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Io's Atmosphere: Support by Sublimation or Direct Volcanic Injection

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Abstract

An outstanding mystery in the study of Io is the nature of its thin SO_2 atmosphere. Since its discovery, there has been uncertainty about what supports the atmosphere. Is its abundance controlled by direct volcanic injection, or via sublimation of the considerable amount of SO_2 frost on the surface? Here, we summarize recent measurements and discoveries concerning Io's atmosphere, with particular focus on the 19 µm SO_2 absorption bands as seen from the TEXES instrument at NASA's Infrared Telescope Facility (IRTF). We fit multiple blended lines to retrieve atmospheric temperature and SO_2 column density from 2001 through to 2010. We show that there is a good match between long-term variations in the observed density of the atmosphere and variations in the sublimation vapor pressure equilibrium of SO_2 frost over seasonal timescales, due to Io's varying heliocentric distance. This correlation indicates a possible predominance of sublimation over volcanic support of Io's atmosphere, though it appears likely that a volcanic component is required in addition, to account for the significant atmosphere remaining at aphelion.

1. Introduction

The Jovian moon Io sustains a tenuous atmosphere due ultimately to the intense volcanic activity caused by tidal heating. The atmosphere predominantly consists of SO_2 along with smaller amounts of SO, S_2 and other trace species such as NaCl. The loss of this atmosphere into the Jovian magnetosphere affects the entire Jovian system. Combined with the unique volcanic contributions and the interaction with surface frost, it makes Io's atmosphere one of the most fascinating atmospheres in our Solar System. The Io atmosphere allows us to study unique atmospheric processes, adding to our understanding of basic atmospheric physics and surface-atmosphere interactions.

1.1 Io's Atmosphere at 19 µm

The first detection of the 19 µm ν_2 SO_2 band was made in November 2001 using the Texas Echelon-cross-Echelle Spectrograph (TEXES) on the 3.0 m NASA Infrared Telescope Facility (IRTF) at Mauna Kea [1]. Passive thermal emission from the solar-heated surface, and radiation from active volcanoes, is absorbed and re-emitted by the atmosphere. It was the first time infrared atmospheric absorption on Io had been detected since the discovery of the SO_2 atmosphere at 7.3 µm. It was discovered that i) the ν_2 lines were almost always in absorption, ruling out a large set of possible combinations of temperature and density, ii) the anti-Jovian hemisphere had a markedly higher SO_2 absorption band strength than the sub-Jovian hemisphere, with 530.41 cm^{-1} band depths of 7% and 1% respectively, iii) the inferred atmospheric kinetic temperature is below 150 K. Given these conditions, the inferred equatorial column density varies from 1.5×10^{17} cm^{-2} at L=180° to 1.5×10^{16} cm^{-2} at L=300°. For a particular longitude, the years in which there were data (2001, 2002, 2004) showed the SO_2 column densities were fairly constant.

2. 2001 – 2010 Atmospheric Change

Here, we present an analysis of our 19 µm data incorporating new observations between January 2005 and June 2010, and a re-analysis of earlier data from November 2001 through January 2004 [2]. Unlike the previous analysis, we have fitted all 16 detected blended absorption lines of the ν_2 SO_2 vibrational line to retrieve the global mean values of

SO_2 column abundance and the gas kinetic temperature. Fitting for temperature directly removes the need to assume an atmospheric temperature to derive column abundances, and provides a more resilient interpretation of the complex non-LTE lines seen at 19 µm than previously possible. By incorporating an existing disk-integrated model of Io's surface temperatures and atmosphere, we retrieve sub-solar column densities. The spectra from all years are best fitted by atmospheric temperatures < 150 K. Best-fit atmospheric temperatures on the anti-Jupiter hemisphere, where SO_2 gas abundance is highest, are low and stable, with a mean of 135 (± 18) K. The sub-solar SO_2 column density between longitudes of 90º to 220º varies from a low of 0.85 (± 0.278) x 10^{-17} cm^{-2}, near aphelion in 2004, to a high of 1.82 (± 0.11) x 10^{-17} cm^{-2} in 2010 when Io was approaching its early 2011 perihelion (Fig. 1). No correlation in the gas temperature was seen with the increasing SO_2 column densities.

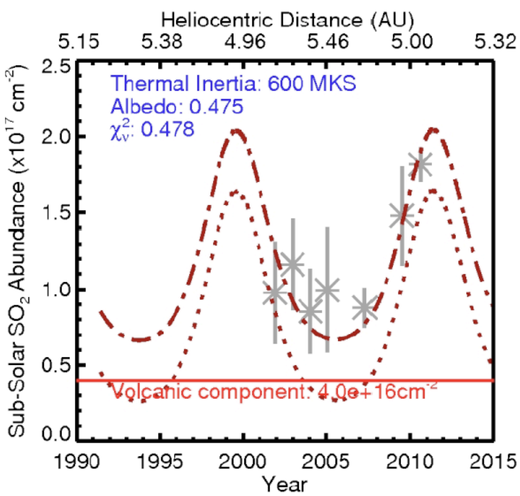

Figure 1. The seasonal variation of SO_2 column abundance in Io's atmosphere on the anti-Jupiter hemisphere, as measured at 19µm, compared to a representative model including vapor-pressure equilibrium and volcanic components. Taken from [2].

2.1 Thermal Inertia and Albedos

Assuming that any volcanic component of the atmosphere is constant with time, the correlation of increasing SO_2 abundance with decreasing heliocentric distance provides good evidence that the atmosphere is at least partially supported by frost sublimation. The moderate amplitude of the variation implies a significant volcanic component that is more constant with time, and perhaps also a high thermal inertia for the surface SO_2 frost, which would moderate its seasonal temperature variations. The thermal inertias and albedos that fit the variation in atmospheric density best are between 200 to 1500 W m^{-2} $s^{-1/2}$ K^{-1} and 0.575 to 0.425 respectively. Photometric evidence favors albedos near the upper end of this range, corresponding to thermal inertias near the lower end. The seasonal thermal inertia we measure probes deeper into the subsurface than previous measurements due to the timescales of many years, while previous studies have determined thermal inertias relevant for timescale of ~2 hours (eclipse) or ~2 days (diurnal curves).

6. Summary and Conclusions

We infer that the atmospheric density of Io has increased with decreasing heliocentric distance over the last few years. We place constraints on the relative contribution of sublimation over volcanism components for the support of the atmosphere. At aphelion, in our best-fit models sublimation contributes 20 to 63% of the total density of the atmosphere (sublimation + volcanic). At perihelion, assuming a constant volcanic background, sublimation support seems to dominate in supporting the atmosphere, with an average of almost 70% from sublimation, but can be as low as parity with the volcanic component. This work shows clear evidence that the global, long-term atmosphere of Io is supported by both sublimation of surface frost, as well as volcanic injection of SO_2, and suggests a modest predominance for the sublimation component over the volcanic component, at least at perihelion.

References

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