Outer Planet Probe Mission Technologies

A. Simon (GSFC), T.R. Spilker (Independent Consultant),
K. Sayanagi (Hampton Univ.), D. Atkinson (Jet Propulsion Laboratory, California Institute of Technology), D. Banfield (Cornell Univ.)

OPAG Technology Forum
Hampton, Virginia
23 February 2018

Jet Propulsion Laboratory
California Institute of Technology

Science Justification for Outer Planet Probes

Comparative planetology *of <u>well-mixed atmospheres</u> of the outer planets is key to the origin and evolution of the Solar System, and, by extension, extrasolar systems.*

Atreya, S. K. et al., "Multiprobe exploration of the giant planets – Shallow probes", Proceedings of the 3rd International Planetary Probes Workshop, Anavyssos, Greece, 2005.

Outer planet measurements that cannot be achieved by remote sensing require entry/descent probes, including

- Multiple Shallow Probes: Spatially variable atmospheric structure, including clouds, thermal profile, and dynamics.
- Medium-depth probe: noble gases, key isotopes, disequilibrium species, and volatiles; atmospheric structure incl clouds, thermal profile, and dynamics
- Deep Probes: Reach further below the (not well-known) cloud condensation layers; Well-mixed composition including noble gases, key isotopes, disequilibrium species, and volatiles

All must be measured at vertical resolutions of fractional scale heights

Enabling Technologies, Enhancing Technologies and Engineering Development

<u>Engineering Development</u> Behaviors of all system components, materials, etc. are known; Key is how to put components together to achieve required performance.

<u>Technology Development</u> Behavior of at least 1 system element is unknown (i.e., uncertainties > design can tolerate) thereby requiring development before component can be used in an engineering design.

<u>Enhancing Technology</u> If an older technology exists to achieve an objective, but a newer technology could do a better job, then that other technology would be considered "enhancing".

<u>Enabling Technology</u> For a given objective, technology is absolutely required to attain that objective. Rarely is enabling technology *only* technology that could attain objective.

T.R. Spilker, Personal Communication (2018)

Coast / Entry Thermal and Telecommunications

During Coast Period from Carrier release to entry

- Probe will be subject to an extreme thermal environment and need to be kept warm for survival to the entry interface point;
- Probe to Carrier telecomm is required for health status and entry configuration confirmation.

Enhancing Technologies Coast telecommunication architecture and systems including coast/entry telecom antennas, RF transparent backshells, and improved high energy density batteries

Notes:

1. High energy density batteries needed to provide energy to operate avionics and instrument during coast without mass/volume penalty.
2. If RHUs not available, high energy density batteries are enabling technology required to maintain probe at survival temperatures during coast.

Thermal Protection Systems

- HEEET (Heatshield for Extreme Entry Environment Technology) is <u>Enabling Technology</u> for Ice Giant and Saturn probe missions.
- FY18: HEEET will be TRL 5+ for missions with recession layer thickness to 0.4”.
- Due to very high heat-load Outer Planet Probe missions will require thicker TPS.
  - Saturn is thickness defining destination.
  - Ice Giant environments are challenging, especially high peak pressure
  - HEEET development for Outer Planet Probe missions needs to address the thickness issue by expanding the current capability and demonstrating it.
  - HEEET needs to be at TRL 6 for OP Probes prior to next NF-5 and flagship mission announcement.
  - Can HEEET be matured to address Jupiter as well? TBD / Not clear yet.
- Completion of HEEET development required prior to NF-5 call to support not only Saturn Probe but also future Uranus/Neptune Flagship missions that include probes.
- Proposed OPAG finding: NASA should complete HEEET development for outer planet probe missions.
- See Ellerby, et al. “Heatshield for Extreme Entry Environment Technology (HEEET) Development and Maturation Status”

How Deep is Deep?

A single deep probe reaching 50-100 bars at Jupiter and Saturn yields better profiles of condensable and disequilibrium species below the likely cloud layers, noble gases, noble gas isotopes, D/H, $^{14}N/^{15}N$.

50 bars at Uranus and Neptune will provide noble gases, C, S, N, and $^{14}N/^{15}N$ not achievable from a 10- to 20-bar probe.

Reference: S. Atreya and T. Owen, “Multiple Probes to Multiple Planets,” 3rd International Planetary Probe Workshop, Athens, 2005.

