VULCAN: A MISSION CONCEPT TO EXPLORE TIDAL HEATING AND EXTREME VOLCANISM AT IO.

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Introduction: A world of extremes, Io is the most geologically active body in our solar system, and would provide a natural laboratory to study volcanic processes and the effects of tidal heating. The Vulcan mission concept was developed through the JPL Mission Design summer school in response to the New Frontiers 5 Announcement of Opportunity (for educational use only). Vulcan, as the first dedicated mission to Io, would answer open questions ranging from the deep interior to the surface.

Mission Objectives: Four science objectives were formulated based on the current state of knowledge regarding Io and its evolution.

Objective One (O1): Determine if Io's upper mantle is a solid plastic asthenosphere with localized melting or a magma ocean. Whether the upper mantle consists of a global magma ocean or a "sponge" with discrete pockets of magma is one of the major outstanding science questions of the Io system [i.e. 1]. By measuring Io's magnetic induction field, libration amplitude, ionospheric parameters, and tidal love numbers with sufficient precision, Vulcan would resolve the debate over the presence of a magma ocean on Io.

Objective Two (O2): Determine if paterae are active lava lakes (connected to a magma reservoir directly underneath) or lava ponds (depressions filled in by lava flows). With this objective, we aim to distinguish between heat pipe volcanism and heat conduction through the mantle. The spatial distribution of temperatures is expected to be different depending on which mechanism generates the patera. By generating high resolution thermal infrared maps of the patera, Vulcan would determine the source of the lava within the patera. This would also allow us to better constrain Io's total heat budget by understanding how much heat is lost through volcanism, as most volcanic activity on Io appears to be within the interiors of paterae [2].

Objective Three (O3): Determine whether Io's surface composition is consistent with material derived from a primitive or differentiated upper mantle. Vulcan would measure silica content of lava flows across Io's surface using infrared spectroscopy in order to determine the relative abundance and distribution of ultramafic, mafic, intermediate, and felsic lava on Io [after 3]. Although a predominantly ultramafic surface would suggest either a magma ocean or deep mantle dissipation, distinction between the two can be drawn based on libration amplitude measurements (see O1). However, if Io's surface is dominated by mafic (and potentially intermediate) lava with only localized ultramafic lava, a 'sponge' mantle scenario is likely present. Io is our solar system's best analog for the early stages of rocky planet formation, including the early evolution of Earth and the Moon, driving interest in understanding its current internal structure.

Objective Four (O4): Determine whether the linear ridge features are dunes (i.e. formed by surface-atmosphere interactions) or whether they are generated by deformation due to tidal stresses. Recently, dunes have been identified on several bodies with tenuous atmospheres (i.e. Pluto, Comet 67P/Churyumov-Gerasimenko). New work by [4] suggests that the previously identified fields of linear ridges on Io may be wind-formed dunes. Dune formation requires mobilization of sand-sized particles, and the work by [4] provides a mechanism by which sublimating gasses driven by heating from lava can generate sufficient wind to mobilize grains. Previous work [i.e. 5] attributed these features to tidal deformation of Io's crust. Our instrument suite would allow for differentiation between these two formation mechanisms and investigation of the proposed mechanism for dune formation. Additionally, this investigation would expand our knowledge of surface-atmosphere interactions on bodies with ephemeral and tenuous atmospheres.

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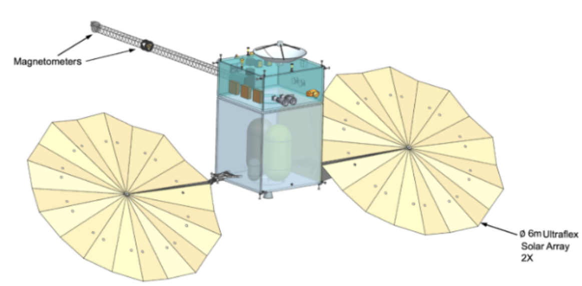

Figure 1. Spacecraft model for Vulcan showing the solar arrays, magnetometer boom, and shielded vault housing the science payload.

