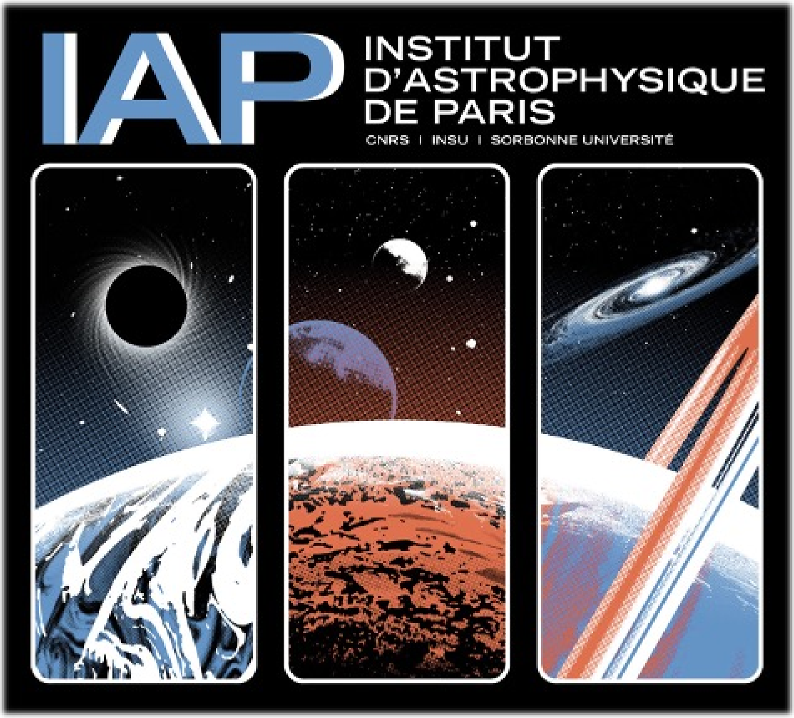
Journée des thèses / PhD day



Friday, 29 March 2024, 10:00 - 16:45
Institut d'Astrophysique de Paris
Amphitheater Henri Mineur

Organizers: Sofia Flores Morales, Kratika Mazde, Aline Vitrier & Théo Vrignaud.

Programme

10:00	*Opening remarks*	
10:05	Kratika Mazde	Bohmian Approach to Quantum Cosmology
10:20	Léonard Lehoucq	Exploring the Uncharted: Proposing High-Frequency Gravitational Wave Detection in the MHz-GHz Range
10:35	Simon Ding	Bayesian inference with physics informed priors from simulations
10:50	Rosa Malandrino	Cosmological information in the shape of cosmic voids
11:05	Abineet Parichha	Unraveling Dark Matter halo dynamics: From Caustics to Universal profiles
11:15	*Break*	
11:40	Sofia Flores Morales	Stellar Dynamics in Galactic Nuclei
11:55	Mathieu Roule	Kinetic theory of self-gravitating stellar systems
12:10	Louise Paquereau	Unveiling the galaxy-halo connection with COSMOS-Web
12:25	Nimatou Diallo	Feedback in galaxies: the role of cosmic rays
12:40	Romane Cologni	Investigating star formation in unquenched super spiral galaxies
12:50	*Lunch buffet*	
14:00	Aline Vitrier	Cosmological parameters constraints from CMB data analysis with the South Pole Telescope
14:15	Anirban Bairagi	A Hierarchical approach for Field level Inference
14:30	Iryna Chemerynska	Probing the Early Universe: Extending the Mass-Metallicity relation to low-mass galaxies at $z>6$
14:45	Arthur Poisson	Probing High Energy Physics with the Cosmological Collider
15:00	Denis Werth	The Cosmological Flow
15:10	*Break*	
15:40	Théo Vrignaud	Exocomets: detection and composition
15:55	Emilie Panek	A re-analysis of chemistry in five hot Jupiters' atmosphere
16:10	David Touzeau	Cosmic Shear Nulling: theoretical uncertainties on Dark Energy parameters derived by Euclid Mission
16:25	Tristan Hoellinger	Novel methods for implicit likelihood inference in cosmology
16:40	*Closing remarks*	

Bohmian Approach to Quantum Cosmology

In quantum cosmology, the problem of time arises from the attempt to reconcile the principles of general relativity with those of quantum mechanics within the context of the universe as a whole. Over the past few decades, multiple attempts have been made to solve the problem of time, i.e., the Wheeler-De Witt (WdW) equation. WdW equation happens to be timeless, the Hamiltonian vanishes and there is no component of time. Quantizing general relativity using the ADM formalism can be crucial to secure a canonical gravity approach in this regard. However, one still struggles to quantize dynamical equations. We shall primarily see that Bohmian approach solves the problem of time at the background level. It becomes natural to introduce a time component which further evolves over dynamical equations. Additionally, minisuperspace is well defined. Assigning an internal degree of freedom to define time could also be immensely helpful in this regard.

