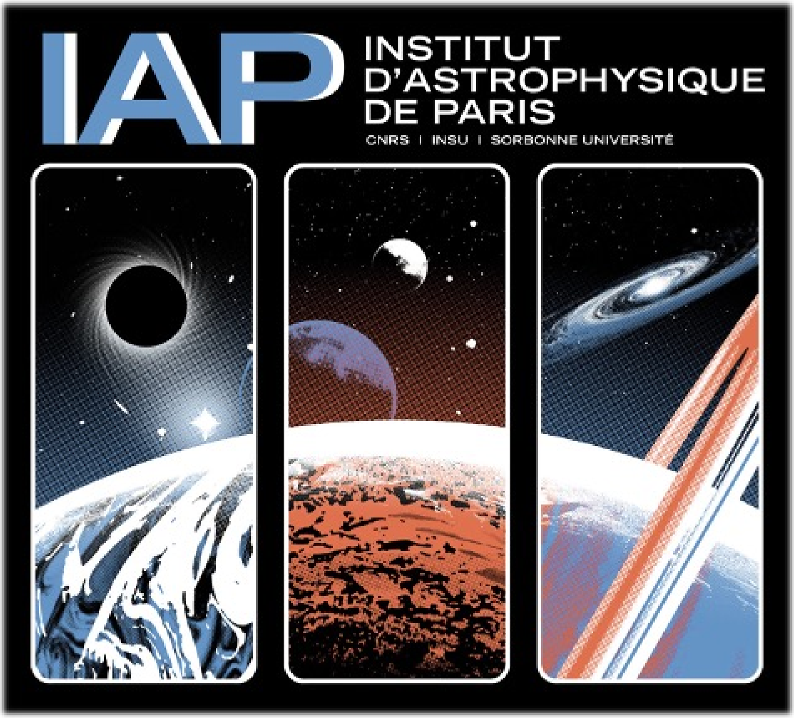
PhD day



Thursday, 21 May 2026, 9:30 - 17:30
Institut d'Astrophysique de Paris
Amphitheater Henri Mineur

Organizers: Nathan Belrhali, Sabri Errachdi, Sylvain Heurtier & Paul Minodier.

Program

9:30	*Introduction*	
9:35	Clément Prévotat	Probing the transition between Galactic and extragalactic cosmic rays with a multi-messenger approach
9:50	Sylvain Heurtier	Decoding the Burstiness of Early Galaxies: Constraints from JWST Spectroscopy and Hydrodynamic Simulations
10:05	Nathan Belrhali	Analytical techniques for cosmological correlators
10:20	Emilie Pernet	Next-generation spectral models for high-redshift galaxies observed with JWST
10:35	Eunhee Ko	Coupling baryons to galactic secular dynamics: SN Bubble-driven orbital diffusion of dark matter cusps
10:45	Anwar El Rhirhayi	From particles to galaxies: fluctuations, collisions and large deviations
11:00	*Coffee break*	
11:20	Nicolas Wozny	Galaxy star-formation histories of Euclid galaxies as a function of their morphologies and cosmic web environment
11:35	Arthur Poisson	Frequency-Momentum Space for Cosmological Correlators
11:50	Théo Vrignaud	Composition and dynamics of exocomets around Beta Pic
12:05	Sabri Errachdi	Impact of the large scale environment on galaxies properties
12:20	Florian Destriez	A new population of substellar companions around M dwarfs with Gaia
12:35	Rosa Malandrino	A Bayesian detection of high-significance voids and its cosmological applications
12:50	*Lunch buffet*	
14:00	Mouad Gnaoui	Does the pair annihilation in the BOAT GRB221009A imply several emission regions?
14:15	Emma Bruyère	Gravitational lensing beyond the eikonal approximation
14:30	Aline Vitrier	Towards constraining cosmological parameters with the SPT-3G Ext-10k survey
14:45	Paul Minodier	Hybrid radio and particle detection of air showers: potential for ultra-high-energy gamma-ray identification
15:00	Emile Dosso	How do the first Massive Black Holes Grow?
15:15	Sofia Flores	Gravitational Turbulence and Universal Spectra in Vector Resonant Relaxation
15:30	*Coffee break*	
16:00	Emeric Seraille	Gravitational radiation-reaction in compact binary systems at 4.5 post-Newtonian order in harmonic coordinates
16:15	Thomas Bizien	Nonlinear dynamics of self-gravitating stellar systems
16:30	Manon Gilles	Combining the Euclid and Roman space missions to measure the mass of cold terrestrial planets
16:45	Lorenzo Evangelista	The multiphase circumnuclear region of Centaurus A - from JWST/MIRI MRS observations
17:00	Mayeul Aubin	sCOLA Lightcones : Simulating Only What We Observe with Perfect Parallelism
17:15	Mathieu Venet	The parameter space of BNS populations: formation channels and merger rates

