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SPECTRAL CHARACTERIZATION AND SIMULATED OBSERVATIONS WITH THE JAMES WEBB SPACE TELESCOPE OF THE YOUNG EXOPLANET HD 95086 b

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Abstract. The young system HD 95086 hosts a 4-5 MJup directly-imaged giant planet b located between two debris belts. The exoplanet b is one of the reddest sub-stellar object known, which could be associated to the presence of dust surrounding the planet. We extract for the first time the spectrum in the J and H bands with the SPHERE instrument at the Very Large Telescope (VLT). Combined to archival data from VLT/NaCo and Gemini/GPI instruments, we carry out an in-depth spectral characterization based on these near-infrared measurements. In addition, we simulate forthcoming observations in the mid-infrared from the James Webb Space Telescope with MIRI and what it could reveal on the atmosphere of HD 95086 b.

Keywords: instrumentation: adaptive optics - instrumentation: high angular resolution - methods: observational - stars: individual: HD95086 - planetary systems

1 Introduction

Over the 5 000 exoplanets discovered to date, only a small fraction have been discovered by direct-imaging. The system HD 95086, located at 86.2 ± 0.3 pc in Carina (or Sco-Cen association, Booth et al. 2021), is one of these young ($13.4^{+1.1}_{-0.6}$ Myr) emblematic directly-imaged exoplanetary systems among lie HR 8799, Beta Pictoris, PDS 70 or 51 Eri, to name but a few. Although the host star of HD 95086 is more massive than the Sun (1.6 $M_{\odot}$), to some extent, the architecture of HD 95086 shares similarities with the one from our Solar system: a double-belt architecture (7–10 au, 106–320 au, Moór et al. 2013) with a 4–5 $M_{\rm Jup}$ giant planet discovered by Rameau et al. (2013) inside a large cavity (see Fig. 1). One or two additional inner giant planets are yet very likely to be found based on dynamical studies to account for the width of the cavity and are plausible with current detection sensitivity from observations (Su et al. 2015; Rameau et al. 2016; Chauvin et al. 2018; Desgrange et al. 2022).

The spectral properties of the giant exoplanet HD 95086 b correspond to the late L to L/T transition but the exoplanet is under-luminous compared to the field dwarfs of similar spectral types, and has a red color (Galicher et al. 2014; De Rosa et al. 2016; Chauvin et al. 2018). This is typical of young L/T objects as shown Fig. 1 and could be caused by a dusty atmosphere. In this proceeding, we briefly present in Section 2 our spectral characterization published in Desgrange et al. (2022) of the exoplanet HD 95086 b by using spectroscopic and photometric points spanning from 1.2 μm to 3.8 μm. Based on our spectral results, in Section 3, we simulate observations with the James Webb Space Telescope (JWST, Gardner et al. 2006) and its instrument MIRI Rieke et al. (2015) in its coronagraphic (Boccaletti et al. 2015) and medium resolution spectrograph (MRS, Wells et al. 2015) modes, which will extend the spectral coverage up to 28 μm.