Supervisor: Patrick Peter

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Exploring the Uncharted: Proposing High-Frequency Gravitational Wave Detection in the MHz-GHz Range

The gravitational wave (GW) spectrum is a vast frontier, teeming with diverse sources and spanning a wide range of frequencies. The groundbreaking work of LIGO/Virgo in the kHz regime has unveiled approximately 100 compact binary mergers, with ongoing observations in its O4 run promising new and intriguing detections. In the nHz band, pulsar timing arrays (PTAs) are diligently exploring the cosmos, providing initial evidence of a low-frequency stochastic gravitational background, likely emanating from the cosmic dance of supermassive black hole mergers.
Looking ahead, the recently accepted LISA project by the European Space Agency (ESA) holds promise for probing the mHz band in the near future. However, the terrain above LIGO/Virgo frequencies remains largely unexplored. This talk aims to address the intriguing question: What lies in the high-frequency realm, specifically in the MHz-GHz range? Are there plausible sources that could generate GWs at such elevated frequencies, and what innovative detection strategies could be envisioned to unlock this GWs symphony?

Supervisors: Irina Dvorkin & Cyril Pitrou

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Bayesian inference with physics informed priors from simulations

Upcoming surveys such as DESI, Euclid, LSST, SPHEREx, and SKA will push cosmology into a data-driven era with their unprecedented survey volume and instrument sensitivity. The effectiveness of how much we can leverage the informational wealth and statistical power contained in the observational data will greatly depend on the accuracy of our data models. To this end, using cosmological simulations is established as a principal method to test and validate a given inference pipeline. Furthermore, simulations are also leveraged to gain insights into the properties of the expected survey data. However, these physical intuitions gained from simulations are often empirically quantified and not directly connected to the final model parameters of interest. Therefore, more conservative prior choices are still necessary. In this talk, I will introduce a fully Bayesian formalism on how to distil implicit priors for a given model by leveraging existing suites of cosmological simulations. The method is model-agnostic and can improve parameter constraints without introducing biases.

Supervisors: Guilhem Lavaux & Jens Jasche (Stockholm University)

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Cosmological information in the shape of cosmic voids

Cosmic voids are a well-established probe to gather cosmological information from the large-scale structure of the Universe. They emerge from the underdense regions of the primordial density field and evolve under the effect of the cosmic expansion. As such, void statistics are sensitive to dark matter, dark energy and the gravitational effect of neutrinos.
Despite being extracted from the same data used in clustering analysis, voids have been shown to be complementary to traditional probes like the power spectrum, thus allowing us to extract additional cosmological information from galaxy surveys and obtain tighter constraints. Various summary statistics have been analyzed so far, but other properties remain relatively unexplored.
We investigate the information content of the shapes of voids using Fisher forecasts, extending the definitions of previous works in order to obtain a more complete characterization. In light of this knowledge, we then employ these new summary statistics in a Simulation Based Inference framework with the goal of constraining the posterior distribution of the cosmological parameters.

Supervisor: Benjamin Wandelt

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Unraveling Dark Matter halo dynamics: From Caustics to Universal profiles

The study of dark matter halos is pivotal in unravelling the nature of dark matter particles, their detection and structure formation in the universe. Furthermore, it is a promising ground for the application and testing of a wide class of theories.
The goal of my project is to track and investigate dark matter halo dynamics, from the formation of caustics seeded by tiny perturbations to the gradual evolution of the collapsed halos into the universal NFW(Einasto) profile. We examine a specific set of halos, generated from CDM and SIN-wave initial conditions, in numerical simulations using Ramses-N body and ColdIce-Vlasov codes. We propose to apply lagrangian and post-collapse perturbation theory to predict the shape of the first caustics, their extent and density profile. However, this treatment loses its validity shortly after the first crossing of particle trajectories, which is followed by relaxation and the formation of a cusp. Prior studies claim that the halos accrete largely onto intermediate and large radii with little to no impact on the inner cusp, eventually reaching the universal NFW(Einasto) profile. Despite the complex late-time dynamics, there exist self-similar solutions to the equations of motion of the particles, which can be exploited to understand and model the particle trajectories, phase space distribution, mass and density profiles. We intend to test these claims and construct a qualitative description of early and late-time halo dynamics of our own.
In this talk, I will detail the numerical experiments I have conducted, theoretical models and inferences drawn from their comparison.

