Europa Ice Penetrator

Towards a Hybrid Ice-Penetrating System

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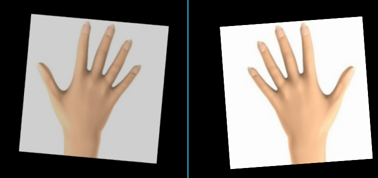
*Jason C. Swenson and †Alexandre M. Kling

* USRA Education Associate, Mission Design Division (Code RD), NASA Ames Research Center Bldg N202 Room 200.
† USRA Education Associate, Space Science and Astrobiology Division (Code SST), NASA Ames Research Center Bldg N245 Room 280.

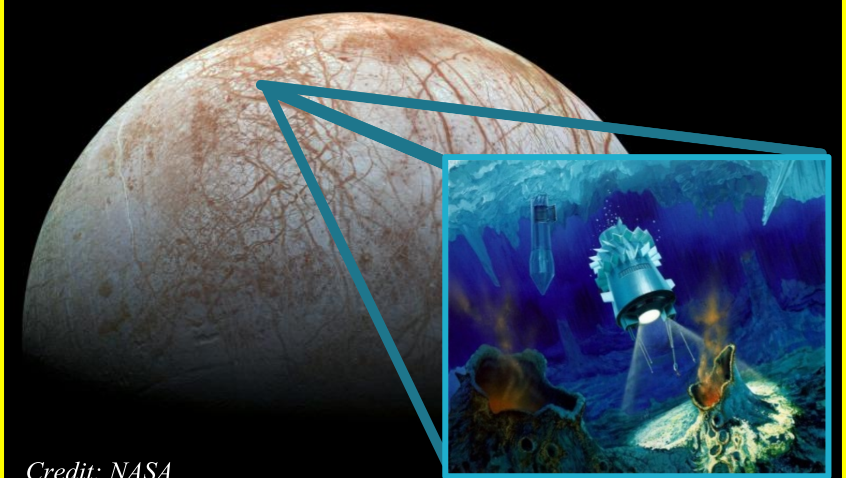
Accessing the Subsurface Constituents on Europa

A Hypothesized Subsurface Ocean

Evidence for life?

