Warming Early Mars with CO_2 and H_2

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ABSTRACT

The presence of valleys on ancient terrains of Mars suggests that liquid water flowed on the surface ~4 Gyr ago. The above-freezing temperatures required to explain valley formation could have been transient or they could have been caused by long-lived greenhouse warming. Our 1-D climate model calculations demonstrate that an atmosphere containing 1.3 – 4 bar of CO_2 and water, in addition to 5–20% H_2, could have raised the mean surface temperature of early Mars above freezing. A dense early atmosphere is consistent with the recent Kite et al. study based on cratering data.

INTRODUCTION

❖ The climate of early Mars has been debated for at least the past 30 years. Nearly all researchers agree that the martian valleys and valley networks were formed by running water

❖ Debate has persisted as to how warm the surface must have been to form these features and how long this warmth must have lasted

❖ The widely cited impact hypothesis (Segura et al.,2002; 2008) suggests that large impacts occurring during the Heavy Bombardment Period could have heated the surface for brief intervals and that the valleys were formed by the ensuing water that rained out

❖ Other workers have pointed out that the valleys are more extensive than originally realized, and Hoke et al. (2011) have argued that the amount of time and surface runoff needed to form them was much larger than Segura et al. (2008) assumed

Even though the early martian climate was probably warm, all previous 1D CO_2 and H_2O climate models have been unable to produce above-freezing surface temperatures because of a combination of CO_2 condensation and Rayleigh scattering

❖ The recent study by **Ramirez et al. (2014)** is the first to demonstrate a feasible warm and wet greenhouse solution for early Mars

CLIMATE MODEL

- ❖ 1-D cloud-free radiative convective climate model
- ❖ A delta two-stream approximation parameterizes gaseous absorption across 38 solar intervals and 55 infrared intervals
- ❖ A time-stepping routine is used that iterates until:
  - ❖ Absorbed and emitted fluxes in the stratosphere are balanced
  - ❖ Surface temperature converges to a steady state value
- ❖ New HITRAN 2008 coefficients for CO_2 and HITEMP 2010 coefficients for H_2O were derived
- ❖ The BPS continuum of Paynter and Ramaswamy (2011) is employed for the far wings of H_2O. This replaces Roberts (1976)
- ❖ The Gruszka-Borysow-Baranov (GBB) parameterization is used for CO_2-CO_2 collision-induced absorption (CIA)
- ❖ The H_2-N_2 CIA data of Lothar and Frommhold (1986) are used as a proxy for H_2-CO_2. Self-broadening by H_2-H_2 pairs follows Borysow (2002)