Supervisor: Stephane Colombi

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Stellar Dynamics in Galactic Nuclei

The stars of the Galactic Center follow quasi-Keplerian precessing orbits around the supermassive black hole Sgr A*. These stars exhibit diffusion in their orbital plane orientation, resulting from coherent torques between the stellar orbits. This diffusion process is known as Vector Resonant Relaxation. By studying such Hamiltonian dynamics, I derive the evolution equation for the correlation of the potential fluctuations in the system, and I address the closure problem underlying its structure by adopting a generalized statistical closure scheme. I finally compare the numerical predictions of the approximation with measurements obtained from N-body simulations of the system.

Supervisor: Jean-Baptiste Fouvry

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Kinetic theory of self-gravitating stellar systems

Self-gravitating stellar systems, such as globular cluster or galaxies, quickly settle into quasi-stationary (non-thermal) states. While stable (and even isolated), they still evolve over long timescales. This slow, noise-driven evolution is analytically captured by the inhomogeneous Balescu-Lenard equation for isolated systems. Such a formalism is particularly valuable because it self-consistently captures some of the key non-linear processes involved in these systems' orbit reshuffling. In this presentation, I will outline the diverse processes at stake in the long-term evolution of self-gravitating systems highlighting their respective contributions across various geometries and regimes.

Supervisors: Jean-Baptiste Fouvry & Christophe Pichon

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Unveiling the galaxy-halo connection with COSMOS-Web

Understanding the intricate relationship between galaxies and dark matter halos is crucial for unveiling the mechanisms of galaxy formation and evolution. Various factors like gas properties within halos, mergers, feedback or the cosmic web's structure significantly impact star formation. However, many questions remain regarding the precise role of these environmental factors, particularly across diverse galaxy populations and back to the universe's earliest epochs. Using galaxy clustering, we can probe this galaxy-halo connection, inferring halo properties and gaining insights into galaxy growth processes.
As JWST's largest extragalactic imaging program, the COSMOS-Web survey offers a valuable opportunity to address these questions by providing a panoramic view of galaxies across cosmic time, from dwarf to massive, and their environments at large and small scales. This presentation begins by an overview of COSMOS-Web, discussing its initial results, including notable depth, redshift and mass coverage. We then delve into the early universe, presenting clustering measurements at unprecedented redshifts, up to z$\sim$14, revealing a strong link between galaxies and halos and putting constraints on early dark matter and stellar mass assembly. Additionally, we analyse the clustering of star-forming versus quiescent galaxies through cross-correlation analysis and halo occupation models, investigating the interplay between environment and quenching mechanisms.

Supervisors: Henry McCracken, Clotilde Laigle & Raphael Gavazzi (Laboratoire d'Astrophysique de Marseille)

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Feedback in galaxies: the role of cosmic rays

Cosmic rays are high-energy particles that interact with plasma via magnetic fields. They are an important energy component of galaxies, and numerical simulations have shown that cosmic rays can significantly affect galaxy dynamics and thus constitute a major source of feedback in galaxies.
However, this influence depends on the propagation properties of cosmic rays, which are still uncertain. Accurate modeling of their energy distribution is needed to better constrain theoretical models with direct observations.
To address this issue, we have developed a new module for cosmic rays that will be implemented in the RAMSES code for galaxy simulation, and which takes into account their spectral energy distribution. In this talk I will present the numerical scheme of the code and the results of simulations of cosmic ray evolution under different processes that I have carried out.

Supervisor: Yohan Dubois & Marta Volonteri

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Investigating star formation in unquenched super spiral galaxies

Very massive galaxies with stellar masses $> 10^{11}$ $M_\odot$ are in general red and dead galaxies, ie Peng et al. (2010). They are preferably found in clusters or groups. The environment is thought to be a possible reason for the suppression of star formation in these objects (dynamical pressure, collisions, tidal effects). The presence of an AGN is also a possible reason for the suppression of star formation in very massive galaxies. Indeed, these 2 mechanisms can affect the gas content and prevent galaxies from forming stars. Yet, Ogle et al. (2016; 2019) found that 6% of the most luminous galaxies (in optical terms) at redshift <0.3 are extremely massive giant spiral super galaxies, with a very high SFR for their mass. As such, they resemble gigantic massive unquenched galaxies (55-140 kpc in optical diameter). A key question is whether these galaxies have massive gas reservoirs and are as efficient at forming stars as their smaller version, the main sequence spirals. Understanding star formation in these objects requires a better knowledge of their gas content, which has been studied in very few of these sources. My work has consisted as for now in the analysis of the observations in molecular gas obtained for 5 such sources. The long-term objective of my thesis will be to question the mechanisms that prevent the extinction of star formation in these massive galaxies and to discuss more generally the efficiency of feedback processes in galaxies.

