



HAL
open science

Comparing the Unexplained Variability of Molecular Oxygen in the Martian Atmosphere to Water Vapor and Argon

T. H. Mcconnochie, S J Vanbommel, D Y Lo, E W Knutsen, Franck Montmessin, T Bertrand, T Fouchet, Clément Royer, S Maurice, A Cousin, et al.

► **To cite this version:**

T. H. Mcconnochie, S J Vanbommel, D Y Lo, E W Knutsen, Franck Montmessin, et al.. Comparing the Unexplained Variability of Molecular Oxygen in the Martian Atmosphere to Water Vapor and Argon. Tenth International Conference on Mars, Jul 2024, Pasadena, United States. pp.LPI Contribution No. 3007, 2024, id.3534. insu-04689674

HAL Id: insu-04689674

<https://insu.hal.science/insu-04689674v1>

Submitted on 5 Sep 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

COMPARING THE UNEXPLAINED VARIABILITY OF MOLECULAR OXYGEN IN THE MARTIAN ATMOSPHERE TO WATER VAPOR AND ARGON. T. H. McConnochie¹, S. J. VanBommel², D. Y. Lo^{1,3}, E. W. Knutsen⁴, F. Montmessin⁵, T. Bertrand⁶, T. Fouchet⁶, C. Royer⁵, S. Maurice⁷, A. Cousin⁷, R. C. Wiens⁸, M. T. Lemmon¹, M. J. Wolff¹, M. D. Smith⁹, A. S. J. Khayat⁹, M. G. Trainer⁹, H. B. Franz⁹, O. Gasnault⁷, J. Lasue⁷, N. Lanza¹⁰, S. K. Atreya³, G. Martinez¹¹, F. Lefèvre¹², F. Daerden¹³, M. H. Hecht¹⁴, M.-P. Zorzano¹⁵, D. Viudez Moreiras¹⁵. ¹Space Science Institute, Boulder CO, USA (tmconnochie@spacescience.org), ²Department of Earth and Planetary Sciences, Washington University in St. Louis, USA, ³University of Michigan, MI, USA, ⁴University of Oslo, Institute for Technology Systems, CENSSS, Norway, ⁵LATMOS, Guyancourt, France, ⁶LESIA, Paris Observatory, France, ⁷IRAP, CNRS, Université de Toulouse, UPS-OMP, Toulouse, France, ⁸Purdue University, West Lafayette IN, USA, ⁹NASA Goddard Space Flight Center, Greenbelt, MD, USA, ¹⁰Los Alamos National Laboratory, Los Alamos, NM, USA, ¹¹LPI/USRA, Houston, TX, USA, ¹²LATMOS, CNRS, Sorbonne Université, UVSQ, Paris, France, ¹³Royal Belgian Institute for Space Aeronomy, Brussels, Belgium, ¹⁴MIT Haystack Observatory, Westford MA, USA, ¹⁵Centro de Astrobiologia, INTA, Spain,

Introduction: O₂ variability in excess of that expected for inert non-condensable trace gases [1] remains unexplained [2]. Photochemical models e.g. [3,4] show O₂ lifetimes of at least 10 years given known chemistry, and consequently photochemical GCMs e.g. [5,6] show a constant ratio of O₂ to other non-condensables such as Argon. In contrast, Mars Science Laboratory's (MSL) Sample Analysis at Mars (SAM) instrument suite shows ~20% O₂ variability relative to Argon [1], and [1,2] argued that a non-atmospheric reservoir of O atoms was required to supply this level of variability.

As we have previously reported e.g. [7,8] both the ChemCam and SuperCam instruments suites, on MSL and Mars 2020 respectively, measure O₂ as well as water vapor and aerosols in the atmospheric column above their respective rovers by performing passive-mode spectroscopy of the sky. The essential features of the passive sky gas measurement technique are that it takes advantage of the different atmospheric path lengths from pairs of elevation angles to remove instrumental uncertainties that would otherwise overwhelm weak absorption lines, and that it uses CO₂ absorption lines as a reference to correct for the effects of aerosol scattering uncertainties on absorption band depths.

The ChemCam passive sky measurements now span nearly six Mars years with a mean sampling interval of 16 sols. We have steadily refined our measurement techniques and data processing/model fitting over time, and this improved accuracy combined with a now large data set allows us to be confident that much of the surprising O₂ variability observed by ChemCam is robust even though there remain some outlier data points that must still be considered unreliable. SuperCam offers very similar capabilities, but SuperCam passive sky data processing is much less mature.

For the present work, we now incorporate MSL Alpha Particle X-ray Spectrometer (APXS)

measurement of the atmospheric argon column [9] to allow us to distinguish chemistry-driven O₂ variability from the effects of atmospheric dynamics combined with the CO₂ condensation/sublimation cycle that perturb the mixing ratios of all non-condensable gases. Although APXS offers only a relative rather than absolute measurement of Ar, unlike SAM it provides measurements at a sampling periodicity comparable to that of ChemCam passive sky.

