Titolo: Understanding the atmospheres of hot and ultra-hot gas giant exoplanets through multi-wavelength, high dispersion spectroscopy.

Supervisore:

Lorenzo Pino

Background:

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 developments in high dispersion spectroscopy (HDS) observations of exoplanet atmospheres (resolving power, R ~ 100,000) we can now reach Solar System-like precision on individual element abundances and longitudinally resolved atmospheric properties of exoplanets (Pino et al., 2020; Beltz et al., 2021; Line et al., 2021).

Hot and ultra-hot gas giant planets (T > 1,200) offer the best opportunities for atmospheric characterization in an environment completely different than our Solar System. Thanks to their high-temperature, they offer the best signal-to-noise ratios, and an unparalleled spectral richness due the prevalence of gas-phase chemical compounds in their atmospheres. This is in contrast with colder exoplanets and the giant planets of the Solar System, which are so cold that most metals have condensed out of the atmosphere and are sequestered in the less-accessible interior (e.g, Atreya et al., 1999).

This PhD project will focus on this class of planets, to enable the next big step in the characterization of exoplanet atmospheres.

Role, activities and goals of the PhD:

The goals of the project are to (1) provide a first detailed characterization of the dayside atmospheres of a statistically significant sample of hot and ultra-hot gas giants; (2) determine the atmospheric processes governing their observed properties.

To achieve these goals, the successful candidate will join L. Pino's international collaboration spanning Italy, the Netherlands (Universiteit van Amsterdam), Switzerland

(Université de Genève), the UK (University of Warwick) and the USA (Arizona State University; University of Chicago). The candidate will have access to HDS observations of the daysides of a sample of more than hot and ultra-hot gas giants, obtained with the best available instruments (ESPRESSO at VLT, MAROON-X at Gemini-N, PI: Pino; additional access to IGRINS at Gemini-S, PI: Line). This is the most comprehensive, highest quality sample of this kind existing.

The candidate will first get accustomed to the various flavors of the cross-correlation technique, which consists in stacking the small signal coming from thousands to millions of planetary lines, building up the signal-to-noise-ratio to detect the unique fingerprints of atomic and molecular species (Fe, Si, Ti, TiO, NH3, H2O, CO, OH, CH4, ...). The candidate will then develop a novel, automatized and standardized pipeline for the extraction of HDS spectra of exoplanets obtained with different instruments, setting a new standard in precision and accuracy with this technique. This pipeline will be applied to the sample of 26 currently available hot and ultra-hot gas giants (plus additional ones observed through dedicated proposals, or available in public archives). The candidate will also perform atmospheric parameter retrieval using state-of-the-art modeling techniques to unveil thermal structure, abundances, and wind patterns in the observed planets, spanning a broad parameter space (temperatures between 1,200 and 4,000 K; gravities between 2.75 and 4.25 dex). Finally, in collaboration with L. Pino and his international collaboration network, the candidate will compare the measured properties with predictions from theory of atmospheric structure, to unveil which physical and chemical processes lie behind observed hot and ultra-hot gas giants properties, opening a new window into the theory of exoplanet atmospheres.

This project is timely. The candidate will become an expert in the rapidly emerging technique of HDS observations of exoplanet atmospheres, ideally positioning them to exploit the upcoming Extremely Large Telescopes (2029+). INAF OAA is the PI instrument of the HDS instrument ANDES to be mounted at the European ELT. One of the primary goals of ANDES is to use HDS to target exoplanet atmospheres, including bio-signatures in small rocky planets orbiting in the habitable zone of M-dwarf stars. Ultimately, the technique developed in this PhD project will make an important contribution in this task.

References:

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