Theoretical Insights into Star Formation: from the Early to the Present Day Universe

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Pisa

Book of Abstracts

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NEGATIVE ION CHEMISTRY AMONG STARS AND CLOUDS : MOLECULAR PROCESSES IN THE INTERSTELLAR MEDIUM

Author: Francesco Gianturco[1]

[1] *Institute of Ion Physics, Innsbruck University, Innsbruck Austria*

Corresponding Author: francesco.gianturco@uibk.ac.at

The last ten years or so have witnessed a tremendous growth
on the detection and observation of charged molecular species in the interstellar medium (ISM), especially within the special environments provided by interstellar and circumstellar clouds. Further observations within the atmospheres of the exoplanets have confirmed the marked ubiquity of these most diverse chemical species in the rather hostile environments of the interstellar space and identified specific regions that are considered to be the most efficient laboratories for molecular formation processes involving molecular anions. In the present talk I shall draw examples from our recent works on the study of molecular mechanisms presiding over ion-molecule reactions which lead to those anionic molecular products which have already been astronomically observed. We have been investigating the most efficient paths which can guide the formation of the recently observed carbon-rich molecular anions and on a variety of possible molecular quantum processes which can take place in the Diffuse and Dark regions of the interstellar clouds and in the atmospheres of some of the exoplanets.

1. F.A. Gianturco et al., Phys. Rev.Lett. 127, 043001 (2021).
2. F.A.G. et al., Phys. Rev. Lett.,131,183002 (2023).
3. F.A.G. et al., The Astrophys. J. 897,75-88 ,(2020)
4. F.A.G. et al., Faraday Disc., 212, 117 (2018).
5. F.A.G. et al.,The Astrophys. J., 850, 42 (2017).
6. F.A.G. et al., J. Chem. Phys. 153, 184309 (2020.
7. F.A.G. et al., MNRAS, 522 , 5775-5787 (2023).
8. F.A.G. et al., The Astrophys. J.,960, 40-52 (2023).
9. F.A.G. et al., The Astrophys. J., 973, 17 (2024)

Session 3 / 4

Signatures of magnetic braking in Class 0 protostars: Exploring the gas kinematics in magnetized models of low-mass star formation

Author: Nacho Añez-Lopez[1]

Co-authors: Anaëlle Maury [2]; Patrick Hennebelle [1]; Ugo Lebreuilly [1]

[1] *CEA Paris-Saclay*

[2] *ICE*

Corresponding Author: nacho.anyez@gmail.com

Only indirect evidence of the role of magnetic braking in regulating gravitational collapse and the formation of circumstellar disks, such as compact disk sizes and the launching of high-velocity collimated protostellar jets, has been found from observational work.

More direct tests of the magnetic braking shaping the angular momentum of the gas in Class 0 protostars are crucially needed to confirm and make progress on the magnetically regulated disk formation scenario.

In the present work we used nonideal magnetohydrodynamic models of protostellar collapse and synthetic observations of molecular gas spectral emission, from the radiative transfer post-processing of these models. We analyzed the synthetic observations to test whether possible kinematic signatures

of the magnetic braking in the gas velocity field can be captured from maps of the molecular gas emission in protostellar envelopes.

By comparing the 3D specific angular momentum of models with varying turbulent energy and magnetization, we show that, in the numerical models of protostellar evolution explored, the increase in magnetization and its consequences on the spatial redistribution of angular momentum modifies the shapes of the radial profiles of specific angular momentum probed along the equatorial plane. However, various analysis of gas kinematics from the synthetic observations of molecular line emission mostly fail to capture the magnitude and differences in radial profiles of specific angular momentum due to different magnetization. Finally, we compare our synthetic observations to observational datasets from the literature to discuss possible magnetic braking signatures in protostellar envelopes.

Our analysis suggests that the detection of symmetric patterns and organized velocity fields in the moment 1 maps of the molecular line emission, and monotonous radial profiles of the specific angular momentum showing a power law decline, should be suggestive of a less magnetized scenario. Protostellar cores where efficient magnetic braking is at work are more likely to present a highly asymmetric velocity field, and more prone to show complex radial profiles of their specific angular momentum measured in the equatorial plane.

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Unveiling the magnetized path of massive star formation with MAGMA

Authors: Alberto Sanna[1]; Chi Yan Law[1]; Daniele Galli[1]; Gabriele Surcis[1]; Jose Miguel Girart Medina[1]; Luca Moscadelli[1]; Marco Padovani[1]; Maria Teresa Beltran Sorolla[1]; Riccardo Cesaroni[1]

[1] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Authors: alberto.sanna@inaf.it, cesa@arcetri.inaf.it, chi.law@inaf.it, girart@ice.csic.es, galli@arcetri.inaf.it, marco.padovani@inaf.it, luca.moscadelli@inaf.it, maria.beltran@inaf.it, gabriele.surcis@inaf.it

Magnetic fields play a dynamically crucial role in massive star formation. Models of massive star formation suggest that the magnetic field could significantly prevent fragmentation, cloud and core collapse, and influence the formation of accretion disks and jets. However, there are many aspects that ultimately lead to the formation of massive stars and star clusters that still remain uncertain, including the relative importance of magnetic fields in setting the large-scale initial conditions, fragmentation and infall properties. Two possible methods to make progress in resolving these open questions are (i) to conduct multi-scale studies to characterise the magnetic field properties (morphology, strength and dynamical importance) from cloud to core to disk/jet scales and/or (ii) to statistically probe the magnetic field properties of a large sample of star-forming regions in different environments, which can help not only to better understand the its role in crucial processes such as star formation, but also to gain insights into their origin and evolution. In this talk I will summarise the preliminary results of the MAGnetic field in MAssive star formation (MAGMA) survey, which combines both methods by accurately characterising the magnetic field properties from cloud to disk scales over a statistically significant sample of high-mass star-forming regions. These preliminary results have already provided crucial insights into the role and relative importance of the magnetic field in high-mass star formation.

Session 3 / 6

ISM Turbulence and Magnetic Fields as regulators of Star Formation

Author: Diego Falceta-Goncalves[1]

[1] *EACH-USP*

Corresponding Author: dfalceta@usp.br

Star formation occurs in dense, turbulent and magnetized regions of the ISM. Gravity, turbulence and magnetic fields play different roles at different scales of the structure formation and collapse process. Both the mass distribution of cores and the formation efficiency/rate are thought to be dependent on these ingredients. Theories have been exploited for each particular process an specific scales, but a complete understanding of a complex, multiscale environment is yet to be provided. He we provide results of a number of high resolution numerical simulations of MHD turbulent ISM under effects of self-gravity. We follow the evolution of initially gravitationally unbound clouds, the structure formation as different levels of turbulence are present and the consequential collapse of these structures as they became individually gravitationally unstable. Different levels of magnetization are also studied. The core mass functions and the formation efficiency are obtained. They are shown to be dependent on the turbulent Mach number, but seem insensitive to the level of magnetization.

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On the multiscale relationship between magnetic field strength and gas density in the ISM

Author: David Whitworth[1]

Co-authors: Aina Palau [2]; Enrique Vázquez-Semadeni [2]; Fred Gent [3]; Juan Diego Soler Pulido [4]; Mordecai Mac-Low [5]; Patrick Hennebelle [6]; Philipp Girichidis [7]; Ralf Klessen [8]; Ralph Pudritz [9]; Rowan Smith [10]; Sundar Srinivasan [11]

[1] *UNAM IRyA*

[2] *Universidad Nacional Autónoma de México, Instituto de Radioastronomía y Astrofísica, Antigua Carretera a Pátzcuaro 8701, Ex-Hda. San José de la Huerta, 58089 Morelia, Michoacán, México*

[3] *Astroinformatics, Department of Computer Science, Aalto University, PO Box 15400, FI-00076, Espoo, Finland*

[4] *Istituto Nazionale di Astrofisica (INAF)*

[5] *Department of Astrophysics, American Museum of Natural History, 200 Central Park West, New York, NY 10024, USA*

[6] *CEA Paris-Saclay*

[7] *Institute for Theoretical Astrophysics, University of Heidelberg*

[8] *Universität Heidelberg, Zentrum für Astronomie, Institut für Theoretische Astrophysik, Albert-Ueberle-Str. 2, 69120 Heidelberg, Germany*

[9] *Department of Physics and Astronomy, McMaster University, 1280 Main Street West, Hamilton, ON, L8S4K1, Canada*

[10] *SUPA, School of Physics and Astronomy, University of St Andrews, North Haugh, St Andrews, KY16 9SS, UK*

[11] *Instituto de Radioastronomia y Astrofisica, Universidad Nacional Autonoma de Mexico (IRyA-UNAM)*

Corresponding Authors: d.whitworth@irya.unam.mx, s.srinivasan@irya.unam.mx, philipp.girichidis@uni-heidelberg.de, juan.soler@inaf.it

The relation between magnetic field strength, B, and gas density, n, in the interstellar medium is of fundamental importance to many areas of astrophysics, from protostellar disks to galaxy evolution. We present and compare a brand new multi-parameter Hierachical Bayesian analyses of the B-n relation for a comprehensive observational data set, as well as a large body of numerical MHD simulations. We extend the original Zeeman relation with 700 observations that use the Davis-Chandrasekhar-Fermi method and find the existence of power-law exponent in the diffuse ISM and a change in the position of the break point, which now appears at higher densities. We also perform a separate analysis on 19 numerical magnetohydrodynamics simulations that cover a wide range of scales, resolutions, initial conditions, and completed with a variety of codes: AREPO, Flash, PENCIL, and RAMSES. The power law exponents derived from the simulations depend on several physical factors including: dynamo effects, time scales, turbulence, and the initial seed field strength. In particularare we find that the simulations that trace the observed density range best, the evolved

dwarf galaxies and Milky Way like galaxy simulations match the observevational result closest with variability in the diffuse gas exponent.

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Magnetic fields in prestellar cores: a new perspective from meter-wavelength radio data

Author: Andrea Bracco[1]

[1] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Author: andrea.bracco@inaf.it

Magnetic fields in starless, prestellar cores are crucial for understanding the formation of stars, as these cores mark the initial gravitationally bound stage in the star-formation process. Typically, these cores accumulate gas from their molecular cloud environments until they overcome magneto-turbulent support and collapse into protostellar objects. Traditional studies of magnetic fields in these cores have primarily used indirect methods, such as infrared dust polarization and molecular-line Zeeman splitting. However, these methods have significant limitations, including large uncertainties and issues like magnetic-field dilution due to beam averaging.

In this talk, I propose a novel technique complementary to the infrared band, utilizing non-thermal synchrotron emission detectable in the radio spectrum to trace magnetic fields in prestellar cores. This approach builds on theoretical studies suggesting that cosmic-ray electrons interacting with magnetic fields can produce detectable synchrotron radiation at low radio frequencies (Padovani+2018). I will present an extensive statistical analysis using the LOFAR telescope at 144 MHz, focusing on the median stacking of a large sample of more than 300 prestellar cores in the Perseus molecular cloud (Bracco+2025). While we only achieved upper limits on magnetic field strengths on the order of 100 uG—due to current telescope sensitivity—this method promises a new avenue for studying magnetic fields in molecular clouds with upcoming advanced radio telescopes like the Square Kilometer Array, which could detect such emissions within a few hours of observation.

Session 5 / 10

Intertwined formation of H2 , dust, and stars in cosmological simulations

Authors: Cinthia Ragone[1]; Gian Luigi Granato[2]

[1] *IATE and INAF*

[2] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Author: gian.granato@inaf.it

Molecular hydrogen (H2) plays a crucial role in the formation and evolution of galaxies, serving as the primary fuel reservoir
for star formation. In a metal-enriched Universe, H2 forms mostly through catalysis on interstellar dust grain surfaces. However, due
to the complexities of modelling this process, star formation in cosmological simulations often relies on empirical or theoretical
frameworks that have only been validated in the local Universe to estimate the abundance of H2.
We model the connection between the formation of stars, dust, and H2 formation processes in cosmological simulations. The model reproduces, reasonably well, the main statistical properties of the observed galaxy population for the stellar, dust, and H2 components. The molecular hydrogen

cosmic density evolution in our simulated boxes peaks around redshift z = 1.5, consistent with observations. Following its peak, ρH2 decreases by a factor of two towards z = 0, a milder evolution than observed. Similarly, the evolution of the molecular hydrogen mass function since z = 2 displays a gentler evolution when compared to observations. Our model recovers the integrated molecular Kennicut-Schmidt (mKS) law between the surface star formation rate (ΣSFR) and surface H2 density (ΣH2) satisfactorily at z = 0. This relationship is already evident at z = 2, albeit with a higher normalization. We find hints of a broken power law with a steeper slope at higher ΣH2. We also study the H2-to-dust mass ratio in galaxies as a function of their gas metallicity and stellar mass, observing a decreasing trend with respect to both quantities. The H2-to-dust mass fraction for the global population of galaxies is higher at higher redshift. The analysis of the atomic-to-molecular transition on a particle-by-particle basis suggests that gas metallicity cannot reliably substitute the dust-to-gas ratio in models attempting to simulate dust-promoted H2.

Session 4 / 11

Star formation history of the Milky Way thick and thin discs from chemical evolution models

Author: Valeria Grisoni[1]

[1] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Author: valeria.grisoni@inaf.it

I will discuss the formation and evolution of the Milky Way thick and thin discs from the point of view of detailed Galactic chemical evolution models. To model the evolution of these two components and explain the observed bimodality in the [α/Fe] vs. [Fe/H] plot, two different approaches can be adopted. In particular, (i) a sequential scenario called two-infall approach where the thick disc forms fast and before the thin disc and by means of a fast gas accretion episode, whereas the thin disc forms by means of a second accretion episode on a longer time-scale; (ii) a parallel approach, where the two discs form in parallel but at different rates. By means of chemical evolution models, I will show new results for the star formation history of the Milky Way thick and thin discs in the light of recent data for abundance patterns, metallicity distributions and age distributions of thick and thin disc stars.

Session 4 / 12

The meaning of star formation efficiency in accreting clouds: gaseous and stellar mass evolution

Authors: Enrique Vazquez-Semadeni[1]; Javier Ballesteros-Paredes[1]; Manuel Zamora-Avilés[2]

[1] *Instituto de Radioastronomia y Astrofisica, Universidad Nacional Autonoma de Mexico*

[2] *Instituto de Astrofísica, Óptica y Electrónica*

Corresponding Authors: j.ballesteros@irya.unam.mx, mzamora@inaoep.mx, e.vazquez@irya.unam.mx

The star formation efficiency per free-fall time, defined as e_ff = (SFR/Mg) tff, where SFR is the star formation rate, Mg is the mass of a cloud, and tff is the cloud's free-fall time, is traditionally interpreted as the fraction of a cloud's mass that is converted into stars during the cloud's free-fall time. However, recent observational and numerical results suggest that molecular clouds are continuously replenished by accretion from their environment, causing their masses to increase in time, until they begin to be dispersed by stellar feedback. In this case, clouds can be viewed as funnels rather than as objects with a well defined mass, and the standard interpretation of e_ff becomes blurry. We propose an alternative interpretation of e_ff as the ratio of the observed star formation rate (SFR) to the theoretical free-fall collapse rate of the cloud. This description allows

understanding the constancy and low values of e_ff as a consequence of the density and accretion rate radial profiles across the cloud, and of the observational approximations made for estimating the SFR, without resorting to any kind of support. In turn, these radial profiles are time-dependent. We present a toy model that simultaneously follows the gaseous and stellar mass evolution in a cloud, and predicts a lower limit to the time required for the appearance of stars that can disrupt the accretion flow.

