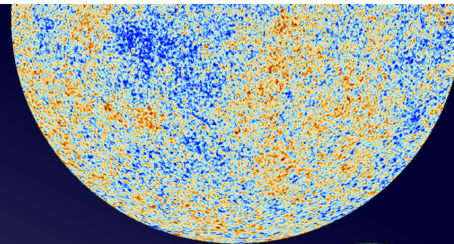
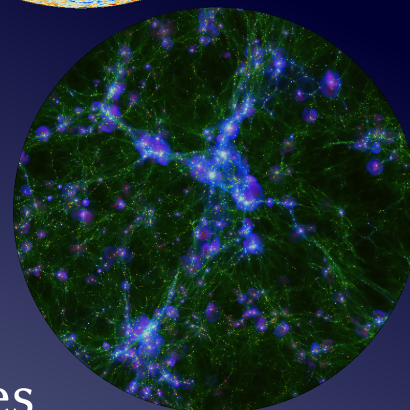
Institut d'Astrophysique de Paris

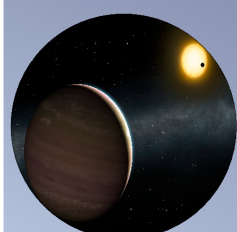


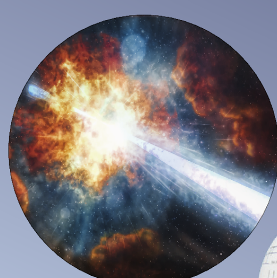
Postdoc & Engineer DAY



Wednesday, 30 April 2025
9h30-17h30, Salle des séminaires

- Meet and discuss with IAP's postdocs and engineers
- Enjoy complimentary coffee breaks and buffet lunch!





Organizing committee:
J. Lewis, N. Heidari, M. Bugli

Program

9:30	Introductions	
9:50	Grégoire Aufort	Denoising diffusion models for Lyman-alpha tomography with WEAVE
10:05	Lisa Mickel	The quantum universe: tetrahedra and superpositions
10:20	Sei Kato	The origin of the sub-PeV Galactic gamma rays
10:35	Coffee Break	
11:05	Matteo Bugli	Numerical models of long gamma-ray burst progenitors
11:20	Margherita Lembo	Digging the Dark: Euclid X CMB as a Goldmine for Cosmology
11:35	Ali Rida Khalife	Resurrecting Gravitational Vector Modes and their Magnetogenesis
11:50	Angelo Caravano †	A Tale of Cosmic Butterflies: How Tiny Quantum Fluctuations Can Shape the Entire Universe
12:05	Lunch	
14:05	Break	Online taxes seminar
15:05	Deaglan Bartlett †	COCA: Correcting Machine-Learned Cosmological Dynamics on the Fly
15:20	Lennart Balkenhol	Cosmic Microwave Background Analysis with a Differentiable Pipeline
15:35	San Han	NewCluster: Simulating a massive galaxy cluster formation in high-resolution
15:50	Coffee Break	
16:20	Kunyang Lily Li	Tracking on-the-fly massive black hole binary evolution and coalescence in galaxy simulations: RAMCOAL
16:35	Etienne Camphuis	Cosmology from SPT-3G Main field data
16:50	Joe Lewis	Can simulations quench enough early massive galaxies?
17:05	Conclusions	

†online contribution

Grégoire Aufort

Denoising diffusion models for Lyman-alpha tomography with WEAVE

(Large scale structures and distant Universe)

Lyman-alpha tomography enables 3D mapping of the intergalactic medium at high redshift, but reconstructing these fields from sparse, noisy spectra is a challenging inverse problem. In this talk, I introduce a new approach using denoising diffusion models — a class of generative machine learning models. Trained on the Horizon-AGN hydrodynamical simulation, and aiming to exploit the data from the coming WEAVE-QSO survey, our model reconstructs the underlying absorption field with improved fidelity and calibrated uncertainty estimates. I will show how this approach compares to previous techniques and highlight its advantages in terms of flexibility and speed.

Lisa Mickel

The quantum universe: tetrahedra and superpositions

(Theoretical physics: gravitation and cosmology)

In the spirit of finding a quantum description for gravity and understanding the origin of our universe we will explore the early quantum cosmos from two perspectives: group field theory and minisuperspace models.