RESULTS

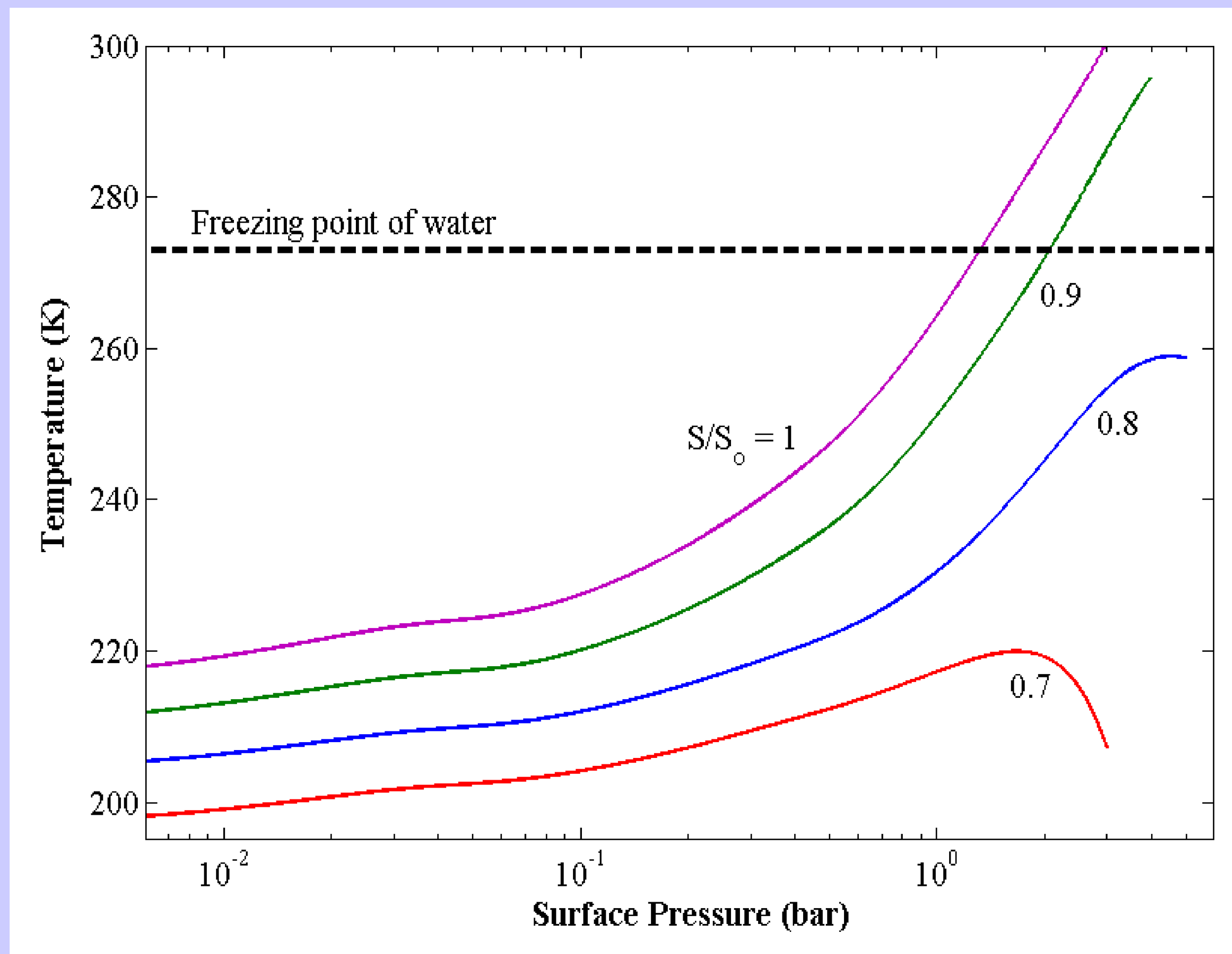

Fig. 1:Mean surface temperature as a function of surface pressure for a fully saturated (95% CO_2, 5% N_2) early Mars atmosphere at different solar insolation levels. The assumed surface albedo is 0.216.