Session 1a / 13

Testing Star Formation Models in Nearby Galaxies: A Focus on Dense Gas

Author: Ashley Bemis[1]

[1] *Waterloo Centre for Astrophysics*

Corresponding Author: abemis@uwaterloo.ca

Regions with higher star formation rates are thought to have more dense, molecular gas that serves as the direct fuel for star formation. However, resolved studies of nearby galaxies find systematic variations in the star formation efficiency of dense gas (SFEdense) with local galactic environment. One physical explanation for this behaviour is the suppression of star formation in dense galactic environments, potentially due to high stellar potentials or enhanced turbulence. For example, variations in the SFEdense are a prediction of turbulent models of star formation. Another possibility is that there are systematic uncertainties with observational proxies of dense gas fraction (i.e. HCN/CO). In recent work, we test this paradigm by modelling emissivities of HCN and CO over a broad range of cloud properties encompassing those found in PHANGS galaxies, as well as nearby mergers and LIRGs. Our CO emissivities and optical depths well-match those produced by simulations as well as recent observational work using multi-J observations of CO in the PHANGS galaxies and Antennae. Additionally, our HCN emissivities agree with those found in Milky Way clouds. We find that the fraction of "star-forming"gas predicted by turbulent models of star formation appears anticorrelated with the dense gas fraction, as well as the modelled HCN/CO intensity ratio in our sample of cloud models. This results in an apparent decrease in SFEdense in models with high dense gas fraction and HCN/CO, which agrees with observations of nearby galaxies. Additionally, we find that the HCN/CO intensity ratio most directly tracks the fraction of gas above moderate (~10^3 cm^-3) densities in our models, but has a steeper relationship with the fraction of dense (>10^4 cm^-3) gas. Combined, these results suggest that while there is potentially a physical origin to variations in SFEdense, we must also consider the systematic effects that impact the emissivities of our observational tracers.

Session 1a / 14

Dust evolution in prestellar dense cores

Author: Valentin Vallucci-Goy[1]

[1] *CEA Saclay*

Corresponding Author: valentin.goy@cea.fr

Dust grains plays an essential role in many fields of astrophysics. In particular, they are the main charge carriers during the protostellar collapse and as such, control the evolution of angular momentum [1,2]. In addition, they are the fondamental bricks for the formation of planetesimals and planets [3].

Firstly, we perform single-zone simulations including a complex chemical network to study the collapse of a dense core accounting for dust coagulation and fragmentation. We find that magnetic

resistivities are highly sensitive to the population of small grains, which are rapidly depleted via ambipolar drift. This results in a very high ambipolar resistivity producing large protoplanetary disks as magnetic braking is rendered inefficient. Since disks are observed to be rather small in size [4], we identify two mechanisms to preserve the small grains and thus alleviate this tension: grain-grain electrostatic repulsion and erosion [5].
Secondly, we perform 1D simulations of magnetized dust in a turbulent magnetized medium reproducing dense core environments, making a full treatment of both the gas and dust dynamics. Turbulence is driven on large scales. We use a sophisticated non-ideal MHD approach including charged dust grains, neutral gas and ions. We observe high levels of dust concentration driven by magnetic effects. The parametric instability [6] is triggered in the dust in shocked regions, producing long-lived dust clumps and dust density enhancements of a factor of 10 to more than 100 [7]. Those clumps persist over time owing to the cold and pressureless nature of dust. This has interesting implications for dust growth in prestellar envelopes. Recent observations suggest the presence of $100\ \mu\mathrm{m}$ grains in such environments [8]. Using an analytical model for dust growth, we find it to possible to form in-situ large grains by pure means of coagulation in a reasonable amount of time provided that the local dust-to-gas ratio $\epsilon \geq 10\%$. Such dust density enhancements are achieved via the novel mechanism previously mentioned.

References :

[1] Zhao B., Caselli P., Li Z.-Y., Krasnopolsky R., Shang H., Nakamura F., 2016, MNRAS.

[2] Hennebelle P., Commerc¸on B., Lee Y.-N., Charnoz S., 2020, A&A.

[3] Testi L., et al., 2014, in Beuther H., Klessen R. S., Dullemond C. P., Henning T., eds, Protostars and Planets VI. p. 339.

[4] Maury, A. J., André, P., Testi, L., et al. 2019, A&A, 621, A76.

[5] Vallucci-Goy, V., Lebreuilly, U., and Hennebelle P., 2024, A&A, 690, A23.

[6] Del Zanna, L., Velli, M. and Londrillo, P., 2001, A&A, 367.

[7] Vallucci-Goy V., Hennebelle P., Lebreuilly U. and Verrier G., A&A submitted.

[8] Galametz, M., Maury, A. J., Valdivia, V., et al. 2019, A&A, 632, A5.

Session 5 / 15

Dust Attenuation of Star-Forming Galaxies in the Early Universe with JWST

Author: Vladan Markov[1]

[1] *FMF, University of Ljubljana, Slovenia*

Corresponding Author: vladan.markov@fmf.uni-lj.si

Dust plays a fundamental role in shaping the formation and evolution of galaxies, regulating star formation through absorption and scattering of stellar light. The dust attenuation curve provides key insights into dust properties and their connection to the interstellar medium (ISM), yet its characteristics in the early Universe remain poorly constrained.

Using JWST/NIRSpec spectroscopy, we analyze a large sample of galaxies at z ~ 2–12, applying a customized SED-fitting approach to simultaneously characterize dust attenuation and global galaxy properties. We find evidence for a significant evolution in attenuation curves with redshift, suggesting changing dust grain compositions and production mechanisms. Additionally, we detect UV bump features in ~30 galaxies, including the most distant case at z = 7.55, placing new constraints on early dust enrichment. Our results provide crucial insights into the link between dust, star formation, and chemical evolution, shedding light on the earliest stages of galaxy assembly.

Session 1a / 16

Gas infall via accretion disk feeding Cepheus A HW2

Author: Alberto Sanna[1]

[1] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Author: alberto.sanna@inaf.it

Located at the edge of the Cepheus Bubble, the massive star-forming region Cepheus A hosts HW2, a very young star growing more than dozen times the mass of our Sun - and the second closest of its kind to us. Using sensitive VLA observations, we have finally imaged its debated accretion disk in hot ammonia at centimeter wavelengths. We have resolved the accretion disk within a few hundred au of HW2, showing that circum-stellar gas is collapsing nearly in free-fall and slowly orbiting at 40% the Keplerian velocity down to 200 au. At this distance from the star, gas piles up at very high infall rates of 0.002 Solar masses per year. I will discuss both state-of-the-art simulations and a toy model which reproduce our observations in detail, commenting on (1) how these new findings advance our knowledge of (proto-)stellar disks at large and (2) how they can drive future observations in the field.

Session 1b / 17

Investigating the origin of stellar masses with ALMA-IMF

Author: Thomas Nony[1]

Co-authors: Fabien Louvet [2]; Frédérique Motte [2]

[1] *Istituto Nazionale di Astrofisica (INAF)*

[2] *IPAG*

Corresponding Author: thomas.nony@inaf.it

The origin of stellar masses and the link between core and stellar mass distributions (CMF and IMF respectively) are a central open issue in astrophysics. I will present the ALMA-IMF Large Program, whose goal is to determine if and how the origin of the IMF depends on the cloud characteristics and evolution. We surveyed 15 massive protoclusters covering a wide variety of Galactic environments and evolutionary stages (Motte et al. 2022; Galvan-Madrid et al. 2024). ALMA-IMF provides the community an homogeneous database of about 1000 cores (Louvet et al. 2024), 25% of which qualify as protostellar as they drive outflows (Nony et al. 2023) and hot cores (Bonfand et al. 2024).
ALMA-IMF results indicate that the mass distributions of cores in these massive environments of the Milky Way present an excess of high-mass cores with respect to the canonical IMF (Pouteau et al. 2022; Louvet et al. 2024). We propose that the CMF deviates from the canonical IMF form when and where a burst of star formation develops (Nony et al. 2023; Pouteau et al. 2023; Armante et al. 2024). Based on the combined analysis of the core distribution (CMF, mass segregation) and cloud structure (PDF), we propose an evolutionary sequence of massive protoclusters, which is in line with the dynamical scenarios of cloud and star formation (e.g., Motte et al. 2018a; Vazquez-Semadeni et al. 2019).

Session 1a / 18

Rotation and angular momentum transport mechanisms in molecular clouds and filaments

Author: Griselda Arroyo-Chavez[1]

Co-author: Enrique Vazquez-Semadeni [2]

[1] *Steward Observatory - University of Arizona*

[2] *Instituto de Radioastronomia y Astrofisica, Universidad Nacional Autonoma de Mexico*

Corresponding Authors: e.vazquez@irya.unam.mx, arroyochavezg@arizona.edu

For many years, evidence of large-scale velocity gradients has been found in molecular clouds and filaments, which are commonly associated with rotation. It is known that during the collapse and fragmentation of these structures, a process of redistribution and loss of angular momentum is involved, such that the fragments possess less angular momentum per unit of mass than their parent structures. The mechanisms responsible for transporting angular momentum out of the fragments are still a matter of debate. Therefore, studying this redistribution process is essential to understand both the star formation process and (since at some point the mechanism responsible for transporting angular momentum at cloud scales should be inefficient on small scales) disks formation.

In this work we focus on the study of the residual angular momentum and the 3D velocity field in and around molecular clouds and filaments. We analyze numerical simulations including turbulence, gravity, and magnetic fiel, and define numerical samples of clumps and filaments. In particular, we address the following issues:

1. Turbulent viscosity: dominant mechanism for transferring angular momentum at molecular cloud scales? Are gravity and magnetic field necessary to reproduce angular momentum scaling in clumps and cores?
2. Angular momentum measurements in filaments: what is the best way to measure it? Do filaments follow the same angular momentum scaling as clumps and cores? And more importantly, do filaments rotate?
3. Filament dynamics: what is the 3D velocity and magnetic field around and inside filaments? Properties of turbulence in filaments? Is the angular momentum of clumps and cores determined by these properties?

Work in progress with openness to discussion and collaboration.

Session 4 / 19

Distinguishing the Central Molecular Zone from Spiral Arms Using Fourier Space Filtering

Author: Stevie King[1]

[1] *Astrophysics Research Insititute Liverpool John Moores University*

Corresponding Author: arisking@ljmu.ac.uk

Accurately determining the properties of the Milky Way's Central Molecular Zone (CMZ) poses a complex challenge for astronomers due to significant contamination from the Galactic Spiral Arms, through which we observe. In position-velocity space, the CMZ is characterised by signals exhibiting high velocity dispersion, while the Spiral Arms show extensive spatial dispersion. To address this obstacle, we have developed a novel method utilising Fourier transform and filtering techniques to effectively separate these signals. We apply these methods to the ^{12}CO & ^{13}CO J = 3 - 2 data obtained as part of the CHIMPS2 survey. By transforming the data to the frequency domain and applying band filtering techniques, we isolate the distinct frequency components associated with the CMZ and Spiral Arms. Preliminary results demonstrate the efficacy of our method in distinguishing between the CMZ and Spiral Arm signals, and shows promise for enhancing our understanding of the structure and dynamics of these regions and allowing for direct comparison of their properties from single data sets. Additionally, we can obtain preliminary measurements of the newly isolated Spiral Arm's physical properties. This method shows potential as a robust tool for astronomers to

analyse complex galactic environments, facilitating more accurate interpretations of observational data.

Session 6 / 20

Impacts of Energetic Particles from T Tauri Flares on Inner Protoplanetary Discs.

Author: Valentin Brunn[1]

[1] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Author: valentin.brunn@inaf.it

T Tauri stars are known to be magnetically active stars subject to strong flares observed in X-rays. These flares are likely due to intense magnetic reconnection events during which a part of the stored magnetic energy is converted into energetic supra-thermal particles.
Since T Tauri stars are surrounded by accretion discs, these particles may influence the disc dynamics and chemistry. The talk will discuss our methods for modelling particle acceleration in T Tauri flares. We will then examine the ionization rate produced by these flares, relying on data from the Chandra X-ray survey of nearby young stellar objects.
Our work indicates that energetic particles from flares significantly contribute to the ionisation of the disc. The talk will also address the consequences of this additional ionisation source on the inner disc, focusing on its impact on accretion rates, chemical complexity, heating rates, and potential observables by the James Webb Space Telescope.

This talk will provide new insights about the interactions between young stars and the discs surrounding them.

Session 1b / 21

Core Formation in Molecular Clouds: Evidence Favoring Turbulent Over Gravitational Fragmentation

Author: Fumitaka Nakamura[1]

[1] *NAOJ*

Corresponding Author: fumitaka.nakamura@nao.ac.jp

Stars form within dense cores embedded in turbulent molecular clouds. In this study, we investigate the cloud fragmentation process in Galactic molecular clouds with various star formation acttivity. Using astrodendro, we identified over 10^4 dense cores across both nearby molecular clouds and high-mass star-forming clumps. Our central hypothesis is that core mass and separation provide key insights into cloud fragmentation mechanisms.

Our analysis reveals that in nearby clouds, core masses and separations are significantly smaller than those predicted by gravitational fragmentation but agree well with the expectations of turbulent fragmentation. In contrast, in high-mass SF clumps, cores formed via turbulent fragmentation tend to be gravitationally unstable, suggesting that self-gravity plays an increasingly dominant role in higher-density environments.

These findings indicate that turbulent fragmentation is the primary mechanism driving core formation across diverse cloud conditions, with gravitational effects becoming more significant as density increases.

Session 5 / 22

The POPSICLE project: star cluster formation at cosmic dawn

Author: Piyush Sharda[1]

[1] *Leiden University*

Corresponding Author: sharda@strw.leidenuniv.nl

The era of cosmic dawn began with the first stars that formed in the Universe a mere 200 - 300 million years after the Big Bang. These stars produced the first supernovae and black holes, enriched the interstellar medium (ISM) with metals, were the building blocks of the first galaxies, and significantly contributed to cosmic reionization. However, compared to star formation and feedback in metal-rich environments today, the lack of direct observations at low metallicities as well as high redshifts has posed a significant challenge for understanding the physics behind their formation and evolution. In this talk, I will introduce POPSICLE, a new framework for high resolution simulations that caters to star formation and feedback in low metallicity environments reminiscent of redshift > 10 galaxies. I will describe how incorporating the full spectrum of ISM physics coupled to stellar evolution is crucial to constrain the stellar initial mass function (IMF) and feedback in such environments. I will particularly focus on the impacts of non-equilibrium chemistry, cosmic rays, and cooling in these environments, and discuss the interplay between different physicochemical mechanisms that govern the IMF, feedback and black hole growth in the early Universe. I will conclude by showcasing the capability of GPU-accelerated simulations to revolutionize our understanding of the astrophysics of cosmic dawn, and bring theory at par with state of the art observations from JWST.

