IO'S ATMOSPHERE IN 2010: SYNERGISTIC OBSERVATIONS OF LONGITUDINAL DISTRIBUTION IN THE NEAR-ULTRAVIOLET AND THE MID-INFRARED. C. C. C. Tsang[1], J.R. Spencer[1], K.L. Jessup[1], Southwest Research Institute, Department of Space Studies, 1050 Walnut Street, Suite 300, Boulder, 80302, USA

Introduction:

Io's atmosphere is known to vary in longitude, latitude and time. The atmosphere is directly supported both by volcanic injection of its primary constituent, SO_2, and also, by the reservoir of SO_2 in the form of surface frost sublimation. However, uncertainties remain to what degree these two components affect the density of the atmosphere, what timescales these components act on, and even the absolute magnitude of the atmospheric density. Here, we present a set of unique analysis of quasi-simultaneous observations of Io's atmosphere, separated by a few months in 2010, from the near-ultraviolet and the mid-infrared. The two spectral regimes provide good agreements in the longitudinal distribution of Io's atmosphere.

Background:

Io's constant and global volcanism dissipates internal energy generated by gravitational tidal heating [1]. This volcanic activity produces a SO_2 dominated atmosphere, with a sub-solar column density of ~10^{17} cm^{-2} [2], with a surface pressure of ~ a few nbar. The large escape flux of different molecular and atomic species from the atmosphere populates the Jovian magnetosphere. Io's atmosphere is spatially inhomogeneous both in latitude and longitude. Initial latitudinal gradients were positively identified by ultraviolet spectroscopy and imaging [11]. Since then, many published works spanning all wavelengths in the EM spectrum, have attempted to elucidate the exact density and variability of the Io atmosphere. Table 1 shows a small subset of these observations, taken from [3]. A range of densities have been deduced, from ~10^{15} through ~10^{18} cm^{-2}, since the discovery of the Io atmosphere in 1979 [1]. Reconciling these differences is difficult due to (i) differing model assumptions of the atmosphere and surface at the wavelengths of interest, (ii) volcanic eruptions can be highly variable and their contribution to the bulk atmosphere can be difficult to quantify (noting however authors of [3] showed from their ten years of 19 µm data surprisingly constant atmospheric density with time, apart from the seasonal variations) and (iii) the long-term seasonal atmospheric variation due to sublimation of surface frost must be taken into account. Here, we present observations, separated only by a few months, from both the mid-infrared at 19 µm, and also in the near-ultraviolet, from 2100 – 2300 Å, in an attempt to reconcile some of these contradictions of the Io atmosphere. A difficulty with interpretating the mid-IR data is the absorption bands depend on both the atmospheric and surface temperatures. Its analsysi si therefore quite highly model dependent. This is not the case in the near-UV, where atmospheric temperature is little effect, and surface temperature has no effect, on the spectra. The UV data therefore provides an independent check on the atmospheric density, less sensitive to model assumptions.

Observations:

Mid-Infrared IRTF-TEXES Data

Authors	Spectral Region	SO_2 Column Density (cm^{-2})
[1]	7.3 µm Voyager/IRIS (IR)	$5x10^{18}$
[2]	7.3 µm Voyager/IRIS (IR)	$2.5 – 20x10^{17}$
[8]	1980 – 2300 Å HST/FOS (UV)	$6x10^{15} – 3x10^{17}$
[9]	0.2 – 0.24 µm HST/FOS (UV)	3.25×10^{16}, 1.5×10^{16}, and 7×10^{15}
[5]	0.2 – 0.3 µm HST/STIS (UV)	1.25 – 1.8 ($\times10^{17}$)
[6]	19 µm IRTF/TEXES (IR)	0.5 – 1.5 ($\times10^{17}$)
[7]	Lyman-α 1216 Å HST/STIS (FUV)	1.0×10^{16} sub-Jovian Hem. 4.0×10^{16} anti-Jovian Hem.
[10]	345 GHz SMA	0.52 – 5.9 ($x10^{16}$)
[3]	19 µm IRTF/TEXES (IR)	0.61 – 1.51 ($x10^{17}$)

Table 1: Taken from [1], showing a number of different studies of Io's atmosphere at different wavelengths, and their derived SO_2 column densities.

Our mid-infrared observations span 529 – 530.5 cm^{-1} (19 µm), at resolving powers of ~57,000, and were taken on NASA's Infrared Telescope Facility using the TEXES mid-infrared spectrograph [4] between May 30 and June 7, 2010. Six disc-integrated longitudes from 112 through 313° were sampled.

Near-Ultraviolet HST-COS Data

The near-ultraviolet data, from 2100 – 2300 Å, were taken by the Cosmic Origins Spectrometer (COS) on HST, with resolving power ~25,000. The observations were taken between September 27 and October 8, 2010. This set of six disc-integrated spectra were obtained, at similar longitudes to the 19 μm data. These data represents the highest spectral resolution observations in this spectral region of Io to date.

