MARTIAN METHANE FROM A COMETARY SOURCE: 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: In recent years, methane in the martian atmosphere has been detected by 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]. An additional potential source exists: meteor showers from the emission of large comet dust particles 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, generating methane via UV photolysis [12,13].

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 location [6] etc. To date no convincing correlations have emerged. We collected the dates of historical methane detections in literature to investigate other potential correlations, and found a temporal correlation between methane detections and the expected dates for Mars/comet orbit encounters [16,17] (Figure 1). Specifically, all known methane detections were 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).

Approximate Upcoming Mars/Cometary Orbit Encounters	
Comet	**Date**
C/2007 H2 Skiff	8-Mar-16
(SDA Meteor Shower)	12-Sep-16
1P/Halley	8-Mar-17
13P Olbers	10-May-17
5335 Damocles	16-Aug-17
275P/Hermann	28-Oct-17

Table 1: Upcoming Mars/ comet orbit encounter dates, or opportunities to test the cometary origin hypothesis.

Methane Formation Mechanism: Direct addition of methane from cometary gases to the Mars atmosphere should be volumetrically insignificant [2]. However, carbonaceous solids such as those of cometary origin can generate a significant volume of methane (20% of total carbon yield) under UV irradiation [12,13]. Carbonaceous material delivered to Mars in meteor showers of cometary origin would be largely comprised of heated, newly disaggregated fine particles. Exposing this material to Mars-ambient UV may release a sufficient volume of methane to accommodate historical methane observations. The naturally occurring, steady flux of IDP is sufficient to maintain only parts-per-billion levels of CH_4 via UV irradiation [12,13,15]. However, this steady IDP flux cannot explain the sudden appearance of methane plumes [e.g. 4]. To explain these plumes, one must invoke large non-steady delivery of carbonaceous material to Mars,

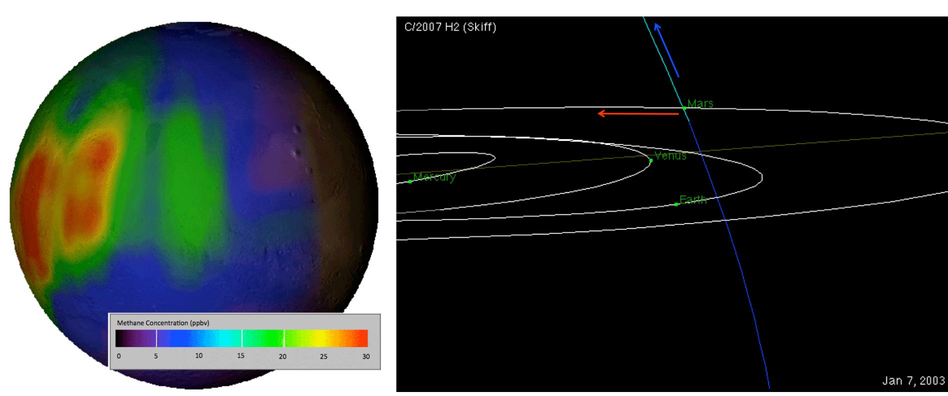

Figure 1: Methane plume noted on Mars by [4]. Four days previously, Mars encountered the orbit of comet C/2007 H2 Skiff at a distance of ~150,000 km, about half the Earth-Moon distance [16]. Red arrow indicates Mars' movement, and the blue arrow indicates the motion of debris in Skiff's orbit.

and cometary infall is a reasonable mechanism. Also, material falling onto Mars survives to a greater abundance than infall onto Earth. Flynn and McKay [19] estimate that more than 3 times as much material survives unmelted through the infall process due to lower infall velocity and proximity to the asteroid belt, to provide source material for methane production via UV photolysis. The estimates in [19] and elsewhere disregard larger masses (>1240 µm diameter, [19]), which melt on infall, as is convention for considerations of infall onto Earth. While this is reasonable for discussion of material on Earth since our oxidizing atmosphere will combust the carbonaceous fraction, it stands to reason that the mainly CO_2 martian atmosphere will retard the combustion process to produce additional volatiles and a refractory residuum. These volatiles should include a significant CH_4 fraction and so surviving mass may be underrepresented in [19] and similar works. In sum, however, it is currently unclear if the mass of material deposited into the martian atmosphere by cometary debris is sufficient to generate the observed methane detection events. Since the timing of Mars/comet orbits is known, however, this hypothesis is directly testable.

	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. Figure 2 further illustrates the multiple data points in MSL data.

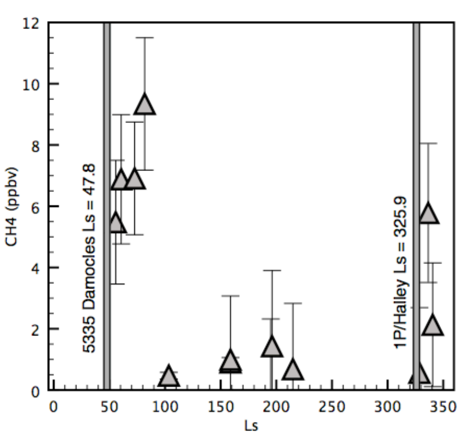

Figure 2: Methane detections by the Mars Science Laboratory rover with cometary encounters from Table 2 inserted. Data adapted from [6]. Note the appearance of methane shortly after Mars' interactions with the orbits of 5335 Damocles and 1P/Halley, both of which are large cometary bodies

The correlation between Mars/cometary orbit interactions and historical methane detections represents either coincidence or causality. The hypothesis 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 (Table 1), watching for meteor shower activity and appearance of atmospheric methane.

References: [1] V.A. Krasnopolsky, et al. *J. Geophysical Research* **102**, E3, 6525-6534 (1997). [2] V. A. Krasnopolsky, J. P. Maillard, T. C. Owen, *Icarus* **172** 537-547 (2004). [3] V. A. Krasnopolsky. *Icarus* **217** 144-152 (2011). [4] M. J. Mumma, et al. *Science* **323** 1041-1045 (2009). [5] V. Formisano, *et al Science* **306** 1758-1761 (2004). [6] C.R. Webster *et al Science*, **347**, 6220, 415-417 (2015). [7] A.S. Wong, S.K. Atreya, T. Encrenaz. *J. Geophysical Res.: Planets* (1991–2012), **108**(E4) (2003). [8] M.E. Kress, C.P. McKay. *Icarus* **168**, 2 475-483 (2004). [9] C. Oze, M. Sharma. *Geophys. Res. Letters*, **32**(10) (2005). [10] B.K. Chastain, V. Chevrier. *Planetary and Space Science*, **55**(10), 1246-1256 (2007). [11] Fries M. *et al Geochem. Persp. Let.* **2** (2016) 10-23. [12] A.C. Schuerger, *et al. J. Geophys. Res.: Planets* (1991–2012), **117**(E8) (2012). [13] F. Keppler, *et al. Nature* **486** 93-96 (2012). [14] Villanueva G. *et al Icarus* **222** (2013) 11-27. [15] Geminale A. *et al Plan. Space Sci.* **56** (2008) 1194-1203. [16] Christou A., *Mon. Not. R. Astron. Soc.* **402**,4 (2010) 2759-2770. [17] Treiman A. and Treiman J. *J. Geophys. Res.:Planets* **105** (E10) (1991-2012) 24571-24581. [18] Flynn G., *Earth, Moon and Planets* **72**, 1-3 (1996) 469-474. [19] Flynn G. and McKay D. *J. Geophys. Res.* **95** (1990) 14497-14509.