MARTIAN ATMOSPHERIC METHANE PLUMES FROM METEOR SHOWER INFALL: A HYPOTHESIS. M. Fries[1], A. Christou[2], D. Archer[3], P. Conrad[4], W. Cooke[5], J. Eigenbrode[4], I. L. ten Kate[6], M. Matney[1], P. Niles[1], M. Sykes[7], A. Steele[8], A. Treiman[9]. [1]NASA JSC, Houston, TX, [2]Armagh Observatory, College Hill, Armagh, Northern Ireland, [3]Jacobs, NASA JSC, Houston TX, [4]NASA Goddard SFC, Greenbelt MD, [5]NASA Marshall SFC, Huntsville AL, [6]Dept. of Earth Sciences, Utrecht University, Netherlands, [7]Planetary Science Institute, Tucson AZ, [8]Geophysical Laboratory, Carnegie Institution for Science, Washington DC, [9]Lunar and Planetary Institute, Houston, TX. Email: marc.d.fries@nasa.gov

Introduction: Methane plumes in the martian atmosphere have been detected using Earth-based spectroscopy [1-4], the Planetary Fourier Spectrometer on the ESA Mars Express mission [5], and the NASA Mars Science Laboratory [6]. The methane's origin remains a mystery, with proposed sources including volcanism [7], exogenous sources like impacts [8] and interplanetary dust [2,6], aqueous alteration of olivine in the presence of carbonaceous material [9], release from ancient deposits of methane clathrates [10], and/or biological activity [2]. To date, none of these phenomena have been found to reliably correlate with the detection of methane plumes [6]. An additional source exists, however: meteor showers could generate martian methane via UV pyrolysis of carbon-rich infall material [11]. We find a correlation between the dates of Mars/cometary orbit encounters and detections of methane on Mars. We hypothesize that cometary debris falls onto Mars during these interactions, depositing freshly disaggregated meteor shower material in a regional concentration. The material generates methane via UV photolysis [12,13], resulting in a localized "plume" of short-lived methane.

Multiple Lines of Evidence:

1) Temporal Correlation Between Cometary Interactions and Methane Detection: It is important to determine the source of martian methane in order to explore the geochemical and/or astrobiological implications of its formation mechanism(s). For this reason investigators have attempted to identify correlations between the appearance of methane and factors such as martian seasons [14, 15], proximity to martian volcanoes [3,14], proximity to hydrated minerals [4], local winds, diurnal time, small-scale detection variations [6], etc. To date no convincing correlations have emerged. We collected the dates of historical methane detections in literature to investigate additional potential correlations, and found a temporal correlation between methane plume detections and the dates for Mars/comet orbit encounters [16,17] (Figure 1). Specifically, all known methane reports were detected within 16 days after an encounter between Mars' orbit and the orbit of a comet capable of producing a meteor shower on Mars [16,17] (Table 2 and Figure 2, following page). It is important to note that this correlation occurs between the comet/Mars interaction date and the *detection* date of a methane plume – it is possible that the methane plume occurred on the date of the encounter itself and was not noticed until the measurement was performed up to 16 days later.

2) Spatial Correlation Between Meteor Showers and Plume Size: Meteor showers arise from interactions between a planet and debris scattered along the orbit of a comet or asteroid. Meteor showers may persist for days at a very low meteor rate, but often feature strong meteor rates for a period of a few hours as the planet encounters the relatively dense debris near the parent body's orbit [18]. This short-lived activity peak results in deposition of most of a meteor shower's material on a regional (as opposed to global) area on the planet. This effect has been directly noted on Mars. Crismani [19] reported that the MAVEN spacecraft detected a regional and sudden appearance of Mg^{+} consistent with a meteor shower during the 08 Mar 2016 encounter between Mars and the orbit of C/2007 H2 Skiff, as predicted in [11]. MAVEN is not designed

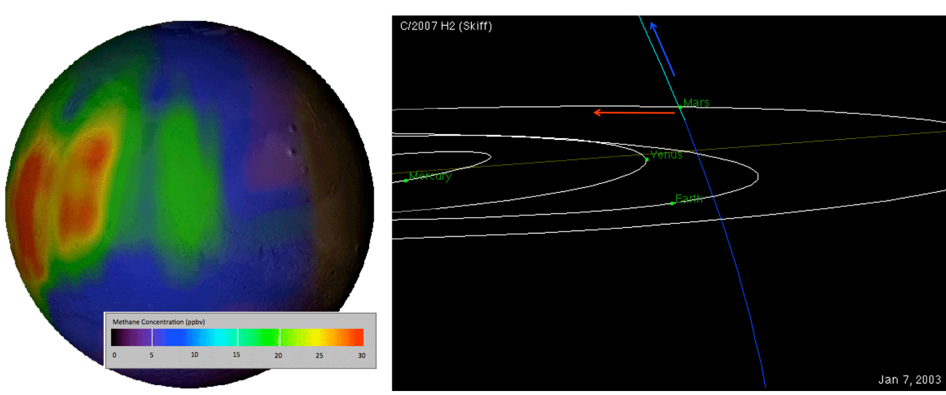

Figure 1: Methane plume noted on Mars by [4]. Four days before the measurement, Mars encountered the orbit of comet C/2007 H2 Skiff at a distance of ~150,000 km, about half the Earth-Moon distance [16]. Red arrow indicates Mars' movement, and blue arrow indicates the motion of debris in Skiff's orbit.

