FY23 Topic Areas Research and Technology Development (TRTD)

# How many cracks does it take to get to the water on Enceladus?

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**Strategic Focus Area:** Ocean Worlds

## Background

Enceladus is prioritized as an Ocean Worlds flagship target and is a focal point in New Frontiers 5-7 in the current Decadal Survey. Its South Polar Terrain (SPT) "Tiger Stripes" comprise linear fractures, ejecting jets of water vapor and icy grains, forming a vast plume. While the plumes betray information about the near-surface environment, fluid transport from the ocean to the subsurface is likely to be affected by interactions between the background stress field and existing fractures and faults, mechanical stratification within the shell, ice shell rheology, compositional evolution of the fluids during transport, residence in fully and partially molten reservoirs, physical and thermal interactions between the magma and surrounding ice, surface topography, tectonic activity, and geologic history. Thus, there is a risk that measurement and spacecraft requirements rely on under-constrained assumptions about rapid (hours to days) transport timescales from the ocean to the surface and magma evolution with depth and time, as well as a risk that the geometries required for deep in situ vent exploration do not reflect physical multiphase transport and eruption. This work aids in understanding Enceladus as a habitable system by further constraining ocean-surface transport, and matching Cassini observables to physical predictions of the near-surface environment.

## Objectives

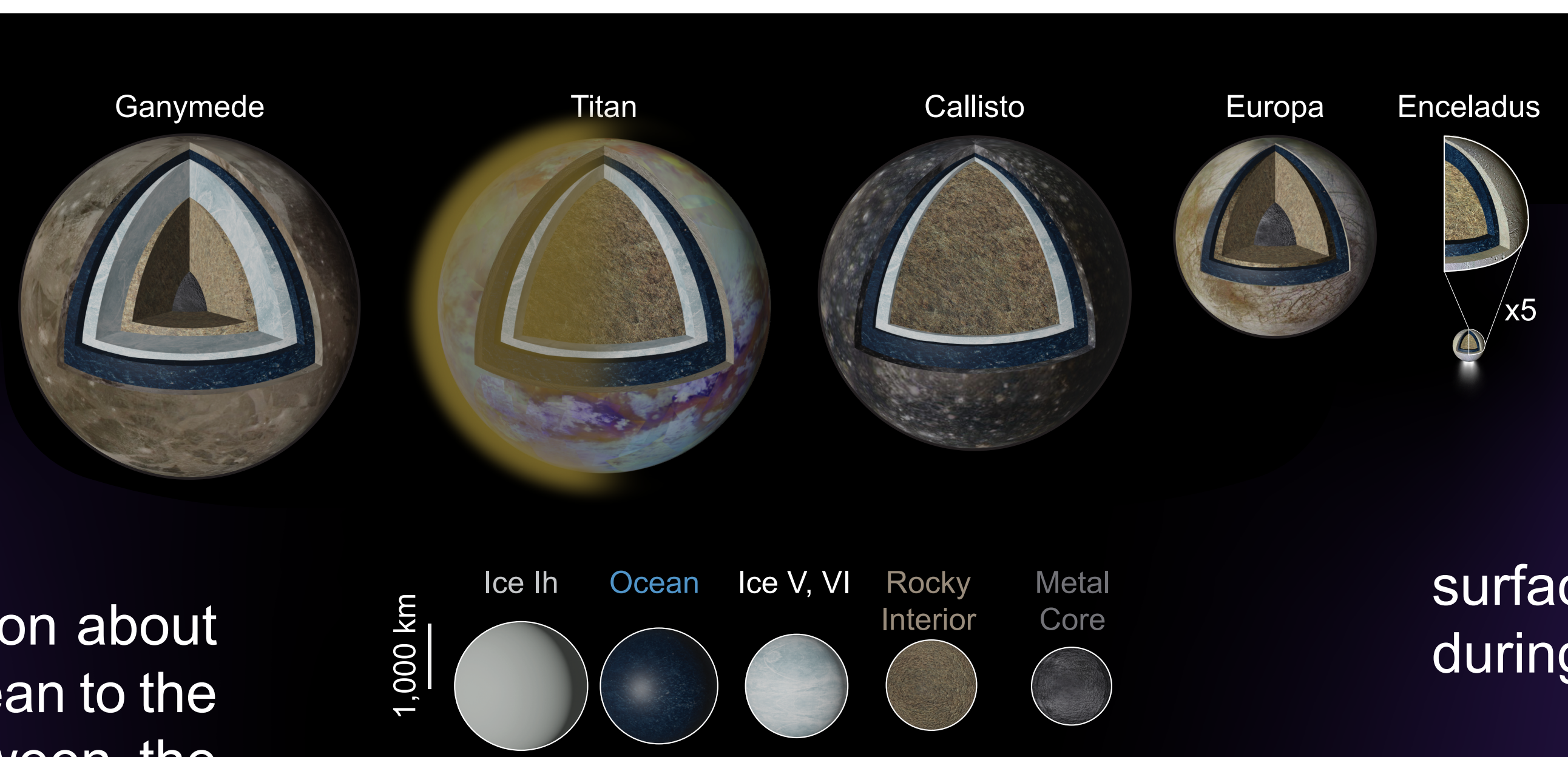
The objectives of this work are to:

