Jet Propulsion Laboratory
California Institute of Technology

Probe Technologies

Power, Telecom, Thermal, Structural

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International Planetary Probe Workshop Short Course on the Ice Giants

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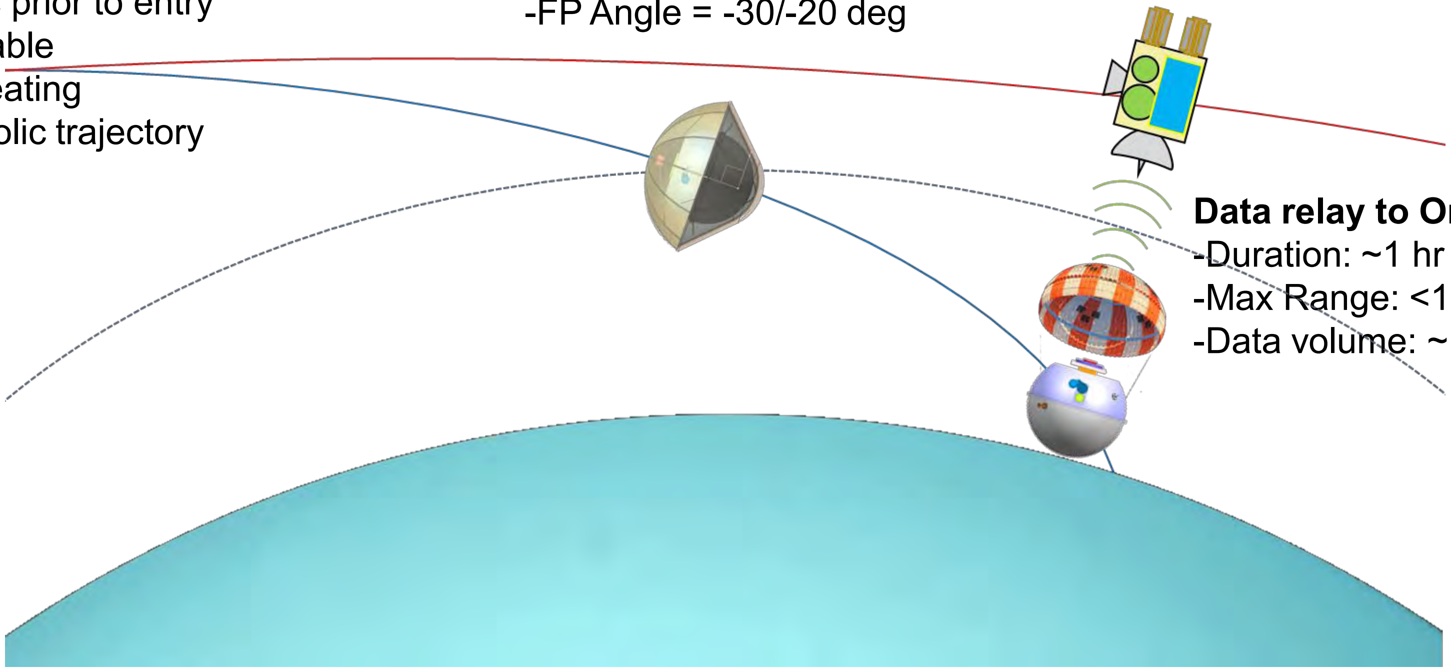
Entry and descent probe is necessary for in situ sampling of Giant Planet atmospheres for comparative planetology

