetic processes and provide a review of observational works putting constraints on the two main agents responsible for the coupling in star-forming cores: dust grains and ionized gas. I will put emphasis on the processes and observational methods, which allow to trace the magnetic field topology and its intensity in embedded protostars and review the main steps, success, and limitations in comparing real observations to synthetic observations from the non-ideal MHD models. Finally, I will conclude suggesting we now have several threads of observational evidence that suggest a key role of magnetic fields for star and disk formation, and propose a scenario solving the angular momentum for star formation, also highlighting the remaining tensions that exist between models and observations.

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*Speaker

Dense core chemistry

Helena Mazurek*[1] and The Orion-B Consortium

[1]LUX – Institut National des Sciences de l'Univers, Observatoire de Paris, Centre National de la Recherche Scientifique, Sorbonne Universite, PSL Research University, Paris – France

Abstract

In this talk, we explore the chemical diversity of prestellar and protostellar cores residing in the Orion B giant molecular cloud selected on their dust continuum emission to provide an unbiased view of their line emission properties and how they vary as a function of the core parameters and the environment. We will present our findings on the key factors explaining the variation of the line emission pattern inferred using a Principal Component Analysis, as well as discuss the core stability criteria refined by the information on the line widths measured along the lines of sight of cores.

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*Speaker

Model-Based Deconvolution and Fusion of JWST/MIRI Multispectral and Hyperspectral Data.

Nicolas Monnier*†1, François Orieux‡2, Alain Abergel§1, and Dan Pineau3

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[3]Université du Luxembourg – Luxembourg

Abstract

The Mid-Infrared Instrument (MIRI) on the James Webb Space Telescope (JWST) offers complementary observing modes with a trade-off between spatial and spectral performance. The imager (MIRIM) provides a wide field of view and high spatial resolution multispectral images at very low spectral resolution, while the Medium Resolution Spectrometer (MRS) produces hyperspectral images at a much higher spectral resolution but a lower spatial resolution and a smaller field of view. MIRI data features large spectral cubes with wavelength-dependent spatial blurring, limited spatial sampling, and significant noise levels. Therefore, hyperspectral-multispectral data fusion is a promising strategy for effectively operating both observing modes and enhancing data quality, thereby improving spatial and spectral resolution. This challenge requires an integrated approach that combines deconvolution, denoising, and super-resolution techniques.

We propose the first instrumental model-based fusion framework for MIRIM and MRS data, applied to the photo-dominated region NGC 7023. The fusion approach relies on forward instrumental modeling of both instrumental models. Moreover, the reconstruction relies on modeling the observed sky with a linear mixing model, which significantly reduces the number of unknown parameters. This joint-fusion formulation enables spatial deconvolution, spectral preservation, and noise regularization within a consistent inverse-problem framework. It finally achieves a significant improvement in spatial resolution through strong deconvolution, super-resolution, and denoising.

This work presents the first model-based hyperspectral-multispectral fusion and deconvolution framework. It demonstrates the potential of joint instrument modelling to recover high-fidelity spatial and spectral information from complementary observation modes. Our approach was developed specifically for MIRI, but it can be used for any ground-based or space-based instrument.

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[*] Speaker

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ALMA-IMF

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Abstract

To be filled.

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*Speaker

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A model for late accretion streamers and chemical replenishment in protoplanetary disks

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Abstract

Protoplanetary disks are not born in isolation. The accretion of surrounding gas that was not initially gravitationally bound is thought to be typical of intermediate and high-mass star formation. These episodes of accretion, called late accretion, are increasingly recognized as important actors in the evolution of protostellar disks and their chemical composition. However, their physical and chemical impact has not been investigated in detail yet. For the first time, we present a detailed study on the chemistry of late accretion, using radiation-magnetohydrodynamic simulations of core collapse and Lagrangian tracer particles.

Our setup includes a collapsing sphere of 5M of gas that evolves for 3.6e5 years. As the collapse proceeds, magnetized filamentary structures develop as a consequence of the magnetic interchange instability. These structures channel gas from the outer envelope onto the disk and protostar, providind a natural mechanism for late accretion streamers. The filaments predicted by our simulation reproduce the observed sizes, masses, and infall rates of observed streamers using molecular tracers.

By tracking back in time the properties of the gas channeled through these filaments, we observed that the origin and the physical history (evolution of density and temperature over time) of late-infalling gas are markedly different from those of the gas that initially forms the disk. The chemical post-processing of the tracer particles reveals how late accretion brings pristine material with a distinct chemical composition to the disk as it is accreted. This is particularly relevant for COMs, since late accretion provides the disk with higher abundances of icy COMs, even in the inner disk. As such, late accretion therefore becomes an important factor in setting the chemical composition of the future planetary system.

