# SNAP

## Small Next-generation Atmospheric Probe

## A Multiprobe Flagship Mission to Explore Ice Giant Uranus

**NASA Planetary Science Deep Space SmallSat Studies**

**March 18, 2018**


**Kunio Sayanagi, Principal Investigator**
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**Robert A. Dillman, Chief Engineer**
**NASA Langley Research Center**

# Study Team

| | |
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| Robert A. Dillman | NASA Langley Research Center |
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| Sarag Saikia | Purdue University |
| Jing Li | NASA Ames Research Center |
| Drew Hope | NASA Langley Research Center |
| W. Chris Edwards | NASA Langley Research Center |

**Mission Design Center:**

**NASA Langley Research Center Engineering Design Studio**


# Mission Science Objectives

**Tier-1 Objectives:**

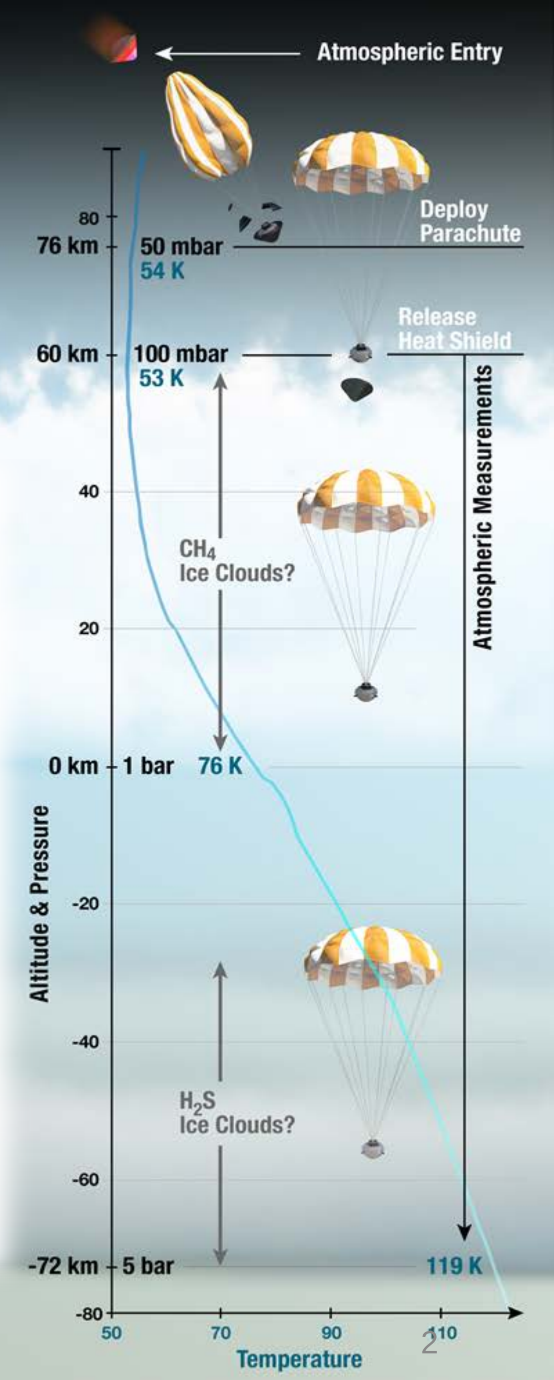
*Determine spatial variability in atmospheric properties:*

- Vertical distribution of cloud-forming molecules
- Thermal stratification and static stability
- Atmospheric dynamics as a function of depth

**Tier-2 Objectives (Tech Search only in this study):**

*Determine Bulk Composition:*

- Measure abundances of the noble gases (He, Ne, Ar)
- Measure isotopic ratios of H, C, N, and S

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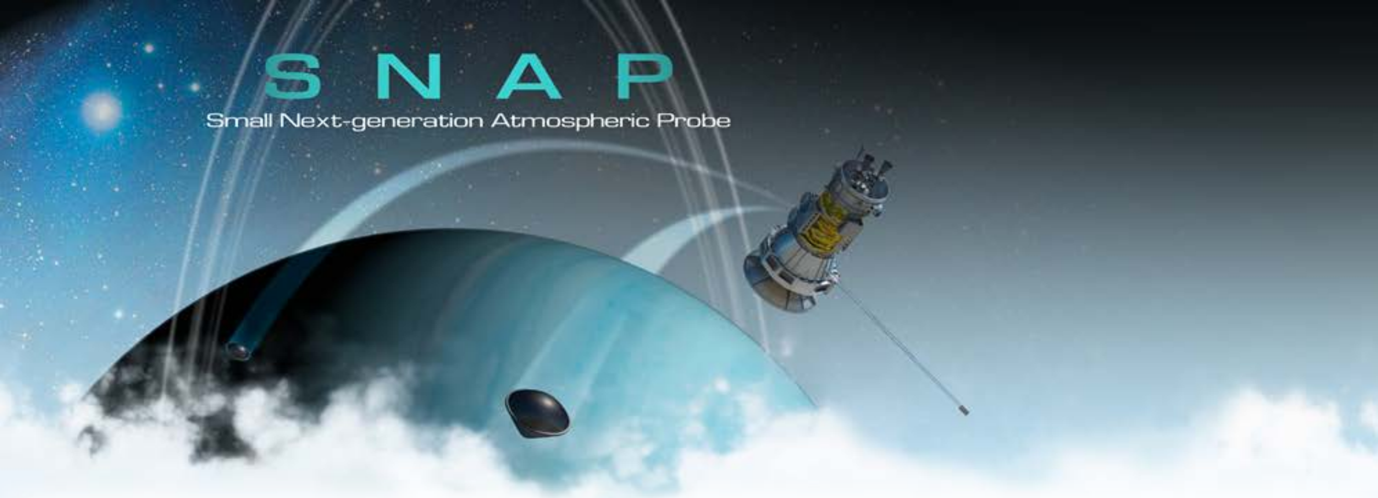



