IO'S ATMOSPHERE IN JUPITER ECLIPSE: MODELING SURFACE TEMPERATURES AND ATMOSPHERIC DENSITIES TO ELUCIDATE ATMOSPHERIC SUPPORT.

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Introduction: The Jovian moon of Io is home to a tenuous and inhomogeneous atmosphere. Primarily made up of SO_2, the atmosphere is supported by a combination of direct volcanic injection and sublimation of SO_2 ice, which covers large areas on the surface. Ever since the discovery of Io's atmosphere during the Voyager 1 flyby, the question of the relative proportion and importance of these two end member mechanisms in supporting Io's atmosphere remains largely unresolved. Here, we discuss the first observations of the bulk molecular SO_2 atmosphere of Io as it enters eclipses by Jupiter. By removing sunlight, the eclipse allows study of the effect of ice sublimation on the atmosphere.

Background: A number of studies of atmospheric emissions by atomic S and O have been made of Io's atmosphere going into and out of eclipse by Jupiter in order to study atmospheric support [1, 2]. These observations tend to show decreased emissions in eclipse, suggesting the atmospheric density decreases significantly in eclipse, and thus is primarily supported by SO_2 ice sublimation. At the same time, measurements of near-IR absorption of SO_2 ice on the surface as a function of time after eclipse egress have been made. If an atmosphere is supported by ice sublimation, the band depths of the ices should decrease as the surface is heated soon after eclipse egress. Observations before and after eclipse have proved inconclusive, with Cassini-VIMS observations showing significant desorption compared to preclipse values [3] suggestive of ice sublimation support of the atmosphere. Conversely, followup IRTF ground-based observations showed no change of the surface bands soon after eclipse egress [4].

More recently, we made observations from the Hubble Space Telescope with the Cosmic Origins Spectrometer of atmospheric SO_2 in absorption on Io at near-ultraviolet wavelengths. Two post-eclipse reappearance observation of the atmosphere showed no change in atmospheric density in response to sunlight after eclipse; the increase in surface temperature appeared not to affect the atmospheric density as would be expected if ice sublimation supported the atmosphere [5]. This was intepreted to be evidence for a largely volcanic supported atmosphere, at least on the Jupiter facing hemisphere.

Observations: We wanted to observe Io going into eclipse to confirm the post-eclipse observations conclusions that resulted from our HST-COS data. We wanted to see if mid-IR atmospheric bands showed the same non-response behavior as the UV. 19 μm spectroscopy of atmospheric SO_2 absorptions seen against the thermal emission from Io's surface [6] can probe the bulk molecular atmosphere even during Jupiter eclipse. However the low flux levels in eclipse require the use of 8-meter class telescopes to obtain sufficient SNR. We present observations by the TEXES mid-infrared spectrometer of Io at 19 μm, taken at the Gemini North telescope on November 17 and 23, 2013, where Io was observed before, during and in eclipse by Jupiter. Spectra were taken at a spectral resolution of ~80,000 with signal-to-noise (on the continuum) of between 100 and 200 at ~8 minute intervals. Observations span 45 minutes before Jupiter eclipse ingress to 50 minutes after. Figure 1 shows an example of the spectra taken. We fit a radiative transfer model to measure the band depth, which contains information on atmospheric SO_2 column abundance and temperature.

Results: These data from Gemini-TEXES are the first ever observations of Io's bulk molecular atmosphere in Jupiter eclipse. They provide constraints on the response of the atmosphere in eclipse, as well as (via the total thermal flux), the surface cooling during eclipse. Figure 2 shows the total flux and SO_2 band depth at 530.42 cm^{-1} before and after eclipse ingress. After 50 minutes, the 19 μm thermal flux drops to 33% of its pre-eclipse value, as the surface cools in the absence of sunlight. At the same time the SO_2 band depth also decreases, from 2.5% pre-eclipse to < 0.5% after 50 minutes in eclipse. One possible interpretation is the atmosphere has truly collapsed in eclipse; as the surface temperature drops, SO_2 vapor pressure drops with surface temperature. However, further modeling is needed to confirm this interpretation, as the rot-vib temperatures of SO_2 that generate the absorption are in non-local thermodynamic equilibrium (non-LTE) which depend strongly on atmospheric and surface temperatures, and surface temperatures (perhaps atmospheric temperatures too) change rapidly after eclipse ingress. Both the 19 μm thermal flux and the spectra themselves can help us constrain the surface and atmospheric temperatures during the eclipse period. In addition, we have thermophysical models [5] that can predict the temperature behaviour of SO_2 ice and frost-free regions.

