AN EXTENDED VIEW OF OZONE ON MARS

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Introduction: We present an ongoing effort to characterize chemistry in Mars' atmosphere in multiple seasons on timescales longer than current missions. This is achieved through coordinated efforts by GSFC's HIPWAC spectrometer and *Mars Express* SPICAM, through ground-based infrared heterodyne archival measurements, and through tests and application of photochemical model predictions.

The trace species ozone (O_3) is an effective probe of atmospheric chemistry because it is destroyed by chemically active odd-hydrogen species (HO_X) that result from water vapor photolysis. Observed ozone abundance on Mars is a critical test for three-dimensional photochemistry-coupled general circulation models (GCM) that make specific predictions for the spatial, diurnal, and seasonal behavior of ozone and related chemistry and climatological conditions.

ESA's *Mars Express* SPICAM [1] is the first instrument to study ozone from Mars orbit since *Mariner 9* (1971-72), operating from 2004 to the present. Spectroscopy of ozone from the NASA Infrared Telescope Facility with GSFC's InfraRed Heterodyne Spectrometer (IRHS, decommissioned) and Heterodyne Instrument for Planetary Wind And Composition (HIPWAC) dates from 1988 to the present [2,3,4], in seasons accessible during Mars apparitions and covering the latter half of a 32-year gap in the spacecraft record. These infrared heterodyne measurements are the only direct observations of ozone on Mars possible from the ground, with sufficient spectral resolving power ($\lambda/\Delta\lambda>10^6$) to distinguishing it from telluric features [5,6]. The synergistic combination of space-based and ground-based measurements is a powerful tool for investigating long-term atmospheric behavior and supports a more complete interpretation of ozone chemistry.

Probing Chemistry and Climate: Previous coordinated measurements by HIPWAC and SPICAM [4] quantitatively linked mission data to the 22-year IR heterodyne ozone data record through simultaneous measurements and by verifying column abundance retrievals from IR and UV spectroscopic techniques. Further measurements in December 2009 and March 2010 made by HIPWAC in direct coordination with SPICAM operation are an additional source of verification. The coordinated efforts are the basis for studying long-term behavior, by validating direct quantitative comparison between SPICAM measurements in this decade and IR heterodyne measurements made prior to the *Mars Express* mission and in previous decades.

Prior work revealed unanticipated inter-decadal variability from ozone abundances measured by HIPWAC and SPICAM in 2008 and by IRHS in 1993 (Fig. 1). High latitude measurements are gen-