# Science Instruments

**NanoChem Atmospheric Composition Sensor:**

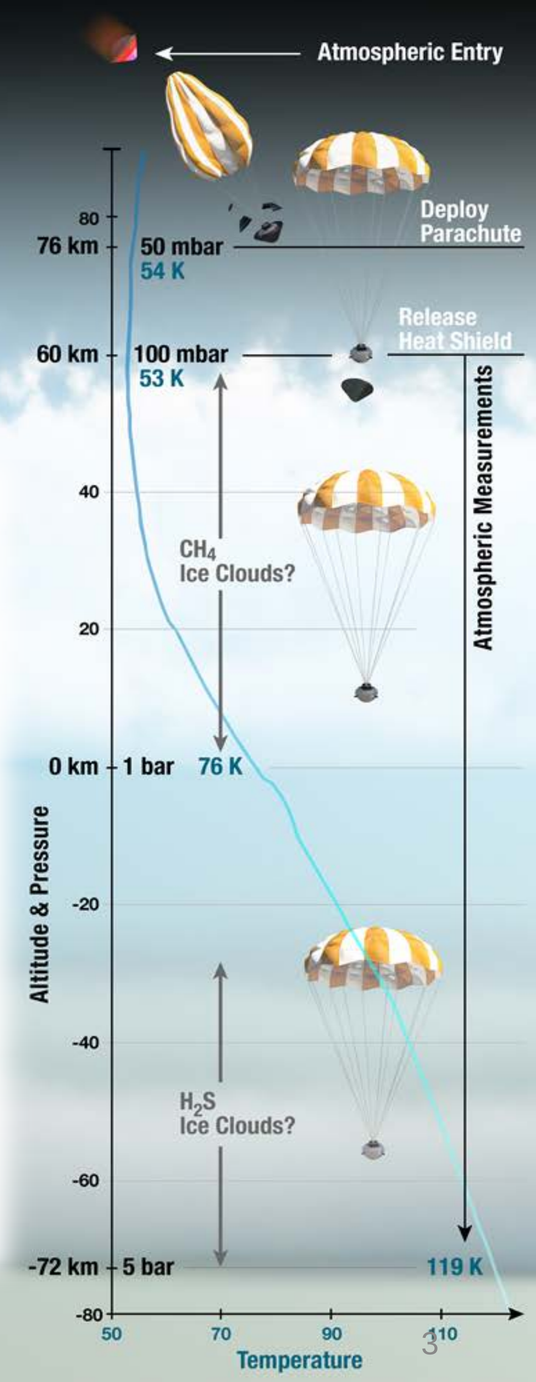
Vertical distribution of cloud-forming molecules

**Atmospheric Structure Instrument (ASI):**

Thermal stratification and static stability

**Ultra-Stable Oscillator (USO):**

Atmospheric dynamics as a function of depth (Through Doppler Wind Experiment)

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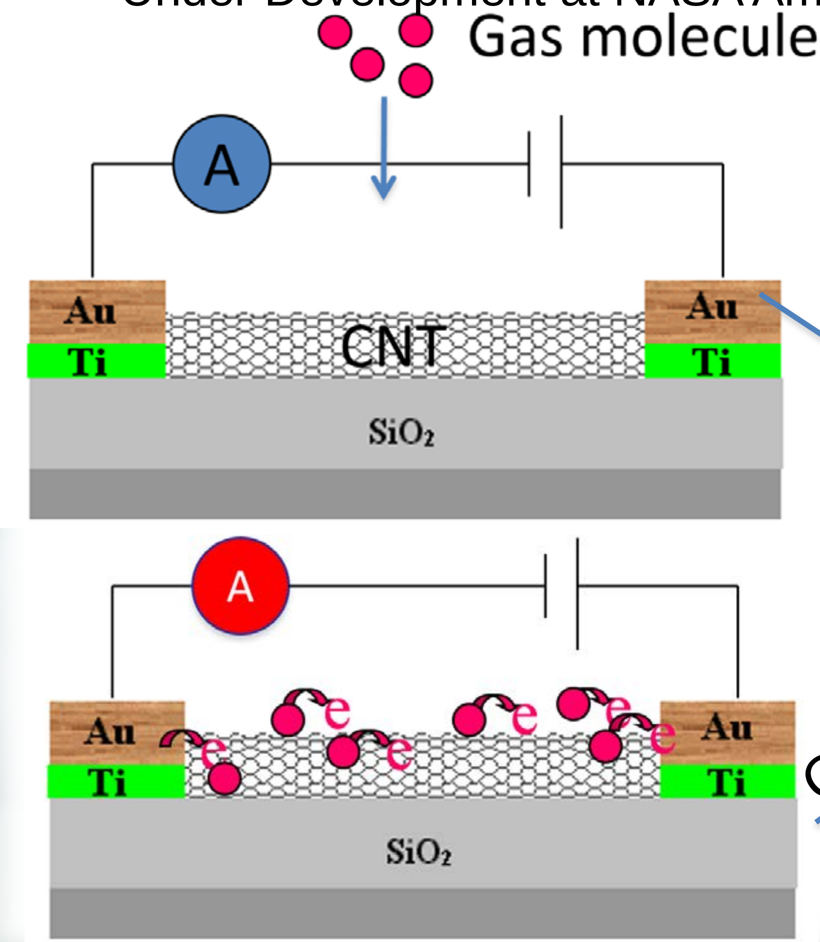
# Science Instruments

| Instrument | Measurement | Mass | Power | SNAP Data Return |
|---|---|---|---|---|
| **NanoChem** | Atmospheric Composition | 1.0 kg | 0.1 W | 1.08 Mbit |
| **Atmospheric Structure Instrument** | Pressure<br>Temperature<br>Acceleration | 1.3 kg | 5.7 W | 6.25 Mbit |
| **Ultra-Stable Oscillator** | Doppler Wind Experiment | 1.7 kg | 3.2 W | 0.05 Mbit<br>(Housekeeping Only) |
| **Total** | | **4 kg** | **9 W** | **7.35 Mbit** |