Probing the transition between Galactic and extragalactic cosmic rays with a multi-messenger approach

The transition energy between Galactic and extragalactic cosmic rays (CRs) remains an open question. Thanks to the new generation of observatories, observational windows have opened in PeV energies in neutrinos (IceCube, GVD and KM3NeT) and gamma rays (HAWC, LHAASO), complementing CR measurements in this energy range. This expanded dataset provides a more comprehensive framework for investigating the origins of CRs.

In this work we explore the transition between Galactic and extragalactic CRs using a multi-messenger approach. We model the distribution of extragalactic CRs in the Milky Way and compute the spectra of gamma rays and neutrinos produced during their propagation using the simulation framwork CRPropa. Our results are then compared with the corresponding latest observations, showing a weak contribution to the flux of those secondaries.

Supervisors: Rafael Alves Batista & Kumiko Kotera

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9:50 – 10:05 Sylvain Heurtier

Decoding the Burstiness of Early Galaxies: Constraints from JWST Spectroscopy and Hydrodynamic Simulations

Recent JWST observations suggest that star formation at high redshift is characterized by rapid, intense bursts, particularly in low-mass systems. However, the exact duty cycle and prevalence of these bursts remain major observational uncertainties. In this talk, I present a systematic study of star formation rate (SFR) variability on short timescales (10 - 100 Myr) across the redshift range 3¡z¡9. Leveraging a large sample of galaxies from several JWST spectroscopic surveys, we probe the low-mass regime (below Mstar 10^8 Msol) by comparing star formation indicators across different timescales, including Balmer line emission, UV luminosity, and Balmer break intensity. We perform a systematic comparison between these observations and mock galaxies from the MEGATRON and SPHINX simulations to constrain star formation histories (SFHs) and "burstiness" as a function of galaxy properties. Furthermore, we employ an analytical model to describe the distribution and scatter of Halpha and Halpha/UV ratios under varying SFH scenarios. This work provides a physically motivated framework for understanding galaxy assembly and feedback in the first billion years.

Supervisor: Hakim Atek

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Analytical techniques for cosmological correlators

Inflation is an accelerated expansion era introduced at the beginning of the universe timeline to address causality problems of the FLRW model. It can be realized with a scalar field theory minimally coupled to gravity. This scalar field has a background classical part that drives the accelerated expansion, and quantum fluctuations that, stretched by this expansion, give rise to large scale structures. These fluctuations can be mathematically described as quantum massive fields that propagate in a curved time-dependent space-time, and we can study their correlations functions called cosmological correlators.

I this talk, I will review some features of the physics of inflation and briefly present some analytical techniques to compute cosmological correlators.

Supervisor: Sébastien Renaux-Petel

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Next-generation spectral models for high-redshift galaxies observed with JWST

The James Webb Space Telescope has revealed interstellar spectral features in galaxies at cosmic dawn which differ markedly from those in lower-redshift galaxies, posing new challenges for existing spectral-interpretation models. A novel approach combining the GALSEVN stellar population synthesis code with the CLOUDY photoionization code has been shown to reproduce more accurately the high-ionization emission lines observed in metal-poor, actively star-forming galaxies at lower redshift than previous models. This framework offers a promising way to investigate the origin of the new features seen at cosmic dawn. We have built a comprehensive library of such models spanning full ranges in metallicity, hydrogen density, C/O and N/O abundance ratios, ionization parameter, dust-to-metal ratio, and binary-star fraction. Using the BEAGLE tool, we apply these models to interpret the spectra of a homogeneous sample of high-redshift galaxies from the JADES DR4. We investigate the new perspectives this analysis offers on inferred galaxy properties, such as star formation rate, element abundance ratios, and ionizing-photon production efficiency, compared to those derived using existing, less complete spectral libraries.

