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MARS ATMOSPHERIC SCIENCE WITH SUPERCAM'S VISIBLE AND NEAR-INFRARED PASSIVE SPECTROSCOPY MODES. T. H. McConnochie^{1,2}, T. Fouchet³, F. Montmessin⁴, P. Beck⁵, B. Chide^{6,7}, R. Francis⁸, O. Gasnault⁷, J. Lasue⁷, C. Legett⁹, M. T. Lemmon¹, S. Maurice⁷, R. T. Newell⁹, C. E. Newman¹⁰, D. M. Venhaus⁹, R. C. Wiens⁹, and M. J. Wolff¹, ¹Space Science Institute, Boulder, CO (tmconnochie@SpaceScience.org) ²University of Maryland, College Park, MD, ³LESIA, Meudon, France, ⁴LATMOS, Guyancourt, France, ⁵IPAG, Grenoble, France, ⁶ISAE-SUPAERO, Toulouse, France, ⁷IRAP-CNRS, Toulouse, France, ⁸JPL, Caltech., Pasadena, CA, ⁹LANL, Los Alamos, NM, ¹⁰Aeolis Research, Pasadena, CA

Introduction: The Mars 2020 “Perseverance” rover’s SuperCam instrument suite [1, 2, 3, 4] provides a wide variety of active and passive remote sensing techniques [5, 6, 7, 8] including passive visible & near-infrared (“VISIR”) spectroscopy [9]. Here we present our plans to use the VISIR technique for atmospheric science by observing solar radiation scattered by the Martian sky or by one of SuperCam’s rover-mounted calibration targets [4]. See, e.g., [8], which describes the SuperCam microphone, for non-VISIR SuperCam atmospheric science. The technique of using VISIR-like passive-mode spectra of the sky, known as “passive sky”, has previously been demonstrated with ChemCam on the Mars Science Laboratory (MSL) rover [10]. SuperCam provides a superset of the ChemCam capabilities used in [10], and in particular it adds a near-infrared 1300–2600 nm spectral range that includes important gas and aerosol absorption and scattering features.

This presentation will focus on the objectives and methods of SuperCam VISIR atmospheric science. We do not expect that observations targeted for VISIR atmospheric science will have occurred prior to this year’s conference. However, data acquired for other purposes may provide enough instrument performance information to yield preliminary validation of predicted atmospheric science capabilities, and we will present such validation results if available.

Objectives:

O₂ column abundance. O₂ (like H₂O) is a key player in Martian photochemical cycles, and its chemistry is crucial to the long-term stability of CO₂ [e.g. 11]. It had been universally expected to have such a long chemical lifetime [e.g. 12, 13, 14] that it behaves like an inert trace gas on timescales relevant to atmospheric circulations and annual cycles. However, in-situ atmospheric sampling by the Sample Analysis at Mars (SAM) Quadrupole Mass Spectrometer (QMS) on the MSL rover showed unexpected seasonal and interannual variability in the O₂ mixing ratio [15]. The magnitude of the unexpected variability was too large to be explained by any purely atmospheric source or sink because CO₂ photolysis is known to be too slow and water vapor abundances are too small [15]. This led the authors [15] to suggest source and sinks in surface soils and to note that perchlorates represent a sufficiently

large reservoir of oxygen atoms, albeit one lacking a known mechanism for sufficiently rapid exchange with the atmosphere.

Recent numerical modeling of perchlorate chemistry implying the release of oxygen from perchlorates in the combined presence of silicates, water vapor, and UV radiation [16] in Mars-like conditions suggests a potential way forward for the O₂ variability problem. Our objectives for O₂ measurements are therefore to confirm the surprising results of [15] at a second site, and to test potential correlations between excess O₂ variability and local or global water vapor abundance as well as local or global aerosol opacity (which modulates surface UV flux.) The desired precision for O₂ measurements is ± 50 ppm in column-averaged volume mixing ratio, comparable to the typical precision in [15].

CO column abundance. In contrast to O₂, CO has been observed [17] to follow the expected seasonal cycle of a chemically inert non-condensable trace gas. To resolve the expected seasonal cycle of CO, our target measurement precision is ± 100 ppm.

Water vapor column abundance. Local water vapor measurements are particularly valuable for assessing exchanges of water vapor between the atmosphere and surface materials. Our primary objective for water vapor is therefore to routinely sample the daytime water vapor column, for direct comparison with nighttime mixing ratio measurements made by the Mars 2020 Mars Environmental Dynamics Analyzer (MEDA) humidity sensor [18], but also to help connect in-situ measurements by MEDA with measurements from orbit. We will target a precision of ± 0.5 precipitable μm , comparable to ChemCam [10].

