A COMMON PROBE DESIGN FOR MULTIPLE PLANETARY DESTINATIONS

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2018 International Planetary Probe Workshop **June 12, 2018**

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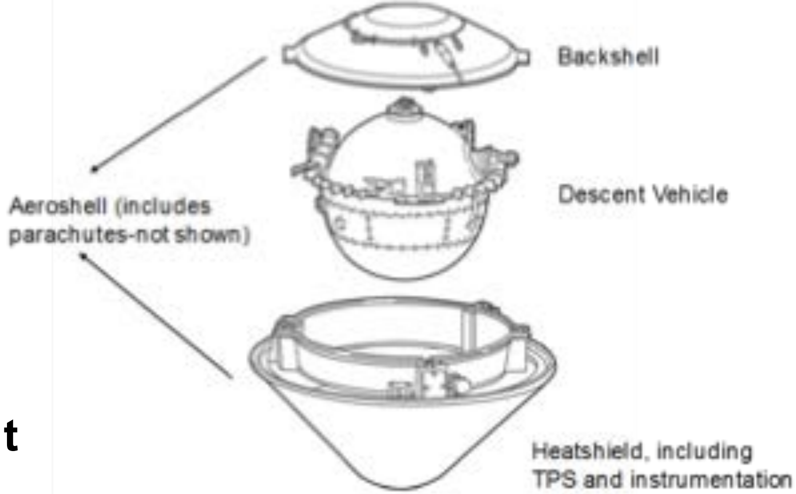
Background and study goals

- **At IPPW-14 (in 2017), during the Outer Planets session it was noted that many of the atmospheric probe designs seemed similar**
  - Are we designing the same probe over and over again?
  - Can we increase efficiency by designing one probe and using that design at multiple destinations?
  - Can we further increase efficiency by building multiple copies of that probe and store them for future use (and offer to mission designers as GFE)?
  - What potential risks or inefficiencies are introduced by using a common design and building multiple copies?
- **The Planetary Science Division of the NASA Science Mission Directorate funded a study from October 2017 – June 2018, involving 4 NASA Centers (ARC, GSFC, JPL, and LaRC), to address these issues**