Supervisor: Stéphane Charlot

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Coupling baryons to galactic secular dynamics: SN Bubble-driven orbital diffusion of dark matter cusps

In the limit of weak deflections induced by local potential fluctuations, the rate of orbital diffusion of dark matter or stellar particle can be computed as a three-step process involving i) quantifying the effect of an individual deflection, ii) characterizing the statistical impact of many deflections via a local power spectrum, iii) finally phase-averaging this power spectrum over their orbits to compute diffusion coefficients as a function of orbital parameters. This strategy is applied to the cusp-core transformation of dark matter profiles induced by supernovae explosions. Simple but accurate analytic expression for the corresponding relaxation rates are presented for purely radially anisotropic, isotropic and anisotropic distributions of dark matter particles. They are successfully validated against Monte Carlo simulations. The initial rate of cusp flattening is derived from the corresponding Fokker Planck equation. Prospects of disentangling the effect of modified dark matter from baryonic physics are discussed. The methodology could be straightforwardly applied to other physical processes such as the heating of self gravitating stellar disc or the dissolution of galactic bars by giant molecular clouds, supernovae or turbulence.

Supervisor: Christophe Pichon

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From particles to galaxies: fluctuations, collisions and large deviations

The secular evolution of star clusters and galaxies is essentially driven by two-body relaxation, where the cumulative effect of small-angle gravitational encounters dictates macroscopic structural changes.

We will begin this presentation by reviewing the deterministic Landau equation, the standard framework for modeling the mean evolution of the velocity distribution in dispersion-dominated, finite-N systems subjected to frequent, grazing deflections.

Though successful, this kinetic equation fundamentally ignores the finite-N dynamical fluctuations.

Building upon Large Deviation theory, we present a physically consistent system of Langevin equations that simultaneously recovers the mean Landau dynamics, but also accurately captures the corresponding fluctuations among different realisations.

Furthermore, we demonstrate how the Large Deviation Principle yields a BBGKY-like hierarchy of deterministic partial differential equations, called the Lyapunov-Bogolioubov hierarchy, that fully describe the correlations of these dynamical fluctuations.

We extensively validate these equations against tailored direct N-body simulations, showing an exquisite level of agreement.

Supervisor: Jean-Baptiste Fouvry

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Galaxy star-formation histories of Euclid galaxies as a function of their morphologies and cosmic web environment

We know that disk galaxies tend to evolve into elliptical structures over cosmic time. While disk galaxies are mostly star forming and ellipticals are mostly quiescent, a shutdown of star formation is occurring in parallel with the morphological transition. Furthermore, galaxies evolve within an environment composed of filamentary structured ordinary and dark matter, called the cosmic web. This complex environment influences the fate of galaxies, particularly the correlation between star formation and morphology. In this project, we aim to investigate the effects of the cosmic web on the morphology and the star formation history of galaxies within the deep fields of Euclid Data Release 1. The excellent resolution of the VIS data allow to measure accurately galaxy morphologies through Sersic fits. Star formation histories are extracted from the photometry using Simulation Based Inference. Finally, the cosmic web is extracted using DisPerSE algorithm.

Supervisors: Henry Joy McCracken, Clotilde Laigle & Marc Huertas Company

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Frequency-Momentum Space for Cosmological Correlators

In many inflationary scenarios, primordial correlation functions are encoded in late-time observables in de Sitter spacetime, where even the simplest processes already involve highly nontrivial time integrals. I will show that this difficulty can be overcome formulating quantum field theory in a momentum-space representation adapted to de Sitter isometries. This construction is based on diagonalizing the Casimir operator rather than the Hamiltonian, effectively trading the usual (d+1)-dimensional Fourier space for the Kontorovich–Lebedev–Fourier (KLF) space.

