PROBING THE DISTRIBUTION OF OZONE ON MARS. K. E. Fast[1,6], T. Kostiuk[1], T. Hewagama[2], T. A. Livengood[3,6], F. Lefèvre[4], J. Annen[1,6], J. D. Delgado[2,5,6], [1]NASA Goddard Space Flight Center (Planetary Systems Laboraty, Code 693, Greenbelt, MD 20771, Kelly.E.Fast@nasa.gov), [2]University of Maryland (Dept. of Astronomy, College Park, MD, 20742). [3]Universities Space Research Association (Code 693, Greenbelt, MD 20771), [4]Université Pierre et Marie Curie/CNRS (Paris 06, Service d'Aéronomie, Paris F-7500523), [5]Current affiliation: Universiteit Leiden, [6]Visiting *Astronomer at the Infrared Telescope Facility, which is operated by the University of Hawaii under Cooperative Agreement no. NCC 5-538 with the National Aeronautics and Space Administration, Science Mission Directorate, Planetary Astronomy Program.*

Introduction: We present the application of infrared heterodyne line shapes of ozone on Mars to those produced by radiative transfer modeling of ozone profiles predicted by photochemistry-coupled general circulation models (GCM), and to contemporaneous column abundances measured by Mars Express SPICAM.

Ozone is an important tracer of photochemistry in Mars' atmosphere, serving as an observable with which to test predictions of photochemical models. Infrared heterodyne measurements of ozone absorption features on Mars have been obtained at various Martian seasons from 1988 until present at the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawai'i [1]. The NASA/Goddard Space Flight Center spectrometers used were the Infrared Heterodyne Spectrometer (IRHS) [2, 3] and, since 2003, the Heterodyne Instrument for Planetary Wind and Composition (HIPWAC) [4]. A description the infrared heterodyne technique applied to ground-base observations of Martian ozone can be found in [1]. The most recent measurements on February 21-24 2008 UT at L_S=35° were made by HIPWAC on or near the Mars Express orbital path with the goal of acquiring spectra that can be directly compared to nadir observations by SPICAM.

IR Heterodyne Measurements: Ozone measurement techniques include ultraviolet observations from spacecraft [*e.g.*, 5, 6] and from Hubble Space Telescope [*e.g.*, 7, 8]. High-altitude ozone abundance can be inferred from $O_2(^1\Delta)$ emission [*e.g* 9, 10, 11]. Infrared heterodyne spectroscopy with spectral resolving power R>1,000,000 is the only technique with sufficient spectral resolution to directly measure Mars ozone features from the surface of the Earth [1, 12]. The measurements at ~9.5 μm are not strongly sensitive to normal amounts of dust in the atmosphere, allowing them to probe down to the surface. The fully-resolved absorption line shapes (Fig. 1) depend on the abundance and vertical distribution of ozone. Information on the thermal profile is retrieved through simultaneous measurement of a fully-resolved CO_2 absorption line shape (Fig. 1).

Target ozone features are chosen so that the relative velocity of Mars and Earth is sufficient to Doppler shift the Martian ozone features away from their terrestrial counterparts into regions of higher telluric transmittance. At IRTF, the ~1" instrumental beam covers ~10° of Martian latitude in most cases (~15° at high latitudes). Pointing is maintained at a constant Mars local time, and each spectrum tends to cover ~10°-40° of longitude on Mars. The Martian components of the spectra are modeled using the line-by-line radiative transfer package BEAMINT [13] and the terrestrial components are generated and fine-tuned through calls to GENLN2 [14].

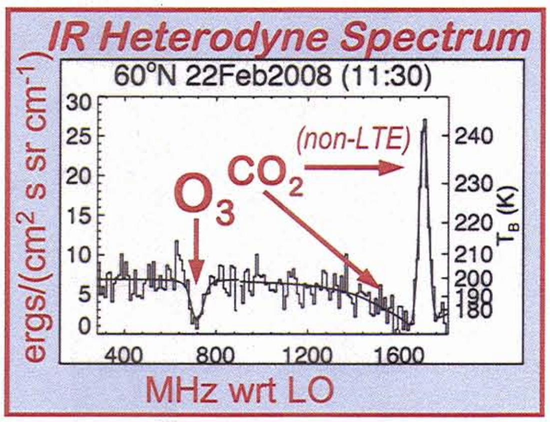

Fig. 1. Infrared heterodyne spectrum of Mars at 60°N and 11:30 Mars local time measured with the GSFC HIPWAC spectrometer. Telluric contribution and one Mars sideband have been removed through radiative transfer modeling. A deep ozone absorption feature is shown at this high-latitude location, whose shape depends on the abundance and vertical distribution of ozone and the local temperature. Also shown are the wing of a temperature-probing CO_2 absorption feature and a narrow (~100 MHz) high-altitude non-LTE emission line.

