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Development of a modified Tau-REx retrieval framework for processing the ExoMars TGO NOMAD data

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Abstract

We present our research on the development of a Mars modified version of Tau-REx (Tau Retrieval for Exoplanets)[1], an exoplanetary atmospheric retrieval framework, designed to retrieve areo-located $^{13}CH_4$, $^{12}CH_4$ and C_2H_6 volume mixing ratios (VMRs), using the ESA ExoMars Trace Gas Orbiter (TGO) Nadir and Occultation for MArs Discovery (NOMAD) radiance spectra. The VMRs, of C_2H_6 and the isotopologues of CH_4, are of great interest in exploring whether CH_4 in the Martian atmosphere is biotic or abiotic.[2] Whilst $^{13}CH_4$, $^{12}CH_4$ and C_2H_6 VMRs areo-located retrievals are yet to be obtained, we present transmission and emission spectra, simulated using a Mars modified version of Tau-REx with the Mars Climate Database Version 5.2 (MCDv5.2)[3]. Finally, we present a series of movies of the global variation of the atmosphere and climate of Mars, created using the MCDv5.2 and comment on their use in the development of DeepMars, a deep neural network (DNN) retrieval framework.

1. Introduction

In 2003, methane, CH_4, was detected in the Martian atmosphere (10 ppbv)[4], which has, at most, a photochemical lifetime of a few hundred years.[5] This short lifetime of CH_4 in the Martian atmosphere implies that CH_4 should be uniformly distributed over Mars. However non-uniform distributions of CH_4 are observed.[6] This raises questions with regard to the source(s) and sink(s) of CH_4. Abiotic and biotic sources have been suggested to explain the detection, ranging from serpentinisation of olivine to methanogenesis[6] by methanogenic archaea.[7] ESA's ExoMars TGO NOMAD instrument is expected be able to measure the isotopic ratios of carbon-based molecules in the Martian atmosphere.[8] On Earth, the ratios of $^{13}CH_4/(C_2H_6 + C_3H_8)$ and $\delta^{13}C_{CH4}$ and $\delta^{2}H_{CH4}$, can be used to infer whether sources of CH_4 are biogenic or abiogenic.[2] Assuming similar conditions hold on Mars, NOMAD measurements have the potential to address this question.

2. Methods

2.1 A Mars modified Tau-REx

Tau-REx is a fully Bayesian retrieval framework that uses Multinest/MCMC/Nested Sampling to sample the entire likelihood space, unlike other planetary atmosphere retrieval frameworks that often only find the MAP solution, which may be biased.[1] Tau-REx can also be used to produce posterior distributions of model parameters. The posterior distributions of the VMRs of $^{13}CH_4$, $^{12}CH_4$ and C_2H_6, with one another (and other model parameters) are particularly relevant for associating a likelihood to the nature of CH_4 on Mars; abiotic or biotic, by showing whether the retrievals of different state vector parameters are correlated. Our research has involved modifying the Tau-REx radiative transfer model (RTM) module, which acts within the Tau-REx retrieval framework, for Mars. The RTM has been used with vertical temperature, pressure and VMRs profiles derived from the MCDv5.2 (Figure 1), to produce simulated

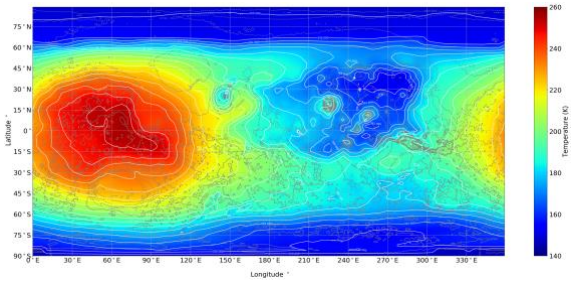

Figure 1: A single frame of a movie of the global atmospheric temperature (K) of Mars at 1m above the local surface, created using the MCDv5.2.

Mars emission (Figure 2) and transmission (Figure 3) spectra over NASA's MSL location (4.5◦S, 137.4◦E). The developed framework will eventually use calibrated ESA PSA files, generated from NOMAD measurements. These are expected to be publicly released by ESA in September 2018. Through inverting measured radiance spectra, with simulated spectra with $^{13}CH_4$, $^{12}CH_4$ and C_2H_6 present, Tau-REx can obtain volume mixing ratios (VMRs). After the Mars modified Tau-REx has obtained areo-located profiles of trace gas VMRs, we intend to attempt to validate these results against the NASA Mars Science Laboratory (MSL) Curiosity rover SAM-TLS measurements in Gale Crater. [6]

2.2 The Mars Climate Database

We also present a set of movies of the global variation of the atmosphere and climate of Mars created with the MCDv5.2, (Figure 1), e.g. the average solar scenario climatology, with increasing solar longitude and local times, at the local surface and 1m above, can be viewed by the reader online at: https://www.youtube.com/watch?v=shQGEKYFW8U&t.

2.3 DeepMars

In parallel to a Mars modified Tau-REx retrieval framework, a machine learning Mars retrieval framework is being developed; DeepMars, which uses a DNN to empirically derive a statistical relationship between an ensemble of NOMAD radiance spectra (using an extremely large training database of Mars modified Tau-Rex RTM simulated spectra) and different state vector parameters.[9]

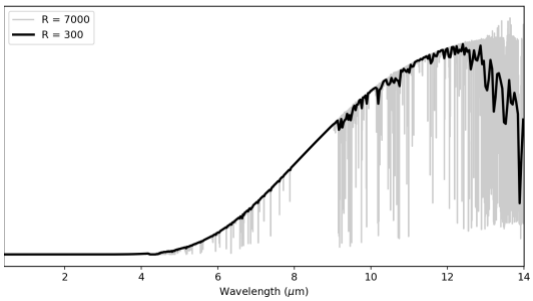

Figure 2: A simulated emission spectrum created, using a Mars modified Tau-REx retrieval framework, exploiting a vertical atmospheric profile at NASA's MSL location (4.5◦S, 137.4◦E), using the MCDv5.2.

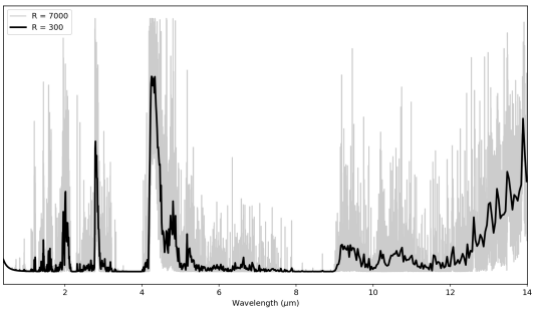

Figure 3: A simulated transmission spectrum, created using a Mars modified Tau-REx retrieval framework.

3. Conclusions

Our research has described the development of two retrieval frameworks; a Mars modified Tau-REx together with DeepMars, which will be used for the interpretation of future NOMAD observations, in particular to assess whether CH_4 detected in the Martian atmosphere is biogenic or abiogenic.

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