THESES DAY

Journée des thèses

FRIDAY, 23 March 2018

09:00 - 18:00

Institut d'Astrophysique de Paris

Amphithéâtre Henri Mineur

Theses day, Journée des thèses

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Institut d'Astrophysique de Paris

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09:20	Adèle Plat	Modeling and interpretation of spectral properties of primeval galaxies
09:35	Martin Pernot Borras	Numerical simulations and data analysis of the MICROSCOPE mission : Modified Gravity and screening mechanisms
09:45	Florian Sarron	Galaxy clusters in the cosmic web
10:05	Gohar Dashyan	Cosmic ray feedback in dwarf galaxies
10:20	Shweta Dalal	Giant planets survey with SOPHIE at OHP
10:30	*Coffee*	
11:00	Doogesh Kodi Ramanah	Cosmological inference from self-consistent Bayesian forward modelling of deep galaxy redshift surveys
11:15	Simon Rozier	The secular evolution of dark matter halos: using the kinetic theory to explain the cusp to core transformation
11:25	Tanguy Marchand	4.5 Post-Newtonian order development on compact binary systems
11:45	Amaël Ellien	Diffuse light in galaxy clusters: detection and star formation rate
11:55	Hugo Pfister	Supermassive black holes from kpc to pc scales
12:10	Oscar Ramos	Testing Lorentz Invariance by Binary Black Holes
12:30	*Lunch*	
14:00	Claire Guépin	High energy astroparticles from transient sources
14:15	Jesse Palmerio	Gamma-Ray Bursts as probes of the early Universe
14:35	Siwei Zou	The cold gas in the ISM of high-z galaxies
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15:10	Céline Gouin	The prediction of the Gravitational Lensing signal with Hydrodynamical Cosmological Simulations
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16:00	Arno Vanthieghem	Stability analysis of a periodic system of relativistic current filaments
16:15	Camilia Demidem	Particle acceleration in relativistic magnetohydrodynamic turbulence
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16:45	Matteo Rizzato	Information content of high order correlation functions for Weak Lensing
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Ultra-high-energy neutrino : from sources to detection

Neutrinos have attracted much attention lately, with 2 Nobel Prizes and the first detection of very high energy neutrinos with IceCube in 2013. Ultrahigh energy neutrinos, with energies 10^{18}eV, remain unchartered territory: they have not been detected yet, and their sources remain a mystery. Their existence is guaranteed however, as they are bound to be produced by the interaction of ultrahigh energy cosmic rays (charged nuclei that bombard the Earth with energies $> 10^{20}\, eV$, and that are routinely detected), with the cosmic backgrounds, on their way from their source to the Earth.

Because of their low flux, the detection of ultrahigh energy neutrinos requires to build gigantic detectors. The recent progress on the detection of astroparticles using radio-techniques has launched a novel idea: deploying 100,000's of radio antennas - that are intrinsically cheap - over 100,000's of km^2 in order to achieve the required sensitivities. I will briefly introduce this project, called GRAND (Giant Radio Array for Neutrino Detection), and show with basic modeling how different array layouts and ground topologies can enhance the neutrino sensitivity to guarantee the detection of these neutrinos, and show that the angular resolution will be good enough to do neutrino astronomy.

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Modeling and interpretation of spectral properties of primeval galaxies

The James Webb Space Telescope (JWST, to be launched in 2018) will enable the direct exploration of primeval galaxies near the Epoch of Reionization, at the end of the Dark Ages. To best interpret these upcoming observations in terms of constraints on theories of galaxy formation and evolution, we require models of the light emitted by the first galaxies. A particularly critical task is to identify spectral diagnostics of the different ionizing sources capable of powering the first galaxies, such as young massive stars and accreting black holes, and of the leakage of ionizing radiation into the intergalactic medium. This is the focus of my thesis.

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Numerical simulations and data analysis of the MICROSCOPE mission : Modified Gravity and screening mechanisms.