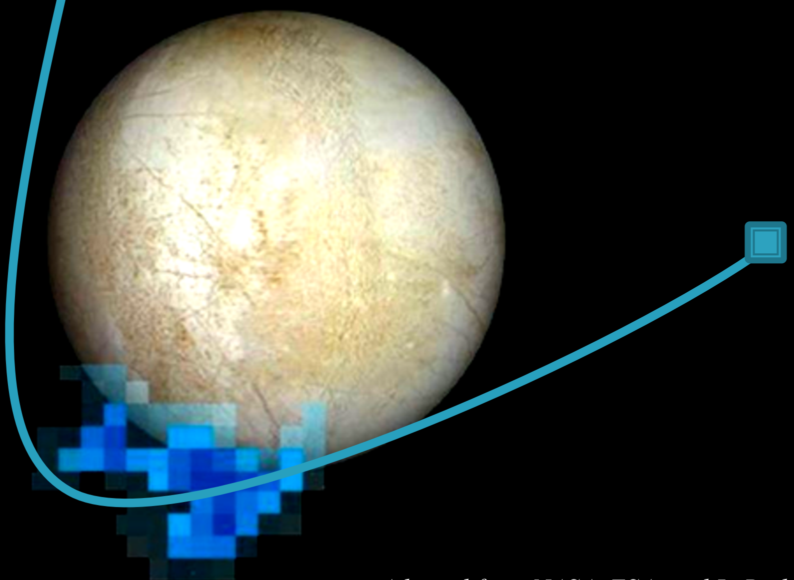


Method 1: Penetrate the surface

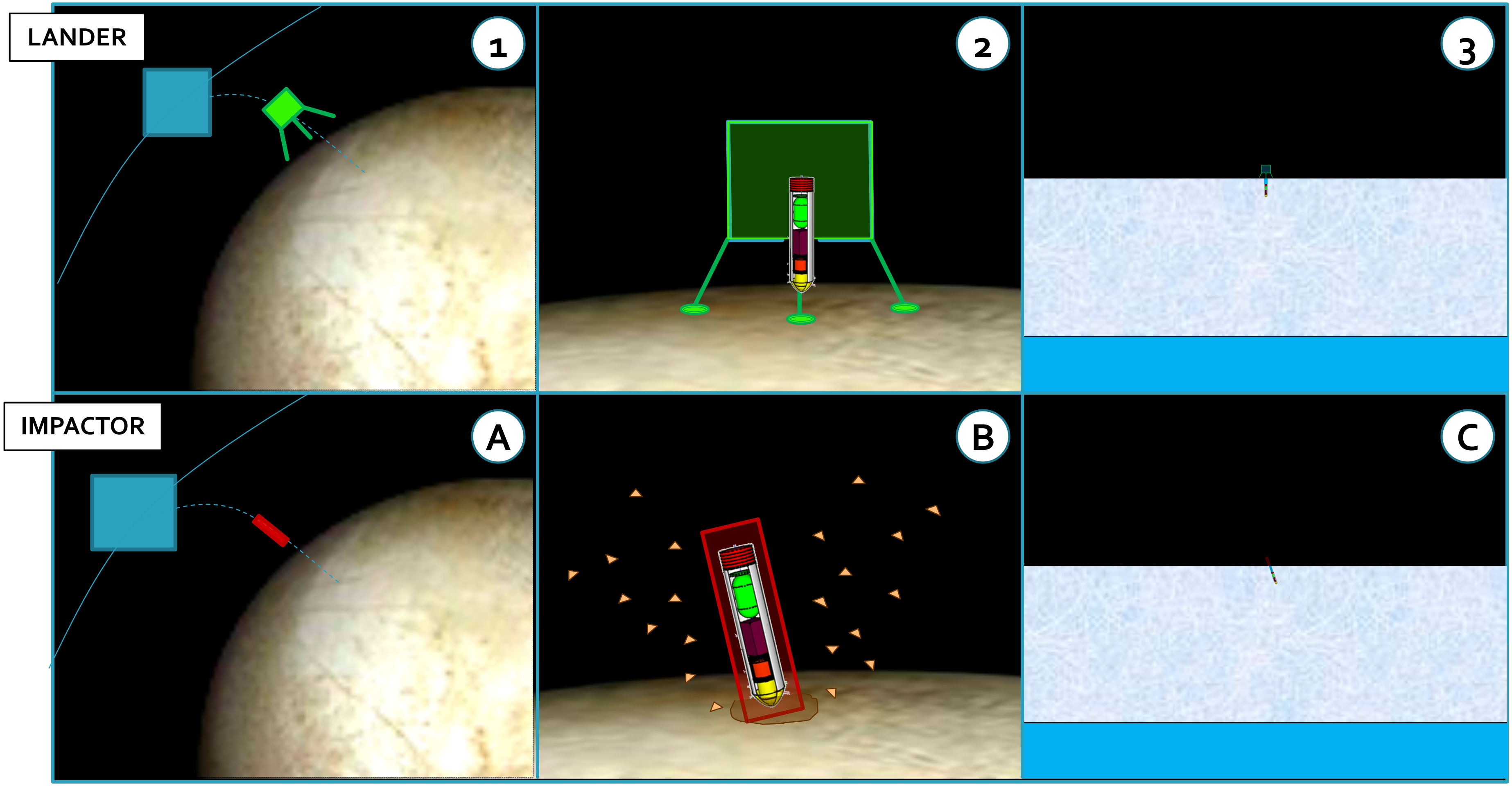


Credit: NASA

Method 2: Sample and analyze the plume



ConOps Possibilities



** For conceptual purposes only. Not all potential mission sequences are discussed.*

Use of Small Spacecraft?

Earth-based techniques	Flagship-class mission	Small(er) spacecraft
➢ Non-applicable due mass and volume constraints	➢ Is this the way to go? (Perhaps…)	➢ Can we do something? (requires understanding of payloads involved)

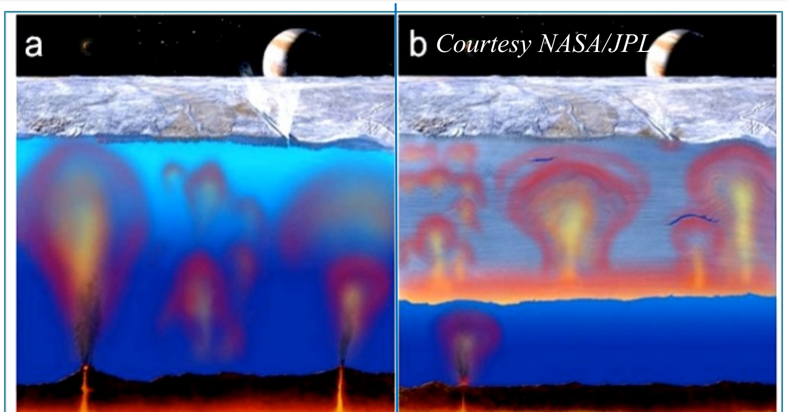
Courtesy Y. Bar-Cohen, K. Zacny

"Aliens of the Deep ", James Cameron

ISSC 2015

***Low-cost* scientific studies can be enabled with strict constraints on spacecraft *mass* and *volume*.**

Global Ice Shell Discrepancies



Thin conductive ice shell	*Thin conductive shell over a thicker layer of convective warm ice*
Few km	*Tens of km*

Methods

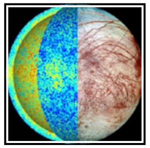
?

