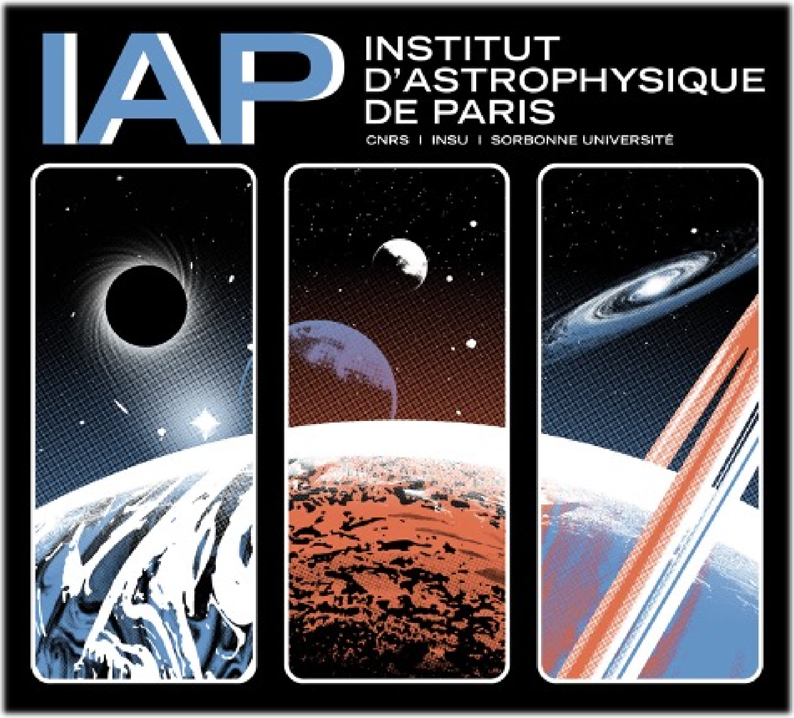
Journée des thèses / PhD day



Tuesday, 04 May 2021 09:00 - 16:30

Institut d'Astrophysique de Paris

Hosts: Nai Boonkongkird, Simon Chiche, Kerwann Tep

Program of the day

09:00	*Welcoming*	
09:15	Amélie Gressier	HST WFC3 G141 data analysis: exploring the transition from Super-Earth to Sub-Neptune
09:30	Pierre-Cécil König	Improving exoplanet detection and characterisation by understanding magnetic activity *jitter*
09:35	Louis Quilley	A quantitative morphological sequence of nearby galaxies through disk+bulge model-fitting
09:40	Florian Livet	Catalog-free modeling of galaxy types in deep images: Massive dimensional reduction with neural networks
9:45	Kerwann Tep	Mapping the Galactic centre's dark cluster via Resonant Relaxation
10:00	*Discussion session*	
10:30	*Break*	
10:45	Marko Shuntov	Weak lensing magnification to probe the galaxy-halo relation
11:00	Lukas Furtak	The build-up of stellar mass in primeval galaxies
11:15	Alexandre Barthelemy	1-point statistics of weak gravitational lensing: accurate first-principles theoretical modeling
11:20	Aline Chu	Tracing the history of the most massive galaxies in the Universe with the Hubble Space Telescope
11:25	Clément Pellouin	Binary Neutron Star mergers in the multi-messenger astronomy era
11:30	*Discussion session*	
12:00	*Lunch*	
13:30	Raphaël Duque	Gamma-ray burst afterglows: new insight on flares and plateaus from jet structure
13:45	Virginia Bresci	Acceleration and dissipation in Pulsar Wind Nebulae
14:00	Simon Chiche	Towards an autonomous radio-detection of cosmic-ray air-showers
14:15	Warren Massonneau	Beyond the Eddington limit, formation of massive black holes at high-z
14:20	Quentin Henry	Tidal effects in binary neutron-star systems
14:25	Francois Larrouturou	Testing GR with the exoplanet HD 80606b
14:30	*Discussion session*	
15:00	*Break*	

15:15	David Trestini	Gravitational waveforms in massless scalar-tensor theories
15:20	Nai Boonkonkgird	Deep learning for cosmology with the Lyman-Alpha forest
15:25	Etienne Camphuis	Present and future of CMB data: Constraining cosmological parameters with SPT3G data
15:30	Lucas Pinol	Primordial non-Gaussianities: using the Universe as a particle detector
15:35	Amaury Micheli	Quantumness and decoherence of cosmological perturbations
15:50	Nicolas Chartier	The cosmological simulation bottleneck: a history of variance
16:05	Julien Froustey	Neutrino decoupling in the early universe: precision calculation and physical consequences
16:20	*Closing remarks*	

