TPS for Outer Planets

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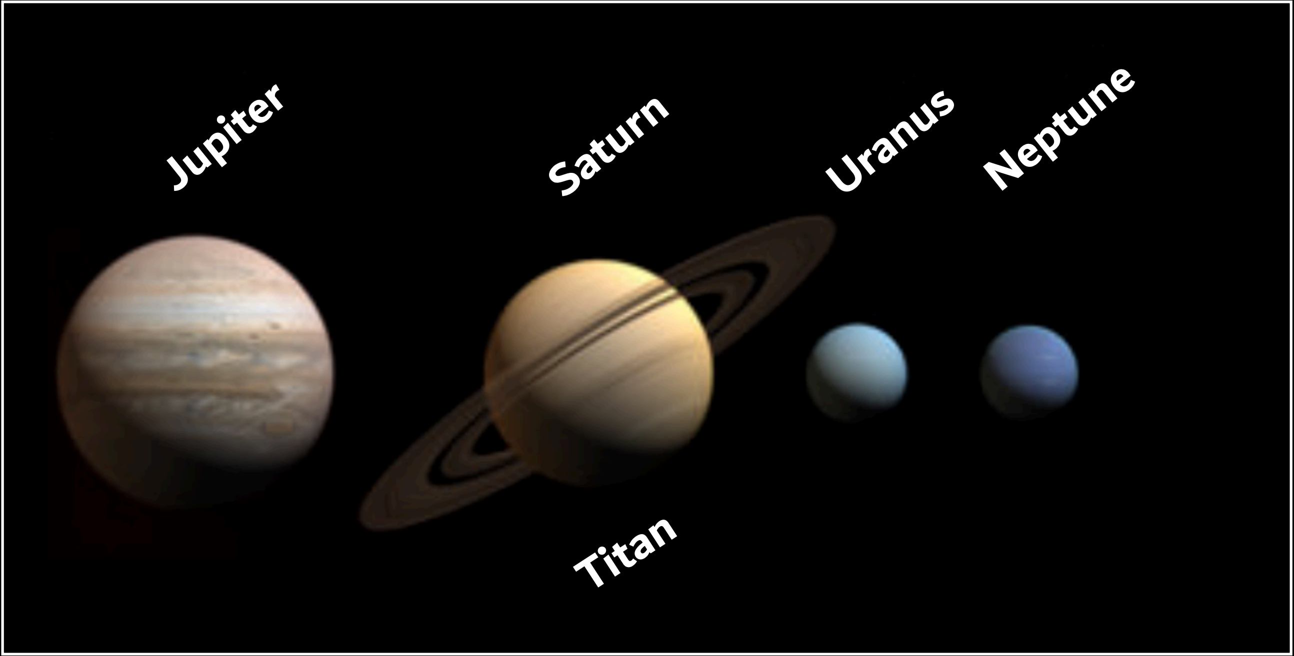
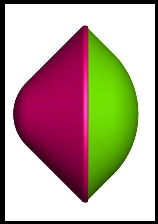


Probes / Landers



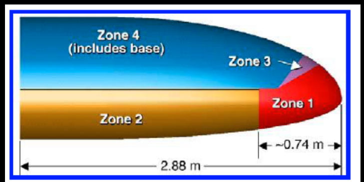


Figure 16. TPS zones.

