SCIENTIFIC RETURN OF A DUST ANALYZER AT IO. T. N. Harrison[1], J. Szalay[2], C. W. Parker[3], R. Potter[4], H. Trammell[5], S. Shkolyar[6], T. Suer[7], M. L. Cable[8], J. Cumbers[9], D. Gentry[10], S. Naidu[11], S. Padovan[11], J. Reimuller[12], C. Walker[13], J. Whitten[14], [1]University of Western Ontario, London, ON (tharri43@uwo.ca), [2]University of Colorado Boulder, Boulder, CO, [3]Boston University, Boston, MA, [4]Lunar and Planetary Science Institute, Houston, TX, [5]University of Houston, Houston, TX, [6]Arizona State University, Phoenix, AZ, [7]Stony Brook University, Stony Brook, NY, [8]Jet Propulsion Laboratory, Pasadena, CA, [9]NASA Ames (USRA), Moffett Field, CA, [10]Stanford University, Stanford, CA, [11]University of California Los Angeles, Los Angeles, CA, [12]Integrated Spaceflight, Boulder, CO, [13]University of Michigan, Ann Arbor, MI, [14]Brown University, Providence, RI.

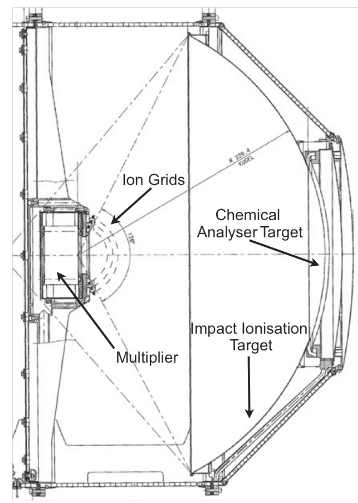
Introduction: Io is the most geologically dynamic body in the Solar System. Its surface is covered with active volcanoes (the largest in the Solar System) with plume heights in excess of 400 km above Io's surface [e.g. 1]. High temperature lavas on Io resemble Archaean-aged komatiite lavas on Earth [2], and eruptions on Io are similar in scale to those of ancient terrestrial, Martian and Venusian flood basalts [3]. Volcanism is a key geological process, and Ionian volcanism could be a potential laboratory for investigating early volcanic episodes and evolution on terrestrial planets.

Based on the most recent planetary science decadal survey [4] and New Opportunities in Solar System Exploration (NOSSE) report [5], an Io Observer mission was included in the 2009 New Frontiers Announcement of Opportunity [6]. The decadal survey called for the Io Observer to focus on determining Io's internal structure and to investigate the mechanisms contributing to its extensive volcanic activity. The recommended mission payload consisted of a narrow angle imager, thermal mapper, ion and neutral mass spectrometer, and a flux gate magnetometer.

Here we propose an additional instrument that would enhance our understanding of Io—a dust analyzer—which would be capable of determining the composition of dust grains in Io's atmosphere and volcanic plumes, providing direct and indirect analysis of Io's volcanic activity as well as insights into Io's formation, interior and surface structure, and atmosphere.

Dust Analyzer: The proposed instrument is an impact-ionization dust analyzer with time-of-flight (TOF) mass spectra capability, similar to the Cosmic Dust Analyzer (CDA) aboard Cassini (Fig. 1) [7]. A high velocity impact on the hemispherical target transforms the striking dust particle into a mixture of particle fragments and impact plasma. After separation by an electric field, ions and electrons are collected by separate electrodes. To integrate a linear TOF mass spectrometer into the dust analyzer, the hemispherical impact target has a chemical analyzer target with a biased grid directly above it. This grid accelerates the ions, which are focused into the multiplier yielding spectra for each impact. The proposed instrument will have dual polarity functionality in order to measure both positive and negative ion spectra.

Figure 1. Schematic of the dust analyzer, showing both chemical analyzing target and non-chemical analyzing target. [8]



Utilization at Io: A dust analyzer is capable of directly and indirectly observing volcanic activity on Io, allowing for nearly continuous observations of volcanic activity throughout the entire orbit of the spacecraft (assuming a Jupiter-centric orbit due to radition conditions at Io). Near Io, other spacecraft instruments can directly observe Io and the dust analyzer can sample any material through which the spacecraft flies, such as a Io's atmosphere, the plasma/neutral tori, or a volcanic plume. Indirectly, observations of charged dust grains may be made in other parts of the orbit when Io is not in view or is too distant to be observed by other instruments on the spacecraft.