Galileo's Doppler & Magnetometer Data

- Internal structure, thickness of H_2O layer

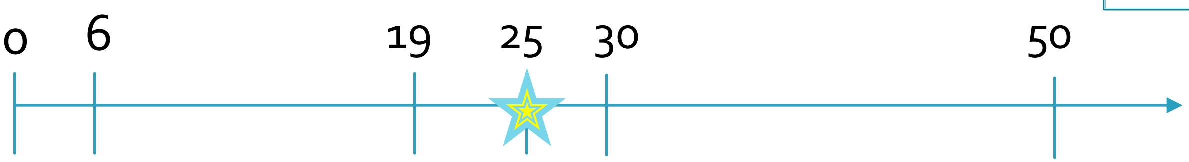
Observation of geological features

- Domes, pits, flexure, and craters



Thermal modeling

- Tidal heating, heat dissipation



6-30 km: supported topography

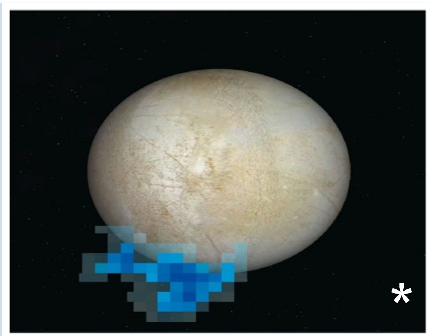
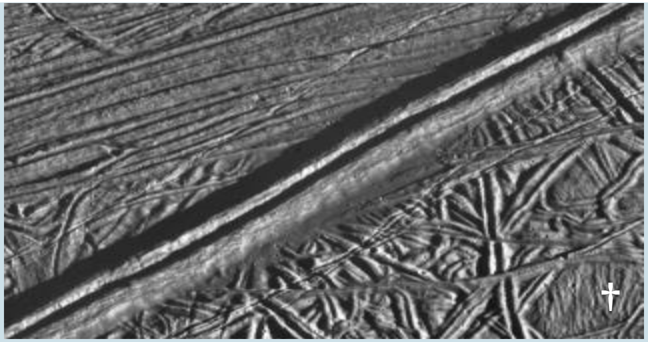
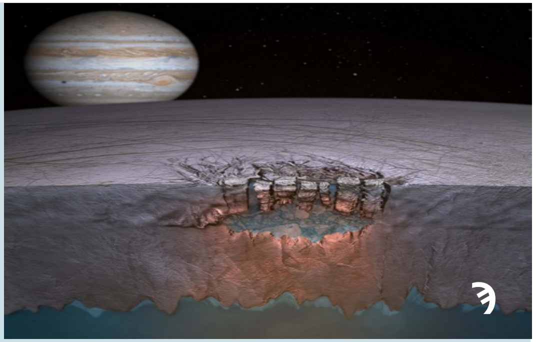
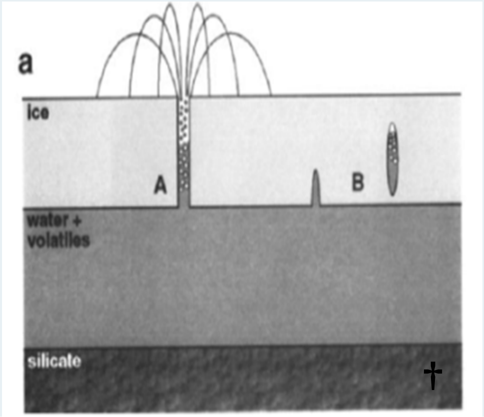
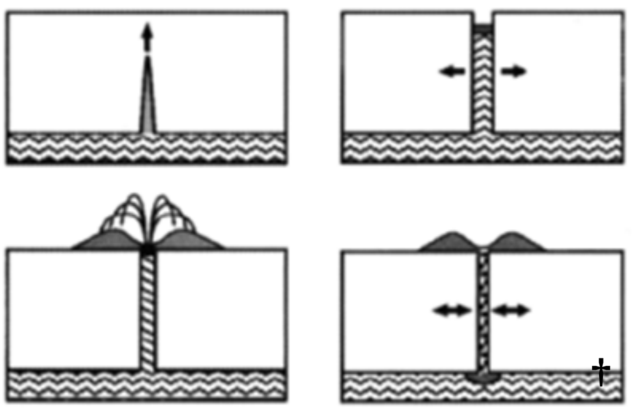
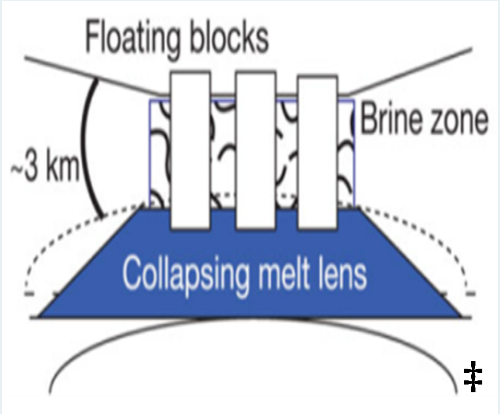
25-50 km: thermal modeling