1) Determine how fractures of various size, ranging from the Tiger Stripes to small-scale linear features, interact at the surface in response to the tidal stresses encountered during an Enceladus orbit.

2) Determine the dominant controls on fracture activity throughout the ice shell, and the resulting surface displacement field, during an Enceladus orbit for a range of potential ice shell configurations.

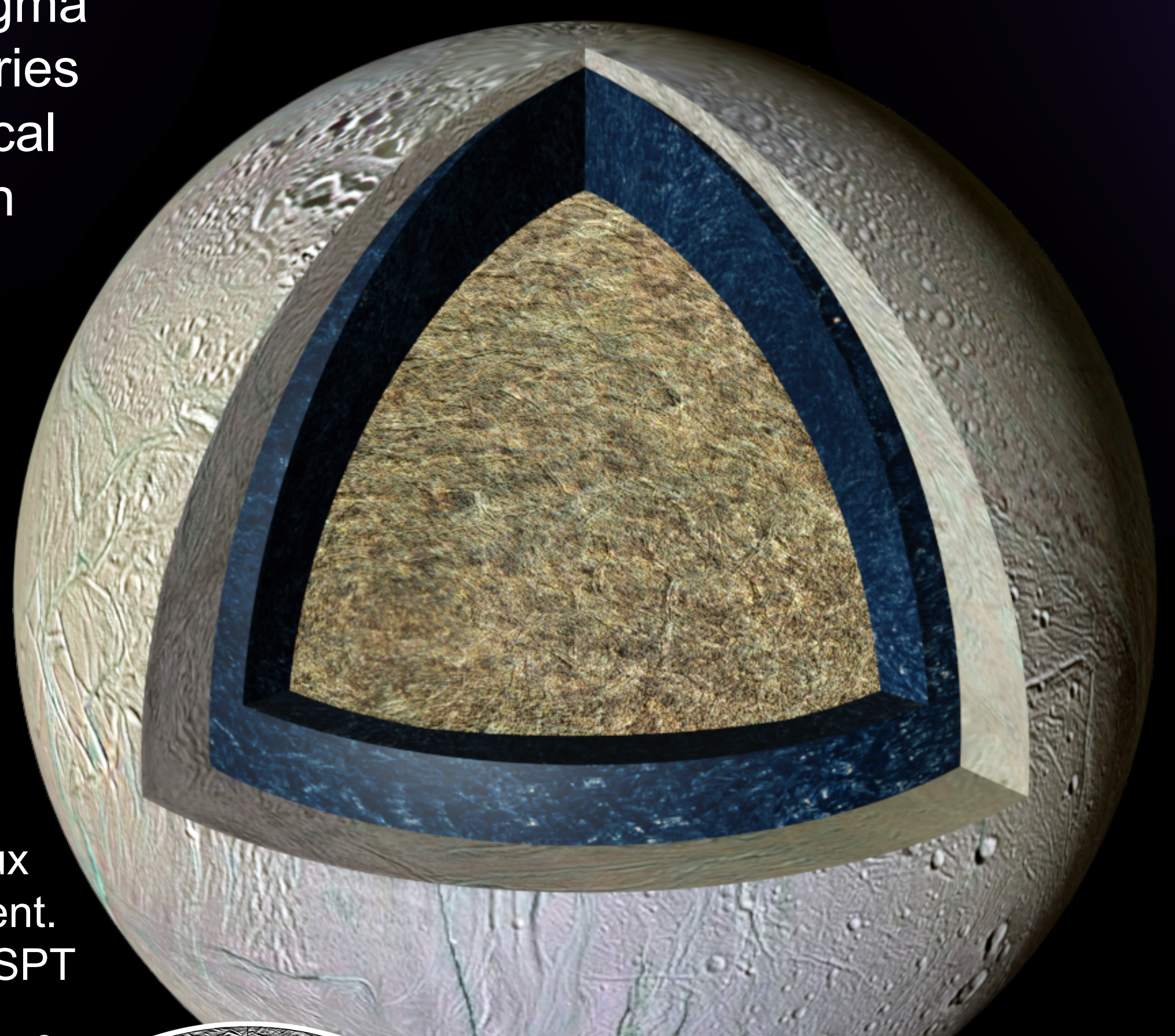
3) Determine distributions in the following key constraints with depth, time, and lateral location: permeability, conduit aperture, conduit orientation, mass, fraction of material in each phase, material velocity for each phase, and residence timescale of each phase.