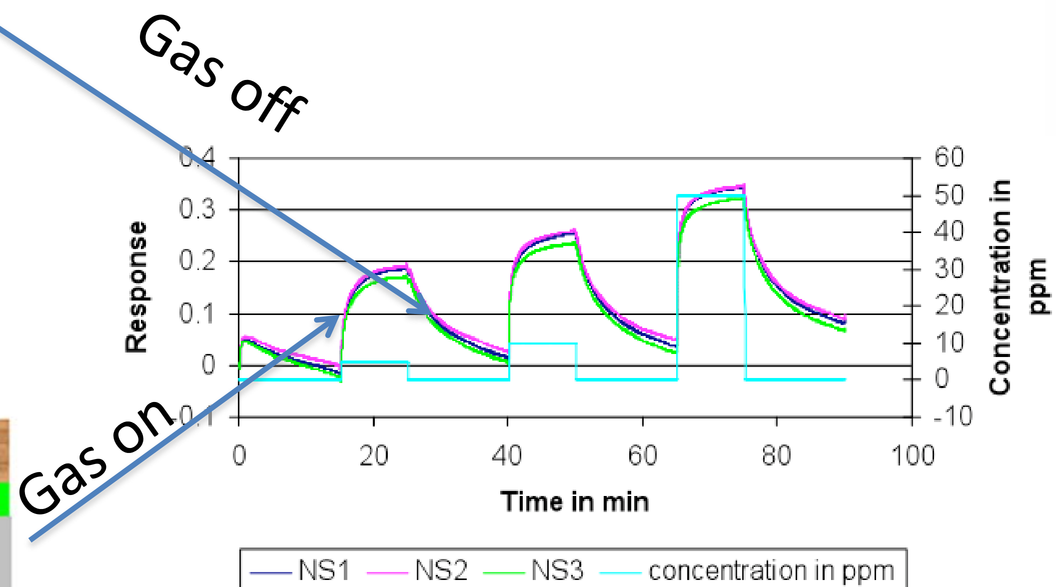
# NanoChem: How it works

- Measures <u>Changes in Resistivity</u> in response to gas composition
- Sensor Heads can be arrayed up to 16 x16 grid on a single chip
- Under Development at NASA Ames (PI: Jing Li)




**<u>NanoChem Advantages:</u>**

- Small Sensor Package
- Low Mass, Lowe Power
- Can operate without Vacuum Pump



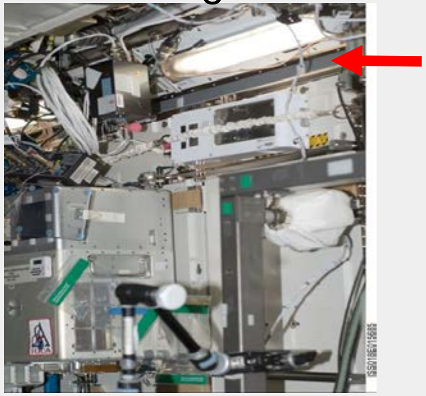

NanoChem response to ammonia

# NanoChem: TRL = 4 Today

**Launched and Operated in Space**

Navy MidSTAR-1 satellite in 2007

Environmental Monitoring on ISS



Sensitivity demonstrated for:

… $CH_4$, $H_2O$, and $NH_3$, among others

… in Mars and Earth conditions

Need to develop sensitivities for:

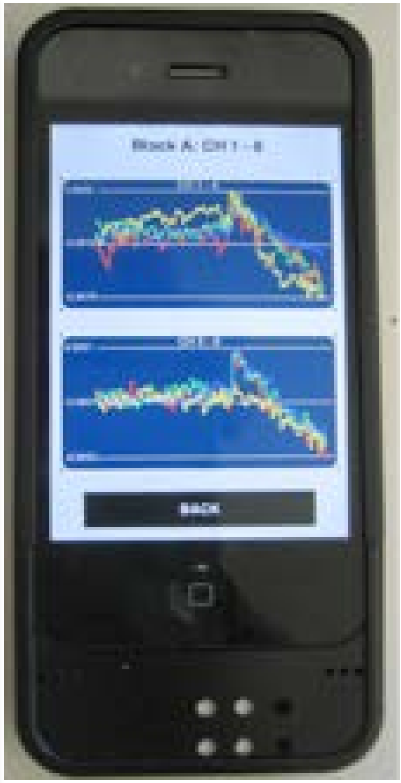
… $H_2S$

… in Giant Planet Conditions

| Analyte | Sensitivity/Detection Limit |
|---|---|
| $CH_4$ | 1 ppm in air |
| Hydrazine | 10 ppb tested |
| $NO_2$ | 4.6 ppb in air |
| $NH_3$ | 0.5 ppm in air |
| $SO_2$ | 25 ppm in air |
| HCl | 5 ppm in air |
| Formaldehyde | 10 ppb in air |
| Acetone | 10 ppm in air |
| Benzene | 20 ppm in air |
| $Cl_2$ | 0.5 ppm in $N_2$ |
| HCN | 10 ppm in $N_2$ |
| Malathion | Open bottle in air |
| Diazinon | Open bottle in air |
| Toluene | 1 ppm in air |
| Nitrotoluene | 256 ppb in $N_2$ |
| $H_2O_2$ | 3.7 ppm in air |

