Art by James Tuttle Keane

The Io Volcano Observer (IVO)
Follow the Heat!

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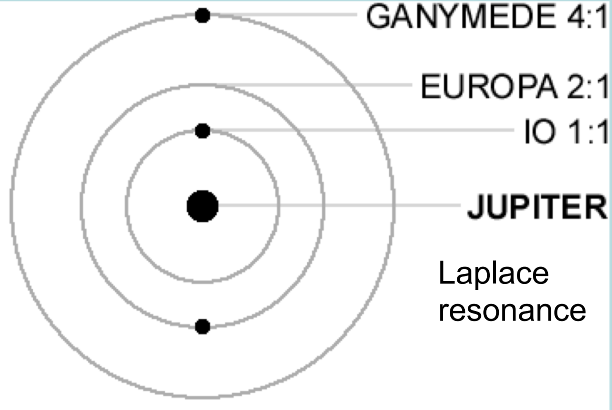
Mission Overview:

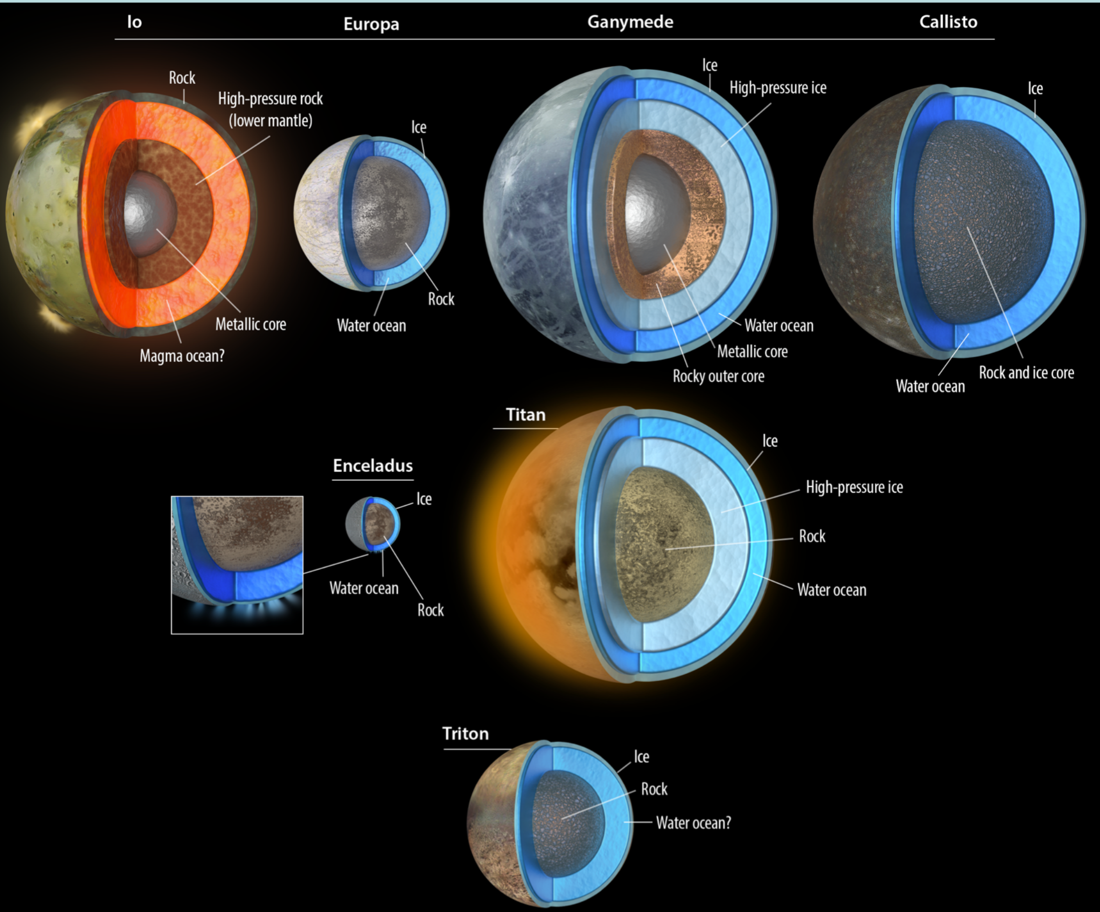
- **Launch 2028**
- **Orbit inclined ~45º to Jupiter's orbital plane**
- **10 Flybys of Io**
- **Five instruments +SCO +TDO**

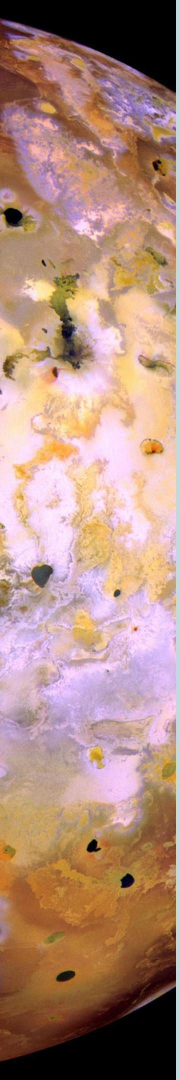
Why is Tidal Heating so Important?