MICROSCOPE is a French space mission developed by ONERA and CNES, launched on the 25th of April 2016, which aims to improve the test of the Weak Equivalence Principle (WEP) by two orders of magnitude and reach a level of $10^{-}15$ on the Eötvos parameter. The experiment is based on testing the WEP's experimental manifestation known as the Universality of Free Fall, with an ultrasensitive accelerometer composed of two test masses of different composition. The results of this experiment should be able to provide new constraints on alternative theories of gravity. This work aims to compute these constraints. It focuses on a class of such theories called scalar-tensor theories, which introduce a new scalar field besides Einstein's gravity. By coupling to matter, it gives rise to a 5th force that can violate WEP or induce other effects that should appear in MICROSCOPE data. The Chameleon model is particularly interesting for MICROSCOPE. This scalar field was proposed as a dark energy candidate that could satisfy local gravity constraints through a screening mechanism. Such mechanism makes its dynamics such, that its associated 5th force is expected to be negligible in high density environment. Being in space, MICROSCOPE is expected to be an unprecedented opportunity of testing the existence of a chameleon.

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Galaxy clusters in the cosmic web

Numerical simulations of the formation of large scale structures in the universe paint the picture of galaxy clusters being located at the intersection of cosmic filaments and accreting galaxies and groups of galaxies along these preferred directions throughout cosmic time. In this context, it is important to understand the effect of environment on galaxy properties.

With this aim, I have developed an improved version of the AMACFI cluster finder (now AMASCFI) and apply it to the 154 deg^2 of the Canada France Hawaii Telescope Legacy Survey (CFHTLS) to obtain a large catalogue of 1371 cluster candidates up to redshift $z \leq 0.7$. This sample is 90% pure and 70% complete.

We study the evolution of these clusters with mass and redshift by computing the i'-band galaxy luminosity functions (GLFs) for the early- (ETGs) and late-type galaxies (LTGs). Our large sample allows us to break the degeneracy between cluster mass and redshift.

Our results show that the cluster red sequence is mainly formed at redshift $z > 0.7$, and that faint ETGs continue to enrich the red sequence through quenching of brighter LTGs at $z \leq 0.7$. The efficiency of this quenching is higher in large-mass clusters.

Since galaxies are accreted along cosmic filaments onto clusters, these filaments might have an influence on the formation of cluster red sequence. I am currently working on the detection of such filaments in the CFHTLS using photometric redshifts. As a first step, I am assessing the quality of the cosmic web reconstruction for various photometric redshift errors using mock data from a large simulation lightcone. I will show preliminary results.

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Cosmic ray feedback in dwarf galaxies

In the cold dark matter (CDM) cosmological model, larger structures form through successive mergers. Therefore, dwarf galaxies ($M_{vir} < 10^{11} M_{\odot}$) are the smallest probes of cosmological structure formation. There are a number of puzzles surrounding dwarf galaxies that pose important challenges to our theoretical understanding of galaxy formation (Too big to fail, missing satellites, and cusp core problems). The inclusion of baryonic feedback could potentially solve these issues. To achieve this, one would like to directly simulate the physics responsible for driving galactic winds and reducing star formation. The problem is that the exact nature and extent of these feedback processes are still strongly debated and are implemented in terms of subgrid physics. In this context, I will tell you about our current work on cosmic ray physics and their inclusion in numerical simulations through supernova feedback. Cosmic rays have several properties which make them a promising candidate for helping driving galactic winds in dwarf galaxies.

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Giant planets survey with SOPHIE at OHP

SOPHIE spectrograph was installed at Haute Provence Observatory in 2006 in particular to perform various radial velocity surveys to study exoplanets. The goal of one of the SOPHIE surveys is to improve the statistics on giant extrasolar planets. The current version of this catalog includes stars up to distance of 60 pc and B-V in between 0.35 and 1. The statistical survey of these giant planets allows us to obtain correlation between the different parameters of the exoplanets and their host stars. It gives us an opportunity to follow-up multi-planet systems and study their characteristics. Thus, detecting and characterizing new giant planets under this program not only allow us to explore the diversity of planetary systems but also put constraints on the models of their formation. I will present few results from this survey and also talk about constraining the obliquity of an exoplanet using Rossiter-McLaughlin effect.

