

Program Options to Explore Ocean Worlds

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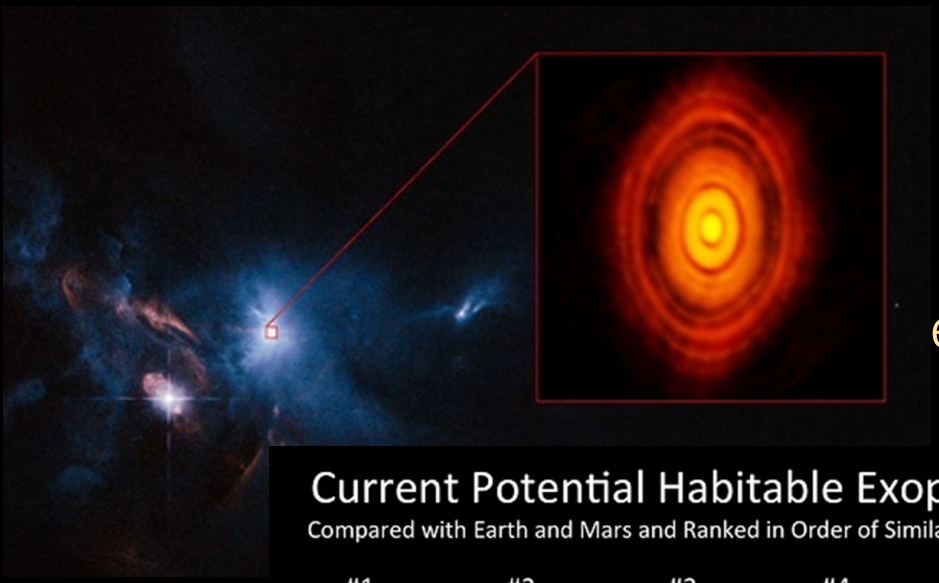
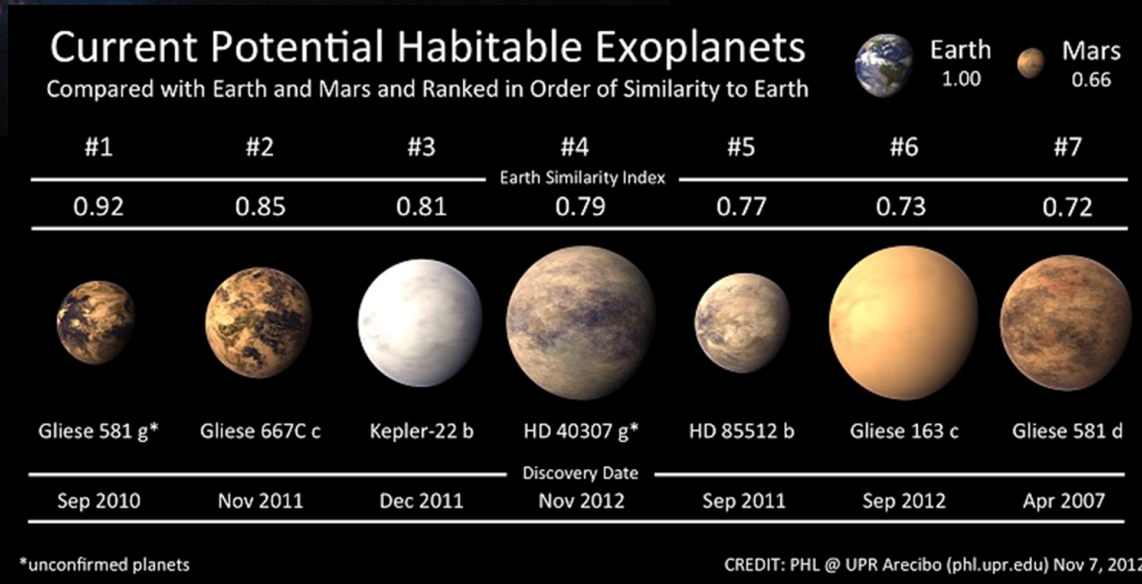
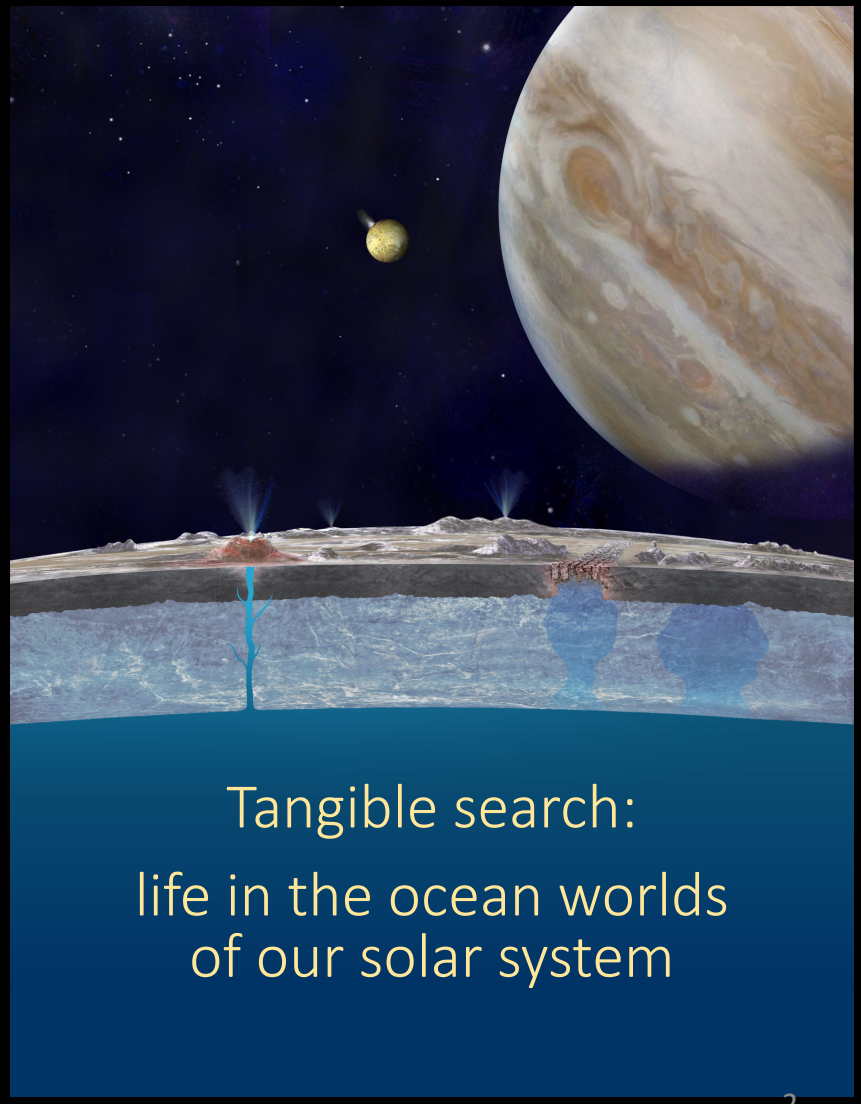
Is there life elsewhere in the universe?



