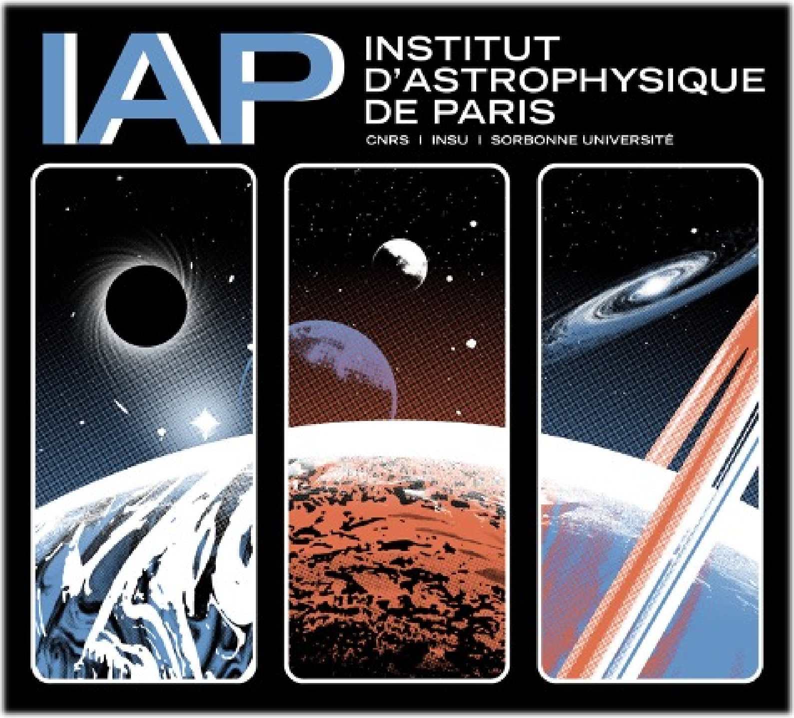
Journée des thèses / PhD day



Friday, 22 April 2022 10:00 - 16:30

Institut d'Astrophysique de Paris

Amphitheater Henri Mineur

Hosts: Tianxiang Chen, Marie Lecroq, Mathieu Roule & Denis Werth

Planning

10:00	*Welcoming*	
10:10	Pierre-Cécil König	A warm super-Neptune around the G-dwarf star TOI-1710 revealed with TESS, SOPHIE and HARPS-N
10:20	Etienne Camphuis	Building an accurate power spectrum covariance matrix for the South Pole Telescope cosmological analysis
10:35	Nai Boongoonkird	LyAl-Net: A high-efficiency Lyman-α forest simulation with neural network
10:50	Emma Ayçoberry	Joint analyses of cosmic microwave background and galaxy surveys
11:00	*Break*	
11:30	Axel Lapel	New statistical tool for a cosmological inference of the absolute neutrino mass scale
11:40	Clément Pellouin	The Off-Axis Afterglow of GW170817: Flux prediction at Very High Energies
11:55	Chi An Dong Paez	Multimessenger modelling of massive black holes with the Obelisk simulation
12:05	David Trestini	Gravitational waves in general relativity and beyond
12:20	Mike Moss	Towards a Physically Motivated Description of GRB Prompt Emission
12:30	*Lunch buffet*	
14:00	Filippo Santoliquido	The evolution of compact objects and their host galaxies across cosmic time
14:15	Virginia Bresci	Acceleration and dissipation in Pulsar Wind Nebulae
14:25	Simon Chiche	Missing energy in the radio-emission of particle cascades
14:40	Hugo Lévy	Numerical investigation of scalar-tensor gravity with MICROSCOPE and future gravity space missions
14:50	Denis Werth	Decoding Inflationary Correlators
15:00	*Break*	
15:20	Mathieu Roule	Long-term relaxation of self-gravitating systems
15:30	Kerwann Tep	Non-resonant relaxation of anisotropic globular clusters
15:45	Aline Chu	Physical properties of Brightest Cluster Galaxies through time
15:55	Louis Quilley	Color bimodality of galaxies : bulge growth and disk quenching of morphological types across the Green Valley
16:10	Tianxiang Chen	Chemical evolution of the Milky Way galaxy in the GAIA era
16:20	Marie Lecroq	Modelling of primeval galaxies in the JWST era
16:30	*Closing remarks*	