19 - 25 km: impact craters

Estimation

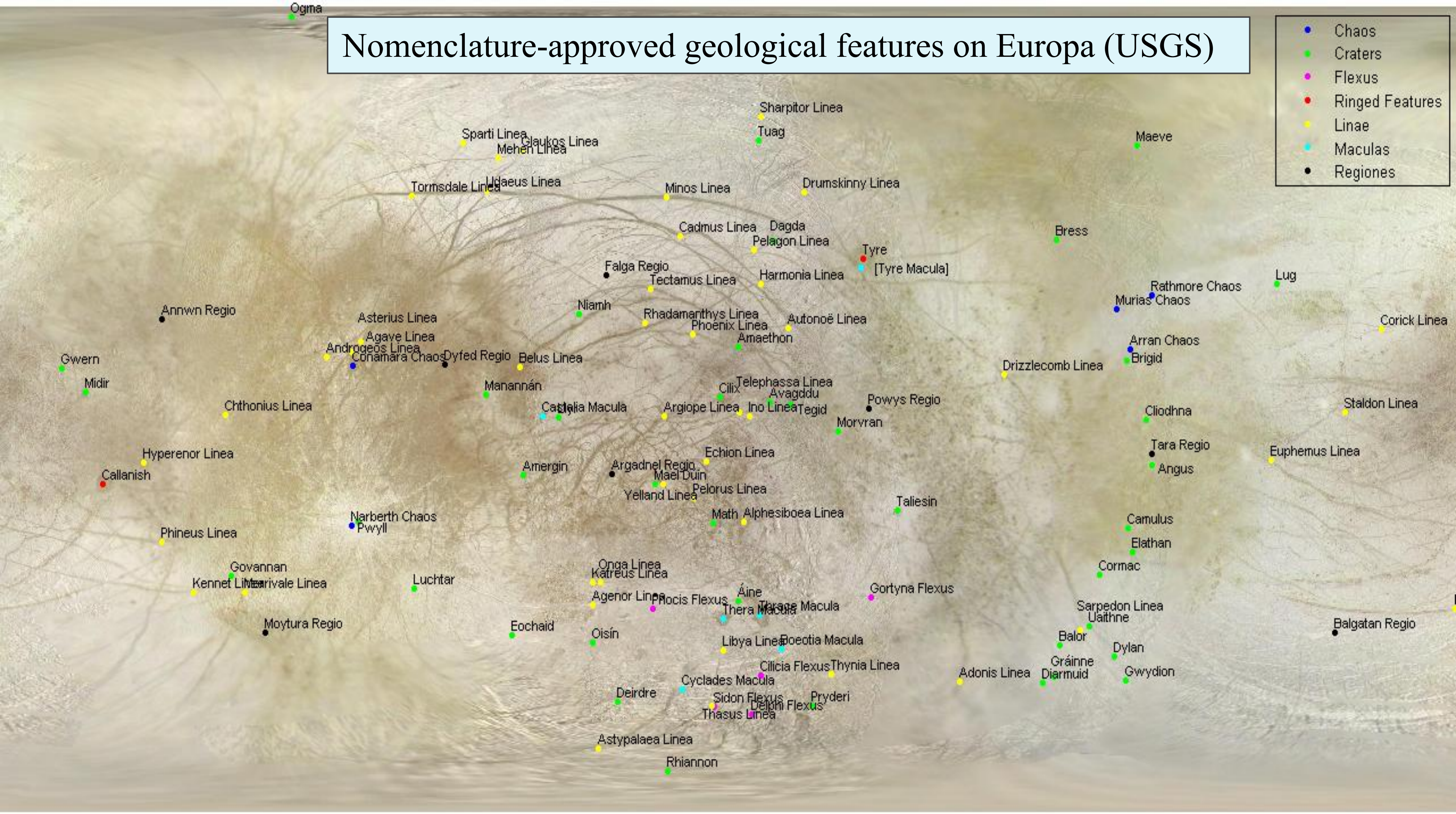
<u>25 km</u> is a *plausible* estimate

Local Ice Shell Discrepancies

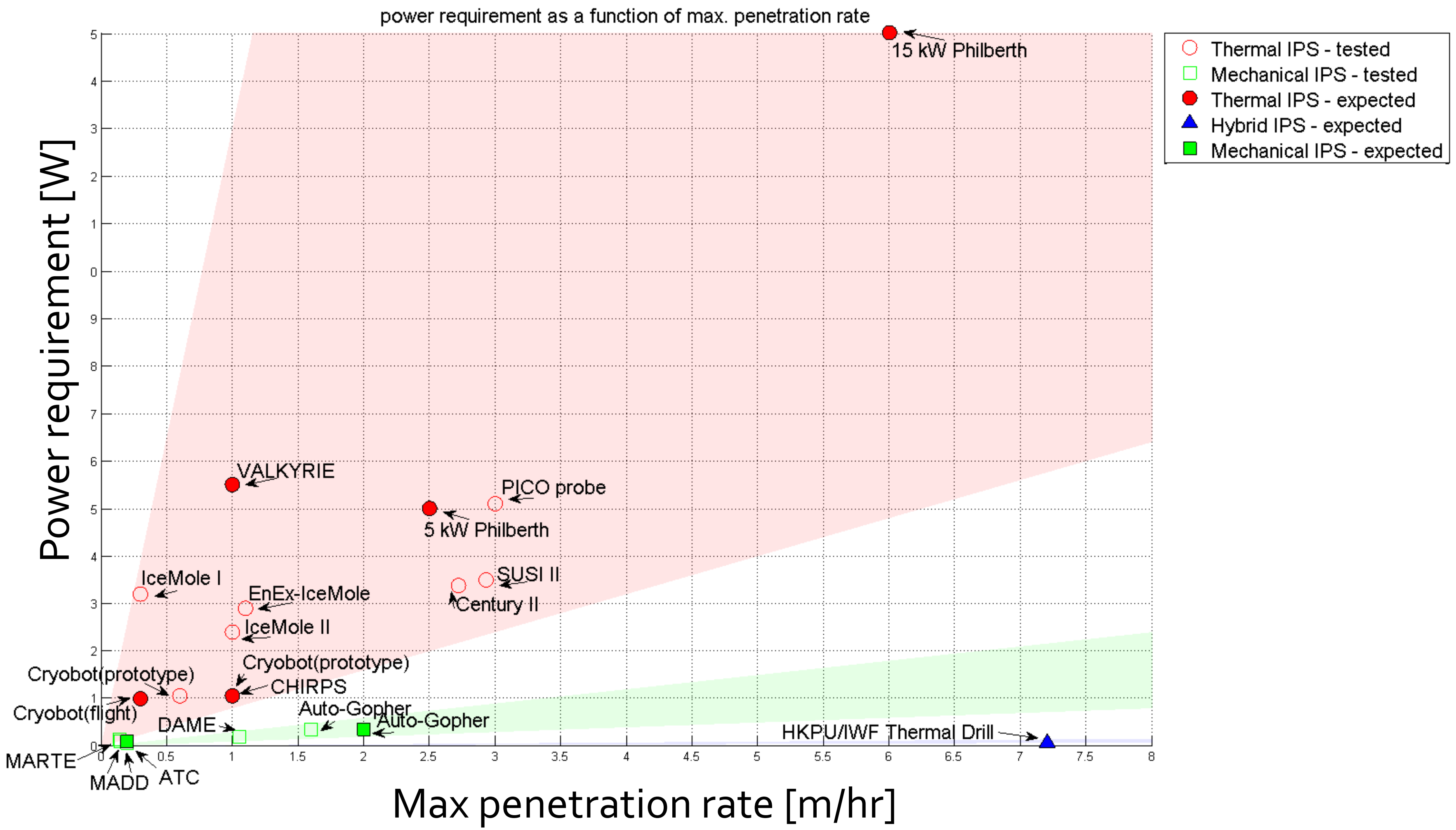
	Plumes	Ridges	Chaos Terrain
Observations			
Models			

* *Courtesy of NASA, ESA, and L. Roth*
ℨ *Courtesy of University of Texas, Austin*
† R.T.Pappalardo, 1999. Does Europa Have a Subsurface Ocean? Evaluation of the Geological Evidence. *Journal of Geo. Research,* Vol 104, pp. 24.015-14;055.
‡ Schmidt, B. E et al., 2011. Active Formation of 'Chaos Terrain' over Shallow Subsurface Water on Europa. *Nature,* 479(7374), pp. 502-504.

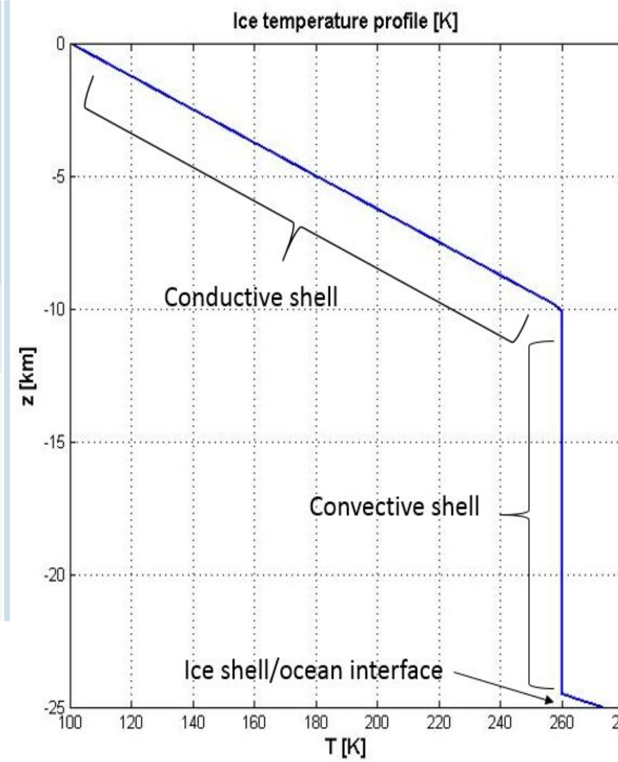
Deployment Sites

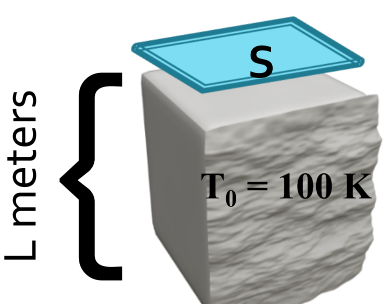


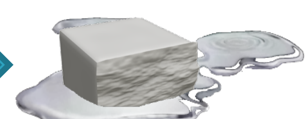
Ice-Penetrating System (IPS) Technology Review