Volcanic eruptions on Io are a continuous source of dust in the Jovian system. Analysis of multiple volcanic plume observations indicate plumes may contain up to 10^6 kg of grains ranging from tens to hundreds of nanometers in diameter [9]. Once in the plume, these grains may collect charge and eventually spiral out of the Jovian system under the influence of Jupiter's corotating electric and magnetic fields [10]. As demonstrated previously with Ulysses [10], Galileo [11], and

Cassini [1], the trajectories of these particles can be correlated to Io origins using a dust analyzer.

Science Return: The analysis of iogenic dust and volcanic ejecta provided by a dust analyzer provides information on Io's volcanic processes as well as Io's interior, surface, and atmosphere. The identification of silicates in plume ejecta will provide information about the type and distribution of Ionian magma, a topic currently debated by the scientific community [e.g. 12; 13; 14; 15]. Varying silicate content between different plumes may indicate different volcanic processes, while similar proportions might point to a single dominant volcanic process for Io, and potentially a central body of magma (e.g. a "magma ocean" [16]).

Determining plume compositions could aid in resolving the question of whether sulfur or silicate volcanism dominates on Io. Earth-based spectral data points toward predominantly sulfur [e.g. 17], while Io's bulk density and topography suggest abundant silicates [e.g. 18; 19; 20]. Lava flow temperatures on Io also point to silicates, as some measured temperatures are too high to be molten sulfur (>800K) [21; 22].

A dust analyzer can also be used to probe Io's interior as it is capable of detecting volcanic crystal compounds, as well as making measurements of specific isotopic ratios, such as O^{16} and O^{18}. The identification of volcanic crystal compounds such as orthopyroxenes and the presence of alkali- or magnesium-rich silica can constrain models of the degree of melting and differentiation that Io's interior has undergone. Isotope ratios can provide information on Io's formation and the state of its interior. Ratios similar to that of the solar nebula would indicate that Io's composition is relatively primordial while differing ratios may be indicative of an internal production process.

Measurements of the particulate distribution of volcanic and impact ejecta from Io will aid in determining its mass flux and the density profile of Io's atmosphere. The loss of volatiles from Io's atmosphere can be investigated by identifying elements such as Na, K, Cl, and S in plume ejecta, as plumes are thought to be a primary source of Io's transient atmosphere [23].

Conclusions: Inclusion of a dust analyzer on an Io mission will allow measurements of the composition of iogenic dust grains, and therefore help answer questions regarding Io's formation, interior structure, volcanic mechanisms, surface chemistry and atmosphere put forward in the decadal survey. The breadth of results available from a dust analyzer make it an invaluable instrument on any future Io mission.

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References: [1] Postberg, F. et al. (2006), *Icarus*, 183, 122–134. [2] McEwen, A. S. et al. (1998), *Science*, 281, 87–90. [3] Keszthelyi, L. et al. (2006), *Jour. Geo. Soc.* 163, 253–264. [4] Committee on the Planetary Science Decadal Survey Space Studies Board, Division on Engineering and Physical Sciences (2011), *Vision and Voyages for Planetary Science in the Decade 2013–2022*. [5] Committee on New Opportunities in Solar System Exploration: An Evaluation of the New Frontiers Announcement of Opportunity (2008), *Opening New Frontiers in Space: Choices for the Next New Frontiers Announcement of Opportunity.* [6] NASA NNH09ZDA007O (2009). [7] Srama, R. et al. (2004), *Space Sci. Rev.,* 114, 465–518. [8] Kempf, S., et al. (2012), *Planet. Space Sci.,* 65, 10–20. [9] Geissler, P. and Goldstein, D. (2009), in *Io After Galileo,* 167–171. [10] Horanyi, M, et al. (1993), *Nature*, 363, 144-146. [11] Theissenhusen, K. U. et al. (2000), *Icarus,* 144, 89–98. [12] Schubert, G. et al. (1981), *Icarus*, 47, 46–59. [13] Ross, M. N. and Schubert, G. (1985), *Icarus*, 64, 391–400. [14] Spencer, J. R. and Schneider, N. M. (1996), *Annu. Rev. Earth Planet. Sci.*, 24, 125–190. [15] Keszthelyi, L. et al. (1999), *Icarus*, 141, 415–419. [16] Khurana, K., et al. (2011), *Science,* 332, 1186-1189. [17] Wamsteker, W. et al. (1974), *Icarus*, 10, 1–7. [18] O'Leary, B. T. and Van Flandern, G. F. (1972), *Icarus*, 17, 209–215. [19] Clow, G. D. and Carr, M. H. (1980), *Icarus*, 44, 729–733. [20] Davies, M. E. (1982), *Satellites of Jupiter*, D. Morrison (ed.), 911–914. [21] Johnson, T. V. et al. (1986), *Science*, 242, 1280–1283. [22] Veeder, G. J. et al. (1994), *Jour. Geophys. Res.,* 99, 17095–17162. [23] Lellouch, E. et al. (1992), *Icarus*, 183, 323.