Indirect search:

observation of extra-solar planets

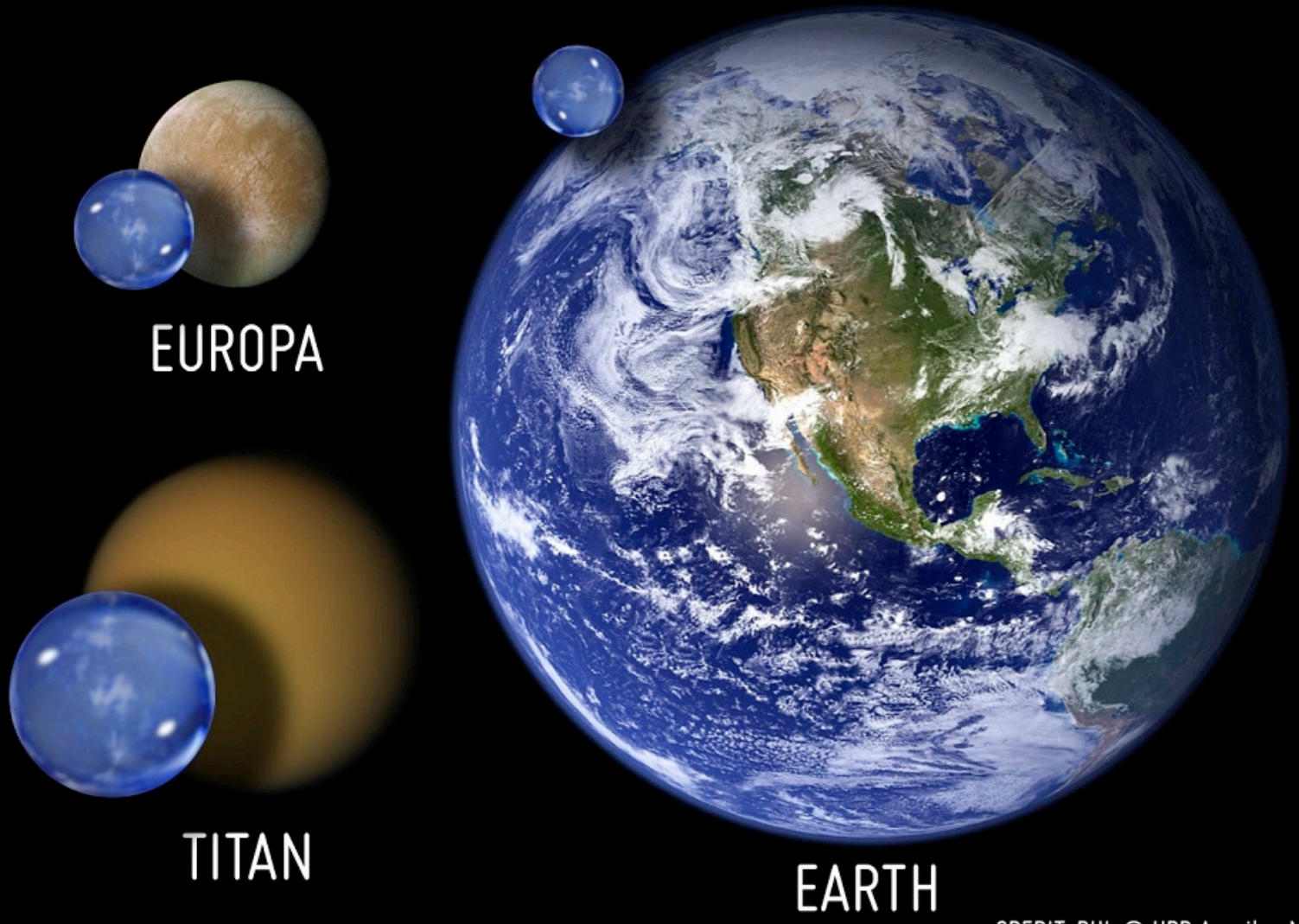




Tangible search:

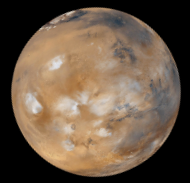
life in the ocean worlds of our solar system