- Tidal heating expands habitable zone
- Important for tidally locked exoplanets
- Io is the best place to understand tidal heating as a fundamental planetary process
  - Intense volcanism driven by tidal heating from 4:2:1 orbital resonance of Io-Europa-Ganymede
  - Can remotely measure the heat flow
  - Volatile history unknown



Laplace resonance





Keck Institute workshop on Tidal Heating October 15-19, 2018

http://kiss.caltech.edu/programs.html#tidal_heating

Identified 5 key questions:

1. What do volcanic eruptions tell us about the interior?

2. How is dissipation partitioned between solid and fluid layers?

3. Does Io have a melt-rich layer (magma ocean) that decouples the lithosphere?

4. Is the Jupiter/Laplace system in equilibrium?

5. Can stable isotopes inform long-term evolution?

***IVO* can help address all 5 questions**

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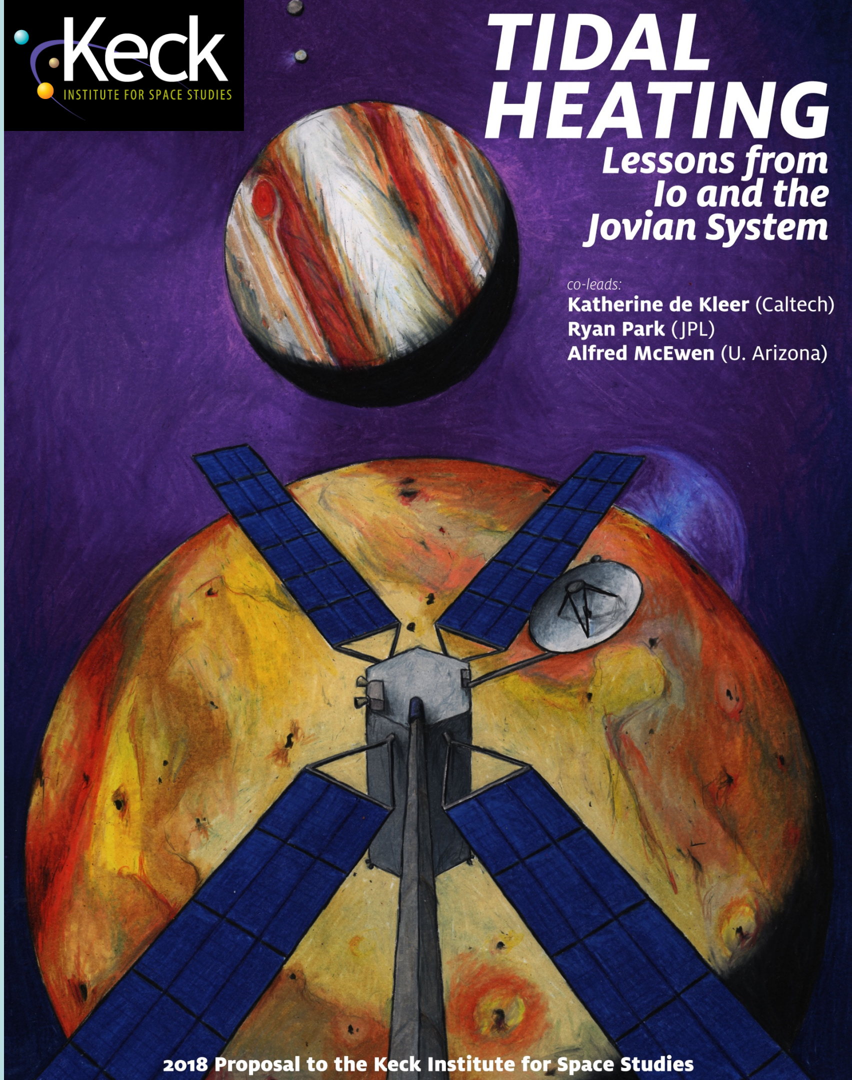