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Cosmological inference from self-consistent Bayesian forward modelling of deep galaxy redshift surveys

We describe the development of a large-scale Bayesian inference framework to constrain cosmological parameters using galaxy redshift surveys, via an application of the Alcock-Paczýnski (AP) test. Our physical model of the non-linearly evolved density field, as probed by galaxy surveys, employs Lagrangian perturbation theory (LPT) to connect Gaussian initial conditions to the final density field, followed by a coordinate transformation to obtain the redshift space representation for comparison with data. We implement a Hamiltonian Monte Carlo sampler to generate realizations of three-dimensional density field from a highly non-Gaussian LPT-Poissonian density posterior given a set of observations. This hierarchical approach encodes a new self-consistent AP test, exploiting the full complexity of galaxy redshift surveys, to infer cosmological parameters, while accounting for a non-linear bias. We perform several tests on a mock galaxy catalogue, taking into account a highly structured survey geometry and selection effects. This framework will eventually incorporate the statistical reconstruction of the underlying 3D power spectrum. We also present an introductory overview of our code DANTE, currently being developed for pure E/B decomposition on the sphere.

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The secular evolution of dark matter halos: using the kinetic theory to explain the cusp to core transformation

The Navarro-Frenk-White profile is supposed to describe the radial profile of any spherical dark matter halo after its gravitational collapse and virialisation. This cuspy structure is a quasi-stationary state, in the sense that it will not evolve over a Hubble time if unperturbed. However, both observations and simulations of dwarf galaxies reveal a cored structure of small halos, leading to the cusp-core problem. Simulations of such systems show that the transition from cusp to core may be driven by baryonic effects, which perturb the dynamical state of the halo. Through the dressed Fokker-Planck equation, the kinetic theory of self-gravitating systems provides the tools to study the secular diffusion of the orbital structure of a halo driven by perturbations from the inner galaxy. The halo‚Äôs self-gravity is able to amplify the potential perturbations entailed by supernovae, leading to a reshuffling of the orbits of dark matter particles on secular timescales. I will describe the three main parts of my PhD project: How can we model the potential perturbations coming from the supernovae? How can we compute the linear response of a dark matter halo to potential perturbations? How can we use the dressed Fokker-Planck equation to study the transformation from cusp to core?

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4.5 Post-Newtonian order development on compact binary systems

Post-Newtonian (PN) theory enables us to predict the waveform of the gravitational waves emitted by a system of two compact objects coalescing in its inspiral phase. State-of-the-art works provide the phase of the expected signal up to 3.5PN (i.e. up to $1/c^7$). Comparison with numerical relativity, as well as the promising evolution of gravitational wave detectors incite us to pursue this computation to a higher order. In our current attempt, we are trying to reach the phase of the signal at the 4.5PN order (i.e. $1/c^9$) for spinless compact binaries in circular orbit. For this purpose, the flux emitted by such a system has to be known at 4.5PN, and the equation of motion at 4PN. I will explain the methods we are currently using at IAP to tackle this problem and our latest results.

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Diffuse light in galaxy clusters: detection and star formation rate

Intra-cluster diffuse light (ICL) is the diffuse optical component of galaxy clusters, composed of stars unbound to galaxies but associated with the cluster gravitational potential. It is believed to form mainly through galaxy interactions (tidal stripping, mergers), and is theoretically one the most revealing signatures of cluster formation history. Despite its importance, the ICL is still widely unexplored, due to its very low surface brightness (a few percent of the sky background) and to instrumental effects contaminating the data (scattered light). Here we improve a wavelet-based detection algorithm initially proposed by C. Da Rocha, and plan to apply it to images from the Canada France Imaging Survey (CFIS) that have been treated with the ELIXIR-LSB software developed by J.C. Cuillandre. The two deep optical bands of the CFIS (u and r) should allow us to probe the color properties of the ICL and to compare them to the colors of cluster galaxies. In this way, we hope to test not only the main formation scenario for the ICL (old stars stripped from galaxies), but also the possibility for star formation directly in-situ.

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Supermassive black holes from kpc to pc scales

Supermassive black holes (BHs) reside in the center of most massive galaxies and are thought to play a crucial role in the big picture of galaxy evolution. Since galaxies merge, we expect BHs to get closer and form binaries, an inevitable step before their merger and the emission of gravitational waves that we might observe with LISA. We focus on the formation of the binary and show, using ideal simulations of galaxy mergers, that this process is far to be captured in cosmological simulations. This prevents from predicting self-consistently the merger rate of supermassive BHs using cosmological simulations. We present a new model which will overcomes this issue.

