Atmospheric Erosion along the Cosmic Shoreline

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: The *cosmic shoreline* is an empirical division separating solar system bodies with and without atmospheres, based on their insolation and escape velocity (see Figures 1 and 2; [1, 2]). While thermal escape is implicated as the primary mechanism of atmospheric loss in the solar system, for the rocky M-dwarf exoplanets that are amenable to characterization with JWST, other processes may shape the cosmic shoreline, such as XUV-driven escape and stellar activity. Only dedicated observations with JWST can test this hypothesis and empirically determine which planets have atmospheres and the processes that dictate atmospheric retention. To accomplish this goal, we advocate for a broad and deep search for rocky M-dwarf planet atmospheres using NIR transit spectroscopy to detect molecules in the planet's atmosphere, MIR secondary eclipse spectroscopy to determine if the temperature is consistent with a bare rock or an atmosphere, and panchromatic stellar spectroscopy to separate out the transit light source effect and characterize the host star XUV flux. This science case is required for any and all follow-up characterization of rocky exoplanets known to have atmospheres, including potential habitability assessments and biosignature searches. Only JWST can test the cosmic shoreline in M-dwarf systems, and doing so will establish a lasting legacy for JWST by contributing foundational knowledge on rocky planet atmospheres that is necessary in advance of NASA's Habitable Worlds Observatory (HWO) and the search for life beyond the solar system.

Anticipated Science Objectives: *At what distance, and around what type of star, can rocky planets retain secondary atmospheres?* This pivotal science question flows into the following three primary science objectives: (1 - "the planet") confirm or rule out the presence of high mean molecular weight atmospheres down to $<$1 bar surface pressures as a target selection filter for more intensive follow-up characterization efforts; (2 - "the star") characterize the panchromatic SEDs of M dwarf host stars to understand the stellar context of each planetary environment; (3 - "the population") constrain the planetary and stellar properties that dictate atmospheric retention and shape the cosmic shoreline in M-dwarf systems.

Urgency: All follow-up terrestrial atmospheric characterization (e.g., for habitability and biosignatures, etc.) requires this dedicated initial reconnaissance to be completed prior to onset. HST must be operational for UV observations of diverse M star hosts. JWST is critical to understanding the prevalence of rocky planet atmospheres and characterizing the cosmic shoreline in M-dwarf systems both to inform HWO's search for life, and because HWO will not be able to address this science case due to a limited sample of M dwarfs amenable to direct imaging.

Risk/Feasibility: This science objective is high-risk, high-reward. A significant time investment is required to perform a search for rocky exoplanet atmospheres using transits and eclipses, but this search may be conducted over the course of several cycles. If the majority of targets do not posses atmospheres, this will still answer the key population-level question of the position of the cosmic shoreline in M-dwarf systems (Figures 1 and 2). Parallel efforts to mitigate the transit light source (TLS; [3]) effect will benefit this program.

Timeliness: The search for life on exoplanets requires the foundational context offered by this science case. Astro2020 endorsed addressing "the impact of the host star on atmospheres... for a large sample of systems and spectral types" (E-Q3c), how the "assessment of habitability requires determining the presence... of an atmosphere" (E-Q3d), and that "an empirical census of atmospheres on terrestrial worlds... both in and outside the HZ, will be needed" to support a comprehensive biosignature assessment framework (E-Q4b) [4].

Cannot be accomplished in the normal GO cycle: A coordinated community effort is required to accomplish these ambitious science objectives with interdisciplinary themes. Several large GO programs ([5, 6, 7]) have begun this effort, but a robust census of the cosmic shoreline will require a multi-cycle plan with well-considered target selection criteria [8], a larger time allocation than a GO program, and an entire community prepared to analyze and interpret the results.

