Statistical survey of intermediate mass planets

Thematic Areas (Check all that apply):

☒ (Theme A) Key science themes that should be prioritized for future JWST and HST observations
☐ (Theme B) Advice on optimal timing for substantive follow-up observations and mechanisms for enabling exoplanet science with HST and/or JWST
☐ (Theme C) The appropriate scale of resources likely required to support exoplanet science with HST and/or JWST
☒ (Theme D) A specific concept for a large-scale (∼500 hours) Director's Discretionary exoplanet program to start implementation by JWST Cycle 3.

Summary: Intermediate mass planets provide an important probe of the process through which rocky planets turn into gas giants. They exhibit rich diversity in their compositions and dynamical properties and are observationally favorable targets. We thus recommend a large-scale survey of Neptune and Saturn mass planets to complement existing large programs of Jupiter and sub-Neptune-like planets to constrain the formation and evolution of exoplanets at the statistical level. Transit observations using JWST NIRISS/SOSS and NIRSPEC/G395H of the 39 best targets will ensure strong constraints on the abundance of the main carbon and oxygen-bearing species as well as on the atmospheric metallicity for a total of ∼500 hours. This will provide important information on the formation and evolution pathways of Neptune-like planets and enable a study of how composition correlates with planetary and stellar properties. This potential for high-reward science combined with the relatively low risk involved in observing these favorable targets makes a large study of Neptunes and Saturns highly desirable.

Anticipated Science Objectives: Constraining the formation and evolution of exoplanets is one of the main objectives of the next decade (NASA 2020 Decadal Survey). Intermediate mass planets (Neptunes and Saturns) offer unparalleled snapshots of processes that turn rocky planets into gas giants. Differences in formation history are more apparent in the atmospheres of these planets since their compositions are not necessarily dominated by hydrogen and helium ([1, 2], Figure 1). In addition, their dynamical configurations (eccentricities, spin-orbit misalignment) exhibit rich variety and hint at diverse formation and migration channels of close-in massive planets [3, 4]. These non-zero eccentricities can enhance the internal heat fluxes of Neptunes via tidal heating and measurements of atmospheric composition also allow us to probe this effect [5]. Moreover, these planets are less common than their lighter and heavier counterparts [3] due to atmospheric mass loss, which can impact their composition and lead to large observable outflows [6]. Therefore, a large-scale survey is necessary to explore the diversity of these worlds as a function of their mass, incident irradiation, dynamical configuration, age, and stellar spectral type and to derive statistical conclusions. We thus urge an ambitious program targeting a magnitude-limited sample (H-mag$<$9.5) of the 39 best Neptune and Saturn-mass planets (Figure 2) with well-constrained mass ($<$20%) and radius ($<$10%) to be observed in transit with NIRISS/SOSS and NIRSPEC/G395H to characterize the H_2O, CO, CO_2, CH_4 bands as well as aerosols and the He triplet.

Urgency and Timeliness: Understanding the formation and evolution of exoplanets is a critical goal of the field that can only be accomplished by large-scale surveys. A survey of Neptune-class planets will provide greater scientific context for the Uranus Orbiter and Probe as well as the Neptunes at 1-10 AU that will be discovered by the Roman space telescope.

Risk/Feasibility: For all planets, the NIRISS/SOSS and NIRSPEC/G395H observations will have sufficient S/N to constrain molecular abundances (even for non-detections). The presence of aerosols is unlikely to thwart our larger effort of atmospheric characterization because of the large wavelength coverage. The survey can identify how aerosols correlate with planet properties and the optical to near-infrared coverage can constrain the aerosol microphysical properties.

Cannot be accomplished in the normal GO cycle: The strategy aims at observing each planet with NIRISS/SOSS and NIRPSEC/G395H. With an average time of 6.5 hours per transit, the total requested time is $\sim$500 hours, which cannot be done in a normal GO cycle.

References

[1] Jonathan J. Fortney et al. “A Framework for Characterizing the Atmospheres of Low-mass Low-density Transiting Planets”. In: 775.1, 80 (Sept. 2013), p. 80. DOI: 10.1088/0004-637X/775/1/80. arXiv: 1306.4329 [astro-ph.EP].

[2] J. I. Moses et al. “Compositional Diversity in the Atmospheres of Hot Neptunes, with Application to GJ 436b”. In: 777.1, 34 (Nov. 2013), p. 34. DOI: 10.1088/0004-637X/777/1/34. arXiv: 1306.5178 [astro-ph.EP].

[3] T. Mazeh, T. Holczer, and S. Faigler. “Dearth of short-period Neptunian exoplanets: A desert in period-mass and period-radius planes”. In: 589, A75 (May 2016), A75. DOI: 10.1051/0004-6361/201528065. arXiv: 1602.07843 [astro-ph.EP].

[4] O. Attia et al. “DREAM. II. The spin-orbit angle distribution of close-in exoplanets under the lens of tides”. In: 674, A120 (June 2023), A120. DOI: 10.1051/0004-6361/202245237. arXiv: 2305.00829 [astro-ph.EP].

[5] Jonathan J. Fortney et al. “Beyond Equilibrium Temperature: How the Atmosphere/Interior Connection Affects the Onset of Methane, Ammonia, and Clouds in Warm Transiting Giant Planets”. In: 160.6, 288 (Dec. 2020), p. 288. DOI: 10.3847/1538-3881/abc5bd. arXiv: 2010.00146 [astro-ph.EP].