A warm super-Neptune around the G-dwarf star TOI-1710 revealed with TESS, SOPHIE and HARPS-N

We report the discovery and characterization of the transiting extrasolar planet TOI-1710 b. It was first identified as a promising candidate by the Transiting Exoplanet Survey Satellite (TESS). Its planetary nature was then established with SOPHIE and HARPS-N spectroscopic observations via the radial-velocity method. The stellar parameters for the host star are derived from the spectra and a joint Markov chain Monte-Carlo (MCMC) adjustment of the spectral energy distribution and evolutionary tracks of TOI-1710. A joint MCMC analysis of the TESS light curve and the radial-velocity evolution allows us to determine the planetary system properties. From our analysis, TOI-1710 b is found to be a massive warm super-Neptune ($M_p = 28.3 \pm 4.7 M_{\mathrm{Earth}}$ and $R_p = 5.34 \pm 0.11 R_{\mathrm{Earth}}$) orbiting a G5V ($T_{\mathrm{eff}} = 5665 \pm 55$K) dwarf star on a nearly circular 24.3-day orbit ($e = 0.16 \pm 0.08$). Considering the closeness of the orbital period of this planet with the estimated rotation period of its host star $P_{\mathrm{rot}} = 22.5 \pm 2.0$ days, and given its low Keplerian semi-amplitude $K = 6.4 \pm 1.0$ m/s, we performed additional analyses to show the robustness of the retrieved planetary parameters. With a low bulk density of 1.03 ± 0.23 g/cm^3 and orbiting a bright host star ($J = 8.3$,$V = 9.6$), TOI-1710 b is one of the best targets in this mass-radius range near the Neptunian desert for atmospheric characterization via transmission spectroscopy, a key measurement in constraining planet formation and evolutionary models of sub-Jovian planets.

Supervisors: Guillaume Hébrard & Gaitee Hussain (ESA)

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Building an accurate power spectrum covariance matrix for the South Pole Telescope cosmological analysis

The South Pole Telescope (SPT-3G) is a ground based experiment observing the cosmic microwave background (CMB) in both intensity and polarization, with unprecedented resolution and noise levels. It aims at putting constraints on cosmological parameters as tight as those of the Planck satellite. Accurate covariance matrices are required for a reliable estimation of cosmological parameters from pseudo-power spectrum estimators. We present for the first time an algorithm that allows the computationally expensive exact calculation of analytical covariance matrices. We then use this as a reference to test the accuracy of existing fast approximations of the covariance matrix, evaluating their precision at the 5% level on our footprint. We also propose a new approximation which improves over the old ones reaching a precision of 1%.

Supervisors: Silvia Galli, Karim Benabed & Eric Hivon

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LyAl-Net: A high-efficiency Lyman-α forest simulation with neural network

The inference of cosmological quantities needs accurate and large cosmological simulations. Yet, the computational time takes millions of CPU hours for a modest coverage in cosmological scales ($\sim(100 Mpc/h)^3$). This ML method could have a decisive impact on the results derived from QSO surveys, e.g., SDSS3/4 data, which has a resolution power of $R = 1500$ and $R = 2000$. But it could be critical for upcoming surveys like WEAVE-QSO with $R = 20000$ in high-res mode. We used the Horizon-NoAGN simulation to train the U-Net, to predict the neutral hydrogen physical properties; density, temperature, and velocities. The flux derived from the predictions is nearly identical to the original flux from simulation with $R \gtrapprox 30000$. More generally, the computation of individual fields from the dark matter density agrees well with regular physical regimes of the cosmological field. This approach provides fast and robust numerical simulations, not only for the Lyman-α forest but also a tool for other applications.