HST WFC3 G141 data analysis: exploring the transition from Super-Earth to Sub-Neptune

Exoplanets with size between the Earth and Neptune (1-4$R_\oplus$) do not have any equivalent in our Solar System and remain challenging to characterize. Yet, there are ubiquitous in the Galaxy and Fulton et al. (2017) showed that their distribution (number of planets per star vs radius) is bimodal highlighting a gap in the number of planets around 1.7$R_\oplus$. Planets with a radius below 1.7$R_\oplus$ are thought to be rocky planets, and called Super-Earth, above this limit planets are most likely made of gas and called Sub-Neptune. We made use of the available data from the Hubble Space Telescope in Near-Infrared (HST WFC3 G141) and gathered 18 transmission spectra of planets with size below 6 $R_\oplus$ to study the transition between rocky and gaseous planets. First, we used TauREx3 (Al-Refaie et al. 2019), a Bayesian retrieval code, to rule out atmospheric scenarios. We proved that a primary clear atmosphere dominated by Hydrogen and Helium is rejected with more than 3σ for a large majority of planets in the sample. Then, we measured the amplitude of the spectra in the water absorption band (around 1.4μm) and compared observational values to simulated one using a self-consistent modeling code ExoREM (Baudino et al. 2015; Charnay et al. 2018). We explored the connection between the water absorption amplitudes and the temperature by setting the stellar and planetary parameters to those of HD 3167 c (2.7 $R_\oplus$, 8.33 $M_\oplus$) and trying different metallicities (1, 10, 100 and 1000 x solar), cloud compositions and temperatures (300-1200K).

Supervisors: Jean-Philippe Beaulieu & Emmanuel Marcq (LATMOS)

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Improving exoplanet detection and characterisation by understanding magnetic activity *jitter*

As the precision of astronomical observation tools improves, as the statistics on the incidence of extrasolar planets become more robust and their fundamental properties better known, the focus of these studies falls on the increasingly challenging task of detecting smaller planets, whose signatures are often buried below variability caused by stellar magnetic activity. This project is to analyse the effect of magnetic activity on both detecting extrasolar planets as well as characterising their environments. Thus, it will involve the analysis of spectropolarimetric data collected using a range of cutting edge facilities, including ESO HARPS-South and CFHT SPIRou. The first part of the project is to trace the effect of changing magnetic activity levels on its line profiles in a young solar analogue - allowing us to quantify the effect of *activity jitter* on the detectability of lower mass planets in this system - which is already known to host a Jupiter-mass planet. This involves applying the latest techniques to map, model and disentangle stellar activity signatures from those of exoplanets. The two techniques that we currently employ are derived from Doppler imaging and Gaussian process regression; they are entirely independent of each other and have been successful in uncovering some of the youngest known exoplanets in very active stars, using the radial velocity technique. Extending the use of similar techniques to less active systems promises to help with the ongoing search for lower-mass to Earth-like planets.

Supervisors: Guillaume Hébrard & Gaitee Hussain

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A quantitative morphological sequence of nearby galaxies through disk+bulge model-fitting

My work aims at fitting 2D luminosity models on the images of the 20k galaxies of MorCat, a complete magnitude-limited catalog of nearby galaxies (z<0.05). I first focus on a subsample called EFIGI of 4463 galaxies with morphological types and 16 morphological attributes. This will allow me to derive the main parameters (effective radius, Sersic index, flux and color...) describing the bulges/spheroids and disks of galaxies, and to do so across the Hubble sequence, since all galaxy types are represented in EFIGI. I am using the Euclid SourcExtractor++ program to perform the model-fitting of galaxies, which presents two main advantages compared to its predecessor. The first one is the ability to apply priors: unconstrained disk+bulge model-fitting suffers from degeneracies leading to large errors in the bulge parameters. The second improvement comes from the ability to model simultaneously the galaxy in 5 bands (ugriz), thus obtaining color gradients. The objective of this work is to obtain a sequence of bulge and disk structural parameters along the Hubble sequence and to revisit the scaling relations of these components(Kormendy 1977; De Jong 1996). Separate ages, stellar masses and star formation rates of the bulges/spheroids and disks could also be derived from this analysis.