4) Perform inreach at JPL to infuse physical constraints into scientific analyses and technology/concept formulation, and prioritize next steps, including follow-on ROSES funding opportunities.



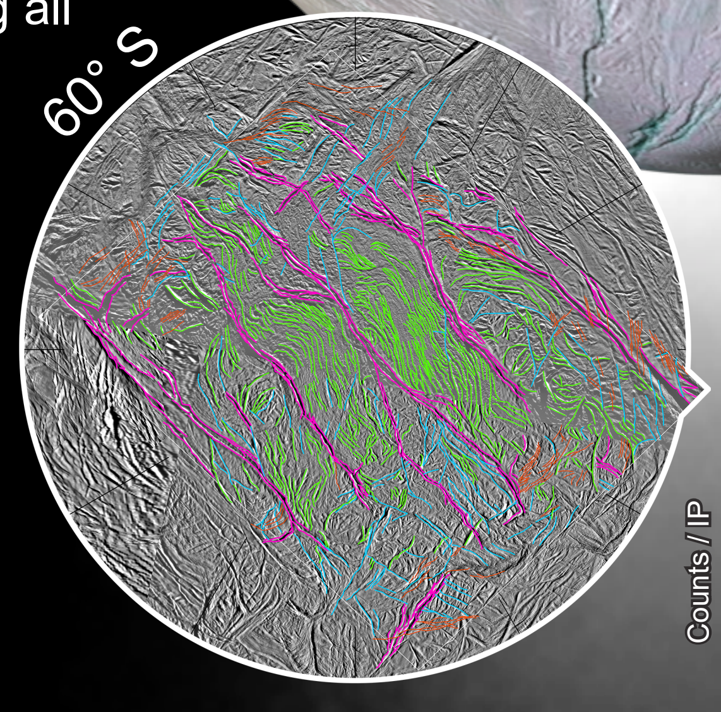
*(Above) Among the most plausible Ocean Worlds, the escape of putative interior ocean water from Enceladus is benefitted by its small size and relatively low gravity.*