Aerocapture

OPAG – Technology Forum

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Objective and Outline

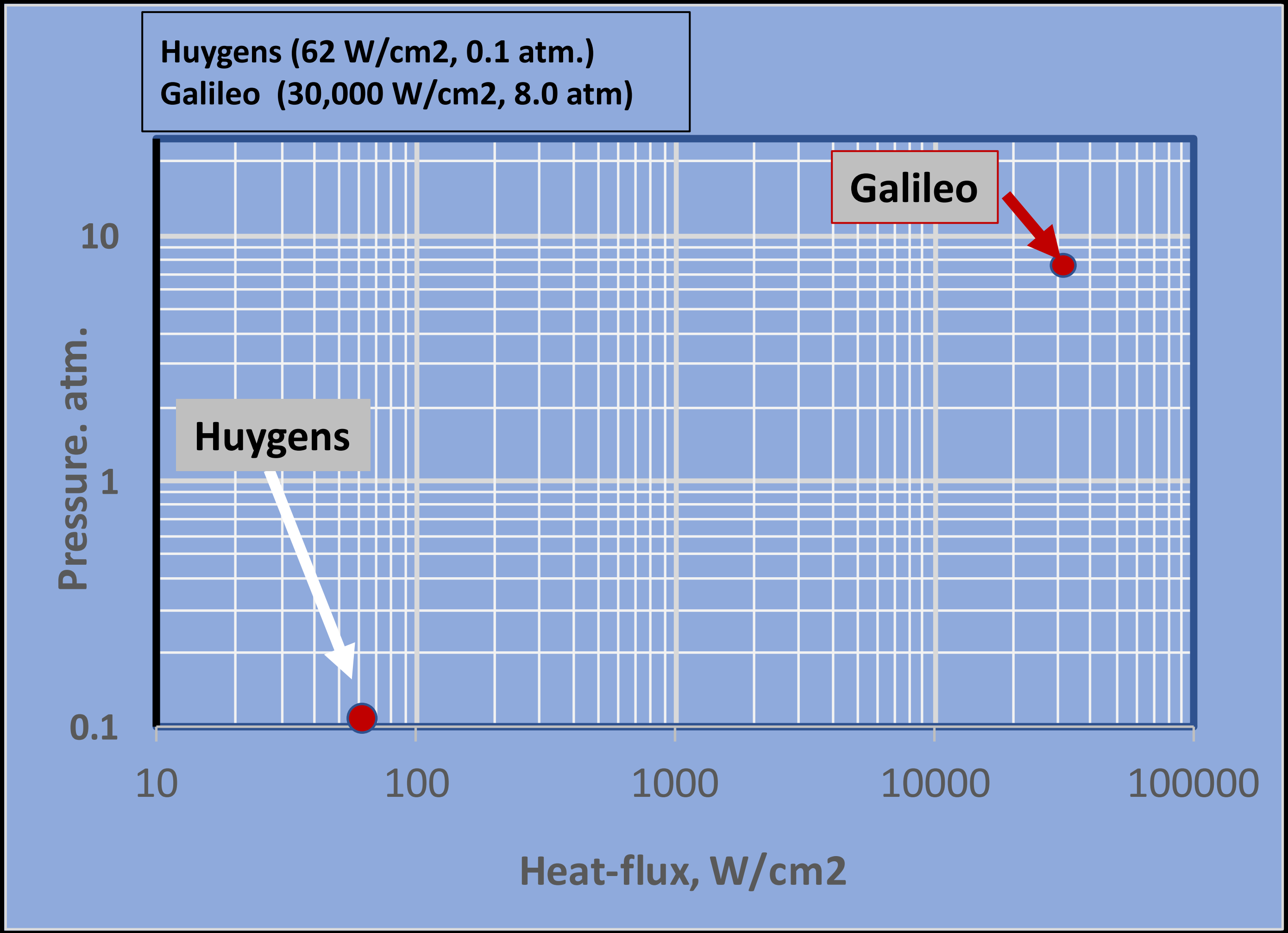
To provide insight into what TPS is needed and the current state of readiness to enable future Outer Planet Missions

- Mission Science Drivers for TPS
    - Modest environments for Titan
    - Severe to extreme environments for Icy/Gas Giants
- Current state of readiness
    - PICA
    - HEEET
- Sustainability
    - Challenges and solutions