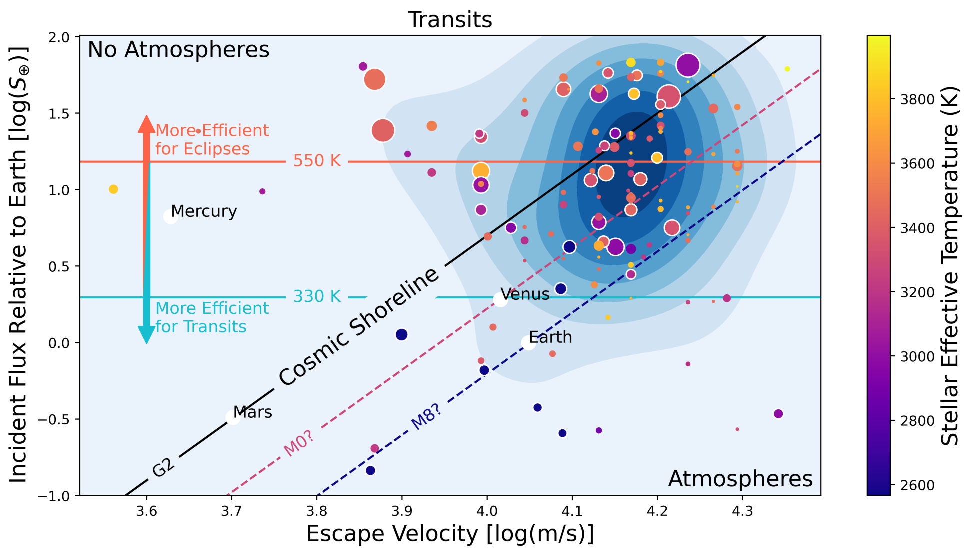

Figure 1: The cosmic shoreline (solid black line; [2, 9]) divides Solar System bodies (white points) based on their incident flux and escape velocity, but does it divide the rocky M-dwarf exoplanet population (colored points)? Rocky exoplanet targets with $R_p < 1.7R_\oplus$ are shown as points colored by stellar effective temperature and sized relative to their atmospheric detectability via transmission spectroscopy. Targets circled in white are amenable to atmospheric reconnaissance in fewer than 6 transits (for eclipses see Figure 2). The cosmic shoreline and hypothetically shifted shorelines based on enhanced incident XUV flux (dashed lines; from [10]) fortuitously cut across a region of high population density (KDE shown with blue contours), making the location, shape, and confounding factors that impact the cosmic shoreline in M-dwarf systems a feasible and premier testable hypothesis with JWST.

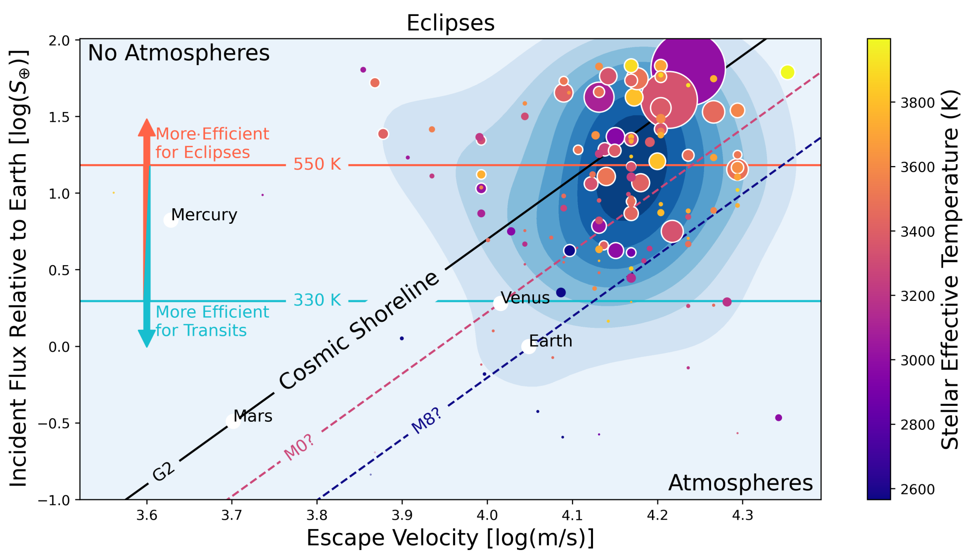

Figure 2: Similar to Figure 1 except the size of points is scaled relative to each planet's 15μm MIRI eclipse detectability.

References

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