MEASUREMENT OF IO'S ATMOSPHERE DURING THE IVO MISSION.

P. Wurz[1], A. Vorburger[1], A.S. McEwen[2], K. Mandt[3], A. G. Davies[4], S. Hörst[5], N. Thomas[1], [1] University of Bern, Bern, Switzerland (peter.wurz@space.unibe.ch), [2] Lunar and Planetary Laboratory, Tucson, AZ, USA, [3] Johns Hopkins University-Applied Physics Laboratory, Laurel, MD, USA, [4] Jet Propulsion Laboratory-California Institute of Technology, Pasadena, CA, USA, [5] Johns Hopkins University, Baltimore, MD, USA.

Introduction: The Io Volcano Observer (IVO) is a proposed NASA Discovery-class mission (currently in Phase A), that would launch in early 2029, arrive at Jupiter in mid-2033, and perform ten flybys of Io while orbiting Jupiter [1]. IVO's mission motto is to 'follow the heat', shedding light onto tidal heating as a fundamental planetary process. Specifically, IVO will determine (i) how and where heat is generated in Io's interior, (ii) how heat is transported to the surface, and (iii) how Io has evolved with time. The answers to these questions will fill fundamental gaps in the current understanding of the evolution and habitability of many worlds across our Solar System and beyond where tidal heating plays a key role, and will give us insight into how early Earth, Moon, and Mars may have worked.

One of the five key science questions IVO will be addressing is determining the composition of Io's atmosphere and its mass loss via atmospheric escape. Understanding Io's mass loss today will offer information on how the chemistry of Io has been altered from its initial state and would provide useful clues on how atmospheres on other bodies have evolved over time. IVO plans on measuring Io's mass loss in situ with the Ion and Neutral Mass Spectrometer (INMS), a successor to the instrument that has been built for the JUpiter Icy moons Explorer (JUICE) [2,3].

The Ion and Neutral Mass Spectrometer: INMS is contributed by University of Bern to the IVO mission. INMS is a time-of-flight (TOF) mass spectrometer that provides high mass resolution, high temporal resolution, and large dynamic range in a small package. The INMS instrument is identical to that flying on JUICE, being part of the Particle Environment Package (PEP) [12], with extensive heritage from earlier designs [10, 11, 13]. INMS will measure neutrals and ions in the mass range 1 – 300 u/e, with a mass resolution ($M/\Delta M$) of 500, a dynamic range of $> 10^5$, a detection threshold of 100 cm^{-3} for an integration time of 5 s in the radiation environment at Io, and a cadence of 0.5 – 300 s per mass spectrum.

As a TOF mass spectrometer, INMS measures the abundance of ion and neutral species according to their mass [10,11]. INMS has three operation modes, to address different measurement objectives. Two modes are used for measuring neutral composition. In these modes, neutrals enter the instrument either through the closed source (thermal mode) or the open source (neutral mode). Neutrals are then ionized in the ion source, which produces packets of ions through pulsed extraction by a high-voltage start pulse with repetition frequency 10 kHz. The ion source has two filaments to provide redundancy of the critical part of the ion source. When measuring ions, ambient ions enter through the open source (ion mode) and pass through the ion source, which is not operating because ionization of the target gas is not necessary.

Packets of ambient ions or ions produced by electron impact ionization of neutral gas are then guided into the ion optics. All ions in the packet have the same kinetic energy, so their mass-dependent speeds result in different travel times across the TOF section. Separation by species is achieved by measuring the travel times of all ions in the packet and is further enhanced using an ion mirror to lengthen the ion path, which about doubles the mass resolution.

Io Atmosphere Modelling: In preparation for the INMS measurements on IVO, we model atmospheric density profiles of species known and expected to be present on Io's surface from both measurements and previous modelling efforts. Based on the IVO mission design, we investigate three different measurement scenarios for INMS we expect to encounter at Io during the flybys: (i) a purely thermal atmosphere from sublimation, (ii) the 'hot' atmosphere evaporated from lava fields, and (iii) the plume gases resulting from volcanic activity. These scenarios are shown Figure 1.

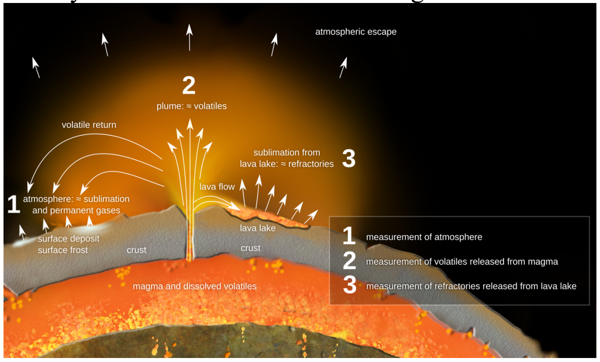

Figure 1: Overview of the INMS measurements of Io's atmosphere on the IVO spacecraft. Figure adapted from Keck Institute for Space Sciences / C. Carter & J. T. Keane.