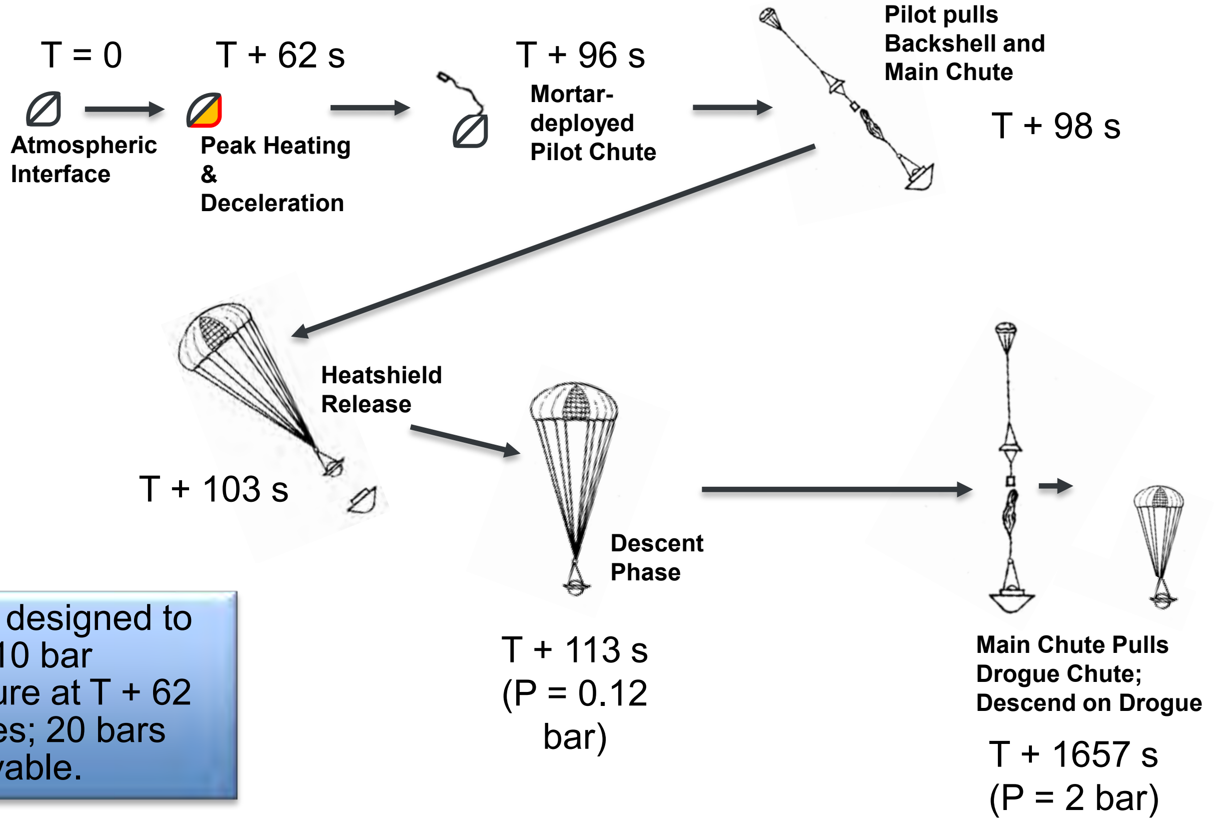
Release:
- -60 days prior to entry
- -Spin stable
- -RHU heating
- -Hyperbolic trajectory

Entry (Uranus/Neptune):
- -Entry V = 23.5/24.1 km/s
- -FP Angle = -30/-20 deg



Data relay to Orbiter:
- -Duration: ~1 hr
- -Max Range: <100k km
- -Data volume: ~15 Mbit

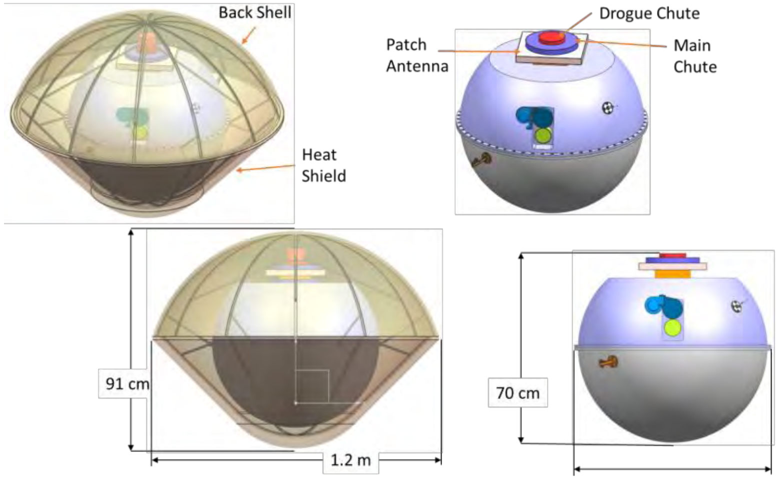
We understand how to fly them based on Galileo experience (Uranus example shown)



Probe designed to meet 10 bar pressure at T + 62 minutes; 20 bars achievable.