Science Goals

A. How and where is tidal heat generated?

B. How is tidal heat transported to the surface?

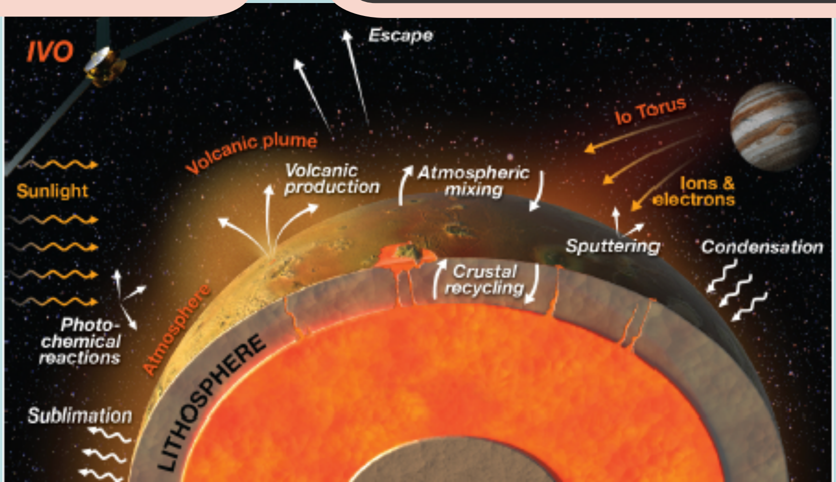
C. How is Io evolving?

Science Objectives

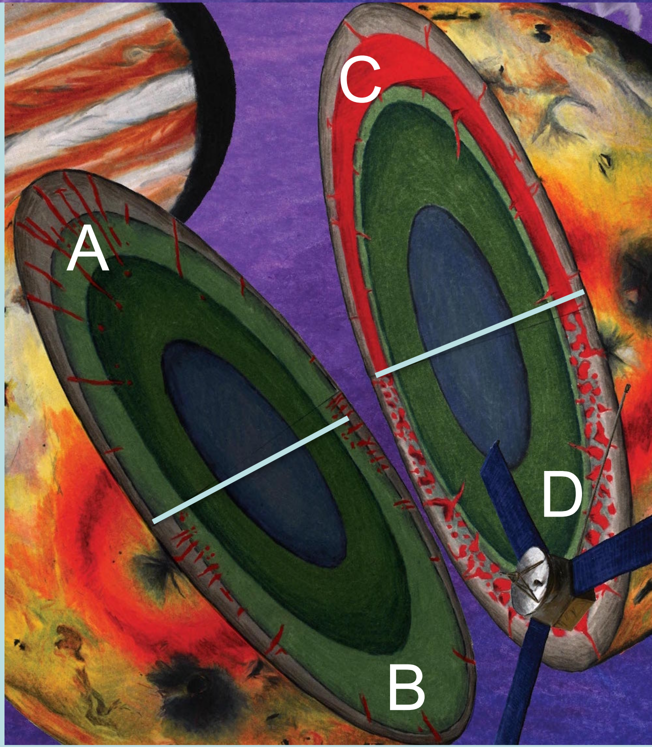
Determine if Io has a mechanical magma ocean

Determine if significant heat is carried by processes other than the silicate eruptions

Determine if Io is evolving at a significant rate for the history of the Jovian system



	tidal deformation:	libration amplitude:	magnetic induction:	lava temperature:	heat flow distribution:
A Solid Io, with heating in the deep mantle	low	small	weak	high-T basaltic	more polar
B Solid Io, with heating in the asthenosphere	low	small	weak	basaltic	more equatorial
C Io with a magma ocean	high	large	strong	very high-T ultramafic	more equatorial or uniform
D Io with a magma "sponge"	low	small	strong	very high-T ultramafic	more equatorial or uniform



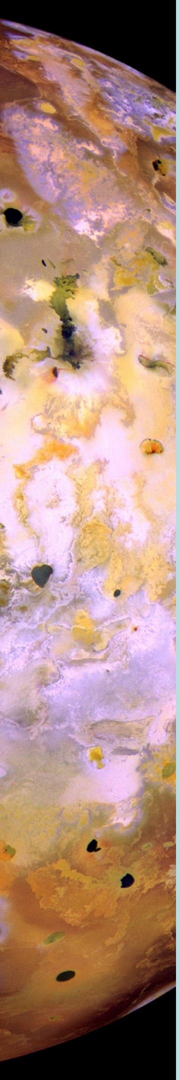
Synergy between IVO and Exoplanets

Follow the Heat!

