Title: “Exploring the physical diversity of young exoplanets and brown dwarfs through high-resolution spectroscopy at VLT and ELT”

Location:

- Max Planck Institute for Astronomy, Heidelberg, Germany
- Laboratoire J.-L. Lagrange, Observatoire de la Côte d’Azur, Nice, France,

Funding:

- Joined grant between ANR-MIRAGES, Multi-Resolution Analysis of Giant Exoplanets & the MPIA ExoWorld Imaging Group programme (fund already available)

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Supervisors:

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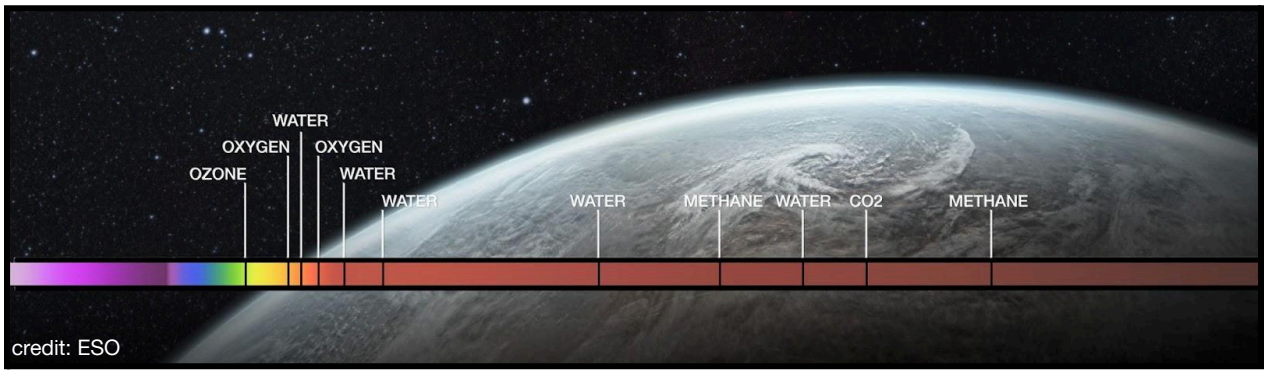

Context: The era of the characterization of exoplanets has already started two decades ago with the atmospheric characterization of hot and strongly irradiated Hot Jupiters using transit observations (in transmission and emission). Such observations have been reported for over 30 exoplanets to date, including old (0.5-10 Gyr) hot Jupiters, hot Neptunes, and even super-Earths. More recently, observations with spectrographs at high-spectral resolution (R_λ =

100 000, hereafter referred as **high-dispersed spectroscopy, HDS**) showed that spectral features from planetary atmospheres can be disentangled from telluric and stellar lines making use of the radial velocity variation of the exoplanet (transiting or non-transiting). The deblending of the molecular lines (in transmission, emission but also reflection) allows astronomers to search for molecular signatures and to ultimately map their spatial distribution using Doppler imaging techniques. These observations enabled the study of the composition, the spatial structures and dynamics of the exoplanetary atmosphere to explore the processes of thermal inversion observed for hot Jupiters, vertical mixing, global circulation and evaporation.

For young (1-100 Myr) exoplanets that can be spatially resolved, **high-contrast imaging (HCI)** techniques (extreme adaptive optics, coronagraphy, integral-field spectrographs…) currently provide high-fidelity spectra of self-luminous massive Jupiters at mainly low-spectral resolution (R_λ = *100-1000*). They are typically made of tens to thousands of data points over a broad wavelength range (0.5–5μm) and can be acquired in a few hours of telescope time. They offer the opportunity to explore the bulk properties of young Jupiters as well as their composition, and the presence of clouds. They eventually give a very complementary view of exoplanetary atmospheres compared to the transit and HDS studies of older exoplanets.

In the perspective of the European Extremely Large Telescope (ELT) https://elt.eso.org, one of the ultimate goals is to characterize the atmosphere of temperate terrestrial planets and to detect the first biosignatures. The combination of HDS with HCI techniques offers a very promising approach. This synergy of techniques is currently foreseen for various instruments like HARMONI, METIS, ANDES and PCS. These facilities will implement different levels of instrumental specifications that are not always matching all the requirements to image and characterize terrestrial planets.

Proposed work: In the context of a Ph.D. between the Max Planck Institute for Astronomy and Laboratoire Lagrange, we propose a project that is declined into two strategic lines of research:

1/ The exploration of the physical (atmospheric and orbital) properties of imaged exoplanets and brown dwarfs at high-spectral resolution. The PhD student will lead the analysis of observing programs dedicated to the study of young massive Jupiters using the molecular mapping technique applied to high-resolution spectra in the context of the VLT/HiRISE project (https://astro.vigan.fr/hirise.html). This work will enable us to explore the physics of the atmosphere of giant exoplanets (composition, signs of accretion, atmospheric structure and circulation), as well as the radial and rotational velocities of the exoplanets connected to the planet obliquity, orbital and rotational period, and more generally in connection with the history of formation and dynamical evolution.

2/ The study of the detection and characterization performance of SCAO-IFU, the future spectro-imager mode of ANDES (https://elt.eso.org/instrument/ANDES/) at the ELT that will combine both innovative techniques of HCI and HDS. Our goal will be to particularly explore for ANDES detection performance of the HCI mode including the possible requirement for a coronagraphic mode, to determine the yield of exoplanets that will be detected in emitted and potentially reflected light, and to study the characterization performance in terms of detection of atomic and molecular signatures connected to the exoplanet atmosphere characteristics. This study will be done with the ANDES consortium, and in synergy with other studies of ELT instruments (e.g. HARMONI, METIS, and MICADO) and JWST, to identify the main science cases of the ANDES instrument for the characterization of exoplanetary atmospheres.

Team & environment: The PhD student will work at the Max Planck Institute for Astronomy with G. Chauvin as a member of the new ExoWorlds Imaging group and in close connection with the PSF/APEx departments (M. Benisty/L. Kreidberg). She/he will also work at the J.-L. Lagrange Laboratory of Côte d'Azur Observatory with M. N'Diaye, A. Chiavassa and V. Parmentier at Lagrange. Visits will be foreseen to work with A. Vigan from Laboratoire d'Astrophysique de Marseille (PI of the VLT/HiRISE project). She/he will be a member of the HiRISE and ANDES consortia, and will collaborate with experts in the field of brown dwarfs and exoplanets, adaptive optics, coronagraphy and high resolution spectrographs at LAM (Marseille), IPAG (Grenoble) or exoplanetary atmosphere models at ENS-Lyon, LESIA (Paris), and CEA (Paris-Saclay). She/he will in addition potentially develop skills in programming (python), observations (SPHERE, CRIRES+, but also ERIS, SPIRou...), will benefit from a rich national and international scientific environment, and will have the opportunity to share her/his work with the community through international schools and conferences.

Keywords: observations, formation, statistical techniques, atmospheres, exoplanets, high resolution spectroscopy.