Deep Atmosphere Survival

Predictions for deep troposphere thermal structure will change significantly based on assumptions of static stability:

Neutral static stability (dry adiabatic) provides warmest possible temperatures for deep troposphere

Positive static stability results in significantly cooler temperatures

Saturn 100-bar temperature: 300 K (positive static stability) → 1000 K (dry adiabat)

Notes:

* >>100-bar : Uranus and Neptune water solution clouds

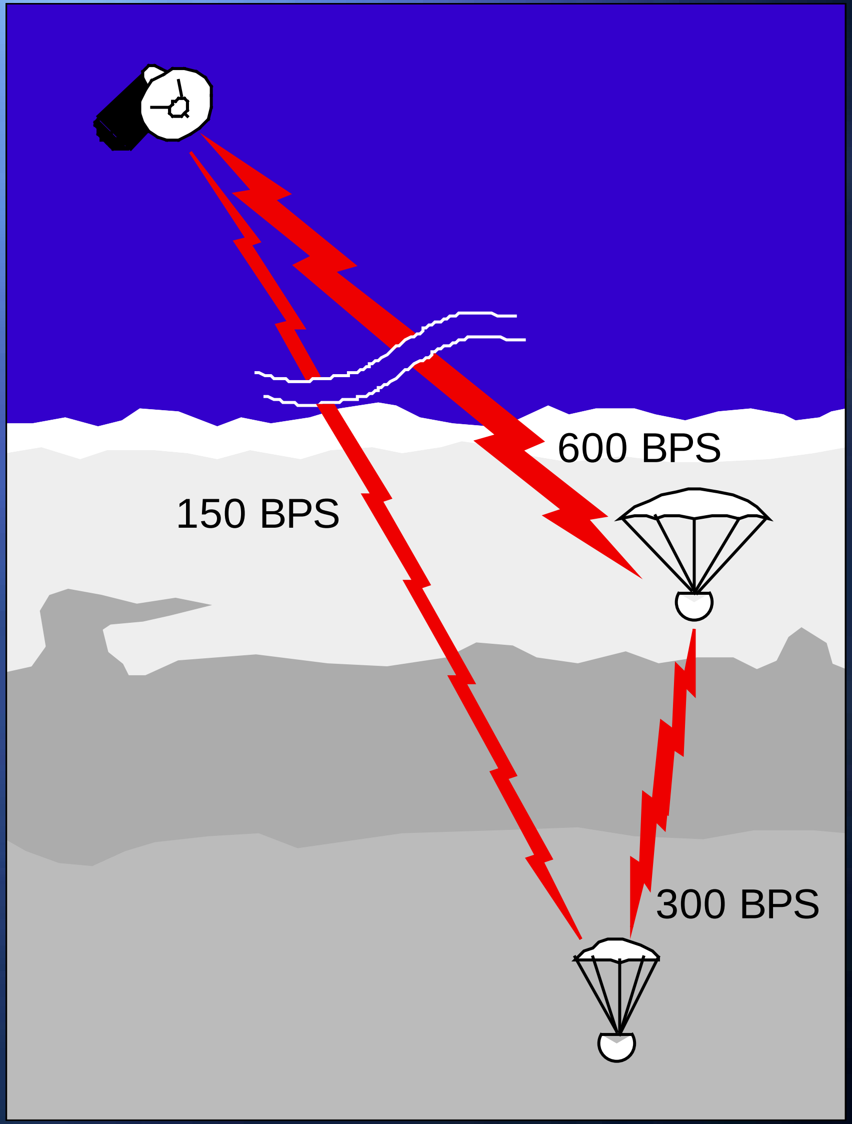
* 100-bar ~similar to Venus surface → Design of pressure vessels and seals from Venus likely adaptable for expected outer planet deep atmospheres.

* Heat content of H_2/He atmospheres always less (per unit volume) a CO_2 Atmosphere (Venus) → Heat/Volume for Saturn at 700K is << extreme than environment of Venus at 700K.

<u>Engineering Development</u> Deep atmosphere probe design for pressure and thermal survival.