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*Speaker

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LEGO: Connecting Probes of Dense Gas from the Milky Way to External Galaxies

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Abstract

I will present recent results from the IRAM 30m large program ”Line Emission as a tool for Galaxy Observations” (LEGO; Kauffmann+17, Barnes+20, Neumann to be subm., Stelter et al. to be subm.). This survey aims at studying star-forming regions in the Milky Way across a wide range of environments to help interpret extragalactic observations of molecular line emission. Here, I will present new results from the three high-mass star-forming regions of the LEGO sample (Neumann to be subm.; see link below), which are the ideal candidates to connect to external galaxies which are actively forming stars, such as those probed by the PHANGS/ALMOND (Neumann+23a, Neumann+25) and EMPIRE (Jimenez-Donaire+19) surveys. Moreover, I will show results from Stelter et al. to be submitted (link below), which links the parsec scale observations from LEGO to sub-parsec local clouds, as well as nearby galaxies, comprising a data compilation which spans more than four orders of magnitude in physical scale.

Our key findings are that, in the high-mass star-forming regions (W49A, W43, G45.1+0.1), molecular line emission from N2H+ is the only robust tracer of cold, dense gas. On the contrary, classical extragalactic dense gas tracers, such as HCN, HCO+, HNC or CS are not only selective of dense gas, but originate also from moderate gas densities. However, if averaged over the whole extent of the cloud, HCN (HCO+, HNC, CS) and N2H+ have a roughly fixed line ratio, suggesting that HCN is still a decent proxy for dense gas at cloud scales, i.e. larger than 10 pc. In conclusion these findings point towards a self similar density structure of molecular clouds, such that HCN, although not selective of dense gas, is linked to the dense gas traced by N2H+. Furthermore, I will show that the HCN-to-CO line ratio is sensitive to gas density from sub-parsec (PropStar), over parsec (LEGO) and 100 parsec (Neumann+24a) to kiloparsec scales (Neumann+24b), indicating that HCN traces, on average, denser gas than that traced by the low-J CO transitions and hence remains a powerful extragalactic tool to study physical gas conditions in external galaxies
Links to articles to be submitted:

Neumann et al. to be subm.: https://u.pcloud.link/publink/show?code=XZEibd5ZbjrzInzBwSJL1GDKY5PiHLbp
Stelter et al.to be subm.: https://u.pcloud.link/publink/show?code=XZiibd5ZJM0dqUzLwL4n0YvODMgoghbC34

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[*] Speaker

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Deep priors for approximate posterior sampling in imaging inverse problems

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Abstract

Deep learning methods are now state-of-the-art for inverse problems in imaging. Among them, direct inversion methods train a specific network for a given problem, and generally provide a point estimation of the restored image without the associated uncertainties. Alternatively, deep regularization methods learn a deep prior on target images before plugging it, as the regularization term, into a model-based optimization scheme. In this talk, I will present variational Bayes latent estimation (VBLE), a deep regularization method that solves the inverse problem in the latent space of a variational compressive autoencoder (CAE). VBLE estimates relevant uncertainties jointly in the latent and in the image spaces by sampling an explicit posterior estimated with variational inference. This enables approximate but fast posterior sampling. I will illustrate the interest of VBLE in the context of high-resolution satellite image restoration, where VBLE achieves state-of-the-art restoration results while offering meaningful and scalable uncertainty quantification. References:
- Maud Biquard, Marie Chabert, Florence Genin, Christophe Latry & Thomas Oberlin. Deep priors for satellite image restoration with accurate uncertainties. IEEE Transactions on Geoscience and Remote Sensing, 2025.
- Maud Biquard, Marie Chabert, Florence Genin, Christophe Latry & Thomas Oberlin. Variational Bayes image restoration with compressive autoencoders. IEEE Transactions on Image Processing, 2025.

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*Speaker

Observational study of a hot corino cluster bathed by an external UV radiation field

