IO’S SURFACE AND SO₂ ATMOSPHERE: FIRST DISK-RESOLVED MILLIMETRIC OBSERVATIONS
A. Moullet¹, E. Lellouch¹, R. Moreno¹, M. Gurwell², C. Moore³
¹LESIA-Observatoire de Paris, 5 place J.Janssen 92195 Meudon, France ²CFA-Smithsonian institute, 60 Garden Street, Cambridge MA 02138, USA ³The University of Texas at Austin, Austin, TX 78712, USA

Introduction: Io has a very tenuous atmosphere mainly composed of SO₂, which exhibits high spatial variability [1]. First interpretation of SO₂ disk-averaged lines at millimeter wavelengths suggested a very hot (250-700 K) and localized atmosphere (5-20 % of the surface) [2]. We report on the first disk-resolved millimeter-wave observations of Io’s SO₂ atmosphere and continuum emission at 1.3mm, obtained with IRAM-Plateau de Bure interferometer (PdBI)¹.
Mapping of the SO₂ emission is needed to disentangle between temperature, distribution and dynamical effects. The ultimate goal is to distinguish between volcanic outgassing and SO₂ frost sublimation equilibrium as possible gas replenishment mechanisms.

Observations: Leading and trailing hemispheres were observed on January 28 and February, 2005. PdBI (6 antennas of 15m diameter) was employed in its then most extended configuration, producing a 0.5x1.5 arcsec HPHW synthetized beam: Io (1 arcsec) was resolved in its longitudinal direction. The target line was the SO₂ rotational line at 216.643 GHz and the spectral resolution was 40 kHz, adequate to resolve the 0.6 MHz line width. Continuum emission at 1.3 mm was observed in a broad 320 MHz band.

Continuum analysis: Total flux measurements of continuum emission indicate brightness temperatures of 93 K on the leading side and 99 K on the trailing side, which is significantly lower than surface temperatures [3]. The temperature difference between the two sides reflects the albedo changes.

On the trailing side, zero-point position of UV-plane visibilities is measured (Fig 1.). Best fit is obtained for a uniform brightness temperature. According to the thermal model proposed in [4], it implies very low variations of physical temperature and emissivity with solar zenith and emission angles, that constrain surface dielectric constant to low values (ε<1.2). All these results strongly suggest that we are actually measuring subsurface thermal emission.

Line data analysis: UV-plane analysis of the SO₂ emission maps integrated over the line width (Fig. 2) shows that:
- the emission region is marginally narrower than continuum: resolved size is 0.85±0.2 arcsec on the leading, and 0.55±0.2 arcsec on the trailing (40% and 70% of the disk, broader than previous estimates)
- the emission maximum is displaced (at 2σ) to the (sky)-East with respect to continuum.

On the leading side, resolved spectra could be retrieved with enough S/N. This provides the first observational constraint on gas dynamics, showing:
- a Doppler shift gradient (Fig. 3) in the prograde direction with a 0.4±0.1 km/s limb-to-limb shift differ-

---
¹ IRAM is supported by INSU/CNRS (France), MPG (Germany) and IGN (Spain)

Fig. 1: Trailing side continuum visibilities real-part around zero-point, plotted against temperature/emissivity models.

Fig. 2: Interferometric maps of SO₂ emission at 216 GHz integrated over 600 kHz. Left: leading side, Right: trailing side.
ence, and ~0.1 km/s redshift at central longitude - high variations of the line width from 300 to 700 m/s over the disk.

**Hydrostatic interpretation:** Data was interpreted through a radiative transfer model, assuming an hydrostatic atmosphere in LTE conditions, which is realistic for a sublimation-driven atmosphere. Two SO$_2$ distribution models were tested:

- one based on HST spatially resolved data [5]
- one based on IR-disk-averaged spectra [3], more localized and with higher column densities than [5]

Column densities being fixed, free parameters are gas temperature and dynamics. We find that SO$_2$ distribution model from [5] reproduces quite well data emission maps shapes, though the column densities proposed appear ~ 30% too low to explain total flux.

The SO$_2$ line obtained on the leading side at PdBI is fitted together with disk-integrated lines obtained in 1999 with IRAM-30m antenna (Fig. 4). Best fits of SO$_2$ lines are obtained with atmospheric temperature between 150-230 K, much colder than previous estimations. A dynamic effect is also needed to explain the line-width, such as a zonal wind. Low Doppler-shifts of the disk-integrated data exclude a day-to-night flow (typical for a sublimation-driven atmosphere), then a prograde wind about 230±50 m/s wind is preferred. This wind also reproduces the measured Doppler-shift limb-to-limb difference (Fig. 3), but with no red-shift at central longitude, and no variation of the line-width across the disk.

**Volcanic interpretation:** We used the DSMC models from [6] to describe volcanic plumes in terms of column density, temperature and dynamics, and the resulting SO$_2$ line emission. First calculations show that the particles falling from the plume produce high Doppler-shifts, whose sign depends on the plume position. The presence of a sublimation layer over which particles bounce lowers this effect. Based on known plume positions, emission maps show that more gas is needed to reproduce total flux and emission shape, as well as the high redshift measured at western limb.

**Conclusions:** Interpretation of data through hydrostatic models is only partially satisfying: the distributions models can explain observed line flux, line width, and emission shape, but the superrotating wind hypothesis is not consistent with the red-shift observed at central longitudes, and variations of the line-width are not reproduced. Volcanic models can help this. A sublimation layer should be still present to explain the total emission flux, the emission shape and the recessing wind at western limb. Further calculations will help better constraining the contribution of each gas source.

**References:**


**Acknowledgments:** We thank Lori Feaga who kindly collaborated.