Deep Atmosphere Telecommunications Staged Probe Data Relay Strategies

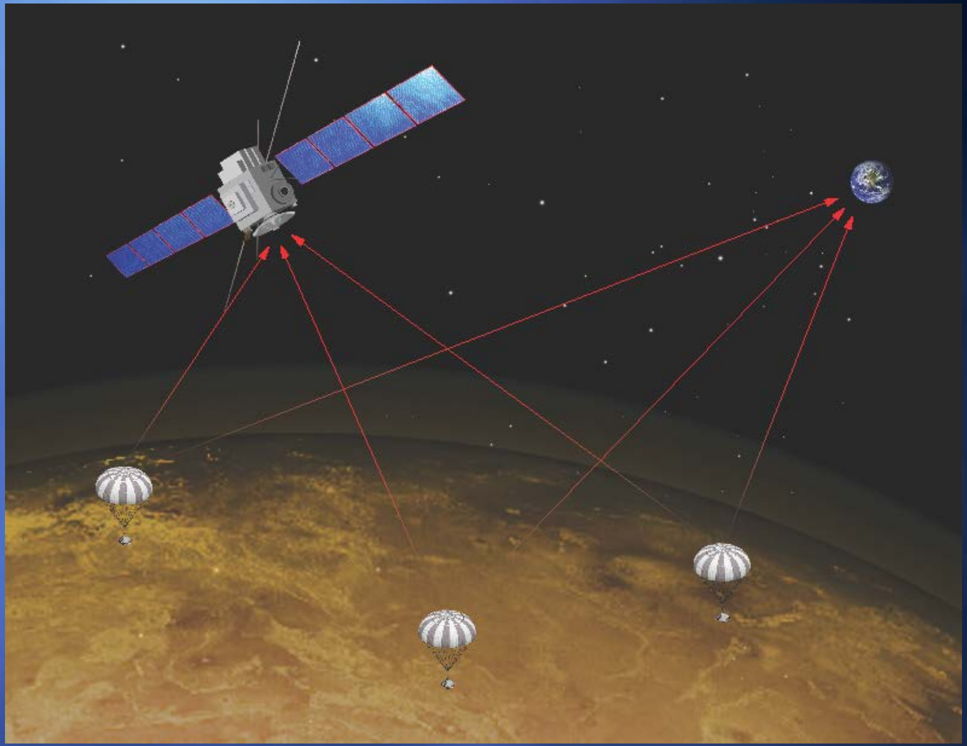
- Outer planet atmospheres primarily H_2/He but with significant radio-absorbing species: NH_3, H_2O
- At UHF frequencies, shallow probes (10-20 bars) remain within relatively "clear" atmosphere → low opacity
- Communication through deep absorbing atmospheric overhead → greatly reduced data throughput.
- Architecture: Shallow probe descending slowly releases deep probe for rapid descent.
- Telecommunications: Potential to overcome deep RF opacity that would otherwise yield significantly reduced data rates.
- <u>Enhancing Technologies & Engineering Development</u> Staged probe UHF relay telecomm systems including antenna design, small probe one-way relay (transmit) capabilities.



T.R. Spilker "Planetary Entry Probes In the Foreseeable Future: Destinations, Opportunities, and Techniques,", International Workshop on Planetary Probe Atmospheric Entry and Descent Trajectory Analysis and Science, Lisbon, 2003.

Small Probes

- Shallow: 5-10 bars
- Science Goal: In situ measurements for improved temporal and spatial coverage of atmospheric structure and properties
- Lifetime: tens of minutes to ~1 hour
- Possible Mission Architectures:
  - Secondary probe to primary deep composition probe
  - Element of probe constellation to study spatially varying properties – thermal structure, clouds, dynamics.
- Telecom Notes:
  - Jupiter (e.g., Galileo): L-band
  - Saturn: UHF
  - Uranus/Neptune: S-band to 10-12 bars; Deeper requires UHF



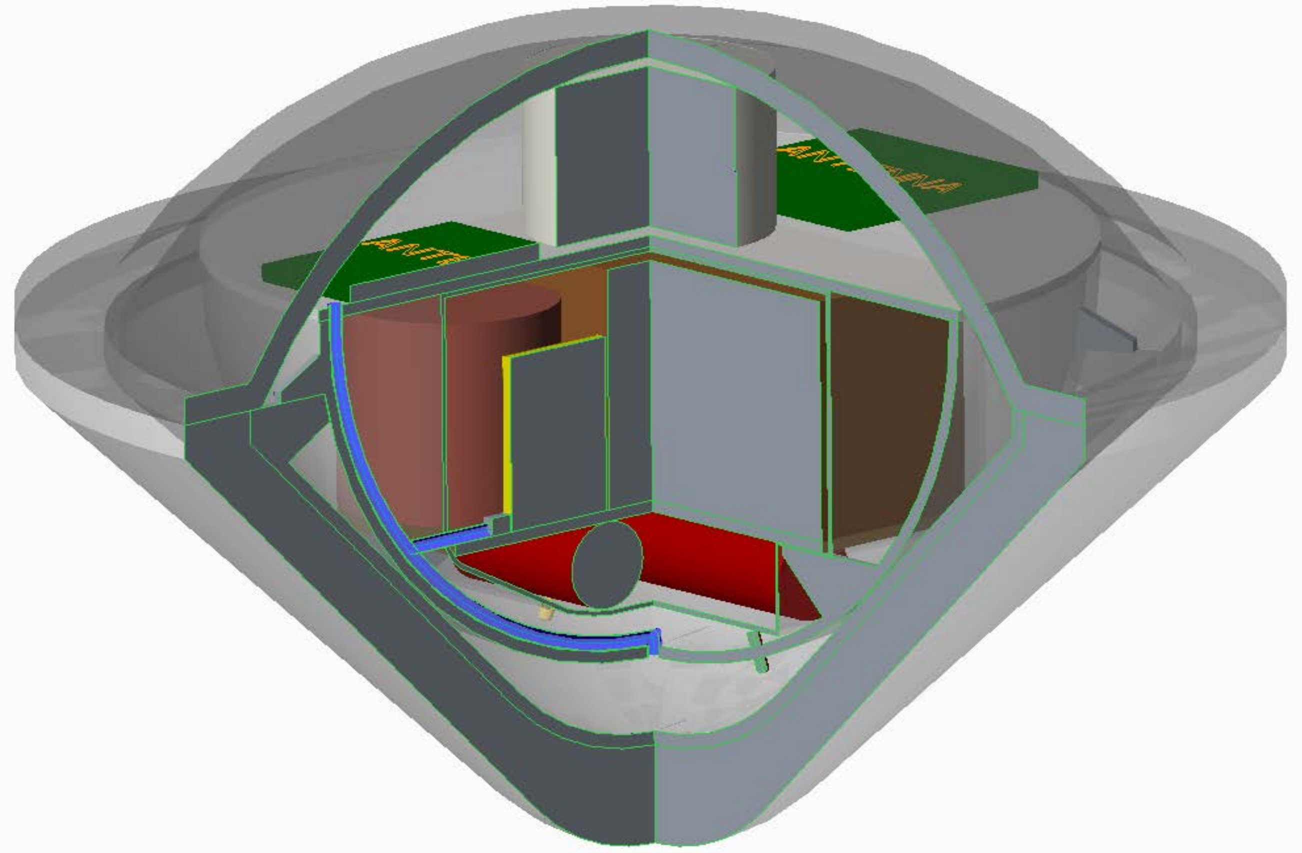
Engineering Development Small probe telecommunication systems, antennas, avionics; small probe power & power management