Ocean worlds contain vast quantities of water



More than a dozen ocean worlds within reach

Ocean Relicts



Mars

Ceres

Jovian icy moons

Europa

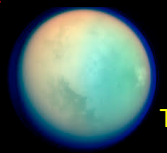
Ganymede

Callisto

Saturnian icy moons

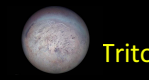
Enceladus

Dione



Titan

Kuiper Belt Objects



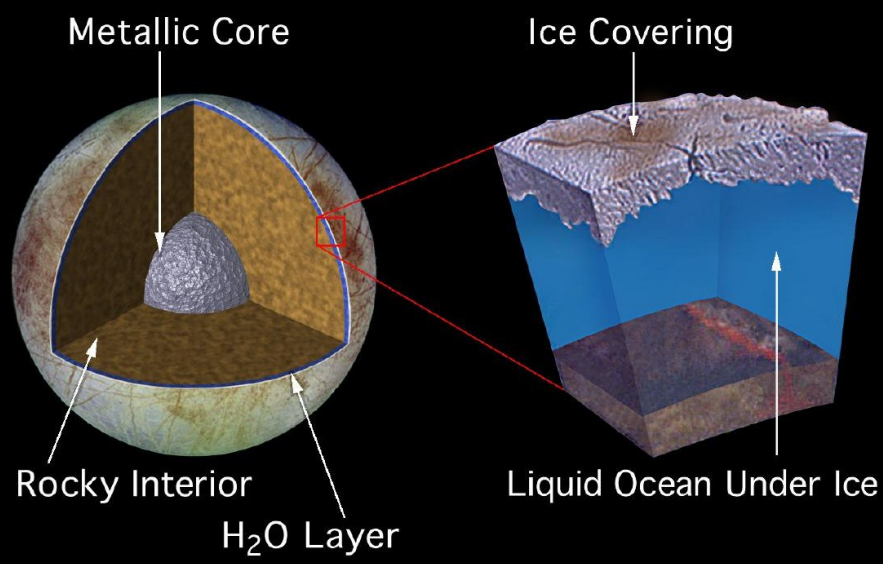
Triton

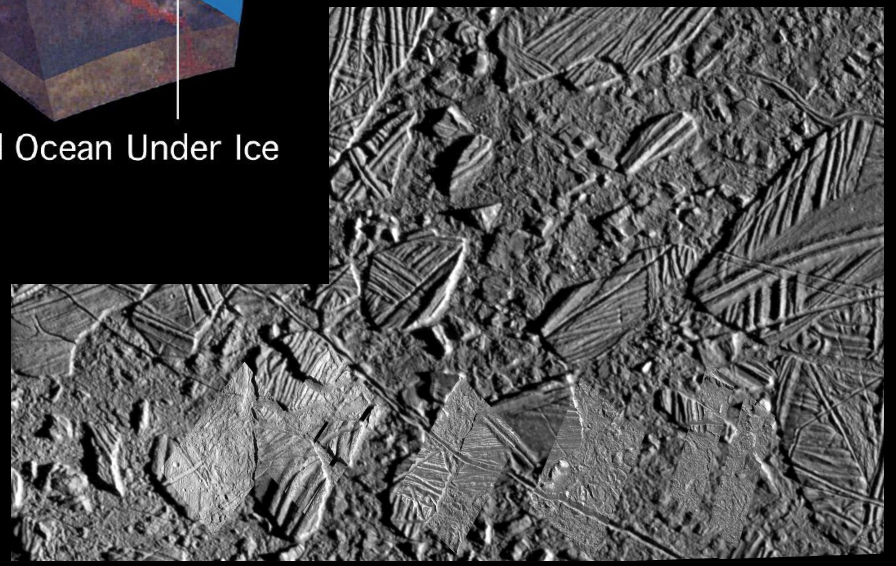
Pluto

Charon

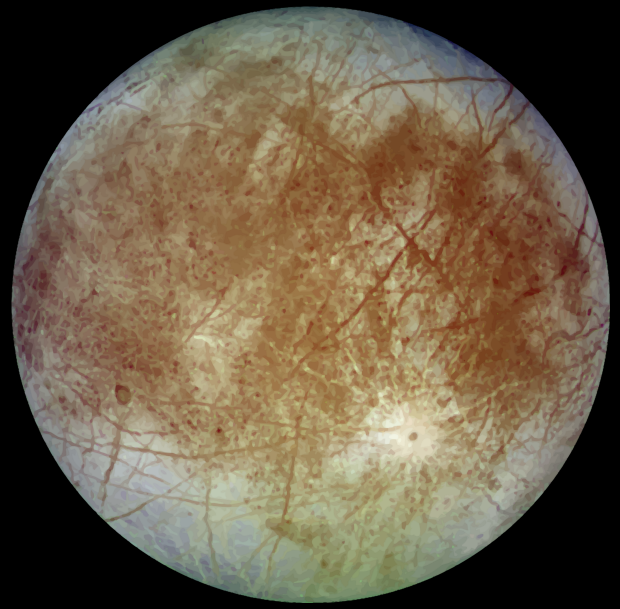
Europa: best place for life?

- Almost as large as Earth's Moon
- Ocean in contact with silicate rock
- Possible mechanism to sustain redox disequilibrium