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Abstract

Hot corinos are dense, compact and hot sources that present a particularly rich chemistry including Complex Organic Molecules (COMs), and that are linked to the earliest stages of low-mass star formation. Although they are clue objects to understand the chemical environment where planets will form, there are many unanswered questions related with them. One important question is the role of the initial conditions (dense gas abundances, ionization) in the natal cloud where these objects form. In order to answer these questions, we conducted a search of COMs with sensitive ALMA observations at 1.3 mm towards the nascent cluster Orion Molecular Cloud 1 South, OMC-1S, about 0.07 pc to the southwest of the Trapezium. Using a LTE code, we identified and fitted the spectra of 8 hot corinos with COM emission such as N-bearing (13CH3CN, CH3CH2CN, HNCO), O-bearing (HCOOCH3, CH3OCH3, CH3COCH3, CH3CH2OH) and simple species such as S-bearing (OCS, SO2, H2S). Two additional tentative hot corinos are further identified. Taking into account that the cluster harbors at least 14 protostellar sources, OMC-1S turns out to be one of the regions with highest hot corino detection rates, of _˜70%, and the region with highest density of hot corinos known so far. Combining our ALMA data with JWST, ALMA+IRAM30m N2H+(1–0), and VLT/MUSE data tracing electron density and temperature, hints of interaction of the Trapezium UV field with the OMC-1S nascent cluster are identified, and potential relations between the specific COM chemistry of the hot corinos and the properties of the ambient cloud are explored. This constitutes one of the first works that directly study the potential relation of the hot corino chemistry with the properties of their natal ionized and molecular cloud.

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[*] Speaker

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BEETROOTS, a new bayesian framework for inverse problems,

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Abstract

The current generation of millimeter (mm) receivers is capable of producing cubes of 800 000 pixels over 200 000 frequency channels to cover a number of square degrees over the 3 mm atmospheric window. Estimating the physical conditions of the interstellar medium (ISM) with an astrophysical model on the basis of such large datasets is challenging. Common approaches either fail to scale to large maps or tend to converge to local minima and end up poorly reconstructing regions with a low signal-to-noise ratio (S/N) in most cases.

We introduce BEETROOTS, an all-in-one Bayesian inference python package dedicated to multi line observation maps. It relies on a flexible and accurate statistical model, exploits spatial regularization to guide estimations, and uses state-of-the-art algorithms. It can also assess the ability of the astrophysical model to explain the observations, providing feedback to improve ISM models.

In this presentation, we demonstrate the power of BEETROOTS with the Meudon PDR code on synthetic data. We then show results on real data, namely the full Orion molecular cloud 1 (OMC-1) star-forming region based on Herschel molecular line emission maps.

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*Speaker

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Probing the potential for kinematically colder H I component as a tracer for star-forming gas in nearby galaxies

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Abstract

Molecular gas, the fuel for star formation, is often traced by CO rotational transition lines, which are challenging to detect in metal-poor dwarf galaxies. In this talk, I present a study exploring the potential of kinematically cold atomic hydrogen as an alternative tracer of star-forming gas in dwarf galaxies. We analyse narrow (cold) and broad (warm) kinematic components by decomposing HI 21 cm data cubes for seven nearby galaxies, both dwarfs and spirals, using the Bayesian Markov Chain Monte Carlo tool BAYGAUD-PI (Oh et al. 2019). By mapping these components together with star-formation rate tracers, we investigate their spatial association with star-forming regions in dwarf galaxies. Accounting for these components, dwarf galaxies consistently show a larger fraction of narrow HI gas compared to spirals. These results highlight the potential role of kinematically cold HI as a tracer of the cold neutral medium and molecular gas in low-metallicity environments, where traditional tracers such as CO are difficult to use. We also emphasise the need for high-resolution HI observations to better understand the atomic-to-molecular gas transition and its role in regulating star formation across different galaxy types.

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*Speaker

Deciphering Photodissociation Regions: Radiative Feedback, High-Resolution Infrared Tracers, and Advanced Astrochemical Modeling.

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Abstract

Photodissociation Regions (PDRs) are the critical interfaces where stellar radiation governs the physical and chemical evolution of the interstellar medium. Despite their central role, the detailed mechanisms operating in these regions remain incompletely understood, particularly the impact of radiative feedback from massive stars. This feedback establishes a delicate and competitive balance: intense far-ultraviolet (FUV) radiation dissociates molecular hydrogen (H2) and disperses molecular clouds, thereby suppressing star formation. At the same time, the same radiation field can generate localized overpressure fronts that compress the gas and potentially trigger subsequent episodes of star formation. PDRs are therefore intrinsically complex environments in which chemistry, thermodynamics, and radiative transfer are tightly coupled and jointly determine the physical state of the gas, making them particularly challenging to model and interpret.

Recent advances in high-resolution spectroscopy have significantly enhanced our observational capabilities in this field. Five emblematic PDRs, including the Orion Bar, the Horsehead Nebula, and S140, were observed with the ground based IGRINS spectroscope.These observations provide an unprecedented dataset, featuring over a hundred H2 rovibrational lines detected from v=1 to v=13. Enabled by a high spectral resolution of R=45,000, this work offers a uniquely detailed view of highly excited molecular states.