Supervisor: Guilhem Lavaux

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Joint analyses of cosmic microwave background and galaxy surveys

The distribution of matter in the Universe is a powerful probe of cosmology. Measuring the efficiency with which gravity produces clusters against expanding Universe is the key to understanding, e.g. the equation of state of dark energy. Numerous projects aim at measuring the matter distribution across time in the Universe but no observable gives the perfect figure of this distribution (because of instrumental limitation, astrophysical limitation, or because they probe different redshifts). Cross-correlation of different probes is a powerful way to lift these limitations. My PhD aims to construct a robust halomodel of the thermal Sunyaev-Zeldovich power spectrum (one such tracer of the LSS) and to cross-correlate it with different probes of the distribution of matter (lensing, CMB lensing, galaxy count,...). This work will allow us to construct the first 10×2pt analyses and derive cosmological parameters. I will give an overview of my current results and perspectives.

Supervisors: Karim Benabed & Yohan Dubois

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New statistical tool for a cosmological inference of the absolute neutrino mass scale

Despite their success, current standard models of cosmology and particle physics provide an incomplete description of the Universe and its constituents. Among the questions raised through the ever-increasing data from particle experiments and astronomical observations, the value of the mass of neutrinos is a challenging but nonetheless essential question to address. Fortunately, cosmic neutrinos were produced in such a large quantity in the early Universe that they were able to affect its dynamical history, making cosmology a sensitive tool to infer their absolute mass scale. On a less bright note, traditional methods to analyze current and next-generation surveys are plagued by the degeneracy between massive neutrinos and other cosmological parameters/baryonic effects and possible systematics. Furthermore, it is thought that there is extra information to obtain from higher-order statistics of the late Universe matter distribution. Because of all that, we are interested in this project to develop new statistical tools for future CMB and Large Scale Structures analyses to constrain the absolute mass of neutrinos. I will provide an overview of my current project for the implementation of massive neutrinos in a forward modeling approach to assess the information content at the field level. I will also briefly present future plans to develop Simulation-Based Inference methods and prepare cross-correlations analysis between galaxy clustering and CMB/LSS lensing toward refined constraints on massive neutrinos.

Supervisors: Guilhem Lavaux, Karim Benabed & Pauline Zarrouk (LPNHE)

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The Off-Axis Afterglow of GW170817: Flux prediction at Very High Energies

The binary neutron star merger gravitational-wave event GW170817 and observations of the subsequent electromagnetic signals at different wavelengths have helped better understand the outflows that follow these mergers. In particular, the off-axis afterglow of the jetted ejecta has allowed to probe the lateral structure of such jets, especially thanks to VLBI imagery of the source. In this talk, I will present our model of this afterglow including a decelerating jet with lateral structure, while synchrotron emission and synchrotron self-Compton scatterings power the jet radiation. In particular, we extend our analysis to very high energies and predict the light curve in the energy range of H.E.S.S. and the CTA. I will finally discuss how future detections of afterglows by these observatories can help break the degeneracies in some key physical parameter measurements, and allow to probe efficiently a sub-population of fast-merging binaries.

Supervisors: Frédéric Daigne & Irina Dvorkin

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Multimessenger modelling of massive black holes with the Obelisk simulation

Massive black hole (BH) mergers, which generally follow the merger of two galaxies, are expected to play a significant role in the evolution of their host galaxy. The upcoming generation of gravitational wave observatories, and in particular LISA, is expected to detect a large number of massive black hole merger events. Meanwhile, the detection of electromagnetic counterparts can give insight into the physics of accreting binary black holes. We investigate the properties and detectability of black hole mergers in a cosmological context. We use a BH population based on the Obelisk simulation, a high-resolution, cosmological radiation-hydrodynamics simulation following the evolution of a protocluster to redshift $z = 3.5$. This simulation incorporates detailed physical modelling of BHs, which makes it ideal for our purposes.

Supervisors: Marta Volonteri & Yohan Dubois

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Gravitational waveforms in general relativity and beyond

In this talk, I will cover recent advances in gravitational wave template computations, both in massless scalar-tensor theory and general relativity. I will cover the main concepts used in the post-Newtonian formalism, and highlight the differences in the two theories.