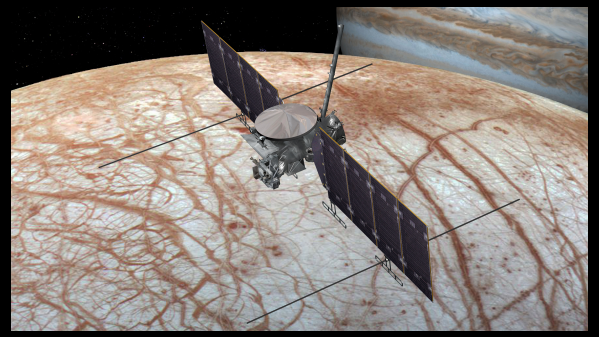


A Europa program in three steps



Comprehensive investigation of the icy moon's habitability

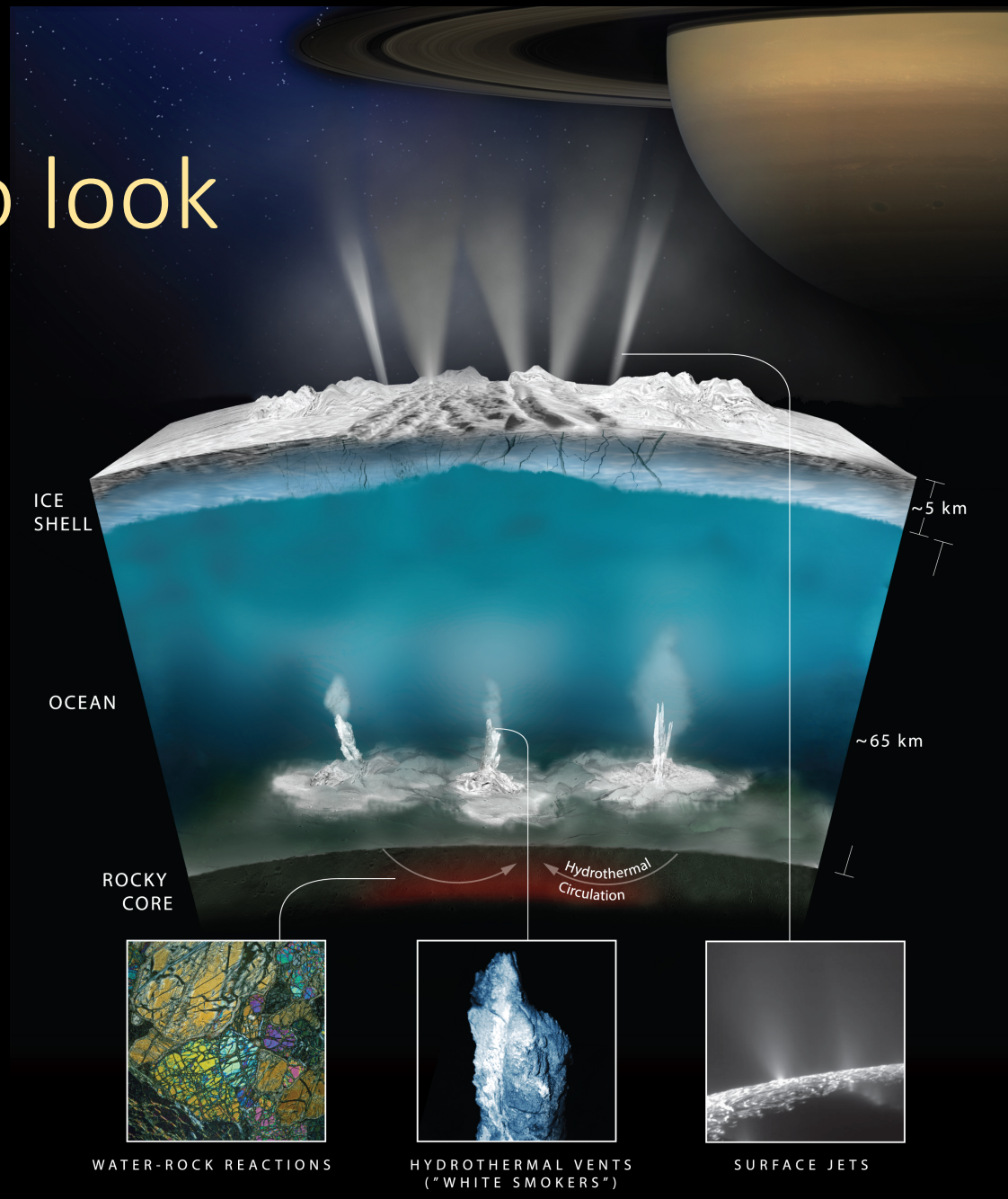
- Near-global hyper mapping
- Lander-scale surface imagery



- 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

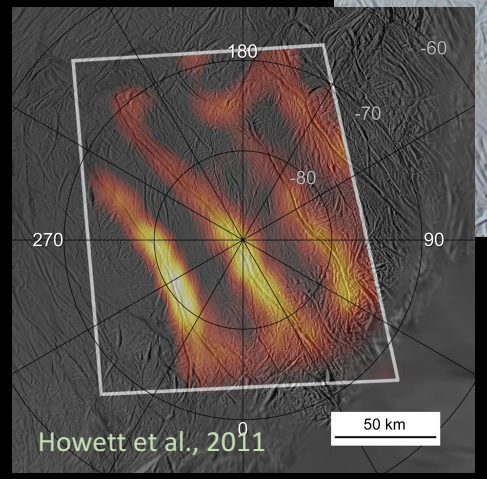
Enceladus: easiest place to look

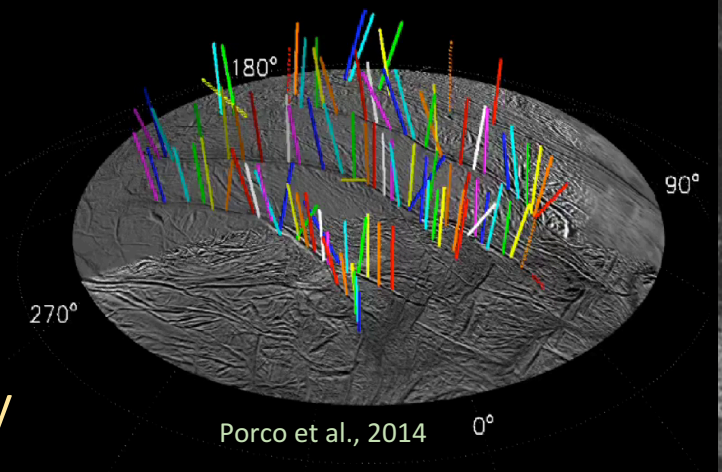
- Salt-water ocean with hydrothermal activity
- Predictably expressed into space by a big plume, ripe for sampling
- By today's standard, the most habitable place known off Earth