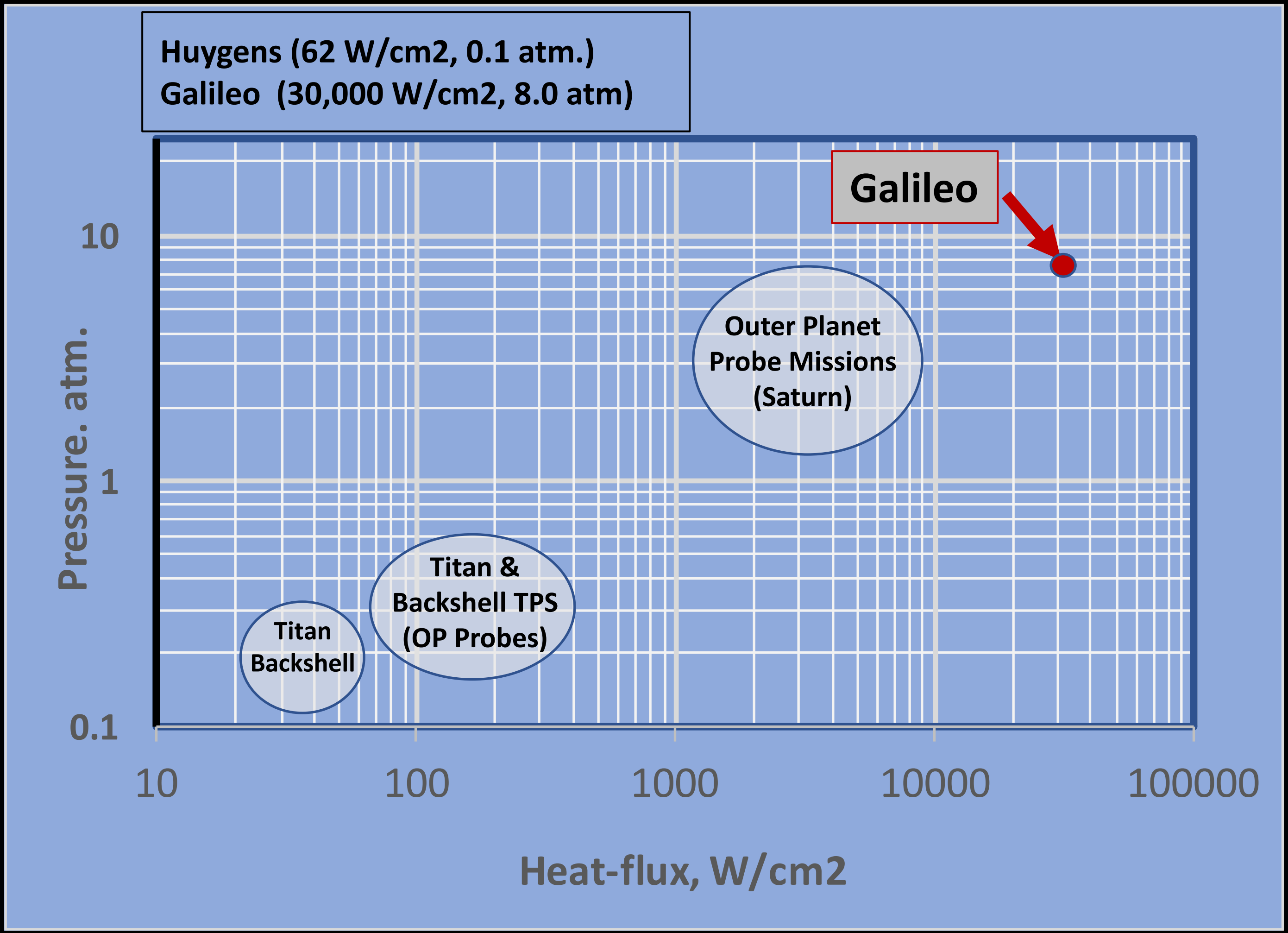
Science, Mission Design and Entry Environment Considerations for TPS Selection

- Destinations
  - Jupiter, Saturn, Titan, Uranus and Neptune
- In Situ Science
  - Probes at Ice/gas Giants,
  - (Aerial Platforms, Landers, Boats, and Submarines) at Titan
- Mission Architecture and Vehicle
  - Ballistic, Direct Entry
  - Lift Guided Entry (Direct or Aerocapture followed by Entry)
  - Rigid Aeroshell (for both ballistic and lift guided)
    - Deployable may be applicable to Titan
      - ADEPT and HIAD are at Low TRL – out of scope in this talk
- TPS must not fail during entry
  - Must be manufacturable at relevant scale including thicknesses to withstand heat-load

