IO VOLCANO OBSERVER (IVO). A. McEwen[1], L. Keszthelyi[2], J. Spencer[3], N. Thomas[4], T. Johnson[5], P. Christensen[6], P. Wurz[4], K.-H. Glassmeier[7], C. Shinohara[1], T. Girard[8], G. Heinsohn[8], R. Furfaro[1], T. Gardner[9], D. Cheeseman[9], R. Beatty[5], J. Ludwinski[5], T. Kowalkowski[5], C. Yen[5], T. Elliott[5], E. Turtle[10], K. Strohbehn[10], J. Janesick[11], C. Falco[1], R. Evans[12] [1]University of Arizona (Tucson, mcewen@lpl.arizona.edu), [2]USGS, [3]SwRI/Boulder, [4]U. Bern, [5]JPL, [6]ASU, [7]IGEP, [8]Microsat Systems Inc., [9]Raytheon MS, [10]APL, [11]Sarnoff Corp., [12]Gibble Corp.

Introduction: In early FY2008, NASA solicited study concepts for Discovery/Scout-class missions that would be uniquely enabled by use of 2 government-furnished Advanced Stirling Radioisotope Generators (ASRGs) [1-2]. Each ASRG can provide ~140 W electric from just 0.8 kg Pu^{238} , as well as ~100 W thermal that can be redistributed to heat spacecraft (S/C) components. Given the great scarcity of Pu^{238} the ASRGs have tremendous potential value, but NASA wants the first flight to be on a relatively low-cost mission. We proposed an Io Volcano Observer (IVO) study concept, because the ASRGs enable pointing flexibility and a high data rate from a low-cost mission in Jupiter orbit. An Io Observer is a high priority to the NASA science community as a candidate New Frontiers mission [3-4], but we think the top science priorities might be achievable from a mission capped at $450M (including launch), with a GFE ASRG power system and some contributed payload elements.

Science Objectives: Io presents a rich array of interconnected orbital, geophysical, atmospheric, and plasma phenomena [5-6]. It is the only place in the Solar System (including Earth) where we can watch very large-scale silicate volcanic processes in action, and it provides unique insight into early high-temperature volcanic processes that probably were important in the early histories of the terrestrial planets. Io is the best place to study tidal heating, which greatly expands the habitable zones of planetary systems. The coupled orbital-tidal evolution is key to understanding the histories of Europa and Ganymede. Our focused top-level objectives are to better understand (1) active volcanic processes, (2) tidal heating, and (3) loss of material from Io and effects on the magnetosphere, plasma torus, and neutral clouds. Jupiter system science is a secondary objective.

Mission Concept: Jupiter's trapped radiation belts pose the major challenge to a mission that gets close to Io. We adapted the strategy of an elliptical orbit inclined > 45º to Jupiter's orbital plane with repeated fast flybys of Io [7]. The nominal mission features launch in early 2015, VEEGA trajectory, Jupiter Orbit Insertion (JOI) in early 2021, and 7 Io flybys including one immediately prior to JOI. The orbit will be pumped down from an initial 200-day period to ~30 days, with flyby distances ranging from ~100-1000 km. The total ionizing dose (TID) for this mission is ~115 krads behind 100 mils Al, but we expect to have a design margin of at least 2 and an extended mission with at least 7 additional flybys should be possible. One extended mission concept is to pump the orbital period back out to ~1 year (over ~4 orbits) to enable a long-term life test of the ASRGs and longer-term Io and Jupiter system monitoring. The mission will end with impact into Io to meet Planetary Protection requirements.

The Io flybys will have nearly constant illumination (except for that before JOI), which facilicates monitoring of changes over time. The view of Io on approach and departure will be nearly polar, enabling unique measurement and monitoring of polar heat flow (key to tidal heating models), equatorial plumes, and magnetospheric interactions. The payload will be designed to collect data throughout the closest approach in spite of the ~19 km/s relative velocity. We expect to collect and return ~20 Gbits per flyby via 34-m DSN stations, >1000 times the Io data return of Galileo. For comparison, Juno is expected to return at least 3 Gbit over its nominal mission [8].

Science Payload: The minimal payload we considered as part of JPL's concurrent engineering design process, Team X, included just 4 experiments: (1) a radiation-hard narrow-angle camera (RCam), (2) a thermal mapper (ThM), (3) an ion and neutral mass spectrometer (NMS), and (4) a pair of fluxgate magnetometers (MAG).