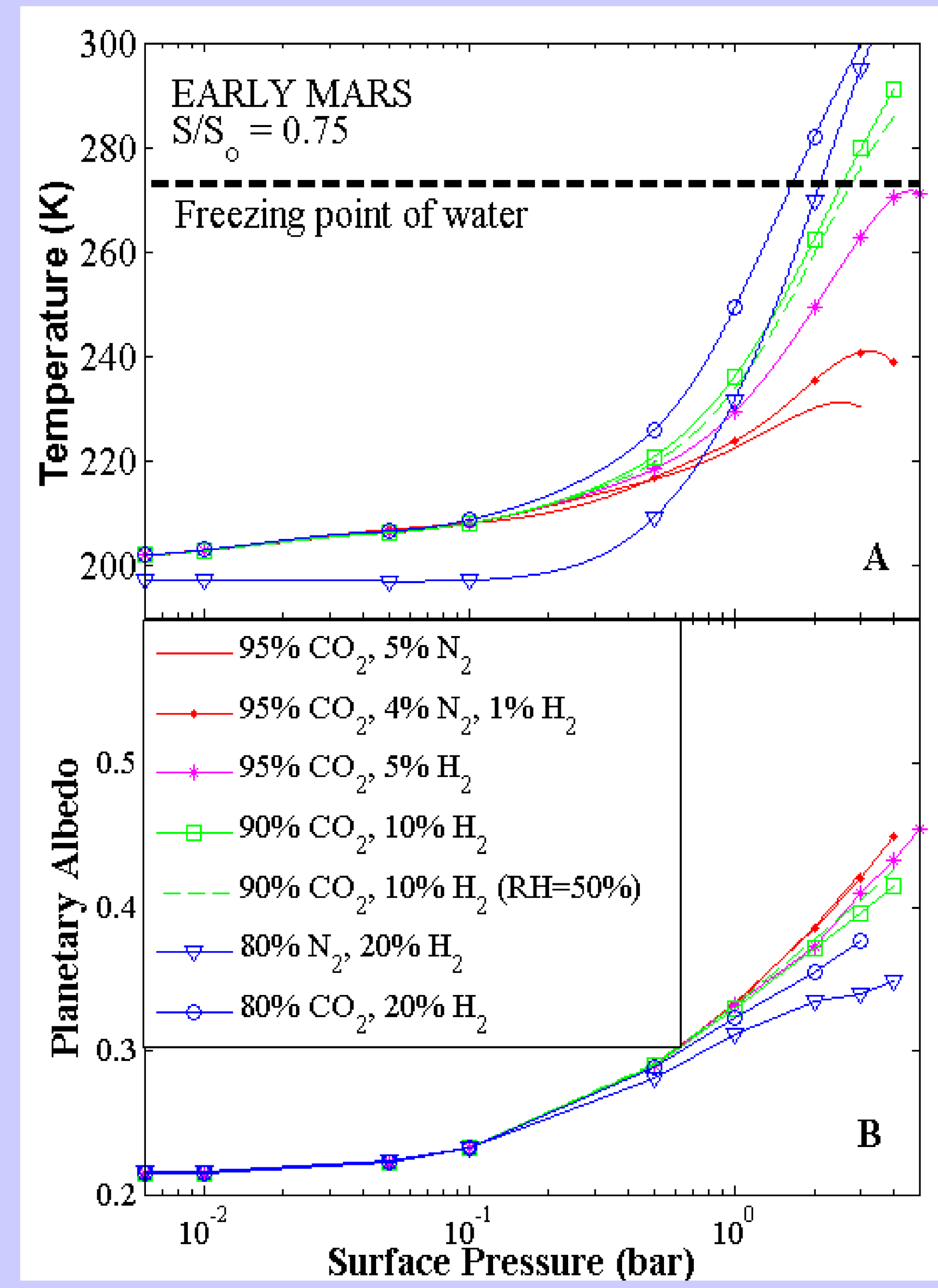

Fig. 2: Surface temperature (a) and planetary albedo (b) as a function of surface pressure for different early Mars atmospheric compositions.