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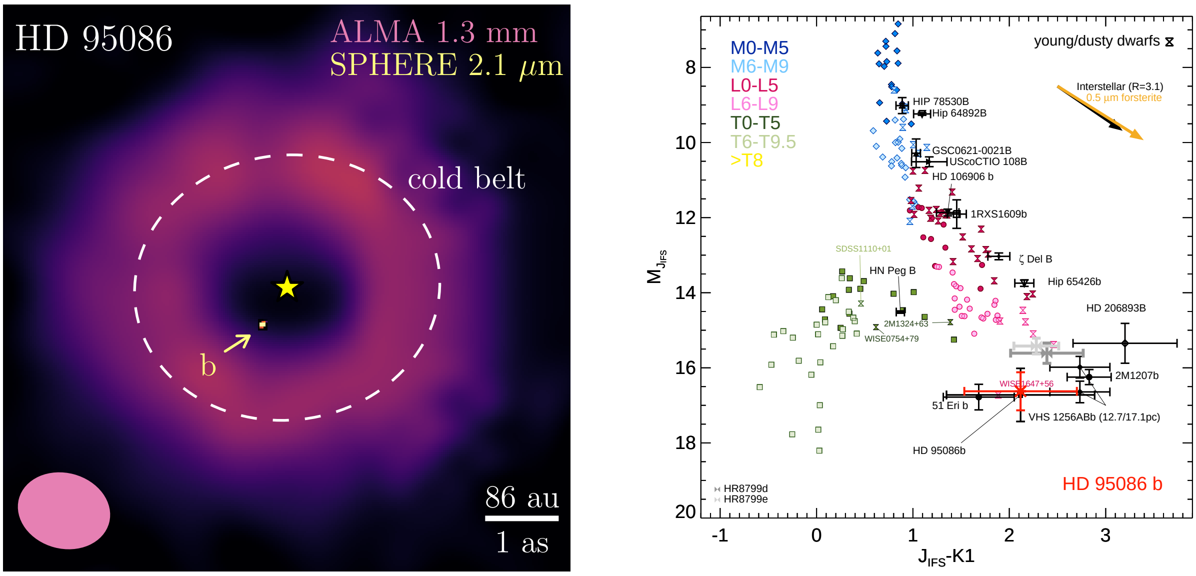

Fig. 1. Left: Overview of the system HD 95086 based on a composite ALMA-continuum (at 1.3 mm) and SPHERE/IRDIS(at 2.1 μm) observations of HD 95086 (see Su et al. 2017; Chauvin et al. 2018). The exoplanet b is represented by the yellow dot. The *white dashed* ring at 180 au represents the peak location of the outer cold belt. The inner warm belt is not resolved with ALMA. The pink ellipse represents the ALMA synthetic beam. **Right:** Figures from (Desgrange et al. 2022).

2 Spectral characterization

By using ten observations with the SPHERE instrument at the Very Large Telescope (VLT) and archival data from the telescopes and instruments Gemini/GPI and VLT/NaCo, we investigate the atmosphere properties of HD 95086 b and the possible presence of a circumplanetary disk around the planet. For the first time in Desgrange et al. (2022), we extract the spectrum of HD 95086 b in the J and H bands by stacking the best observations from the integral field spectrograph (IFS) of SPHERE in which we correct for the keplerian motion of the exoplanet b (see Fig. 2). By using atmosphere and circumplanetary models, we confirm that the giant exoplanet HD 95086 b is surrounded by dust. Our results show that this dust could either be located around the planet in a circumplanetary disk or in the upper layers of the exoplanet atmosphere, inducing an atmosphere with a super-solar metallicity. This super-solar metallicity might hint for a core accretion formation for the exoplanet b. Yet, it raises questions as the planet is located relatively far from its host star, at a semi-major axis between 51 and 73 au at a 1σ confidence level (Desgrange et al. 2022).

3 Simulated observations with the James Webb Space Telescope

HD 95086 is planned to be observed with the JWST during Cycle 1 within the Guaranteed Time of Observation with several of its instruments and modes: including NIRCAM (Rieke et al. 2005) in its coronagraphic mode (Krist et al. 2009) and MIRI in its coronagraphic modes as well. In spite of the closeness of the exoplanet HD 95086 b to its star ($\sim$ 0.63"), expected performances from the instruments NIRCAM and MIRI in their coronagraphic mode indicate that the exoplanet b should be detected with both of these modes. However, simulated observations using the MIRI-MRS mode and the data processing technique called molecular mapping show that the exoplanet b would hardly be detectable in this mode (see Fig. 3 and Mâlin et al., subm.). Water features of its atmosphere might be retrieved if the effective temperature of the exoplanet is of about 800 K, but not at higher temperatures such as 1400 K, which are both solutions given from different atmospheric models fitting the photometric and spectroscopic measurements (Desgrange et al. 2022). We note that the presence of dust around the exoplanet b and in particular if located in a circumplanetary disk could flatten the molecular features of the exoplanet and hence curb the effectiveness of the molecular mapping processing.

