**FLYBY OF IO WITH REPEAT ENCOUNTERS (FIRE): A NEW FRONTIERS MISSION DESIGNED TO STUDY THE MOST VOLCANIC BODY IN THE SOLAR SYSTEM** R. W. K. Potter[1], M. L. Cable[2], J. Cumbers[3], D. M. Gentry[4], T. N. Harrison[5], S. Naidu[6], S. Padovan[6], C. W. Parker[7], J. Reimuller[8], S. Shkolyar[9], T-A. Suer[10], J. R. Szalay[11], H. J. Trammell[12], C. C. Walker[13], J. L. Whitten[14] and C. J. Budney[2], [1]Lunar and Planetary Institute, Houston, TX, USA, potter@lpi.usra.edu; [2]Jet Propulsion Laboratory, Pasadena, CA, USA, [3]NASA Ames, Moffett Field, CA, USA, [4]Stanford University, Stanford, CA, USA, [5]University of Western Ontario, London, ON, Canada, [6]University of California, Los Angeles, CA, USA, [7]Boston University, Boston, MA, USA, [8]Integrated Spaceflight, Boulder, CO, USA, [9]Arizona State University, Tempe, AZ, USA, [10]Stony Brook University, Stony Brook, NY, USA, [11]University of Colorado at Boulder, Boulder, CO, USA, [12]University of Houston, Houston, TX, USA, [13]University of Michigan, Ann Arbor, MI, USA, [14]Brown University, Providence, RI, USA.

**Introduction:** Io, the innermost of Jupiter's Galilean moons, is the most volcanically active body in the Solar System. As volcanism is a key geological pro cess, Io, therefore, represents an ideal laboratory to improve our understanding of volcanic processes and their relation to outgassing and atmosphere formation which are believed to be pivotal events in the early stages of terrestrial planet evolution.

Here, we outline an Io mission concept designed to directly address the science objectives for an Io mission as laid out in the most recent planetary science decadal survey [1] and the 2009 New Frontiers Announcement of Opportunity [2].

**Mission overview:** Our mission concept, FIRE (Flyby of Io with Repeat Encounters), has a low complexity, uses off-the-shelf systems for reliability, has a redundant design for failure tolerance, and a novel instrument suite for high-value science return. FIRE will be launched on an ATLAS V rocket and will use ASRG (Advanced Stirling Radioisotope Generator) power. The nominal mission includes ten close (altitude above Io's surface ~100 km) flybys of Io while the spacecraft is on a Jupiter-bound orbit.

**Mission objectives:** The objectives of the mission are split into two categories: Io interior and Io surface processes. Objectives for the interior are: (1) to understand the bulk composition of Io in the context of the Jupiter system, (2) examine tidal heating in the context of habitable zones, and (3) determine how endogenic processes are connected to surface processes. Objectives for Io's surface processes are: (1) to test our current understanding of volcanism, (2) relate volcanism on Io to the early stages of planetary evolution, and (3) use volatiles on Io to understand outgassing processes.

**Instruments:** To achieve the mission objectives, FIRE will investigate Io's tidal heating, interior structure, magnetic field, eruption mechanisms, tectonics and surface chemistry by measuring the gravitational field, tidal signature, magnetic field (induced and, if present, intrinsic), magma mineralogy, and volatiles in volcanic dust. This will be done using a suite of four instruments (Figure 1).