Session 1b / 23

Observations of spiral and streamer on a candidate proto-brown dwarf

Author: Basmah Riaz[1]

[1] *LMU, Germany*

Corresponding Author: basriaz@gmail.com

Spirals and streamers are the hallmarks of mass accretion during the early stages of star formation. We present the first ALMA observations of a large-scale spiral and a streamer towards a very young brown dwarf candidate in its early formation stages. These observations provide a unique insight into the influence of external environment that results in asymmetric mass accretion via feeding filaments on to a candidate proto-brown dwarf. We have provided two possible theoretical scenarios to interpret the observations: (i) a pseudo-disk twisted by core rotation, and (ii) the collision of two low-mass dense cores. Both models support a gravitational infall scenario of brown dwarf formation, albeit with some fundamental differences. The first model argues for the presence of a strong magnetic field in brown dwarf formation while the second model suggests that a minimal magnetic field allows large-scale spirals and clumps to form far from the candidate proto-brown dwarf. We have also found evidence that the impact of the large-scale streamer has triggered warm carbon-chain chemistry and affected the chemical composition in the close vicinity of the candidate proto-brown dwarf.

Session 1a / 24

Understanding the mix of thermal and non-thermal emission in HII regions

Author: Alvaro Sanchez-Monge[1]

Co-authors: Fanyi Meng [2]; Marco Padovani [3]

[1] *Institute of Space Sciences (ICE, CSIC)*

[2] *University of Chinese Academy of Sciences*

[3] *INAF - Osservatorio Astrofisico di Arcetri*

Corresponding Authors: asanchez@ice.csic.es, mengfanyi@ucas.ac.cn, marco.padovani@inaf.it

The giant molecular cloud Sagittarius B2 (hereafter SgrB2) is the most massive region with ongoing high-mass star formation in the Galaxy. In the southern half of the 20-pc large envelope of SgrB2, we encounter the SgrB2(DS) region which hosts more than 60 high-mass proto-stellar cores distributed in an arc shape around an extended HII region. We use the Very Large Array in its CnB and D configurations, and in the frequency bands C (4-8 GHz) and X (8-12 GHz) to observe the whole SgrB2 complex. Continuum and radio recombination line maps are obtained. We detect radio continuum emission in SgrB2(DS) in a bubble-shaped structure. Using data from 4 to 12 GHz, we derive a spectral index between -1.2 and -0.4, indicating the presence of unexpected non-thermal emission. Moreover, the radio recombination lines in the region are found to not be in local thermodynamic equilibrium (LTE) but stimulated by non-thermal emission. The detected fraction of thermal free-free emission is likely tracing an HII region ionized by an O7 star, while the non-thermal emission is likely being generated by relativistic electrons created through first-order Fermi acceleration. Is SgrB2(DS) a peculiar case, or are there other similar HII regions in the Galaxy? Future observations could reveal new insights into the properties of HII regions, and their interaction with the surrounding medium.

Session 1a / 25

ALMAGAL: Evolutionary study of high-mass protocluster formation in the Galaxy

Author: Alvaro Sanchez-Monge[1]

Co-authors: Cara Battersby [2]; Paul Ho [3]; Peter Schilke [4]; Sergio Molinari [5]

[1] *Institute of Space Sciences (ICE, CSIC)*

[2] *University of Connecticut*

[3] *ASIAA - Institute of Astronomy and Astrophysics, Academia Sinica*

[4] *Universitaet zu Koeln*

[5] *INAF - Istituto di Astrofisica e Planetologia Spaziale*

Corresponding Authors: cara.battersby@uconn.edu, asanchez@ice.csic.es, schilke@ph1.uni-koeln.de, pho@asiaa.sinica.edu.tw, sergio.molinari@inaf.it

Stars form preferentially in clusters deeply embedded inside massive molecular clouds. Some of these clusters contain high-mass stars that influence their immediate environment through gravitational, mechanical and radiative interactions, and eventually through supernova explosions. Therefore, a comprehensive understanding of star formation requires characterizing the formation and early evolution of (high-mass) stellar clusters. The ALMA Large Program ALMAGAL has observed over 1000 high-mass star forming regions distributed throughout the Galaxy, sampling different evolutionary stages and environmental conditions. For the first time, a large sample has been observed at high spatial resolutions (1000 au) and mass sensitivities (0.1 Msun), enabling statistically relevant studies. In this talk, we will present the ALMAGAL project. This includes the observation strategy and main challenges during the data reduction process, as well as a glimpse to the first scientific results and the potential and legacy value of the project. Overall, ALMAGAL aims at providing answers to key questions of the star formation process such as: What are the processes that govern fragmentation and allow the formation of star clusters? How do the different cluster members gain mass, and how feedback may influence the process? How does chemistry evolve in time during the star formation process?

Session 1a / 26

From cosmic dust to planet formation : Building new dust models

Author: Marie-Anne CARPINE[1]

Co-authors: Anaëlle Maury [2]; Nathalie Ysard [3]

[1] *CEA/DRF/DAp - AIM*

[2] *Institute of Space Sciences (Barcelona) & CEA Astrophysics department (Paris-Saclay)*

[3] *IRAP, CNRS, Université de Toulouse, Toulouse, France*

Corresponding Authors: marie-anne.carpine@cea.fr, anaelle.maury@icrea.cat

The characterisation of cosmic dust properties is key for understanding, among other things, star and planet formation processes. Astronomical observations provide us information from which it is possible, but not trivial, to deduce physical properties of cosmic dust. For instance, recent observations of 12 young protostars found dust emissivity indices with values $\beta < 1$ [Maury et al. 2019, Galametz et al. 2019], which would imply that dust coagulated into grains over 100µm in size [Ysard et al. 2019], much larger than what predicts actual paradigms of planet formation at this stage of stellar evolution. However, relating the grain sizes to their opacity measured in the millimetre bands is not straightforward and rely heavily on the validity of current dust models used as astrophysical analogues in the community. For example, the optical properties of large dust aggregates in cold environments, as observed in millimetre wavelengths were not explored in a systematic way, limiting the astrophysical interpretation that can be done from the measurements, especially for the dense ISM. Our work addresses this blind spot, building new physically-motivated dust models to interpret the dust signatures in protostellar environments.
Our study concentrates on the optical properties of a few examples of dust grains. Using laboratory-measured material properties from the THEMIS 2 dust model [Ysard et al. 2024], we derive various grain shapes in the scope of picturing the evolution from small compact grains to potentially large fluffy aggregates. We used the Discrete Dipole approximation (DDA) code ADDA [Yurkin et al. 2011] to compute our grains'optical properties. First results show a heavy dependence of these optical properties on the shape, but also on the composition of dust grains.
Building reliable dust models is decisive in the interpretation of observations of the dense ISM, in our understanding of dust evolution towards planet formation, and dust interactions with gas and magnetic fields for instance. We hope to build a robust model of dust grains population, challenge fiducial dust models, and permit to make progress in these fields.

Session 3 / 28

The launching mechanism of protostellar winds via water masers

Author: Luca Moscadelli[1]

[1] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Author: luca.moscadelli@inaf.it

The formation of astrophysical objects of different nature, from black holes to
gaseous giant planets, involves a disk-jet system, where the disk drives the mass accretion onto a central compact object and the jet is a fast collimated ejection along the disk rotation axis. Magnetohydrodynamic disk winds can provide the
link between mass accretion and ejection, which is essential to ensure that the
excess angular momentum is removed and accretion can proceed. Through sensitive
Global Very Long Baseline Interferometry observations of the polarized emission
of the 22 GHz water masers, we have traced individual streamlines of the magnetohydrodynamic (MHD) disk wind associated with the intermediate-mass YSO IRAS 21078+5211. Our resistive-radiative-gravito-MHD simulations of a jet around a forming massive star are able to closely reproduce both

the observed maser kinematics
and magnetic field configuration in the inner jet cavity. By recent multi-epoch Very Long Baseline Array observations, we have determined the maser 3D velocity field, too. This talk discusses the results of these new observations and their contribution to better characterize the disk wind physics.

Session 1a / 29

Understanding Present-Day Low-Mass Star Formation Through Second-Collapse Calculations

Author: Adnan Ali Ahmad[1]

Co-authors: Benoît Commerçon [1]; Matthias Gonzàlez [2]; Patrick Hennebelle [3]; Ugo Lebreuilly [3]

[1] *CRAL - ENS LYON*

[2] *Université Paris Cité*

[3] *CEA*

Corresponding Authors: ugo.lebreuilly@cea.fr, matthias.gonzalez@cea.fr, patrick.hennebelle@cea.fr, benoit.commercon@ens-lyon.fr, adnan-ali.ahmad@cnrs.fr

Describing the collapse of a gravitationaly unstable cloud core to stellar densities requires one to tackle a huge dynamical range, where a first core in hydrostatic equilibrium forms, which then collapses again following the dissociation of H_2 to form a protostar. Since R. Larson's (Larson 1969) pioneering work, second-collapse calculations have advanced significantly by incorporating realistic initial conditions, angular momentum, radiative transfer, and magnetic fields in 3D (Machida+ 2006, Vaytet+ 2018, Wurster+ 2020, 2022). However, computational constraints often limit these simulations to shortly after protostellar birth.
In a suite of papers presenting the highest-ever 3D resolution second-collapse calculations (Ahmad+ 2023, 2024, Ahmad+ 2025 submitted) using the RAMSES code with Adaptive Mesh Refinement, we extend these calculations to later stages, simulating the first few years of the protostar while focusing on the innermost sub-AU scales.
We find that the protostar's rapid accretion of angular momentum causes its outer layers to reach rotational breakup, forming a hot, eccentric, and highly-flared disk. The protostar and disk act as a continuous system, with the accretion shock enveloping both, a result which has implications for the angular momentum problem. Magnetic fields alter the disk and protostar's properties by affecting the angular momentum budget. This in turn affects the disk density, which has repercussions on the disk mass problem; a discrepancy between observed and simulated disk masses. The disk's rapid outward expansion may have left its mark on the meteoric record of the early solar system, as high-temperature condensates in the form of calcium-aluminum inclusions and amoeboid olivine aggregates show evidence of rapid outward transport (Morbidelli+ 2024).
Having resolved the accretion shock, we were also able to measure its radiative efficiency, which we found quickly reaches unity, thus ensuring cold accretion. This result has substantial implications for pre-main sequence models, as it dictates the entropy content of the protostar and thus its evolution (Baraffe+ 2012).
We also study the magnetic properties of the protostar, and how this fits into the wider magnetic flux problem.
By pushing state of the art calculations further out in time, and by placing our focus on the smallest spatial scales relevant to star and disk formation, we have revealed a number of physical processes that carry substantial implications on several issues in the field.

Session 1b / 30

Investigating massive star formation with ALMAGAL: clump fragmentation statistics, compact source catalog and evolution of the core population

Author: Alessandro Coletta[1]

Co-authors: Sergio Molinari [2]; Eugenio Schisano [1]; Alessio Traficante [1]; Davide Quintino Elia [1]; Milena Benedettini [1]; Chiara Mininni [3]; Juan Diego Soler Pulido [1]; Alvaro Sanchez-Monge [4]; Peter Schilke [5]; Cara Battersby [6]; Gary Fuller [7]; Henrik Beuther [8]; Qizhou Zhang [9]; Maria Teresa Beltran Sorolla [1]; Beth Jones [10]; Ralf Klessen [11]; Stephanie Walch [10]; Francesco Fontani [1]; Adam Avison ; Crystal Brogan ; Seamus Clarke ; Perry Hatchfield ; Patrick Hennebelle [12]; Paul Ho [13]; Todd Hunter ; Katherine Johnston ; Pamela Klaassen ; Patrick Koch ; Rolf Kuiper ; Dariusz Lis ; Tie Liu ; Stuart Lumsden ; Ylenia Maruccia [1]; Tobias Moller ; Luca Moscadelli [1]; Alice Nucara [14]; Andrew Rigby ; Kazi Rygl [1]; Patricio Sanhueza ; Floris Van der Tak ; Molly Wells ; Friedrich Wyrowski ; Fabrizio De Angelis [14]; Scige"John Liu [1]; Aida Ahmadi ; Leonardo Bronfman ; Liu ; Su ; Ya-Wen Tang ; Leonardo Testi [15]; Hans Zinnecker

[1] *Istituto Nazionale di Astrofisica (INAF)*

[2] *INAF - Istituto di Astrofisica e Planetologia Spaziale*

[3] *Università degli Studi di Firenze - INAF*

[4] *Institute of Space Sciences (ICE, CSIC)*

[5] *Universitaet zu Koeln*

[6] *University of Connecticut*

[7] *University of Manchester, Univ. Koln*

[8] *Univ. Heidelberg*

[9] *Cambridge*

[10] *Univ. Koln*

[11] *Universität Heidelberg, Zentrum für Astronomie, Institut für Theoretische Astrophysik, Albert-Ueberle-Str. 2, 69120 Heidelberg, Germany*

[12] *CEA Paris-Saclay*

[13] *ASIAA - Institute of Astronomy and Astrophysics, Academia Sinica*

[14] *INAF-IAPS*

[15] *Dipartimento di Fisica e Astronomia, Università di Bologna*

Corresponding Authors: schilke@ph1.uni-koeln.de, asanchez@ice.csic.es, milena.benedettini@iaps.inaf.it, scige.liu@inaf.it, maria.beltran@inaf.it, luca.moscadelli@inaf.it, sergio.molinari@inaf.it, kazi.rygl@inaf.it, alessandro.coletta@inaf.it, alessio.traficante@inaf.it, francesco.fontani@inaf.it, juan.soler@inaf.it, leonardo.testi@inaf.it, eugenio.schisano@inaf.it, pho@asiaa.sinica.edu.tw, davide.elia@inaf.it, ylenia.maruccia@inaf.it, cara.battersby@uconn.edu, mininni@arcetri.astro.it

The physical mechanisms behind the fragmentation of high-mass dense clumps into compact star-forming cores and the properties of these cores are fundamental topics that are heavily investigated in current astrophysical research. The ALMAGAL survey (Molinari et al. 2025, A&A, in press) provides the opportunity to study this process at an unprecedented level of detail and statistical significance, featuring high-angular resolution 1.38 mm ALMA observations of 1013 massive dense clumps at various Galactic locations. These clumps cover a wide range of distances ($\sim 2-8$ kpc), masses ($\sim 10^2 - 10^4\,\mathrm{M}_\odot$), surface densities ($0.1-10$ g cm^{-2}), and evolutionary stages (luminosity over mass ratio indicator within $\sim 0.05-450\,\mathrm{L}_\odot/\mathrm{M}_\odot$).
In this contribution (based on Coletta et al. 2025, A&A, in press), I present the catalog of compact sources obtained with the *CuTEx* algorithm from continuum images of the full ALMAGAL clump sample combining ACA-7m and 12m ALMA arrays, reaching a uniform high median spatial resolution of ~ 1400 au (down to ~ 800 au). In detail, I characterize and discuss the revealed fragmentation properties and the estimated physical parameters of the core population. The ALMAGAL compact source catalog includes 6348 cores detected in 844 clumps (83% of the total), with a number of cores per clump between 1 and 49 (median of 5). The estimated core diameters are mostly within $\sim 800-3000$ au (median of 1700 au). Core temperatures were assigned based on the L/M of the hosting clump; estimated core masses range from 0.002 to $345\,\mathrm{M}_\odot$ (complete above $0.23\,\mathrm{M}_\odot$), and exhibit a good correlation with the core radii ($M \propto R^{2.6}$). Furthermore, I discuss the variation in the core mass function (CMF) with evolution as traced by the clump L/M, finding a clear, robust shift and change in slope among CMFs within subsamples at different stages. This important finding suggests that the CMF shape is not constant throughout the star formation process, but rather it builds (and flattens) with evolution, with higher core masses reached at later stages. Moreover, all cores within a clump appear to grow in mass on average with evolution, while a population of possibly newly formed lower-mass cores is present throughout. The number of cores increases with the core masses, at least until the most massive core reaches $\sim 10\,\mathrm{M}_\odot$.
Such statistically robust results favor a clump-fed scenario for high-mass star formation, in which cores form as low-mass seeds, and then gain mass while further fragmentation occurs in the clump.