Group field theory is a background-independent approach to quantum gravity in which field excitations are seen as elementary building blocks of space. We will discuss how a bouncing universe emerges in the cosmological sector of the theory. We will also sketch an avenue to include cosmological perturbations in group field theory cosmology. In minisuperspace models one quantises the reduced classical system, in this case the flat FLRW spacetime (with perturbations). We focus on the case in which the state of the universe is given by a superposition and compare two methods to extract quantum corrected quantities, such as the effective scale factor of a bouncing universe.

Sei Kato

The origin of the sub-PeV Galactic gamma rays

(High energy astrophysics and early Universe)

Galactic diffuse gamma-rays emission (GDE) in the sub-PeV energy range ($E > 100$ TeV $= 10^{14}$ eV) was first detected by the Tibet ASγ experiment in 2021, ensuring the presence of PeV cosmic-ray accelerators in the Galaxy. On the other hand, in 2023 the Large High Altitude Air Shower Observatory (LHAASO) detected GDE covering an energy range between 10 TeV and 1 PeV. Interestingly, the sub-PeV GDE flux measured by LHAASO from the inner Galactic Plane region ($15^\circ < l < 125^\circ$ & $|b| < 5^\circ$) is lower than that measured by Tibet ASγ ($25^\circ < l < 100^\circ$ & $|b| < 5^\circ$) by a factor of five.

To study the discrepancy between the results of the two observatories, we estimate the contamination of the Tibet GDE flux from the sub-PeV gamma-ray sources presented in the first LHAASO catalog, accounting for the source masking scheme used in the Tibet GDE analysis. We conservatively limit the source contamination of the Tibet GDE flux less than 30% in the sub-PeV energy range, which cannot explain the discrepancy between the Tibet and LHAASO GDE fluxes. Using a GDE theoretical model of Lipari and Vernetto (2018), we also find that the residual discrepancy can be accommodated with the GDE flux from the source masking regions in the LHAASO GDE analysis. Our result supports that the Tibet GDE flux has minor contamination from existing gamma-ray sources and is indeed dominated by the diffuse emission. The result also gives some important implications such as a dominance of GDE over the total Galactic sub-PeV gamma-ray emission and significant GDE contamination of the gamma rays from the Cygnus Super Bubble.

Matteo Bugli

Numerical models of long gamma-ray burst progenitors

(High energy astrophysics and early Universe)

Gamma-ray bursts are bright flashes of gamma-ray radiation associated to the most violent explosive events happening since the Big Bang. Their extraordinary brightness allows us to explore the Universe over cosmological scales, while their production sites are a laboratory to test our understanding of fundamental physics in extreme conditions. Numerical simulations are an invaluable tool for the modeling of these explosive events, since they allow us to probe the physical processes that lead to the formation of their central engines, which in the case of "long" GRBs are associated to the collapse of a massive star. Numerical models are also crucial to describe the complex dynamics of the relativistic jets launched by such explosions and their propagation through the surrounding medium, whose properties are a key ingredient to understand how particles can be efficiently accelerated, thus producing the high-energy transients we observe.

In this talk I will present some of my work on the modeling of extreme stellar explosions and relativistic jets associated with gamma-ray bursts. I will showcase the qualitative impact of fast rotation and strong magnetic fields in shaping the dynamics of the explosion, along with their impact on the associated multi-messenger emission (i.e. neutrinos and gravitational waves) and the nucleosynthesis of heavy elements. I will then present some recent models of relativistic jets that explore the role of a finite electric conductivity, showing the improvements that come from adopting a more realistic description of how magnetic fields dissipate.

Margherita Lembo

Digging the Dark: Euclid X CMB as a Goldmine for Cosmology

(Large scale structures and distant Universe)

Despite its success, the ΛCDM model leaves critical gaps in our understanding of the Universe, with fundamental questions about dark energy, dark matter, and inflation still unresolved. The Euclid mission will deliver high-resolution optical and near-infrared imaging and spectroscopy across about 14,000 square degrees of extragalactic sky. Optimized for weak gravitational lensing and galaxy clustering, Euclid satellite will leverage two of the most sensitive probes for investigating dark energy and gravity on cosmological scales.

The combination and cross-correlation of Euclid's upcoming data with Cosmic Microwave Background (CMB) measurements promises an unprecedented lever arm over epochs ranging from recombination to structure formation across the entire past light cone. This talk will highlight Euclid's key cosmological science cases and demonstrate how cross-correlations with CMB data can reduce the impact of nuisance parameters and enhance the precision of cosmological constraints. In the context of cross-correlating Euclid data with current CMB observations, I will outline essential elements for a successful analysis for the first data release (DR1) and present forecasts on key parameters of the standard cosmological model, as well as potential extensions.