We analyze these rich datasets using the Meudon PDR Code (https://pdr.obspm.fr), a state-of-the-art numerical model developed and continuously improved over the past three decades to model PDRs as 1D stationary models. The code explicitly solves for non-local thermodynamic equilibrium (non-LTE) conditions, coupling an extensive chemical network, comprising hundreds of species and thousands of interconnected reactions, with detailed radiative transfer that includes absorption and emission lines from the ultraviolet to the radio domain.

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*Speaker

In this work, we show that confronting this unique observational dataset with such a comprehensive numerical model enables us to tightly constrain the fundamental macroscopic parameters of these PDRs, in particular the thermal gas pressure and the intensity of the incident FUV radiation field. Beyond deriving these static physical conditions, our detailed analysis clearly reveals the dynamical signature of photo-evaporation, demonstrating how stellar radiation actively erodes the surrounding molecular clouds. Crucially, this study also provides the first robust empirical constraints on the nascent excitation state of molecular hydrogen formed on dust grains. We present strong evidence that in moderately irradiated environments, such as the Horsehead Nebula, H2 forms and desorbs from grain surfaces in highly vibrationally excited but rotationally cold states.

Furthermore, this work highlights the contrast between moderately excited regions and strongly irradiated environments such as the Orion Bar. To investigate this latter PDR, we combine to our H2 analysis a new analysis based on a unique NIRSpec observation of ro-vibrationally excited CO. This rare detection of CO in vibrational states in a PDR gives us access to deeper and warmer molecular layers, allowing us to probe the complex thermodynamic and chemical processes occurring well beyond the main H2 dissociation front.

Ultimately, this presentation will show how our framework accurately constrains both the large-scale macroscopic conditions-such as thermal pressure and UV intensity-and the fundamental microphysical mechanisms, including H2 formation pumping and collisional rates. By contrasting distinct regimes of irradiation and expanding our diagnostics to encompass novel CO transitions, we build a picture of the structural transitions within these regions, tracing the influence of stellar feedback from the highly exposed surfaces down to the shielded interiors.

The Structure of Nearby Molecular Clouds Revealed by Ammonia

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Abstract

Ammonia (NH) inversion transitions provide a powerful probe of the temperature, column density, and kinematics of dense molecular gas in star-forming clouds. Large surveys such as the Green Bank Ammonia Survey (GAS) have mapped NH emission across nearby molecular clouds with high sensitivity and spatial coverage, revealing the detailed structure and dynamics of dense gas.

These observations show that dense cores are embedded within complex filamentary structures and are frequently surrounded by gas with supersonic NH linewidths, highlighting the dynamic environments in which cores form. Subsonic velocity dispersions, often associated with coherent core interiors-do not appear at a universal column density threshold, indicating that the transition from turbulent to quiescent gas depends on local conditions rather than a single characteristic density. By combining GAS observations with dust-based core catalogues, it is also possible to constrain the dynamical state of dense cores, with many appearing to be pressure confined rather than purely gravitationally bound.

Complementary observations combining GBT and VLA data are now probing the internal structure of dense cores and investigating the possible depletion of ammonia at high densities. These studies reveal significant substructure within cores and highlight the need for higher angular resolution observations to further explore how turbulence dissipates and how coherent core interiors emerge.

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*Speaker

From IR dark clouds to evolved Hii regions: a machine learning approach to identifying evolutionary stages of molecular clumps

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Abstract

Star formation is a key process shaping the structure and evolution of galaxies. Large-scale Galactic surveys now provide vast amounts of molecular observations that contain rich information about the physical and chemical state of the molecular clumps. These data sets span multiple evolutionary stages, from infrared dark clouds to protostars and HII regions. However, molecular line observations have rarely been used directly to derive evolutionary classifications of the clumps. Traditional classification schemes rely primarily on infrared (IR) emission and morphological criteria, which can be affected by distance uncertainties, ambiguous observational signatures and heavily obscured IR emission, often leave a significant fraction of sources without reliable evolutionary classification. In this work, we explore a data-driven approach for identifying evolutionary stages of molecular clumps using integrated line intensities from the MALT90 survey, complemented by Spitzer IR fluxes. We employed unsupervised machine learning techniques to investigate whether intrinsic structures in the molecular line parameter space reflect underlying evolutionary stages. As a result, we found three stable clusters corresponding to consequent evolutionary stages: regions without active star formation, clumps hosting embedded protostars, and more evolved HII/photodissociation regions. Using supervised learning algorithms we managed to assign most likely evolutionary stages to around 70% of MALT90 sources with previously uncertain classifications. Overall, our results demonstrate that molecular line integrated intensities contain meaningful information about clump evolution, and machine learning techniques are able to complement and traditional IR-based classification approaches.