Session 1b / 31

Tracking Star-Forming Cores as Mass Reservoirs in Clustered and Isolated Regions Using Numerical Passive Tracer Particles

Author: Shingo Nozaki[1]

Co-authors: Hajime Fukushima [2]; Kazuki Tokuda [3]; Masahiro N. Machida [1]

[1] *Kyushu University*

[2] *University of Tsukuba*

[3] *Kyushu University, National Astronomical Observatory of Japan*

Corresponding Author: nozaki.shingo.307@s.kyushu-u.ac.jp

Understanding the physical properties of star-forming cores as mass reservoirs for protostars and the role of turbulence is essential in star formation studies. We implemented passive tracer particles in clump-scale numerical simulations with turbulence strengths of $M_{\mathrm{rms}} = 2, 10$. Unlike core identification methods based on density thresholds, we identified 260 star-forming cores by tracking tracer particles falling onto protostars. Our results show that star-forming cores do not always coincide with high-density regions. In clustered star-forming environments, they tend to exhibit a fragmented, clumpy structure as gas selectively accretes onto protostars. We constructed convex hull cores from the identified star-forming cores and evaluated their filling factors. Regardless of turbulence strength, cores with lower filling factors tend to be more massive, larger, and contain more protostars, suggesting that clustered regions host systematically larger and more massive cores. The filling factor thus serves as a useful indicator for distinguishing between isolated and clustered star-forming regions. Most convex hull cores are gravitationally bound, but in the $M_{\mathrm{rms}} = 10$ model, the fraction of low-mass, unbound cores is higher than in the $M_{\mathrm{rms}} = 2$ model. In particular, $16\,\%$ of the convex hull cores in the $M_{\mathrm{rms}} = 10$ model are unbound, which may be explained by the inertial-inflow model. These results highlight the impact of turbulence on core mass and gravitational stability.

Session 6 / 32

Anomalously High Deuteration Fraction in a Translucent Molecular Cloud

Author: Gan Luo[1]

Co-authors: Di Li [2]; Serena Viti [3]; Thomas Bisbas [4]; Zhiyu Zhang [5]

[1] *IRAM*

[2] *Tsinghua University*

[3] *Leiden*

[4] *Zhejiang Lab*

[5] *NJU*

Corresponding Authors: luo@iram.fr, tbisbas@zhejianglab.com

We report the first detection of DCN in a low-density translucent sightline (n_{H_2}~390 cm^{-3}, Av~0.85 mag) through sensitive absorption-line observations with NOEMA. The observed DCN/HCN ratio is two orders of magnitude higher than the elemental deuterium-to-hydrogen abundance ratio (D/H~10^{-5}), challenging predictions from current chemical models. This discrepancy suggests a significant and unexpected boost in deuterium fractionation under low-density conditions. To reconcile this result, we propose that the observed cloud may represent a dispersal phase of a previously denser core, where the gas density in its evolutionary history must have exceeded 10$^{3.5}$ cm^{-3}.

Session 3 / 33

Dust Properties of Taurus Protostellar Twins in a Magnetized Environment

Author: Asako Sato[1]

Co-authors: Anaëlle Maury [2]; Josep-Miquel Girart [1]

[1] *Institut de Ciències de l'Espai, CSIC*

[2] *ICE*

Corresponding Author: sato.asako.astro@gmail.com

The evolution of astrophysical dust during early star formation phases is crucial for understanding planet formation and the magnetic fields have a role in regulating this process. Theoretical models mainly proposed two dominant mechanisms of dust polarization with mm/sub-mm wavelengths; dust alignment due to the magnetic fields (e.g., Lazarian 2007) and self-scattering of dust grains (e.g., Kataoka et al. 2015). It is, however, still unclear how to distinguish the dominant mechanisms in observations due to the entanglement of many factors, requiring more polarization observational samples to constrain it.
IRAS 04166+2706 (K66) and IRAS 04169+2702 (K69) are young protostars within the B213 filament in the Taurus molecular cloud. These sources provide ideal laboratories for studying dust evolution and the role of magnetic fields in the early stages of star formation because they share similar ages born within the common dusty region where previous observations presented configurations of the magnetic fields at the filament scale. Here, we will present our ALMA program towards this unique system, and discuss the properties of polarized dust emission, obtained at unprecedented spatial resolutions from ~20 au to 1000 au, resolving for the first time both the protoplanetary disks and the surrounding envelopes.
Our data reveals striking differences between the two sources, despite them being embedded and born in the same environment. In particular, K66 likely has hourglass-shaped B-fields at >200au scales, and both the B-fields and self-scattering are dominant at the 20 au scale. K69 likely has compact toroidal B-fields at >200au scales and the self-scattering is dominant at the 20au scale. In this talk, I will discuss implications of these differences between the twins, focusing on dust evolution and the role of magnetic fields in shaping the star formation there.

Session 6 / 34

Study of cosmic ray transport in young protostars: Impact of in-situ CR acceleration on hydrogen ionization

Author: Nai Chieh Lin[1]

Co-authors: Benoît Commerçon [2]; Joakim Rosdahl [3]

[1] *CRAL / ENS de Lyon*

[2] *CRAL - ENS LYON*

[3] *CRAL / Observatoire de Lyon*

Corresponding Authors: benoit.commercon@ens-lyon.fr, nai-chieh.lin@ens-lyon.fr, karl-joakim.rosdahl@univ-lyon1.fr

The formation of stars and planetary disks is a complex, multi-scale, and multi-physics process. While large-scale numerical simulations commonly incorporate magnetic fields and radiative transfer, the role of cosmic rays remains underexplored. As the primary ionizing agent in the gas-dust mixture, cosmic rays significantly influence its coupling with magnetic fields and the prominence of non-ideal magnetohydrodynamic (NiMHD) effects, which play a crucial role in protoplanetary disk formation. Recent observations indicate an increasing cosmic ray ionization rate toward the centers of active young protostars, suggesting that cosmic rays may be accelerated in these environments.

Elevated ionization rates enhance the gas-magnetic field coupling, impacting the magnetic braking mechanism that governs disk formation.

To address this gap, we employ the adaptive mesh refinement code RAMSES to simulate the injection and propagation of cosmic rays from young stellar objects. This study investigates the temporal and spatial evolution of cosmic rays in protostellar environments. I will present 3D numerical experiments solving the two-moment cosmic ray transport equation, incorporating cosmic ray injection, accounting for cosmic ray cooling, and analyzing the impact of varying diffusion coefficients on their spatial distribution. Furthermore, I will examine the extent to which in-situ acceleration contributes to ionization in the protostellar environment.

Session 1b / **35**

Gravity at Work: Energy Budget in Simulated Hub-Filament Systems

Author: Vianey Camacho[1]

Co-authors: Aina Palau ; Enrique Vazquez-Semadeni ; Manuel Zamora-Aviles

[1] *National Taiwan Normal University*

Corresponding Authors: vcamacho@ntnu.edu.tw, mzamora@inaoep.mx, e.vazquez@irya.unam.mx, apalu@irya.unam.mx

We investigate the kinetic and magnetic energy budget in a hub-filament system that arises self-consistently in an adaptive mesh refinement (AMR) simulation of a molecular cloud undergoing global hierarchical collapse (GHC). Our goal is to assess whether the energy distribution and dynamics of the formed structure are consistent with observations and to explore the role of magnetic fields along the cloud-to-core hierarchy within hub-filament systems. To quantify the energy budget, we analyze the kinetic Larson ratio, virial parameter, and their magnetic counterparts; we examine the scaling of kinetic and magnetic energies with the gravitational one across multiple spatial scales. This approach allows us to trace how energy is partitioned as substructures emerge and evolve within the collapsing cloud. Our results show that the energy distributions in the simulated clumps align well with those observed in real molecular clouds, reinforcing the hypothesis that GHC is the dominant mechanism driving the formation and evolution of substructures.

Session 1b / **36**

Exploring Accretion Variability via Jet Evolution in G023.01-00.41

Author: Tatiana Rodriguez[1]

Co-authors: Alberto Sanna [2]; Esteban Araya [3]; Peter Hofner [4]

[1] *University of Cologne*

[2] *Istituto Nazionale di Astrofisica (INAF)*

[3] *Western Illinois University (WIU); New Mexico Tech (NMT)*

[4] *New Mexico Tech (NMT); National Radio Astronomy Observatory (NRAO)*

Corresponding Authors: alberto.sanna@inaf.it, rodriguez@ph1.uni-koeln.de, ed-araya@wiu.edu, peter.hofner@nmt.edu

A complete understanding of high-mass (> 8 M_{Sun}) star formation, including the overall process of jet emission and its behavior, remains elusive. Whether or not the accretion variability broadly observed in low-mass star formation is also a common process regulating the formation of massive stars has been highly debated in the last decade. We have recently discovered that the 1.3 cm continuum brightness of the massive protostellar jet G023.01−00.41 has decreased by ~50% since 2008

(Rodriguez et al., submitted). Follow up observations confirm a brightness variation is found throughout the radio spectrum, and the jet morphology appears to have changed as well. The implications of our results will be discussed in the context that changes in jet emission, which are expected to be directly related to accretion outbursts, may be common during high-mass star formation.

Session 6 / 37

Chemical signatures of a prestellar cluster in the Galactic Center

Author: Laura Colzi[1]

[1] *Centro de Astrobiologia (CAB), CSIC-INTA*

Corresponding Author: lcolzi@cab.inta-csic.es

The Central Molecular Zone (CMZ) contains most of the mass of our Galaxy but its star formation rate is one order of magnitude lower than in the Galactic disk. This is likely related to the fact that the bulk of the gas in the CMZ is in a warm (>100 K) and turbulent phase with little material in the prestellar phase.
In this talk, I will first present D/H ratios of HCN, HNC, HCO^+, and N_2H^+ obtained toward the CMZ molecular cloud G+0.693-0.027 (Colzi et al. 2022). These observations clearly show, for the first time, the presence of a colder, denser, and narrow component, with a line width of about 9 km s^{-1}, in addition to the typical gas component of the CMZ, warm, less dense, and turbulent with a line width of about 20 km s^{-1}. For this new component D/H ratios > 10^{-4} and excitation temperatures of 7 K for all molecules have been found, suggesting kinetic temperatures < 30 K and H_2 densities >5×10^4 cm^{-3}. This new method indicates that the degree of deuteration of different molecules, such as N_2H^+ and HCO^+, and their line profiles can be used to reveal the different gas components in the line of sight to the CMZ.
Then, I will present HC_3N excitation-derived gas densities and temperatures of the gas components towards the same source, using multiple transitions coupled with spatially resolved HC_3N images of the source. This approach allows us to identify denser gas that possibly is on the verge of gravitational collapse and that will host future protostars in the CMZ (Colzi et al. 2024).

Session 3 / 38

How Does a Protostar Form by Magnetized Gravitational Collapse?

Author: INDRANI DAS[1]

Co-authors: Hsien Shang ; Ruben Krasnopolsky

[1] *Academia Sinica Institute of Astronomy and Astrophysics (ASIAA)*

Corresponding Author: indranidasbethune@gmail.com

Star formation through the dynamical magnetized collapse remains an active area of astrophysical research. We carry out a comprehensive exploration on the magnetized gravitational collapse of a nonrotating self-gravitating initially spherically symmetric prestellar cloud core using two-dimensional nonideal magnetohydrodynamic simulations incorporating ambipolar diffusion and Ohmic dissipation. Our study encompasses a broader range of equations of state (EOSs) in the form of $P(\rho) \propto \rho^\Gamma$, with the aim of constraining the choice of EOSs for allowing star formation. Our results reveal that the collapse with a Γ no stiffer than $4/3$, complemented by magnetized virial theorem, allows the dynamical contraction of the prestellar core to happen continuously where a central point mass forms and steadily builds up its mass from the infalling envelope, with a mass accretion rate of the order of c_s^3/G. The choice of an isothermal EOS most naturally facilitates the collapse as a magnetic analog of the inside-out collapse. In addition to that, our study exhibits that the nonisothermal magnetized

collapse models with a Γ no stiffer than 4/3 qualitatively demonstrate similar infall features to those of an isothermal EOS. Furthermore, the collapse models with a Γ stiffer than 4/3 fail to ensure the sufficient cooling to allow the direct mass growth of the central point mass, thus delaying the infall. Our work can offer deeper insights in understanding the significance of EOSs on the magnetized gravitational collapse, enabling star formation.

Session 6 / 39

Transport of spectrally-resolved cosmic-ray protons and electrons in the multiphase interstellar medium

Author: Lucia Armillotta[1]

[1] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Author: lucia.armillotta@inaf.it

Modeling cosmic-ray (CR) transport on galactic scale is a challenging task due to the complex physical processes that couple CRs to the thermal gas, which are not yet fully understood. As a result, in most interstellar-medium (ISM) studies involving CRs, the interaction between CRs and their scattering waves, that is unresolved on macroscopic scales, is treated via a constant scattering coefficient, whose value is motivated by observational constraints. To improve upon this approach, we recently developed a physically-motivated prescription for the transport of CRs, in which the scattering coefficient varies with the properties of the ambient gas, with a functional form motivated by the theory of self-confinement. In this talk, I will present our application of this prescription to compute the transport of spectrally-resolved CR protons and electrons with energies between 1 and 100 GeV within the TIGRESS MHD simulations of star-forming galactic disks. I will discuss the evolution of the CR spectral distribution as these particles propagate through the multiphase, magnetized ISM, and compare our simulation results with direct observations in the solar neighborhood, highlighting the remarkable agreement we found.