Current Ice Giant probe requirements are met with SOA instruments and existing technology – Galileo

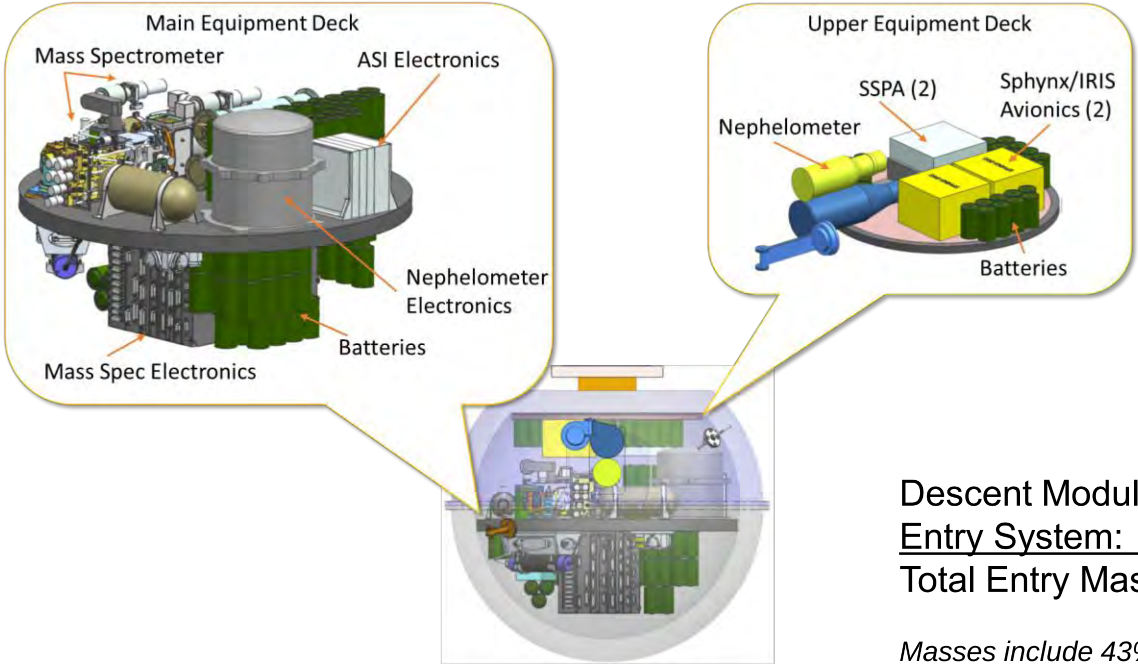
Common probe design for Uranus and Neptune



- Instruments
  - Mass Spectrometer (MS)
  - Atmospheric Structure (ASI)
  - Nephelometer
  - Ortho-para Hydrogen Measurement

- C&DH
  - Redundant Sphinx Avionics
- Power
  - Primary batteries
    - 17.1kg, 1.0 kW-hr EOM
  - Redundant Power Electronics
- Thermal
  - RHU heating, passive cooling
  - Vented probe design
  - Thermally isolating struts
- Telecom
  - Redundant IRIS radio
  - UHF SSPA
  - UHF Low Gain Antenna (similar to MSL)
- Structures
  - ~50kg Heatshield
    - 45deg sphere cone
  - ~15kg Backshell
  - ~10kg Parachutes
  - ~15kg Probe Aerofairing

While SOA is adequate, it drives probe size and complexity; designers can do better with emerging technologies



Descent Module: 174 kg, 0.73 m dia
<u>Entry System: 147 kg, 1.2 m dia</u>
Total Entry Mass: 321 kg

