

Ocean Worlds, Icy Bodies, and RTG Concepts for Exploration

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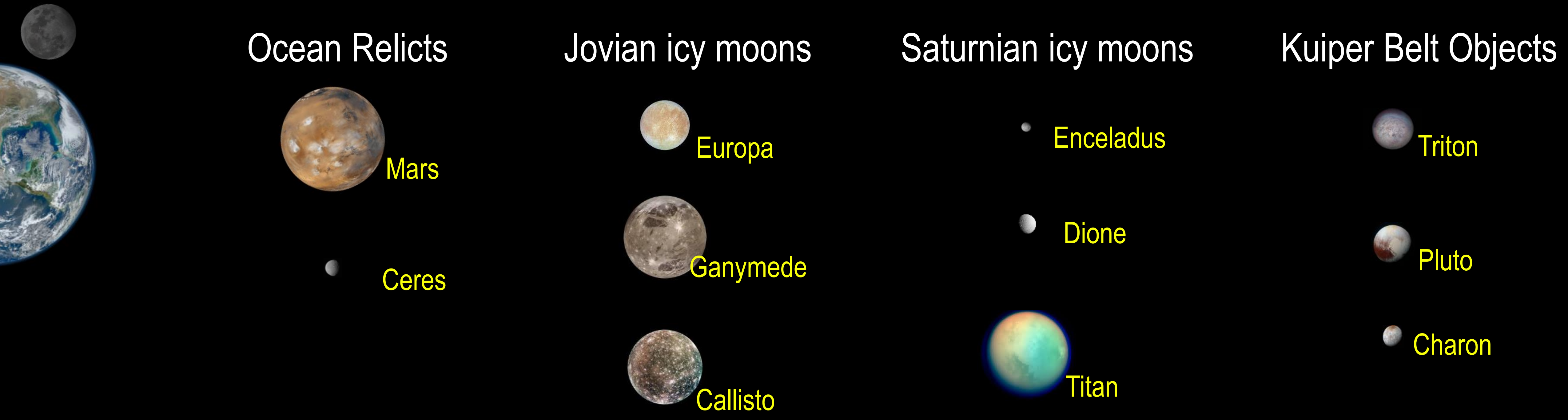
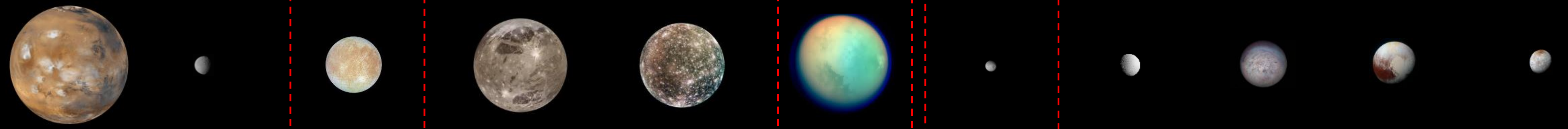
More than a dozen ocean worlds within reach



Known and Potential Ocean Worlds

B. Sherwood, J. Lunine, C. Sotin, T. Cwik, F. Naderi, *Program Options to Explore Ocean Worlds*, Global Space Exploration Conference Beijing, June 2017

	Mars	Ceres	Europa	Ganymede	Callisto	Titan	Enceladus	Dione	Triton	Pluto	Charon
Diameter	3390 km	473 km	1561 km	2634 km	2410 km	2576 km	252 km	561 km	1353 km	1187 km	606 km
Distance from Sun, AU	1.5	2.7	5.2	5.2	5.2	9.5	9.5	9.5	30.1	39.5	39.5
Gravity, m/s^2	3.7	0.28	1.32	1.43	1.24	1.35	0.11	0.23	0.78	0.62	0.29
Group			Jovian icy moons	Jovian icy moons	Jovian icy moons	Saturnian icy moons	Saturnian icy moons	Saturnian icy moons	Kuiper Belt Objects	Kuiper Belt Objects	Kuiper Belt Objects



Three—Jupiter's moon Europa, and Saturn's moons Enceladus and Titan—have subsurface oceans whose existence has been detected or inferred by two independent spacecraft techniques.