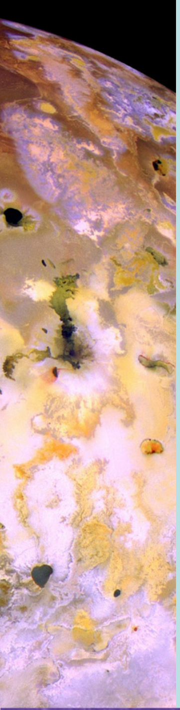
Tidal heating: This is a fundamental process for terrestrial exoplanets orbiting close to their stars. Understanding tidal heating will help us to better understand these planets.

Volcanic atmospheres: IVO will make the first ever in situ measurements of the composition of Io's atmosphere

Jupiter as an exoplanet analog: We will have a payload that could be used to study how Jupiter would appear as an exoplanet.



Backup



A: How and where is tidal heat generated?

IVO will measure tidal k_2, libration amplitude, magnetic induction response, lava temperatures, and map Io's volcanism and heat flow to test four interior hypotheses.

A. Solid Body Dissipation in Deep Mantle:
- Weak magnetic induction
- Polar focused volcanism
- High-T Basaltic magma
- Low k_2 and libration

B. Solid Body Dissipation in Asthenosphere:
- Weak magnetic induction
- Low-latitude focused volcanism
- Basaltic magma
- Low k_2 and libration

	tidal deformation:	libration amplitude:	magnetic induction:	lava temperature:	heat flow distribution:
A Solid Io, with heating in the deep mantle	low	small	weak	high-T basaltic	more polar
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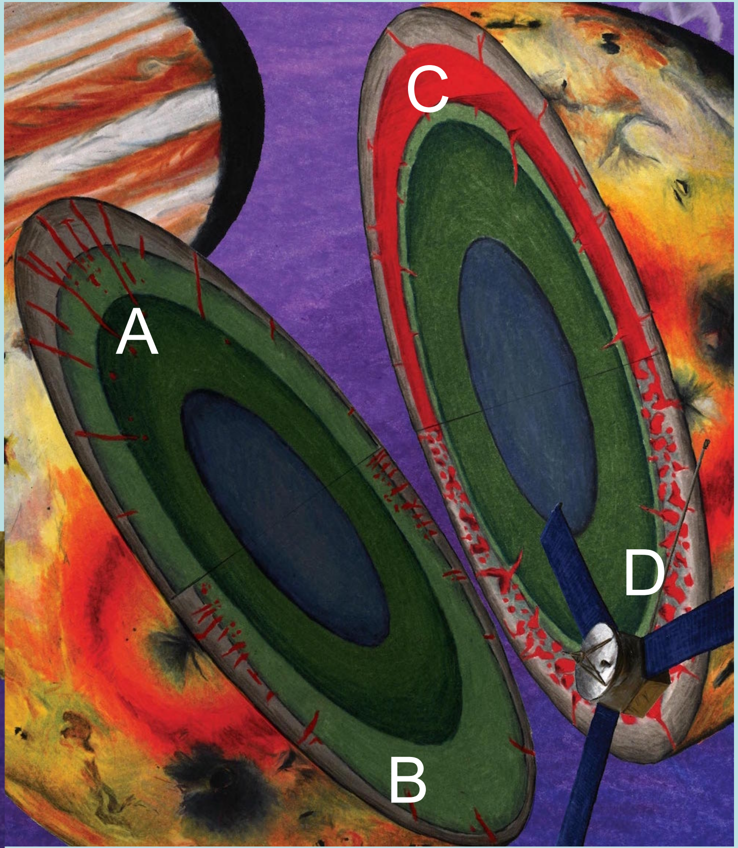
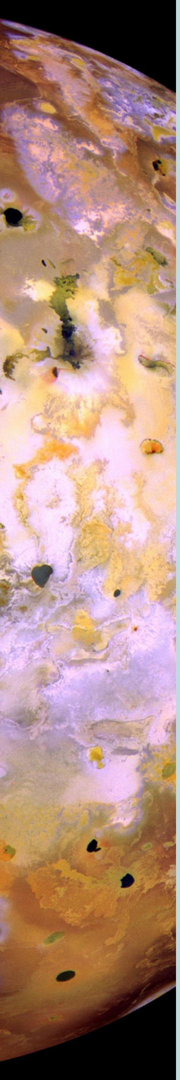