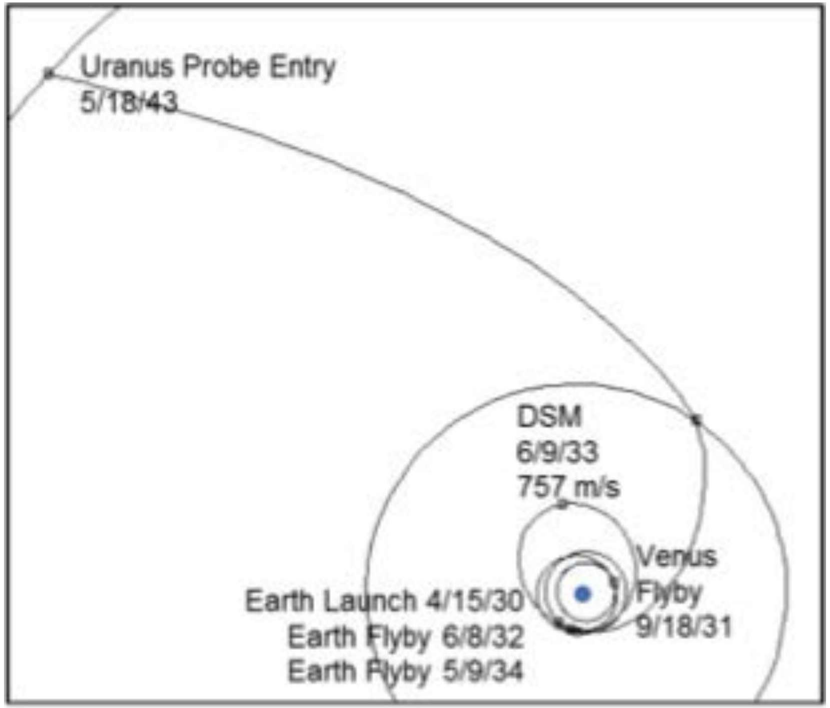
Study scope and assumptions

- **Venus, Jupiter, Saturn, Uranus, and Neptune as destinations considered**
  - In scope: missions with direct, ballistic entries
  - Out of scope:
    - Earth return, Mars, and Titan as destinations
    - Aerocapture
    - Large landers at Venus
- **Carrier spacecraft provides power and communications during cruise (details not studied)**



- **Mass and instrumentation for descent vehicle considered, but detailed mechanical design and interface out of scope of study**
- **Leverage previous missions and studies for detailed analysis, otherwise use mid-fidelity tools for design estimates**
  - Utilize current methods and technologies for design basis (*e.g.*, composite structures, heritage materials, etc.)

Interplanetary Trajectories



*Note: Uranus entries are retrograde

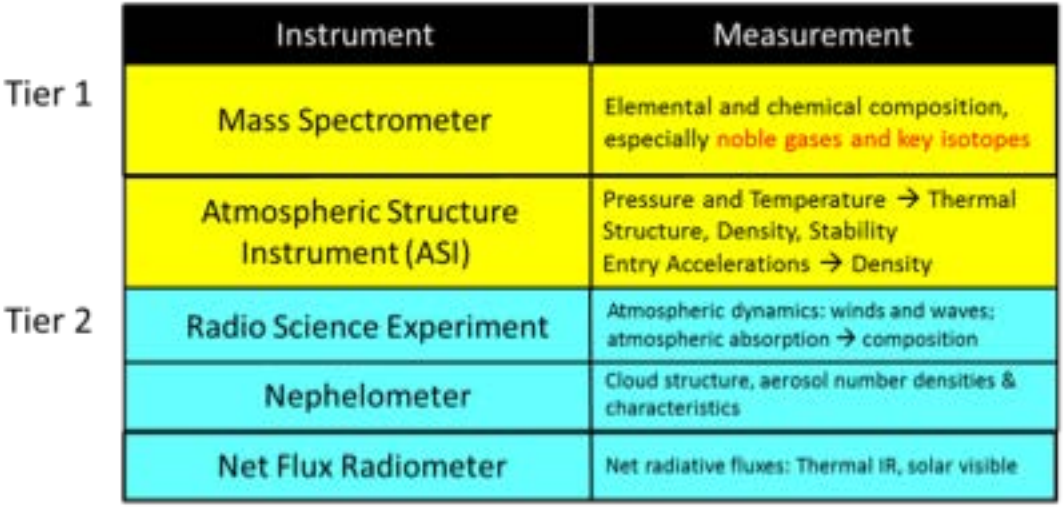
Assumptions

- Launch vehicle with current all-chemical capabilities (ΔV)
- Time of flight < 15 years
- “Shallow” (50-g) and “steep” (150 – 200-g) trajectories for each destination

Please see “INTERPLANETARY TRAJECTORY DESIGN FOR NASA’S COMMON PROBE STUDY,” K. Hughes, *et al.*, poster session