CREDIT: PHL @ UPR Arecibo, NASA

Three steps: Europa, Enceladus, Titan

Europa

Comprehensive investigation of the icy moon's habitability

- Near-global hyper mapping
- Lander-scale surface imagery

Land at ocean-surface exchange zone

Mobility around touchdown point

Subsurface access to pursue fresher material

Trans-shell probe into ocean, sample return

Under-ice exploration of ocean ceiling

Open ocean exploration, including seafloor

Enceladus

Direct access to material known to originate in a habitable place

- Plume transects
- Best compositional analyzers

Wet-chemistry and microscopy of grain material

Collection, preservation, and return of samples

Surface collection of large amounts of material

'Downhole' access to the foaming interface

Under-ice exploration of ocean ceiling

Open ocean exploration, including seafloor hydrothermal systems known to exist

Titan

Comprehensive reconnaissance of a complex world

- Atmospheric organics factory
- Global surface mapping
- Gravity, tidal mapping

Aerial exploration

Buoyant sea exploration

Mobile surface exploration

In situ analysis of weathered organics

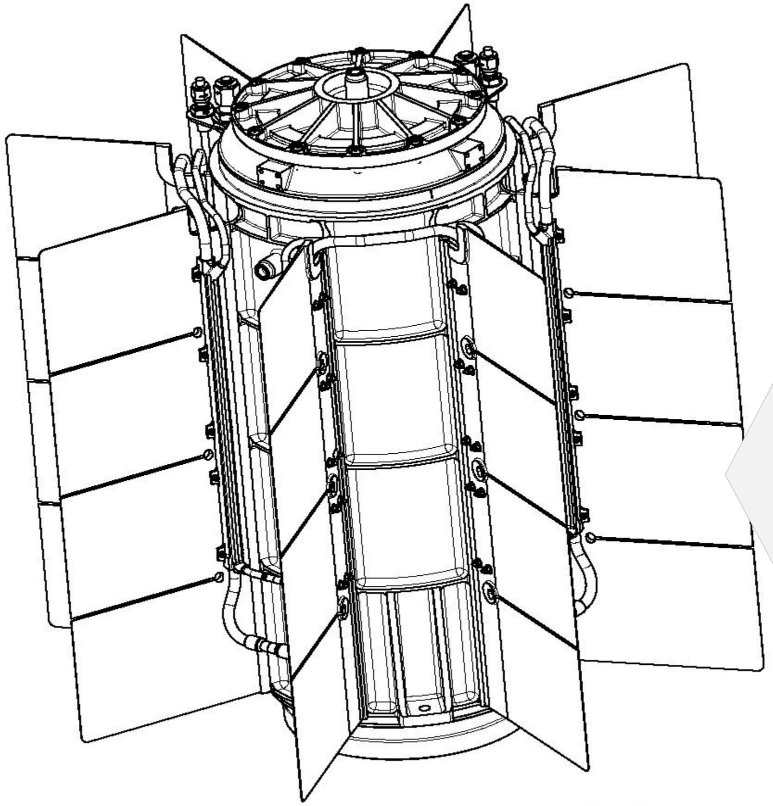
Sample return

Through-crust ocean access

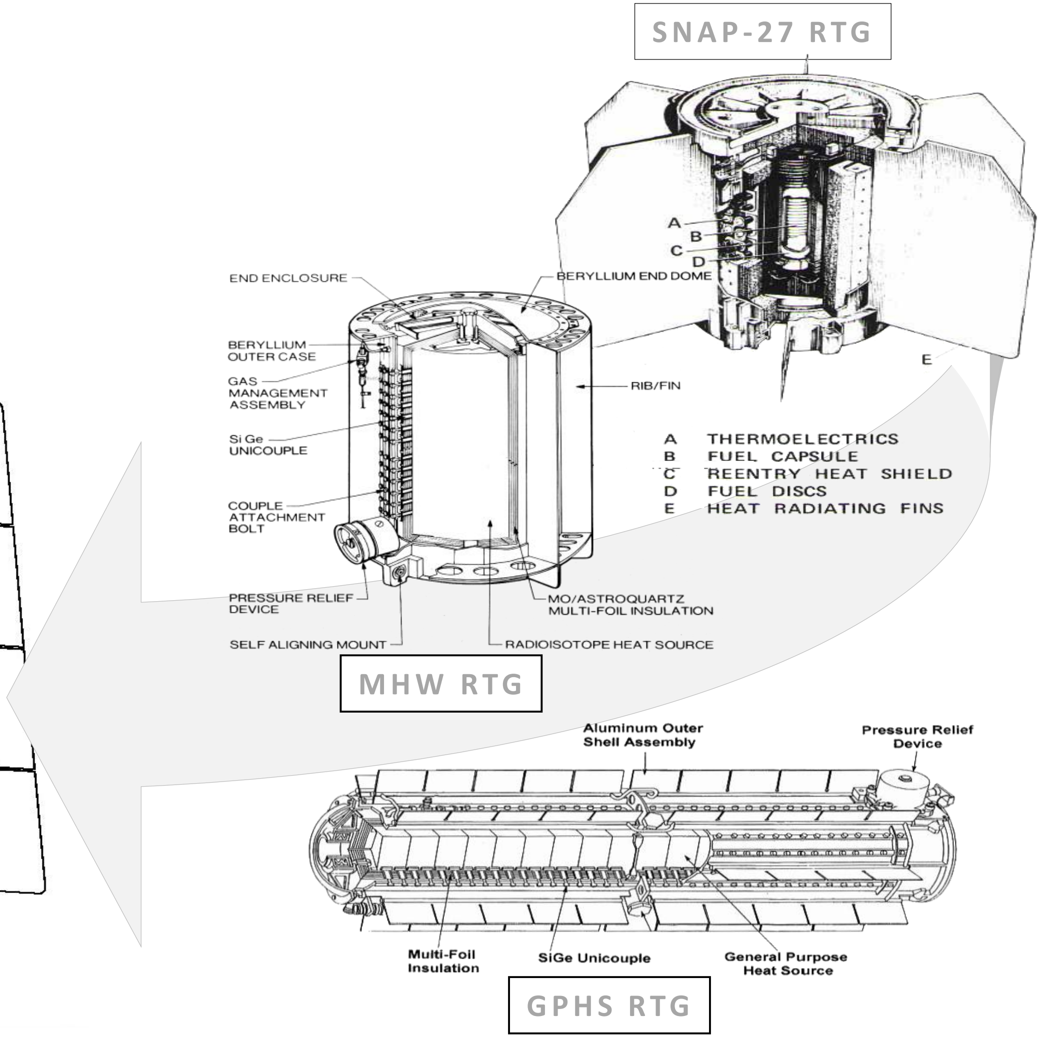
RTGs – General Purpose

- Converts heat produced from the decay of plutonium dioxide into quiet DC power.
- The US Department of Energy has produced a variety of RTGs that have been designed and flown over the last 5 decades by NASA.
- Designed to work in atmospheres and vacuum
- Most have been general-purpose systems

- Only the MMRTG can be procured today.
- Not well-suited for melt probe exploration: low efficiency, low waste heat



MMRTG

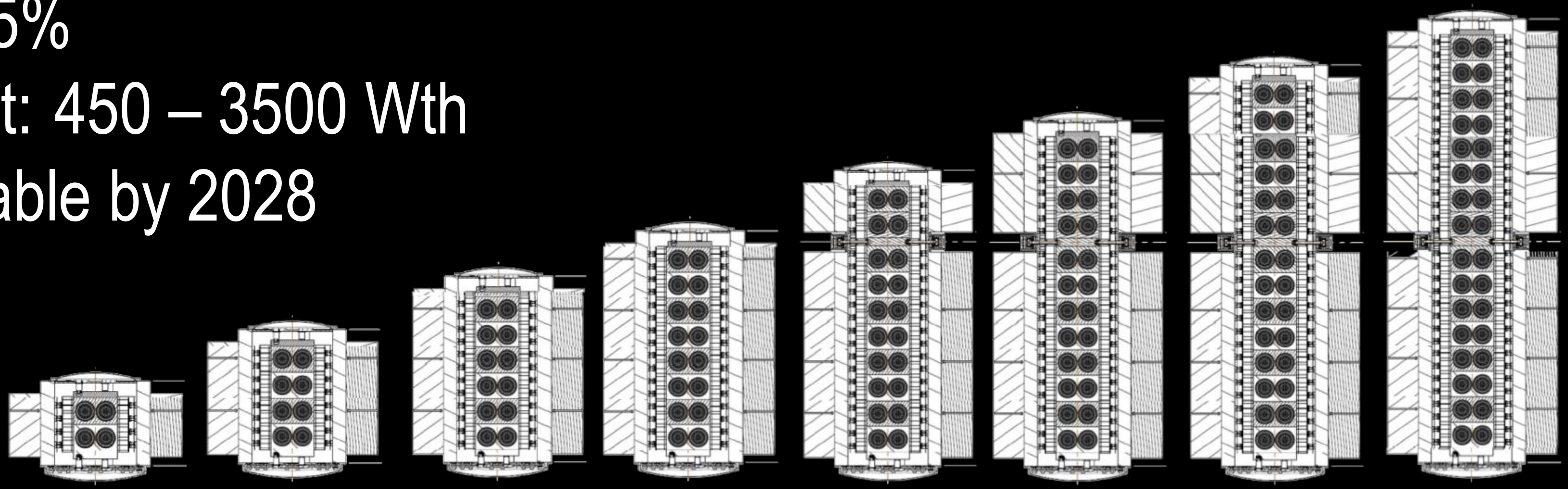


RTG – Radioisotope Thermoelectric Generator

RTGs: A key technology common to all Ocean World targets

- Conceptual Next-Generation RTGs *

Modular: 50 – 500 W (Beginning Of Life)
20 – 60 kg
Efficient: 10-15%
Copious waste heat: 450 – 3500 Wth
Within reach, available by 2028