Masses include 43% contingency

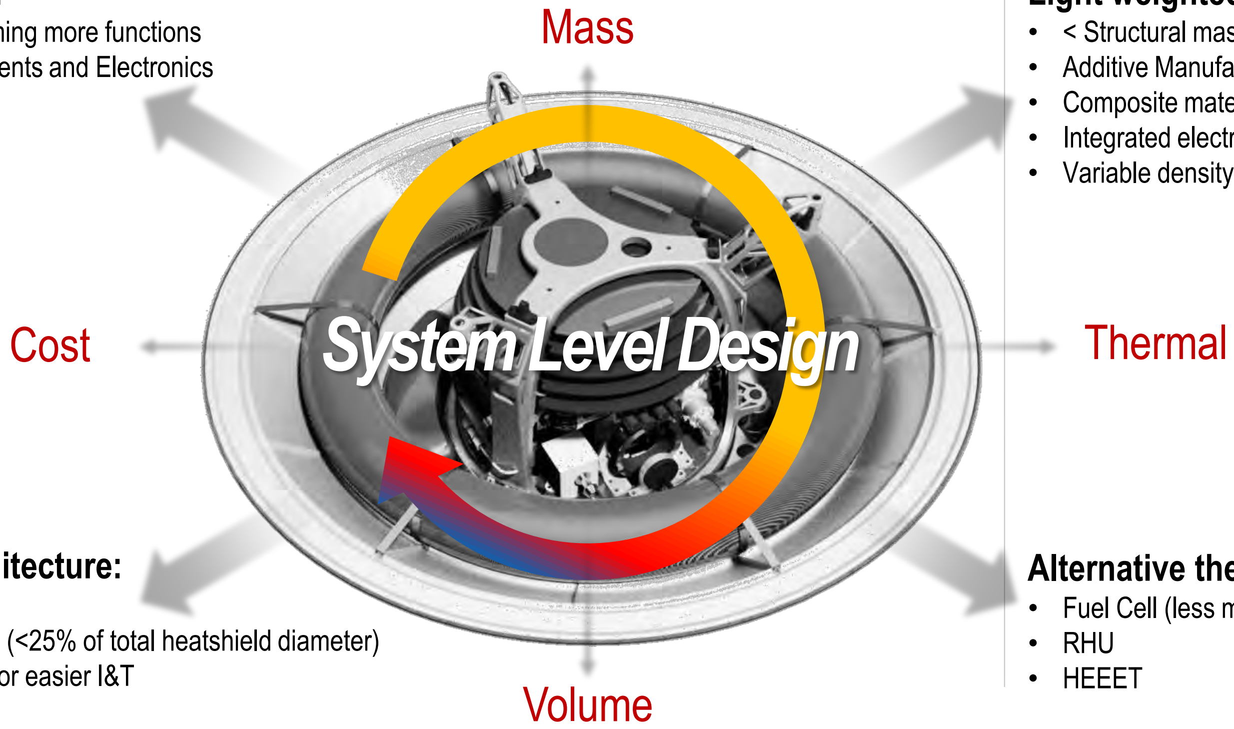
Infusion of emerging technologies and techniques will enable smaller, more efficient and affordable probes

Multifunctional design

- Fewer components performing more functions
- 3 Modules: Power, Instruments and Electronics
- Lighter integrated aft-shell

Light weighted approach:

- < Structural mass (optimized structures)
- Additive Manufacturing (Titanium)
- Composite material for lower mass
- Integrated electronics (low CG, far from heat)
- Variable density heatshield



Highly integrated architecture:

- Less mass and volume
- Low CG for entry purposes (<25% of total heatshield diameter)
- Single chassis/base plate for easier I&T

Alternative thermal management

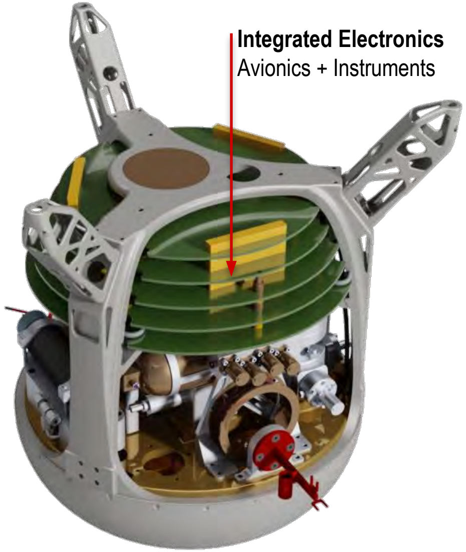
- Fuel Cell (less mass, low CG)
- RHU
- HEEET