Supervisor: Sébastien Renaux-Petel

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Composition and dynamics of exocomets around Beta Pic

Exocomets are comets orbiting other stars than the Sun. They can be detected when their tails transit their host stars, either in photometry (for dust tails) or spectroscopy (for gaseous tails). As tracers of volatile-rich material in young planetary systems, exocomets provide a unique opportunity to probe the interactions between small bodies and forming or recently formed exoplanets. For decades, exocomets have been observed transiting the young star Beta Pictoris (20 Myr), primarily via variable absorption features in atomic lines (Ca II, Fe II, Mg II, etc). However, their element compositions could never be constrained, neither in the Beta Pic system nor in any other system, due to a lack of appropriate data and to a poor understanding of the chemistry of exocometary tails.

In this talk, I will present the results of a new observation campaign of Beta Pic with the Hubble Space Telescope (Program 17790, PI. T. Vrignaud), specifically designed to measure the C/Fe ratios of individual exocomets through observations in C I and Fe II lines. This program led to the detection of several new exocomets, for which large C/Fe ratios were measured (C/Fe = 10-30 in all objects). These compositions are consistent with Solar System comets (e.g. C/Fe = 16 for 1P/Halley), indicating that comets around βPictoris and the Sun share a similar nature, i.e. objects rich in volatiles and formed far from their host stars. In addition, constraints on the transit distances of the detected objects (d $\sim$ 1 au) indicate that exocomets around Beta Pic could be actively transporting volatiles to the inner system, with a potential impact on the composition of exoplanets in the habitable zone.

Supervisor: Alain Lecavelier des Etangs Levallois

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Impact of the large scale environment on galaxies properties

The role of the large scale environment on shaping galaxies properties is key to the success of current cosmological surveys. Indeed, there are now observational and simulated evidence that the cosmic web modulates galaxy properties. However, the measurements remain very noisy as soon as one bins by filament (or walls) since each of them only contains a handful of galaxies. To overcome this limitation, we will use a suite of cosmological simulations that share the same large-scale structure while resampling the small scale. This allows us to populate the same filament(s) and maximise the statistical signal. In this talk, I will present early results on the modulation of dark matter halos from a dark-matter-only suite.

Supervisor: Corentin Cadiou & Christophe Pichon

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A new population of substellar companions around M dwarfs with Gaia

M-type stars, the most common in the universe, are a major focus for surveys because they are well-suited for detecting low-mass planets in the habitable zone. Despite their importance in the formation and evolution of low-mass planets, little is known about giant planets (GPs) in M star systems. Detecting long period GPs (with semi-major axis typically greater than 1 au) is difficult with transit methods and challenging with radial velocities (RV) due to the faintness and relatively high activity level of M stars. This significant limitation can be effectively addressed by combining RV and direct imaging (DI) with Gaia-Hipparcos absolute astrometry.

In this context, I used the GaiaPMEX tool presented in Kiefer et al. (2025) to detect GPs around all M stars closer than 15 pc with Gaia Data Release 3 data. GaiaPMEX uses astrometric data from Gaia and Hipparcos data when available to build a two-dimension confidence map to constrain the mass and the semi-major axis of the companion. When combining these maps with RV and DI detection limits, we can rule out binary companions, as well as identifying and characterizing planetary companions. I built a catalog of M dwarfs within 15 pc and using GaiaPMEX, I performed a systematic search for GPs. This work revealed at least 36 new substellar companions including 10 GPs along with 76 additional substellar companion candidates. I will present the methods and results of this survey which will allow the study of a new population of long period GPs and in particular, to derive the radial distribution of GPs around M dwarfs beyond 1au.

Supervisors: Anne-Marie Lagrange (LIRA), Guillaume Hébrard (IAP) & Flavien Kiefer (LIRA)

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A Bayesian detection of high-significance voids and its cosmological applications

Cosmic voids are the largest objects emerging in the cosmic web, covering the majority of the volume of the Universe. They are a well-established probe to gather cosmological information from the large-scale structure, both from intrinsic summary statistics and through cross-correlation with the cosmic microwave background and weak lensing. Unfortunately, identifying voids in a galaxy catalog is challenging for multiple reasons: observational effects such as holes in the mask or magnitude selection hinder the detection process; galaxies are biased tracers of the underlying dark matter distribution; and it is non-trivial to estimate the detection significance and parameter uncertainties for individual voids. We use the Manticore posterior simulations, a set of constrained simulations of the large-scale structure that are consistent with the observed galaxy positions, effectively representing statistically independent realizations of the probability distribution of the cosmic web. In this Bayesian framework, we are able to assess the uncertainties of emerging structures and thus identify high-significance voids. This results in a catalog with posterior distribution of the void properties, as well as characterization of their full shapes. As a reliable template for density environment, we cross-correlate these high-significance voids with the cosmic microwave background, with a particular focus on detecting the Sunyaev-Zeldovich effect at low redshift.