	Date	Mixing Ratio (ppbv)	Days Between Cometary Encounter and Detection	Encountered Cometary Orbit
Earth-Based Telescopic Observations				
Krasnopolsky 1997	28-Jun-88	70 +/- 50	**0**	(SDA Meteor Shower) Marsden Group Comets
Krasnopolsky 2004	24-Jan-99	10 +/- 3	**6**	C/1854 L1 Klinkerfues
"	27-Jan-99	10 +/- 3	**9**	C/1854 L1 Klinkerfues
Mumma 2009	11-Jan-03	max. ~40 +/- 6	**4**	C/2007 H2 Skiff
Krasnopolsky 2011	10-Feb-06	~10	**15**	13P/Olbers
ESA *Mars Express* Orbiter Observations				
Formisano 2004	Jan-Feb 2004	10 +/- 5	**3**	1P/Halley
Mars Science Laboratory Rover				
Webster 2014	16-Jun-13	5.78 +/- 2.27	**16**	1P/Halley
"	23-Jun-13	2.13 +/- 2.02		
"	29-Nov-13	5.48 +/- 2.19	**16**	5335 Damocles
"	6-Dec-13	6.88 +/- 2.11		
"	6-Jan-14	6.91 +/- 1.84		
"	28-Jan-14	9.34 +/- 2.16	**4**	275P/Hermann
"	17-Mar-14	0.47 +/- 0.11		
"	9-Jul-14	0.9 +/- 0.16		

Table 2: Historical Mars methane detections shown by publication (column 1), observation date (column 2), and reported methane concentration (column 3). Column 4 shows the number of days between a Mars/cometary orbit encounter and the methane observation, and column 5 identifies the comet encountered.

to measure methane and could not test for a correlation between the meteor shower and the appearance of methane. The comet Skiff is the same comet implicated in the methane plume reported by Mumma et al [4] (Figure 1), during the 2003 Mars/Skiff orbit interaction.

3) Appearance of High Altitude Dust: Deposition of meteor shower material into the martian atmosphere may result in optically visible, high altitude dust. MAVEN has reported [20] the unexplained appearance of dust clouds at altitudes of 150-300 km possibly attributable to meteor shower input. Sanchez-Lavega [21] reports two occasions when dust became visible at Mars' limb. One occurred on 17 May 1997, the same day as another interaction between Mars and the orbit of comet C/2007 H2 Skiff. The other was noted on 12 Mar 2012, four days after an interaction between Mars and the orbit of 275P/Hermann, a comet that is also implicated in one of the methane detections by the MSL rover (Figure 2).

4) Methane Loss Rate: It has been noted [3,6] that methane loss rates following a plume appear to be higher than expected for Mars near-surface atmospheric chemistry. At high altitude, however, Wong et al [7] noted that UV photolysis produces CH_4 degradation rates at altitudes above ~90 km more amenable to observed rates. Meteor shower-based methane production should generate methane at a range of altitudes to include high altitude. And methane detections to date have been incapable of detecting the methane's altitude: Earth-based and Mars orbital observations have made measurements through the full thickness of the martian atmosphere, and the MSL rover is a point measurement. Methane might be produced at higher altitudes and diffuse down to the rover, which is consistent with MSL's measurements in the 1-10 ppb range while many methane plumes feature measured concentrations in the 10s of ppb [1-6].

5) The Parent Body Size/Distance Relationship: Of the seven parent bodies implicated in methane plume detection (Table 2), the largest and arguably dustiest objects (1P/Halley, 5335 Damocles, 13P/Olbers, Marsden group comets) interact with Mars at the greatest orbital distances (~0.016 to 0.064 AU) while the other three, less well known bodies interact at shorter distances (~0.0008 to 0.0086 AU). This is not proof by itself but is inherently reasonable if these bodies are the source of methane-producing material.

The hypothesis stated here and in [11] is inherently testable, using the missions, instrumentation, and expertise that currently exist. One method for testing this hypothesis would be an extended observing campaign of Mars during a period that includes multiple interactions with cometary debris while watching for meteor shower activity and the correlated appearance of atmospheric methane plumes.

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