Technology Summary: Integrated Electronics

Now

TRL: 6
Heritage:
- Customization of Boards (common practice)
- Stocked connectors (e.g., CubeSats)

Feasibility: Feasible according to JPL experts
Main Risk: Incompatibility of some design
Mitigation: Alternative board design, test board prototypes
Cost: Different shapes do not necessary mean a big extra cost



1. Integrated Electronics

Each one of the configurations in the design session used an approach that integrated all of the electronics on to a series of custom fitted and shaped boards located at the top of the probe, in order to minimize the volume of the probe, reduce the CG and locate the more sensitive electronical parts far from the heatshield area. This included all of the electronics for the radio, control systems and the electronics for each of the instruments as well. This is a level of integration that has not been seen on previous spacecraft designs.

Technology Summary: Additive Manufacturing

Now

TRL: 9 (in Europe)
Heritage:
- Metal 3D printed parts have flown (E.g., Juno)
- Well understood process for titanium
- Statistically bases for material behavior (America makes)

Feasibility:
- Feasible according to JPL experts
- Geometry cannot be implemented with traditional methods (e.g., hollow parts)

Main Risk: Problems design printing, post-process
Mitigation: Easy to build more copies, test on coupons and general structure to assure performance
Cost: Although post-processing is require we assume due to the complexity of the geometry that the final cost is similar to a traditional method with some clear benefits.

2. Additive Manufacturing for Probe Structure

The mechanical structures on the probe were designed to take advantage of modern additive manufacturing techniques. In this way, the structure will be printed in metal as opposed to being fabricated from a single or multiple pieces of solid titanium or aluminum.

Technology Summary: Optimized Structural Design

Now

TRL: 9 (in Europe)
Heritage:
- Metal 3D optimized printed parts are flying already (E.g., ESA Sentinel 1)
- Structural solvers are broadly used in many industries (e.g., Altair solver)

Feasibility: It has been done successfully in other organizations (E.g. ESA)
Main Risk: Issues in the solver and errors in the load conditions
Mitigation: Traditional structure analysis and mechanical tests
Cost: No extra cost beyond software licenses (Around $2k per license)

3. Optimized Structural Design (bone growth algorithm)

In order to minimize the weight while maximizing the strength of the structures in the probe, new methods and software were used as part of the design process. Commercial software (SolidThinking's Inspires) that utilizes a bone growth algorithm to determine the optimal configuration to carry loads given an initial design was used to optimize the structure of the probe.

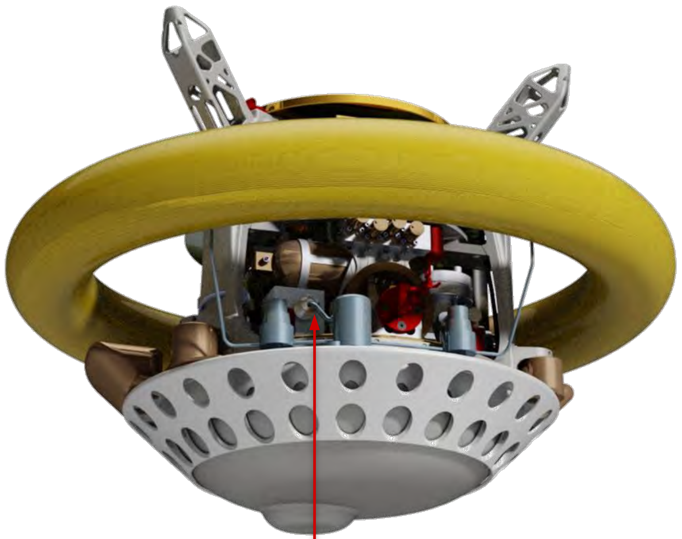
Technology Summary: Fuel Cells for Cruise Heating

Now

TRL: 9 for general fuel cell in space, TRL 6 for this approach (?)
Heritage:
- Fuel systems on ISS
- Apollo program
- http://www.nasa.gov/topics/technology/hydrogen/hydrogen_2009.html

Feasibility:
- Feasible according to JPL experts
- The inefficiency of the system is heat
- It reduces the weight in comparison with batteries with higher energy density

Main Risk: Problems in the design, issues with the release of conductors
Mitigation: Test in space conditions chambers
Cost: This requires more detailed explanation



4. Thermal Regulation by Fuel Cells

An innovative approach to the challenge of thermal management was to rely upon the exothermic property of the reaction between hydrogen and oxygen to create water. Through the use of tanks, oxygen and hydrogen could be stored for release during the cruise stage of the mission for thermal management of the probe and its components.