Ali Rida Khalife

Resurrecting Gravitational Vector Modes and their Magnetogenesis

(Large scale structures and distant Universe)

The detection of primordial tensor modes, i.e. gravitational waves, through primordial CMB B-modes is considered the smoking gun signal for inflation. However, in order to solidify this conclusion, we need to ensure that other primordial mechanisms do not produce the same signal. To that end, primordial gravitational vector modes (V-modes) and their sourcing of primordial magnetic fields (PMF), i.e. magnetogenesis, is revisited in this talk. As the adiabatic V-mode generically decays with expansion, we consider three exotic initial conditions, involving both the neutrino and dark sectors, which circumvent this issue and lead to observational imprints. The best fitting parameters in these three cases to CMB and BAO data are found, and their resulting B-mode spectra are compared to data from BICEP/Keck and SPTpol. The outcome is that none of the proposed initial conditions can produce large enough PMFs to seed every type of magnetic fields observed. However, the resultant V-modes are still consistent with the data and ought to be constrained for a better understanding of the primordial Universe before its hot big-bang phase.

Angelo Caravano

A Tale of Cosmic Butterflies: How Tiny Quantum Fluctuations Can Shape the Entire Universe

(Theoretical physics: gravitation and cosmology)

Inflation, the brief epoch of accelerated expansion in the early universe, explains the origin of all cosmic structures. While large-scale fluctuations from inflation are observed in the cosmic microwave background, small-scale fluctuations remain hidden. Gravitational-wave interferometers are beginning to change this, offering a new window into the small-scale physics of the early universe.

Using simulations, we explored this regime and uncovered a surprising phenomenon: small deviations from the usual slow-roll behavior, with no effect on large scales, can have dramatic consequences for the evolution of the entire cosmos. In some scenarios, the universe becomes trapped in an eternally inflating state. In others, only certain regions get stuck, opening a new channel for primordial black hole formation. Much like the flap of a butterfly's wings, small-scale phenomena can have far-reaching effects. More broadly, our work highlights the power of simulations in probing the complex, non-linear dynamics of inflation—particularly in regimes relevant for gravitational-wave astronomy.

Deaglan Bartlett

COCA: Correcting Machine-Learned Cosmological Dynamics on the Fly

(Large scale structures and distant Universe)

Machine learning has become a popular tool for accelerating cosmological N-body simulations, offering fast approximations to expensive calculations. However, a key challenge remains: standard emulators are not guaranteed to obey the underlying physical laws, and their errors can accumulate in ways that are difficult to control. In this talk, I'll present COmoving Computer Acceleration (COCA) — a hybrid framework that combines the speed of machine learning with the physical accuracy of traditional solvers. COCA leverages machine learning to predict an approximate frame of reference and then solves for the residual particle dynamics using the true equations of motion. This guarantees convergence to the correct solution while substantially reducing computational cost. I'll demonstrate COCA's performance on particle-mesh simulations guided by a convolutional neural network, showing that it maintains high accuracy even when applied beyond the training set. COCA turns emulators from approximators into accelerators, correcting their errors by construction — and bringing us closer to trustworthy, fast cosmological simulation pipelines.

Lennart Balkenhol

Cosmic Microwave Background Analysis with a Differentiable Pipeline

(Large scale structures and distant Universe)

Upcoming data from ground-based Cosmic Microwave Background (CMB) data will allow us to substantially improve on Planck results by measuring the polarisation of the CMB at high precision. But with great data comes great responsibility; the results will only be as credible as the underlying analysis pipeline is robust.

In this talk, I present candl: a modern, user-friendly, python-based likelihood for CMB data. Crucially, candl is written with JAX support, which makes the calculation of the derivatives of the likelihood - and by extension Fisher matrices - robust, quick, and easy. I illustrate the benefits of this access to derivatives using a series of examples, including forecasting, data robustness tests, data compression techniques, and the exploration of the posterior surface. I also show how the interaction between candl and OLE - a machine-learning based emulator of Boltzmann solvers - allows for the construction of new inference methods. Both codes, candl and OLE, are publicly available alongside a series of tutorials.