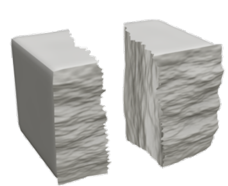
Dimensional Analysis

	Presence of Salts	Presence of Rocks	Temperature Profile
Hypothesis	➢~85% of Europa's surface is ice or frost ➢Probable non-ice candidates: ($MgSO_4 \cdot 6H_2O$, $MgSO_4 \cdot 7H_2O$,) or $Na_2Co_3 \cdot 10H_2O$ ➢Concentrations: 1%, 5%, 20%? ?  *Courtesy NASA/ JPL-Caltech/SETI Institute*	➢ Presence of rocks unlikely ➢ Ecliptic impact probability of Europa relative to Jupiter: 6.6 x 10^{-5}  *Courtesy: National Geographic*	





Melting energy :
$E_{melt} \approx 450$ MJ/m^3 (surface)



Specific cutting energy:
$E_{cut} \approx 5$ MJ/m^3

- ➢ Energy, E, required to melt L meters of ice
- ➢ Power → time required to deliver E
- ➢ penetration rate

Thermal IPS

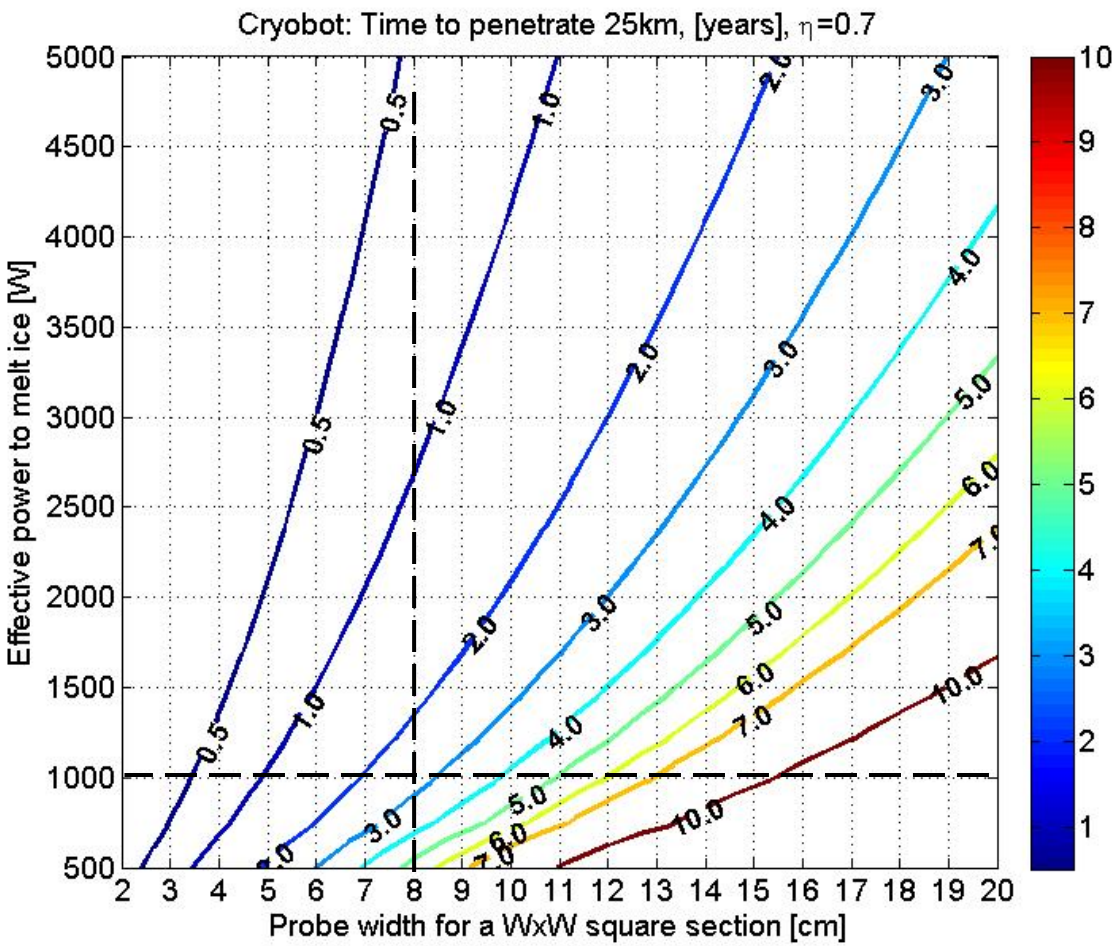
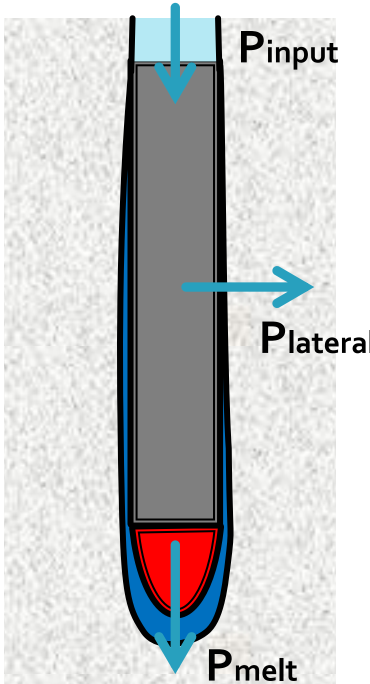


Chart derived from equations in the following reference: Aamot, H. W. C., 1967. *Heat Transfer and Performance of a Thermal Probe for Glaciers;* Thermal IPS chart does not consider lateral heating.