Technology Summary: Multi-function System Design

Now

TRL: 3

Heritage:

- Multifunctional design is a general principle applied in many industrial fields

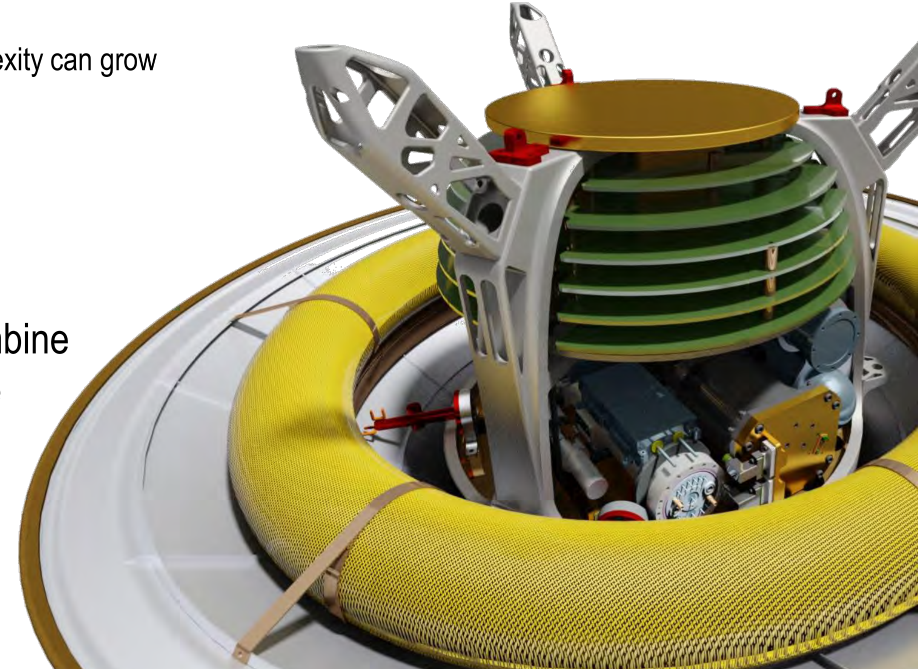
Feasibility:

- Feasible according to JPL experts

Main Risk: Incapability to combine several functions in one component, complexity can grow

Mitigation: Different design, more components

Cost: Potentially this reduces cost (mass, volume)



5. General System Level Design: Multi-functionality principle

The general design principles behind this concept were to combine as many functions as possible in each component, simplify the integration and manufacturing process and make the probe as compact and light as possible.