# NanoChem Commercialization

- Development at NASA Ames
  PI: Jing Li
- A/D on NanoChem Attachment
- Power from Phone (~mW)
- Processing on the Phone
- High sensitivity – ppb to ppm
- Data Transmission through Cellular Network

# Mission Design Assumptions

1. Baseline Carrier Mission: Uranus Orbiter with Probe Mission Architecture #5 by Ice Giants Flagship SDT:
   - 1913 kg Uranus Orbiter
   - All-chemical Propulsion (no SEP)
   - 50 kg Science Payload on Orbiter
   - 321 kg Probe (= Primary Probe = PP)
2. Add SNAP as a Second Probe
3. Deliver PP and SNAP at Uranus with large spatial separation
4. PP/SNAP and CRSC trajectories must enable data relay

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# SNAP Study Goals

**Enable Future Multi-Probe Planetary Missions:**

– Advocated by past Decadal Surveys

– Provide data on spatially varying atmospheric phenomena.

– **2003 Survey**: Advocated for a Jupiter Multi-Probe mission

– **2013 Survey:** Emphasized that a second probe can significantly enhance the scientific value of a probe mission

– Never realized due to perceived high-cost.

– SNAP Design applicable to Saturn, Uranus and Neptune (with possibilities for Venus)

**SNAP Enables Future Multi-Probe Missions**

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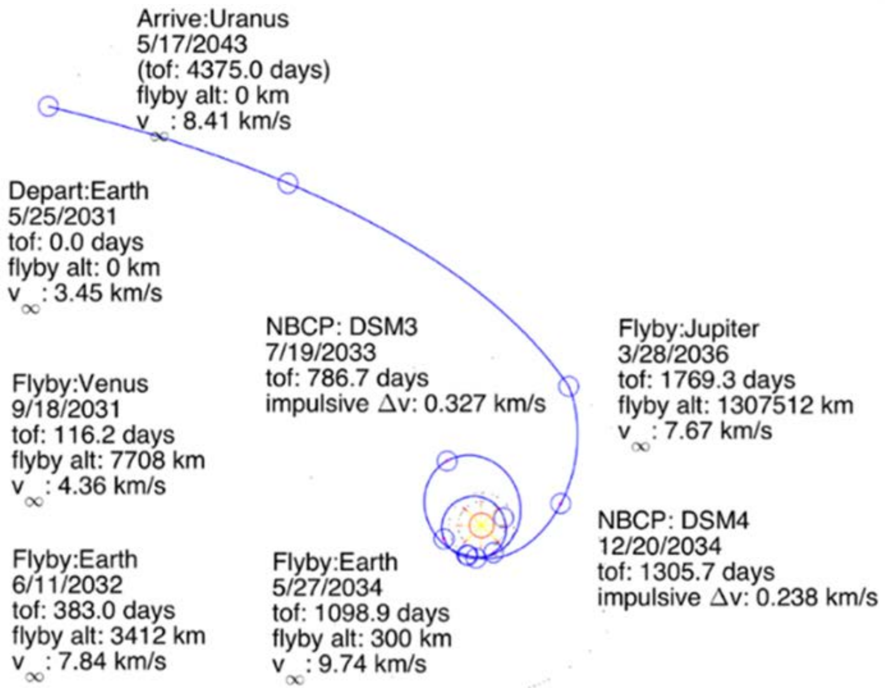
# Baseline Carrier Mission

**Earth-VEEJ-Uranus (Modified NASA Ice Giants SDT Architecture #5)**

- Launch: 5/25/31, VEEJ gravity-assists + Two DSMs
- Launch Vehicle: Atlas V541,
  ~4450 kg $C_3 = 11.9\ km^2/s^2$
- 12-year cruise to UOI




**Uranus Arrival: May 17, 2043**

- Close to 2049 Equinox
- After 2028 Northern Summer Solstice
- Voyager flyby 1986 was during Southern Summer Solstice
- Periapsis $r_p = 1.05\ R_U$
- Capture orbit period = ~142 days

# Impact on Carrier Mission

Trajectory:

– Release SNAP after Uranus Orbit Insertion

Hardware:

– Mounting & deployment hardware

– Pre-deployment power & data connections

– Orbiter propellant

Software & operations:

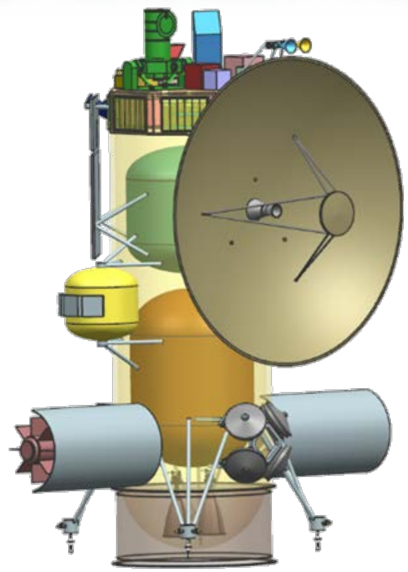
– Accommodate second probe delivery and data relay