Supervisor: Valérie de Lapparent

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Catalog-free modeling of galaxy types in deep images: Massive dimensional reduction with neural networks

I will present an overview of our recent work in developing the various aspects of Bayesian forward modeling to constrain the parameters of the luminosity function of elliptical and spiral populations of galaxies directly from multiband deep field images. This is a new technique that bypasses the extraction of catalogs in which flux/size properties are affected by selection effects (Malmquist, Eddington, cosmological dimming, ...) and are almost impossible to suppress. The forward approach (see also Carassou et al. 2017) relies on simulated deep fields with the same characteristics and the same observational conditions as the real observations and consequently the same selection biases affect both the real and the simulated surveys. The large size images are massively compressed using the Information Maximising Neural Network (IMNN) method developped by Charnock et al. (2018) and an Inception network (Szegedy et al. 2015) is trained to maximize the Fisher information of the images. Then, we calculate a distance between the compressed simulations and the compressed observations and we run likelihood-free Bayesian inference techniques (Approximate Bayesian Computation and Population Monte-Carlo) to constrain the density parameters of the luminosity functions of elliptical and spiral populations of galaxies. Our results are in good agreement with other catalog-based studies and validate this new approach

Supervisors: Valérie de Lapparent & Damien Le Borgne

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Mapping the Galactic centre's dark cluster via Resonant Relaxation

Supermassive black holes in the centre of galaxies dominate the gravitational potential of their surrounding stellar clusters. In these dense environments, stars follow nearly Keplerian orbits, which get slowly distorted as a result of the potential fluctuations generated by the stellar cluster itself as a whole. In particular, stars undergo a rapid relaxation of their eccentricities through both resonant and non-resonant processes. In my talk, I will present how an efficient implementation of the resonant diffusion coefficients allows for detailed and systematic explorations of the parameter space describing the properties of the stellar cluster. In conjunction with recent observations of the S-cluster orbiting SgrA*, this framework can be used to jointly constrain the distribution of the unresolved, old, background stellar cluster and the characteristics of a putative dark cluster. Specifically, I will show how this can be used to estimate the typical mass and cuspide exponent of intermediate-mass black holes consistent with the relaxed state of the distribution of eccentricities in the observed S-cluster. This should prove useful in constraining super massive black hole formation scenarios.

Supervisors: Cristophe Pichon & Jean-Baptiste Fouvry

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Weak lensing magnification to probe the galaxy-halo relation

The galaxy-halo relation refers to the distribution of the properties of galaxies and the dark matter halos which host them. Of particular interest is the relation between galaxy stellar mass and the halo mass (stellar-to-halo mass relation, or SHMR) that once measured can constrain constrain galaxy growth and quenching mechanisms. This relation is rather poorly constrained by existing techniques based on clustering and galaxy-galaxy lensing at redshifts larger than 1. The topic of this thesis is to develop a new technique based on the weak lensing magnification effect in order to probe the SHMR in deep, multi-band galaxy surveys. Using the state-of-the-art photometric redshift catalogue COSMOS2020 we measure the magnification effect manifested in positional correlations between two spatially separated galaxy samples. The goal is to demonstrate the constraining power of magnification in combination to other probes in redshift regimes where other weak lensing techniques fail.

Supervisors: Henry-Joy MC Cracken, Raphaël Gavazzi & Martin Kilbinger

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The build-up of stellar mass in primeval galaxies

Early star-forming galaxies at redshifts z>6 in the epoch of cosmic reionization are at the frontier of observability with the current instrumentation and represent the progenitors of present-day galaxies. The galaxy stellar mass function (GSMF) at $z \approx 6 - 9$ is therefore a robust and crucial tool to study the build-up of stellar mass in the Universe and provides the tightest constraints on cosmological simulations. Since these objects are intrinsically very faint, the observation and study of high-redshift galaxies is however particularly difficult and remains prone to large uncertainties arising from the limits of instrumentation, gravitational lensing systematics and stellar population assumptions. I will present my work on constraining the z>6 GSMF using the gravitational lensing magnification of the Hubble Frontier Fields clusters and new methods to robustly assess the uncertainties and sample completeness.

Supervisors: Hakim Atek & Matthew Lehnert

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1-point statistics of weak gravitational lensing: accurate first-principles theoretical modeling

Weak-gravitational lensing is a very interesting probe of the large-scale structure of our universe and motivated the build up of new generation large galaxy surveys such as the Legacy Survey of Space and Time (LSST) or Euclid.