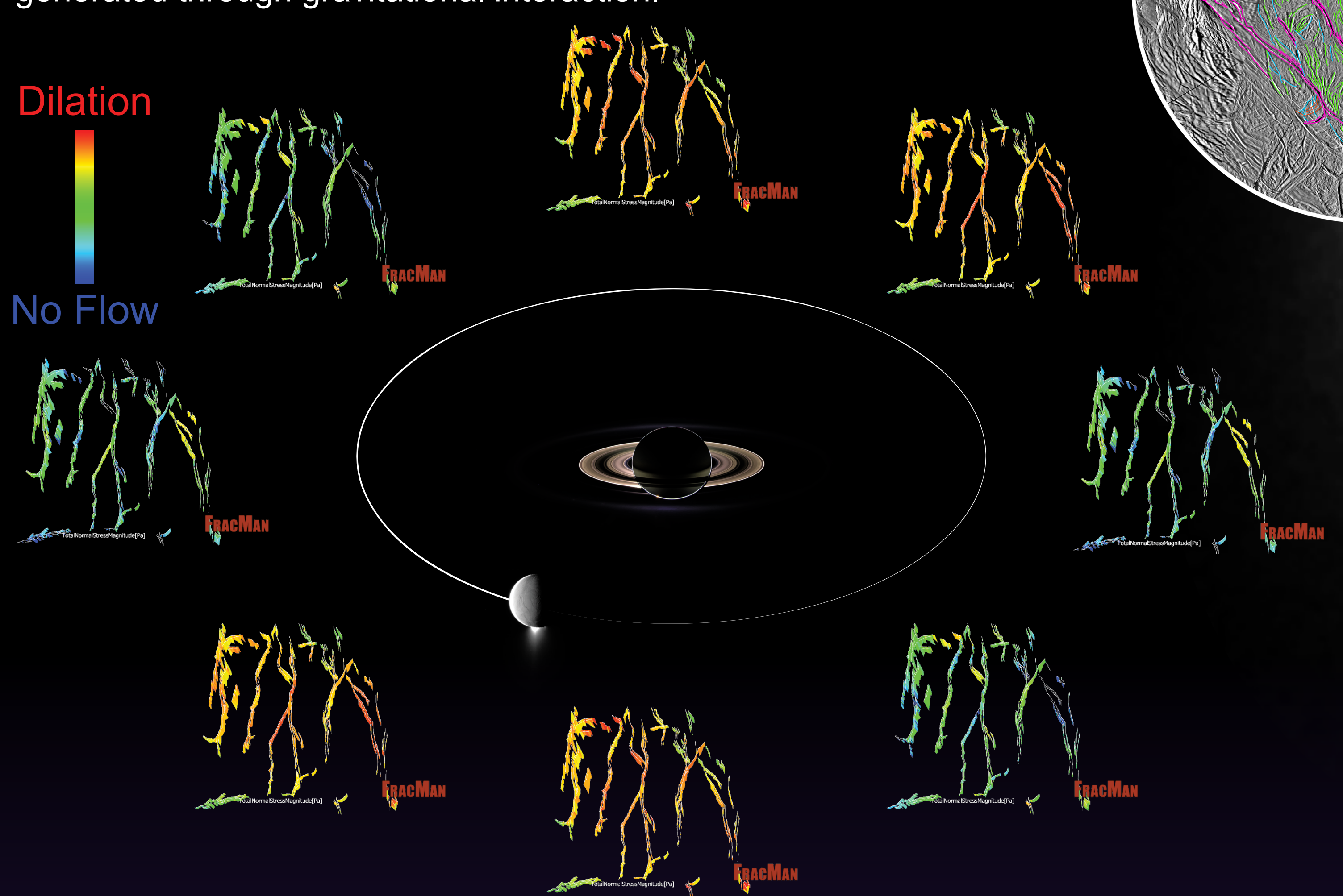
*(Below) Enceladus cross-section. Ice thickness is minimal at the poles.*