Session 4 / 40

Revisiting the Milky Way's Star Formation Rate: A New and Improved Estimate

Author: Davide Quintino Elia[1]

[1] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Author: davide.elia@inaf.it

This presentation explores three methods for estimating the total star formation rate (SFR) of the Milky Way, two of which leverage Herschel far-infrared imaging observations. The first method derives SFRs by positioning Hi-GAL star-forming clumps on the luminosity–mass diagram, incorporating a variable gas-to-dust ratio that varies with Galactocentric distance. The second method, inspired by extragalactic studies, introduces a novel approach that estimates SFRs based on the total 70 μm emission in Hi-GAL maps. The third method examines molecular clouds identified through CO emission lines, adjusting masses and SFRs according to Galactocentric radius and applying a star formation efficiency per free-fall time that depends on the cloud's virial parameter.
All three approaches yield not only a global SFR estimate for the Milky Way but also its Galactocentric profile and a detailed 2D face-on projection. While the methods show overall consistency, some intercalibration differences and localised discrepancies persist, which will be discussed. Additionally, the presentation includes a test of the Kennicutt-Schmidt relation using Milky Way regions, providing a valuable link to extragalactic studies.

Session 1b / **41**

Dust dynamics during the protostellar collapse

Author: Gabriel Verrier[1]

Co-authors: Patrick Hennebelle [2]; Ugo Lebreuilly [2]

[1] *CEA-AIM Saclay*

[2] *CEA Paris-Saclay*

Corresponding Author: gabriel.verrier@cea.fr

Interstellar dust grains, about one percent of the mass of the diffuse interstellar medium, strongly affect star formation. In particular, the local distribution, from small grains to the larger ones, play various roles during the protostellar sequence, from the thermodynamics and the chemistry of molecular clouds, to the opacity of collapsing protostellar cores and the coupling between the gas and the magnetic field, down to planet formation in young and evolved disks around protostars.
We have implemented a dust multifluid module to treat a distribution of neutral grains in the RAMSES code. This allow us to simulate protostellar collapses for a large dynamical range while controlling the initial grain size distribution and initial level of turbulence, two parameters that impacts the dust enrichment in the first hydrostatic core and in the protostellar envelope (Verrier et al, in prep).
In this paper, we present a novel numerical method informed by the wave physics in a gas and dust mixture.

Session 1a / **42**

eDisk: A Compact but Structured Keplerian Disk and Large-scale Streamers in the Class I Protostellar System IRAS 04169+2702

Author: Ilseung Han[1]

[1] *Institut de Ciències de l'Espai, CSIC*

Corresponding Author: ihan@ice.csic.es

We present high-resolution (0.05"; 8 au) dust continuum and molecular line observations toward the Class I protostellar system IRAS 04169+2702 in the Taurus B213 region (d = 156 pc), as part of the ALMA Large Program *Early Planet Formation in Embedded Disks (eDisk).* The 1.3-mm dust continuum emission traces a circumstellar disk with a central depression toward the protostar. Our supplementary VLA observations of the same target reveal a single central peak dominated by the free-free emission, which coincides with the depression of the thermal emission. The mean spectral index of the thermal dust emission over the wavelength from 1.3 mm to 1.4 cm is approximately 2.8, suggestive of the presence of grains grown to millimeter or centimeter sizes in the disk. Velocity gradients along the disk major axis are seen in emission from ^{12}CO (2−1), ^{13}CO (2−1), and C^{18}O (2−1) molecular lines. The position-velocity diagrams of these lines unveil a Keplerian-rotating disk with a radius of 21 au around a 1.3-$M_\odot$ protostar, similar to our Solar System, as well as an infalling and rotating envelope with the angular momentum conserved. In addition to the compact disk, large-scale infalling spiral structures, streamers, are discovered in C^{18}O (2−1), SO (6_5-5_4), and H_2CO ($3_{0,3}-2_{0,2}$) as well as in the 1.3-mm continuum emission. Notably, in the region closer to the protostar, the spatial coincidence of C^{18}O and SO within the spirals may indicate the presence of a shock related to accretion through arms.

Session 3 / **43**

Resistive Collapse of 2D Non-rotating Magnetized Isothermal Toroids: Formation of Pseudodisks

Authors: Ya-Chi Wang[1]; Hsien Shang[1]; Ruben Krasnopolsky[1]

[1] *Institute of Astronomy and Astrophysics, Academia Sinica, Taipei 106216, Taiwan*

Corresponding Authors: ycwang@asiaa.sinica.edu.tw, ruben@asiaa.sinica.edu.tw, shang@asiaa.sinica.edu.tw

The collapse of singular magnetized toroids (Li & Shu 1996) is a natural representation of an early phase in star formation, bridging the prestellar and protostellar phases of the collapse of molecular cloud cores. We revisit the collapse study of Allen et al. (2003), now with explicit nonideal MHD (Ohmic diffusivity η) and higher resolution using a code able to cover a broader range of the magnetization parameter $_0$. Galli-Shu equatorial pseudodisks form for all values of H_0 and η, and the asymptotic central mass growth rate is in the scale $\dot{M}_* \sim (a^3/G)(1+H_0)$, where a is the sound speed, consistent with previous results and predictions. The explicit Ohmic diffusivity makes the field line structure less radial than in previous work, connecting the pseudodisk more effectively to its surroundings. Matter can fall efficiently onto the pseudodisk surfaces, forming oblique shocks, where shock heating and large density gradients raise the possibility of rich astrochemistry. Pseudodisk size and structure are influenced by magnetic diffusivity. Force and velocity ratios were computed to explore the magnetic support within the pseudodisk and its induced slowdown in infall velocity. Magnetic diffusivity was measured to control the strength of these effects and their location within the pseudodisk. The dependence of the field line configurations, pseudodisk structure, and velocity ratios on magnetic diffusivity has observable consequences for collapsing envelopes.

Session 3 / 44

Planets Formation via Gravitational Instability: Magnetic Fields, Opacity Limited Fragmentation, and the Mass Distribution

Author: Fred Adams[1]

[1] *University of Michigan*

Corresponding Author: fca@umich.edu

This talk revisits the mass scales for planets that form through the action of gravitational instability in circumstellar disks. After including the effects of magnetic fields, we show that several alternate ways to specify the mass of forming planets converge to the same result under the constraint that the parental disks are marginally stable (with stability parameter Q=1). Next we show that the well-known constraint that the formation of secondary bodies requires rapid cooling is equivalent to that of opacity limited fragmentation. These results are then used to derive a mass function for planets forming through disk instability. The resulting distribution is relatively narrow, with gaussian-like shape and a characteristic mass scale of order 10 Jovian masses.

Session 6 / 45

Cosmic rays and star formation

Author: Elena Redaelli[None]

Corresponding Author: elena.redaelli@eso.org

Cosmic rays (CRs) play a crucial role in the physics and chemistry of the interstellar medium (ISM). At the high densities found in molecular clouds, they represent the main ionising agent of the gas, affecting its heating and evolution. CRs ionise molecular hydrogen, quickly producing H3+, setting the gas ionisation fraction. The latter affects the timescale of ambipolar diffusion —the drift of neutral matter across the magnetic field lines—a mechanism that allows the collapse of subcritically magnetised prestellar cores. Furthermore, CRs initiate the rich chemistry of molecular ions in molecular clouds. In this regard, it is of particular importance the formation of H2D+, the precursor

of deuterated species in the gas phase, and that of He+, the first step towards ammonia formation. In my review talk, I will describe the different physical and chemical properties of star-forming regions that are affected by CRs. I will focus, in particular, on how we can observationally measure their impact through the CR ionisation rate (CRIR), discussing the different methodologies used in recent years, and I will show the most recent results in these regards. I will conclude with a few details on the future perspective regarding the study of cosmic rays especially from an observational point of view.

Session 1b / **46**

Accretion disks and massive stars: New light on an ancient history

Author: Riccardo Cesaroni[1]

[1] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Author: cesa@arcetri.inaf.it

Investigating the formation of the most massive stars has since ever been a theoretical challenge and a difficult observational task. Substantial progress has been made recently on both fronts and it appears that circumstellar accretion disks (and the associated jets) are key to explain how these stars form. We will report on our contribution to this topic in the last twenty years, with special attention to the most recent results obtained with the Atacama Large Millimeter and submillimeter Array.

Session 1a / **47**

Characterizing the emission of molecular clouds using a sampling technique

Author: Mario Tafalla[1]

Co-authors: Antonio Usero [1]; Alvaro Hacar [2]

[1] *Observatorio Astronomico Nacional (Spain)*

[2] *University of Vienna*

Corresponding Author: m.tafalla@oan.es

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 the full 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.

Session 6 / 48

Interpretable Machine Learning for Astrochemistry

Author: Tommaso Grassi[None]

Corresponding Author: tgrassi@mpe.mpg.de

Machine learning is revolutionizing astrochemistry by providing new ways to analyze complex datasets and accelerate computationally expensive models. However, interpretability remains a key challenge, especially when extracting physical insights from data-driven approaches. In this talk, I will present recent advancements in applying interpretable machine learning techniques to astrochemical problems, focusing on two case studies. First, I will discuss how neural networks and SHapley Additive exPlanations (SHAP) can be used to identify spectral features that retain key physical information in synthetic observations of prestellar cores. Second, I will showcase a novel approach that leverages autoencoders and optimization techniques to reduce the dimensionality of large chemical networks while maintaining accuracy and interpretability. These methods not only enhance our understanding of astrochemical processes but also provide practical tools for improving the efficiency of numerical simulations. I will conclude by discussing the broader implications of interpretable machine learning for astrophysical modeling and future directions for the field.

Session 3 / 49

Magnetized Clustered Star Formation in Orion

Author: Bo Huang[1]

Co-author: Josep-Miquel Girart [2]

[1] *Institute of Space Sciences (ICE-CSIC)*

[2] *Institut de Ciències de l'Espai, CSIC*

Corresponding Author: hb6170@gmail.com

Interferometric polarization observations have revealed that magnetic fields are crucial in the star formation process. However, their relative importance in different environments and their role in stellar multiplicity remain poorly understood. The B-field Orion Protostellar Survey (BOPS) recently observed 870 μm dust polarization observations of 61 young protostars in the Orion molecular cloud, probing scales from 400 to 2000 au. The observations reveal standard hourglass magnetic field morphologies in collapsing cores, highlighting the interplay between magnetic fields and gravity, while misaligned or twisted fields indicate the growing influence of rotation and turbulence. Our findings suggest that magnetic fields play a key role in regulating fragmentation within dense envelopes: strong magnetic fields suppress fragmentation by stabilizing against gravitational instabilities, whereas weaker fields allow the formation of binary or multiple star systems. We also find that the magnetic field affects disk formation through magnetic braking, that significant misalignment between the magnetic field and outflow axes tends to reduce magnetic braking, leading to the formation of larger disks.

Session 1b / 50

Theoretical models for filamentary structures and collapse of prestellar cores

Authors: Claudia Toci[1]; Daniele Galli[2]

[1] *European Southern Observatory (ESO)*

[2] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Authors: galli@arcetri.inaf.it, claudia.toci@inaf.it

Molecular are the sites of star formation, made by networks of filaments (e.g., Andre'et al. 2014, Hacar et al. 2023).
Individual filaments composing a molecular cloud accumulate mass by accretion from the parental cloud, until they become gravitationally unstable and fragment into cores, that eventually collapse into stars and stellar clusters. The candidates for supporting the clouds are large-scale magnetic fields and turbulence (e.g., Pattle et al. 2023).
In a contest where these processes are interplaying at different time- and length-scales, is crucial to understand their role in the equilibrium and in the dynamical evolution of molecular clouds as well as how the gravitational collapse can affect them.

In this talk, I will present an analysis of the stability and contraction of molecular clouds both in the hydrodynamical and magnetohydrodynamical case, in the quasi-static and dynamical phase of evolution. Under the hypothesis that the observed filaments and
cores can be represented by a sequence of hydrostatic or magnetostatic models, I will analytically study their radial density profiles and stability properties (Toci & Galli 2015 a,b).
However, molecular clouds must contract and fragment in order to form stars.
I will show an analysis of the growth of small-scale density perturbation during the hydrodynamical collapse of a molecular core, simulated using a modified version of the ECHO (Del Zanna et al.2017) code to include a generic anisotropic metric that allows stretching in all directions. I also analytically estimated the transition time to non-linear regime in analogy with the Burgers equation.
The results point out that the formation of shocks and the subsequent dissipation prevents the onset of gravitationally unstable perturbations, thus other kind of mechanism are needed to explain the process of fragmentation in cores (Toci et al. 2021).

Session 1b / 51

How we think planet formation disks are forming? The past, the present and the future

Author: Patrick Hennebelle[1]

[1] *CEA*

Corresponding Author: patrick.hennebelle@cea.fr

Protoplanetary disks are fundamental objects for our understanding of planet formation. Whereas they are in essence a consequence of angular momentum conservation, the exact amount of mass and angular momentum which are delivered towards the proto-star remain largely unknown. Indeed, this process seems to be largelly controlled by magnetic field and more specifically by magnetic braking. However the outcome sensitivelly depends on the ionisation degree as well as the charge carriers, which appear to be not only the electrons and the ions but also the dust grains. This adds considerable complexity in the problem.
During the talk, I will review our understanding of the protoplanetary disk formation process, adopting an historical perspective and stressing what are the important steps for the future.

Session 3 / 53

Self-similarity of the magnetic field in G31.41+0.31 from cloud to circumstellar scales

Author: Maite Beltrán[1]

[1] *INAF-Osservatorio Astrofisico di Arcetri*

Corresponding Author: maria.beltran@inaf.it

In this presentation, I will discuss the magnetic field properties at all spatial scales (cloud, core, disk) of one of the best studied high-mass star-forming regions, the massive protocluster G31.41+0.31. Dust polarization observations of this massive core carried out with the SMA at 870 microns and 1" (3750 au) have revealed one of the most clear examples up to date of an hourglass-shaped magnetic field in the high-mass regime. ALMA observations at higher angular resolutions have revealed that the magnetic field maintains its hourglass-shaped morphology down to circumstellar scales (~300 au). All this is supported by the modelling of the polarized emission, which confirms the poloidal shape of the magnetic field. Recent JCMT polarization observations of the cloud indicate that the orientation of the hourglass B-field observed at core and circumstellar scales is preserved at large scales. This self-similarity in the B-field orientation suggests that the field is connected from cloud to circumstellar scales despite the difference in density and spatial scales.

Session 1b / **54**

Dusty protostellar collapses simulations in 3D with dust growth

Authors: Maxime Lombart[1]; Ugo Lebreuilly[2]; Anaëlle Maury[3]

[1] *CEA Paris/Saclay*

[2] *CEA Paris-Saclay*

[3] *Institute of Space Sciences (Barcelona) & CEA Astrophysics department (Paris-Saclay)*

Corresponding Authors: maxime.lombart@cea.fr, anaelle.maury@icrea.cat

Dust grains are essential ingredients in star formation and play a significant role in gas/dust dynamics, chemical reactions, and radiative transfer. The efficiency of all these physical processes depends on the grain-size distribution and how it evolves in time. Thus, accurate dust modeling is a much needed feature of star formation simulations. Dust growth and fragmentation are mathematically described by the Smoluchowski coagulation and the fragmentation equations. Solving these equations accurately while preserving tractable computational costs is a tremendous numerical challenge, yet critical for understanding the formation of stars, disks and planets. In particular, low-order schemes do strongly overestimate the formation of large particles. We present a novel high-order discontinuous Galerkin algorithm (Lombart+,2021,2022,2024) that addresses all these issues. We aim to perform the first 3D simulations of dusty protostellar collapses that include realistic dust growth/fragmentation.