Supervisors: Luc Blanchet & Laura Bernard

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Towards a Physically Motivated Description of GRB Prompt Emission

Gamma-Ray Bursts (GRBs) are the brightest explosions to occur in our universe. After 50 years of study, the particle distributions, acceleration mechanisms, and emission processes occurring within a GRB are all still unknown. Using evidence from observations one can make assumptions on the physical properties of a GRB and therefore develop a model describing the physics of the prompt emission. The goal of my thesis research will be to compare several models commonly used in the literature by using the data from a handful of bright GRBs. The strength of each model will be determined by comparing the observationally motivated theoretical constraints placed on each model and through fitting the models to data using finely time-resolved spectral analysis methods. A key component of my work will be to investigate the evolution of the components and features within each model. An automated spectral-analysis pipeline will be developed to enable efficient and consistent spectral analysis across all GRBs used.

Supervisors: Frédéric Daigne & Robert Mochkovitch

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The evolution of compact objects and their host galaxies across cosmic time

The merger rate density evolution of binary compact objects and the properties of their host galaxies carry crucial information to understand the sources of gravitational waves. In this talk, I will present `galaxyRate`, a new code that estimates the merger rate density of binary compact objects and the properties of their host galaxies, based on observational scaling relations. We generate our synthetic galaxies according to the galaxy stellar mass function of star forming and passive galaxies. We estimate the metallicity according to both the mass-metallicity relation (MZR) and the fundamental metallicity relation (FMR). Also, we take into account galaxy-galaxy mergers and the evolution of the galaxy properties from the formation to the merger of the binary compact object. We find that the merger rate density evolution with redshift changes dramatically depending on the choice of the star-forming galaxy main sequence, especially in the case of binary black holes (BBHs) and black hole neutron stars (BHNSs). The slope of the merger rate density evolution of BBHs and BHNSs is steeper if we assume the MZR with respect to the FMR, because the latter predicts a shallower decrease of metallicity with redshift. Overall, BBHs and BHNSs tend to form in low-mass metal-poor galaxies and merge in high-mass metal-rich galaxies, while BNSs form and merge in massive galaxies. The metallicity distribution of the host galaxies is significantly affected by the adopted metallicity relation. We predict that passive galaxies host at least ∼5-10%, ∼15-25%, and ∼15-35% of all BNS, BHNS and BBH mergers in the local Universe.

Supervisors: Irina Dvorkin, Stanislav Babak (APC) & Michela Mapelli (Università di Padova)

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Acceleration and dissipation in Pulsar Wind Nebulae

The main topic of my PhD is, in general, particle acceleration to extreme energies. In recent years, particle acceleration at shocks has been extensively studied by means of particle-in-cell kinetic simulations which highlighted the non-linear connection between turbulence and particles and the need of a more comprehensive understanding of the microphysics behind the acceleration processes that results in observable radiation from non-thermal particles. In the first part of my PhD I focused on the saturation mechanism of a particular instability (current filamentation instability - CFI) in asymmetric conditions, as it is the case of relativistic weakly magnetised shocks, whose formation is mediated by the CFI. In the second part, I studied the combined interaction of magnetic turbulence and the shock as a promising candidate of particle energisation through dissipation of turbulent magnetic field energy. The scenario we have in mind is relevant for various high energy astrophysical systems, from PWNe to AGNs and GRBs.

Supervisors: Martin Lemoine & Laurent Gremillet (CEA)

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Missing energy in the radio-emission of particle cascades