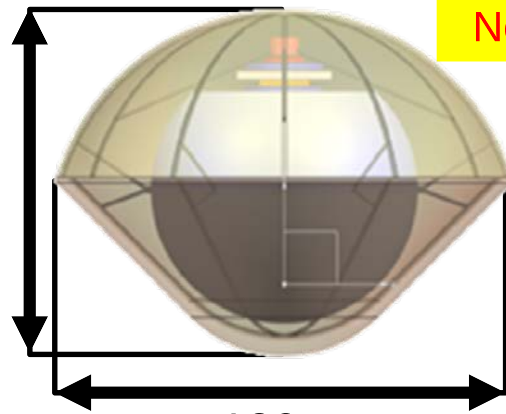
# Add SNAP as a Second Probe

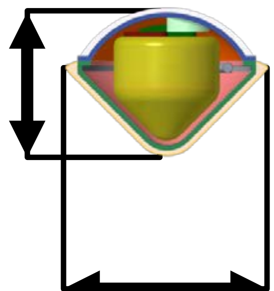
**From Ice Giant SDT Study**

**SNAP**

Not to scale with Orbiter






**Orbiter (CRSC)**

- Mass in orbit: 1913 kg
- Payload Mass: 50 kg
- UOI $r_p$: 1.05 $R_U$
- Orbital Period: ~142 days

**Primary Atm. Probe (PP)**

- Mass: 321 kg
- Diameter: 1.2 m, 45° sphere-cone
- 10-bar* pressure altitude
- Probe release: ~60 days
- EPFA: -20° to -50°

Baseline Orbiter and Probe: Ice Giant SDT Architecture #5

**SNAP**

- Mass: 30 kg
- Diameter: 0.5 m, 45° sphere-cone
- 10-bar* pressure altitude
- Probe release: 30–60 days
- EPFA: -20° to -50°

*10-bar is requirement for hardware operation for margin, science objective is to reach 5-bar.

# Interplanetary Trajectory Options

- A broad of catalog of ballistic chemical gravity-assist trajectory options
- SEP options not investigated due to high mass

| Launch Date | Launch Vehicle | Flyby Sequence | Launch $C_3$ ($km^2/s^2$) | Interplanetary Cruise (yrs) | DSM (m/s) | Arrival Mass (kg) | UOI ΔV (m/s) | Mass in Orbit (kg) |
|---|---|---|---|---|---|---|---|---|
| 5/25/2031 | Atlas V 541 | Earth-VEEJ-Uranus | 11.9 | 12 | 565 | 3582.5 | 1680 | 1850 |
| 7/18/2031 | Delta IV Heavy | Earth-VEJ-Uranus | 20.3 | 10.9 | 737 | 5265 | 2240 | 2393 |
| 4/6/2031 | Delta IV Heavy | Earth-VVE-Uranus | 25.5 | 11.5 | 1063 | 4751 | 1580 | 1885 |

Baseline

**Dual probe delivery architecture possible for multiple interplanetary trajectory options**

# Challenges of Multi-Probe Missions

- Deliver PP and SNAP at two significantly different locations (latitude, longitude, time-of-day)

- During each probe's atmospheric descent:
  - CRSC used to receive data from probe, relay to Earth
  - CRSC must be within 30 degree comm. cone around zenith.
  - Each probe must reach at >5-bar while CRSC is in 30-deg cone.

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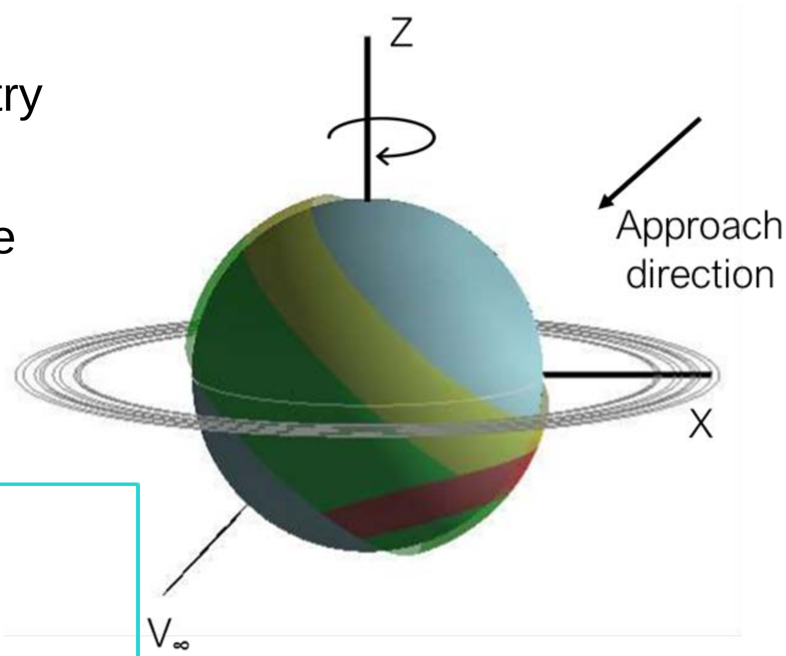
# Uranus Entry Locations