Strawman Payloads

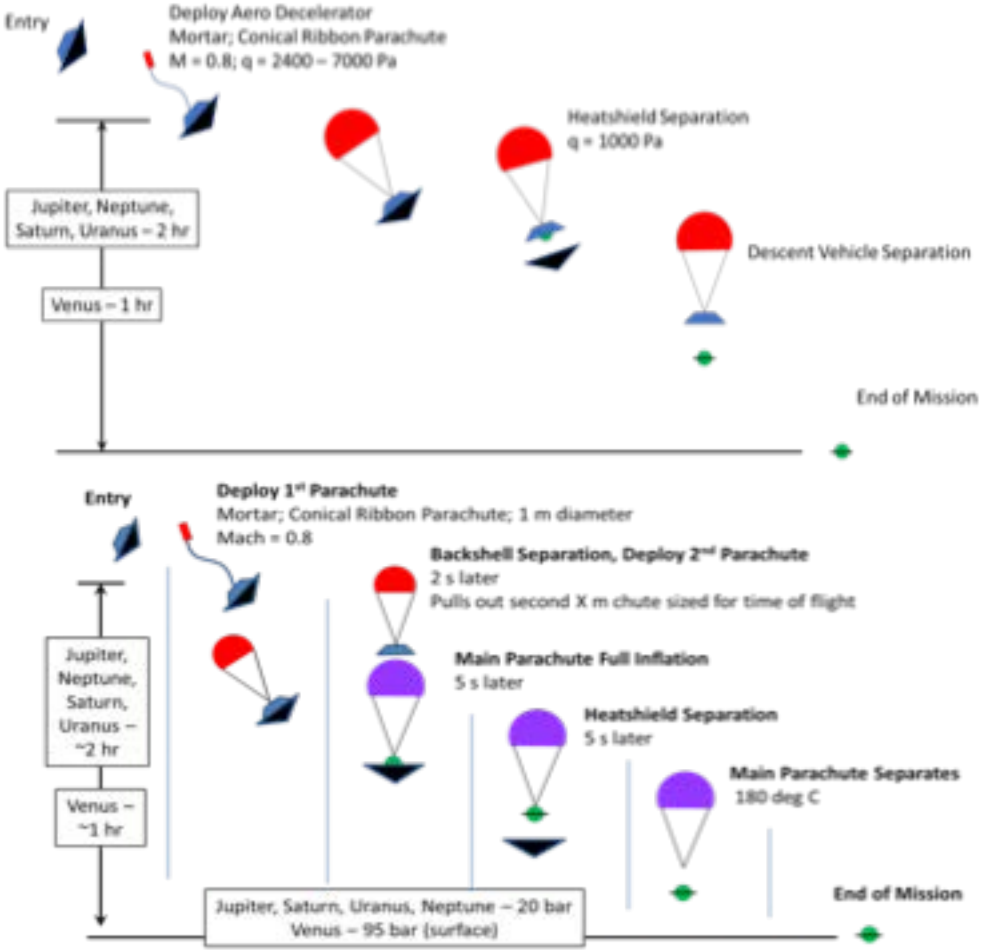
- **Science and payload team (JPL, GSFC) examined potential instruments for missions to 5 destinations and prioritized based on Tier 1 and 2 science**
- **Estimated a descent module of 0.75 m diameter could accommodate the minimum payload at the 5 destinations based on packaging ratios from previous missions and studies**



	Instrument	Measurement
Tier 1	Mass Spectrometer	Elemental and chemical composition, especially noble gases and key isotopes
	Atmospheric Structure Instrument (ASI)	Pressure and Temperature → Thermal Structure, Density, Stability Entry Accelerations → Density
Tier 2	Radio Science Experiment	Atmospheric dynamics: winds and waves; atmospheric absorption → composition
	Nephelometer	Cloud structure, aerosol number densities & characteristics
	Net Flux Radiometer	Net radiative fluxes: Thermal IR, solar visible

Details in "SCIENCE GOALS AND PAYLOADS FOR COMMON PROBE MISSIONS TO VENUS AND THE GIANT PLANETS," D. Atkinson, *et al.*, following presentation

