Thermal and Radiative Conditions in Mini-Neptune Atmospheres

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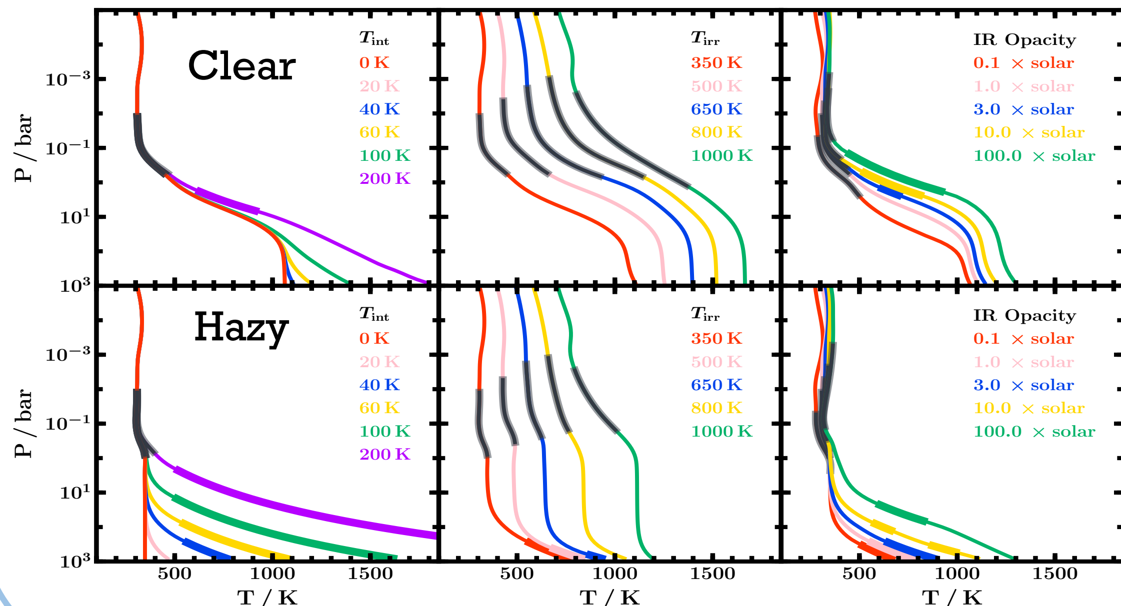
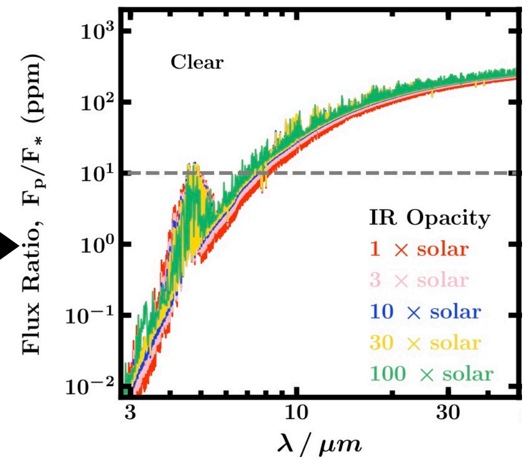
Introduction

- Mini-Neptunes (considered here to be planets with masses and radii smaller than Neptune) are typically expected to have large hydrogen-rich atmospheres. Furthermore, their interior compositions - and therefore their bulk densities - can span a wide range of possibilities. Recent work has shown that mini-Neptunes with the right mass and radius (e.g. K2-18b) could host significant water reservoirs in their interiors and potentially have liquid water oceans beneath their atmospheres [2].
- **In this work, we explore the atmospheric conditions of mini-Neptunes, including the conditions required to allow for a liquid water ocean beneath the hydrogen-rich atmosphere, potentially at habitable temperatures.**

Effects of atmospheric parameters

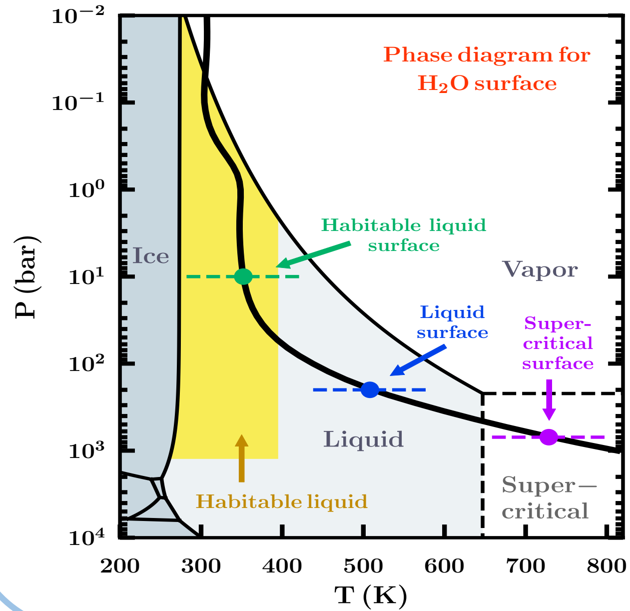
Internal temperature ↓ | Irradiation ↓ | IR opacity ↓