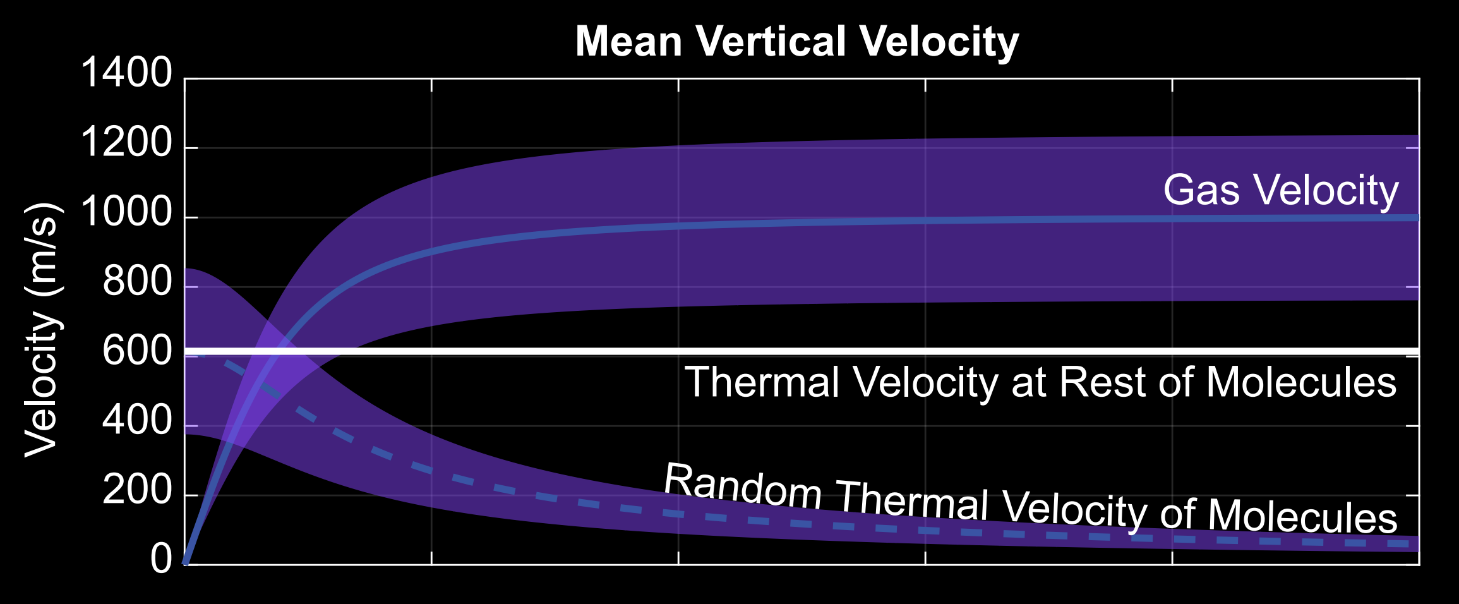


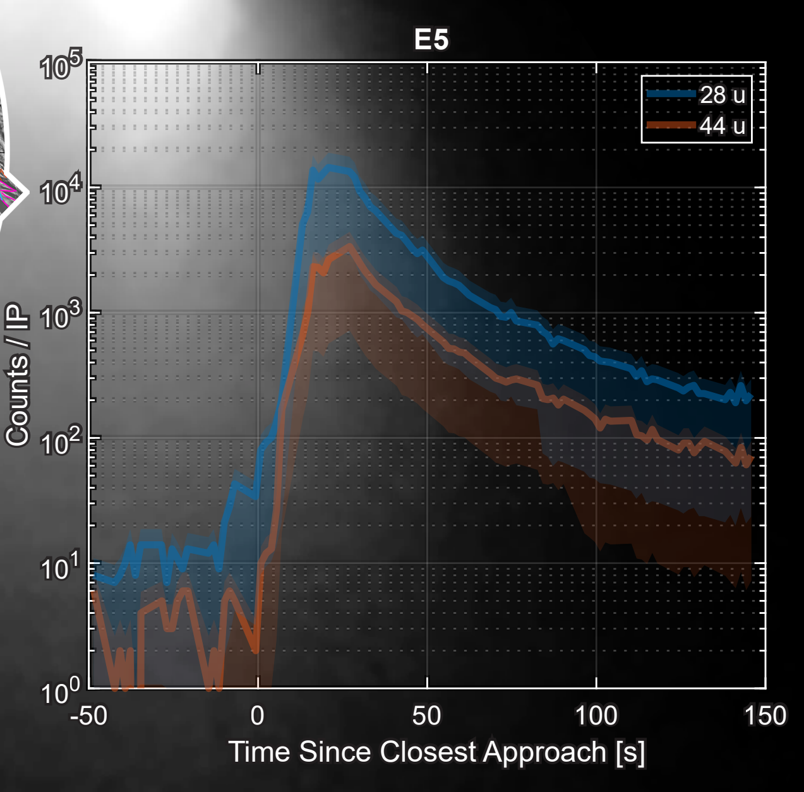
## Approach and Results

We are characterizing the fracture environment using physical and modeling approaches. We have identified new physical controls on near-surface eruptions and composition, and are working to characterize plume mass flux uncertainty in order to inform conceptual and numerical model development. Additionally, we have created a new, comprehensive fracture map of the SPT using globally controlled USGS mosaics at a scale of 1:250,000, mapping all linear features > 250 m in scale. We classify each potential fracture based on morphology, structural association, and predominant orientation. This initial fracture map is being used to create a two-dimensional (map view) discrete fracture network using FracMan. We apply time- and spatially-varying stress fields to the SPT that reflect the diurnal stresses generated through gravitational interaction.