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Comparative lifetime of atomic and molecular clouds in nearby galaxies

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Abstract

Nearby galaxies observed at high spatial resolution with JWST, ALMA, MUSE and HST allow us to address fundamental questions about the influence of young stars on their surroundings : Which physical mechanisms regulate the collapse of gas clouds and star formation? How do such processes affect the timescales of Giant Molecular Clouds (GMCs) ? I will describe the timescales and physical mechanisms associated with the evolution of GMCs in massive, star-forming galaxies from PHANGS survey, including their dust-embedded star formation phase. I will give an overview of the methods available to measure timescales associated with the molecular and atomic gas in galaxies, and highlight some key results and perspectives in this field.

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*Speaker

Study of the physical and chemical properties of the clouds along the line of sight of Sgr A*

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Abstract

For this project, we used high spectral resolution ($\leq$ 1 km/s) and spatial resolution ($\leq$ 1") observations of Sgr A* extracted from various projects in the ALMA archive. The ALMA bands covered are 3, 5, 6, 7, and 8 for different species, such as CN (the main target), HCN, CO, CS, and isotopologues.

The data were calibrated using CASA pipeline tasks, which apply calibration and marking tables to a raw MS file, thereby restoring a calibrated MS. The imaging process used tclean for the fractionated data, containing different spectral windows; in this process, we used the highest possible spectral resolution, but during imaging, we forced the beams to be the same size for all data (1"), making them comparable to each other for subsequent LTE and non-LTE modeling.

Thanks to these data, and thanks to the numerous absorption lines observed from the cold/warm gas in the molecular clouds absorbing the strong continuum radiation from Sgr A*, we were able to determine a large number of components (_˜60, with Vlsr ranging from -275 km/s to +106 km/s) along this line of sight.

For that, we used different species :
1/ 12CO, 13CO and C18O, since they have single lines, to evaluate the number of components and their Vlsr needed to reproduce the spectra.
2/ H12CN, 12CN, species suitable for determining the chemical properties of the cloud thanks to their numerous HFS lines.
In our high spectral resolution spectra (_˜0.5 km/s), we can fairly well fit the isolated lines with a two-component Gaussian function, two components which we must use in our modeling.

To determine the physical and chemical parameters of the clouds in the line of sight, we performed a MCMC minimization with an LTE model for the CO lines, as their critical density is low enough to assume that the gas is in LTE. This is not the case for the CN lines, which have a much higher critical density. We therefore performed a non-LTE MCMC minimization for these lines using RADEX in CASSIS.
For CO lines, the free parameters of the LTE minimization were N(species), Vlsr, FWHM,

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*Speaker

and Tex for the narrow component, but only N(species), Vlsr, and FWHM for the broad component, with Tex = 80 K for all clouds.

For the CN and HCN lines, the free parameters of the narrow components were n(H2) and N(species) when Tkin was set to the Tex values determined with LTE minimization on the CO lines for each component. For the broad component, the only free parameter used was N(species), as we do not believe the others to be very important in this beam (using Vlsr, FWHM, size, Tkin = Tex as determined by LTE minimization of the CO lines, and assuming a constant n(H2) = 1e8 for all clouds).

In this presentation, we will present our results concerning various physical and chemical parameters of the approximately 60 clouds identified along the line of sight.
a/ From the Vlsr, we determined the position of these clouds in the Galaxy and thus evaluated their galactocentric distance.
b/ We calculated the 12C/13C and 16O/18O isotope ratios for all clouds located in the line of sight, as well as the potential galactocentric gradient of variation in these ratios.
c/ We determined the CN/CO, HCN/CO, and CN/HCN ratios for all clouds located in the line of sight.

We will discuss the implications of these results for the physical and chemical properties of molecular clouds in the inner Galaxy and in various spiral arms crossed by the line of sight towards Sgr A*.

Toward robust estimates of the physicochemical properties of interstellar molecular clouds without ground truth

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Abstract

Stars form in giant molecular clouds (GMCs) that have extreme combined physical conditions impossible to reproduce on Earth: a temperature between 10 and 100 K and a volume density between 100 and 10ˆ6 cm-3. Remote observation is therefore the only way to determine these physical conditions. However, under these typical conditions, molecular hydrogen, which is by far the most abundant molecular species, is mostly invisible. The properties of the gas are indirectly probed by the lines emitted by minor molecular tracers such as carbon monoxide (CO). The estimates derived from multi-species analyses necessarily rely on a priori constraints (e.g., cloud geometry) which significantly bias the results when incorrect. It is therefore necessary to develop a methodology for reliably fitting multi-species observations in order to deepen our understanding of star formation.