Supervisors: Damien Le Borgne & Philippe Salomé (LERMA)

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Cosmological parameters constraints from CMB data analysis with the South Pole Telescope

Observations of the cosmic microwave background (CMB) anisotropies in temperature and polarization are one of the most powerful probes of cosmology. The ESA Planck satellite provided high precision measurements of cosmological parameters, nonetheless a huge quantity of cosmological information is waiting to be uncovered from the E and B modes of polarization and from the temperature at small angular scales. This data will be crucial to address contemporary tensions of cosmology, such as the Hubble tension, the difference between the Hubble constant value infered from CMB maps of the early universe and the value measured from late universe observations of type Ia supernovae light curves calibrated with Cepheids. Thus, ground based telescopes aim to improve our knowledge of the universe composition and evolution. The South Pole Telescope (SPT) observes the CMB with its 10m primary mirror from the South Pole. Its third generation camera SPT-3G started collecting data in 2018 and the unprecedented resolution of the final maps will allow cosmological parameters constraints to rival Planck's. A new field of observation called the Wide Field has been recently defined and extends the survey region to cover 25% of the sky. In this talk I will introduce this new field, and briefly present the impact of a masked sky on the power spectrum analysis.

Supervisors: Karim Benabed, Silvia Galli & Eric Hivon

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A Hierarchical approach for Field level Inference

Advancing cosmological parameter inference with reduced uncertainties is a vibrant area of research, especially with the wealth of data from next-generation surveys like Euclid, DESI, and the Vera Rubin Observatory. This talk focuses on Simulation-Based Inference (SBI), utilizing summary statistics such as the Power Spectrum (P(k)) and Bispectrum (B(k)). However, these summaries fail to fully harness the non-Gaussian and non-linear features of the cosmological density field. To extract this crucial information, a field-based analysis is preferable, although its success hinges on model architecture, hyperparameter tuning, and the ability to fit high-resolution density fields into GPUs. We introduce a hierarchical approach that combines small-scale information from sub-volumes (patches) with large-scale information from the Power Spectrum. Our method demonstrates enhanced Fisher information about the parameters compared to using P(k) or B(k) alone.

Supervisor: Benjamin Wandelt

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Probing the Early Universe: Extending the Mass-Metallicity relation to low-mass galaxies at z>6

The mass-metallicity relation provides crucial insights into the baryon cycle in galaxies and provides strong constraints on galaxy formation models. I will discuss our findings on the mass-metallicity relation (MZR) in low-mass galaxies. We studied eight galaxies at a redshift of around 7, which were observed as part of the JWST/NIRSpec follow-up of the JWST Cycle 1 program, UNCOVER, targeting the lensing cluster A2744. By combining ultra-deep NIRSpec observations with strong gravitational lensing, we were able to derive the first spectroscopic constraints on the properties of ultra-faint galaxies during the first billion years of the Universe.
We use the strong-lines method, comparing the most recent high-redshift metallicity calibrations, to derive the gas-phase metallicity in galaxies with stellar masses between 10^6 and 10^8 solar masses. Exploring for the first time this low-mass regime at z>6 provides us with better constraints on the overall slope of the mass-metallicity relation, and whether metal enrichment is different in low-mass systems. Comparing our results to theoretical models, we find that these low-mass galaxies have slightly higher metallicities than expected from the extrapolation of hydrodynamical simulations, or lower redshift constraints. These results may indicate weaker outflows and a lower efficiency of gas removal. The observed dispersion can also be the consequence of highly stochastic star formation and ISM enrichment, which is expected in these low-mass systems.

Supervisor: Hakim Atek

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Probing High Energy Physics with the Cosmological Collider

It is well established that the paradigm of cosmological inflation is the correct framework for understanding the physics of the very first moments of our universe. It states that the universe went through a short phase of accelerated expansion in which the microscopic quantum fluctuations of its matter content were stretched to macroscopic scales, becoming the seed for all the observed structures of the cosmos e.g. the Cosmic Microwave Background or the Large Scale Structures.
Apart from its manifest interest in the understanding of the first moments of the universe, it is also the best way we know to probe the fundamental physics at very high energies. In particular, the spontaneous production of massive particles due to the expanding background can leave potentially visible imprints in the correlation functions known as the cosmological collider signal.
In this talk, I will expose a framework that allows one to treat the interactions of the necessary present inflaton field fluctuations and some massive particles and I will review the kind of processes that can lead to the above-mentioned signal. In particular, the theory features a necessary quadratic mixing which allows flavor oscillations between the two fields which will be the subject of our future work.