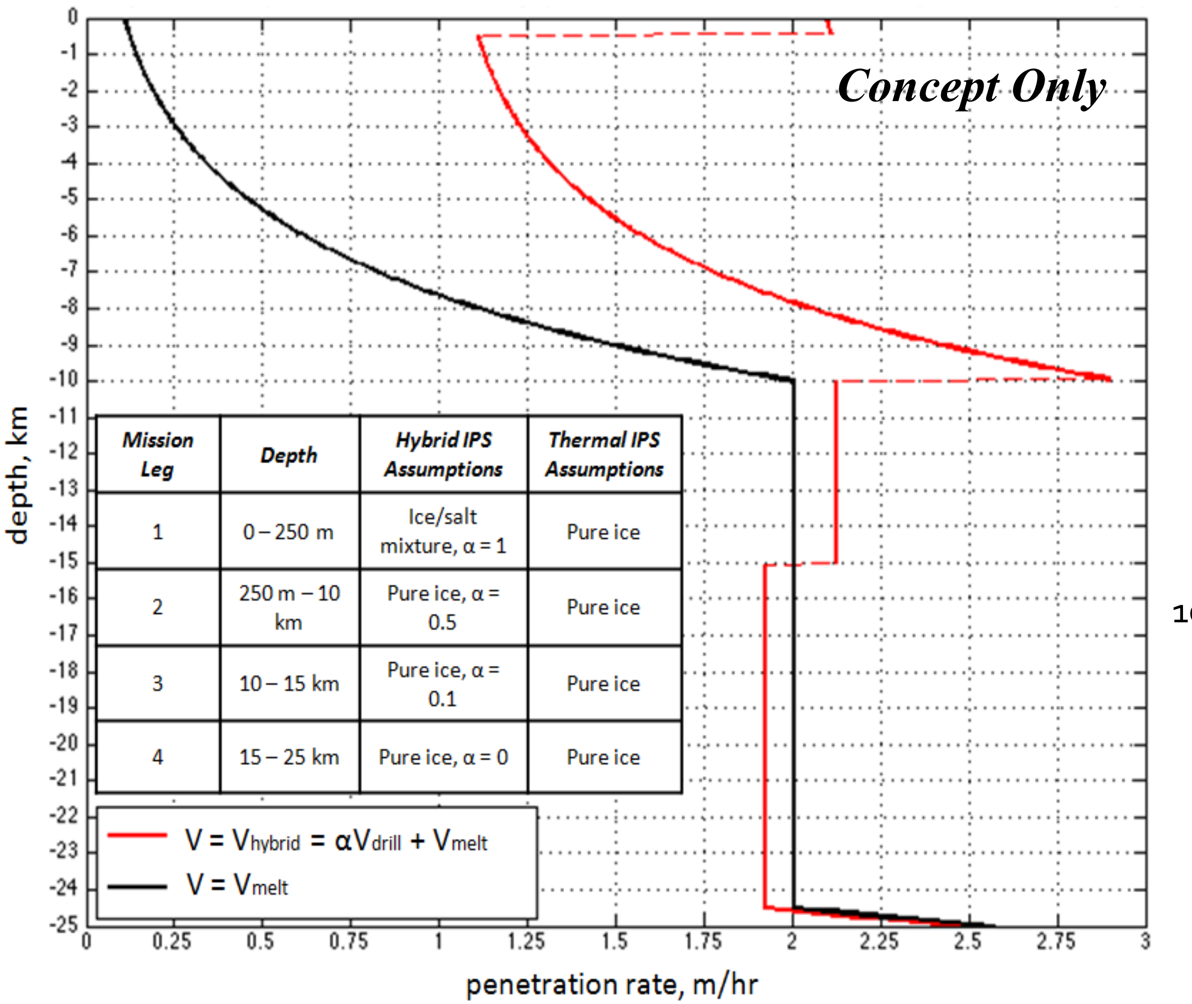
Lateral Heating Considered?	Input Power	Total Penetration Time (TPT)
NO	> 1 kW	< 2.75 years
YES	2 kW	~4.5 years

- In practice, 1000 W hardly initiated melt at the surface



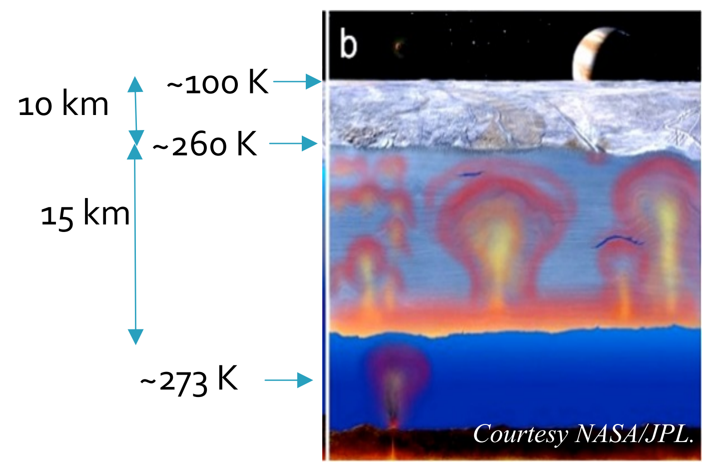
Hybrid IPS

8 x 8 cm Hybrid IPS (70 – 2000 W, 1.60 yr) vs. 8 x 8 cm Thermal IPS (2000 W, 4.36 yr), 25 km



Mission Leg	Depth	Hybrid IPS Assumptions	Thermal IPS Assumptions
1	0 – 250 m	Ice/salt mixture, $\alpha = 1$	Pure ice
2	250 m – 10 km	Pure ice, $\alpha = 0.5$	Pure ice
3	10 – 15 km	Pure ice, $\alpha = 0.1$	Pure ice
4	15 – 25 km	Pure ice, $\alpha = 0$	Pure ice

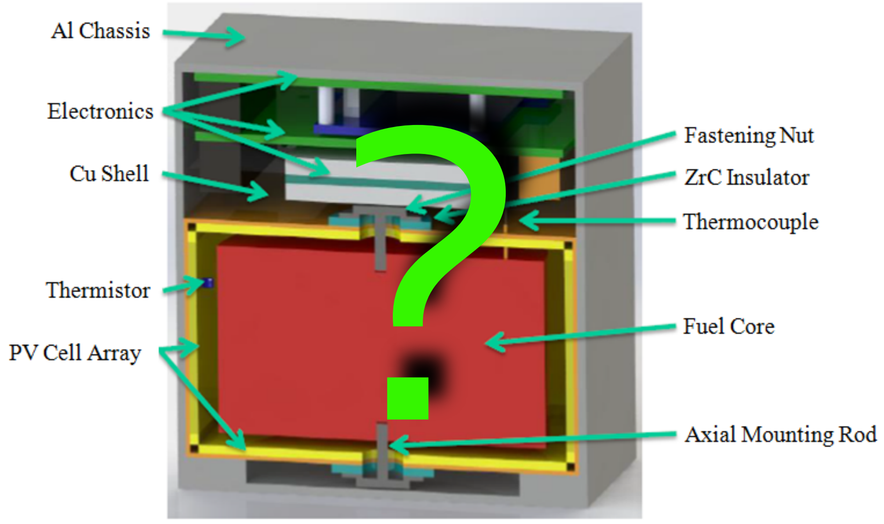
- Melting at the surface is highly inefficient
- Mechanical drilling allows faster penetration rate at the surface
- If convection is initiated within the crust, the ice shell is thick and temperatures rise quickly
- (In our model, dT/dz = 16 K/km)



System Considerations: Power Distribution and Communication

How to power an IPS traversing 25 km?