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Testing Lorentz Invariance by Binary Black Holes

The recent detection of gravitational waves has opened a new avenue towards the highly-relativistic and dynamical strong-field regime of the Einstein equations. It's therefore possible to test GR in a new arena characterized by velocities comparable to the speed of light and by large, dynamical curvatures. After describing how gravitational waves and binary black holes can be used to test GR, we will focus upon one particular alternative: Lorentz-violating gravity. Although Lorentz-invariance is at the heart of theoretical physics, it's violation in the gravitational sector may lead to a quantum theory of gravitation, for instance. Thus, we will show some new results on the properties of black hole solutions in Lorentz-violating gravity as well as how GW signals help us to test Lorentz invariance in gravity.

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High energy astroparticles from transient sources

The growing field of multimessenger astronomy is giving us new insights into high energy phenomena. With the advent of gravitational wave astronomy, and of neutrino astronomy in the near future, with ambitious observatories like GRAND or POEMMA, modelling and predicting the properties of high energy transient phenomena is needed more than ever.

We present robust and widely applicable analytical criteria that we have established for the detectability of transient neutrino emissions from explosive transients. From this study, tidal disruptions by massive black holes stand out as promising candidate sources of ultrahigh energy messengers. We investigate this scenario by simulating the propagation and interaction of ultrahigh energy cosmic-rays in the environments of these objects and predict associated multi-messenger signatures.

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Gamma-Ray Bursts as probes of the early Universe

Gamma-Ray Bursts (GRBs) are short, intense bursts of electromagnetic radiation in the hard X-rays and soft gamma-rays caused by the birth of a stellar mass black hole. Because of their detectability up to very high redshift (z $>$ 9) and their transient nature, GRBs and their associated phenomena offer a unique tool to probe the distant universe. More specifically, Long GRBs (LGRBs) are associated with the core-collapse of some massive stars, and as such potentially provide a tracer of star formation. However, the precise nature of the progenitor stars remains elusive, with multiple channels envisaged. In this talk I will first give a quick overview of the current paradigm for GRBs, then I will present the results of the study of a complete sample of long GRB host galaxies with the aim of assessing the use of LGRBs as (potentially biased) tracers of star formation. I will then show how the redshift distribution of LGRBs can be constrained by a population model and combine both approaches to consider the consequences for progenitors.

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The cold gas in the ISM of high-z galaxies

A quasar is an extremely bright point source in the high-z universe, providing an unique technique to probe the medium along the line-of-sight. The emission of a quasar goes through a galaxy, the spectroscopic absorption lines gives us information about interstellar-medium (ISM) in the galaxy. Thus the absorption lines are widely used as a strong tool to study the physical conditions of the gas in the intervening systems. I will introduce how we select the sample, obtain the physical properties of the ISM from the quasar spectrum and how we connect the results to the star formation and galaxy evolution.

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Transitioning HI-H2 clouds at high redshift

My project aims at studying the transitioning HI-H2 clouds in the early universe. We do this by looking at absorption lines created in the background quasar light in a specific line of sight. High column density atomic gas leads to saturation of the QSO light at specific wavelengths (like Lyman-alpha, beta, etc.) creating a damped voigt profile and hence, a specific class of these systems called the Extremely Strong Damped Lyman-Alpha Absorbers (or ESDLAs) are tracers of very high-column density gas at these redshifts. ESDLAs are found, in the past, to be located within their host galaxy. Hence, probing ESDLAs with the highest HI column density ($N(HI) > 10^{(21.8)}$), we are likely to detect HI-H2 transitioning gas, inter-stellar medium(ISM)/molecular clouds() (in absorption at Lyman-Werner bands) and star-forming regions (in lyman-alpha emission, optical emission lines), at high redshift, in a way which is not selected based on the strength of the emission, and hence represents the general star-forming population at high redshifts. The primary aim of the project is to look at large samples of ESDLAs to understand HI-H2 conversion and star-formation processes better in the early universe and further compare them to the local universe.

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The prediction of the Gravitational Lensing signal with Hydrodynamical Cosmological Simulations

In the context of large future cosmological surveys, such as the Euclid mission, we ought to make accurate pedictions of the gravitational lensing signal over large-enough volumes with the state-of art Horizon-AGN hydrodynamical cosmological simulation.