**Accessibility of Entry Locations**

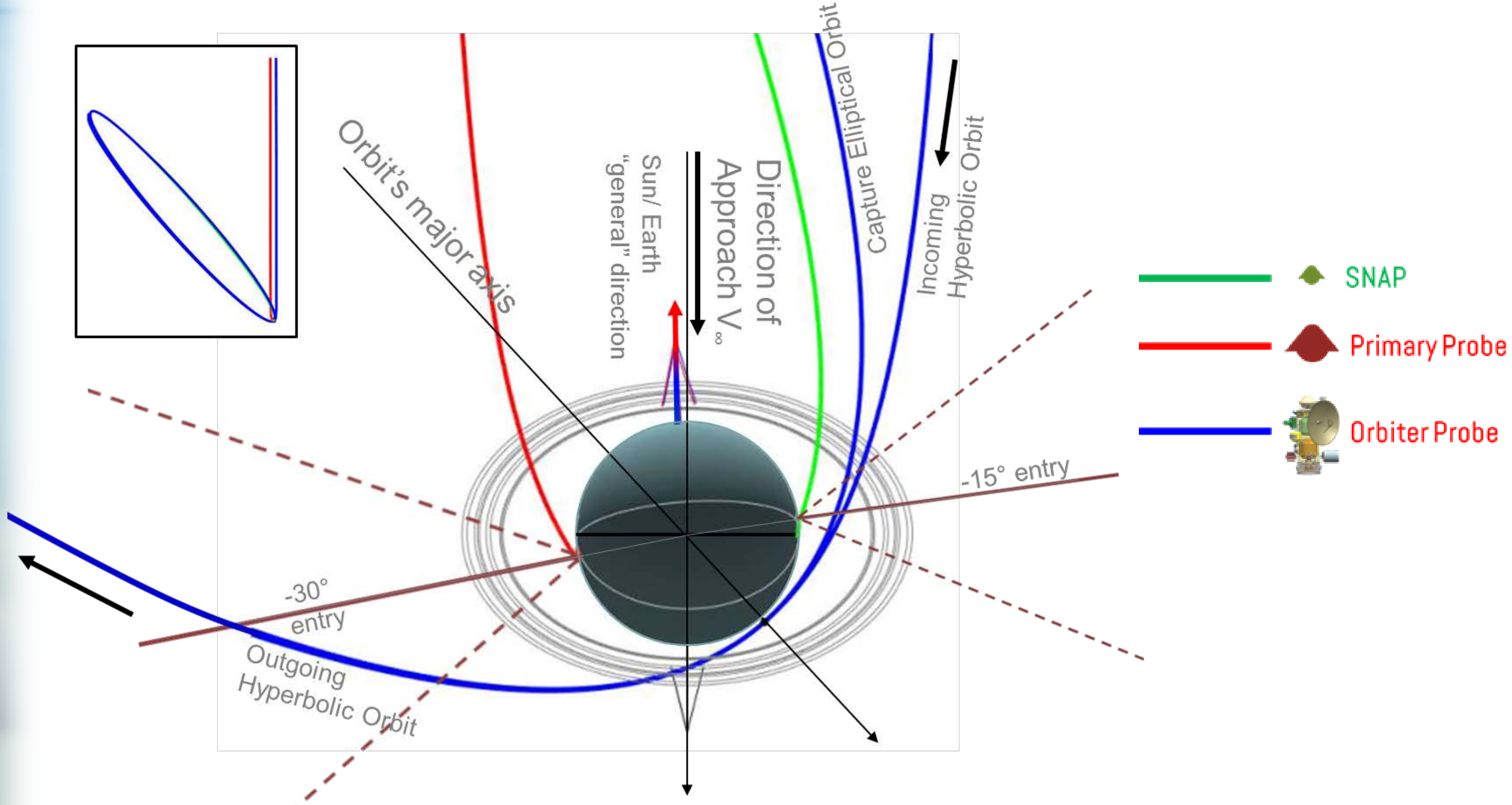
- Trajectory gives access to a wide range of latitudes and spatial distribution for the entry probes
- One probe can enter the night side and the other on the day side (After 2028 Northern Summer Solstice)




| | |
|---|---|
| Red: | Crosses rings |
| Yellow: | Exceeds 200g during entry |
| Green: | Feasible |

# Dual-Probe Delivery Trajectories

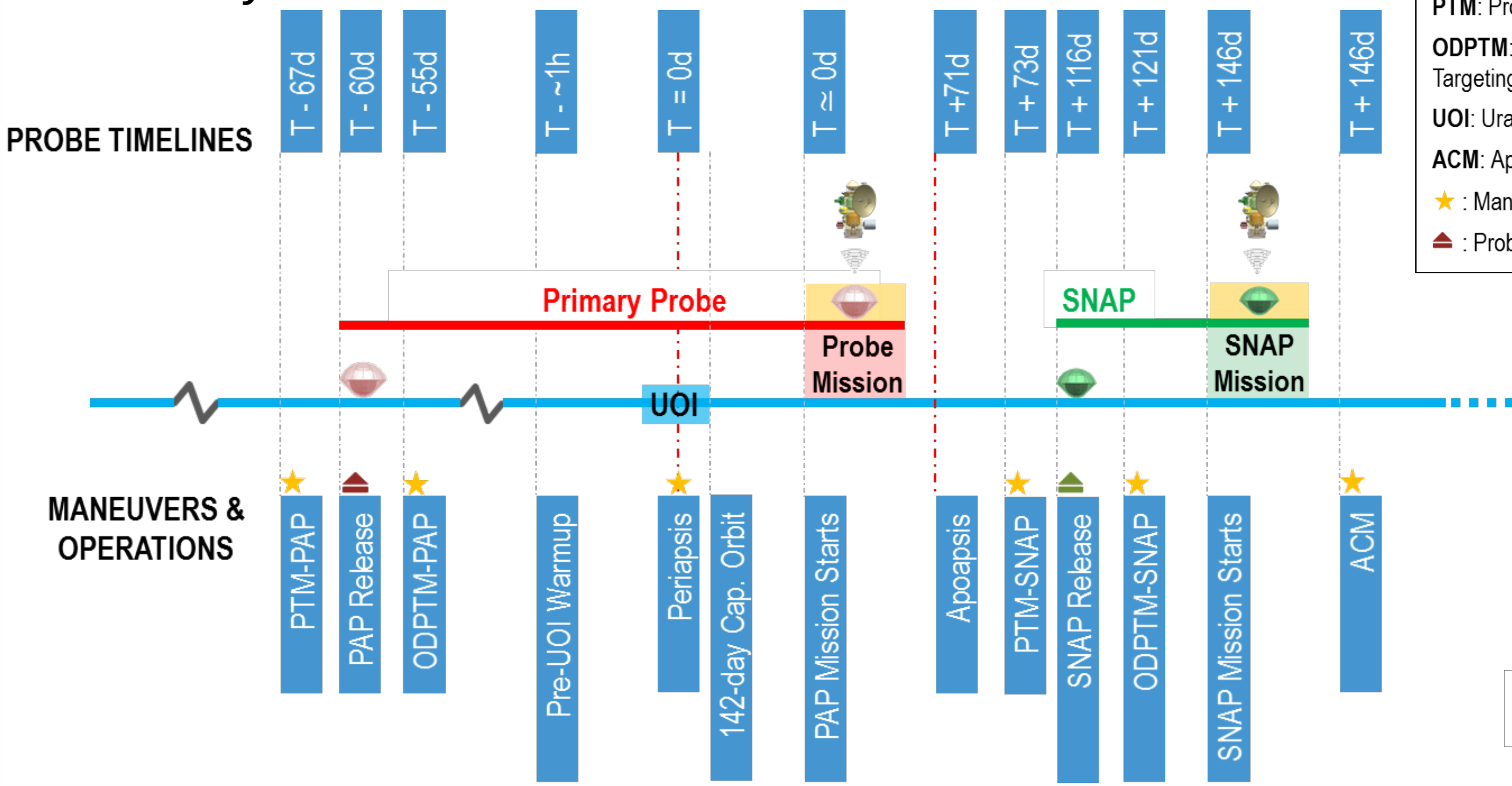
## Trajectory Solution to add SNAP to Ice Giant SDT Architecture #5