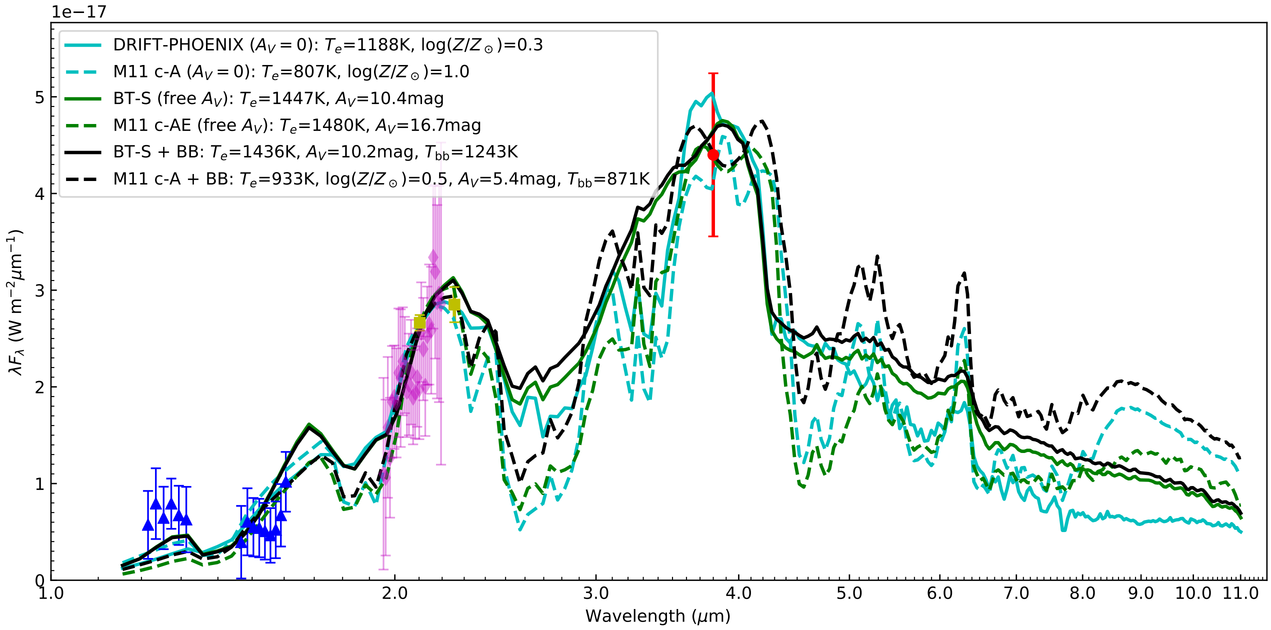

Fig. 2. Spectrum of the planet HD 95086 b. Blue triangle markers correspond to SPHERE-IFS spectroscopic measurements, pink diamond markers correspond to GPI spectroscopic measurements, yellow square markers correspond to SPHERE-IRDIS photometric measurements, while yellow the red circle correspond to NaCo photometric measurement. The different curves show the most likely atmospheric models (Drift-Phoenix, Madhusudhan et al. (2011) cloud A i.e. "M11 c-A" or cloud AE "M11 c-AE", BT-Settl i.e. "BT-S") coupled or not with a circumplanetary disk modeled by a blackbody component ("BB"). Figure from Desgrange et al. (2022).

4 Conclusion

As the young exoplanetary system HD 95086 hosts a double-belt architecture, a known 4–5 M_{Jup} giant exoplanet and likely others, it is an emblematic system to peer in with current astronomical facilities by looking into both the planetary and disk components. HD 95086 would be a prime target for the upcoming telescopes and instruments e.g. to understand better planetary formation in this specific system. Hopefully, it will help in a more general case our comprehension of planetary formation, as well as our Solar system formation.