50 W ⟷ 500 W

* Artist concepts from: Woerner, et al, *Next-Generation Radioisotope Thermoelectric Generator Study Final Report* June, 2017, JPL-internal Document: JPL D-99657

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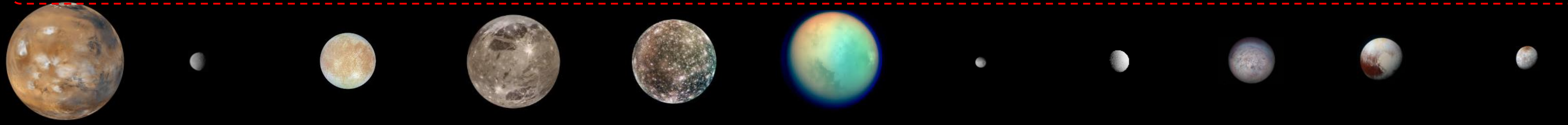


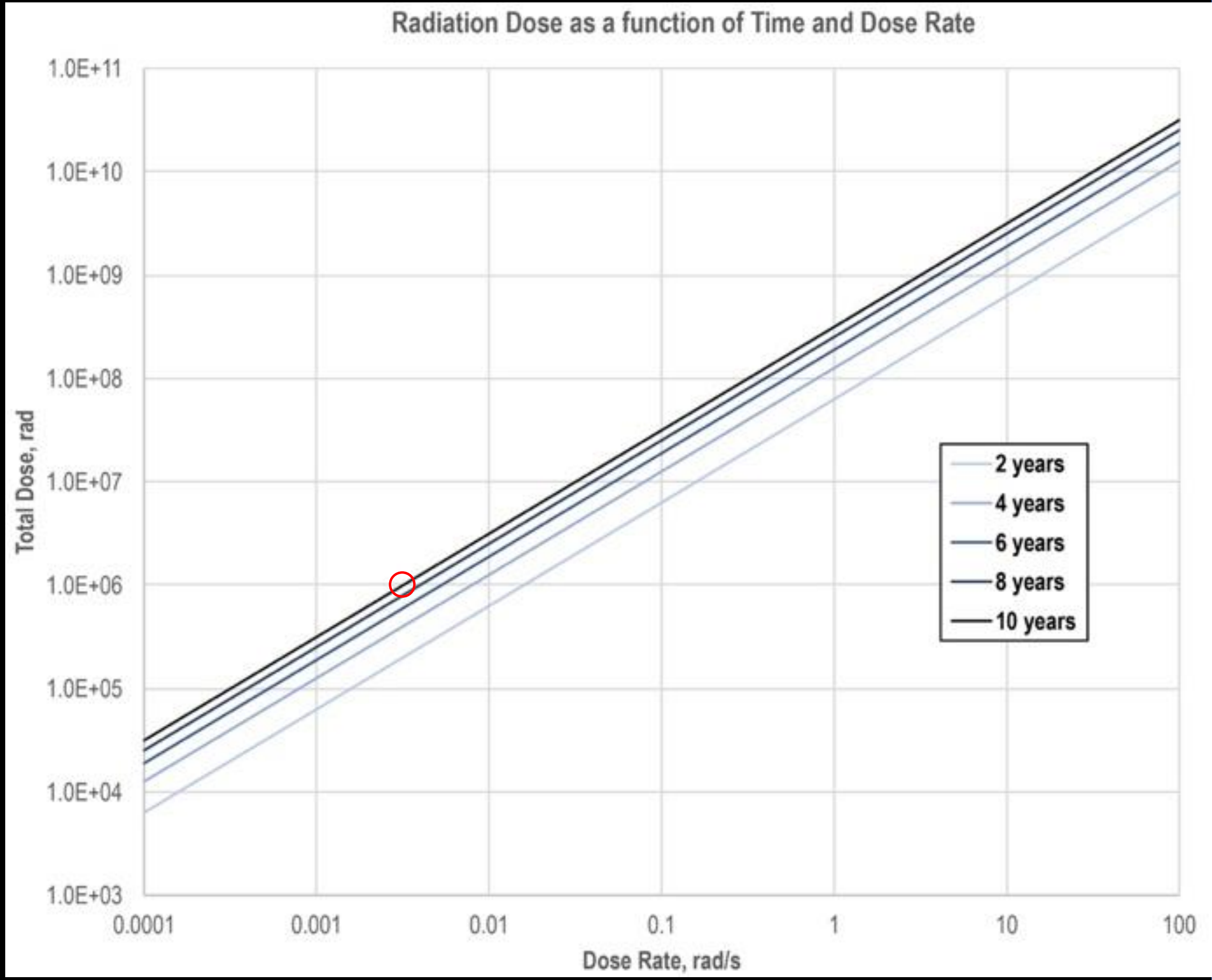
Jovian icy moons — Saturnian icy moons — Kuiper Belt Objects

A universal melt probe is unlikely. Weak gravity will require propulsion, ice thickness will change design life requirements, atmosphere or not at target, and so on.