Sublimated Atmosphere: For the sublimated atmosphere (dayside at 130 K, IVO flybys 3, 4, 5, 6, 8, 10) we consider SO_2 [4], and the derived species SO, O_2, O_3, and H_2S and H_2O, which might be part of the SO_2 frost

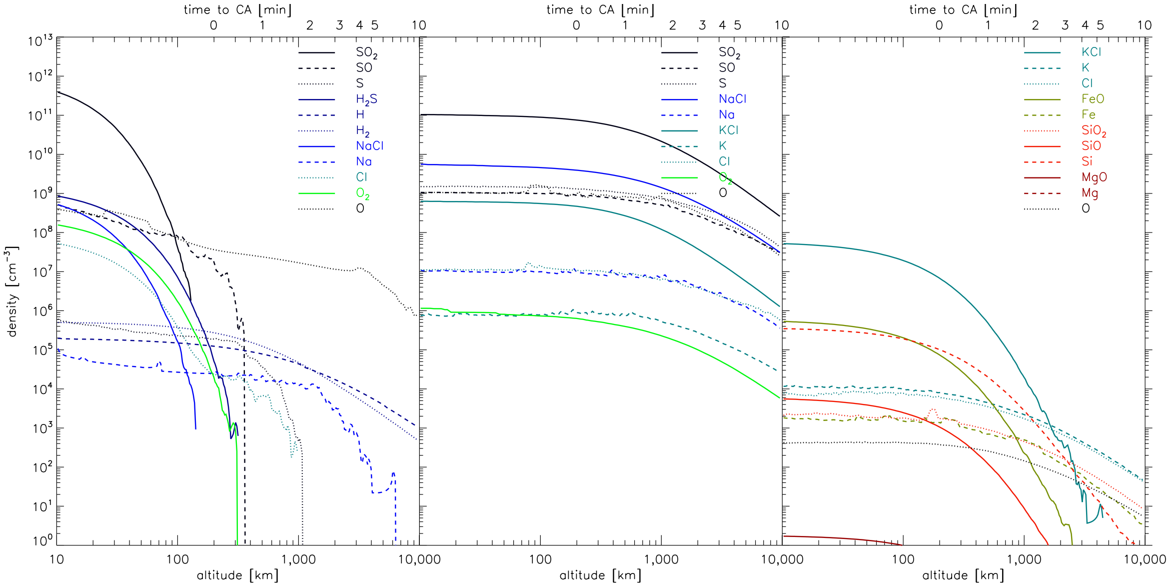

Figure 2: Density profiles for the sublimated atmosphere (left panel), for the atmospheric contribution from evaporation of lava fields (middle panel), and for the atmospheric contribution from volcanic plumes (right panel).

on the surface [5]. In addition, there is some sputtering from the surface by the co-rotating plasma on Io's upstream side (IVO flybys 4, 6, 8, 10). Sputtering will contribute Na and Cl (from NaCl) and K (from KCl) to the atmosphere, with Na already being observed in Io's atmosphere [6].

Hot atmosphere: For the species of the hot atmosphere, we consider the species contributed by the lava lakes. For lava composition we use a high temperature, low-viscosity silicate lava [7], similar to Hawaiian basalt [8]. Typically, only a small fraction of the lava surface is at ≥1350 K, and contributing to the atmosphere. IVO flybys 1 and 2 are over extensive lava lakes on Io's night side, thus little interference from the regular atmosphere is expected, IVO flyby 4 is over Loki Patera on the day side where multi-instrument imaging will be available. We use the thermodynamic data to calculate evaporation from the hottest surface fractions of the lava lakes. The contributions from the evaporation of a lava lake are KCl, KO, K_2O, FeO, SiO_2, SiO, AlO, MgO, CaO, NaO, Na_2O, and their fragment atoms K, Cl, Fe, Si, Mg, Ca, Al, and O.

Plume Gases: We assume that the dominant species in the plume at the altitudes sampled by the spacecraft are volatiles (IVO flyby 6), which were initially dissolved in magma and released when the lava erupts from the volcano. The composition of these volatiles is based on earlier modelling of the volatiles in Pele's plume [9], which are SO_2, S_2, NaCl, KCl, S_2O, SO_3, O_2, and the respective fragments.

We calculate atmospheric density profiles for all known and expected species for these three measurement scenarios, considering the actual IVO observation conditions. These density profiles are displayed in Figure 2. In addition to the release of these species into the atmosphere, there are the usual processes of deposition on the surface, re-sublimation, aggregation at cold spots (like the polar areas), chemical processes on the surface, radiolysis, and atmospheric loss via escape or ionization. Io's mass loss is very important for Jupiter's magnetosphere since Io releases about 1100 kg/s of SO and almost 100 kg/s SO_2, forming Io's neutral clouds and ion torus, which serves as major source of the particle population in Jupiter's magnetosphere.

From the density profiles we calculate the expected mass spectra to be recorded by INMS during the IVO flybys for the three atmospheric scenarios.

Acknowledgments: This work was supported by the Swiss National Science Foundation.

References: [1] McEwen A. S. et al. (2021), this conference. [2] Föhn M., et al., *IEEE Aerospace proceedings*, (2021), in press. [3] Lasi, D. et al., *IEEE Aerospace Proceedings* (2020), 20 pages, DOI: 10.1109/AERO47225.2020. 9172784. [4] Lellouch E. et al., in *Io After Galileo*, eds. R. Lopes and J. Spencer, Springer, 2007. [5] Salama F. et al., *Icarus*, 107, 413 (1994). [6] Burger M.H. et al., *Astrophys. J.*, 563, 1063 (2001). [7] Davis A.G. et al., *Geophys. Res. Lett.*, 38, L21308 (2011). [8] Wright T.L. *Geological Professional Paper* 735 (1971). [9] Moses J.I. et al., *Icarus* 156, 76 (2002), *Icarus* 156, 107 (2002). [10] Scherer S. et al., *Int. Jou. Mass Spectr.*, 251,73 (2006). [11] Wurz, P. et al., *Planet. Sp. Science*, 74, 264 (2012). [12] Barabash S. et al., *European Planetary Science Congress*, 8 (2013), EPSC2013-709. [13] Abplanalp, D. et al., *Adv. Space Res.* 44, 870 (2009).