Supervisor: Sebastien Renaux-Petel

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The Cosmological Flow

Cosmological correlators hold the key to high-energy physics as they probe the earliest moments of our Universe. However, even at tree-level, perturbative calculations are limited by technical difficulties absent in flat-space Feynman diagrammatic. As a result, a complete dictionary mapping the landscape of inflationary theories and the corresponding observable signatures is not yet available.
In this short presentation, I will present the Cosmological Flow: a complete formalism to systematically compute tree-level inflationary correlators. The method is based on following their time evolution from their origin as quantum zero-point fluctuations to the end of inflation, and bypasses the intricacies of Feynman diagram computations.

Supervisor: Sebastien Renaux-Petel

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Exocomets: detection and composition

Extrasolar comets – or exocomets – are icy bodies placed on elliptical orbits which sublimate when they reach their periastron, producing extensive clouds of dust and gas – the so-called 'cometary tails'. The most famous star known to harbor such objects is Beta Pictoris, a young (20 Myr) A-type star, for which transiting comets are detected daily using photometry and absorption spectroscopy.
However, despite more than 35 years of observations, still very little information on the composition of these objects is known. Here, I will present a new analysis of archival HST/STIS data, leading to the first measurement of the abundance of several metallic species – Si, Fe, Ni, Mn... - within the tails of Beta Pictoris exocomets, and to the estimate of their physical properties. These results are of crucial importance to better understand the history of these objects and the main mechanisms at work within their gaseous tails.

Supervisor: Alain Lecavelier

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A re-analysis of chemistry in five hot Jupiters' atmosphere

Studying chemical composition is fundamental to modeling the formation history of planets and planetary systems. With the first JWST data and the upcoming Ariel satellite, we expect a leap forward in the exoplanet's atmosphere field. That's why we propose here an analysis of five targets to improve the determination of their composition and the chemical mechanisms that take place in their atmospheres, combining multiple instruments and using retrieval methods. Our five targets are HAT-P-12b, HD 209458b, WASP-6b, WASP-17b, and WASP-39b, which have temperatures ranging from 1000K to 1700K and radii ranging from 0.9 to 1.9 Jupiter radius. We use spatially scanned observations from the Wide Field Camera 3 and the Space Telescope Imaging Spectrograph on the Hubble Space Telescope, with a wavelength coverage of 0.4 to 1.7 microns. We analyze these data with the publicly available Iraclis pipeline (Tsiaras et al. (2018)). We performed a bayesian inference analysis considering molecular abundances varying freely and with equilibrium chemistry ACE (Agúndez, M. et al. (2012, 2020)) and FastChem (Stock et al. (2018)). This work is detailed in a dedicated paper Panek et al. (2023). For very hot planets, thermochemical equilibrium may be close to reality, but for less hot planets, vertical mixing and photodissociation bring these planets out of equilibrium. That's why I am also presenting today new results extended to a non-equilibrium thermochemistry model (Venot et al. (2020)).

Supervisors: Pierre Drossart, Jean-Philippe Beaulieu & Olivia Venot (LISA)

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Cosmic Shear Nulling: theoretical uncertainties on Dark Energy parameters derived by Euclid Mission

The Weak Lensing Shear is a powerful probe of cosmology. Along with Galaxy Clustering and the cross-correlation of those two probes, it gives the most effective set of Data, used by cosmological observations, to constrain cosmological parameters and study the large-scale structure of the universe. Yet, the nature of the Dark Energy, representing around 68% of the energy content of our current universe, is still unknown. Thus, any additional cosmological feature, data or probe that would give new constrains or information on cosmological parameters is of interest. One of those features could be the BNT (Bernardeau, Nishimichi, Taruya) transform as it provides a mostly geometrical property of Weak Lensing: The Nulling of the Cross-Spectra. This feature does not depend on the Galaxy Power Spectrum but only on Dark Energy Parameters and brings few additional systematics to the current analysis on Weak Lensing and Galaxy Clustering. As part of the Euclid consortium, we wish to exploit the Nulling property of the BNT transform to reduce theoretical uncertainties on Dark Energy parameters derived by the Euclid Mission.

Supervisor: Francis Bernardeau

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Novel methods for implicit likelihood inference in cosmology

We present methodological advances to perform implicit likelihood inference in cosmology from arbitrarily complex probabilistic forward models of cosmological surveys.

Supervisors: Florent Leclercq & Guilhem Lavaux

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