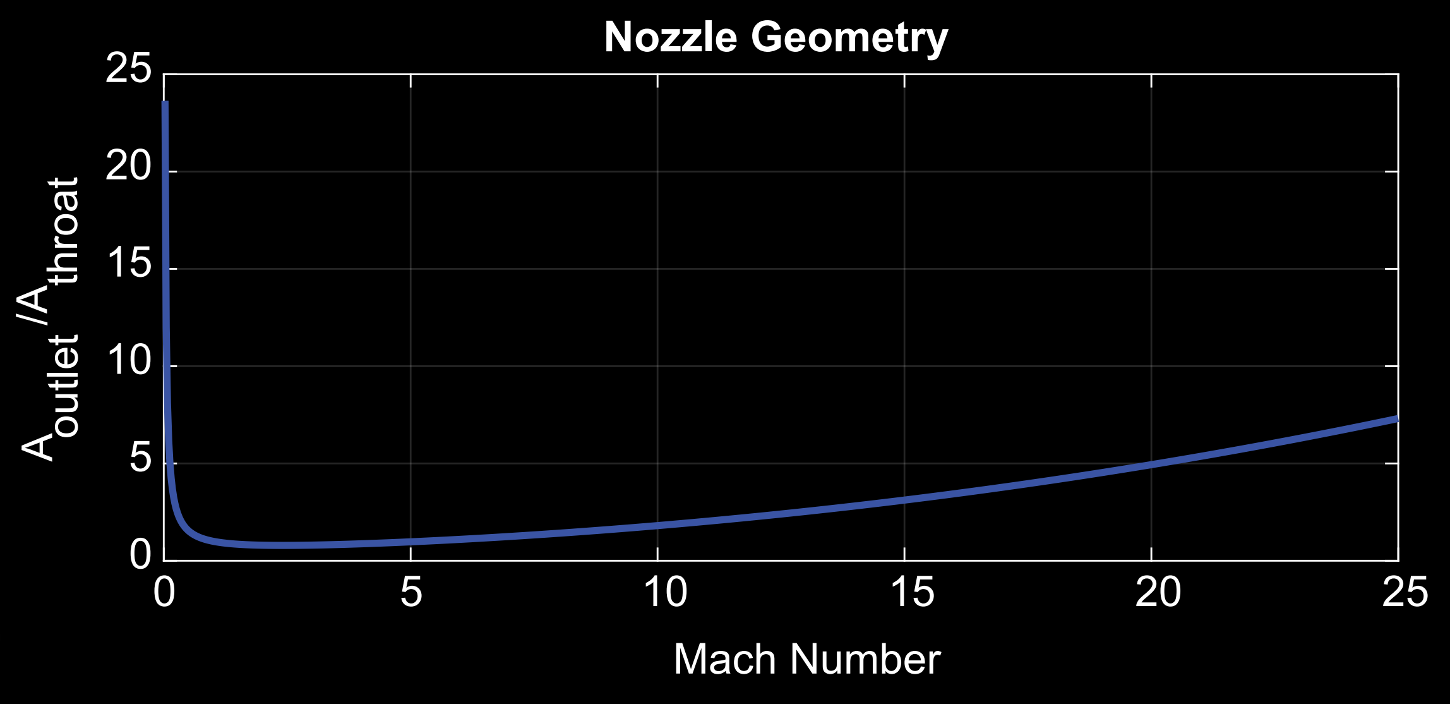






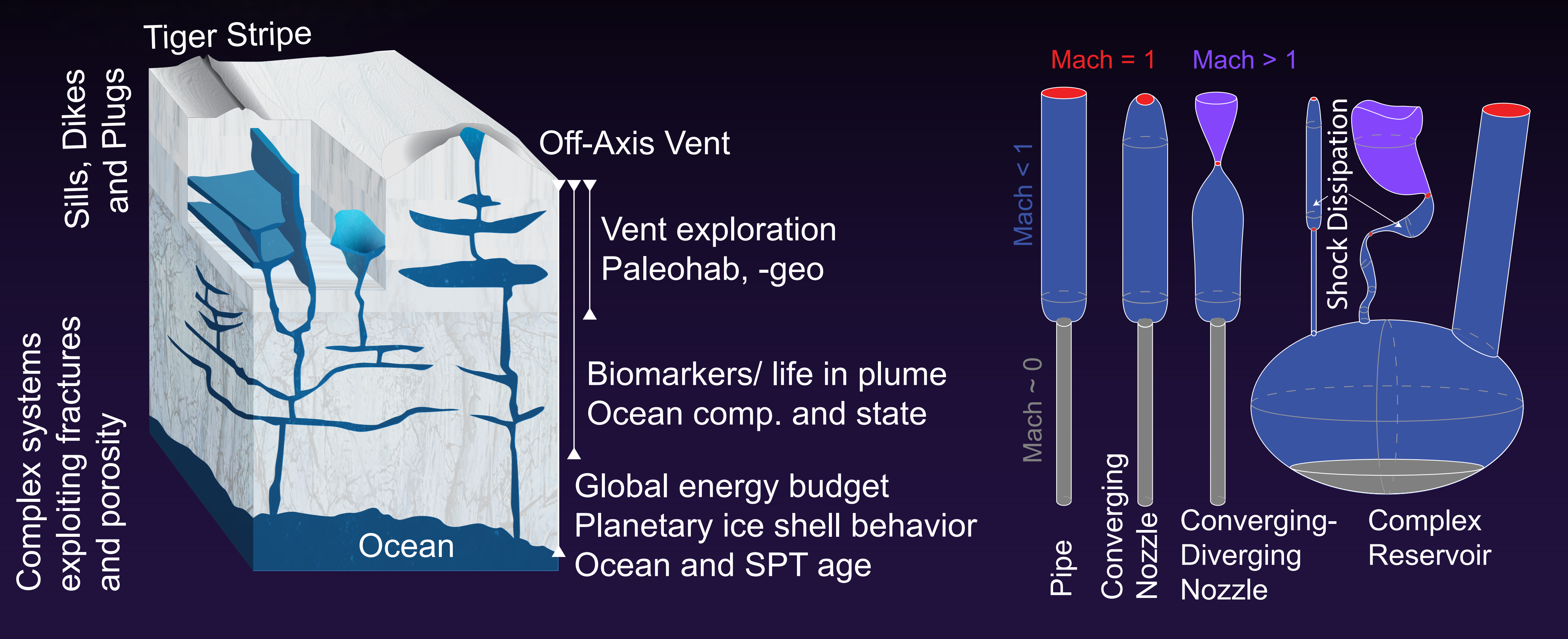


INMS Error propagation for N2 and CO2 water analogues, with mean values matching Perry et al. (2015).



While geometry (e.g. conduit diameter, average pore diameter for grain-filled vents) is non-unique, maximum velocity and mass flux can be uniquely constrained, where increasing Mach number results in lower density and temperature to maintain an average velocity as a function of converging-expanding nozzle geometry.

(Left) Illustration showing potential range of complex plumbing systems on Enceladus, each of which is described by (Right) fundamental flow properties derived only from Kinetic Gas Theory, structure of a water molecule, and isentropic properties of compressible flow. All systems, from porous flow to vertical “straws” can be represented by a combination of the three systems on left right and scaling terms.



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