Supervisors: Guilhem Lavaux & Benjamin Wandelt

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Does the pair annihilation in the BOAT GRB221009A imply several emission regions?

GRB221009A, nicknamed “The BOAT” is the brightest GRB observed to date. On top of being relatively close to earth, it has unprecedented rest frame energetics that make for a truly unique case of study. One of its' remarquable properties is the presence of a narrow high energy emission component at >1MeV, which was detected for the first time in GRB221009A. A promising candidate for explaining this line is leptonic pair annihilation. The properties and temporal evolution of the line can be interpreted as due to the High Latitude Emission (HLE) effect, but this implies constraints that are hard to satisfy. We study the scenario where the emission comes from an optically thin part of the outflow, and evaluate the possibility of reproducing the line properties with a single emitting region.

Supervisors: Frédéric Daigne & Claire Guépin

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Gravitational lensing beyond the eikonal approximation

Waves propagating through a gravitational potential exhibit wave-optics effects when their wavelength is not significantly smaller than the lensing scales. We study the propagation of a scalar wave, governed by the wave equation in curved spacetime, to focus on effects on amplitude and phase, while leaving aside the issue of wave polarization which affects electromagnetic and gravitational waves. Using the Newman–Penrose formalism, we obtain the first corrections beyond the geometric optics in the expansion in the inverse frequency. In vacuum, that is for Weyl tensor lensing, there is no wave effect at first order in G and wave effects start at order G^2 . Conversely, if the wave travels through a non-vanishing matter density, the first corrections start at order G. We check these analytic results by solving numerically the equations dictating the evolution of the corrections either in the vicinity of a Schwarzschild black hole or through a transparent star.

Supervisor: Cyril Pitrou

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Towards constraining cosmological parameters with the SPT-3G Ext-10k survey

Ground-based telescopes designed to observe the cosmic microwave background (CMB) aim to improve our knowledge of the composition and evolution of the universe. Information from the E- and B-modes of polarization and from the temperature at small angular scales will be crucial for addressing current tensions in cosmology. The South Pole Telescope (SPT) conducts arcminute-resolution observations of the CMB with its third-generation camera, SPT-3G. Between 2019 and 2024, SPT-3G surveyed approximately 25 % of the southern sky while avoiding the Galactic plane, with further observations planned until 2029. The observations were divided into three surveys: the Main field, the Summer fields, and the Wide fields, whose combination is defined as the Ext-10k survey. The Wide survey is divided into nine fields spread across the Southern Hemisphere around the Galactic plane, with declinations ranging from -20deg to -80deg. These features represent new challenges that must be taken into account in the analysis. I describe the current status of the Wide fields analysis and present SPT-3G Ext-10k forecasts on cosmological parameter constraints.

Supervisors: Silvia Galli, Karim Benabed, Federica Guidi & Eric Hivon

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Hybrid radio and particle detection of air showers: potential for ultra-high-energy gamma-ray identification

The autonomous radio-detection of extensive air showers initiated by ultra-high-energy (UHE) particles arriving with very inclined zenith angles has seen significant advancements in recent years, with several large-scale surface arrays planned and prototypes already in operation. Hybrid arrays combining radio antennas and scintillators, could serve as competitive UHE photon detectors. Indeed, for inclined showers, radio emissions can be detected by antennas for both cosmic-ray and photon primaries, while the muon-rich signatures of the former would typically trigger the scintillators. In this talk, I will show that effective separation between the two types of showers could be achieved in a hybrid radio antenna and scintillator setup, using two key observables—the total root mean square of the radio signal and the total energy deposit recorded in the scintillators. As a case study, I will apply this method to the layout of the prototype of the Giant Radio Array for Neutrino Detection (GRAND), GRANDProto300, complemented by Telescope Array-type scintillators. Such a hybrid array could set competitive upper limits on the integral photon flux in the energy range of 0.1 to 3 EeV, opening a yet uncharted territory for photon searches at UHE, by targeting very inclined air showers.