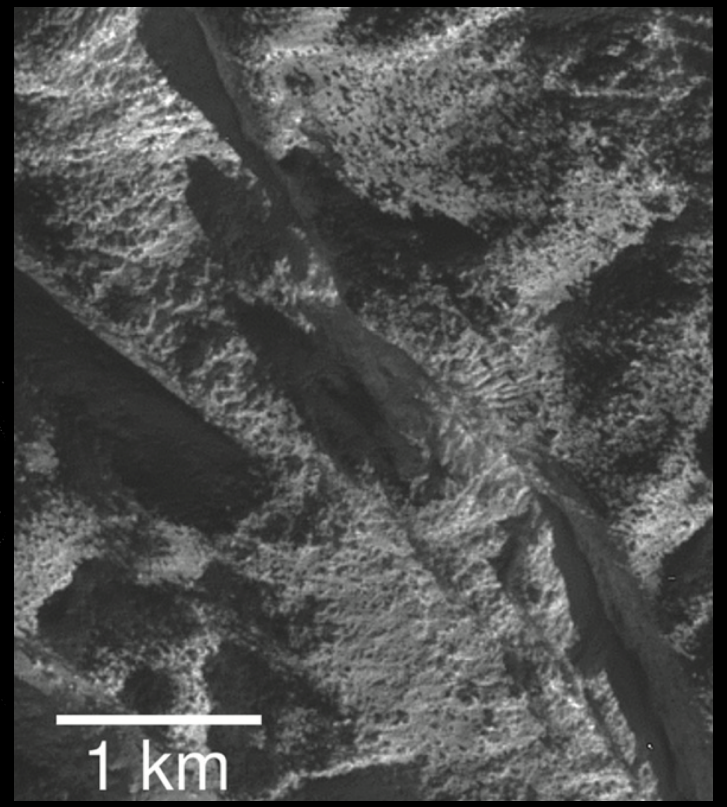


Awaiting focused missions

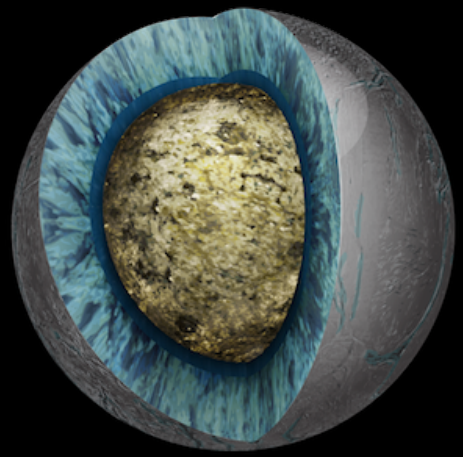
- Ice crust split by warm fissures
- > 100 geysers send large plume far into space, easy to transect
- Ice grains include silica dust and frozen ocean spray
- Salt water, hydrothermal circulation, organic chemistry







An Enceladus program in three steps

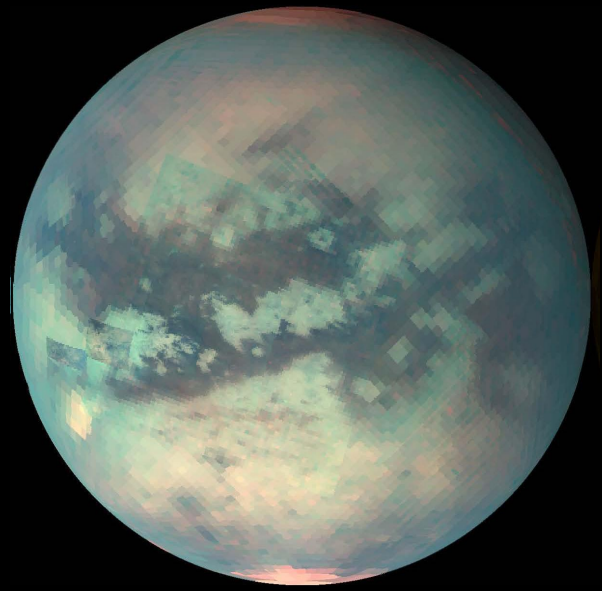


Direct access to material known to originate in a habitable place

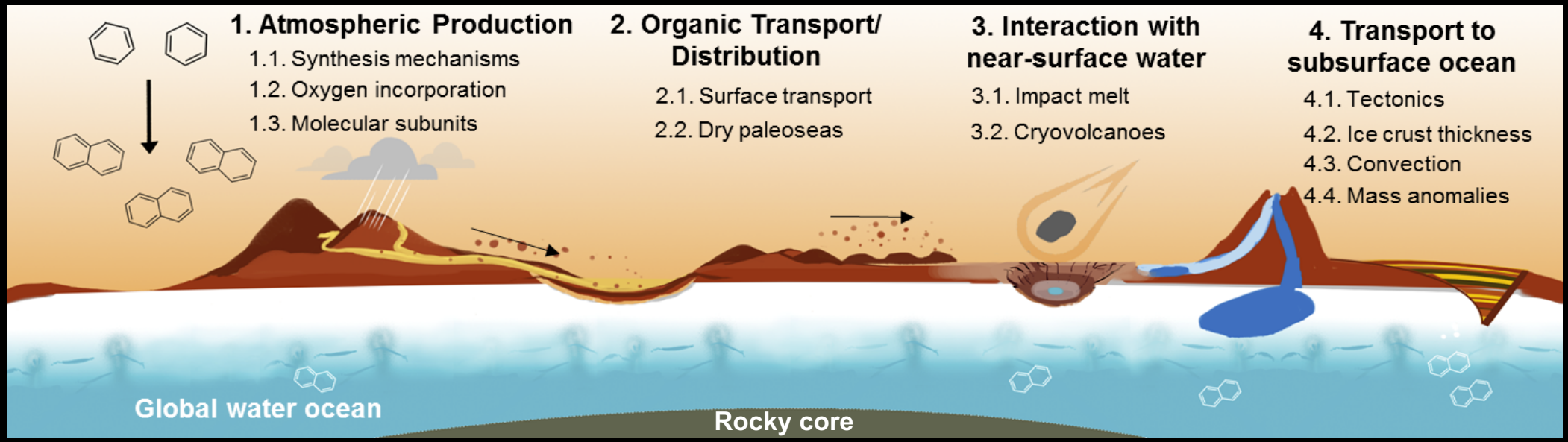
- Plume transects
- Best compositional analyzers