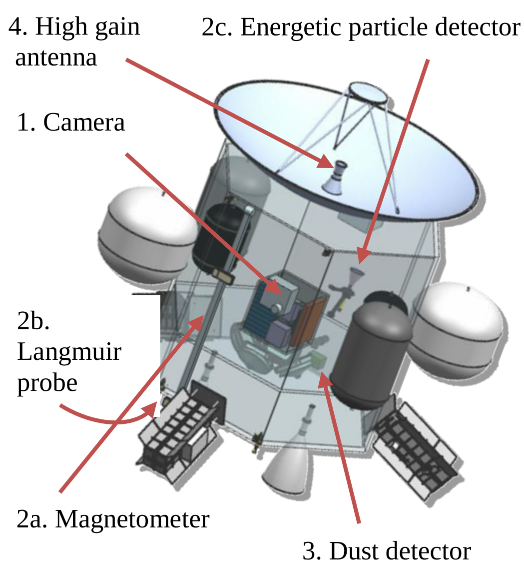


**Figure 1:** The FIRE spacecraft highlighting the positions of various components of the instrument suite.

*1. VOLCANO* (Visible OpticaL Camera And Near-infrared Observer) is a visible and near IR camera which will characterize the composition and morphology of Io's surface and hot spot thermal emissions. The science return from this instrument will include imagery of (new) volcanic and topographic features, surface mineralogy and temporal variations in surface features.

*2. MAGMA* (Multi-Axis Geophysical MAgnetometer) is a magnetic instrument sub-package combining magnetic field, plasma, and charged particle measurements, that will test the presence of Io's putative magma ocean and provide important clues on its interior structure.

*3. CALDERA* (Comprehensive AnaLysis of Dust from ERuptions and Atmosphere) is a dust analyzer capable of determining the composition of dust grains in Io's atmosphere and volcanic plumes. This will allow direct identification of silicates and other species improving understanding of volcanic activity and related outgassing processes. Additional science return from this instrument will include the type, distribution and mineralogy of magma, mass flux, and a density profile through the atmosphere.

*4. FLARE* (FieLd Analysis through Radio Exploration) is a radio science instrument which takes advantage of a gimbaled, two-band high gain antenna to measure both the static and the time-variable components of Io's gravity field, thus informing on the radial distribution and physical state of matter in the interior of Io.

**Mission trajectory:** The spacecraft will have a Venus-Earth-Earth gravity assist, arriving at Jupiter almost six years after launch. The spacecraft will conduct ten flybys of Io, getting to within 100 km of Io's surface at closest approach. The ten flybys will be completed in approximately four months. Wide latitudinal coverage (Figure 2) will enable a broad imaging campaign, including multiple plume observations and allow magnetic field measurements at a variety of latitudes and longitudes.

**Risk and mitigation:** The FIRE spacecraft will travel through a high radiation environment because of Jupiter's magnetic field and radiation belts. Radiation may affect the reliability of spacecraft components. To minimize this risk, spot and Whipple (bumper) shielding will be added around navigational components as well as components outside the spacecraft bus. Due to the low altitude (~100 km) orbits, the spacecraft is also vulnerable to damage from particles in Io's volcanic plumes. This risk can be mitigated by carrying out plume-related measurements during the final flybys thereby maximizing instrument safety during the majority of the mission.

**Cost:** As a New Frontiers class mission, the cost cap was \$991M (FY2012) (\$927M base cap with a \$64M launch vehicle cost credit). Using a quasi-grass roots cost estimate model, our FIRE mission concept was within the cost cap (\$990M) and included significant cost reserves.

**Conclusion:** As the most volcanically active body in the Solar System, Io is an ideal laboratory to study volcanic processes. Here we have outlined our Io mission concept, FIRE. FIRE takes advantage of instrument flight heritage, has significant system redundancy, is low risk, and is able to address a preponderance of science questions about Io's interior and surface processes using its suite of four instruments during ten flybys all within the New Frontiers cost cap.

**Acknowledgments:** This document does not represent an actual mission and was created by students as an educational activity at the 2012 NASA Planetary Science Summer School, held at the Jet Propulsion Laboratory, Pasadena, CA, USA. We would like to acknowledge the invaluable assistance provided by Charles Budney, Karl Mitchell, Trisha Steltzner and Leslie Lowes, as well as JPL's Team X members.

**References:** [1] National Research Council (2011) *Vision and Voyages for Planetary Science in the Decade 2013-2022*, National Academies Press, Washington, D.C., 382 pp. [2] NASA (2009) *Announcement of Opportunity, New Frontiers 2009*, NNH09ZDA007O

**Figure 2 (below):** Altitude ground track plot showing the path of the ten flybys, each individually labeled, over Io. The colors on the tracks represent altitude. Red zones indicate volcanic plumes.