Supervisors: Kumiko Kotera

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How do the first Massive Black Holes Grow?

JWST observations up to $z \approx 11$ have uncovered unexpected populations of high- redshift AGN, suggesting a much higher abundance of massive black holes (MBH) in the early Universe than predicted by prior extrapolations of observational datasets. However, state-of- the-art simulations of MBH accretion yield results inconsistent with these findings: they suggest that massive black holes grow too inefficiently in low-mass galaxies—systems similar in mass to the hosts of high-redshift AGN detected by JWST—to explain such observed abundance at these early times. Indeed, star formation and supernova feedback cause gas to become very turbulent, and it is continuously stirred and ejected by stellar explosions, hence suppressing MBH growth.

Hence, the goal of my PhD thesis is to assess how stellar feedback influence MBH growth, galactic structure, and the stellar-to-halo mass relation in high-redshift dwarf galaxies. Feedback from massive stars is not just SNe: Cosmic Rays, pre-heating by OB stars and modeling of star formation itself are important.

To try to comprehensively study these phenomena, I run zoom-in cosmological simulations focusing on individual galaxies at $z \geq 4$ in their environment, with increasing physical complexity, which will lead to “full-physics” models with radiative and magneto- hydrodynamical simulations. The goal is to realize “agnostic” simulations, i.e. I do not want to artificially enhance MBH growth to make it consistent with JWST observations, but instead try to independently understand the concerned parameter space. Depending on the conclusions, it could indicate that perhaps some observational results on high-z black hole masses and the number of AGN have to be taken with a grain of salt.

Supervisors: Marta Volonteri, Yohan Dubois & Maxime Trebitsch

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Gravitational Turbulence and Universal Spectra in Vector Resonant Relaxation

In this talk, I will present results from numerical simulations of Vector Resonant Relaxation, the correlated dynamical process governing the orientation precession of stellar orbits around a supermassive black hole. I will focus on the statistical properties of the system's fluctuations, presenting both predictions and numerical measurements of their power spectra. The results reveal cascade phenomena analogous to turbulence in plasmas, suggesting the emergence of universal spectra in long-range interacting systems. I also test this universality by exploring how modifying the interaction kernel between the massive annuli reshapes the power spectrum and its scaling laws.

Supervisor: Jean-Baptiste Fouvry

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Gravitational radiation-reaction in compact binary systems at 4.5 post-Newtonian order in harmonic coordinates

Compact binaries are the primary sources of gravitational waves measured by gravitational-wave detectors. In this context, obtaining the equations of motion in different approximation schemes is essential for producing waveform templates with the accuracy required by future detections. In this presentation, I derive the gravitational radiation-reaction force on a compact binary system at the fourth-and-a-half post-Newtonian (4.5PN) order of general relativity. This represents a significant improvement, as harmonic coordinates are unique, provide a manifestly Lorentz-invariant formulation, and offer a much simpler expression than the Burke-Thorne coordinates in which the radiation-reaction was originally derived. This result also enables comparisons with other approximation schemes (such as post-Minkowskian) at 4.5PN order. Using the harmonic radiation-reaction acceleration, we also derive from first principles the flux-balance laws and the center-of-mass position, in a general frame, at 2PN relative order.

Supervisor: Luc Blanchet & Cédric Deffayet

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Nonlinear dynamics of self-gravitating stellar systems

The focus of this presentation will be the dynamics of self-gravitating stellar systems. Two limits of such systems will be discussed, the marginal stability regime (low velocity dispersion) and the finite-N limit (low number of stars). This regime is essential to model disc galaxies, which are notoriously marginally stable. In these particular limits, the stellar distribution can exhibit large fluctuations around its equilibrium. This dynamical regime is not well suited for the usual quasi-linear theories that assume small fluctuations.

In this presentation, I will introduce a non-linear theory that predicts quantitatively observables of marginally stable systems with a finite number of stars. This theory will be compared with N-body simulations, and applications to astrophysical systems will be discussed.