This presentation aims to give an overview of the statistical treatment developed during my PhD to achieve this goal, based on estimation theory and performance bounds such as the Cramér-Rao bound (CRB), which provides a lower bound of the precision for any unbiased estimator. The latter is used to 1) verify the efficiency of the proposed maximum likelihood estimator, 2) to provide error bars for the actual parameter estimates, 3) to quantify the loss of precision when the presence of calibration errors affecting the data is deliberately neglected in order to simplify the adjustment procedure.

We use this statistical tool to the analysis of a radiative transfer multilayer cloud model in order to study heterogeneous properties (column density, volume density, kinetic temperature, thermal pressure, and the gas kinematics) along any line of sight toward filaments and dense cores. Applied to low-J transitions of CO and HCO+ isotopologues in the Horsehead Nebula, the main findings are : 1) a minimal heterogeneous model (only three layers) is sufficient in this case, as it fits the seven selected molecular lines over the considered field

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*Speaker

of view, 2) CO is depleted from the gas phase to dust ice for lines of sight toward the two embedded dense cores, and 3) the data show a signature of accretion motions from the foreground translucent layer toward the denser internal gas. This proof of concept, combined with the codes shared with the community, paves the way for processing larger fields of view.

T—3D Presenting The First 3D-Temperature-Map Of Our Galaxy

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Abstract

The multiphase structure of the interstellar medium (ISM) is fundamental to star formation and gas cycling in galaxies, yet until today, we have lacked a 3D view of where these phases exist in galactic space.

In this talk I will present the first 3D map of gas temperature across the neutral ISM revealing the spatial distribution of cold (T≤300 K), unstable (300≤T≤6000 K), and warm (T≥6000 K) neutral medium (CNM/UNM/WNM, respectively), within 500 pc of the Sun and with _˜2 pc resolution.

This is achieved by combining state-of-the-art 3D dust maps with a new 3D model of the UV radiation field, accounting for individual O/B stars and clusters.

I will show that the CNM and UNM dominate near the Galactic midplane, transitioning to WNM beyond —z—_˜X pc. Strikingly, _˜X% of the ISM mass in the disk resides in the thermally unstable regime, providing direct evidence that turbulent mixing operates faster than thermal equilibration.

I will discuss how this connects to ISM turbulence, molecular cloud formation, and the gas cycling processes that fuel star formation in galaxies.

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*Speaker

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A High-Resolution View of Dense Gas Across Galactic Environments: Insights from M51 and Beyond

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Abstract

Star formation is a fundamental process shaping the evolution of galaxies, yet its dependence on the local galactic environment remains poorly understood. A key to unlocking this relationship lies in the dense molecular gas phase which serves as the fuel for star formation. In this talk, I present cloud-scale observations of N2H+, HCN and additional molecular lines in the 3mm regime across multiple environments in the nearby spiral galaxy M51 as part of the SWAN survey. This includes its spiral arms, interarm regions, nuclear bar and AGN-dominated center. These dense gas tracers show pronounced environmental variations, highlighting systematic changes in gas properties on _˜100pc scales. Lastly, I will place the M51 results in a broader context of both Galactic and extragalactic observations. These early results suggest that environmental effects play a significant role in shaping dense gas properties and may influence how reliably commonly used tracers such as HCN probe the star-forming dense gas phase. This motivates a more systematic reassessment of dense gas diagnostics across different galactic environments.

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*Speaker

Stratified sampling in the Gould Belt molecular clouds

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Abstract

Characterizing the molecular emission from whole molecular clouds is critical to identify the physical and chemical processes that act at different spatial scales and lead to the formation of stars. It is also needed to connect spatially-resolved observations of galactic clouds with extragalactic observations that do not resolve the clouds.

The traditional approach of characterizing the emission of clouds using mapping techniques is very time consuming since it requires fully sampling the emission over many square degrees in the sky, and for this reason, it can only be carried out over a very limited sample of clouds. As an alternative to mapping, we have developed a new technique of characterizing the multi-line emission from clouds using statistical sampling. Our method uses available extinction maps to select a relatively small sample of cloud positions that cover thefull range of column densities in the cloud, and that can be observed with only a modest investment of telescope time.

We present the results of applying our sampling technique to the three nearby clouds California, Perseus, and Orion A, for which we have used the IRAM 30m telescope to cover the full 3mm wavelength band. Although the clouds present very different rates of star formation, their emission properties are remarkable similar, and the intensity of all their tracers correlates strongly with the amount of column density. The observed similarities in the emission suggest that despite their star-forming differences, the clouds have a similar underlying physical structure and a chemical composition dominated by a few critical ingredients that include outer photodissociation, inner freeze out, and localized stellar feedback.