EDL ConOps + Mission Design



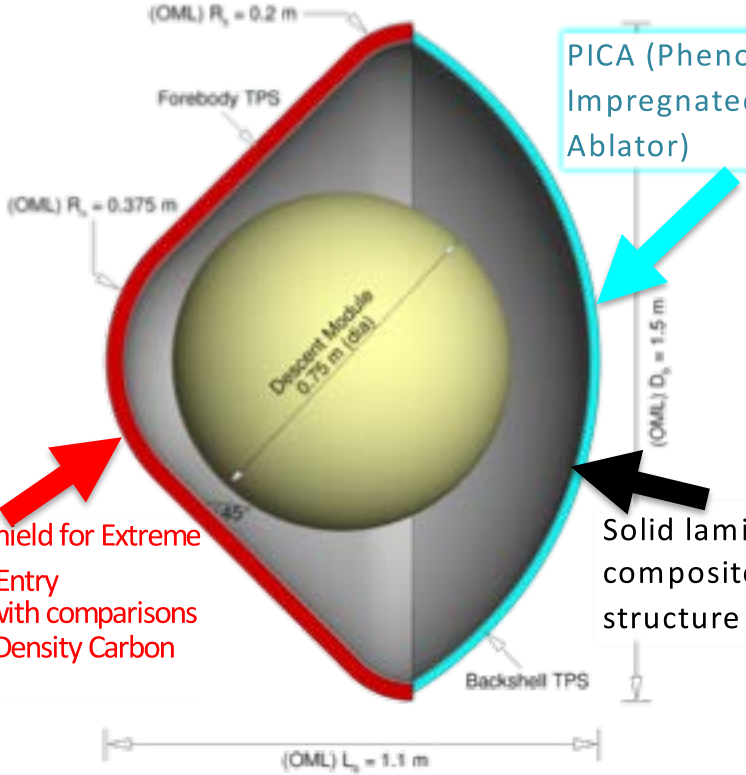
- **Two different scenarios**
  - 1 main parachute, 2.0 m diam conical ribbon, works for all 5 destinations
  - 1 pilot + 1 main:
    - Pilot is 1 m diam conical ribbon
    - Main parachute sized for destination
- **Both options are feasible, indicating flexibility in designing a concept of operations for Entry, Descent, and Landing**

Please see "EVALUATION OF COMMON PROBE TRAJECTORIES AT MULTIPLE SOLAR SYSTEM DESTINATIONS," A. Cianciolo, *et al.*, later this session

Aeroshell design assumptions

- **45°-sphere cone forebody (aerodynamic stability)**
- **Hemispherical-cap backshell (design simplicity)**
- **Probe diameter and nose radius similar to Pioneer Venus Large Probe (PVLP)**
- **Structure is solid laminate composite to provide a better coefficient of thermal expansion (CTE) match with the thermal protection system (TPS) materials**
  - Pioneer Venus and Galileo were metallic structures
  - Mass of structure assumed to be the same for all TPS thickness

	Base diameter (m)	Nose radius (m)	Ballistic Coefficient (kg/m^2)	Entry mass (kg)
Common Probe	1.5	0.375	216	400
PVLP	1.42	0.36	188	316
Galileo	1.26	0.222	256	335



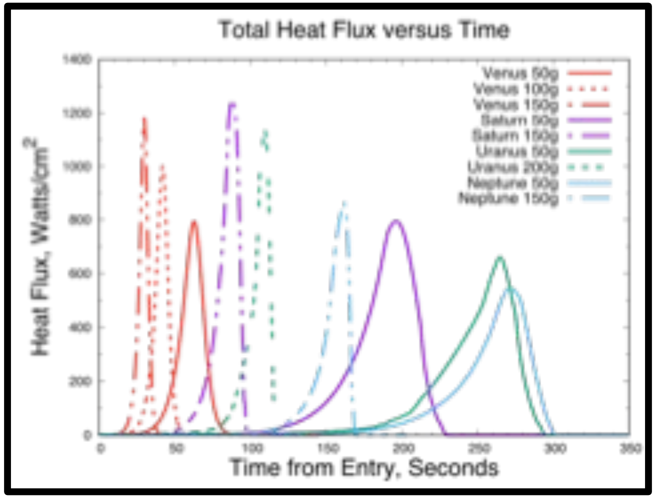
PICA (Phenolic Impregnated Carbon Ablator)