Aerosol particle sizes and composition. Both MEDA [18] and Mastcam-Z [19] on the Mars 2020 payload provide direct measurements of column aerosol opacity in addition to sky brightness measurements that can substantially constrain particle sizes. SuperCam will contribute to constraining particle sizes and will, with its broad spectral range and near-infrared coverage, be uniquely well-suited to constraining the relative contributions of water ice and dust to column opacity, and to distinguishing the dust aerosol particle size distribution from that of water ice.

Relationship to Mars 2020 mission objectives. Because both O₂ and H₂O cycle into and out of Martian

soil, that soil is currently or was in the recent past in some kind of equilibrium with these atmospheric volatiles. Thus the atmospheric H₂O and O₂ cycles are an important part of the geochemical and geological context for near-surface samples and the Jezero field site. Aerosols, too, provide relevant geological context because some portion of surface-accumulated aerosols will inevitably be present in returned samples. In addition, evaluation of airborne dust hazards is an important precursor to human exploration, and aerosols along with water vapor and carbon monoxide are important for validating global atmospheric models. These species are important for model validation because they are tracers of dynamical processes, and because surface-atmosphere exchange of dust and volatiles are important modeled physical processes.

Measurement approach:

The SuperCam spectrometers used for VISIR mode are: a ChemCam-heritage reflection spectrometer covering 385–465 nm (“violet”) with < 0.2 nm res. [3]; an intensified transmission spectrometer covering 536–853 nm with 0.3–0.7 nm res. [3]; an acousto-optic-tunable-filter (AOTF)-based IR spectrometer on the rover mast covering 1300–2600 nm with 20–30 cm⁻¹ res. [2, 9].

Primary “passive sky” observing strategy. Our primary observing strategy is the same approach used for MSL ChemCam “passive sky” observations [10]: we point SuperCam at two different elevation angles in the sky that yield two different path lengths through the gas absorptions of interest. Ratioing instrument signals from the two pointing positions eliminates solar spectrum and instrument response uncertainties that are ~100x and ~10x larger than signals of interest for the transmission and AOTF IR spectrometers, respectively. For the intensified transmission spectrometer, instrument response will fluctuate significantly with instrument temperature, hence we must ratio different atmospheric pointings acquired within minutes of each other. To obtain the sensitivity objectives for O₂ and H₂O vapor, we estimate ~15 minutes of observation time will be required including slew time and integration with all three spectrometers. (We estimate 5–10 additional required minutes if the CO objective is included.)

Single-point observing strategy. AOTF instrument response is expected to be sufficiently repeatable over periods of tens of days, allowing a relative calibration for single pointings spanning these time periods. Therefore, between primary passive sky observations we will sample H₂O and aerosols with single pointings directed at the white SuperCam calibration target, which serves to scatter direct solar flux toward the optics.

Aerosol-only observing strategy. If we drop the requirement for the extremely high precision needed to measure gas absorption (which is S/N ~ 3,000 for the

transmission spectrometer and ~1,000 for the IR spectrometer), we can better constrain aerosol properties by observing at significantly more than two pointing positions in a reasonable amount of time; the improved constraint comes from sampling numerous points on the aerosol scattering phase function.

Background subtraction. The AOTF IR spectrometer is designed to acquire a dark current measurement with every integration. For the violet and transmission spectrometers a portion of spectral acquisitions measure dark current by acquiring non-illuminated detector rows, and by leaving the intensifier effectively switched off, respectively. Small remaining background residuals, due to dark current non-uniformity and intensifier background, are likely negligible (~0.5 DN per acquired spectrum), but we will measure them with occasional calibrations acquired at night with the rover in total darkness.

Radiative transfer modeling and retrieval approach: We will use the same discrete ordinates multiple scattering radiative transfer model (with correlated-k gas absorptions) used by [10] to model ChemCam “passive sky” observations and retrieve gas and aerosol abundances. The planned retrieval will proceed by using downhill-simplex optimization to solve for dust and ice particle size, ice opacity contribution, plus one dust and one ice vertical profile parameter, simultaneously. The vertical profile parameters are controlled by the depth of CO₂ absorption bands near ~790 nm and ~2000 nm. We have shown [10] that these CO₂-band driven parameterizations remove the influence of aerosol scattering uncertainties on gas absorption band models. The non-CO₂ gas absorption bands are fitted individually with a grid-search approach.

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