Results:

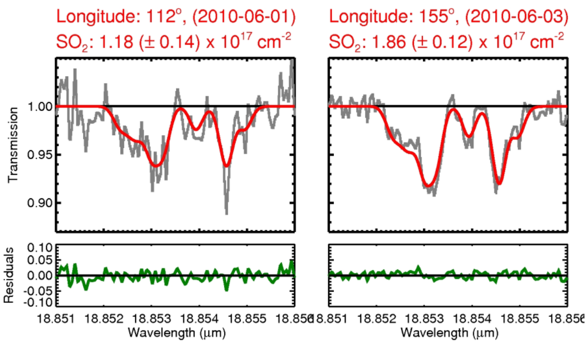

Figure 1: *IRTF-TEXES mid-infrared data from 2010 (gray), with model fits (red) and their residuals (green)*

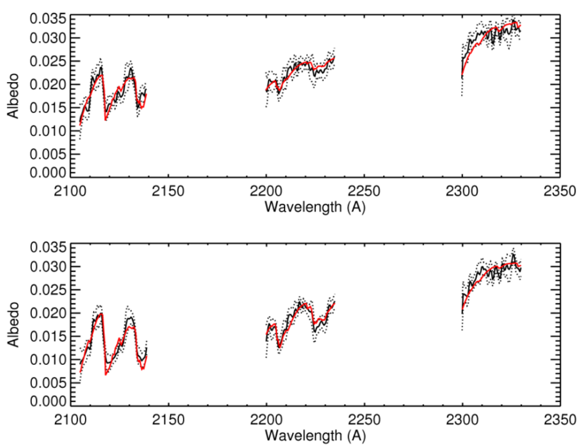

Figure 2: *HST-COS near-ultraviolet data from 2010 (solid black), with radiometric errors (dotted) and preliminary best fit spectra (solid red), for longitudes =25 (top) and 155 (bottom). The abundances retrieved were 3 x 10^{16} cm^{-2} and 0.8 x 10^{17} cm^{-2} respectively.*

We fitted the the IR (Fig 1) and UV (Fig 2) observations using two atmospheric models. In the IR, non-LTE calculations of vibrational temperature were used to determine band strength as a function of assumed atmospheric temperature [3], and UV band strengths were determined by a transmission model similar to the one presented in [5]. The models assume the atmosphere has a latitudinal dependency which decreases from equator to pole, according to the "modified latitudinal model" described in [6]. The spectra were fitted according to the fitting routines outlined in [3]. Initial results show the HST-COS observations exhibit the same longitudinal trends as the IRTF-TEXES observations, validating the qualitative results of [3, 6, 7] [Fig 3], although the exact variation is more muted in the UV. We will also present solutions of atmospheric temperature and SO in this presentation during the meeting.

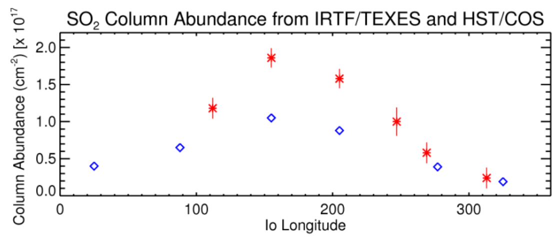

Figure 3: *Initial results of retrieved SO_2 column densities as a function of Io longitude. The UV observation (blue) confirm the atmospheric density peaks in the anti-Jupiter hemisphere seen in the IR (red).*

Conclusions:

We have taken observations in the mid-infrared and near-ultraviolet in the 2010 epoch and retrieved the sub-solar column abundance of Io's atmospheric density. Both the ultraviolet and infrared column densities show a similar variation in band strength with longitude (Fig. 1). This work shows (i) the longitudinal variability of Io's atmosphere seen at 19 μm [1, 4] and at Lyman-A [5] is confirmed in the near-UV and (ii) synergistic observations taken at two different wavelengths, employing different radiative transfer models, have the potential to resolve discrepancies of Io's atmospheric properties.

Acknowledgements:

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References: [1] Pearl J. et al. (1979), *Nature*, **280**, 755-758, [2] Lellouch E. et al (1992), *Icarus,* **98**, 271-295, [3] Tsang, C.C.C. et al., (2012), *Icarus*, **217**, 277-296. [4] Lacy J. et al. (2002), *PASP*, **114**,153-168, [5] Jessup K.L. et al. (2004), *Icarus,* **169**, 197-215, [6] Spencer J.R. et al. (2005), *Icarus,* **176**, 283-304, [7] Feaga L.M. et al. (2009), *Icarus,* **201,** 570-584, [8] Ballester G.E. et al., (1994), *Icarus,* **111**, 2-17, [9] McGrath M.A. et al (2000), *Icarus,* **146**, 476-493, [10] Moullet A. et al., (2010), A&A, **208,** 353-365 [11] Jessup et al. (2007), *Icarus,* **192,** 24-40