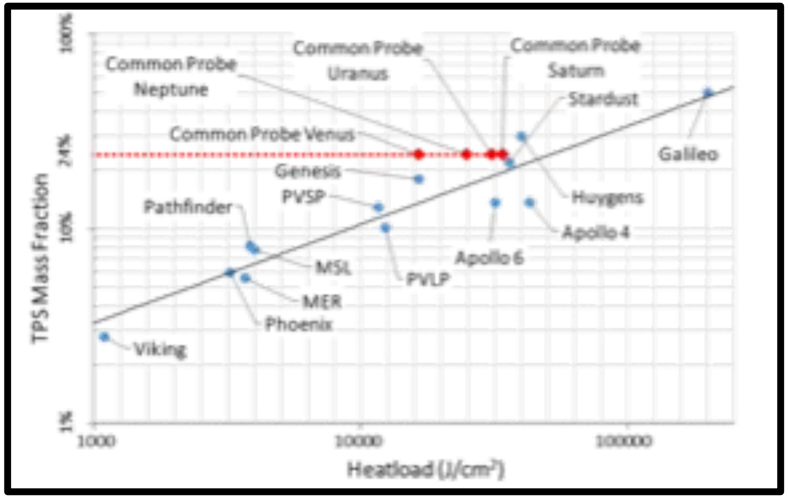
HEEET (Heatshield for Extreme Environment Entry Technology) with comparisons to FDCP (Full Density Carbon Phenolic)

Solid laminate composite structure

Thermal Protection System (TPS) sizing

- Aerothermal environments (radiative + convective heating) estimated on the forebody stagnation point using a 3DOF simulation, TRAJ
- 2 forebody materials considered: HEEET and FDCP, sized using FIAT
- Backshell TPS assumed to be PICA: mass estimated based on forebody stagnation point environments
- Common TPS thickness viable for 4 destinations but not Jupiter (heat loads 10x higher)
- TPS mass fraction in-family with historical missions





Please see "AEROTHERMAL DESIGN OF A COMMON PROBE FOR MULTIPLE PLANETARY DESTINATIONS," G. A. Allen, Jr., *et al.*, poster presentation

Master Equipment List

Probe - Total		FLIGHT HARDWARE MASSES		
Subsystem/Component		Total Mass, kg (CBE)	Contingency %	Total Mass, kg (CBE+Cont.)
Probe				
Descent Vehicle		108.1	*30.0%*	140.5
Instruments		34.2	*30.0%*	44.5
Aeroshell		193.3	*30.0%*	251.2
Total Mass		**335.5**	***30.0%***	**436.2**

Probe - Descent Vehicle (DV)			# OF UNITS	FLIGHT HARDWARE MASSES		
Subsystem/Component	Unit Mass, kg (CBE)	Unit Power, W (CBE)	Flight Units	Total Mass, kg (CBE)	Contingency %	Total Mass, kg (CBE+Cont.)
C&DH	3.3	9.0	1	3.3	*30.0%*	4.3
Power	12.4	5.0	1	12.4	*30.0%*	16.2
Structure & Mechanisms	68.6	0.0	1	68.6	*30.0%*	89.1
Telecom	13.2	243.0	1	13.2	*30.0%*	17.1
Thermal	10.6	0.0	1	10.6	*30.0%*	13.8
Total Mass				**108.1**	***30.0%***	**140.5**

Probe - Instruments			# OF UNITS	FLIGHT HARDWARE MASSES		
Subsystem/Component	Unit Mass, kg (CBE)	Unit Power, W (CBE)	Flight Units	Total Mass, kg (CBE)	Contingency %	Total Mass, kg (CBE+Cont.)
MS	16.0	65.0	1	16.0	*30.0%*	20.8
TLS	6.5	35.0	1	6.5	*30.0%*	8.5
ASI	3.0	3.5	1	3.0	*30.0%*	3.9
NFR	2.0	4.5	1	2.0	*30.0%*	2.6
Ortho/Para	3.0	4.0	1	3.0	*30.0%*	3.9
Nephelometer	2.3	3.0	1	2.3	*30.0%*	3.0
Helium Abundance Detector	1.4	0.9	1	1.4	*30.0%*	1.8
Total Mass				**34.2**	***30.0%***	**44.5**