Spacecraft and Payload: The science payload consists of four instruments, in addition to a high gain radio antenna. The antenna will be used to conduct gravity science in both the Ka and X bands. The instruments onboard include (1) a wide-angle and two narrow angle cameras (WAC and NAC, respectively, based on the Lunar Reconnaissance Orbiter cameras), (2) a thermal infrared spectrometer (TIRS; similar to the OSIRIS-REx OTES instrument), (3) a pair of magnetometers (MAG; miniaturized models of the Juno and MAVEN magnetometers), and (4) a pair of ion and electron electrostatic analyzers (DIPA; based on the Parker Solar Probe ANalyzers-A).

The spacecraft is designed to be launched on a high performance launch vehicle using a 5 m fairing. The propulsion subsystem would be comprised of a main liquid bi-propellant 100-lbf ME Aerojet HIPAT engine running off of nitrogen tetroxide oxidizer and monomethylhydrazine fuel with a Helium system for pressurization. The power subsystem would be comprised of single-axis articulating two wing Ultraflex solar panel arrays (Figure 1).

Mission Design: Following a ~6 year cruise to the Jovian system, Vulcan's primary science mission would consist of 78 Io flybys over two years from a 10-day Jovian orbit. 12 flybys would be dedicated to gravity science, and the closest approaches of the 66 primary science flybys would be distributed roughly evenly between the dayside (32) and nightside (34), see Figure 2.

The flyby periapsis would be 50 km. The flybys have been selected to target specific surface features that would enable us to fulfill our science objectives and data sufficiency needs (Figure 3).

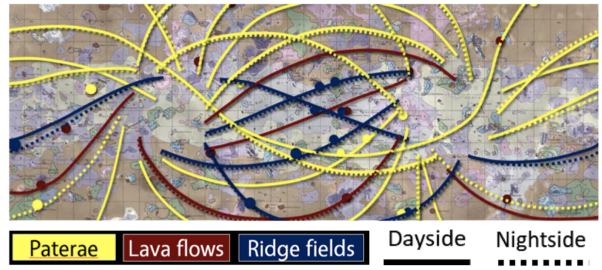

Figure 2. Ground tracks for Io flybys, colored by surface targets. Yellow – O2, Red – O3, Blue – O4.

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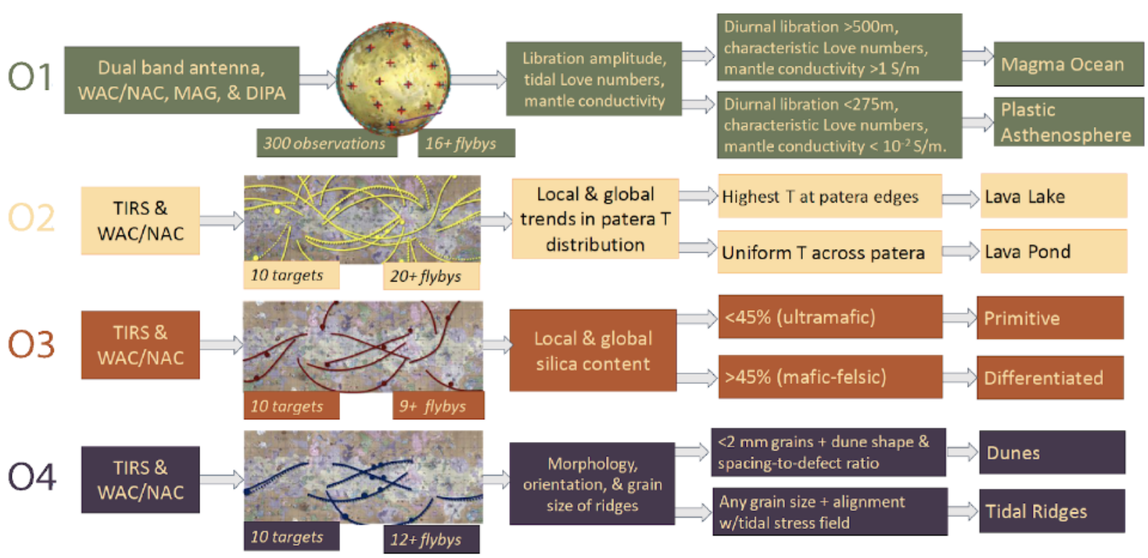

Figure 3. Data Sufficiency for the Vulcan Mission Objectives. This chart shows how the different instruments of the science payload would collect data to address the mission objectives and answer our science questions.