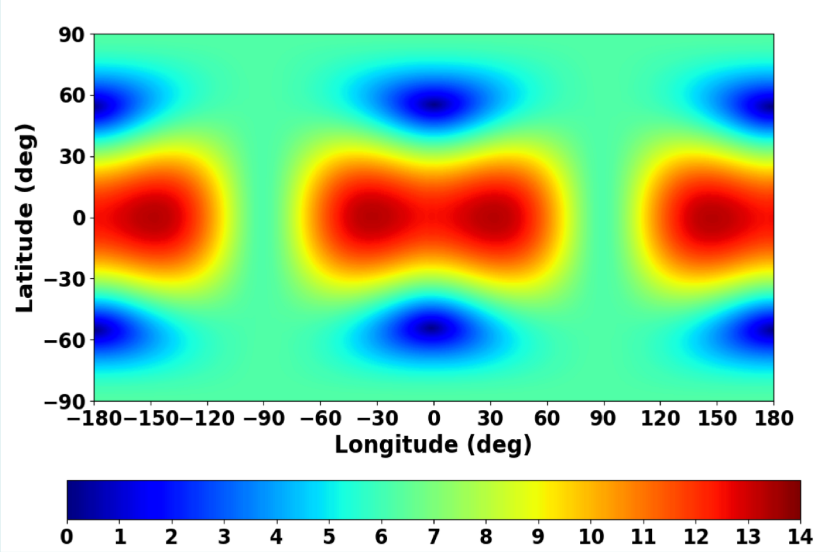
C. Fluid Body Dissipation in Magma Ocean:
- Strong magnetic induction
- Volcanism more uniform
- Very high temperature ultramafic magma
- <u>High</u> k_2 and libration

D. Fluid Dissipation in Magmatic Sponge:
- Strong magnetic induction
- Volcanism more uniform
- Very high temperature ultramafic magma
- <u>Low</u> k_2 and libration



Jupiter tour to measure tidal k_2

- Must pass over the right places at the right times.
- Given IVO's orbit, this requires waiting for Io's orbit to precess.
- Need >3 yrs to measure two periapse-apoapse pairs of encounters.
  - ➢ Increases delta-v, but Mars gravity assist available in late 2020s.
- Side benefit of longer tour is that the subsolar longitude moves significantly
  - ➢ Can image >90% of Io in sunlight or Jupitershine at <300 m/pixel.



Max difference from periapse to apoapse in gravitational signal (mgals)