Probe - Aeroshell (AS)			# OF UNITS	FLIGHT HARDWARE MASSES		
Subsystem/Component	Unit Mass, kg (CBE)	Unit Power, W (CBE)	Flight Units	Total Mass, kg (CBE)	Contingency %	Total Mass, kg (CBE+Cont.)
Heatshield	144.1		1	144.1	*30.0%*	187.3
Heatshield structure (composite)	53.8					
Heatshield TPS (HEEET)	73.4					
Heatshield separation system	7.0					
Aeroshell instrumentation	10.0					
Backshell	25.1		1	25.1	*30.0%*	32.7
Backshell structure (composite)	13.4					
Backshell TPS (PICA)	11.7					
Mechanisms etc	4.0		1	4.0	*30.0%*	5.2
Parachutes	20.0		1	20.0	*30.0%*	26.0
Total Mass				**193.3**	***30.0%***	**251.2**

- **HEEET baselined for mass and cost (more mass efficient plus investments by NASA)**
- **Initial estimate had 400 kg for probe mass**
- **Including 30% contingency for growth allowance for all items, mass of "common" design is 436 kg (within 10% of original estimate)**
- **Additional mass is due to pressure vessel (required only for Venus)**
- **Another design iteration needed to incorporate updated masses**

Special considerations due to “make ahead”

- **Typically, probes are designed and optimized based on specific mission needs.**
- **Building a probe once a decade has sustainability issues**
  - Maintaining heritage material availability (*e.g.*, precursor and constituents to carbon phenolic)
  - Skilled labor for assembly and integration (HEEET requires use of gap fillers and specially-developed integration techniques)
- **Building multiple copies of a common design can alleviate the sustainability issues, but introduces new risks:**
  - Long term storage and aging of the system
    - Will HEEET and a cyanate ester composite structure age at the same rate when bonded together?
    - Can accelerated aging coupon tests be performed?
    - Galileo and Phoenix are data points for ground storage
  - Qualification of the design across multiple destinations

Cost to build multiple copies of aeroshell

- **Preliminary costing which estimates the non-recurring vs recurring engineering portions indicates that cost savings could be realized by building multiple units at the same time**
  - Structure
  - Parachutes
  - TPS
  - EDL instrumentation
- **Storage costs not included in roll up**
- **As an example, building 5 units could reduce the cost of a probe by factor of ~3 (potentially less than $20M per probe)**
- **Higher fidelity costing is recommended as a follow-on activity**