Constraints on the pre-eclipse atmospheric temperature can be made from fitting our observations with model spectra. The expected time constants for atmospheric temperature change [7], and the existing surface eclipse thermal models [8] provide additional constraints on the surface temperatures. Fig 3 shows a likely scenario, where for low atmospheric temperatures (~100K), the change in band depths (BD) at 530.42 cm^{-1} due to surface cooling (130 K to 90 K) is very small (ΔBD<0.5%) for a constant SO_2 density. The fact we see much larger changes (ΔBD~2.5%) potentially indicates atmospheric collapse.

Conclusions: We present unique mid-infrared observations of Io's bulk SO_2 atmosphere during Jupiter eclipse, which show rapid reduction in SO_2 band strength following eclipse ingress. Derived atmospheric and surface temperatures are will be discussed, and models to interpret the data will be presented. The question of whether Io's primary atmosphere has collapsed during eclipse will be discussed, pending further analysis.

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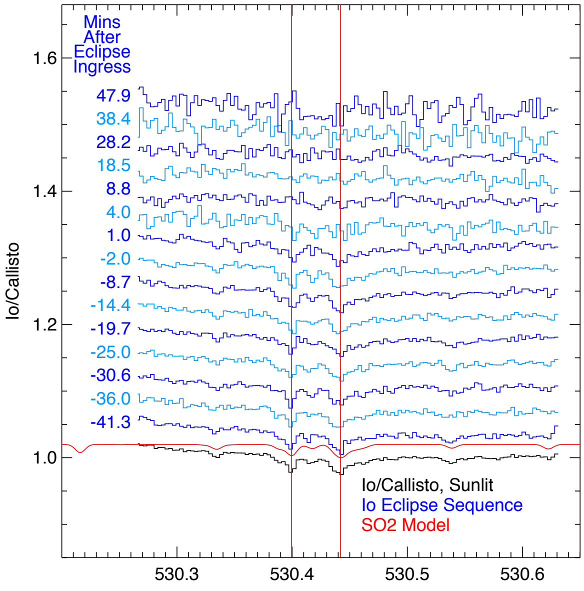

Fig 1: Transmission spectra from Io taken before and during eclipse. The main band at 530.42 cm^{-1} (18.853 µm) is highlighted (red vertical lines). As Io enters and remains in eclipse, the atmospheric bands start to decrease.

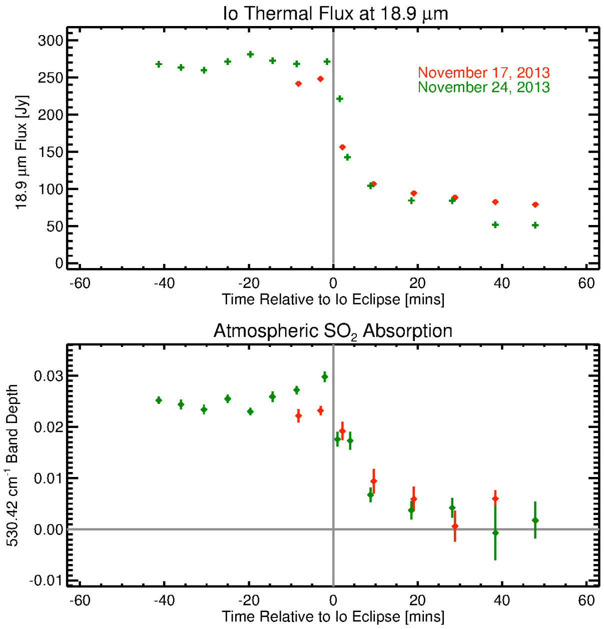

Fig 2: Io's response to eclipse by Jupiter (top) Thermal flux at 19 µm (bottom) Main atmospheric SO_2 absorption at 530.42 cm-1 (18.853 µm).

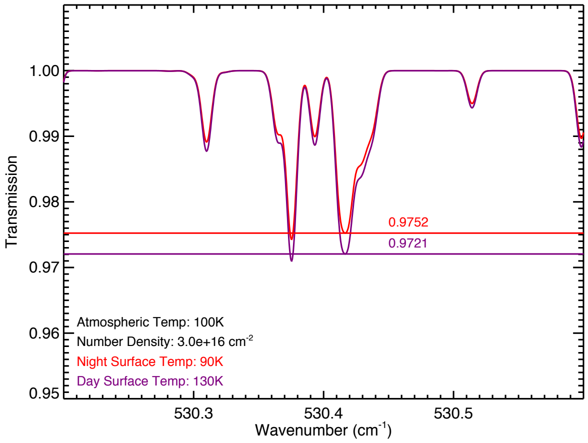

Fig 3: Synthetic spectra which potentially shows the observations of Io's atmosphere has collapsed during eclipse. For low atmospheric temperatures, at a constant SO_2 density, the band depths do not change significantly for a change in surface temperature. The observed 530.42 cm^{-1} band depth change however (2.5% to 0.5%) would therefore indication atmospehric collapse.