Therefore, I propagate light rays through the light-cone of the Horizon-AGN simulation (Dubois et al. 2014), which allows to address the effect of the baryonic component on various observables. In particular, I will present the effect of the baryonic component on the 2-point weak lensing statistics which is altered by the different behavior of hot gas, stars and dark matter. In addition, I will present statistics of strong lensing events which deeply plunge into the inner parts of galaxies.

Additionally, in order to quantify our ability to recover the gravitational lensing signal, we applied the lensing distortions to mock images consistently derived from the simulations. This will allow us to carry on rich end-to-end simulations (including complex photometric errors, complex galaxy morphology, magnification, and shear containing realistic intrinsic alignments...)

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Stability analysis of a periodic system of relativistic current filaments

Homogeneous counterstreaming plasmas are subject to the transverse filamentation (or Weibel) instability that leads to the formation of current filaments. The nonlinear evolution of this instability is of prime interest in astrophysics where it is held responsible for generating the magnetic turbulence in the precursor region of relativistic collisionless shocks [1]. It also plays an important role in high-intensity laser-plasma interactions in accounting for the angular spread of the laser-accelerated particles [2]. In this presentation, we perform a linear stability analysis of a periodic system of relativistic current filaments described by a relativistic fluid model. Using the Floquet theory, we compute the exact eigenmodes of the system, and show the dominant modes transition from coalescence-type to kink-type instabilities with increasing nonlinearity and asymmetry of the two-stream plasma system. Our theoretical predictions are supported by particle-in-cell simulation results. In a symmetric configuration, the stationary system has an analytical expression that tends to the Harris equilibrium. In such a system, We derive a new expression for the relativistic kink instability that matches the results and we give a heuristic criterion for the coalescence or kink dominance in parameter space.

References:
1. M. Milosavljevic and E. Nakar, Astrophys. J. 641, 978 (2006)
2. A. Debayle, J.J. Honrubia, E. d'Humiéres and V.T. Tikhonchuk, Phys. Rev. E 82, 036405 (2010)

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Particle acceleration in relativistic magnetohydrodynamic turbulence

Turbulence is related to a number of fundamental questions of high-energy astrophysics. For instance, it is certainly closely related to the mechanisms by which the kinetic or magnetic energy of powerful astrophysical sources such as pulsar wind nebulae, gamma ray bursts or active galactic nuclei is dissipated into the spectrum of highly energetic particles and radiation revealed by multi-messenger observations.Turbulence also impacts on the confinement in the sources and then on the transport of cosmic rays.

In this picture, my PhD is particularly focused on the role of magnetized turbulence on particle acceleration. Lately, I have been studying this question in the framework of Monte Carlo simulations of test particles involving in a magnetohydrodynamic wave-turbulence. The aim is to determine the diffusion coefficients characterizing the spatial transport and the acceleration of particles, especially in the yet largely unexplored regime of relativistic turbulence.

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How does the cosmic web impact assembly bias?

Recent development have shown that the halo assembly is influenced by the large scale structure of the cosmic web, resulting in the so called assembly bias. Using an extension of the excursion set theory constrained to the presence of a filament type structure, I will show how one can compute the accretion rate and formation time of halos and recover that distinct gradients for different quantities appear. I will argue that this effect can not be explained by a local rescaling of the density but instead encodes the intrinsic anisotropy of the large scale environment.

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Information content of high order correlation functions for Weak Lensing

In order to fully exploit the constraining power of data that future surveys like Euclid will provide, we need to understand how the cosmological information content of the observables of interest is diminished by the quality of our approximations. In particular, the fidelity of the modelling of the statistical properties of the observables is paramount. Semi-analytical models for the non linear clustering have been developed in order to avoid heavy simulations (required for full-sky surveys). However, they might not be as precise as required at all the scales of interest. Along with the survey's specificities, we need to understand how all these aspects can affect our capability in estimating the value of the cosmological parameters. I will present a pipeline capable to describe the dependence of the Fisher information content on the cosmological parameters in the case of weak lensing. The late time dark matter field being non-gaussian, I will show how it is possible to increase the retrieved information by considering the higher order correlation functions of the field.

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