Session 1a / **55**

The first steps of star and planet formation

Author: Paola Caselli[1]

[1] *Max Planck Institute for Extraterrestrial Physics*

Corresponding Author: caselli@mpe.mpg.de

Extremely low temperatures and relatively low densities characterize the interstellar clouds precursors of stars and planets. In these early stages, fundamental chemical and physical processes affect each other, ultimately regulating clouds' dynamical evolution toward the formation of stellar systems like ours, where at least one habitable planet is present. Here, I'll present a journey from clouds to planets, which started in Arcetri with the help of outstanding scientists, including one from Pisa, highlighting the open questions and future perspectives.

Session 3 / 56

Origin of fossil fields in Ap/Bp-type stars

Author: Dominik Schleicher[1]

Co-authors: Daniele Galli [2]; Juan Pablo Hidalgo [1]

[1] *Sapienza University of Rome*

[2] *Arcetri Astrophysical Observatory*

Corresponding Authors: juanpablo.hidalgo@uniroma1.it, daniele.galli@inaf.it, dominik.schleicher@uniroma1.it

Among 10% of intermediate mass stars, particularly the group of chemically peculiar Ap/Bp-type stars, have very strong magnetic fields of order 1 kGauss or even above. As the stars are radiative,, the magnetic fields are difficult to explain via a dynamo, but are often considered to possible have an origin of fossil fields from the interstellar medium. In this talk, we assess this possibility, considering the available magnetic fields in the interstellar medium and their evolution during gravitational collapse. A crucial phase concerns then the protostellar evolution, which may be convective or radiative depending on the accretion rate of the protostars. We will show that it is very difficult for magnetic fields to survive in the convective phase, but more likely in the radiative one, and will show some representative cases for the possible protostellar evolution. We suggest that at least in some cases, suitable protostellar evolution histories can be obtained to explain the origin of magnetic fields in Ap/Bp-type stars.

Session 1b / 57

Morphological comparison of molecular emission with continuum emission in ALMAGAL clumps

Authors: Alessandro Coletta[1]; Alessio Traficante[1]; Alice Nucara[2]; Alvaro Sanchez-Monge[3]; Cara Battersby[4]; Chiara Mininni[2]; Davide Quintino Elia[1]; Eugenio Schisano[1]; Gary Fuller[5]; Henrik Beuther[6]; Juan Diego Soler Pulido[1]; Maria Teresa Beltran Sorolla[1]; Milena Benedettini[1]; Paul Ho[7]; Peter Schilke[8]; Qizhou Zhang[9]; Sergio Molinari[10]; Stefania Pezzuto[1]; Stephanie Walch[11]; Ya-Wen Tang[None]; the ALMAGAL collaboration[None]

[1] *Istituto Nazionale di Astrofisica (INAF)*

[2] *INAF-IAPS*

[3] *Institute of Space Sciences (ICE, CSIC)*

[4] *University of Connecticut*

[5] *University of Manchester, Univ. Koln*

[6] *Univ. Heidelberg*

[7] *ASIAA - Institute of Astronomy and Astrophysics, Academia Sinica*

[8] *Universitaet zu Koeln*

[9] *Cambridge*

[10] *INAF - Istituto di Astrofisica e Planetologia Spaziale*

[11] *Univ. Koln*

Corresponding Authors: davide.elia@inaf.it, milena.benedettini@iaps.inaf.it, alessio.traficante@inaf.it, eugenio.schisano@inaf.it, chiara.mininni@inaf.it, maria.beltran@inaf.it, schilke@ph1.uni-koeln.de, juan.soler@inaf.it, alessandro.coletta@inaf.it, sergio.molinari@inaf.it, cara.battersby@uconn.edu, pho@asiaa.sinica.edu.tw, asanchez@ice.csic.es, stefania.pezzuto@inaf.it

The analysis of the line emission at millimetric wavelengths is a powerful tool for studying the kinematic and thermal conditions of the gas in star-forming regions. However, the question of how well different species trace the emission of dust in the continuum at various scales has been addressed in the literature either by comparing the region of emission of the different lines with the region emitting in the continuum or by using intensity correlators, such as Pearson's coefficient.
In this work, we present an innovative approach to this problem based on the analysis of the correlation between the morphology of the moment-0 maps of lines from eight of the most common molecular species observed in high-mass star-forming regions - namely H2CO, CH3OH, SO, SiO, HCCCN, CH3CN, DCN, and CH3OCHO - and the continuum emission from dust at 1.4 mm on an unprecedented statistically robust sample. The observations are part of the ALMAGAL program, which has observed more than 1000 candidate high-mass star-forming clumps selected from the Herschel Infrared Galactic Plane Survey (Hi-GAL) catalogue (Elia et al. 2017, 2021), with the ALMA interferometer at 1.4 mm. Observed clumps have masses above 500 M⊙, distances up to 7.5 kpc, and cover different evolutionary stages and fragmentation properties.
The morphological analysis we carried out is based on the astroHOG package (Soler et al. 2019), developed to compare the morphology of astrophysical images, or cubes, using the method of the histogram of oriented gradients (HOG). The HOG method is a machine vision tool that uses the intensity gradient orientation to characterise the similarities between two images and evaluates whether the relative gradients in the two images are randomly oriented or preferentially parallel (i.e. the distribution of the angles between the direction of the two gradients peaks around 0∘), implying that the morphology of the two images is similar.
Across the sample of the 1013 ALMAGAL clumps analysed, only the emission of H2CO, CH3OH, and SO transitions significantly overlap with the continuum extended emission. Still, the astroHOG comparison reveals that the morphology is poorly correlated. We also run astroHOG over a masked portion of the continuum emission that corresponds only to the densest regions. In this case, we found that the analysed species can be divided into two groups. CH3CN, DCN, HCCCN, and CH3OCHO show a good correlation, while for H2CO, CH3OH, SO, and SiO, the emission mostly does not follow the morphology of the compact part of the continuum. Analysing the ALMAGAL data with the astroHOG method and Pearson's coefficient, the most widespread tool used for comparing the emission of different tracers in the literature, the former gives more accurate and reliable results.

Session 1b / 58

The Rosetta Stone Project: synthetic observations of high-mass clumps fragmentation

Author: Alice Nucara[1]

[1] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Author: alice.nucara@inaf.it

Star formation, particularly in massive star-forming regions, is a complex, multi-scale process.

To explore the fundamental mechanisms driving the collapse of parsec-scale clumps, ultimately shaping the star-formation outcome, the Rosetta Stone project was developed. This project provides an end-to-end (simulations ⟺ observations) framework for comparing observational data with numerical simulations by systematically generating synthetic observations of clump fragmentation. Such approach enables a self-consistent, quantitative analysis of how the initial conditions of clump collapse influence the observed fragmentation properties.

As a first case study, ALMA 1.3 mm continuum dust emission observations from the SQUALO survey have been compared with a tailored set of post-processed radiative magneto-hydrodynamical simulations of high-mass clump fragmentation.
The numerical models have been initialized combining typical values of clump mass (500 and 1000 $M_\odot$) and radius (~0.4 pc), with two levels of turbulence (Mach number ⍰ of 7 and 10), and three

levels of magnetization (normalized mass to magnetic flux ratio μ of ~3, 10 and 100). They have been post-processed tuning the CASA software to replicate the SQUALO project observing strategy, combining ACA and the 12 m array.

A statistically robust set of ~1000 synthetic maps, collected from following clump evolution over time and along three orthogonal directions, reveals that clump fragmentation extends beyond the initial stages of collapse. Furthermore, fragments continuously accrete mass from the parent clump, remaining tightly coupled to the environment. Among the adopted initial conditions, magnetic fields emerge as the most influential factor in determining the fragmentation outcome at ~7000 AU scales, with magnetized clumps producing fewer fragments.
These initial results demonstrate how the systematic production of synthetic observations could provide a fresh perspective on the physics of clump fragmentation.

Session 6 / 59

The Effect of Weak Cosmic Ray Heating Events on the Desorption of H2

Author: Olli Sipilä[1]

Co-authors: Kedron Silsbee ; Naomi Carbajal ; Paola Caselli [2]

[1] *Max-Planck-Institute for Extraterrestrial Physics*

[2] *Max Planck Institute for Extraterrestrial Physics*

Corresponding Authors: caselli@mpe.mpg.de, osipila@mpe.mpg.de

Cosmic rays (CRs) have a large effect on the physical and chemical evolution of star-forming material. One particular aspect of this is desorption; CRs that impact dust grains deposit energy along their track, heating the grain transiently to a higher temperature. The grain then sheds the deposited energy via (partial) desorption of the ice mantle. This mechanism is arguably the most important means of desorbing icy material in regions well shielded from the interstellar radiation field.

Earlier numerical models of CR-induced desorption have assumed that the grains are always heated to a transient maximum temperature of 70 K, stemming from the assumption that the CRs are iron nuclei and that the radius of the (spherical) grain is fixed at 0.1 microns. In reality, there is a spectrum of CRs, consisting of different particles coming in with a range of energies. This means that dust grains can be transiently heated to temperatures of a few tens of K, which is enough to desorb H2 for example, and in fact such heating events occur much more often than those heating the grains to 70 K.

We present the results of revised CR-induced desorption models where the effect of "weak heating events", that is, those heating the grains to a few tens of K, on gas-phase and ice abundances in star-forming regions is examined. We direct particular attention to H2 ice, which is notorious for appearing in unrealistic amounts in chemical simulations. Surprisingly, we find that even the weak heating events are not enough to remove large quantities of H2 from the grains. The abundances of species other than H2 are however affected by the revision of the CR desorption model to various degrees depending on the physical conditions. We discuss the implications of our results on the understanding of (ice) chemistry in the interstellar medium.

Session 1b / 60

Dynamics and infall properties observed at 5000 AU in the ALMAGAL sample.

Author: Leonardo Berti[1]

Co-authors: Alessandro Coletta [1]; Alessio Traficante [1]; Alvaro Sanchez-Monge [2]; Beth Jones [3]; Cara Battersby [4]; Chiara Mininni [5]; Gary Fuller [6]; Henrik Beuther [7]; Maria Teresa Beltran Sorolla [1]; Paul Ho [8]; Peter Schilke [9]; Qizhou Zhang [10]; Ralf Klessen [11]; Sergio Molinari [12]; Stephanie Walch [3]; Ya-Wen Tang

[1] *Istituto Nazionale di Astrofisica (INAF)*

[2] *Institute of Space Sciences (ICE, CSIC)*

[3] *Univ. Koln*

[4] *University of Connecticut*

[5] *Università degli Studi di Firenze - INAF*

[6] *University of Manchester, Univ. Koln*

[7] *Univ. Heidelberg*

[8] *ASIAA - Institute of Astronomy and Astrophysics, Academia Sinica*

[9] *Universitaet zu Koeln*

[10] *Cambridge*

[11] *Universität Heidelberg, Zentrum für Astronomie, Institut für Theoretische Astrophysik, Albert-Ueberle-Str. 2, 69120 Heidelberg, Germany*

[12] *INAF - Istituto di Astrofisica e Planetologia Spaziale*

Corresponding Authors: mininni@arcetri.astro.it, asanchez@ice.csic.es, cara.battersby@uconn.edu, alessandro.coletta@inaf.it, pho@asiaa.sinica.edu.tw, berti.1761130@studenti.uniroma1.it, schilke@ph1.uni-koeln.de, alessio.traficante@inaf.it, maria.beltran@inaf.it, sergio.molinari@inaf.it

The formation of high-mass stars remains a complex and not fully understood process, differing significantly from that of low-mass stars. Understanding their early evolutionary stages is crucial for uncovering the mechanisms governing their formation and their impact on galactic evolution.
In this poster I present a study of the infall dynamics of dense cores (1000-3000 AU) associated with high-mass star formation. The dataset is drawn from ALMAGAL (Molinari et al. 2025 e Sanchez-Monge et al. 2025, accepted), an ALMA large program designed to investigate all stages of massive star formation across the Galaxy. The ALMAGAL survey offers the opportunity to study this process with an unmatched combination of a uniformly spatial resolution (~1000 AU) and sample size (1013 Clumps observed), allowing for a comprehensive analysis of the physical and kinematic properties of cores. In this study, we use a 5000 AU core catalogue built using the same specifications of the 1000 AU catalogue presented in Coletta et al. 2025. This approach enables a connection to previous studies on clump scales (~1 pc, Traficante et al. 2018), providing a multi-scale perspective on accretion dynamics.
To identify infall candidates, we analysed the H2CO line, selecting sources exhibiting distinctive asymmetric profiles indicative of infall motion. The robustness of this selection is ensured by additional checks on optically thin lines (DCN, HCCCN, CH3CN and CH3OCHO) to exclude potential spurious sources. This approach results in 142 candidates, the largest sample of infall candidates identified at core- envelope scales (~5000 AU), providing a statistically significant basis for estimating accretion rates.
The derived infall velocities span a range consistent with values reported in the literature on clump scales (Vin: 4.06 × 10^ (−3) km/s to 9.05 km/s, with a median value of 0.24 km/s), likely suggesting that the bulk of the accretion process occurs on smaller spatial scales. The estimated mass accretion rates tend to be lower than those inferred on larger scales (Ṁacc: 0.05 × 10^(−4) M□/yr to 269 × 10^(−4) M□/yr, with a median value of 2.74 × 10^(−4) M□/yr), in agreement with the fact that the velocities dispersion generated by infall motion originates primarily at smaller scales, where the integrated mass at 5000 AU is lower, leading to reduced accretion rate. Notably, the accretion rate distributions remain relatively constant when categorized by evolutionary phase, though a subset of sources shows particularly high values of infall motion (5 sources with Vin > 5 km/s), possibly suggesting episodic accretion bursts.

Session 1a / 61

From Psuedodisk Formation in Magnetized Collapse to the Interplay with Multi-faced Outflow Phenomena

Author: Hsien Shang[1]

[1] *Institute of Astronomy and Astrophysics, Academia Sinica*

Corresponding Author: shang@asiaa.sinica.edu.tw

A plethora of new enigmatic phenomena in the innermost parts of protostellar systems associated with jets and outflows have been revealed by ALMA and JWST. These jets and outflows, along with the streamers from their magnetically collapsing prenatal envelopes, are integral parts of the physical processes that assemble the systems. We review the characteristics of these enigmatic, powerful phenomena that constitute telltale signs of the underlying fundamental physics revealed by generations of radio and optical telescopes. The unprecedented revelation of the fine, nested kinematic and morphological structures is consistent with theoretically predicted features of magnetized bubbles blown by magnetized winds from the innermost regions and the pseudo-disks formed inside the large magnetically supported envelopes. The ubiquitous characteristics of the coupled nested velocity and emission components finds a natural explanation in the unique combination of jet–outflow–envelope systems. Tomographic projection of the morphological and kinematic structures naturally connect to high-angular resolution and high-sensitivity observations of the magnetically-interplayed inflow and outflow, enriched by chemical diversity.