Results: Figure 1 shows mixing ratios for ChemCam O₂, SuperCam O₂, ChemCam water vapor, and APXS Ar multiplied by an arbitrary scale factor. We have focused on Mars Year 37 here because it has not been presented previously, and because starting roughly

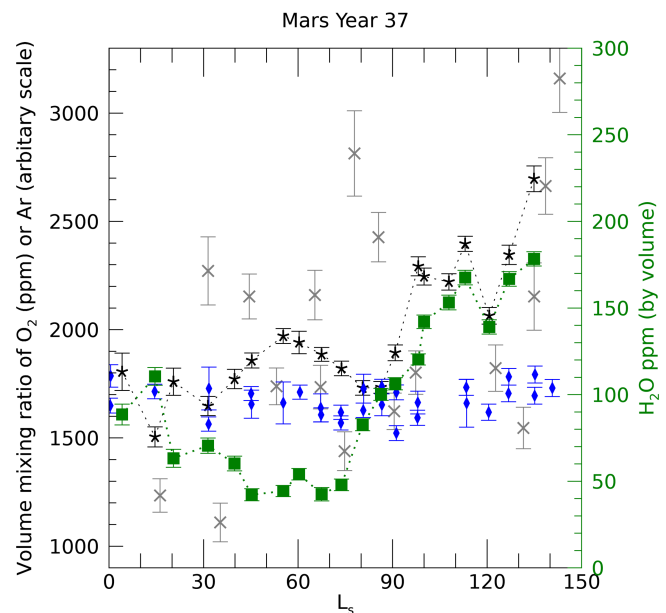


Figure 1. Volume mixing ratios of ChemCam O₂ (black), SuperCam O₂ (grey), ChemCam water vapor (green), and APXS argon (blue), for Mars Year 37. Data after L_s = 145° in Mars Year 37 is not yet publicly released.

at the beginning of Mars Year 37 nearly all ChemCam passive sky measurement were accompanied by an APXS argon measurement on the same or adjacent sol, and because Mars Year 37 to date offers a particularly clear example of apparently chemistry-driven O₂ variability.

ChemCam O₂ clearly grows much more rapidly after L_s = 90 than do non-chemically-active trace gases as represented by argon, and it does so in the same season that SAM has reported most of its observed anomalous rapid increases in O₂ [1]. Not all Mars years of ChemCam O₂ measurements show this particular pattern of deviation from argon, but in none does O₂ match the seasonal pattern of argon. SuperCam O₂ in Mars Year 37 has a great deal of scatter compared to ChemCam O₂ in Mars Year 37, but *average* SuperCam O₂ is consistent with the *average* ChemCam O₂ abundance of 2000±60 ppm [7] and SuperCam O₂ also seems consistent with the same rapid L_s = 90° – 150° seasonal rise that ChemCam sees in Mars Year 37. We presume that the excess scatter in SuperCam O₂ is due to the less mature data processing, but this is a question that we are actively investigating. Lastly, while the ChemCam-measured water vapor column shows no particular correlation with O₂ for the first 90 degrees of L_s in this year, once the rapid seasonal rise of O₂ arrives the water vapor and O₂ are strongly correlated.

Discussion: The correlation between O₂ and water vapor during the season when both are rising rapidly suggests that the excess O₂ variability may have a source region in common with the well-known seasonal rise in water vapor. This in turn implies some kind of association with sublimating seasonal water ice during northern summer, but it is important to note that trends in both water vapor and O₂ during northern summer show substantial inter-annual variability. Note also that no corresponding southern summer seasonal rise in either O₂ or H₂O has ever been observed by MSL, even though high southern latitudes certainly experience summer-season elevated water vapor from sublimation [e.g. 10]. This highlights the fact that the observed seasonal variability in both O₂ and H₂O in the tropics has as much to do with transport as it does with the physical processes the cause those species to be released in the atmosphere.

Consistent with the suggestion in [11] that the atmosphere provides the source of O atoms for perchlorate formation, both [1] and [2] suggest soil oxychlorines as a candidate non-atmospheric reservoir for the O atoms that seem to have interannually variable seasonal exchanges with the atmosphere. Water vapor has been suggested to be critically important for enabling that exchange [2, 12], and the Viking gas

exchange experiments showed release of oxygen from soil upon humidification (Klein, 1978; Oyama & Berdahl, 1977). Thus the high concentration of water vapor provided by seasonal water ice sublimation may be responsible for the observed correlation between excess O₂ and water vapor. However UV flux is also important the degradation of perchlorates [12] so we should expect to also find other correlations related to UV flux and hence atmospheric opacity. UV flux correlations will of course be complicated by transport processes just as the water vapor correlations are.

References:

[1] Trainer et al. 2019, JGR 124. [2] Lo et al. 2024 *PSJ*, 5. [3] Atreya et al., 2006, *Astrobiology*, 6. [4] Lefèvre & Krasnopolsky, 2017, In “The Atmosphere and Climate of Mars”. [5] Lefevre et al., 2004, JGR 109. [6] Daerden et al., 2019, *Icarus* 326. [7] McConnochie et al. 2022. Mars Atmosphere Modeling and Observations. [8] McConnochie et al. 2023, AGU Fall Meeting. [9] VanBommel et al, 2024, LPSC. [10] Smith et al., 2004, *Icarus* 167. [11] Carrier and Kounaves, 2015 *GRL* 42. [12] Escamilla-Roa, E., et al. 2020 *Applied Surface Science*, 512.