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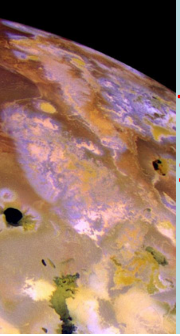
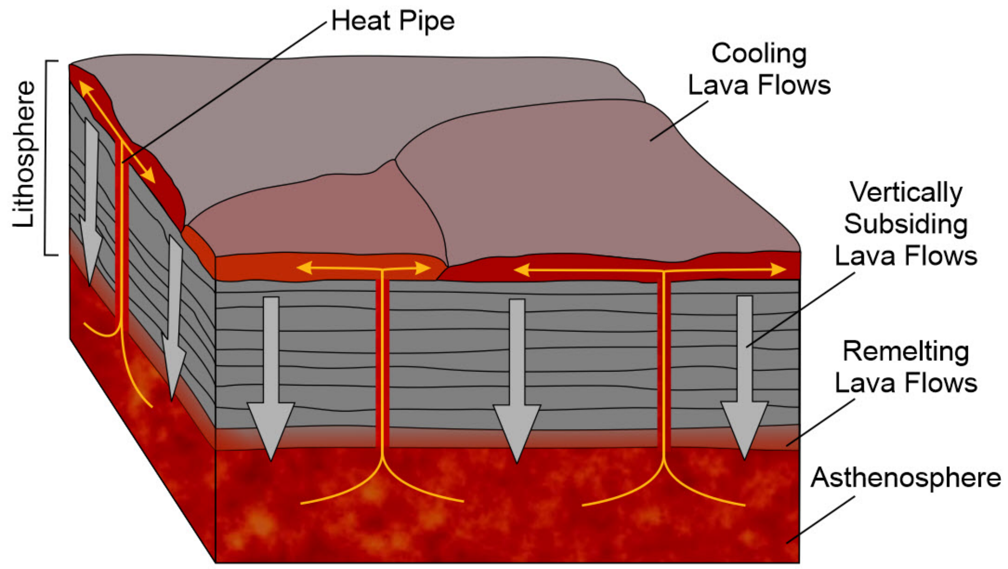
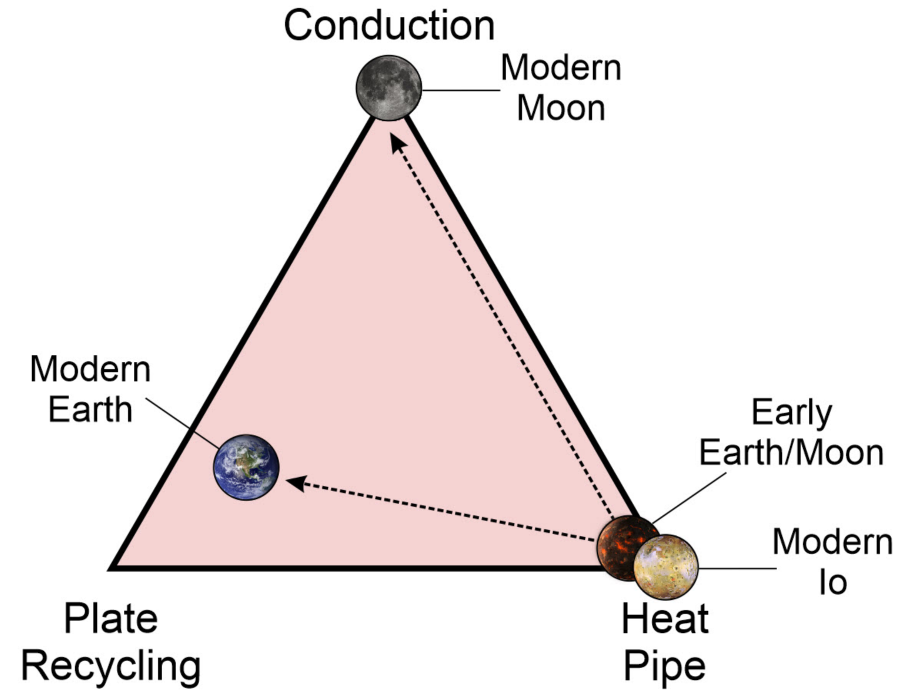


B: How is tidal heat transported to the surface?

The Heat Pipe end-member for how planets lose heat

Early planetary magma oceans cool and solidify, and may lose heat primarily via heat pipes like we envision for Io today (Moore et al. papers).





Conduction cannot keep pace with subsidence rate, so lithosphere is cold and rigid

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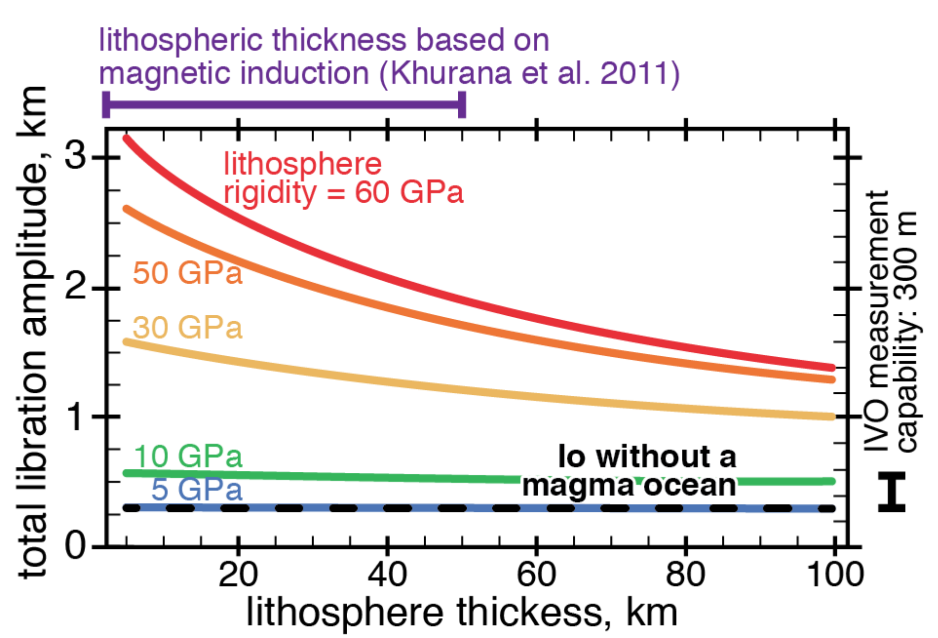
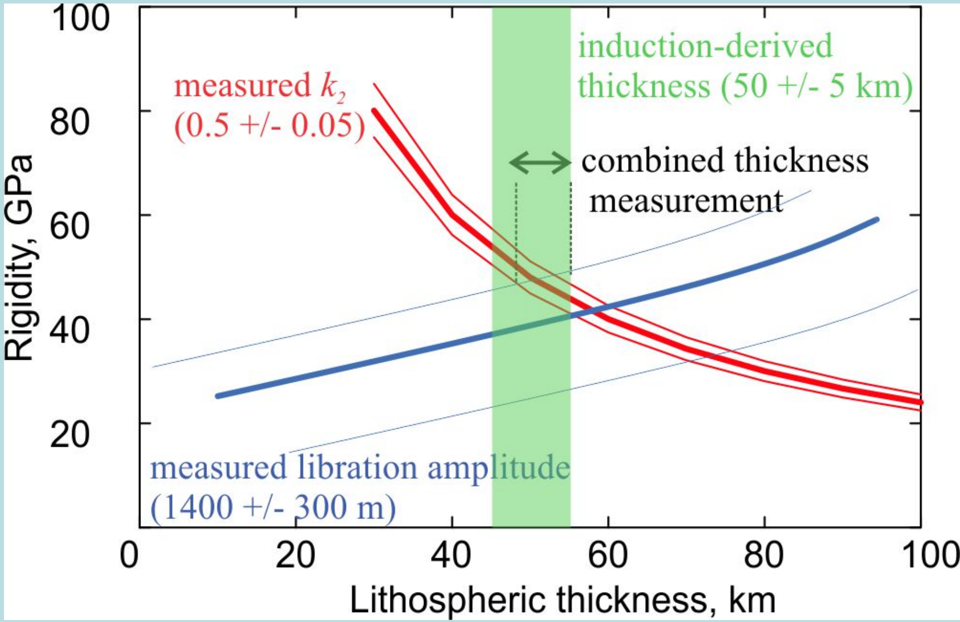
B: How is tidal heat transported to the surface?