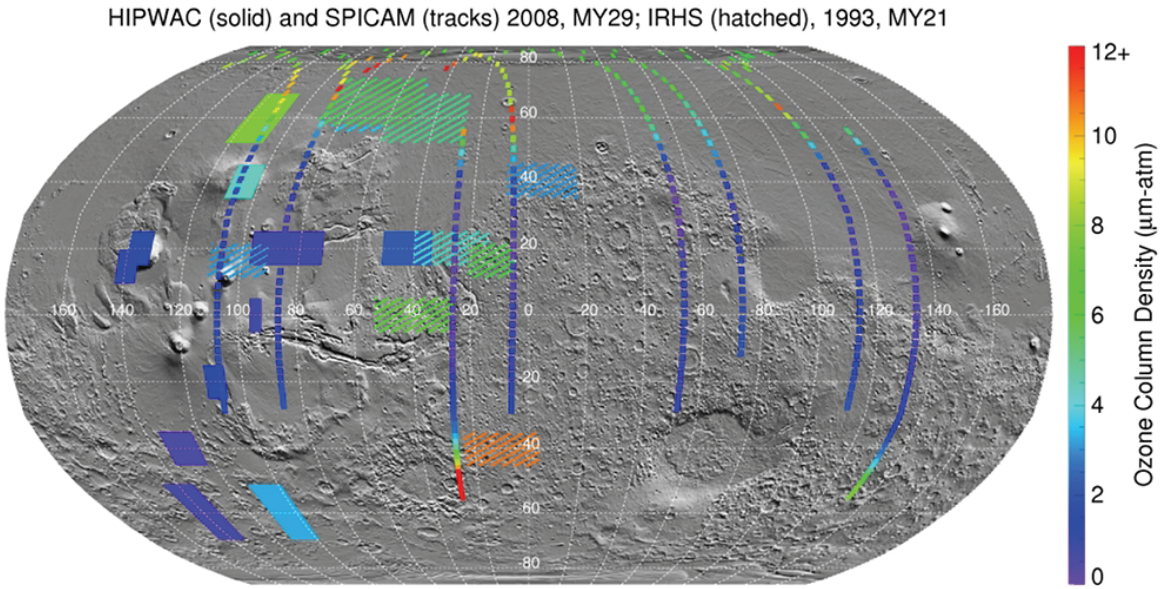

Fig. 1. Coordinated campaigns with GSFC's HIPWAC and *Mars Express* SPICAM tied mission data to the long-term ozone data record, dating back to 1988, and revealed unanticipated long-term variability at low latitudes in the spring, possibly due to heterogeneous chemistry driven by cloud activity [4].

erally consistent but striking differences occur in the low latitude retrievals. Column abundances measured by IRHS in 1993 (MY21) are consistently ~2-4 times higher than those retrieved by the functionally equivalent HIPWAC and by SPICAM in 2008 (MY29), eight Martian years later during the same northern mid-spring season. This increased ozone may be an indicator of increased cloud activity at low latitudes serving as a sink for ozone-destroying species, as indicated by photochemical modeling of heterogeneous chemical processes [4,10,11].

Archival IR heterodyne measurements compared to *Hubble Space Telescope* (HST) UV measurements [7,8] showed generally consistent retrievals for contemporaneous observations as well as for those at similar seasons (L_S) within a few years of each other [3]. However, during L_S=60°-90° (late northern spring) both HST and IRHS yielded approximately two to five times more ozone in the 1990's than was observed by SPICAM at similar seasons, but one decade later. This was attributed to possible interannual variability by Perrier *et al.* [9], who did not report interannual variability during the two consecutive Martian springs measured by SPICAM at the time.

These snapshots are significant, as photochemical models have generally been checked against combined ground-based and spacecraft measurements made over all Martian years that have available data [*e.g.,* 10,11,12]. Although ozone exhibits large spatial, diurnal, and seasonal variability, year-to-year and inter-decadal variability are not well studied and can probe climatology. A detailed study of long-term behavior is critical to refining photochemical models and to characterizing the predictability of Mars' seasonal behavior and the variability of its climate.

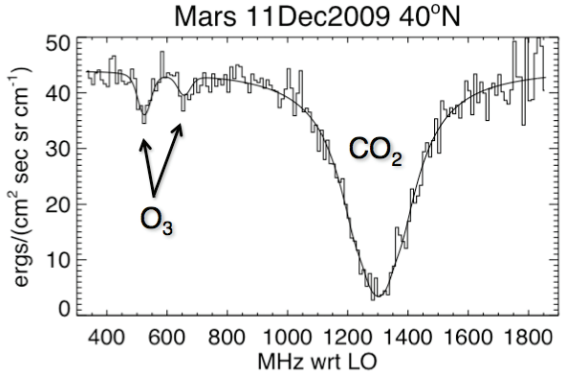

Fig. 2. Ozone (O_3) absorption features at 9.7 µm measured by HIPWAC (histogram) in December 2009 at the NASA Infrared Telescope Facility on Mauna Kea in coordination with *Mars Express* SPICAM. Frequency is presented relative to the local oscillator (LO) frequency used to access this spectral region (1031.4774 cm^{-1}). The CO_2 absorption profile simultaneously constrains temperature in radiative transfer modeling (solid curve).

Recent Work: We present HIPWAC measurements of ozone made during the last Mars apparition, in December 2009 (*e.g.,* Fig. 2) and in March 2010. These observations were made in direct coordination with *Mars Express* SPICAM and are sources of additional verification of consistent total ozone column abundance retrievals from the two techniques. This strengthens the basis for quantitative study of long-term ozone variability in multiple seasons on timescales longer than current missions. Recent heterodyne measurements are also used to test photochemical model predictions [*e.g.,* 10,11] so that they can be used to interpret past measurements and determine the importance of chemical and climatological processes indicated by the observed behavior, such as heterogeneous chemistry catalyzed by cloud particles.

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