A METHANE-RICH EARLY MARS: IMPLICATIONS FOR HABITABILITY AND THE EMERGENCE OF LIFE

Michael L. Wong (Division of Geological & Planetary Sciences, California Institute of Technology, mlwong@caltech.edu), A. James Friedson (NASA Jet Propulsion Laboratory), Karen Willacy (NASA Jet Propulsion Laboratory), Run-Lie Shia (Division of Geological & Planetary Sciences, California Institute of Technology), Yuk L. Yung (Division of Geological & Planetary Sciences, California Institute of Technology, NASA Jet Propulsion Laboratory), Michael J. Russell (NASA Jet Propulsion Laboratory).

Introduction: We investigate the radiation and chemistry of a ~4.0 Ga, CH_4-rich martian atmosphere in an effort to assess whether or not Mars was once habitable and suitable for the emergence of life. While the primary goal of this work is to elucidate mysteries in martian history, our results can help us understand the nature of the numerous small terrestrial exoplanets that we are only beginning to discover and characterize. High atmospheric CH_4 may be consistent with a mantle that does not reach the requisite pressure (24 GPa) and temperature (1900 K) for the silicate spinel-to-perovskite transition (Dale et al., 2012; McCammon, 1997; Wadhwa, 2001; Wood et al., 2006). Impact degassing from chondritic material can also contribute substantial amounts of CH_4 to the atmosphere (Schaefer and Fegley, 2007).

CH_4 plays an important role in atmospheric radiation. Atmospheric models have demonstrated that a purely CO_2 atmosphere, even one as massive as 7 bars, is incapable of heating Mars above an annual-mean surface temperature of 273 K (Forget et al., 2013), although recent studies show that recurring wet states could have been induced in an H_2-rich atmosphere (Batalha et al., 2015, 2016). We show that CH_4 alone is insufficient to warm early Mars above freezing—in fact it produces an anti-greenhouse effect—but it substantially raises middle atmospheric temperatures. We determine whether or not such high temperatures could prolong the photochemical lifetime of SO_2, another potent greenhouse gas.

We use RC1D, a non-gray 1-D radiative-convective equilibrium model, to calculate the atmospheric thermal structure consistent with the radiative heating and cooling associated with the composition computed at each chemical model time step. KINETICS, the Caltech/JPL chemistry transport model (e.g. Nair et al., 1994), determines the chemical makeup of the atmosphere, evaluating steady-state chemical profiles and the synthesis of astrobiologically relevant molecules. H_2O is in vapor pressure equilibrium at the surface. We consider conditions forced by the faint-young Sun's spectrum and luminosity.

By coupling RC1D and KINETICS, we are able to paint a more realistic picture of Mars's early climate, calculating the surface temperature under a CH_4-rich atmosphere, and assessing the production of key electron acceptors, such as sulfate and nitrate.

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