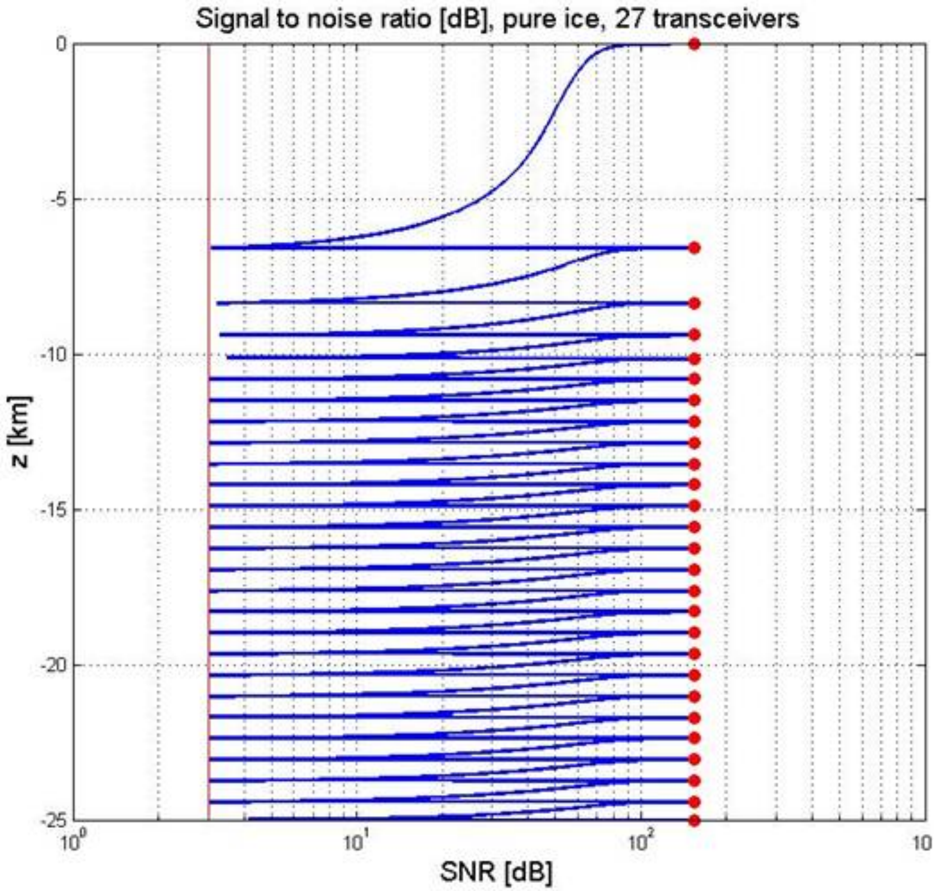
- Surface-based power
  - Large mass requirement
  - Tethers limit achievable depth
- Internal power
  - RPS (e.g. RTPV) could provide 1.4 kW for a melthead / drill actuator



A. Goel, K. Schillo, B. Franz and S. Reddy, 2014. "Radioisotope Thermophotovoltaics (RTPV) Flight Demonstration," Idaho Falls, ID, 2014.

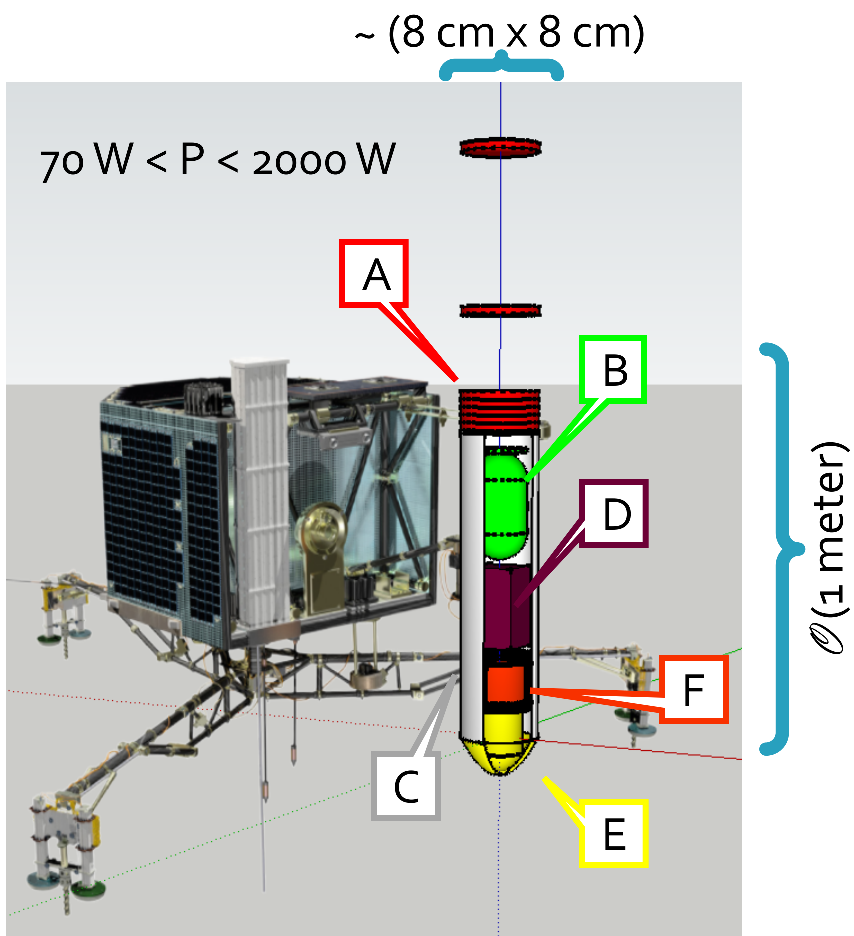
How to communicate through 25 km of ice?