RCam will make use of a 2000 x 2000 CMOS detector with excellent performance after 1 Mrad TID (100 mils Al) [9]. About half of the array will be covered by up to 15 spectral filters from 200-1000 nm, each covering ~64 lines for digital Time-Delay Integration (dTDI). Half of the array will provide clear panchromatic framing images for optical navigation and movies of plumes and other dynamic phenomena. Data will be read off the chip at 240 Mpixel/s, minimizing transient radiation-induced noise, into a Digital Processing Unit (DPU) under development at the Applied Physics Lab (APL). The optics will enable imaging at ~10 µrad/pixel, similar to the LROC NAC [10] or LORRI [11].

One key objective is to acquire nearly simultaneous multispectral measurements to determine the peak lava temperatures. A time differential as short as 0.1 s between color filter images can give spurious results given lava fountaining and rapid radiative cooling [12]. We plan to have a set of 4 color filters (such as >950 nm, >800 nm, 600-800 nm, 400-600 nm) each of which covers just 4 lines, and then repeat that set of narrow filters 16 times. dTDI over multiple lines gives nearly simultaneous color measurements. These peak temperatures in turn constrain the temperature and rheology of Io's mantle [13] and whether or not the heat flow is in equilibrium with tidal heating, with implications for the coupled thermal-orbital evolution of Io and Europa [14].

Other RCam filters will include UV bandpasses for SO_2 and plumes, spectrally narrow filters for Na, O, and other species escaping from Io and Europa, and perhaps silicate mineralogy bands from 800-1000 nm, methane bands for Jupiter, or other candidates.

The Thermal Mapper (**ThM**) will be similar to THEMIS on Mars Odyssey [15], but with a new higher-resolution microbolometer array and perhaps other upgrades. The main purpose of ThM is to monitor hot spots and measure heat flow, so several bandpasses are needed in the 2-20 micron range. The most useful bandpasses for monitoring active volcanism are ~2, 5, 8, and 15 microns [16], and we need 20 microns or longer to measure background temperatures. With up to 10 bandpasses ThM can also perform compositional studies such as measuring the position of the Christiansen emission peak, which varies with SiO_2 content, providing another constraint on lava composition along with the peak temperatures.

The Ion and Neutral Mass Spectrometer (**NMS**) will be contributed by the University of Bern and the Swedish Institute of Space Physics. The composition and spatial distribution of neutrals determines the energy input into the Io Plasma Torus. Other key objectives are to determine the composition of Io's atmosphere and volcanic plumes, providing constraints on Io's interior composition. The NMS is sensitive from 1-300 amu; M/ΔM ranges from 300 to 1000 (increasing with mass), yet the instrument mass is just 4 kg. A proptotype has been tested on the Polar-Balloon Atmospheric Composition Experiment [17]. The entrance aperture is being redesigned for IVO, to provide data for a longer time period near closest approach. The NMS will be mounted orthogonal to the optical remote sensing for measurements in the ram direction while closest to Io.

Two Fluxgate Magnetometers (**MAG**) are to be contributed by the Institut für Geophysik und extraterrestrische Physik of the Technische Universität Braunschweig. This instrument has heritage from Rosetta, Venus Express, and the THEMIS mission [18]. The science goals are to characterize magnetospheric interactions with Io, and perhaps place tighter constraints on whether or not Io has an internally generated magnetosphere. One instrument will be mounted on the spacecraft (S/C) and the other on a bracket ~1 m long, to help calibrate effects of the S/C.

Various science enhancement options are being considered. A wide-angle camera would provide more extensive topographic mapping and imaging of plumes on the polar limb. We could fly a second NMS to get additional data on approach to or departure from Io while pointing the optical remote sensing experiments at Io. Addition of a NIR spectrometer, UV spectrometer, or energetic particle detector might be possible with contributions. A student-built experiment such as a dust detector will be considered.

Spacecraft Design: The S/C concept is very simple, with no deployments or gimbals, and only X-band telemetry. Attitude control is via thrusters only, not reaction wheels, similar to the New Horizons S/C [19]. 200 kg have been allocated for a radiation vault and spot shielding, similar to the ~160 kg allocation of Juno [20]. With launch on the Atlas V 401 and a VEEGA trajectory, there is ample mass margin. The Team X cost estimate, assuming industry build with JPL management and fully compliant with JPL design principles, was $471M, close to but over the $450 M study cap. We are now exploring options to reduce costs; one idea is to emulate the mission operations approach being used for MESSENGER [21].

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