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*Speaker

Fitting AGN and host galaxy emission lines with CIGALE

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Abstract

To interpret high-quality spectra of medium redshift galaxies we need galaxy SED fitting codes, which enables to retrieve physical parameters from spectra with contributions both from the AGN and the host galaxy. We will present how to use the CIGALE SED fitting code to interpret emission lines from HII regions and photo dissocitated regions (Theulé et al.2024). We will also show how to model emission lines from AGN (Zhang et al., submitted). We will detail how lines are modeled in broad and narrow lines regions and combined with the lines of the host galaxy.

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*Speaker

Deep learning for radar image processing

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Abstract

After a brief introduction to remote sensing and radar imaging, I will present several deep learning methods designed to reduce speckle in Synthetic Aperture Radar images. I will discuss the various strategies that can be implemented within a deep learning framework, ranging from "plug-and-play" methods to supervised and self-supervised learning, as well as how physical knowledge can be effectively integrated. For each of these strategies, I will demonstrate how they can be extended to multichannel data, whether interferometric or polarimetric.

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*Speaker

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Multi-line observations of nearby galaxies

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Abstract

In the last decade, the improved sensitivity and bandwidth of (sub)millimeter-wavelength instruments have boosted the study of the molecular ISM in nearby galaxies, a field traditionally built on low-J CO observations. I will review some recent extragalactic surveys that have taken advantage of multi-species and multi-transition observations to constraint the physical and chemical properties of the molecular ISM. I will place emphasis on spatially-resolved studies that have tried to estimate gas density, a key parameter of the star formation process, and link it with the environmental conditions. I will discuss the main challenges and prospects of this line of research, both from the observational and from the modelling point of view.

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*Speaker

Estimating the dense gas mass of molecular clouds using spatially unresolved 3 mm line observations

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Abstract

Many cloud-scale star formation theories posit a direct relationship between the physical properties of molecular clouds (e.g., density, Mach number, boundedness) and the rate or efficiency at which they form stars (1). However, wide-field (i.e., 10s of kpc2) extragalactic molecular gas surveys remain limited to spatial resolutions of 50–100 pc. Consequently, unresolved spectral lines are averages of emission arising from sub-beam distributions of density ranging several orders of magnitude. Emission lines such as HCN(J=1→0) are commonly used in extragalactic observations to trace the dense (nH2 > ∼ 10 cm–3) portion of these sub-beam density distributions. However recent Milky Way studies (2) have challenged their use as unambiguous dense gas tracers, and suggested that a large fraction of their emission in nearby clouds is due to their excitation in lower density gas.
We aim to develop a new empirical method for estimating the dense gas mass and the sub-beam statistical distribution of H2 column densities (N-PDF) using spatially unresolved observations of molecular emission lines in the 3 mm band. We model the integrated intensity of spatially unresolved observations as the average of an emission function weighted by the sub-beam N-PDF. The emission function, which expresses the integrated intensity as a function of column density, is an empirical fit to high resolution (< 0.05 pc) multi-line observations of the Orion B molecular cloud (2). The sub-beam N-PDF is assumed parametric, composed of a turbulence driven log-normal (LN) distribution transitioning to a power-law (PL) at higher densities. This model is combined with a Bayesian inversion algorithm to estimate the sub-beam N-PDF and dense gas mass from observations.

We apply the method to 3 mm band observations of the M51 galaxy (d∼8.58 Mpc). We infer pixel-wise N-PDFs accross the galaxy, as well as dense and gravitationally collapsing gas masses. We then relate these parameters to the star formation activity traced by JWST observations and compare our results to Milky-Way studies (3).

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*Speaker

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The fundamental structure and physical conditions of the Orion Bar as seen by JWST and ALMA

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Abstract

The infrared emission from Photodissociation Regions (PDRs) dominates the spectra of galaxies as they reprocess a significant fraction of the radiation output of massive stars. The intense stellar far-ultraviolet (FUV) radiation incident upon PDRs plays a dominant role in the physics and chemistry of gas and dust. The study of these regions is therefore essential for a better understanding of star formation, stellar feedback and the evolution of interstellar matter. In this context, the Orion Bar, a prototypical PDR, acts as an interesting interstellar laboratory. In this contribution, I will present an overview of the main results obtained with the spectro-imaging data, acquired with the *James Webb Space Telescope* (JWST) (PDRs4All program) as well as with ALMA, of the Orion Bar. I will present how we derived strong constraints on physical conditions (temperature, density, warm chemistry...) using the many tracers observed with these instruments (H2, HD, CH+, HCN, CN). I will show that we observe a high density and thermal pressure gradient near the dissociation front. I will present the spatial morphology of HCN and CN emission observed with ALMA, well-known density tracers due to their high critical densities. Comparing observations with PDR and radiative transfer models, I will show that we derive high densities after the dissociation front but that we do not find major density variation, contrary to what is expected in a small-scale clumpiness scenario. We argue that the structure observed in HCN emission rather originated from the propagation of a UV-driven shock compressing the gas. Finally, I will show that in the extreme conditions found in the Orion Bar (high UV field intensity and gas density), we observe a very active UV-induced chemistry driven by high-temperature with reactions with H2 and FUV-pumped H2.