- 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 is a glimpse of early Earth

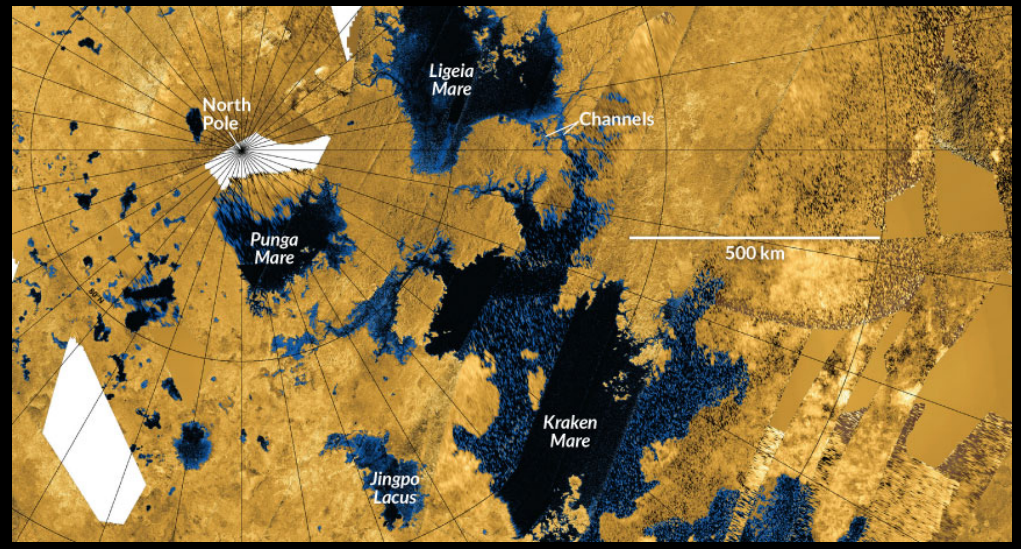


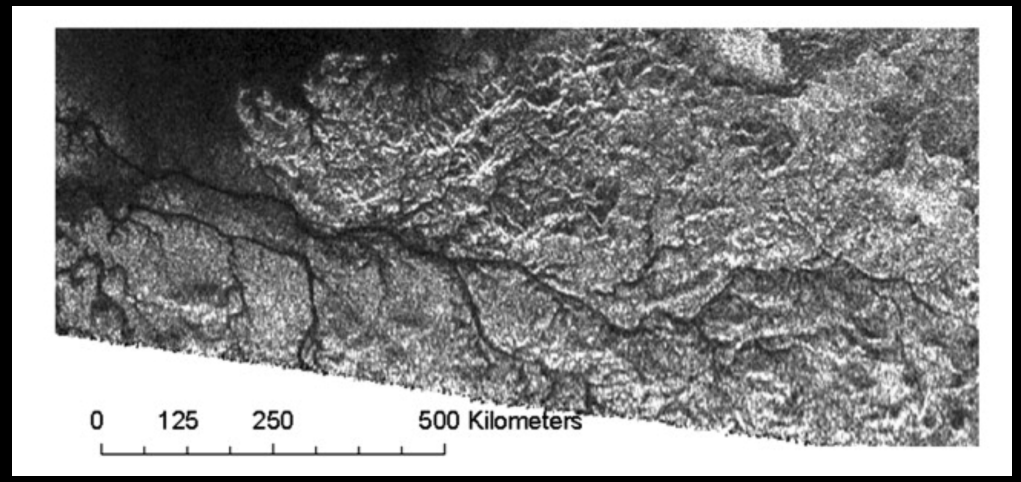
- Before Earth was a “pale blue dot” it was a pale orange dot
- A world of two oceans…



Titan: best place to look for weird life?

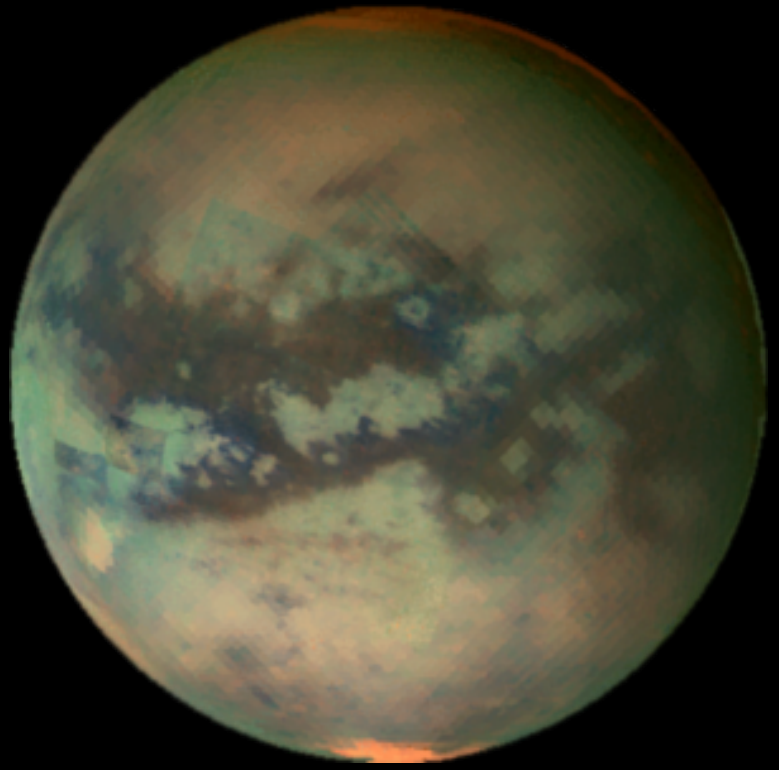
- Large organic molecules capture energy from sunlight in upper atmosphere
- Methanogenic cycle weathers organic sediment on surface
- Vast, global interior salt-water ocean
- Where and how do the organics interact with the water?