A focus on Europa

Environments: *

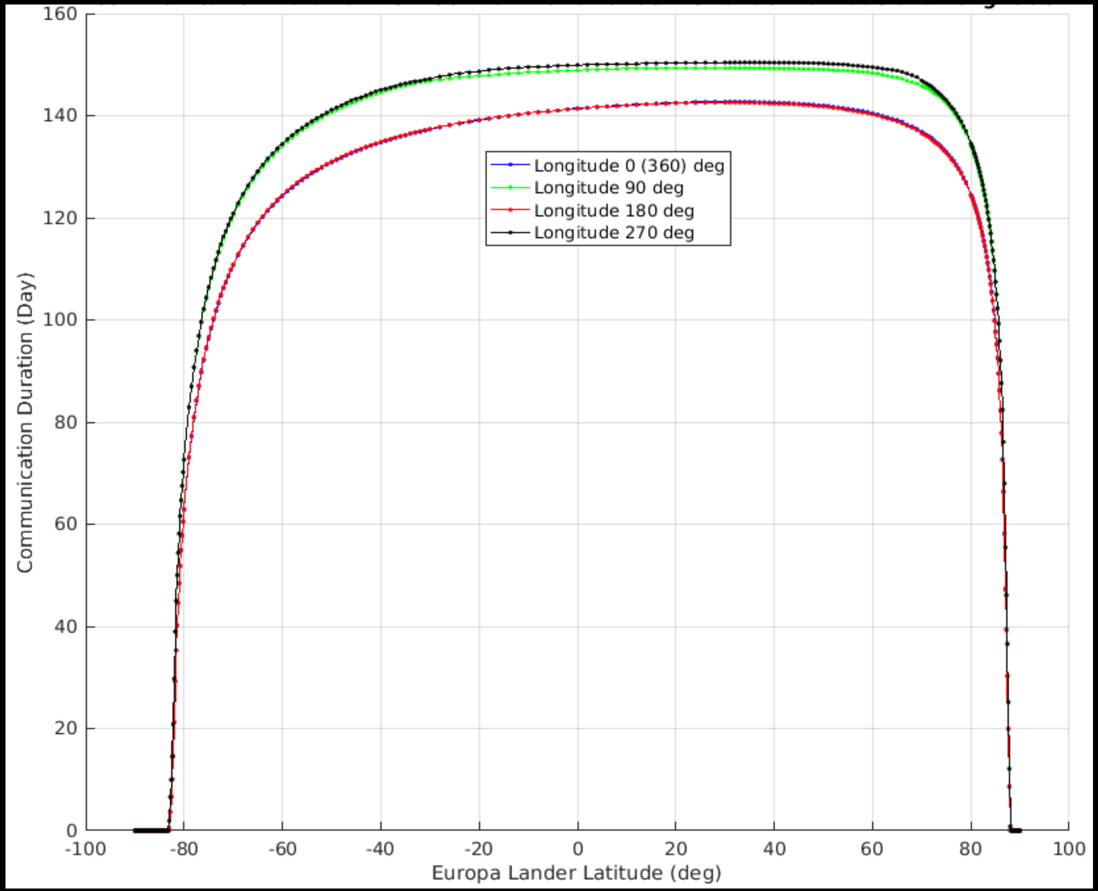
- Radiation: up to 9 Mrad/day unshielded
- Temps: 70 – 132 K
- Thermophysical properties at temp
- Accumulated salts and acid
- Pressure: ~12 Mpa at 10 km