Sensible to the clustering of both baryonic and dark matter, a complete theoretical description of the observable effect on the images of distant galaxies however necessitates an understanding of this clustering of matter at all physical scales and time within the light-cone from the source image to the observer. This is in general beyond our current abilities.

In this flash talk, I will give a brief overview of the techniques I used and the results I obtained during my thesis to nevertheless obtain meaningful and accurate predictions from physical principles, that is without relying on numerical simulations nor phenomenological models. I will focus on the 1-point probability distribution function (PDF) of the convergence and aperture mass and introduce the very useful BNT transform that renders possible accurate theoretical predictions of our observables.

Supervisors: Raphaël Gavazzi, Sandrine Codis & Francis Bernardeau

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Tracing the history of the most massive galaxies in the Universe with the Hubble Space Telescope

Galaxy clusters are the largest gravitationally bound structures in the Universe, and are believed to form by accretion of galaxies and mergers with smaller groups of galaxies. Clusters have generally in their center a very massive galaxy (BCG, the Brightest Cluster Galaxy), which is located at the bottom of the cluster gravitational potential well, and has grown by accreting gas as well as many smaller galaxies. Those extremely massive and bright galaxies, usually described as supermassive elliptical galaxies or cD galaxies, constitute a distinct class of galaxies on their own. BCGs can be up to 2 magnitudes brighter than the second ranked galaxy in their cluster, which makes them easily recognisable. A few studies (West et al. 2017, Durret et al. 2016) also show that BCGs tend to be aligned along a preferential axis, which is the major axis of the cluster in which they reside, hinting at the close link between BCGs and their host clusters. BCGs can give us important clues on the way clusters have formed and evolved, and enable to impose strong constraints on cosmological models by comparing them with the results obtained with numerical simulations.

We studied the physical properties of a large sample of BCGs between redshift 0.1 and 1.8, using high resolution photometry with images taken with the Hubble Space Telescope, and developed a new tool to detect automatically the BCGs on optical images (Chu, Durret, Marquez et al. 2021, in press).

Supervisors: Florence Durret & Isabel Marquez (IAA)

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Binary Neutron Star mergers in the multi-messenger astronomy era.

Binary Neutron Star (BNS) mergers are remarkable extreme astrophysical events with a plethora of observational signatures. On August 17, 2017, the first observation of a BNS merger opened the path for multi-messenger astronomy with gravitational waves thanks to the joint detection of a gravitational waves (GW) signal, followed 1.2 s later by a short Gamma-Ray Burst (GRB). A thermal kilonova was then observed for few days in the visible and infrared, followed by a non-thermal afterglow detected from radio to X-rays and that is still observed to this date. Yet many uncertainties remain to be lifted, both on the underlying BNS population and on the physical mechanisms responsible for the luminous emission. These have direct consequences (1) on the global role played by BNS mergers in the chemical evolution of galaxies, and (2) on our capacity to constrain the coalescence physics from observations. With the upcoming O4 LIGO-Virgo-Kagra observation run and a new generation of follow-up instruments, including the French-Chinese SVOM mission, more BNS mergers will be observed, with electromagnetic counterparts in a small, but high-value sub-sample. In this context, my work aims at answering the former question by coupling binary systems stellar evolution codes with galactic chemical evolution prescriptions, using statistical observational constraints, and the latter using a new generation of afterglow models including a realistic jet structure and detailed radiative processes.

Supervisors: Frédéric Daigne & Irina Dvorkin

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Gamma-ray burst afterglows: new insight on flares and plateaus from jet structure

The jets that produce gamma-ray bursts possess structure: they are composed of a very energetic and relativistic core, surrounded by a sheath of less extreme material. This was spectacularly confirmed by radio photometry and imagery of the remnant of GRB170817A, a historic event in this regard. Many features of gamma-ray burst afterglows remain to be robustly understood; for example their occasional sudden rebrightenings (a.k.a. flares) and extended quasi-constant-flux phases (plateaus). What if plateaus and flares were due to geometrical effects occurring when the observer is slightly misaligned with the gamma-ray burst jet?