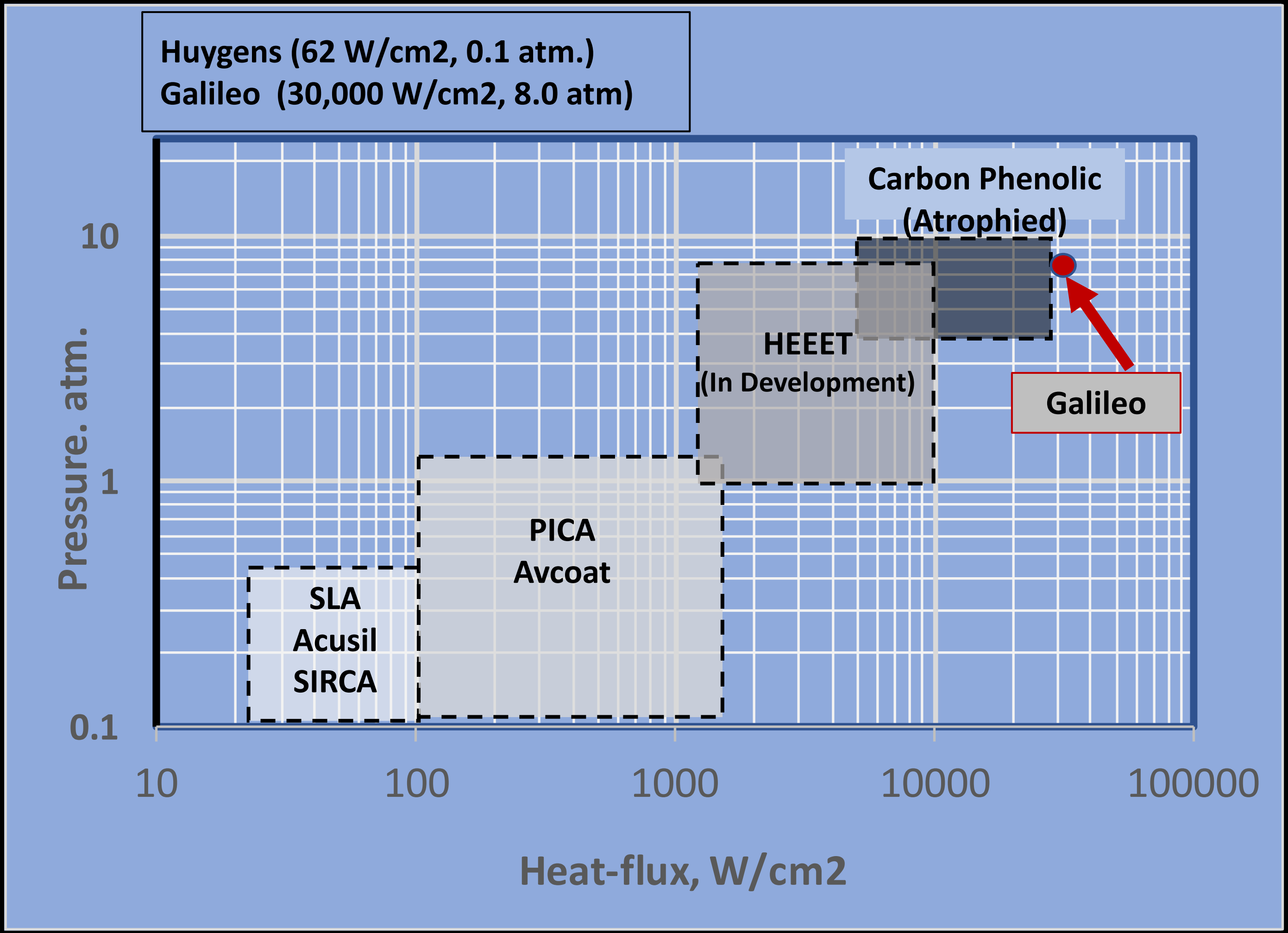
Past Outer Planet Missions and Entry Environment