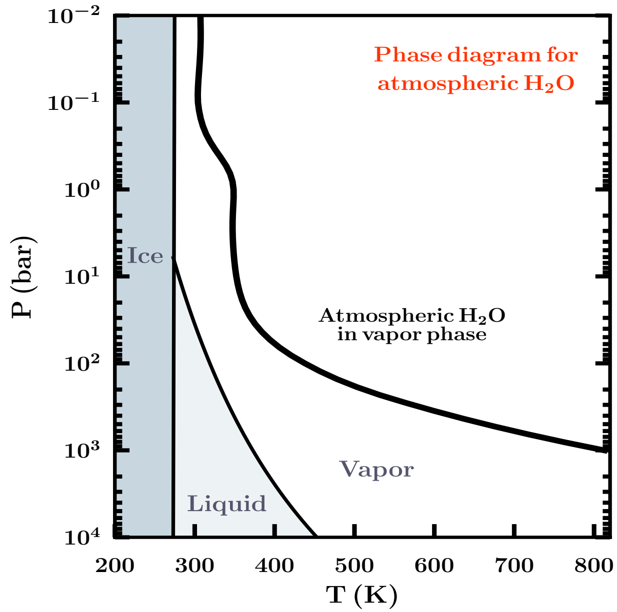




- Different atmospheric parameters can significantly impact the atmospheric temperature profile, with consequences for the interior
- Mini-Neptunes as cool as ~350 K could be observable with the James Webb Space Telescope (JWST) in the mid-IR
- Models computed using adaptation of GENESIS [1]

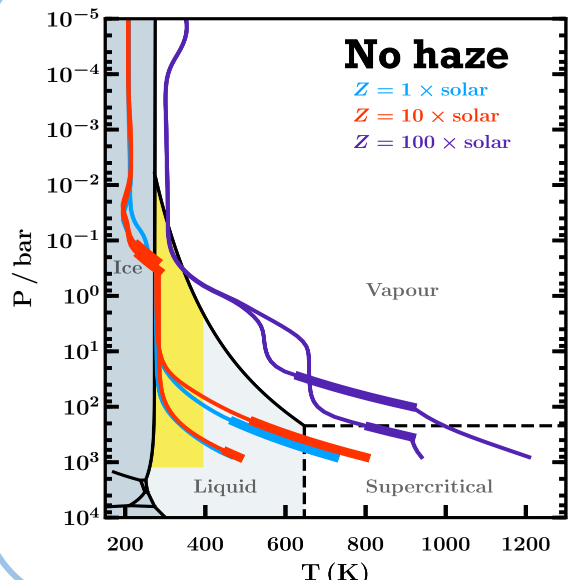
What lies beneath the atmosphere?

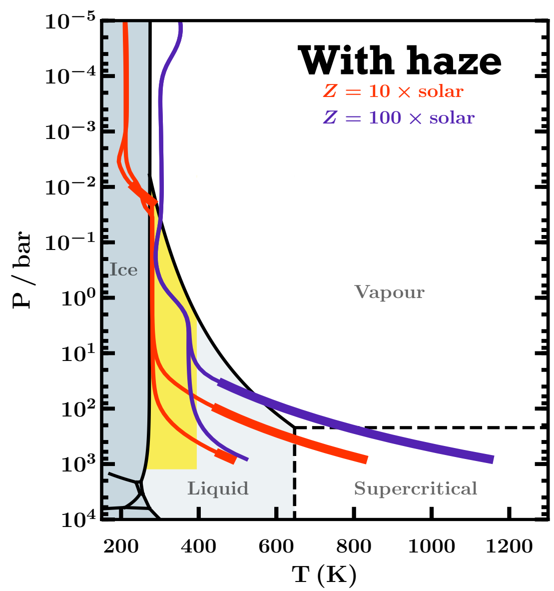




- Mini-Neptunes could have a water-rich layer beneath the hydrogen-rich atmosphere (e.g. [2])
- The phase of the water surface depends on the atmospheric temperature profile (see left panel)
- Right panel shows the phase of the atmospheric water (vapour in this case)
- Subsequent plots show the phase diagram for the water surface, as in the left panel