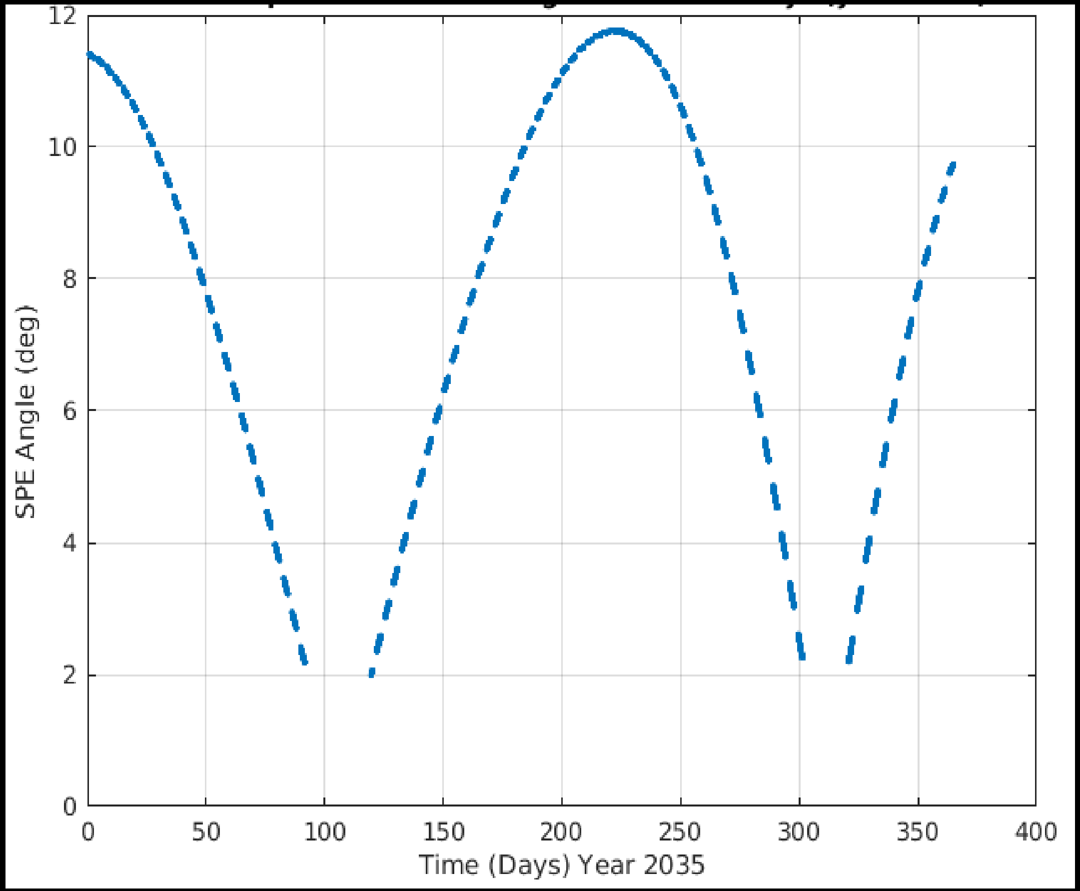
Worst-case dose in years given a a continuous dose rate

