"PNRR-STILES: science with ELT, SKA and their pathfinders: 1. Searching for forming planets in protoplanetary disks; 2. Atmospheres of gas giant exoplanets"

The successful candidate will have the opportunity to work on one of the following projects. Please contact the supervisors for additional information on each project.

Project 1: Searching for forming planets in protoplanetary disks

Supervisors: Linda Podio (INAF-OAA) **linda.podio@inaf.it**
Claudio Codella (INAF-OAA) **claudio.codella@inaf.it**

Abstract:
The research project will be aimed to prepare science cases for ELT, MeerKAT+, and SKA on topics concerning planet formation in disks around young solar analogs and the origin of Life.
The PhD student will work on:
1) data at millimetre and centimetre wavelengths taken with state-of-the-art facilities (VLA, ALMA, and IRAM) in the context of the large programmes exoALMA, FAUST, and ALMA-DOT. The analysis of these data will be aimed at characterising the chemical composition of the disk in the planet formation region and to prepare science cases for the search of prebiotic molecules with SKA;
2) data at infrared wavelengths taken with VLT-SPHERE, VLT-ERIS, and JWST (in GTO and open time, including the large programme DESTINYS), to search for young planets still embedded in their disks and select the best targets for future searches of protoplanets with ELT.

Our team developed advanced data analysis techniques and is involved in the main international collaborations in the field. The student will then have access to state-of-the-art datasets and data analysis tools. An important aspect of the proposed project is the synergy between the study of the dust and the gas components in the planet-forming disks. Based on the results obtained from the analysis of the available datasets the PhD student will define the best strategies to characterise young planets and their atmospheres with ELT, and, in parallel, to study the dust growth and gas chemical composition in the disk's region where planets form, which will be observed with SKA.

The supervisors are experts of star/planet formation and astrochemistry, and are involved in the science team of ELT-MORFEO, and in the preparation of the science cases for

MeerKAT/MeerKAT+ and SKA, as members of the working group Cradle of Life. Moreover, the PhD student will work in close collaboration with both the Italian and the international community in the context of several projects: JEDI, Astrochemistry@INAF, BEYOND-2p, FAUST, ACO, ALMA-DOT, and ECOGAL.

The project will also benefit of collaborations in the context of the recently approved projects:

- *PRIN-MUR 2022: Chemical Origins: linking the fossil composition of the Solar System with the chemistry of protoplanetary disks.*

- *ASI-Astrobiology 2022: modeling chemical complexity: at the origin of this and other Lifes to prepare future space missions – MIGLIORA*

Project 2: Atmospheres of gas giant exoplanets

Supervisor: Lorenzo Pino, lorenzo.pino@inaf.it

Abstract:

The surprising diversity observed among the properties of the more than 4,000 known exoplanets is one of the most exciting results of modern astrophysics and poses some of its most fundamental unanswered questions. Is the Solar System a typical outcome of planet formation processes, or is it a unique case? Can we build a comprehensive theory of planet formation and evolution capable of predicting this wide phenomenology?

The atmospheres of exoplanets are the key to understand this observed diversity. They represent the fundamental interface between a planet and its environment, determining its evolution pathways (Fortney et al., 2021). They also bear marks of the planet's formation history encoded in their composition (Madhusudhan et al., 2012). However, we have so far lacked the sensitivity and precision to seize the opportunity presented by atmospheric studies.

We are now on the verge of a revolution. Thanks to recent technological developments in high dispersion spectroscopy (HDS; resolving power, R ~ 100,000) we can now reach Solar System-like precision on individual element abundances, and we can start measuring longitudinally resolved atmospheric properties of hot gas giants (Pino et al., 2020; Beltz et al., 2021; Line et al., 2021; Pino et al., 2022). This technique is still extremely relevant and complementary to JWST, since (a) it extends to wavelength regions that can not be observed by the JWST (e.g. $\lambda < 600$ nm), and (b) at R ~ 100,000 it is possible to measure the Doppler-shift of lines which are directly sensitive to atmospheric winds (Pino et al., 2022).

This PhD project will focus on the analysis of a sample of about 10 hot and ultra-hot gas giant planets (T > 1,200) observed in the context of a large survey performed with 8m

class VLT ESPRESSO and Gemini-N MAROON-X (about 100 hours in total; PI: Pino). The successful candidate will pursue two main objectives during the project:

1. Reveal the composition, thermal structure, and dynamics (winds) of the atmospheres of a sample of hot gas giants, particularly rich in elements because of the prevalence of gas-phase chemical compounds in their atmospheres (too hot for condensation to sequester metals in deep clouds – in contrast to the colder planets in the Solar System) – thus providing new insight into their atmospheric structure, climate and formation and evolution history through state-of-the-art observations and data reduction techniques.
2. Improve and consolidate state-of-the-art HDS data reduction techniques for exoplanet atmospheres. Indeed, while they have been extensively validated on hot gas giants (e.g. Brogi et al., 2022), state-of-the-art HDS data reduction techniques for exoplanet atmospheres are still relatively young – first developed by Brogi and Line, 2019. The unprecedented precision obtained in the context of the surveys led in Arcetri will allow to push these techniques to the next level, and validate and improve them in an unexplored regime of precision similar to what the ELT will provide.

Relevance in the context of ELT:

This project tackles the science of exoplanet atmospheres, which is among the primary scientific objectives of several ELT instruments (e.g. ANDES, METIS). In addition, the very same HDS technique that is at the core of this PhD project will be employed to analyze exoplanet atmosphere observations with the ELT. Indeed, VLT ESPRESSO and Gemini-N MAROON-X represent the closest predecessors to ANDES, an INAF-led high resolution optical to near-infrared spectrograph to be mounted on ELT (PI: Alessandro Marconi, associato con incarico at INAF – Osservatorio Astrofisico di Arcetri). This project will also help to set the basis to form a new generation of scientists capable to best exploit ELT within INAF.

References:

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