How thick and rigid is Io’s lithosphere?

(Test of heat-pipe model)



Hypothetical example



Combined measurements of k_2, libration amplitude, and lithospheric thickness from magnetic induction tightly constrain the lithosphere’s thickness and rigidity. Low rigidity not expected from heat-pipe model.

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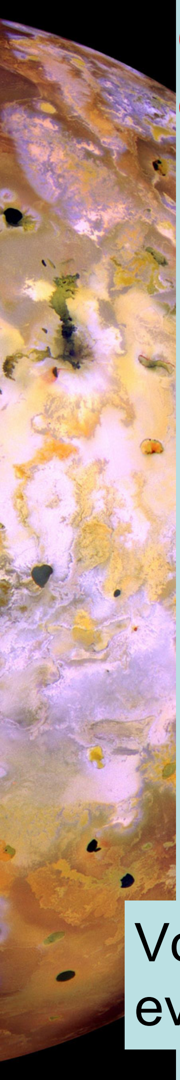
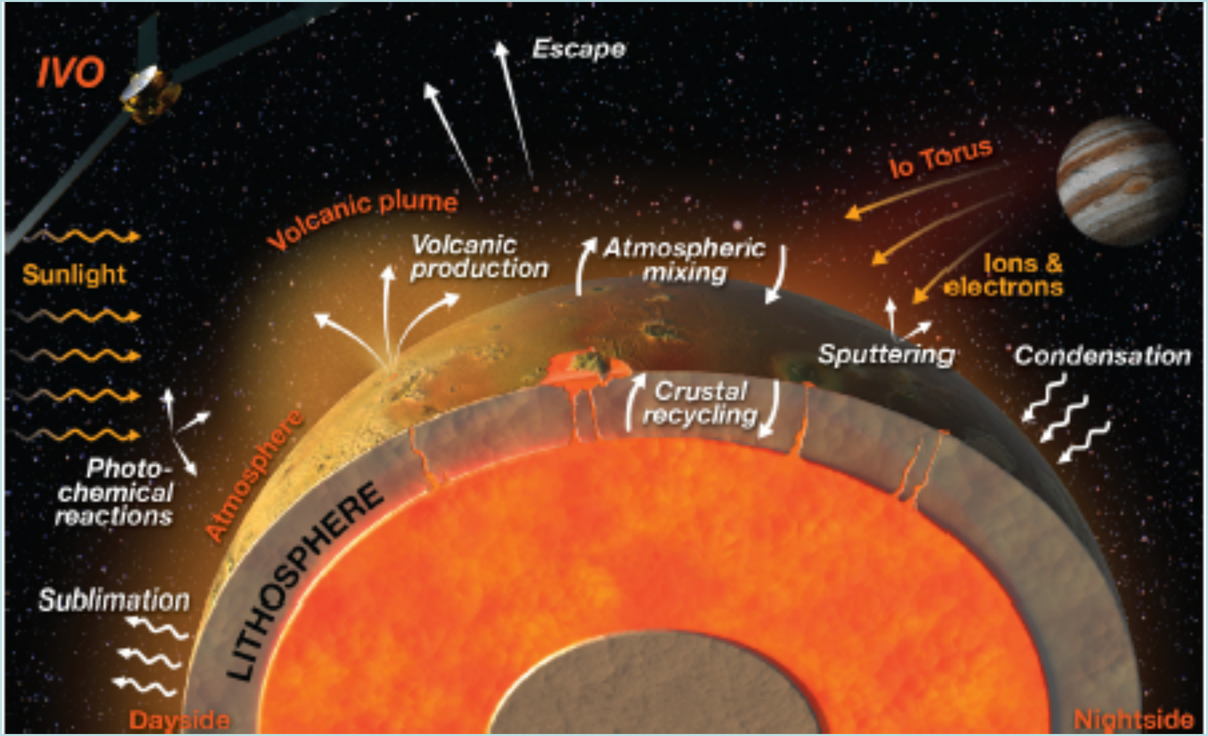