Enhancing Technology High energy density batteries when RHUs available (will allow longer descent mission and/or more instrumentation)

Enabling Technologies HEEET; Small, high energy density batteries for coast thermal control (if RHUs not available)

PSDS3 Small Next Generation Atmospheric Probe (SNAP)

- Atmospheric entry probe to measure vertical cloud structure, stratification, and winds to help understand the chemical and physical processes that shape the atmosphere of Uranus.
  - Mass: 30 kg
  - Diameter: 50 cm, 45° sphere cone
  - Power: Primary Batteries
  - Heatshield: HEEET
  - 5-10 bar pressure altitude



- SNAP design concept enables future small multiprobe missions, or as a secondary probe flying with a primary (composition) probe.

Key Technologies for Entry Systems and Planetary Probes

Investments needed in key entry systems and planetary probe engineering development, enhancing and enabling technologies include:

- Engineering Development
  - Small Satellite UHF/S-band telecomm systems
  - Small low gain antenna for staged probes
  - Power and power management systems
  - Deep probe aerodynamic design, pressure and thermal design
- Enhancing Technologies
  - Small probe transmitters and avionics, Next generation ultrastable oscillators
  - Thermal materials
  - On-board processing
  - Coast telecommunication architecture and systems including coast/entry telecom antennas, RF transparent backshells.
  - Extreme Environment Systems
- Enabling Technologies
  - HEEET
  - High-energy-density batteries (if RHUs not available)

References

Arnold, J. and E. Venkatapathy, "DEVELOPMENTS IN NANOTECHNOLOGY AND IMPLICATIONS FOR FUTURE ATMOSPHERIC ENTRY PROBES," Internatinal Workshop on Planetary Probe Atmospheric Entry and Descent Trajectory Analysis and Science, Lisbon, 6 – 9 October 2003

Atreya, S., and T. Owen, "Multiple Probes to Multiple Planets," 3rd International Planetary Probe Workshop, Athens, 2005.

Atreya, S., "SATURN PROBES: Why, Where, How?" Proceedings, International Planetary Probe Workshop, IPPW-4, Pasadena, California, June 2006

McEwen, A., and OPAG Steering Committee "OPAG viewpoint: Are small spacecraft or low-cost missions useful for exploration of Giant Planets and Ocean Worlds?" July 2017

Beauchamp, P., et al., Technologies for Outer Planet Missions: A Companion to the Outer Planet Assessment Group (OPAG) Strategic Exploration White Paper, 2009.

Sayanagi, K., "Small Next-generation Atmospheric Probe (SNAP)," OPAG Scripps Institute of Oceanography, La Jolla, CA, September, 2017.

Spilker, T.R, "Planetary Entry Probes In the Foreseeable Future: Destinations, Opportunities, and Techniques,", International Workshop on Planetary Probe Atmospheric Entry and Descent Trajectory Analysis and Science, Lisbon, 2003.