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Correspondence to:
S. K. Atreya,
atreya@umich.edu

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Reply to comment by Fries on "Cometary origin of atmospheric methane variations on Mars unlikely"

M. Roos-Serote[1], S. K. Atreya[1], C. R. Webster[2], and P. R. Mahaffy[3]

[1]Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, Michigan, USA, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, [3]NASA, Goddard Space Flight Center, Greenbelt, Maryland, USA

In our *Roos-Serote et al.* [2016] paper, we concluded that there is no compelling evidence for a correlation between Mars atmospheric methane concentrations and predicted meteor stream interaction events based on three factors: (1) accounting for all available methane data, not just the high methane considered by *Fries et al.* [2015]; (2) accounting for all predicted meteor events, not just selective ones considered by *Fries et al.* [2015]; and (3) a simple statistical analysis.

In his comment on our paper, *Fries* [2017] questions the validity of the statistical argument we presented. He states that the use of nondetections of methane in the statistical analysis is flawed by false negatives that could result from the large variability of influx of meteoric material from any given meteor stream from year to year.

It is well known from observations of meteoroid streams that interact with the Earth that any of these streams have an inhomogeneous distribution and can vary significantly from year to year.

We are fully aware of this, and in our paper we recognize the shortcoming of our statistical analysis in which we assume all meteor streams to be of same intensity [*Roos-Serote et al.*, 2016]. However, because of the total lack of observational data on the actual flux of material introduced into Mars by any of the streams, with one exception that we discuss below, treating all streams as equal is the only reasonable assumption to make.

We state this in our paper on page 7 [*Roos-Serote et al.*, 2016] before presenting a simple statistical analysis:

> "Next, we will apply a simple statistical analysis to numerically study the relationship between methane detections and meteor shower events. This was not done by *Fries et al.* [2015] since a predicted encounter of Mars with a meteoroid stream does not guarantee a significant infall of material, because the distribution of meteoroids along the comet's orbit is subject to multiple stochastic processes and likely to be irregular. However, we believe that a simple counting exercise combined with a basic statistical dependency test can provide valuable insight, exactly for the same reason that we have no information on the distribution and evolution of the streams, so that significant and insignificant infall of material are both equally likely. In the absence of any information on the dust content of the streams, we treat all streams equal."

When considering high methane measurements only, we, like *Fries et al.* [2015], also find a statistically significant correlation [*Roos-Serote et al.*, 2016, Figure 1 and Table 3]. We believe, however, that to claim the reality of such a correlation, the full data set must be considered and explained, which is the only scientifically robust approach.

In addition to the entire data set on methane, all meteor streams must be considered. As can be seen from Table 1 and Figure 3 in *Roos-Serote et al.* [2016], there are 33 predicted meteor streams, distributed all along the orbit of Mars. *Fries et al.* [2015] consider only seven of these streams in their analysis, those that are close to the methane plumes. When all predicted meteor streams are included, the methane-meteor correlation of *Fries et al.* [2015] vanishes *Roos-Serote et al.* [2016].

There are 28 methane measurements, 20 of which are made by the Sample Analysis at Mars (SAM) on board the Mars Science Laboratory (MSL) at the surface of Mars. While *Fries et al.* [2015] consider only a subset of the methane observations, our analysis is based on all available data including new measurements made since their publication.

Fries [2017] states that the Mars Science Laboratory data are "less constrained, as it makes point-location measurements well below the altitude where maximum amount of fresh-disaggregated dust is deposited in the Martian atmosphere and therefore where the majority of infall-derived methane may be generated."

It is interesting to note that while on the one hand *Fries et al.* [2015] employ the SAM/MSL observed methane spikes to support their hypothesis *Fries* [2017] on the other hand dismisses the same data set as being less constrained.

Furthermore, we reiterate, as stated previously on page 3 of our paper [*Roos-Serote et al.*, 2016], that passing through a stream can take a few hours to several days. Hence, a large part, or all, of the atmosphere of Mars will be exposed to meteoric infall, because the planet rotates on its axis in approximately 24 h. Mixing in the atmosphere will distribute methane vertically in less than a few days and globally in a few months. This, together with the fact that the photochemical lifetime of methane is much longer than several months, implies that significant methane production anywhere in the atmosphere will very likely be detectable at the surface by the SAM/MSL instrument. Thus, it is crucial that any robust analysis of the origin of the Martian methane includes all SAM/MSL methane measurements, low as well as high.

Finally, recent observations have yielded the only verified meteor stream at Mars to date. The interaction between C/2013 A1 (Siding Spring) and Mars in October 2014 was observed in situ by instruments on the MAVEN spacecraft. This comet had an unusually intense interaction with Mars due its close encounter at a distance of only 140,000 km. However, even for this comet, the analysis by the MAVEN team shows that the fluence of the meteor shower [*Schneider et al.*, 2015] was several orders of magnitude too low compared to that required to produce any methane plumes [*Crismani et al.*, 2017] by the mechanism proposed by *Fries et al.* [2015].

In conclusion, despite the limitation of statistical analysis due to lack of observations on meteor shower fluence, with the exception of Siding Spring discussed above, when taking into consideration all available methane data and predictions of all meteor streams at Mars and the fluence of Siding Spring, we find little evidence in support of correlation between meteor streams and methane plumes at Mars presently. Like *Fries* [2017], we look forward to continued observations with current and future assets. In fact, several SAM-TLS observations have been carried out since the publication of our *Roos-Serote et al.* [2016] paper. In particular, observations done in April 2016 and September 2016 were close to the predicted streams of Houghton-Ensor and the streams A1 Siding Spring, H1 Mrkos, and BTA Taurid, but no plumes of methane were detected. Nevertheless, the flux of extraplanetary organic material entering Mars is a fundamentally important issue in itself that ought to be pursued vigorously, irrespective of methane.

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