Jaumann et al., 2008

A Titan program in three steps



Comprehensive reconnaissance of a complex world

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

Aerial exploration

Buoyant sea exploration

Mobile surface exploration

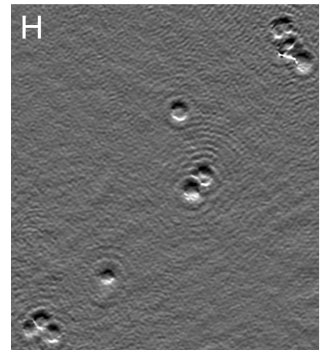
In situ analysis of weathered organics

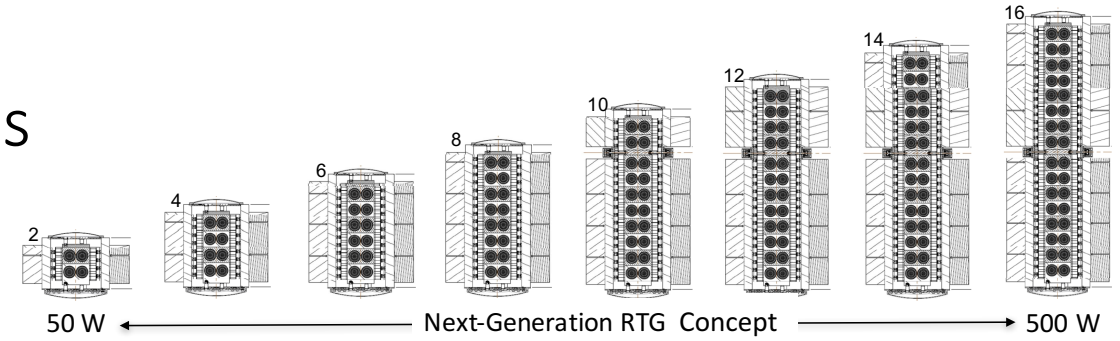
Sample return

Through-crust ocean access

Key technologies are common to all the targets

- Planetary protection of and from ocean-world material
- “Life-detection” measurement techniques and instruments
- Sample acquisition, handling, preservation
- Cryogenic mechanisms and electronics
- Modular radioisotope power systems
- Autonomous exploration that conducts science investigations





From MEP to OWEP

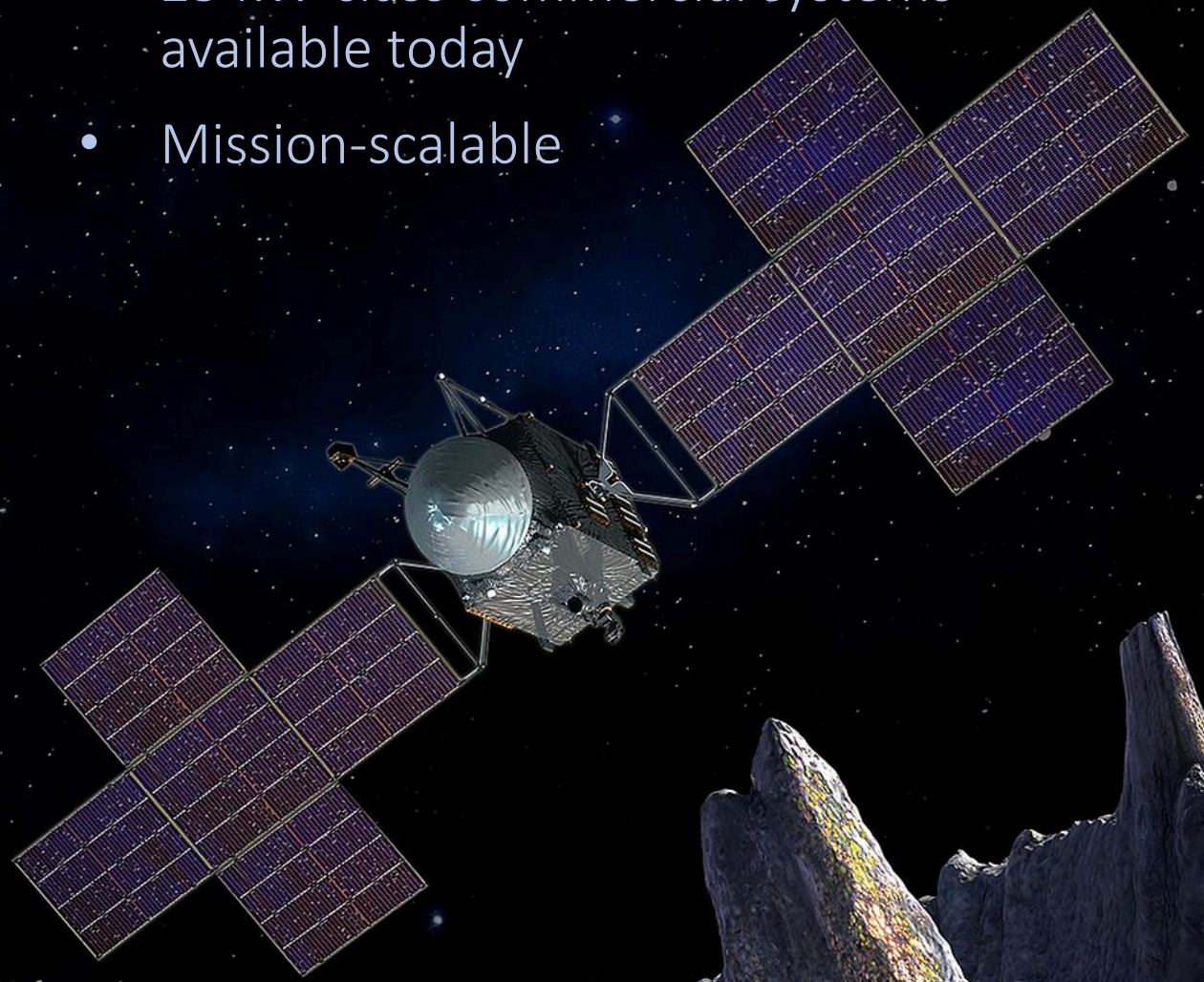
- Mars is technically moderate compared to the icy ocean worlds
- Mars missions can respond to new knowledge on half-decade cadence
- Core capabilities should be developed outside individual flight projects
- Ongoing operational infrastructure can ‘lower the bar’ for each mission
- Projects managed within a program allow planning flexibility
- Medium-class directed-purpose missions form ‘connective tissue’