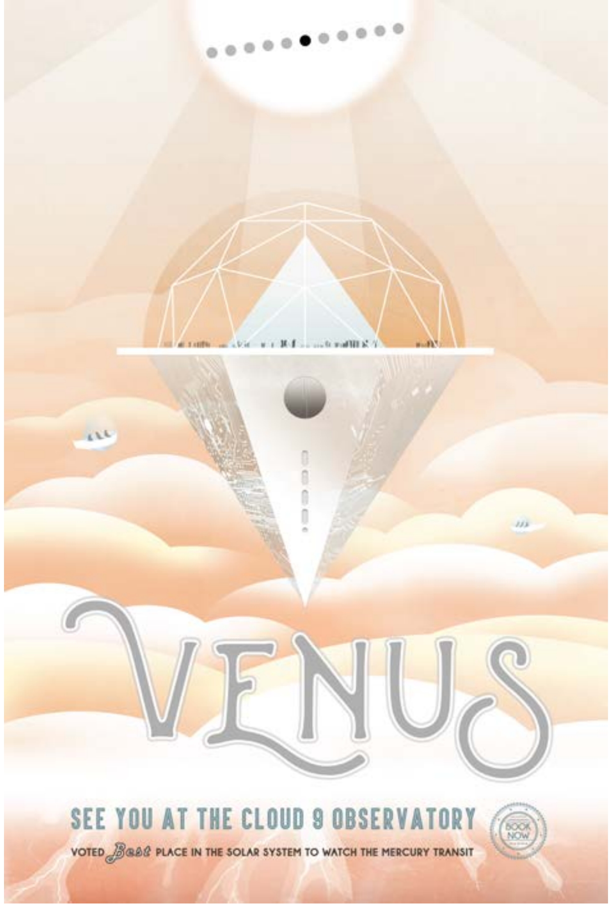
Summary and recommendations

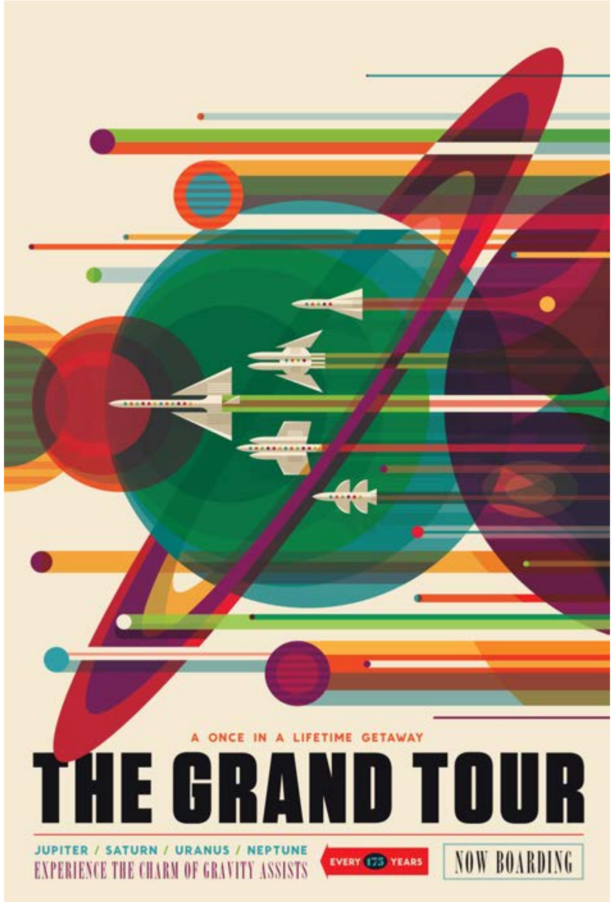
- **A common atmospheric probe design for Venus, Saturn, Uranus, and Neptune missions is feasible**
- **Missions to Jupiter should be considered separately due to heat loads**
- **Further analysis is needed**
  - Additional design cycle to account for updated masses, trajectory changes, etc.
  - Higher fidelity tools (CFD, structural analysis, etc) for better mass estimates
  - Better cost estimates
- **Using one design to build multiple copies and store for later use can offset the risk of losing skills and material resources decades downstream**
  - Venus missions in particular pay a mass penalty—but consequently may have greater mission flexibility (low-g entries)
  - Should explore optimal number of units to build based on cost and schedule
- **Risk of aging should be explored by building coupons and testing (accelerated aging?)**

Next steps

- **Report drafted and will be submitted to PSD/SMD**
  - Will be published as a NASA TM
- **Community feedback!**
  - IPPW
  - OPAG
  - VEXAG
- **Next round of analysis is desired:**
  - High fidelity analysis (CFD for convective aerothermal heating, detailed radiative heating calculations, structural sizing, costing, etc.)
  - Project formulation (~one year to scope effort to design and build multiple copies?)

Questions?





Images:
NASA/JPL-Caltech