What is the origin of ultra-high energy cosmic-rays, these charged atomic nuclei that arrive on Earth with energy $>10^{18}eV$? To collect enough particles and solve this mystery, observatories covering gigantic surfaces have to be built, using efficient detection techniques. Radio detection, i.e., the detection of radio signals from the particle cascades (air-showers) that ultra-high energy particles induce in the atmosphere, is a robust, efficient, scalable and hence promising technique. Cascades induced by particles with inclined arrival directions are of particular interest as they exhibit a large footprint that allows to sample the signal with only few antennas. The construction of several of such large-scale radio-detectors focusing on inclined air-showers are being currently planned (GRAND, BEACON, GCOS). However, the physics of the radio emission of very inclined air-showers is scarcely understood, and needs to be explored with analytical and numerical methods. In the preparation for these large-scale radio-experiments I have developed an innovative fast semi-analytical simulation tool for very inclined air-showers. This tool relies on a deep understanding on the radio signal polarisation and enabled us to identify a new radio emission signature, specific for inclined air-showers, in a new regime that was not described by any model. The understanding of this regime would be a major advancement toward this new era of large-scale UHE astroparticle detection.

Supervisors: Kumiko Kotera & Olivier Martineau (LPNHE)

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Numerical investigation of scalar-tensor gravity with MICROSCOPE and future gravity space missions

Space-based experiments are promising candidates for testing modified gravity theories. The MICROSCOPE mission, beyond setting a tighter constraint on the test of the Weak Equivalence Principle, could also set new constraints on models that deviate from Newtonian gravity. In particular, scalar-tensor models subject to the chameleon or symmetron screening mechanism are among the simplest extensions of General Relativity that may explain the accelerated expansion of our Universe without belying local gravitational tests. However, designing effective and intelligent novel experiments to probe such scalar fields is partly impeded by the difficulty to accurately model them. Indeed, the partial differential equations that drive their dynamics are nonlinear (enabling the screening mechanism) which means analytical techniques are only of little help. In this talk, I will present a numerical tool for computing the field's profile in the presence of arbitrary source's geometries using the finite element method. The nonlinearity is addressed using Newton's iterations while several approaches have been implemented for dealing with situations where the field's behaviour is only known infinitely far away from the sources.

Supervisors: Jean-Philippe Uzan & Joël Bergé (ONERA)

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Decoding Inflationary Correlators

Inflation is a widely accepted paradigm explaining the origin of the observed spatial correlation in cosmological structures. However, the physics of inflation remains elusive, and a key challenge of primordial cosmology is to decipher it through the study of cosmological correlators, which notably encode high-energy physics effects during inflation. As we enter a precision physics era, it is vital to study more realistic models that are analytically intractable and to develop new computational tools to probe these fine features. In this short presentation, I will present an ongoing work on the so-called transport approach that enables one to numerically compute inflationary correlators directly at the level of effective field theories of inflationary fluctuations, hence bypassing the intricacies of Feynman diagrams computations.

Supervisor: Sébastien Renaux-Petel

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Long-term relaxation of self-gravitating systems

The master equation describing the long-term evolution of isolated discrete self-gravitating systems is the so-called inhomogeneous Balescu-Lenard equation. Such a formalism is particularly valuable because it analytically captures some of the key non-linear processes involved in these systems' orbit reshuffling when driven by Poisson shot noise. Yet, this kinetic framework relies on specific sets of asymptotic assumption, e.g., timescale separation and sharp resonance conditions, which may not be strictly fulfilled in practice. Quantitative validation is therefore of interest. We compare theoretical prediction with measurement from N-body simulations for $1D$ self-gravitating systems, whose reduced phase space dimension allows for finer precision. Measurements are found to be in clear agreement with respect to predictions for the orbital diffusion and flux induced by finite-N effects.

Supervisors: Christophe Pichon & Jean-Baptiste Fouvry

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Non-resonant relaxation of anisotropic globular clusters

Globular clusters are dense stellar systems whose core slowly contracts under the effect of self-gravity. The rate of this process was recently found to be directly linked to the initial amount of velocity anisotropy: tangentially anisotropic clusters contract faster than radially anisotropic ones. Furthermore, initially anisotropic clusters are found to generically tend towards more isotropic distributions during the onset of contraction. Chandrasekhar's "non-resonant" theory of diffusion describes this relaxation as being driven by a sequence of local two-body deflections along each star's orbit. When compared to N-body realisations of Plummer spheres with varying degrees of anisotropy, the NR theory is shown to recover remarkably well the detailed shape of the orbital diffusion and the associated initial isotropisation, up to a global multiplicative prefactor which increases with anisotropy.