Technology Summary: TPS and Entry System

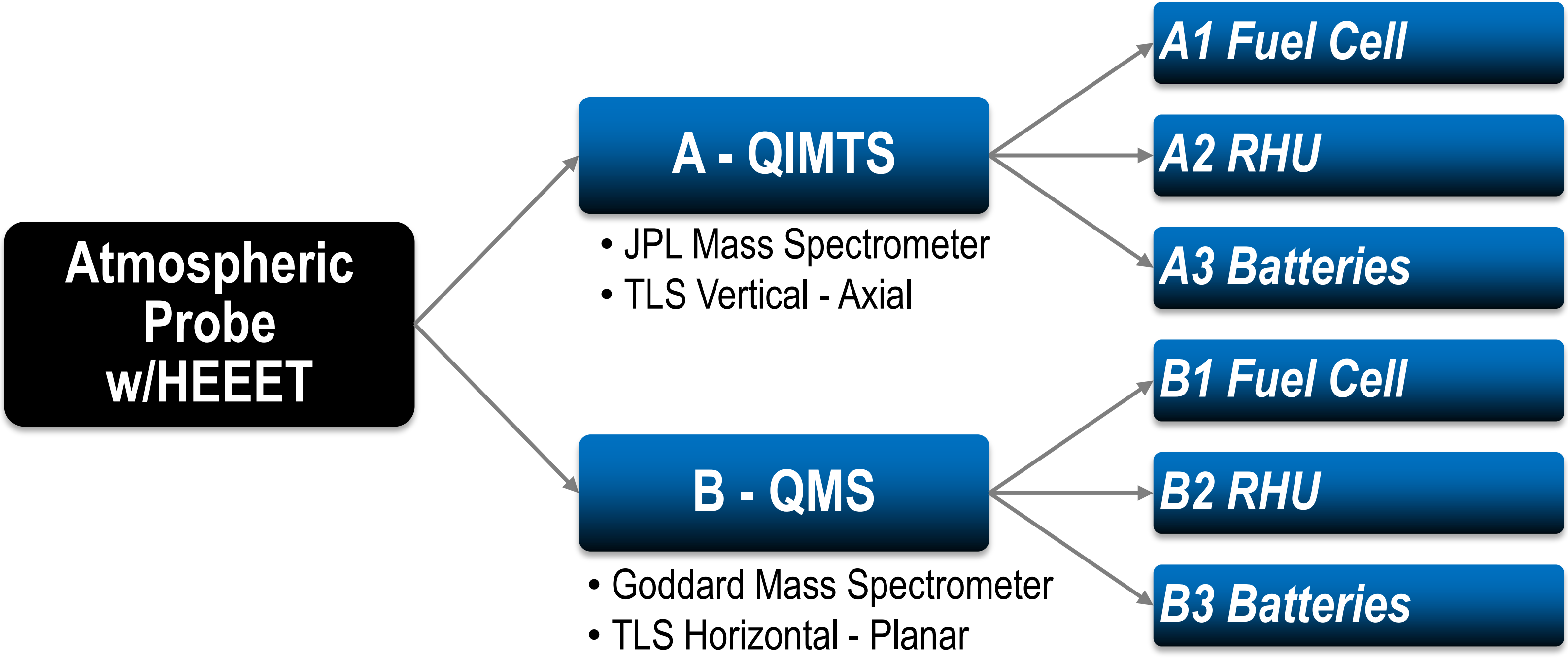
- HEEET (Heatshield for Extreme Entry Environments Technology) 3-D woven, dual-layered high performance material accommodates the high peak heating rates, stagnation pressures and heat loads.
- HEEET promises significant mass and performance benefits for probes in extreme environments.
- Under development to TRL6 by ARC