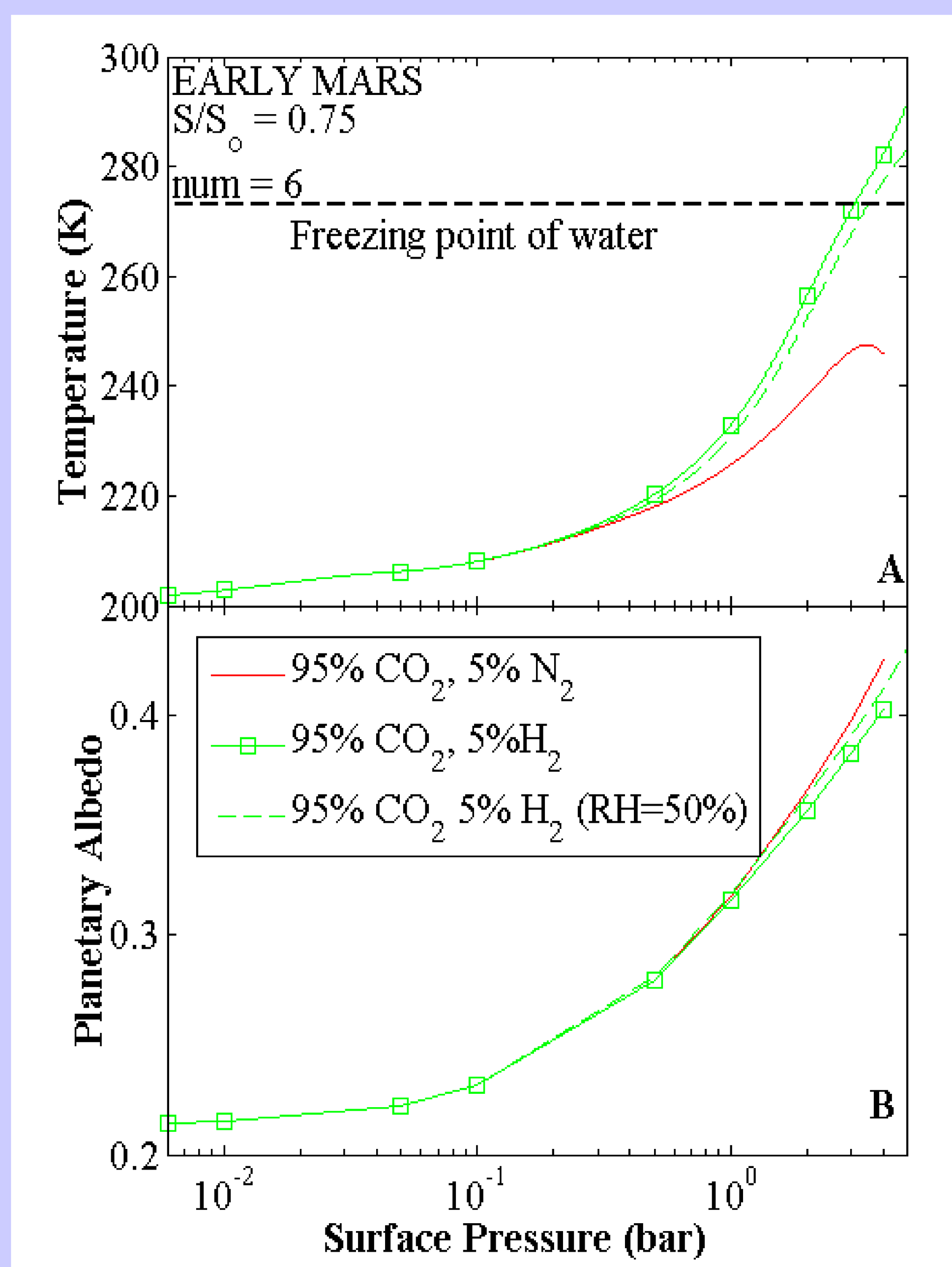

Fig. 3: Surface temperature and planetary albedo as a function of surface pressure for two 95% CO_2, fully-saturated early Mars (S/S_o = 0.75) atmospheres containing (a) 5% N_2, (b) 5% H_2, and (c) 5% H_2 with a relative humidity of 50%. Six solar zenith angles were used.