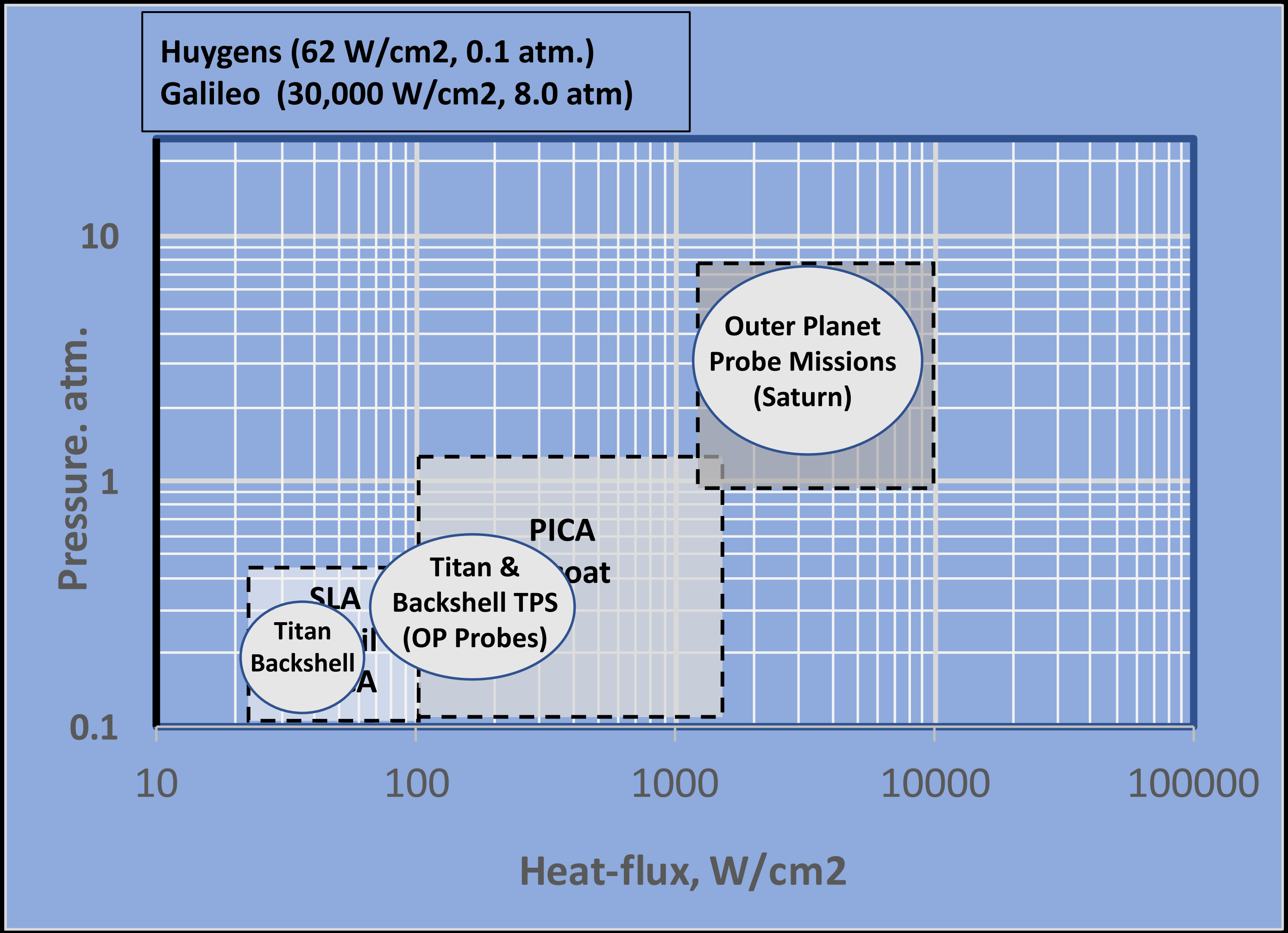
Future Outer Planet Missions and Entry Environment Considered for TPS Development



Current TPS Capability to S upport Outer Planet Missions



Outer Planet Missions and Current TPS



PICA Readiness

(More details can be found in the PICA Poster presented earlier)

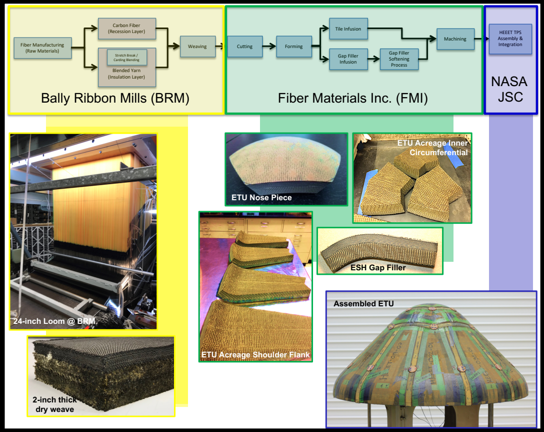
- In 2016 NASA ARC learned that the heritage rayon utilized in PICA was stopping production, leading to a flight-qualified PICA sustainability challenge

