snowpack energy balance model [10], 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), which is reasonable [10, 14]. 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. CO\(_2\) is currently escaping from Mars at >1 mbar/Gyr. Our escape-to-space parameterization follows [15], scaled to higher UV flux of the young Sun. MAVEN will supply improved escape constraints.

**Carbonate formation**: Self-consistently calculating \( P \) also requires considering carbonate formation, because modest amounts of liquid water, \( P > 0.006 \) bar, and cold temperatures are sufficient physical conditions for rapid carbonate formation (e.g., [16-17]). Because low melt rates are sufficient to form carbonate but insufficient for runoff, evidence for climate-driven runoff (e.g., [18-20]) implies physical conditions suitable for carbonate formation over a much wider range of locations and times. Carbonate formation must have occurred on Mars to explain the carbonate dispersed in the soil and in Amazonian alteration veins (e.g., [21-22]); carbonate isotopes indicate “[derivation] from atmosphere interaction with only transient water” [23], while (1-5) wt % abundances reported equate to ~1 mbar CO\(_2\) drawdown per \( 10^5 \) km\(^3\) dust/silt/sand. 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) [8, 11, 25]. Although a potentially significant feedback on climate, the amounts of carbonate formed in our models are two orders of magnitude less than in pre-Mars Exploration Program models of Mars climate evolution, and this relatively modest carbonate inventory is consistent with the paucity of bedrock carbonate. We assumed MgCO\(_3\) formation within parts of the planet experiencing seasonal melting was limited by the supply of weatherable sand, silt and dust (\( \rho = 2000 \) kg/m\(^3\)) at a deposition rate of ~30 \( \mu \)m/yr [26, 27], giving 3 g/m\(^2\)/yr of CO\(_2\) consumed. This assumes that 10% of the input is converted to MgCO\(_3\), high values that are subsequently diluted by mixing with never-weathered materials from outside the spatially-restricted melt zones.

**Results**: The results show a wide range of possible histories (examples shown in Fig. 1). *Size is not fate*: Among the modeled ensemble of Mars-like planets, some are habitable at the present day. For this to happen, obliquity has to stay low for most of the 3.5 Gyr-long simulation (so that carbonate formation does not occur), with a “jump” to high obliquity in the recent past. This is an uncommon, but not impossible, circumstance. Although obviously not representative of the Mars in our own solar system, this shows a pathway by which Mars-sized exoplanets [28] could be habitable late in their histories. Relatively late wet “spikes” define bursts of habitability: Late Hesperian / Amazonian crater alteration ages obtained for alluvial fans can be understood in terms of higher \( L_0 \) at later times favoring surface liquid water. Intriguingly, the expectation of >100 comparably-wet intervals (given 10\(^3\) yr quasiperiodic forcing) is flatly contradicted by the results, which instead show a few very wet “spikes” due to rectification at the melting-point and buffering of \( P \) by carbonate formation (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). Biological isolation of late bursts of habitability: >10\(^5\)-yr global desert conditions are common, due to long periods of low \( \phi \). Long global desert intervals define a challenge for the persistence of life on the Mars surface. The longest continuous run of wet years (each wet year has a dry season) is ~60 Kyr.

We are excited by these results. Work in progress consists of refinement and extension to our forward modeling framework to investigate obliquity’s role in the greater detail allowed by the LMD GCM (e.g. [29]); we will present initial results at the conference.