C: How is Io evolving?

How have volatiles evolved on Io?
(Did Io start out volatile-rich or poor?)



Volatile processes are too poorly constrained to know how they have evolved. Io will make critical measurements to constrain current processes

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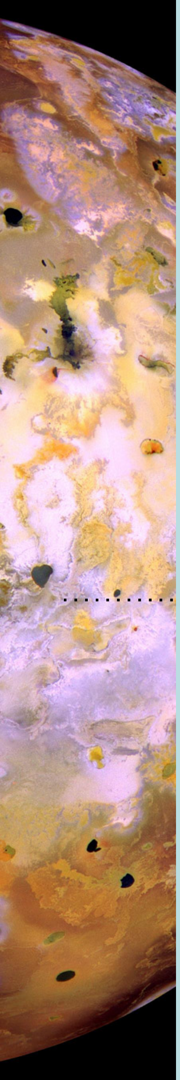
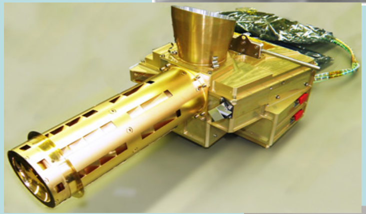


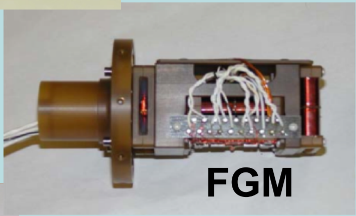
IVO Science Experiments

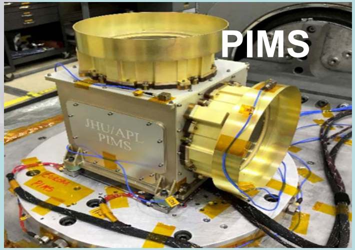
- **Narrow--Angle Camera (NAC)**
  - 10 μrad/pixel, 8 color bandpasses
  - APL, Europa Clipper
- **Dual fluxgate magnetometers (DMAG)**
  - UCLA, multi-mission heritage
- **Plasma Instrument for Magnetic Sounding (PIMS)**
  - APL, Europa Clipper
- **Thermal Mapper (TMAP)**
  - 125 μrad/pixel, 10 bandpasses from 3-14 microns plus radiometer (7-40 microns)
  - DLR, MERTIS
- **Ion and Neutral Mass Spectrometer (INMS)**
  - UBe, JUICE/PEP
- **Radio Science**
  - Tidal k_2
  - Io's orbital migration

NAC and TMAP mounted on pivot: Can always target Io with solar arrays to sun and HGA to Earth.



MERTIS





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New IVO focus in 2019:
Follow the Heat!

Major Partners:

University of Arizona: Science operations, student collaboration camera

JHU APL: Mission and spacecraft design, build, and management; cameras; Plasma Instrument for Magnetic Sounding (PIMS)

UCLA: Dual fluxgate magnetometers

JPL: Radio science, navigation

German Aerospace Center (DLR): Thermal Mapper

University of Bern: Ion and Neutral Mass Spectrometer (INMS)