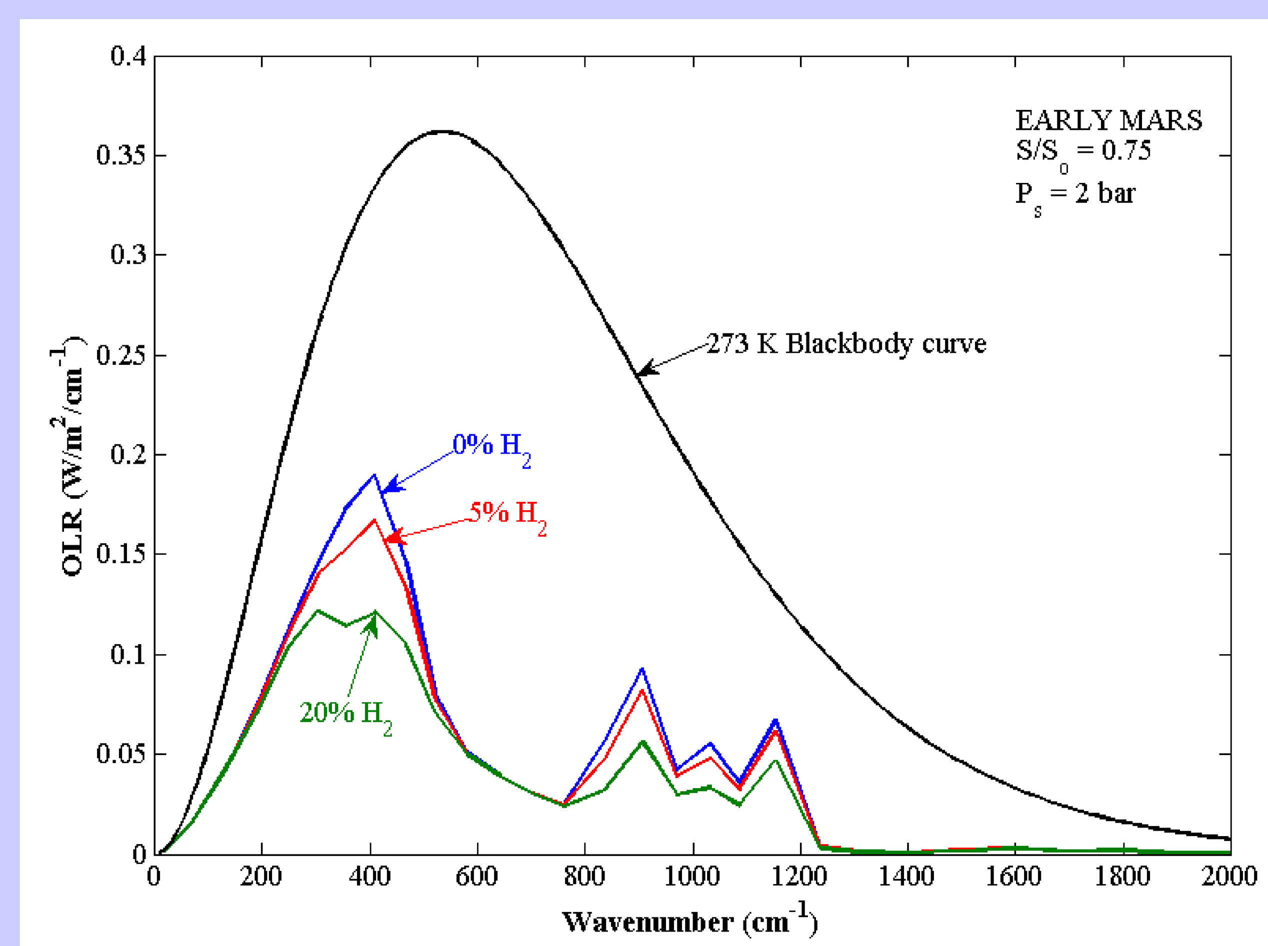

Fig. 4: Emission spectrum for a 2-bar early Mars (S/S_o = 0.75) atmosphere containing 95% CO_2 and 5% N_2 (blue), 95% CO_2 and 5% H_2 (red), or 80% CO_2 and 20% H_2 (green). The surface temperature is 273K, and the stratospheric temperature is fixed at 167 K. Adding 5% and 20% H_2 reduces the outgoing infrared flux by ~6 W/m² and 22 W/m², respectively.

ARE HIGH H_2 AMOUNTS POSSIBLE?

The relationship between mantle fugactiy (fO_2) and the outgassing pressures of H_2 and H_2O, respectively is:

$$\frac{pH_2}{pH_2O} = \sqrt{\frac{K_{eq}}{fO_2}} \; ; \left(\frac{pH_2}{pH_2O}\right)_{Earth} \cong 0.02$$

But Mars' mantle may be up to 5 orders of magnitude more reduced than Earth's (Grott et al., 2011), so much more H_2 can be outgassed.

DEGASSING OF CARBON

- Grott et al. (2011) argued that C would have remained in graphite form and not outgass as CO_2 in a very reduced early Mars atmosphere
- However, C would have likely outgassed as Fe-carbonyl ($Fe(CO)_5$) + minor CH_4 and then get oxidized to CO_2 (Wetzel et al. 2012)

CONCLUSIONS

•The abundance of fluvial features suggests that early Mars (3.8 Ga) was once a warm, wet place

•In contrast to Segura et al. (2002;2008), Hoke et al. (2011) show that voluminous amounts of water over long time scales are required to form the ancient valley networks

•Early Mars could have been warmed with a combination of CO_2, H_2O, and H_2

•Future work requires a 2-D hydrodynamic model that includes spherical geometry

•Treatment of magnetic fields would require a 3-D model

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