Discussed further in talk by Raj

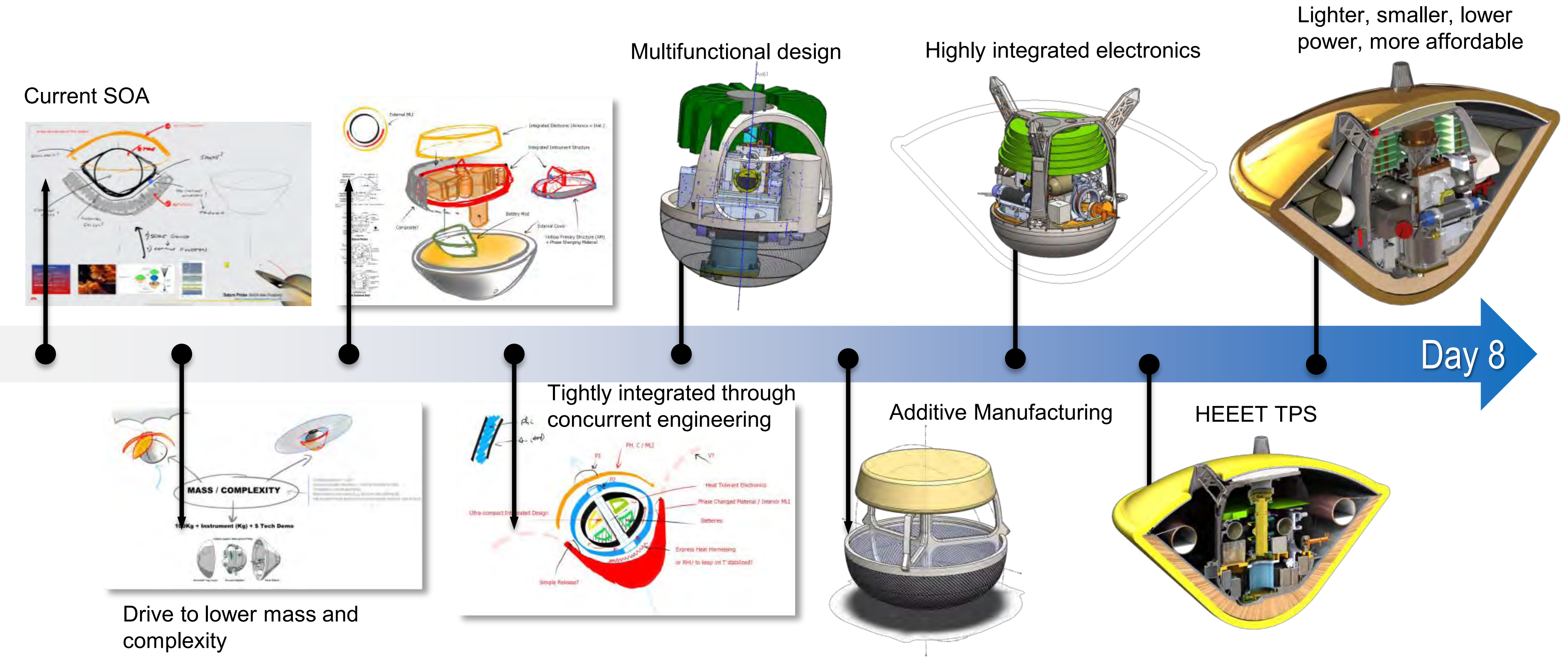
Technology Summary: Communications

- While all science objectives can be met with current DSN and deep space telecom subsystem designs, science data return could be significantly improved by advancing communication technologies – key to data rich flagship missions.
- Optical com promises orders of magnitude improvement in data return if the hurdles associated with great distances and adequate downlink laser pointing can be overcome.
- Improvements in RF techniques are possible and should be pursued.

Does it work? Design example demonstrates potential.



Concurrent Design optimally integrates emerging technologies



Results promise impressive improvements in form, fit and function over SOA baseline

	Adv QITMS – TLS Axial						Heritage QMS – TSL Planar						Baseline
	Electric		Fuel Cell		RHU		Electric		Fuel Cell		RHU		
MASS (kg) | Difference	Mass (kg)	Difference	Mass (kg)	Difference	Mass (kg)	Difference	Mass (kg)	Difference	Mass (kg)	Difference	Mass (kg)	Difference	Mass (kg)
Current Best Estimate + 43%	185.1	-42.2%	174.8	-45.5%	163.7	-58.9%	202.5	-36.8%	192.2	-40.0%	181.0	-43.5%	320.5
Probe Diameter (m) | Difference	0.36	-50.7%	0.36	-50.7%	0.36	-50.7%	0.43	- 41.1%	0.43	- 41.1%	0.43	- 41.1%	0.73
Heatshield Diameter (m) | Difference	0.9	-25%	0.9	-25%	0.9	-25%	0.9	-25%	0.9	-25%	0.9	-25%	1.2
Relative Cost (% of baseline)		68.5%		80.5%		85.5%		68.5%		81.5%		86.0%	100%
Technology Infusion	Additive Manufacturing / Light Materials Integrated Electronics Optimized Structure		Additive Manufacturing / Light Materials Integrated Electronics Optimized Structure Fuel Cell Thermal management Integrated Toroidal Tanks		Additive Manufacturing / Light Materials Integrated Electronics Optimized Structure RHUs		Additive Manufacturing / Light Materials Integrated Electronics Optimized Structure		Additive Manufacturing / Light Materials Integrated Electronics Optimized Structure Fuel Cell Thermal management Integrated Toroidal Tanks		Additive Manufacturing / Light Materials Integrated Electronics Optimized Structure RHUs		

Key take-aways

- While current Probe concepts for Ice Giant missions are shaped by conventional designs dating back to Galileo and flight proven SOA equipment, we can do better.

- Emerging spacecraft and instrument technologies and techniques promise substantial improvements in form, fit, function and affordability.

- Now is the time to reap benefits of technologies that will make the Ice Giant mission of the next decade all that it can be.