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The accretion/ejection properties of Class 0 protostars studied with near-infrared spectroscopy

Author: Valentin Le Gouellec[1]

Co-authors: Antoine Gusdorf [2]; Curtis DeWitt [3]; Doug Johnstone [4]; Ewine van Dishoeck [5]; Logan Francis [5]; Lukasz Tychoniec [5]; Lynne Hillenbrand [6]; Thomas P. Greene [7]

[1] *ICE-CSIC*

[2] *LPENS*

[3] *SOFIA*

[4] *Herzberg observatory*

[5] *Leiden University*

[6] *Caltech University*

[7] *NASA Ames*

Corresponding Authors: doug.johnstone@gmail.com, tom.greene@nasa.gov, curtisdewitt@gmail.com, lah@astro.caltech.edu, valentin.le.gouellec@gmail.com, antoine.gusdorf@phys.ens.fr, francis@strw.leidenuniv.nl, lukasz.tychoniec@gmail.com, ewine@strw.leidenuniv.nl

Sun-like stars are thought to accrete most of their final mass during the protostellar phase, where the protostellar embryo is surrounded by an infalling dense envelope. The so-called Class 0 phase designates the youngest protostellar stage, where the accretion is the most vigorous. Because these objects are highly embedded, it is difficult to retrieve direct diagnostics from the accretion, whose observational imprint lie at small wavelengths, in the near-infrared and below. Therefore, little is known about the accretion properties and mechanisms occurring in the Class 0 phase because of high extinction. However, in rare cases the blueshifted cavity created by the outflow is sufficiently close to pole-on to liberate enough near-infrared scattered light for us to probe the immediate surroundings of the central object.

We present NIR observations of Class 0 protostars recently observed with Keck MOSFIRE and/or JWST NIRSpec. Brγ, several H_2 and CO overtone/fundamental ro-vibrational emission lines are detected and analyzed.
The analysis of the numerous H_2 lines reveal the wind and shocks structures along the jet, which allow comparisons with shock models and robust estimation of the mass ejection rate. CO fundamental ro-vibrational emission lines seem to coincide with the base of the wind/jet system. Stellar CO overtone lines are seen in absorption in several sources either suggesting recent vigorous accretion episodes, or quiescent protostars. They also allow for the first time the exploration of the

photospheric properties of these young protostellar embryos. CO overtone is seen in emission in half of the sources, tracing the dense inner accretion disk. Comparing these results with archival sample of Class I K-band spectra, we find that the CO and Bry emission lines are systematically more luminous in Class 0s, suggesting the accretion is on average more vigorous in the Class 0 phase. Typically associated with the heated inner accretion disk, the much higher detection rate of CO overtone emission in Class 0s indicate also that episodes of ExOr-type high accretion activity are more frequent in Class 0 systems. We modeled the CO overtone emission bands with analytical model of circumstellar disks and found the kinematics of the Class 0 CO overtone emission is consistent with either an accretion-heated inner disk, or material directly infalling onto the central nascent stellar embryo. The CO emission seems to be confined close to the central object surface (1-5 stellar radius). These results could point toward an accretion mechanism of different nature in Class 0 systems than the typical picture of magnetospheric accretion.

The sensitivity and wavelength coverage of JWST of these sources allow for much more precise extinction measurements, analysis of the excitation of molecular and atomic gas, and spatial mapping of the different spectral lines associated to the ejected and accreted material. These near- and mid-IR spectroscopy capabilities shall quantify the actual accretion/ejection properties of the youngest protostars.

Session 6 / 63

Exploring the limits of chemical complexity in the interstellar medium: present and future

Author: Víctor M. Rivilla[1]

[1] *Centro de Astrobiología (CAB, CSIC-INTA)*

Corresponding Author: vrivilla@cab.inta-csic.es

Following the initial detection of a molecule in the interstellar medium (ISM) in the late 1930s, more than 330 different species have been identified to date. The detection rate has increased in tandem with the enhancement of telescope sensitivity, particularly in the centimetre and (sub)millimetre ranges. Remarkably, the field has recently undergone a true revolution, with nearly 100 new species –constituting almost a third of the total number –being discovered in the last four years alone. The identified molecules are characterised by an increase in chemical complexity, as evidenced by the number of atoms and the diversity of their chemical composition. Of particular interest is the detection of species that are well-known precursors of prebiotic chemistry, i.e., the set of chemical processes that led to the emergence of life on early Earth. Consequently, we already know that the interstellar material from which stars and planets are formed contains at least some of the fundamental ingredients for life.

Complementarily, recent analyses of comets and asteroids using "in-situ" and sample-return space missions have revealed that our Solar System was formed in a parental cloud rich in prebiotic molecules, including a wide variety of amino acids and all five nucleobases present in RNA and DNA. However, these complex species have not yet been identified in the ISM, raising obvious questions: *does our Solar System represent a unique case with a particularly rich (prebiotic) chemistry? Or alternatively, are the prebiotic ingredients widespread in many other places in the Galaxy, or even in other galaxies?* In this talk, I will address these questions in the light of the latest results in the field. Firstly, I will summarise the state-of-the-art in the quest to detect new molecules of prebiotic interest in the ISM. Secondly, I will discuss new perspectives for the next years and decades thanks to the advent of a new generation of significantly more sensitive observational facilities.

Session 3 / 64

MHD Turbulence Unified Polarimetry and Zeeman Observations

Author: Hua-bai Li[1]

Co-authors: Shibo Yuan [1]; Zhuo Cao [2]

[1] *The Chinese University of Hong Kong*

[2] *Forschungszentrum Jülich*

Corresponding Author: hbli@cuhk.edu.hk

At the beginning of the 21st century, the prevailing belief was that primarily super-Alfvénic turbulence could rival gravity in the process of star formation. In the following decade, however, perceptions began to shift as polarized thermal dust emission indicated that cloud-scale magnetic fields were predominantly ordered, suggesting that both turbulence and gravitational contraction were **anisotropic**. Meanwhile, the relationship between the magnetic field (B) and density (n), B~n^2/3, derived from Zeeman measurements, was interpreted as **isotropic** gravitational collapse. The discrepancy in the interpretations of these two major magnetic field tracers puzzled astronomers, as discussed in the PPVII review. The logic and data behind the mystery will be discussed, followed the solution – I will demonstrate that a MHD simulation calibrated by polarimetry observations (i.e., ordered cloud-scale B-fields) can naturally replicate Zeeman results.

Session 6 / 65

Cosmic ray ionization in the local Milky Way: How well do we understand it?

Author: Alexei Ivlev[1]

[1] *MPI for extraterrestrial physics*

Corresponding Author: ivlev@mpe.mpg.de

I will present recent advances in understanding properties of low-energy CRs in molecular clouds.

In the first part of my talk I will summarize results of reevaluation of CR ionization rate (CRIR) derived from available measurements. Previous estimates of CRIR for these measurements relied on model-dependent assessments of the gas density along the probed sight lines. Now, we utilized the recently developed 3D dust extinction maps that allowed us to precisely identify the location of molecular clouds probed in each measurement, and also to derive the gas density in these clouds. This helped us to evaluate CRIR in each cloud without involving any model-dependent assumption about the environment. Our results indicate that (i) values of CRIR probed in individual diffuse molecular clouds in the local Galactic environment may vary by an order of magnitude from cloud to cloud, and (ii) the average CRIR value is a factor of 5-10 smaller than that derived previously.

I will also discuss resent theoretical development in understanding dominant mechanisms that govern attenuation of Galactic CRs penetrating molecular clouds. Apart from regular attenuation mechanisms, associated with ionization energy losses, penetrating CRs may also be scattering on self-generated turbulence excited in diffuse envelopes of the clouds. We found that significant self-modulation of non-relativistic CRs may already operate in clouds with the gas column density of a few times 10^21 cm−2, while for a few times 10^22 cm-2 the effect becomes strong for GeV protons. The obtained results are in excellent quantitative agreement with recent Fermi LAT observations of nearby giant molecular clouds.

Session 3 / 66

Magnetized star formation

Author: Josep M Girart[1]

[1] *Institut de Ciències de l'Espai, CSIC*

Corresponding Author: girart@ieec.cat

Molecular clouds have a tiny fraction of ions, but high enough to make them to be dynamically sensitive to the presence of the interstellar magnetic field. The role of the magnetic field in the dynamics of the molecular clouds at all scales, and in the process of the star formation, have been a source of vivid debate for the last 3 decades. A relatively strong magnetic filed can prevent fragmentation and removes efficiently the angular momentum through the magnetic braking process. The magnetic field can also play an important role in the formation of planet-forming disk and their early evolution. However, there are several physical processes that can diminish its importance, such as ambipolar diffusion, Ohmic dissipation, the Hall effect or turbulence reconnection. Measuring the properties of magnetic fields relies mostly on the linear polarization of aligned aspherical dust grains, in the Zeeman effect of species such OH and CN, and in the Goldreich-Kylafis effect in molecular lines. In this talk, I will also talk about the recent progress done since ALMA offered polarization capabilities in some frequency bands. There have been various attempts to better characterize the properties of the magnetic fields at core scales (<0.1 pc) in various surveys such as MagMaR (Magnetic Fields in Massive Star-forming Regions), BOPS (B-field Orion Protostellar Survey) o ALPPS (ALMA Perseus Polarization Survey). The first results of these works will also be presented here.

Session 5 / 67

A 'low' redshift mode of Population III star formation during the Epoch of Reionization

Author: Lisanne van Veenen[1]

[1] *Leiden University*

Corresponding Author: piyush.suneet@gmail.com

Thanks to JWST, we are now in an era where observing campaigns to discover Population III stars has become a possibility. Over the past 3 years, multiple JWST proposals on Pop III stars have secured time, but no definitive detections have emerged. The two most pertinent challenges are: 1.) if most Pop III stars were massive, they would have not survived for a time window long enough for JWST to capture them, and 2.) if they formed at redshifts > 15, which even with the sensitivity of JWST remains notoriously hard to observe. Recent works suggest that Pop III star formation could have continued down to 'low' redshifts, during the Epoch of Reionization (EoR, z ~ 6). If realistic, this could be a game changer since the natural expectation is that such Pop III stars would have been less massive, lived to a longer time period, and are located at cosmological distances within the reach of JWST. Motivated by these possibilities, we carry out the first 3D radiation magnetohydrodynamics simulations of Pop III star formation during the EoR. We find significant differences in the mass, multiplicity, radiation and cluster properties of Pop III stars between z = 6 and z > 15. Contrary to expectations, even though the gas is colder at z = 6, there is less fragmentation within the pristine cloud due to the combined effects of magnetic fields and radiation feedback. Differences in protostellar accretion rates at z = 6 and z > 15 lead to very distinct stellar evolution, which changes the amount of ionizing and dissociating photons produced, and subsequent escape fractions. The differences are even more dramatic when a background Lyman-Werner radiation appropriate at z = 6 is included. By providing realistic, full physics-guided estimates of the mass and radiation properties of these stars, our simulations provide much needed benchmarks for designing Pop III observing campaigns with JWST towards the end of the first billion years.

Session 1a / 68

A mass invariant at the origin of the universality of the Core Mass Function?

Author: Pierre Dumond[1]

Co-authors: Gilles Chabrier [1]; Jérémy Fensch [1]

[1] *ENS Lyon*

Corresponding Authors: pierre.dumond@ens-lyon.fr, jeremy.fensch@ens-lyon.fr, gilles.chabrier@ens-lyon.fr

Explaining the universality of the peak of the Core Mass Function is a major unsolved problem in astrophysics. Recently, Jaupart & Chabrier (2021) suggested that this universality can be related to a mass invariant M_inv first derived by Chandrasekhar (1951) based on several assumptions, namely the statistical homogeneity of the turbulent density field.
This invariant depends on the variance and correlation length of the density field. In this work, we performed numerical simulations of homogeneous and isotropic compressible turbulence to test the validity of this invariant in a medium subject to decaying turbulence or to self-gravity. We study several input configurations, namely different Mach numbers, injection lengths of turbulence, equations of state and average gas densities to cover the variety of star formation conditions. We confirm that M_inv remains constant during the decaying phase of turbulence and also for self-gravitating flows. Furthermore, we develop a theoretical model of the density field statistics which predicts without any free parameter the evolution of the correlation length with the variance of the logdensity field beyond the assumption of the gaussian field for the logdensity. Noting that M_inv is independent of the Mach number, we show that this invariant can be used to relate the non-gaussian evolution of the logdensity probability distribution function to its variance with no free parameters. Finally, we will discuss what we can learn from this invariant in terms of the statistics of the structures formed in star-forming regions and its link to the peak of the core mass function.

Session 1b / 69

Clusters, Associations and the Stellar Mantle

Author: Steven Stahler[1]

[1] *U. C. Berkeley*

Corresponding Author: stahler@astro.berkeley.edu

As a stellar group forms within its parent molecular cloud, new members first appear in the deep interior. Theory suggests, and observations confirm, that these crowded stars continually diffuse outward. I suggest that they also leak out of the cloud, to form an expanding envelope which I call the "stellar mantle." In a nascent OB association, the mantle remains nested deep inside the Galactic tidal radius. In smaller stellar groups, the tidal force erodes the mantle, and determines whether the group becomes a T association or a gravitationally bound open cluster.

Session 5 / 70

Ultra-faint dwarf galaxies as first life-nurseries in the Local Group

Author: Stefano Ciabattini[1]

Co-authors: Stefania Salvadori [1]; Leonardo Testi [2]

[1] *Università degli Studi di Firenze*

[2] *Dipartimento di Fisica e Astronomia, Università di Bologna*

Corresponding Authors: stefano.ciabattini@unifi.it, leonardo.testi@inaf.it

We investigate if Local Group dwarf spheroidal (dSph) galaxies might have formed the first planetary systems able to support life. By exploiting the observed chemical abundances and star formation histories, we developed a novel semi-empirical model which quantifies the probability of dSphs to host life-friendly planets by investigating if their stars: (i) reach the minimum heavy elements abundance to trigger planet formation; (ii) dwell in a safe environment to develop life in its embryonic or intelligent form. Although the fraction of stars with overcritical iron-abundance for planet formation,$[\mathrm{Fe/H}]_{\mathrm{cr}}$, increases with luminosity, we find that bright dSphs are more exposed to sterilization from Supernovae (SNe) and Gamma-ray Bursts, while ultra-faint dSphs (UFDs, $L < 10^5 \mathrm{L}_\odot$) have the highest probability to survive these destructive events ($P_{\mathrm{surv}} \geq 0.8$). Our results show that UFDs are the first and most life-suitable Local Group galaxies if planet formation is possible below $[\mathrm{Fe/H}] \sim -1$. Assuming $[\mathrm{Fe/H}]_{\mathrm{cr}} = -2.5$ we show that $> 50\%$ of stars in UFDs might have hosted life since 13 Gyr ago and sustained it for > 4 Gyrs. By evaluating the abundance of refractory elements relevant for planet formation (Mg, Si and Fe) we find that 50% (1%) of stars in UFDs (dSphs) with $[\mathrm{Fe/H}] < -2.5$ have a refractory index $[\mathrm{Ref/H}] > -2.5$, being Mg-, Si- (and C-) enhanced by primordial SNe. Thus, our findings suggest that UFDs might represent the first life-nurseries of our Local Group, reaching the two key conditions for hosting life during the first billion years of cosmic evolution.