Supervisors: Christophe Pichon & Jean-Baptiste Fouvry

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Physical properties of Brightest Cluster Galaxies through time

Located at the intersection of cosmic filaments in the large scale structures, galaxy clusters present in their center, at the bottom of the cluster potential well, a supermassive galaxy which is also most often the brightest galaxy of the cluster. This galaxy is referred to as the Brightest Cluster Galaxy (BCG). Understanding how BCGs were formed and how they evolve can help us to understand how the clusters which host them were formed. BCGs are the results of billions of years of successive galaxy mergers which can leave an imprint on the galaxy. As a result, BCGs were shown to have properties closely linked to those of their host clusters. I analysed the physical properties of BCGs in two different studies: first by taking a large sample of 137 clusters with HST images in the optical and/or infrared, covering a wide redshift range up to $z = 1.8$; and then by studying more than 1300 potential BCGs detected in the CFHTLS up to $z = 0.7$, to see if their characteristics vary with redshift. Our results agree with the BCGs being mainly formed before redshift $z = 1.8$. The alignment of the major axis of BCGs with their clusters agree with the general idea that BCGs form at the same time as clusters by accreting matter along the filaments of the cosmic web.

Supervisors: Florence Durret & Isabel Marquez (IAA)

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Color bimodality of galaxies : bulge growth and disk quench- ing of morphological types across the Green Valley

Color-magnitude diagrams show a bimodality between the red passive galaxies and the blue star-forming ones. In between the Red Sequence and the Blue Cloud lies the Green Valley, a low density area of intermediate-color galaxies which has raised questions about the evolutionnary pathways of galaxies. By doing luminosity profile-fitting and SED model-fitting, I recreate those diagrams for nearby galaxies in the northern galactic cap. Using data from the EFIGI morphological catalog, I focus on the distribution of the different Hubble types in those diagrams, and complement them with quantitative parameters, such as bulge and disk absolute colors, bulge-to-total ratio, stellar mass or specific star formation rate. The observed trends provides insight on the evolution of galaxies and the build-up of the Hubble Sequence.

Supervisor: Valérie de Lapparent

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Chemical evolution of the Milky Way galaxy in the GAIA era

The formation and evolution of the Milky Way (MW) is studied through the properties (chemical composition and kinematics) of its stellar populations (halo, bulge, thin and thick disks). Past and forthcoming stellar surveys provide data for the chemistry and kinematics of tens or hundreds of thousands of stars. The interpretation of these data has to be made with appropriate models of galactic evolution. Our existing $1D$ model include a complete set of all the stable elements and their isotopes and a parametrized description of various physical processes, including radial migration of stars in the MW disc. My PhD thesis aims to test implications of some recently proposed ideas (Star formation burst in the MW disc, Radial migration of the Sun etc), implement the 2nd dimension (z-axis) to describe vertical structure of the disc and develop appropriate statistical tools to compare the output to the large quantity of existing and forthcoming data. In this talk, I will present my current results and short-term plans.

Supervisor: Nikos Prantzos

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Modelling of primeval galaxies in the JWST era

The James Webb Space Telescope will be the largest and most powerful space telescope ever built. One of its main goals will be to study the birth of the first stars and galaxies of our Universe. Preparing for the exploitation of JWST data requires an improvement of the models currently used to interpret the light emitted by primeval galaxies. To reproduce the emission from such galaxies more realistically than possible today, it is necessary to examine the contribution from massive binary stars, which some recent studies suggest could play a significant role in the production of high-energy radiation in these young star-forming regions. Achieving this requires an extensive exploration of the spectral signatures of these stars and their dependence on galaxy physical parameters. While waiting for JWST observational data, the models can be tested and optimized using ultraviolet and optical spectra of nearby analogs of primeval galaxies. Full fits to such observations, which have never been achieved so far, will confirm the reliability of the models, which could then be used to carry out a statistical study of the distribution of physical parameters of primeval galaxies.

Supervisor: Stéphane Charlot

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