Supervisors: Frédéric Daigne & Robert Mochkovitch

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Acceleration and dissipation in Pulsar Wind Nebulae

Pulsar Wind Nebulae (PWNe) are complex astrophysical environments where an highly magnetized wind made of electron-positron pairs interacts with the surrounding SN remnant through a shock. If MHD modelling can, on one hand, reproduce globally the morphology of PWNe, a refined description of what is behind, i.e. on kinetic scales, is still missing and open questions still persist such as how the energy is efficiently dissipated from the e.m. fields into the particles. On this regard, the possibility that the wind becomes turbulent before crossing the shock offers a promising scenario. By means of Particle-In-Cell simulations we study the physics at play in such picture in order to understand how (and if) a turbulent environment can affect the process of dissipation and acceleration of particles at the shock front.

Supervisors: Martin Lemoine & Laurent Gremillet (CEA)

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Towards an autonomous radio-detection of cosmic-ray air-showers

The interaction of high-energy astroparticles with the atmosphere induces a cascade of secondary particles, namely an “air-shower” with several counterparts that can be detected on Earth. Particularly, radio-detection of air-showers has been shown to be a robust way to infer information about the primary particle initiating the cascade. Still, due to the overwhelming radio noises, this technique has mainly relied on the combination of radio antennas with particle detectors to detect the arrival of the air-shower and trigger the acquisition of the signal by the antennas.

In the context of GRANDProto300, first stage of the GRAND experiment with a radio array of 300 antennas, we investigate how polarization signatures of the radio signal from air-showers could allow for a self-triggering of the antennas and in some cases an identification of the nature of the primary particle.

Supervisors: Kumiko Kotera & Olivier Martineau (LPNHE)

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Beyond the Eddington limit, formation of massive black holes at high-z

A numerous amount of quasars at high-redshift have been discovered throughout the past decade (Wu et al. 2015, Bañados et al. 2017). A common characteristic between these discoveries is that each quasar contains a black hole of approximately $10^9 M_\odot$. Such massive black holes at the early stages of the Universe ($\leq$ 1 billion years) challenges the theories to black hole formation, growth and their co-evolution with their host galaxies. Accretion above the Eddington limit would allow for this very fast growth, but how does a black hole undergoing super-Eddington accretion affect the gas on kpc-scales? I will present preliminary results regarding the work that has been done in this context.

Supervisors: Marta Volonteri & Yohan Dubois

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Tidal effects in binary neutron-star systems

The detection of GW170817 coming from the coalescence of two neutron-stars allowed us, by combining the analytical models with the analysis of the signal, to constrain the equation of state of neutron-stars. Some of them have already been discarded. The post-Newtonian formalism played a crucial role in the extraction of the signal but more precision on the waveform modelling finite-size effects is required, especially for Einstein Telescope.

Supervisors: Luc Blanchet & Guillaume Faye

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Testing GR with the exoplanet HD 80606b

Can we perform ”Solar system”-like tests of General Relativity in distant planetary systems? In this flash talk, I will advertise a recent proposal to perform such a test, that involves not less than three different teams at IAP. In addition to provide a practical test of GR, our method also yields other interesting exoplanetary science payloads.

Supervisors: Luc Blanchet & Cédric Deffayet

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Gravitational waveforms in massless scalar-tensor theories

The LIGO and Virgo detectors have already detected several binary NS and BH-NS mergers. The next generation of detectors, such as the Einstein Telescope in Europe and the space-based interferometer LISA, will detect even more events, from different sources, and with a higher signal to noise ratio. These detections will allow one to test our theory of gravity and fundamental physics with an unprecedented precision. However, such detections strongly rely on our capability to have a bank of precise waveform templates to be matched-filtered against the data. Currently, we only have full waveform templates for general relativity, and modified gravity can only be probed by having full waveform models for particular alternative theories of gravity. In this talk, I will show how the post-Newtonian formalism can be adapted to a particular class of models, massless scalar-tensor theories, to obtain the flux and waveform templates.

Supervisors: Luc Blanchet & Laura Bernard

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Deep learning for cosmology with the Lyman-Alpha forest

Lyman-alpha forest is an observed Lyα absorption in spectra of quasars causing by intergalactic cloud. The information from them can be used to determine the properties of these clouds as well as inferring the dark matter distribution. And to better interpret the observation requires N-body simulation which is computationally expensive. With the recent development of machine learning techniques, we are developing a tool to predict Lyman-alpha forest from N-body simulation for a cheaper model.