Session 4 / 71

Bar-spiral interaction produces star formatin bursts

Authors: Lea Marques[1]; Ivan Minchev[2]

Co-authors: Bridget Ratcliffe [3]; Sergey Khoperskov ; Matthias Steinmetz ; Trey Wenger ; Tobias Buck ; Marie Martig ; Georges Kordopatis [4]; Mathias Schultheis ; Daniel Zucker

[1] *Leibniz-Institut fur Astrophysik Potsdam, Germany (AIP)*

[2] *Leibniz Institut for Astrophysics Potsdam (AIP)*

[3] *Leibniz Institute for Astrophysics Potsdam (AIP)*

[4] *Observatoire de la Cote d'Azur*

Corresponding Authors: bratcliffe@aip.de, lmarques@aip.de, georges.kordopatis@oca.eu, skhoperskov@aip.de, iminchev1@gmail.com

Central bars and spirals are known to strongly impact the evolution of their host galaxies, both in terms of dynamics and star formation. Their typically different pattern speeds cause them to regularly overlap, which induces fluctuations in bar parameters. I will show, using both numerical simulations and observations, how bar-spiral physical overlap produces both migration and star formation boosts on the timescale of their beat-frequency. On the one hand, this mechanism can send stars from the bar radius out to the solar neighborhood on cold orbits. On the other end, it can enhance star formation by a factor of up to 4 when the bar and the spiral are connected, depending on the strength of the spiral structure. This is in agreement with observational studies seeing a revival of star formation rates at the end of the bar, compared to its decrease along the bar major axis. The bursts do not always happen simultaneously at the two sides of the bar, hinting at the importance of odd spiral modes. Various pieces of evidence seem to show the relevance of non-bisymmetric spiral structure in the MW. Such a phenomenon could be investigated thanks to resolved observations of nearby face-on galaxies, by comparing star formation rates from the two sides of the bar.

Session 6 / 72

Bridging Hydrodynamics and Non-Equilibrium Chemistry: The Feasibility of Deep Learning Surrogates in Simulations

Author: lorenzo branca[1]

[1] *University of Heidelberg*

Corresponding Author: lollobranca@gmail.com

Non-equilibrium thermo-chemistry plays a crucial role in shaping the properties of the interstellar medium, from galactic to protoplanetary scales, particularly within molecular clouds. However, accurately modeling its effects in numerical simulations remains a significant challenge due to the complexity of the associated systems of ODEs.

To address this, surrogate models—often based on deep learning—have been proposed as a means to accelerate on-the-fly calculations within simulations. While several surrogate models have been developed in recent years, their reliability remains an open question, and none have yet been integrated into full-scale simulations. In this talk, I will discuss a feasibility study on coupling hydrodynamics with surrogate models for chemistry, highlighting recent advances in controlling model approximation errors. Our findings suggest that these techniques hold great promise for achieving accurate and computationally efficient simulations of astrochemical environments.

Session 1a / **73**

From simulations to theory: revisiting star formation models in high-Mach environnement.

Author: Noé Brucy[1]

Co-authors: Patrick Hennebelle [2]; Tine Colman [1]

[1] *ENS Lyon*

[2] *CEA Paris-Saclay*

Corresponding Author: noe.brucy@ens-lyon.fr

Several attempts have been made to build analytical model for galactic star formation rates. This models prove extremely useful in many contexts, from cosmological and galactic simulations to the interpretation of observations.
In this talk I will present a set of numerical simulations that challenge the existing analytical models for high-Mach numbers. I will then present a set of conceptual changes that can be made to these models to correctly match the behavior of the star formation rate.

Session 1a / **74**

Outflow-Outflow interactions in binary and clustered protostars

Author: Pedro R. Rivera-Ortiz[1]

Co-authors: Ary Rodríguez-González [2]; Iván Castorena [2]; Luis Zapata [1]

[1] *Institute of Radioastronomy and Astrophysics UNAM*

[2] *Instituto de Ciencias Nucleares UNAM*

Corresponding Author: p.rivera@irya.unam.mx

Theoretical models suggest that jet-driven bow shocks govern Class 0/I molecular outflow morphologies extending up to 10^{4-5} au, with additional modifications arising from binary motion, precession,

and ambient interactions due to other outflows produced by clustered or binary protostars. Previous studies have demonstrated that outflow interactions in clustered environments are common, particularly in high-mass star-forming regions such as W43-MM1, where multiple outflows interact at scales of 5×10^3 au. Recent observational advances have enabled the detection of fine structures within these outflows, providing new constraints on theoretical models.

This study aims to investigate the interaction between molecular outflows, studying their occurrence probability and the observational signatures produced by such interaction, and analyzing how these interactions modify the structure and emission characteristics of the protostellar envelope. We use 3D hydrodynamical simulations to model these interactions under realistic physical conditions, incorporating initial conditions derived from observational studies. The simulations allow us to study the dynamic evolution of the system, revealing signatures of outflow collisions that could serve as observational markers. These findings are particularly relevant for future studies using (sub)millimeter interferometers such as ALMA and NOEMA, which can now resolve outflow interactions at scales of less than 10^3 au.

We present our results to understand better the complex dynamics governing molecular outflow interactions in binary systems. By characterizing these interactions, we can refine our models of jet evolution and provide empirical criteria for identifying similar events in other protostellar environments. The results offer valuable insights into the role of multiplicity in star formation and the broader implications of outflow collisions in shaping the interstellar medium.

Session 1b / **75**

Explosive outflows produced by gravitational interactions

Author: Pedro R. Rivera-Ortiz[1]

Co-authors: Ary Rodríguez-González [2]; Jorge Cantó [3]; Luis Zapata [1]

[1] *Institute of Radioastronomy and Astrophysics UNAM*

[2] *Instituto de Ciencias Nucleares UNAM*

[3] *Instituto de Astronomía UNAM*

Corresponding Author: p.rivera@irya.unam.mx

Explosive outflows (EOs) can significantly influence the structure of star-forming environments. EOs present a more complex scenario than conventional bipolar molecular outflows driven by jets and winds. Observed in high-mass star-forming regions, they consist of numerous dense clumps leading gaseous filaments spreading nearly isotropically from a common center. They have been identified in Orion BN/KL, DR21, G5.89-0.39, IRAS 16076-5134, Sh106-IR, and IRAS 12326-6245. Their kinematics resemble a Hubble-like expansion, and they have a similar rate and a kinetic energy comparable to supernovae events, suggesting that EOs may be a common evolutionary stage for massive stars.

The origin of EOs remains uncertain, but current models propose that N-body interactions, resulting in compact binary formation or stellar mergers, release gravitational potential energy, driving these explosive events. The presence of runaway protostars receding from the explosion center in Orion BN/KL reinforces the hypothesis of a violent disintegration of a protostellar multiple system.

We propose that a runaway star could disrupt a dense cluster of prestellar clumps, analogous to compact fingertips producing the Orion BN/KL EO. Using N-body numerical simulations, we analyze the gravitational interactions and energy transfer mechanisms responsible for ejecting cluster members with explosive characteristics. Our study explores the implications of this model in explaining the formation of EOs, providing new insights into the dynamic interactions within young star clusters. We found that when the cluster mass is less than or up to a few times the stellar mass, the collision will produce an explosive outflow, ejecting a significant fraction of the cluster members with velocities larger than the impact velocity. Our models produce the ejections of the cluster members at very high velocities, reinforcing the probability that a close encounter could be responsible for EOs.

Session 1a / 76

Poster session (1)

Marie-Anne Carpine, Alessandro Coletta, Noé Brucy, Pedro R. Rivera-Órtiz

Session 2 / 77

Giovan Battista Donati and the birth of a new physics for stars

Author: Mauro Gargano[1]

[1] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Author: mauro.gargano@inaf.it

In the second half of the 19th century, Italian astronomers made a fundamental contribution to the birth of astrophysics through the first spectroscopic analysis of stellar light. These were the dawn of spectroscopy and astrophysics, transforming our scientific knowledge of the universe through the study of the intrinsic characteristics of stars (chemical composition, temperature, density, velocity), a prospect previously considered unthinkable.
Angelo Secchi and Lorenzo Respighi in Rome, Giuseppe Lorenzoni in Padua, Pietro Tacchini in Palermo, and Giovan Battista Donati in Florence were pioneers in this field. These scientists were protagonists of essential results such as the first spectral classification of stars, the first spectrum of a comet, the development of solar physics, and the establishment of the first scientific society devoted to astrophysical studies.
This talk retraces the key milestones of this extraordinary turning point in Italian astronomy, with a particular emphasis on the Pisan astronomer Giovan Battista Donati, founder of the Arcetri Observatory.

Session 4 / 78

From Island Universes to Noisy Neighborhoods: the chemical evolution of galaxies

Author: Steven N. Shore[1]

[1] *Dipartimento di Fisica, Universita di Pisa*

Corresponding Author: steven.neil.shore@unipi.it

One of the fundamental astronomical discoveries just a century ago, was that the Milky Way is one of a vast number of "islands" within the cosmic sea. One of the great challenges of this century is to understand why they are neither isolated nor monolithic. The pollution of the gaseous, baryonic component by stellar nucleosynthesis is the unique evidence remaining over cosmic time to trace the populations and dynamics of galaxies. The study of the large scale abundance gradients and isotopic compositions is essential for constraining the history of star formation and galactic growth. The talk will review the changing perspectives and significance of the underlying astrophysical assumptions from the first structureless closed box models to the current generation of cosmological numerical simulations, and the new perspective regarding the stochasticity and inherent heterogeneity of that evolution.

Session 3 / 79

Formation and structure of magnetized protoplanetary disks

Author: Susana Lizano[None]

Corresponding Author: s.lizano@irya.unam.mx

Protoplanetary disks are thought to form through the gravitational collapse of magnetized, rotating dense cores. In this talk, I will review work conducted during an enjoyable and fruitful collaboration with Daniele Galli on the gravitational collapse phase and the structure of magnetized protoplanetary disks.
To enable the formation of rotationally supported disks, the magnetic flux from the natal cloud must be lost to prevent catastrophic magnetic braking. During this process, accretion disks threaded by a poloidal magnetic field and irradiated by the central star are expected to emerge. The poloidal field induces sub-Keplerian gas rotation in the disk, which can accelerate planet migration and enhance disk stability against gravitational perturbations. Additionally, magnetic compression reduces the disk scale height compared to nonmagnetic disks. The mass-to-flux ratio, λ, is the key parameter governing these effects. Models of magnetized disks around young YSOs such as HL Tau and TW Hya suggest $\lambda \sim 20 - 30$, significantly higher than the values of the natal cloud, indicating substantial flux loss during disk formation. Determining λ observationally is crucial for understanding this process. Polarized dust emission from protoplanetary disks is primarily dominated by dust scattering rather than emission from grains aligned with the magnetic field. Consequently, measuring disk magnetization requires Zeeman splitting observations with ALMA and the VLA. These measurements are essential for advancing our understanding of protoplanetary disk formation and evolution.

Session 2 / 80

Beyond Academic Boundaries: Scientific Collaboration and Friendship in the Lorenzoni-Abetti Partnership

Author: Valeria Zanini[1]

[1] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Author: valeria.zanini@inaf.it

The scientific relationship between Giuseppe Lorenzoni (1843-1914) and Antonio Abetti (1846-1928) is one of the most significant and enduring partnerships in late 19th-century Italian astronomy. Despite their similar ages, Abetti always regarded Lorenzoni as his Master, a respect that fostered rather than hindered their productive scientific collaboration. Their deep personal bond, which extended to include their families, had an important impact on the scientific development of Italian astronomical research of the time. A prime example of their collaborative work was the expedition to India to observe the transit of Venus across the Sun, of which Lorenzoni was one of the principal organizers and in which Abetti took an active part. The correspondence exchanged between them during this extensive journey provides valuable insights into their close relationship, illuminating both the scientific endeavors and the personal dynamics that characterized their partnership, a collaboration that made remarkable contributions to astronomical advancement in the newly unified Italy.

Session 2 / 81

The life and time of a Pisan Astronomer

Author: Simone Bianchi[1]

[1] *Istituto Nazionale di Astrofisica (INAF)*

Corresponding Author: simone.bianchi@inaf.it

While we celebrate our friend Daniele from Pisa, I will talk about another great Pisan astronomer, Giovanni Battista Donati (1826-1873), pioneer of Astrophysics and founder of the Arcetri Observatory. Despite his many achievements, Donati had received little attention by Italian science historians in the past. In the last two decades, however, the situation has changed, thanks to Daniele, who spent countless night hours to read and transcribe letters and other documents regarding his personal hero (a.k.a. "Bista").
I will illustrate the human aspects of Bista that emerged from Daniele's work (and the fun we had in this research!).

Session 5 / 82

From Island Universes to Noisy Neighborhoods: the chemical evolution of galaxies

Author: Steven N. Shore[1]

[1] *Dipartimento di Fisica, Universita di Pisa*

Corresponding Author: steven.neil.shore@unipi.it

One of the fundamental astronomical discoveries just a century ago, was that the Milky Way is one of a vast number of "islands" within the cosmic sea. One of the great challenges of this century is to understand why they are neither isolated nor monolithic. The pollution of the gaseous, baryonic component by stellar nucleosynthesis is the unique evidence remaining over cosmic time to trace the populations and dynamics of galaxies. The study of the large scale abundance gradients and isotopic compositions is essential for constraining the history of star formation and galactic growth. The talk will review the changing perspectives and significance of the underlying astrophysical assumptions from the first structureless closed box models to the current generation of cosmological numerical simulations, and the new perspective regarding the stochasticity and inherent heterogeneity of that evolution.

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Poster Session (2)

Pierre Dumond, Adnan Ali Ahmad, Valentin Vallucci-Goy, Ashley Bemis, Ilseung Han

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Poster Session (3)

Pedro R. Rivera-Órtiz, Basmah Riaz, Gabriel Verrier, Shingo Nozaki, Vianey Camacho

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Poster Session (4)

Chiara Mininni, Alice Nucara, Leonardo Berti

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Poster Session (5)

Luca Moscadelli, Hua-Bai Li, Indrani Das, David Whitworth, Diego Falceta-Gonçalves, Ya-Chi Wang

Session 5 / 87

Back where it all begins: the formation of the first stars and black holes

The formation of the first stars and black holes marked a fundamental transition in cosmic history, from the cosmic dark ages to cosmic dawn. This event laid the foundation for the Universe as it appears today and shaped the evolution of the first galaxies and active galactic nuclei. The launch of JWST has enabled an unprecedented leap forward in exploring these distant cosmic epochs, raising new and compelling questions. In this talk, I will review our current theoretical understanding of the properties of the first stellar populations and black holes, discussing the many open questions and the prospects of future facilities in the electromagnetic and gravitational wave bands for providing a consistent picture of cosmic dawn.

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Poster Session (7)

Stefano Ciabattini, Gian Luigi Granato

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Poster session (8)

Álvaro Sánchez-Monge, Gan Luo, Lorenzo Branca, Nai Chieh Lin

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Poster session (6)

Enrique Vázquez Semadeni, Stevie King