[6] James E. Owen. “Atmospheric Escape and the Evolution of Close-In Exoplanets”. In: *Annual Review of Earth and Planetary Sciences* 47 (May 2019), pp. 67–90. DOI: 10.1146/annurev-earth-053018-060246. arXiv: 1807.07609 [astro-ph.EP].

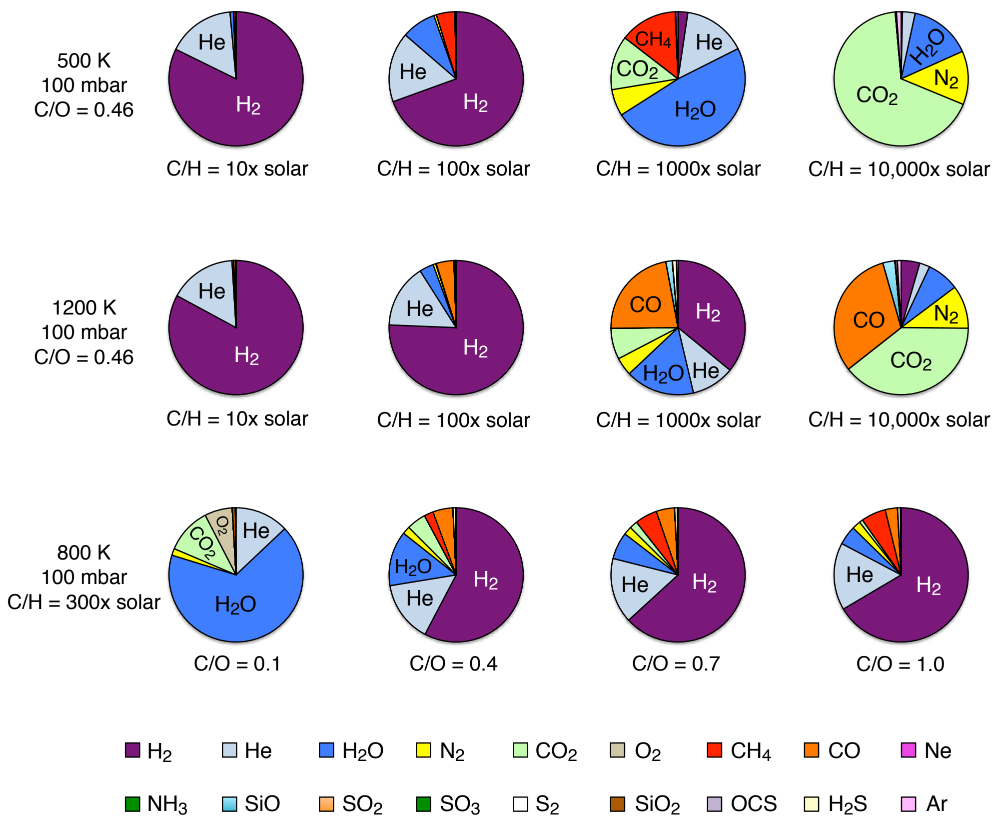

Figure 1: Pie charts, adapted from [2], illustrating equilibrium gas-phase compositions on generic Neptunes for different assumptions about atmospheric properties. It illustrates the diversity of chemical composition that intermediate-mass planets can have.

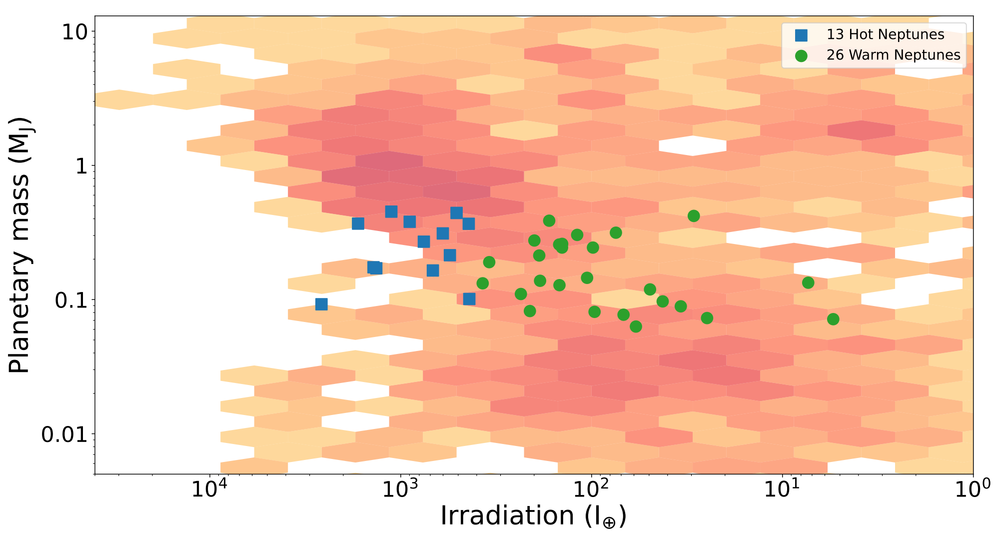

Figure 2: The exoplanet population in a planetary mass - irradiation diagram with the underlying density in a shade of orange. The magnitude-limited sample of 39 intermediate-mass planets is split between hot (blue) and warm (green) based on their equilibrium temperature (threshold at 1200K). Based on NASA Exoplanet Archive.