Supervisors: Guilhem Lavaux

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Present and future of CMB data: Constraining cosmological parameters with SPT3G data

Over the two last decades, the observation of the cosmic microwave background has led to precise measurements of the LCDM parameters, thanks to ESA's Planck satellite. However, while Planck is in very good agreement with the standard model of cosmology, it also faces some interesting tensions that could be either due to data analysis such as systematics or statistical fluctuations, or to new physics. One example is the so-called Hubble tension, that denotes a disagreement of the measurement of the Hubble constant between high-redshift experiments (such as Planck) and low-redshift experiments (for instance SH0ES).

My work with the Planck group and the SPT collaboration is to take an active part in the analysis of the high-quality SPT3G dataset, in order to constrain cosmological parameters, check consistencies of LCDM and tackle issues encountered by the community.

The SPT is one of the CMB leading instruments, located at the Amundsen-Scott research station at the South Pole. It is a 10m telescope providing deep, high-resolution maps of the sky in intensity and polarization, which already enabled several major discoveries. The SPT team has recently deployed the SPT-3G next-generation camera and the first year of data is already of superb quality. The completed campaign will provide the most sensitive maps ever produced at high resolutions, enabling a very rich science case.

Supervisors: Silvia Galli & Karim Benabed

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Primordial non-Gaussianities: using the Universe as a particle detector

In 180s, I will explain that building telescopes to measure primordial non-Gaussianities in the sky, in the form of initial nonlinearities for CMB and large-scale structures evolution, amounts to building a cosmological particle detector. Indeed, particles during inflation leave imprints in the primordial cosmological correlation functions beyond the power spectrum, so called non-Gaussianities, that depend on their masses and interactions. Part of my PhD has been devoted to characterising these imprints, and I will in particular focus on the phenomenological consequences of kinetic interactions during inflation, that have an elegant geometrical interpretation.

Supervisors: Jérôme Martin, Sébastien Renaux-Petel

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Quantumness and decoherence of cosmological perturbations

In the current leading paradigm the density inhomogeneities in the early Universe are seen as emerging from the amplification of vacuum fluctuations during the inflation. The stark contrast between the very large scales at play, perceived as utterly classical, and the quantum origin of vacuum fluctuations is an invitation to investigate the ”quantumness” of the inhomogeneities beyond words. Since the mid-90’s several works have devised precise criteria to test the classicality of the state of these perturbations e.g. Bell inequalities. The consensus is that although their predicted state is genuinely quantum e.g. violates a Bell Inequality, the experimental observability of it is out of reach maybe forever. In addition the quantumness predicted by simple models might well have been spoiled by the effect of decoherence due to interactions between degrees of freedom. In my presentation I will briefly review the state of the art of these quantumness criteria applied in the cosmological context and present results on the robustness of quantumness against decoherence we obtained using a lesser known tool, the quantum discord.

Supervisors: Jérôme Martin & Scott Robertson (IJCLab)

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The cosmological simulation bottleneck: a history of variance

To exploit the constraining power of next-generation large-scale structure data, we need high-fidelity simulations to model the statistics of observables in survey volumes. Simulations come at a towering computational cost, and fast but approximate methods, surrogates (theoretical models, low-fidelity particle-mesh solvers, emulators...), often introduce model error with respect to simulations, especially in the non-linear regime of structure growth. We propose a solution based on variance reduction, CARPool, that involves both intensive computations and surrogate realizations, and guarantees unbiasedness. By applying the technique to several statistics like the matter power spectrum, bispectrum and correlation function, we demonstrate that carefully choosing a sufficiently correlated surrogate, no matter how large the model error is, can accelerate the computation of the first-order moment - the mean - up to two orders of magnitude and provide a ≈10-fold variance reduction in the estimation of the covariance matrix, an essential component to derive constraints on cosmological parameters. To assess the reliability of the CARPool covariance estimate, we calculate parameter constraints from an ensemble of GADGET-III N-body simulations and surrogates computed using COmoving Lagrangian Acceleration (COLA).

Supervisors: Benjamin Wandelt, Nick Kaiser (LPENS) & Yashar Akrami (LPENS)

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Neutrino decoupling in the early universe: precision calculation and physical consequences

The physics of neutrinos in the early Universe is a key component of our understanding of later stages in the evolution of the Universe, such as big-bang nucleosynthesis or structure formation. In particular, missions like Planck allow to constrain the effective number of neutrino species, Neff, that accounts for the overlap between neutrino decoupling and electron-positron annihilations. I will present the most recent and precise prediction of this number, including neutrino oscillations physics. This work paves the way for exploring new physics: neutrino asymmetry, sterile neutrinos.

Supervisor: Cyril Pitrou

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