

MARTIAN ATMOSPHERIC METHANE PLUMES FROM METEOR SHOWER INFALL: A HYPOTHESIS. M. Fries¹, A. Christou², D. Archer³, P. Conrad⁴, W. Cooke⁵, J. Eigenbrode⁴, I. L. ten Kate⁶, M. Matney¹, P. Niles¹, M. Sykes⁷, A. Steele⁸, A. Treiman⁹. ¹NASA JSC, Houston, TX, ²Armagh Observatory, College Hill, Armagh, Northern Ireland, ³Jacobs, NASA JSC, Houston TX, ⁴NASA Goddard SFC, Greenbelt MD, ⁵NASA Marshall SFC, Huntsville AL, ⁶Dept. of Earth Sciences, Utrecht University, Netherlands, ⁷Planetary Science Institute, Tucson AZ, ⁸Geophysical Laboratory, Carnegie Institution for Science, Washington DC, ⁹Lunar 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

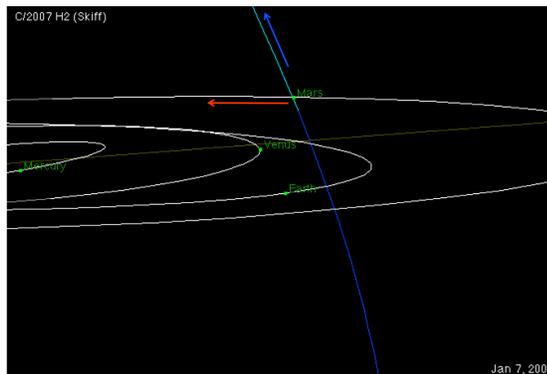
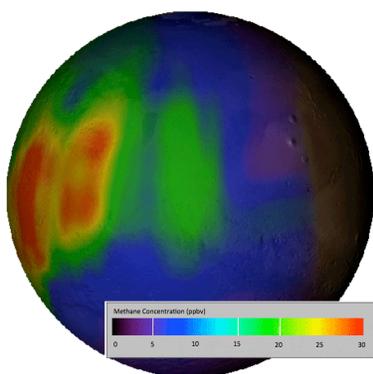


Figure 1: Methane plume noted on Mars by [4]. Four days before the measurement, Mars encountered the orbit of comet C/2007 H2 Skiff at a distance of ~150,000 km, about half the Earth-Moon distance [16]. Red arrow indicates Mars' movement, and blue arrow indicates the motion of debris in Skiff's orbit.

	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 CH₄ 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 alti-

tude: 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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