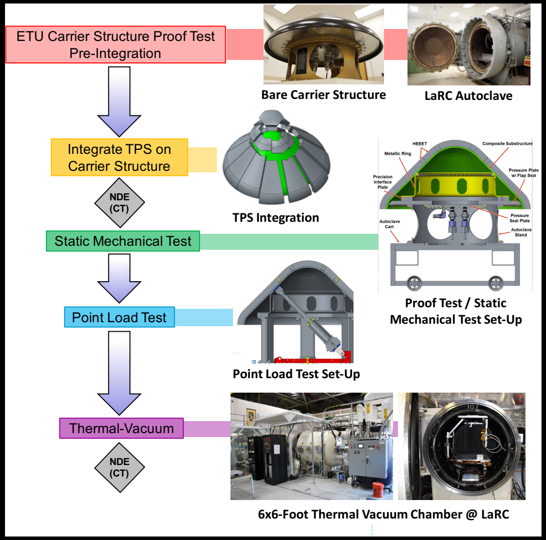
Heatshield Peak Conditions		Pressure atm	Heat Flux W/cm2	Heat Load kJ/cm2
Titan	Titan 1	0.17	150	9.5
	Huygens	0.1	62	3.5
Mars	MSL	0.33	225	6.4

- In FY16/17, NASA ARC was funded by SMD/PSD to address PICA rayon sustainability
- Lyocell Based PICA (PICA-D) was manufactured and limited testing performed
  - **Limited data and comparison indicated PICA-D to be good candidate for potential drop-in replacement for heritage PICA**
- SMD-PSD has initiated two tasks (CY18 and CY19) to:
  - Establish PICA-D as a Drop-in replacement for Heritage PICA
  - Establish the Expanded Capability (Extensibility) of PICA-D
- Successful completion of the above tasks are targeted towards:
  - Titan (& Mars) heatshield TPS and backshell for Outer Planet (& Venus) probes
  - Enable higher speed sample return missions from Comets and Asteroids
- Recent NF-4 Mission study (Dragonfly) compared to Huygens and MSL

HEEET Readiness
(More details can be found in the HEEET Poster presented earlier)

- **Thermal and thermo-mechanical performance of acreage and seam have been established; Material property database developed; Thermal response model completed**
  - > 5000 W/cm2 and > 5 atm. capable
  - Efficient and Enabling
    - All NF-4 proposals able to target < 50g entry
  - Flight design tools validation on going
- **All basic manufacturing steps have been developed and transferred to industry to establish supply chain for future missions**
- **All manufacturing and integration operations have been demonstrated.**
  - 1m scale MDU/ETU can be scaled to larger dia.
  - Loom capable of thicker weaving (current MDU/ETU has 0.5” recession layer and 1.1” insulating layer)
- **Current plans are to complete MDU/ETU testing, AEDC and LHEML testing, design tool validation and documentation in CY’18**





Assessment of HEEET Development for Outer Planet Probe Missions

- Current HEEET Capability is Scalable
  - In areal dimension (funding limitations required us to focus on areal scalability)
  - HEEET system demonstrated at 0.5” thick recession layer (RL) and 1.1” insulating layer (IL) on the 1m diameter MDU/ETU
- Recent Outer Planet mission studies show more severe entry environments
  - Ice-Giants may require seam performance assessment (pressure > 10 atm.)
  - Outer Planet (Neptune and Saturn) missions may require thicker recession layer (~2 X to 3X)
  - Current loom is capable of ~0.7” RL & 0.8” IL (or 0.6” RL & 1.2 ” IL)
  - For thicker than 0.5” RL, manufacturing and integration need to be demonstrated at the system level.
  - The loom capability can be expanded to weave much thicker recession layer, (1.5” – 2.5”) recession layer.

Heat-shiled Environment from Recent Mission Studies		Pressure atm	Heat Flux W/cm2	Heat Load kJ/cm2
Jupiter	Galileo	7.31	32000	200
Saturn	Saturn 1	2	2000	250
	Saturn 2	8	8000	75
Uranus	Uranus 1	12	3500	44
	Uranus 2	9	2500	41
Neptune	Neptune 1	25	9600	82
	Neptune 2	11.5	5500	109
	Neptune 3	6.8	4400	134

	Stag Point		Flank (Shoulder)	
	Recession Lyaer, in	Insulation Layer, in	Recession Lyaer, in	Insulation Layer, in
Saturn			**1.03**	**0.91**
Uranus	0.33	0.877	TBD	TBD
Neptune	**0.69**	**1.1**	TBD	TBD