- Mini RF Ice Transceivers



Bryant, S., 2002. *Ice-Embedded Transceivers for Europa Cryobot Communications.* Big Sky, Montana.

Concept: Hybrid IPS for 25 km Ice Shell

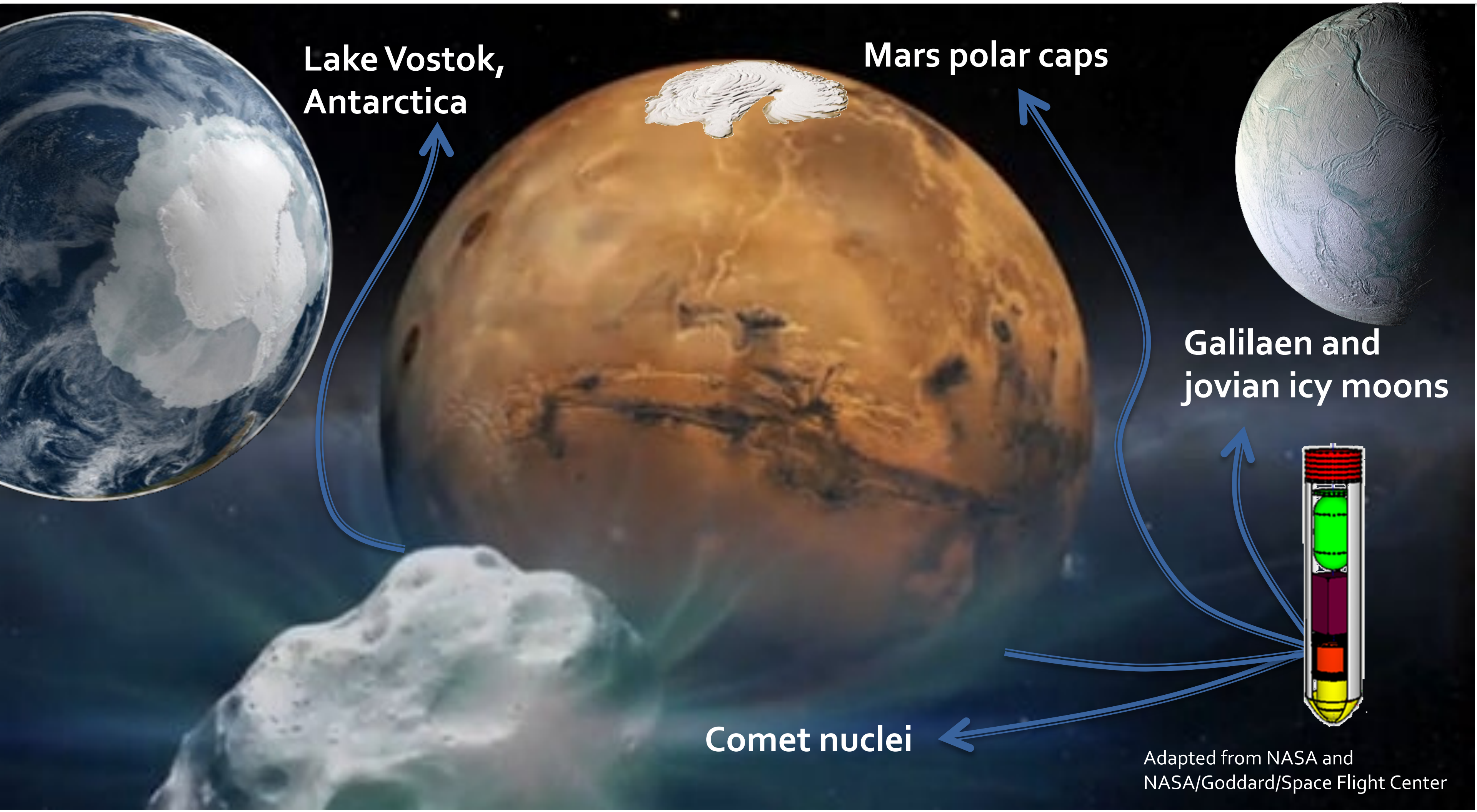


	Component	Remarks
A	Mini RF Ice Transceivers	Robust to ice shell motion and borehole refreezing
B	Science Payload	- "Lab on chip"(€) - Conductivity, Temp. and Depth Sensor (ð) - underwater vehicle
C	IPS Body	Lateral heating
D	Control Unit & Sensors	- IMU sensor - Ultrasound Sensor - Thermal/IR Imager
E	Melthead / Drilling Actuator	- Rotary drill - Hammer drill
F	Radioisotope Power Source (RPS)	If penetration depth >3km, otherwise tether may be possible

€ Butterworth, A.L. et al. Lab-on-a-Chip Organic Analyzer: Instrumentation and Methods for Detecting Trace Organic Molecules and Amino Acid Chirality in Planetary Science. 46^{th} LPSC, 2015.

ð Jonsson, Jet al. Chip-Based Salinity Measurements for Small Submersibles and Biologgers. International Journal of Oceanography, 2013.

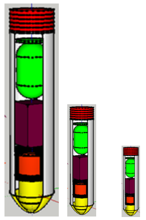
Need for an IPS Able to Penetrate Ice-rock Mixtures



Adapted from NASA and NASA/Goddard/Space Flight Center

Conclusion

- Hybrid (melting and drilling) system would enable drilling through cold surface ice and salts
- A 70 – 2000 W hybrid IPS unit can theoretically complete its mission in approximately 1.6 years, nearly three times faster than a 2000 W thermal IPS with lateral losses included and of the same cross sectional area
- RPS technology is required to achieve large (>> 3 km) penetration depths; 27 ice-embedded mini RF transceivers are required for communications at 25 km
- Potential for a hybrid IPS to explore other icy bodies (moons, comet nuclei, Mars' polar caps, etc.) or study subglacial environments (Antarctica, Arctic, etc.)



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