Exploring the Atmospheres of Sub-Neptunes through Retrievals and Forward Modelling

Ruohan Liu[1], Panayotis Lavvas[2] and Giovanna Tinetti[1]

[1] Department of Physics and Astronomy, University College London, Gower Street, WC1E 6BT London, United Kingdom.

[2] Groupe de spectrométrie moléculaire et atmosphérique, Université de Reims Champagne Ardenne, Reims, France.

Sub-Neptunes ($1.8R_\oplus \leq Rp \leq 3.5R_\oplus$) are the most common class of exoplanets in our galaxy, yet their interior compositions remain elusive, often resulting in degenerate solutions when modelling their atmospheres. Transit observations across a broad wavelength range are essential to break these degeneracies.

For the first time, the James Webb Space Telescope (JWST) has enabled the study of exoplanet atmospheres in the near-infrared (NIR), allowing for unprecedented and detailed characterisation. Since its launch, JWST transmission spectra have been pivotal in the study of hot giant exoplanets (e.g. WASP-39b and WASP-107b).

Temperate sub-Neptunes ($T_{eq} = 200 - 400K$) are also excellent targets for JWST observations, offering valuable insights into their atmospheric composition, interior structure, and potential habitability. TOI-270 d, K2-18 b, and LHS 1140 b are examples of temperate sub-Neptunes with detected atmospheres observed by JWST.

With the influx of new and potentially transformative JWST data, there is a growing need for standardised methodologies across studies to ensure robust exoplanetary characterisation.

We present a comprehensive modelling approach to interpret JWST transmission spectra of temperate sub-Neptunes and investigate key factors influencing atmospheric retrievals. We incorporate opacity data for molecules expected in sub-Neptune atmospheres, primarily sourced from ExoMol. Our atmospheric retrieval framework includes both free and equilibrium chemistry models, enabling constraints on parameters such as metallicity and the C/O ratio. In addition, we perform self-consistent forward modelling that accounts for haze microphysics, disequilibrium chemistry, and radiative feedback, providing a physically motivated understanding of sub-Neptune atmospheres. We compare retrieval and forward model results and discuss their compatibility with current JWST observations.