- Common Probe study is reassessing and may provide a better bounding thickness
  - Integrated system needs to be demonstrated at bounding thickness levels

Aerocapture: Configurations and TPS

- **Entry Environment and Configurations**

	Neptune	Titan	Mars
Entry Velocity, km/sec	29	6.5	5.7
Atm. Scale Height	49	40	10.5
L/D	0.8	0.25	0.25
M/CdA	895	90	148
Convective Heating, W/cm2	8000	46	30
Radiative Heating, W/cm2	(4000- 8000)	(93 - 280)	~ 0
Time of Flight (min)	10	42	10
Ref: Neptune Aerocapture Systems Analysis, Mary Kae Lockwood, AIAA 2004-4951			

Neptune

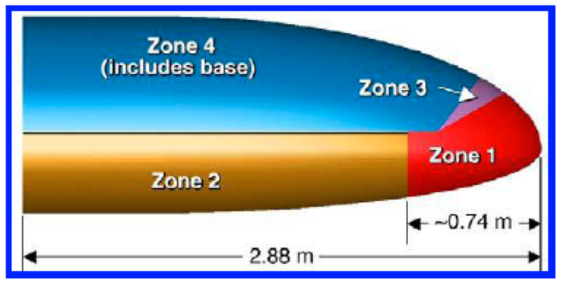
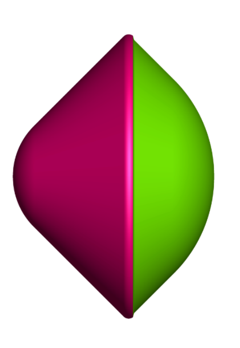


Figure 16. TPS zones.

Titan



- **Neptune:**
  - Multiple TPS needed for optimizing payload mass fraction
  - HEEET, PICA and (SIRCA/SLA/ACUSIL/Tile)
- **Titan: Benign**
  - TPS: Within the current TPS SOA (e.g. PICA/SLA/SIRCA/ACUSIL)

Addressing TPS for ballistic, direct entry will address aerocapture needs

Sustainability of TPS for OP Missions

- Why worry?
  - Missions are few and far between
  - TPS capability is critical and NASA unique
- PICA and HEEET
  - Simple compositional systems and manufacturing is automated
    - Both are essentially carbon and phenolic composition
      - PICA uses rayon. HEEET does not (by choice)
  - Technology capability has been transferred to industry
    - Raw material and processing – off the shelf – need to keep an eye
    - Multiple vendors and processing involved
      - Raw material to processing/manufacturing to assembly and integration
    - NASA has to assess the risk of atrophy periodically
- Approaches to addressing capability availability in the future
  - Periodically assess and take risk mitigation action for sustaining the capability
    - HEEET and PICA are NASA IP and NASA can transfer the technology at any time
  - Build and store a common aeroshell design capable of missions at multiple destinations

Common Probe Study

- Could a common atmospheric probe design be used for missions to Venus, Jupiter, Saturn, Uranus, and Neptune? Could we build multiple units and address sustainability concern?
  - Study funded by SMD-PSD
  - Typical designs have been 45deg sphere cones with high density TPS
  - Study will address inefficiencies or limitations that a common design cause for missions to these destinations
  - 4 NASA Centers involved (ARC, LaRC, GSFC, and JPL)
- Approach:
  - Strawman instrumentation payloads defined for each target based on science community input
    - Shallow and steep entry g-loads defined for each destination based on instrument sensitivity
  - TPS and carrier structure analysis and trades being conducted, including long term storage issues
  - Rough costing for design(s)
- Findings and recommendations to be presented at OPAG, VEXAG, and IPPW
- Final report to be delivered to PSD and published by summer 2018

Concluding Remarks & Recommendations

- TPS needs for Outer Planet Missions falls into two distinct groups
  - Moderate to low heat-flux missions (Titan) – PICA
    - Drop-in replacement for heritage PICA is funded and in progress (Completion by CY'20)
  - Extreme Entry Environment – HEEET
    - HEEET is more efficient, robust and capable
- PICA Replacement and Extensibility development in progress
- HEEET development for Saturn, Uranus or Neptune missions
  - Require thicker recession layer
  - Continued development will meet the future OP mission needs
- Sustainability is critical for extreme entry environment missions
  - Periodic assessment necessary
  - Common Probe – build and store multiple copies – may be a solution