San Han

NewCluster: Simulating a massive galaxy cluster formation in high-resolution

(High energy astrophysics and early Universe)

Galaxy clusters are the most massive gravitationally bound structures in the Universe, and at the same time, one of the least explored regimes in numerical simulations due to their enormous scales and complex, highly interactive characteristics. I will introduce the ongoing NewCluster simulation project, a novel cosmological zoom-in simulation of a galaxy cluster. The talk will cover the initial setup and the application of state-of-the-art implementations of baryonic prescriptions for the hydrodynamic simulation, as well as developing solutions for technical, methodological and astrophysical challenges encountered for simulating such a massive object at a high resolution of 70 pc. I will also present early results on the physical properties of the galaxies from the simulation, which reached a redshift of $z = 0.8$ by 2025, and discuss their potential opportunities for scientific projects.

Kunyang Lily Li

Tracking on-the-fly massive black hole binary evolution and coalescence in galaxy simulations: RAMCOAL

(High energy astrophysics and early Universe)

The detection of gravitational waves (GWs) from massive black hole binary (MBHB) coalescence motivates the development of a sub-grid model. We present RAMCOAL, integrated into the RAMSES code, which simulates the orbital evolution of MBHBs, accounting for stellar and gaseous dynamical friction (DF), stellar scattering, circumbinary disk interactions, and GW emission at scales below the simulation resolution. Unlike post-processing approaches, RAMCOAL tracks the real-time evolution of MBHBs within hydrodynamical simulations of galaxies using local quantities to model dynamics and accretion. This enables more accurate predictions of both GW signals and the properties of merging black holes. We validate RAMCOAL across isolated and merging galaxy setups at resolutions of 10, 50, and 100 pc, with and without black hole accretion and feedback. In addition, we test the model in seven galaxy merger scenarios at 100 pc resolution. These tests demonstrate that RAMCOAL is largely resolution-independent and successfully captures the effects of DF from stars, dark matter, and gas, loss-cone scattering, viscous drag from circumbinary disks, and GW emission – all within a realistic galactic environment, even at low resolutions. With RAMCOAL, we can better estimate MBHB coalescence rates and the GW background, while providing insights into the electromagnetic counterparts of GW sources. This approach bridges the gap between electromagnetic observations and GW detection, offering a more comprehensive understanding of MBHB evolution in cosmological simulations.

Etienne Camphuis

Cosmology from SPT-3G Main field data

(Large scale structures and distant Universe)

SPT-3G, the third-generation camera on the South Pole Telescope, observes cosmic microwave background (CMB) anisotropies with arcminute resolution and 5muKarcmin coadded noise in temperature. Recent analysis of polarization data from the 2019 and 2020 seasons have yielded the most precise reconstruction of the E-mode spectrum above $\updownarrow = 2000$ and the CMB lensing spectrum above $L = 350$. From these measurements, we constrained ΛCDM cosmological parameters, finding results consistent with Planck while indicating a 5.4 σ tension with distance ladder estimates of H_0. Ongoing efforts toward forthcoming SPT-3G analyses, which feature the temperature of the main field and wider observations in both temperature and polarization, will further enhance the constraining power on cosmological parameters, providing robust, independent tests of the ΛCDM model and exploring potential hints of physics beyond the standard model. For the main field particularly, a detailed analysis will be published in a forthcoming study.

Joe Lewis

Can simulations quench enough early massive galaxies?

(Large scale structures and distant Universe, High energy astrophysics and early Universe)

The James Webb Space telescope has increased the number of reported massive quenched galaxies at $z > 2$, further increasing tensions with simulations. Typically, simulations require the growth of massive black holes ($>$ % of galaxy mass) to quench galaxies with kinetic feedback. This reinforced tension suggests faster and more widespread black hole growth in the first few billion years than imagined. At the same time, numerous AGN candidates have been found out to high redshifts, including in lower galaxy masses that previously thought possible.

In this talk, I use zoom simulations of massive Horizon-AGN galaxies to investigate physical model changes that favor early black hole growth and quenching. Higher resolutions tend to inhibit black hole growth at high redshifts. At early times, galaxies are clumpy and experience many mergers. So much so, that black holes are persistently displaced from the galactic centre and wander around the galaxy until a stable dense and central gaseous and stellar structure can emerge. Lowering the star formation efficiency can favor the formation of such structures and promote earlier black hole growth. Tweaking the sub grid-modeling for dynamical and hydrodynamical friction experienced by the black holes can also contribute. However, it appears that Super-Eddington growth periods may be required to quench enough galaxies $z > 2$.