Testing GCMs with ozone: Ozone is a sensitive tracer of photochemistry in Mars' atmosphere since it is destroyed by active odd-hydrogen (HO_x) species ultimately originating from water vapor photolysis. These species are active players in the long-term stability of the CO_2 atmosphere and in the highly-variable spatial, diurnal, and seasonal chemistry of the Martian atmosphere. The growing pool of available ozone observations from spacecraft and from the ground have been matched by the development of photochemistry-coupled general circulation models [*e.g.*, 15, 16, 17] that utilize those observations to test their spatial, temporal, and seasonal predictions of atmospheric chemistry.

Total column abundances retrieved from IR heterodyne measurements have been applied to Lefevre's photochemistry-coupled GCM without heterogeneous chemistry [15, 18]. Recently, those total column abundance have been applied to that model with the addition of heterogeneous chemistry [16] based on laboratory measurements of surface reaction probabilities for HO_2 and OH that have also been adopted in terrestrial research. We investigate the distribution of ozone within the column by comparing the line shapes measured through IR heterodyne spectroscopy to those resulting from ozone distributions predicted by the latest model [16]. Figure 2 shows an example case where a GCM-generated ozone profile was scaled so that a radiative transfer calculation of its absorption line shape matched an observed HIPWAC absorption feature from February 2008 (L_S=35°) at the same areographic position (60°N 112°W), local time, and season. The RMS deviation of model from the data is slightly smaller for the GCM-generated profile than for a line shape produced by a constant-with-height profile, even though the total column abundances were the same, favoring the GCM profile and illustrating the potential for testing and constraining modeled vertical distributions of ozone.

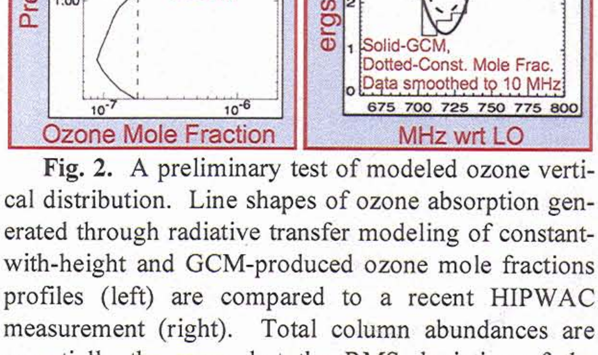

Fig. 2. A preliminary test of modeled ozone vertical distribution. Line shapes of ozone absorption generated through radiative transfer modeling of constant-with-height and GCM-produced ozone mole fractions profiles (left) are compared to a recent HIPWAC measurement (right). Total column abundances are essentially the same, but the RMS deviation of the GCM model line shape is smaller than that from the constant-with-height profile.

Recent HIPWAC observations of ozone from IRTF have been designed to complement those from Mars Express SPICAM by targeting the MEX orbital path, and retrieved total ozone column abundances have been compared. For instance, the example HIPWAC measurement mentioned previously was compared to a contemporaneous measurement made by SPICAM. The resulting ozone column abundance retrieved by matching the model to the observed HIPWAC line shape produced an abundance that was 60% higher than that observed by SPICAM at the same areographic position one day earlier and 2.5 hours earlier in local time. This could be due to day-to-day variability, diurnal variation, or variability in the north polar region, which must be explored, but the IR and UV techniques also have different sensitivities to the ozone profile. IR heterodyne measurements are most sensitive at near the surface. UV measurements are most sensitive to higher altitudes. Also, $O_2(^1\Delta)$ measurements are sensitive to ozone above ~20 km. The different sensitivities of these ozone measurement techniques can be exploited to further constrain the vertical distribution of ozone and hence the photochemistry.

Conclusion: Probing the vertical distribution of ozone through IR heterodyne lineshapes and through the different sensitivies of UV and IR techniques to the ozone profile will provide important information beyond ozone column abudance for expanding photochemistry efforts exploring issues such as heterogeneous chemistry [*e.g.,* 16] and thermal variations due to tidal phenomena [19]. Mars Express SPICAM stellar occultation measurements probe the high-altitude ozone profile [6], and information is needed on the vertical distribution of ozone down to the surface. The next step would be to examine the vertical distribution of the ozone within the column in order to better understand the seasonally-varying chemistry of the Martian atmosphere in three dimensions

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