* More environmental factors described in paper

A word about telecommunications

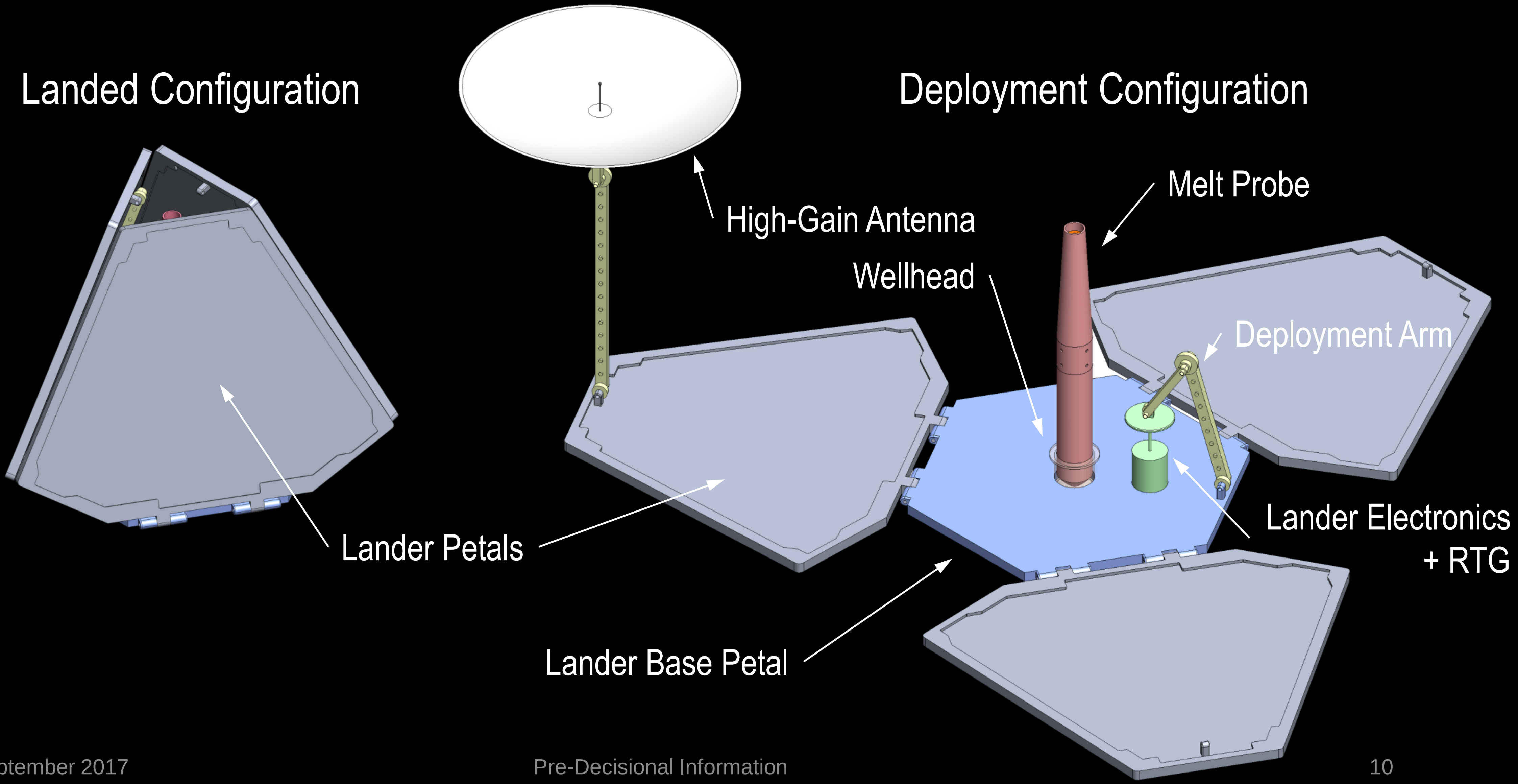


Number of line-of-sight communication days for given latitudes and 4 different longitudes in the year 2035.