# Con-Ops: Dual Probe Delivery

# Overall Mission ConOps

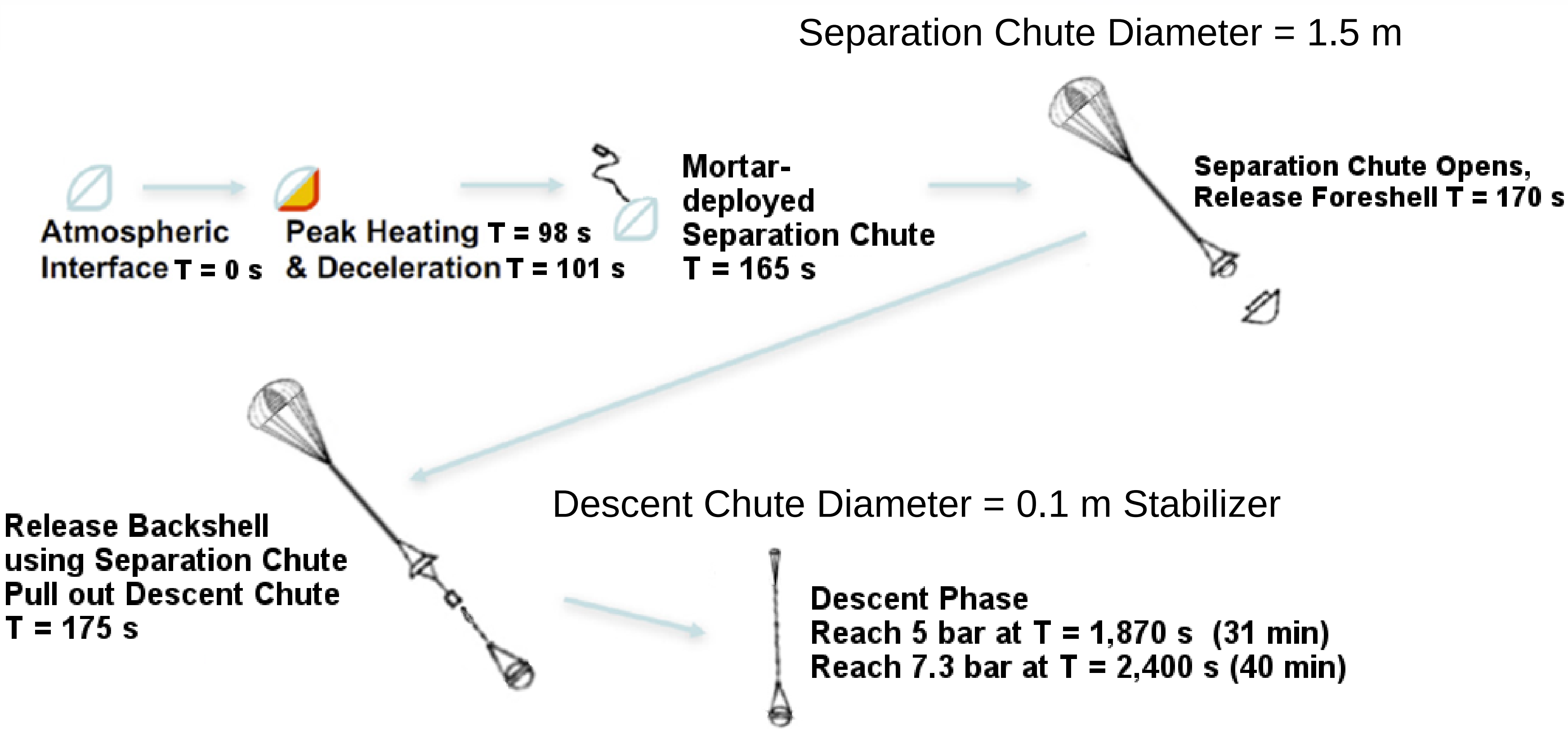
- Overall mission ConOps with critical events
- T = 0 day is UOI