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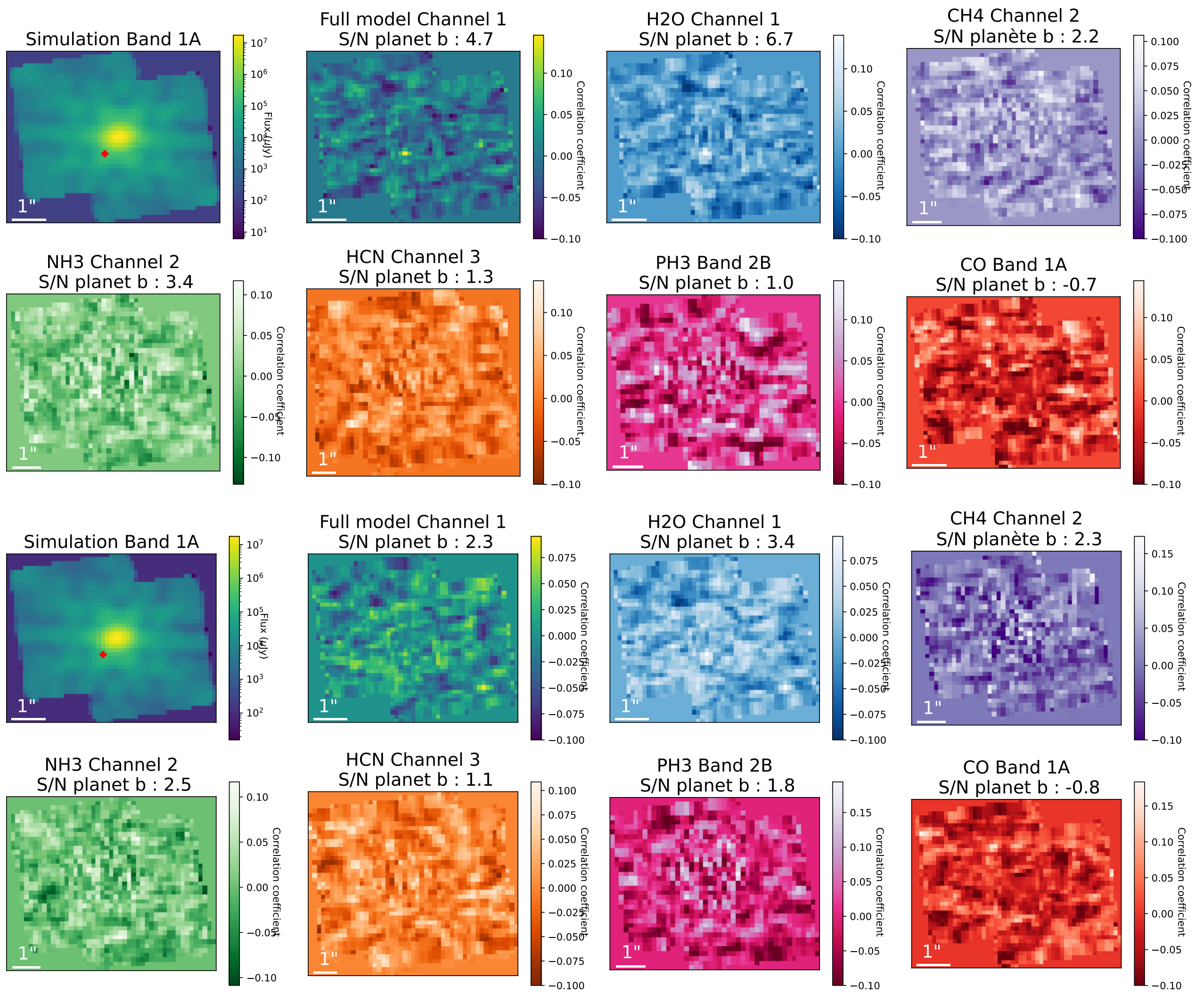

Fig. 3. Simulated observations with the JWST-MIRI in the MRS mode by using different molecular templates and an effective temperature of 800 K (**top**) or 1400 K (**bottom**).

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