Supervisor: Jean-Baptiste Fouvry

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Combining the Euclid and Roman space missions to measure the mass of cold terrestrial planets

The study of exoplanets beyond the snow line is essential to understand planetary formation mechanisms. In this context, gravitational microlensing is a particularly effective indirect detection method to identify cold and faint planets located at distances of approximately 1 to 10 AU from their host star. This work is part of the Nancy Grace Roman space mission, dedicated to the detection of exoplanets via gravitational microlensing. It aims to improve the mass measurement of terrestrial exoplanets detected through this method. The adopted approach combines the modeling of microlensing photometric light curves with the analysis of high-angular-resolution images obtained several years before or after the event peak. The lens mass–distance relations derived from these two analyses allow us to tightly constrain its physical parameters, such as the planetary mass. This approach, which can also be applied to Euclid observations and future Roman surveys, will contribute to a better demographic characterization of cold exoplanets in the Milky Way.

Supervisors: Clément Ranc & Jean-Philippe Beaulieu

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The multiphase circumnuclear region of Centaurus A - from JWST/MIRI MRS observations

Galaxy evolution is regulated by gas accretion, mergers, and feedback: processes that operate across a broad range of spatial scales. Gas inflows into galaxies fuels star formation and, in the central regions, feed the SMBH, triggering phases of active galactic nucleus (AGN) activity. AGNs inject vast amounts of energy into their surroundings, heating the interstellar medium (ISM) and driving outflows, thus regulating star formation and limiting the growth of massive galaxies. However, infrared observations reveal that AGN activity also induces efficient cooling of the molecular gas. Understanding how AGN feedback couples to the ISM is essential for solving key problems in AGN feeding, feedback cycles, and the regulation of galaxy growth. I present JWST/MIRI MRS integral-field spectroscopy of H2 emission over the central 170 pc x 100 pc at 0.3"–0.7" (5–12 pc) resolution. My results show complex morpho-kinematics for H2, with strongly inhomogeneous excitation, a scale-dependent interplay between radiative heating and mechanical cooling, an overall strong impact of turbulence on gas excitation, and the coexistence of inflows and outflows of gas at the same scale.

Supervisors: Pierre Guillard & Philippe Salome

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sCOLA Lightcones : Simulating Only What We Observe with Perfect Parallelism

To understand the large-scale structure of the universe, cosmologists need to simulate the gravitational evolution of billions of particles across vast volumes — and match what telescopes like Euclid or DESI actually observe. These observations are inherently /lightcone/ measurements: light from distant galaxies was emitted billions of years ago, so we never see the universe at a single moment in time. State-of-the-art simulations handle this well, but at enormous cost — tens of millions of CPU hours per run. In this talk, I present *sCOLA lightcones*, a framework that makes these simulations orders of magnitude cheaper. The key idea is to split the simulation volume into thousands of small, independent /tiles/, each evolved separately. This "perfect parallelism" means no costly communication between compute nodes. More importantly, tiles far from the observer crossed the lightcone long ago — so we can stop simulating them early, avoiding wasted computation. Combined with two new algorithmic improvements (a particle inflow approximation and a better gravitational boundary condition), sCOLA achieves percent-level accuracy on the matter power spectrum while being * 2,700× faster* than a reference N-body code. This opens the door, with only a small computational budget, to large mock catalog ensembles essential for covariance estimation, simulation-based inference, and tests of fundamental physics.

Supervisor: Florent Leclercq & Guilhem Lavaux

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The parameter space of BNS populations: formation channels and merger rates

Binary neutron stars (BNS) play a central role in various high-energy astrophysical phenomena,from short gamma-ray bursts to kilonovae.

Even though the number of known systems is currently relatively small, upcoming observations are expected to drastically increase the size of both Galactic and extragalactic BNS populations.

Population synthesis codes offer a powerful tool to study large BNS populations. However, the numerous physical processes involved —each governed by uncertain parameters— introduce strong degeneracies, making it challenging to interpret the resulting populations.

In this talk, I will present a systematic exploration of the key parameters governing BNS formation. I will describe the methodology developed to analyze a large ensemble of synthetic populations and to identify the dominant BNS formation channels. I will then show how variations in these parameters can impact BNS formation and merger rates. Finally, I will discuss the implications for electromagnetic and gravitational-wave observations, linking specific formation channels to the transient phenomena they are expected to produce.

Supervisor: Irina Dvorkin

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