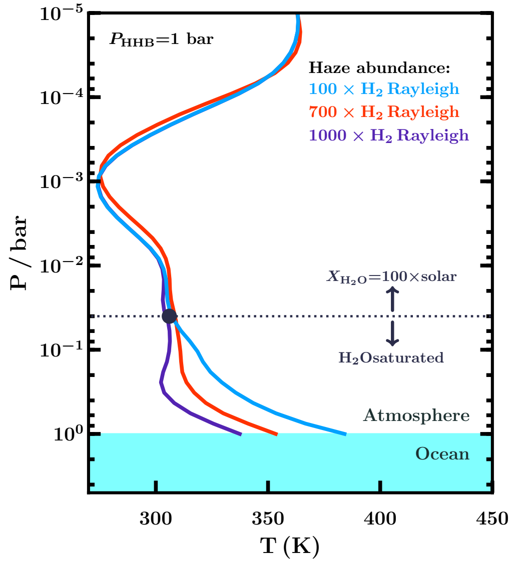
Case Study: K2-18 b



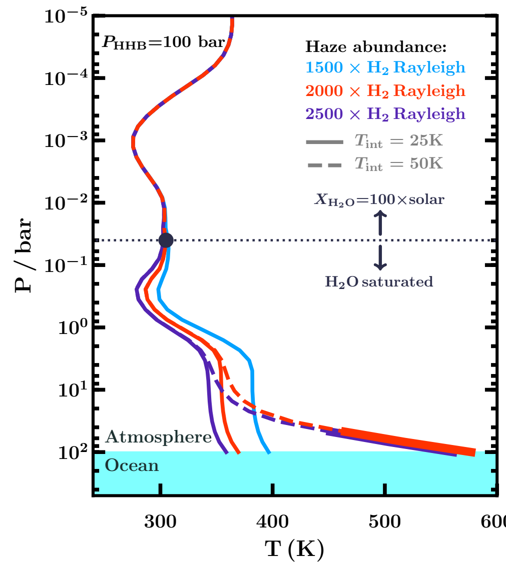


- K2-18 b is a habitable-zone mini-Neptune and its density suggests a water-rich interior [2]
- Its observed transmission spectrum suggests an atmospheric water abundance of ~1-100×solar [2,3,4]
- **Some model solutions with lower metallicity and/or haze allow for a liquid water ocean beneath the atmosphere**