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*Speaker

Connecting Star Formation in the Milky Way and Nearby Galaxies – Consistency of Star Formation on Molecular-Cloud Scales Across Galaxies

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Abstract

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Star formation on molecular-cloud scales is investigated across 23 galaxies, including the Milky Way and 22 nearby galaxies.

Molecular clouds are identified using a dendrogram-based method, and their molecular masses (M_{cloud}) and star-formation rates (SFR$_{cloud}$) are derived from integrated CO and mid-infrared emission.

Overall, all systems follow a similar M_{cloud}–SFR$_{cloud}$ relation that is insensitive to galactic environment or galactocentric radius.

A theoretical framework based on the initial clump mass function of molecular clouds reproduces the observed M_{cloud}–SFR$_{cloud}$ relation across galaxies, demonstrating that the underlying mechanism is robust and broadly applicable. The results further indicate that Milky Way molecular clouds provide reliable templates for interpreting cloud-scale star formation in nearby galaxies. Although the physical conditions of molecular clouds vary within and among galaxies, as extensively discussed in the literature, such variation does not necessarily imply differences in star-forming capability. Molecular clouds themselves are not the fundamental units of star formation; rather, their dense clumps are. The weak dependence of clump-scale star formation on the surrounding environment offers a natural explanation for the remarkable uniformity of the M_{cloud}–SFR$_{cloud}$ relation across galaxies.

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[*] Speaker

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Grain growth in the early stage of star formation revealed by NIKA2 observations and 3D radiative transfer modeling

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Abstract

In the early phases of star formation, dense and cold structures such as filaments and prestellar cores are commonly probed and studied via observations of thermal dust emission. The inferred core properties from these observations are thus critically dependent on the adopted dust model, which must therefore be carefully characterized.

In this talk, I will present our study of L1506C, a fragment of the filament L1506 in the Taurus molecular cloud (D ~ 140 pc). Previous studies using dust and gas tracers suggest that it is a prestellar core in the making, and revealed signatures of dust evolution. Our goal is to bring further constraints on both the cloud structures and dust properties. We used observations of dust emission covering for the first time a broad wavelength range, from the far-infrared (FIR) to mm range, as well as 3D radiative transfer modeling, also taking into account constraints from extinction data.

We used our own developed data processing method to combine the Herschel FIR observations and new complementary mm wavelength observations with NIKA2. The analysis of spectral energy distributions (SEDs) over the whole spectral range was first performed with modified black body (MBB) fits. The data were then analyzed with 3D modeling using the radiative transfer code SOC and the latest THEMIS 2 dust models.

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*Speaker

MBB modeling over the wavelength range of 160 micron to 2 mm reveals that L1506C is fragmented into two cores with N_H2 < 7.5 x 10ˆ21 cmˆ-2 and masses smaller than their Jeans masses. Dust color temperature (T) drops from 16 K in the filament to 11 K in the cores and the spectral index beta increases from 1.4 to 1.9, showing clear T-beta anti-correlation and change in grain properties. Grains more evolved than the diffuse interstellar medium (ISM), with grain size up to 0.7 micron, 50% porosity and 50% ice content are required to model the source with 3D radiative transfer modeling. With our model, we are able to reproduce the observed mm emission within 10% residual in the central core region, near-infrared scattering (coreshine) within 1 sigma and extinction within a factor _˜2.8. The transition between diffuse and evolved grains may already happen at 1500 < n_H < 4500 cmˆ-3. Adopting the model with a transition threshold of n_H=3000 cmˆ-3, evolved grains account for 50% of the dust content along the line-of-sight at where A_V = 4 on the observed extinction map.

Our study shows that grain growth up to _˜0.7 micron can already happen at very early stage of star formation, even before the onset of gravitational collapse. It is difficult to constrain precisely the cloud properties with 3D radiative transfer modeling only with dust emission observation, because some of the parameters are degenerate. Observations of near-infrared extinction, scattering and independent measurements from molecular line data are crucial to complement these data, providing independent constraints and breaking degeneracies in the analysis.