LATE BURSTS OF HABITABILITY ON MARS: QUANTIFYING THE INTERMITTENCY OF MARS SURFACE HABITABILITY.

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Introduction: Could surface life on Mars have persisted from Noachian to the present day? Small amounts of snowmelt can wet the Mars soil during the Late Hesperian and Amazonian. Supraglacial channels and fresh shallow valleys are not spatially correlated with impact events, suggesting climate-driven habitability. Habitable climates could not have been both long-lasting and global because post-Noachian terrain lacks deep weathering and erosion. Understanding the intermittency of post-Noachian Mars habitability requires better constraints on the role of stochastic, long-term transitions in obliquity.

Method: Mars' obliquity varies chaotically, so we generated orbital histories for Mars using the `mercury6` N-body code to integrate the solar system for 3.5 Gyr. We then applied an obliquity code (10 randomly chosen spin-axis orientations per `mercury6` simulation). The results show a remarkably wide spread of equally possible orbital forcings (Fig. 1). This raises the question – did Mars' small size seal its fate, or are there orbital roads not taken that would have allowed habitable conditions at the present day?

We used the spin-orbit output to drive a simple snowpack energy balance model, which was in turn coupled to an atmospheric evolution model. The *energy balance model* assumes that warm-season snow was only present in cold traps (locations that minimize annual-average sublimation rate). It calculates snow temperatures taking into account sensible and latent heat exchange with the atmospheric surface layer, Rayleigh scattering, greenhouse warming, time-of-day, and season, and the solid-state greenhouse effect. The *atmospheric evolution model* assumes that the initial atmospheric pressure (P) was 100 mbar. If $P(t)$ had not decreased over the last 3.5 Gyr then habitability would have increased over time, the opposite of what is observed. Our escape-to-space parameterization is scaled to the higher UV flux of the young Sun. Self-consistency also requires considering carbonate formation. Carbonate formation must have occurred on Mars to explain the carbonate dispersed in the soil. Because $>>10^6$ km^3 dust/silt/sand was cycled through the weathering-prone diurnal skin depth since 3.5 Ga (e.g., [24]), there is a potential for liquid water availability to feed back on P (as on Earth). We assumed $MgCO_3$ formation within parts of the planet experiencing seasonal melting was limited by the supply of weatherable sand, silt and dust.

Results: Results show a wide range of possible histories. *Relatively late wet "spikes" define bursts of habitability:* Late Hesperian / Amazonian crater-retention ages obtained for alluvial fans can be understood in terms of higher $L_\odot$ at later times favoring surface liquid water. The expectation of >100 comparably-wet intervals (given 10^5 yr quasiperiodic forcing) is flatly contradicted by the results, which instead show a few very wet "spikes." (Fig. 1). *Intermittency of liquid water at all timescales:* Although the details of the orbital histories vary greatly, a common trend is that surface liquid water availability is more intermittent (at all time scales) than are high-obliquity conditions (Fig. 1). *Are late bursts of habitability are biologically isolated?:* $>10^8$-yr global desert conditions are common, due to long periods of low φ. Long global desert intervals define a challenge for the persistence of life on the Mars surface from the Noachian to the present day. The longest continuous run of wet years (each wet year has a dry season) is ~60 Kyr.

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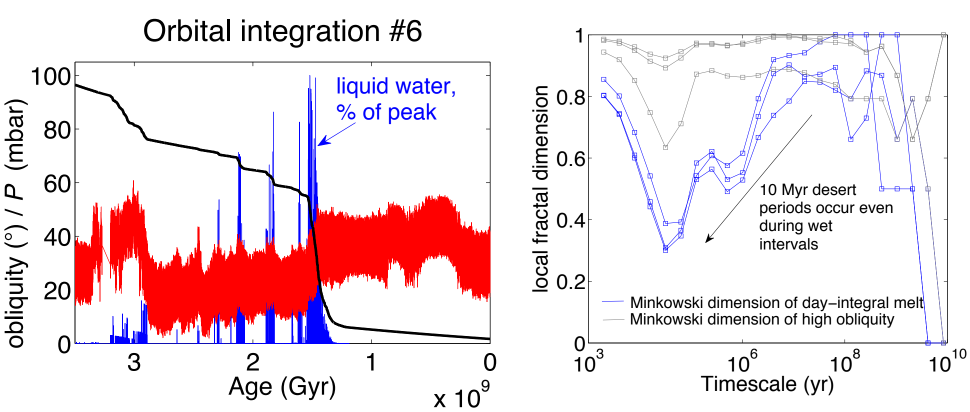

Figure 1. Intermittency of liquid water (peak day-integral melt, blue) predicted by using our obliquity tracks (red) to drive a simple energy balance model of snowmelt. Atmospheric pressure (black) is reduced by escape-to-space and by carbonate formation. One example shown. Bottom right: Intermittency of surface liquid water (blue) is much greater than intermittency of high-obliquity (gray). Though the specifics of the tracks differ greatly, the three tracks show common intermittency-spectrum characteristics.