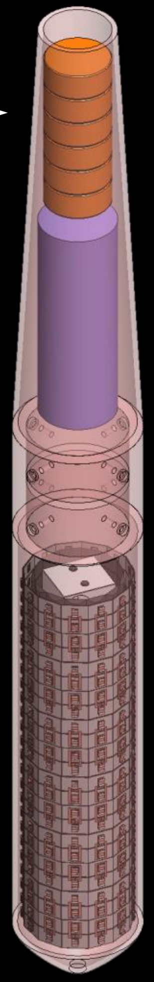


Sun-Probe-Earth Angles for 2035 from Lat = 30 deg, Lon = 45 deg, ~143 days total

A concept driven by Europa



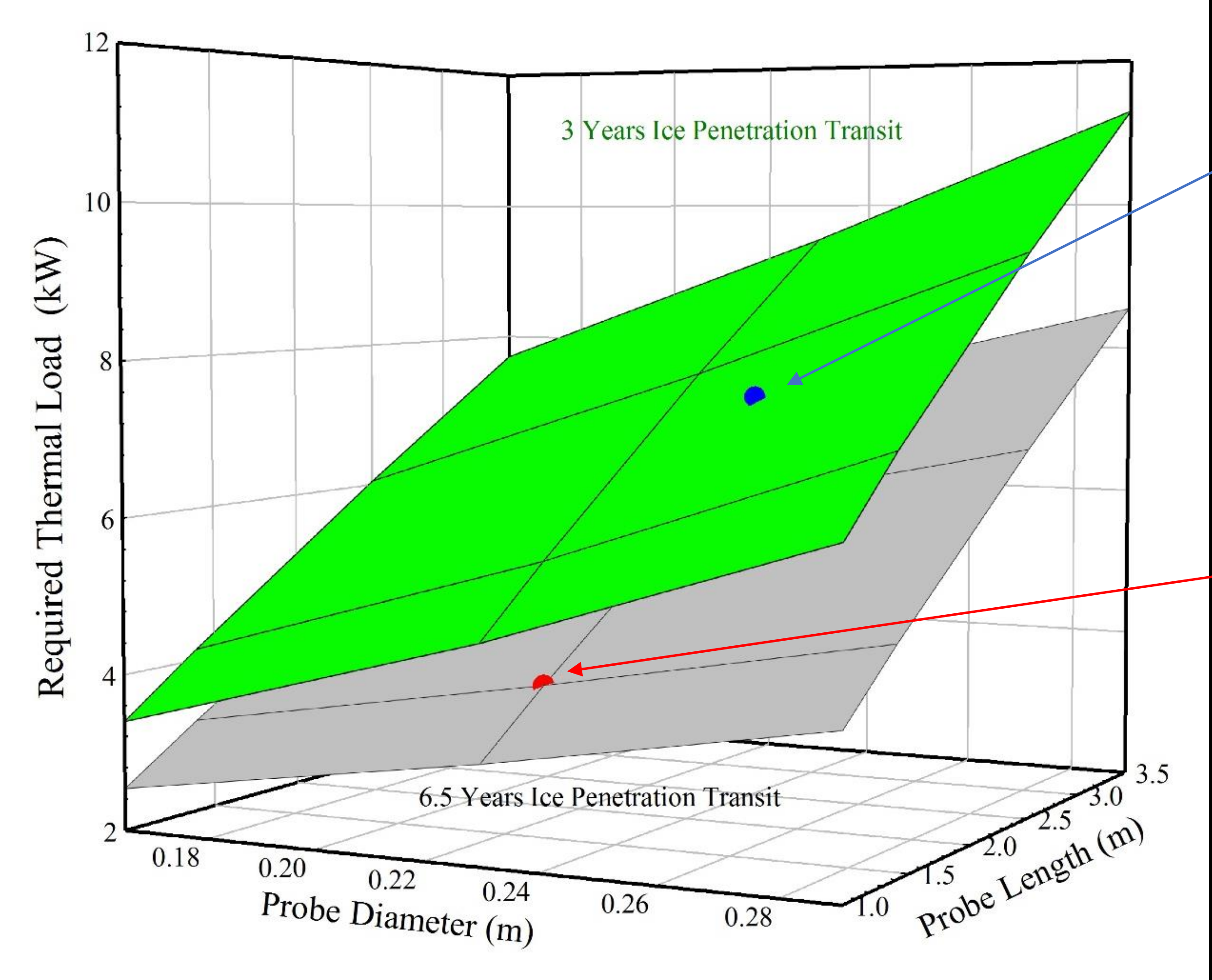
A concept driven by Europa



- Tapered trailing pressure vessel to redirect side forces
- Differential heating for steering
- 17 year design Life of RTG
- 400 We, continuous, DC, for science, telecomm, avionics, thermal, etc.

Conceptual Melt Probe Configuration

Transit times and waste heat

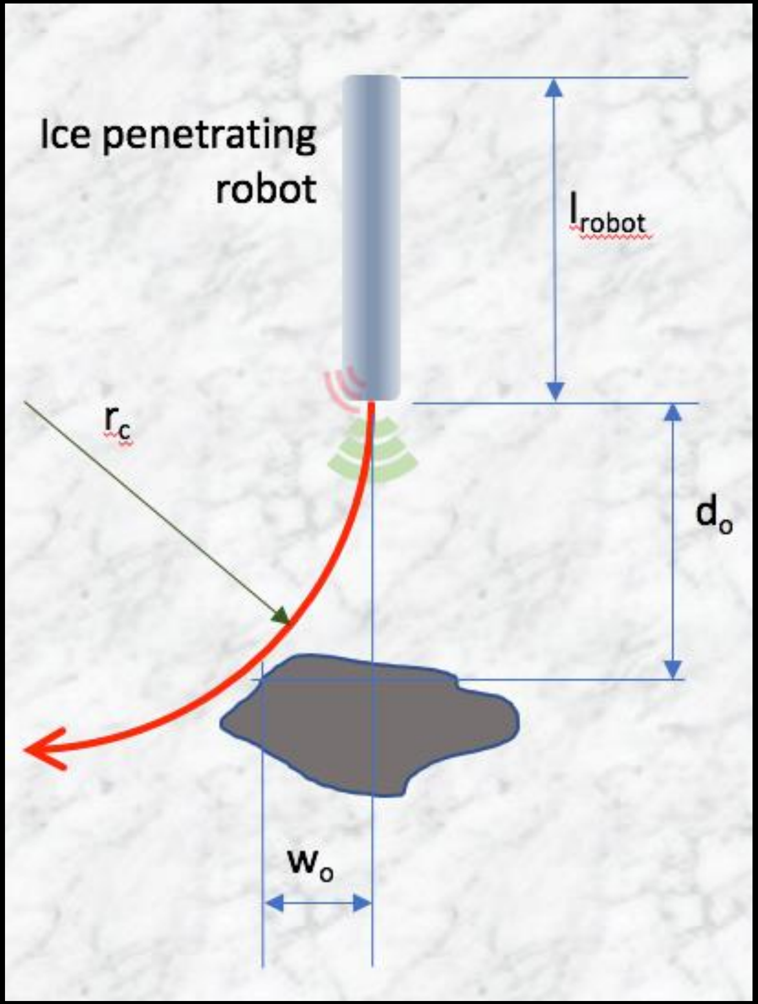


- Theoretical Higher-Power-Density Heat Source, 7000 Wth

compared with a

- Largest (16 GPHS) Next-Generation RTG, 3500Wth

Steering



- To maneuver around an obstacle of one-half width w_o as soon as it is detected at a distance d_o, the robot must be capable of executing a turn with a radius of at least $r_c = (w_o^2 + d_o^2)/(2w_o)$.
- Ground penetrating radar has a range of 100s of meters in ice.
- Assuming a minimum sensor range of 100m, the minimum radius of curvature needed is on the order of 10,000m to avoid an obstacle of size 1m (w_o=0.5m).
- For a robot length of 2m, the lateral deviation it will need to make over its length of travel is 2x10-4m i.e. 0.2mm.

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