Case study: high humidity above a water ocean



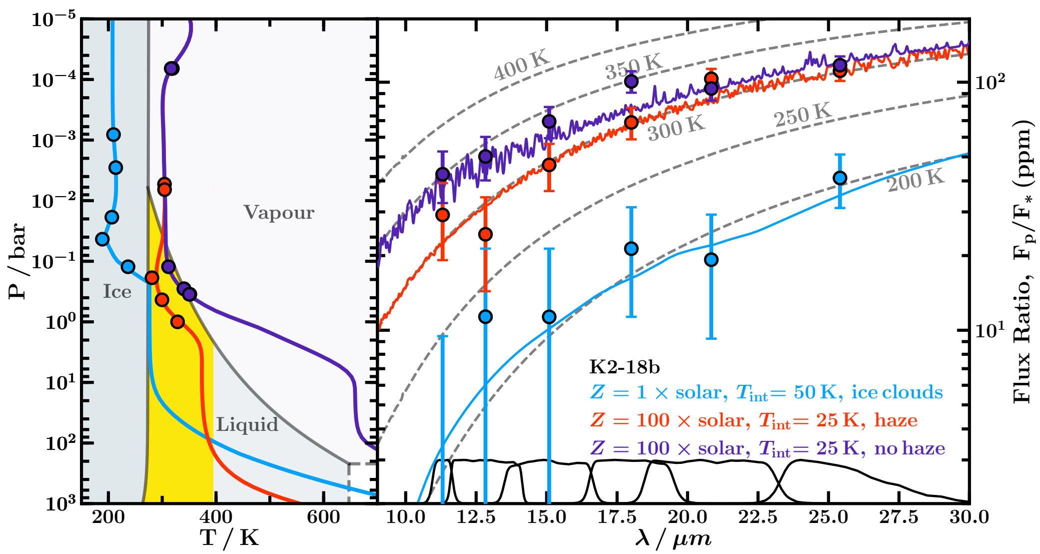
Ocean @ 1 bar



Ocean @ 100 bar

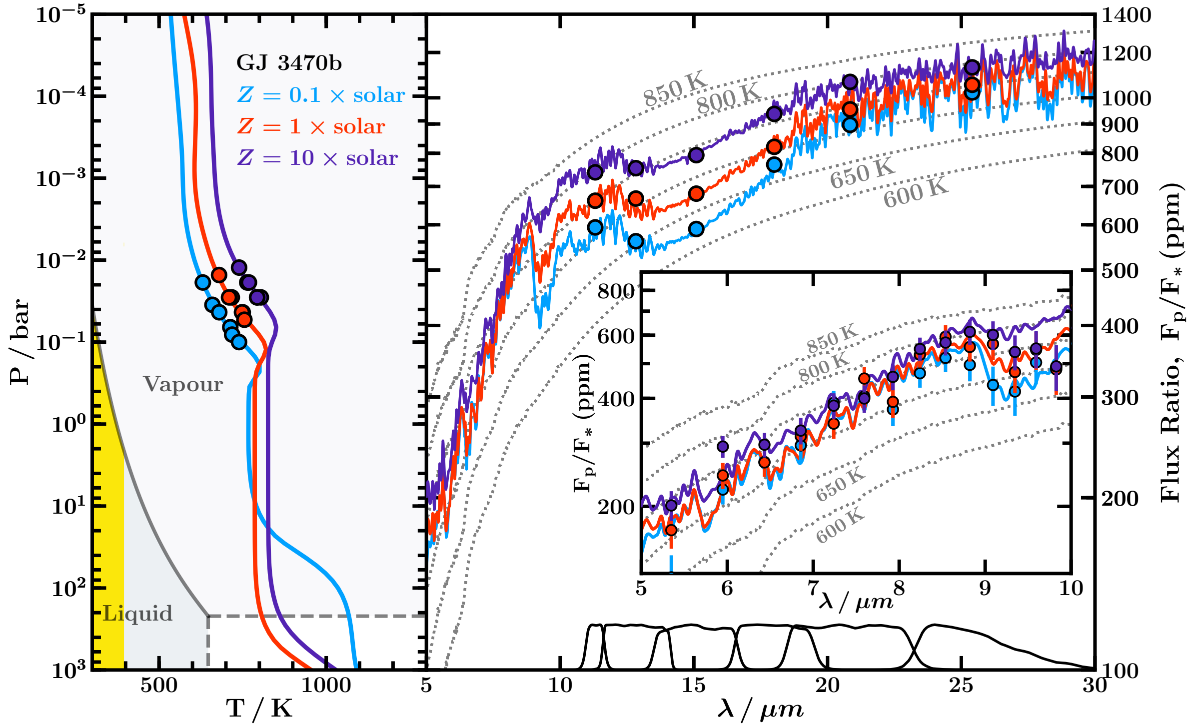
- A higher atmospheric water abundance results in a hotter atmospheric temperature profile – so can this still allow for a liquid water ocean beneath the atmosphere?
- Yes – **even with 100% relative humidity above the ocean surface, atmospheric solutions cool enough for a liquid water ocean exist.**

Temperate mini-Neptunes with JWST/MIRI



- MIRI photometry can constrain the photospheric temperature of temperate mini-Neptunes
- The photospheric temperature is a lower limit on the surface temperature
- **MIRI photometry can therefore be used to select promising candidates for further atmospheric characterisation of potentially-habitable exoplanets**

Warm mini-Neptunes with JWST/MIRI



- MIRI LRS and photometry can constrain the composition and temperature profiles of warmer mini-Neptunes
- E.g. simulated MIRI LRS data is shown in the inset assuming 1 eclipse (error bars from Pandexo, [5])
- Molecular features such as H2O and CO2 are present in this spectral range

Takeaway points

- **A range of atmospheric conditions could allow mini-Neptunes to host liquid water oceans under their hydrogen-rich atmospheres**
- **With the right atmospheric conditions (e.g. clouds/hazes), this ocean could even be habitable**
- **JWST will be able to place constraints on the habitability of some temperate mini-Neptunes (and more detailed constraints on the atmospheres of warmer mini-Neptunes)**

References: **1)** Gandhi & Madhusudhan (2017), MNRAS, 472, 2334, **2)** Madhusudhan et al. (2020), ApJL, 891, L7, **3)** Tsiaras et al. (2019), NatAs, 3, 1086, **4)** Benneke et al. (2019), ApJL, 887, L14, **5)** Batalha et al. (2017), PASP, 129, 064501