Heavy-lift launch

- 2-yr transfer for Europa Clipper
- Enabling for a Europa lander
- 3-4 years to Saturn orbit

Solar Electric Propulsion

- 5-6 years to Saturn with standard LV
- 25 kW-class commercial systems available today
- Mission-scalable



Program options for an OWEP

Case 0 – Status quo today

Case 1 – Select two New Frontiers missions in 2019

Case 2 – Select two New Frontiers missions every 5 years

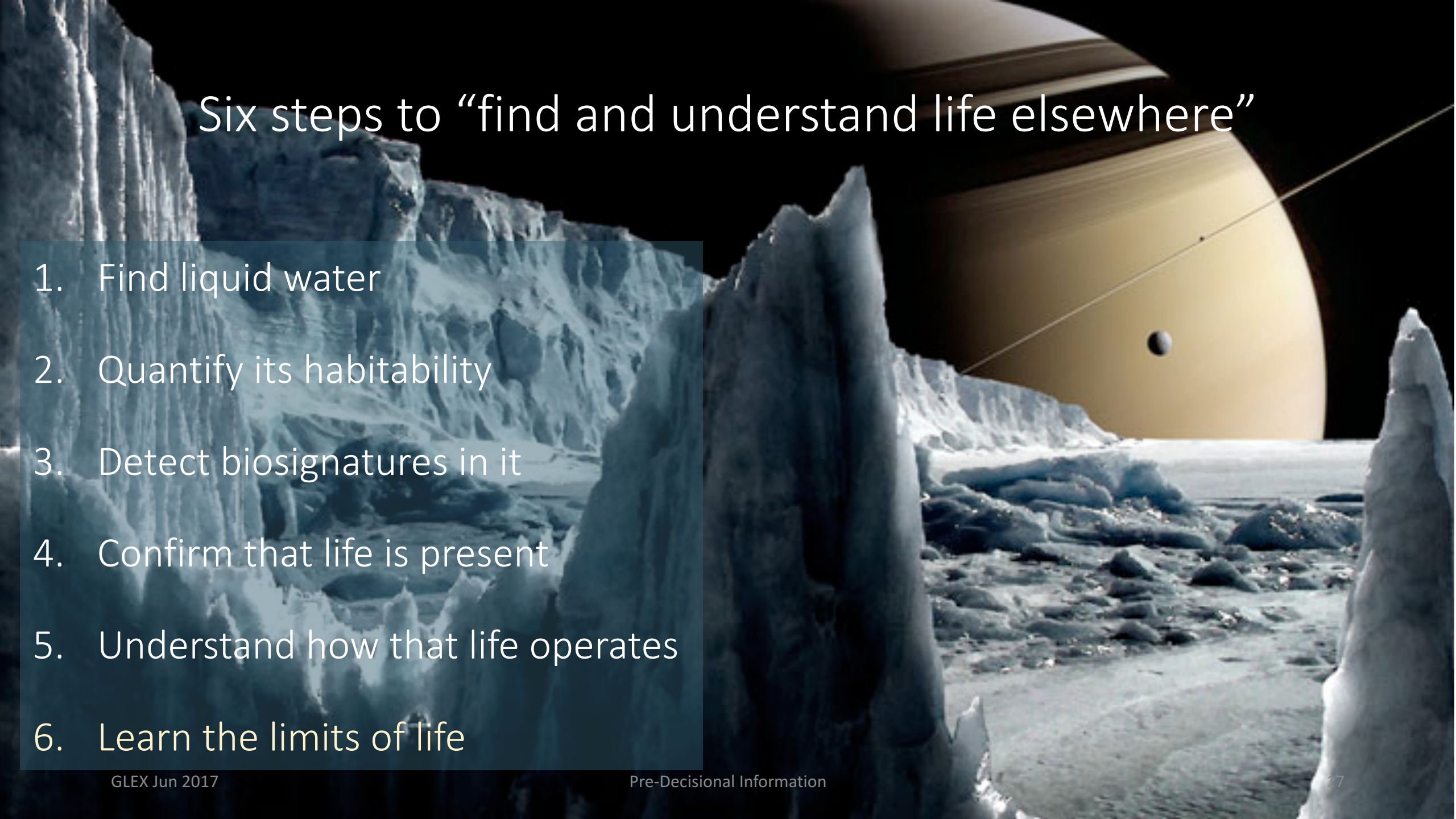
Case 3 – Create $1B directed-purpose mission class for OW

Case 4 – Add strategically managed OW Technology Program

Case 5 – Establish a formal Ocean Worlds Exploration Program

Significant progress would increase NASA's budget by about 1/40th

Six steps to “find and understand life elsewhere”



1. Find liquid water
2. Quantify its habitability
3. Detect biosignatures in it
4. Confirm that life is present
5. Understand how that life operates
6. Learn the limits of life

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