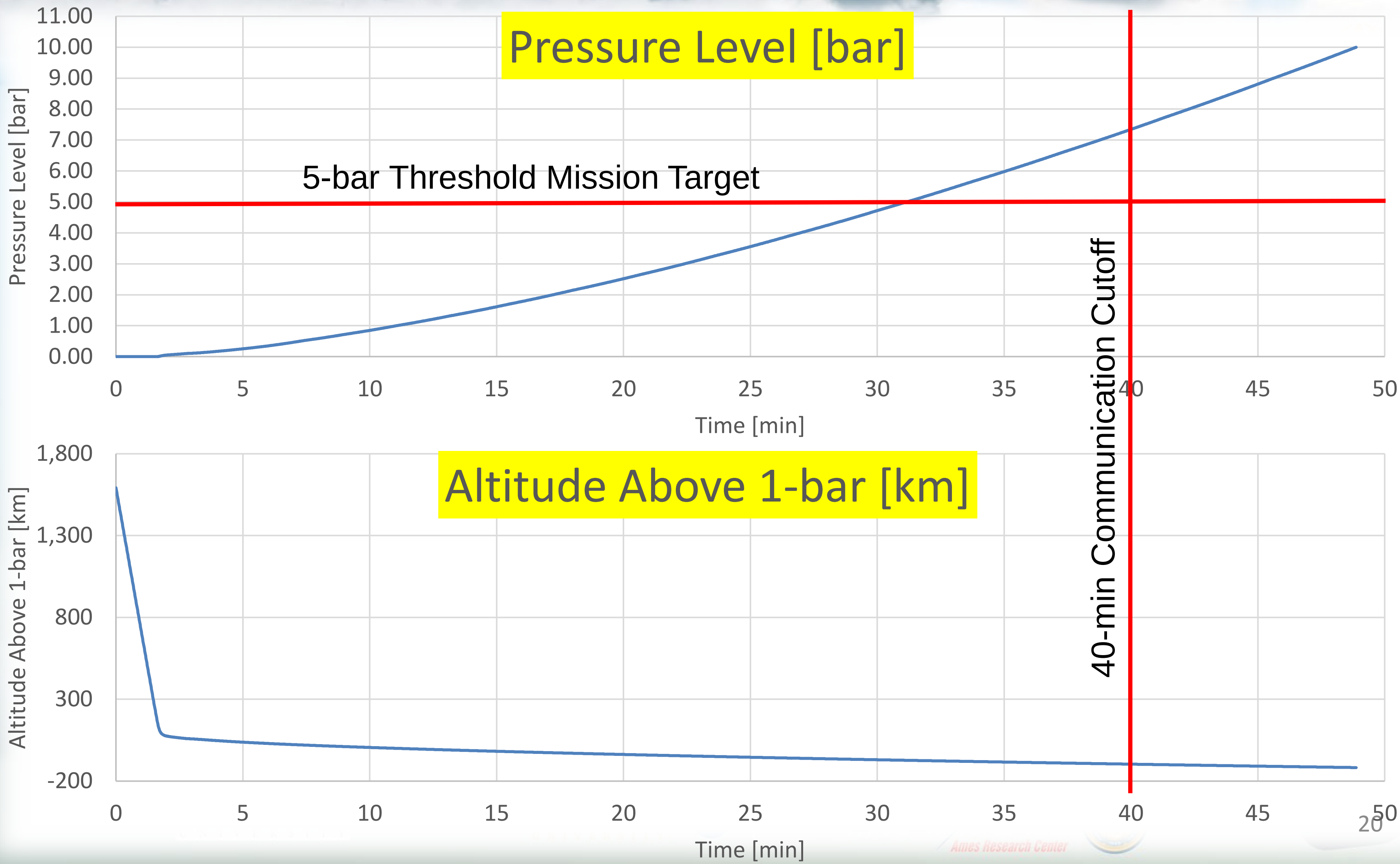

**PAP**: Primary Atmospheric Probe
**SNAP**: Small Next-generation Atmospheric Probe
**PTM**: Probe Targeting Maneuver
**ODPTM**: Orbiter Divert and Periapsis Targeting Maneuver
**UOI**: Uranus Orbit Insertion
**ACM**: Apoapsis Correction Maneuver
★ : Maneuver
⏏ : Probe ejection event

*Not to Scale*

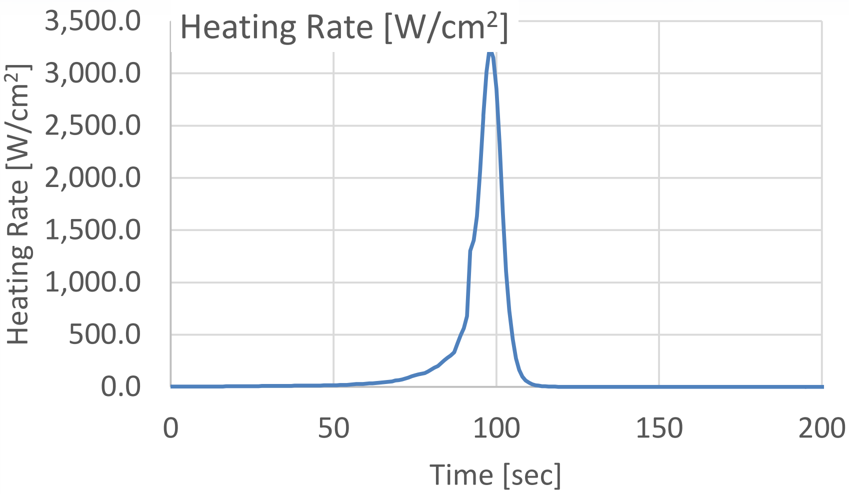
# Atmospheric Entry & Descent

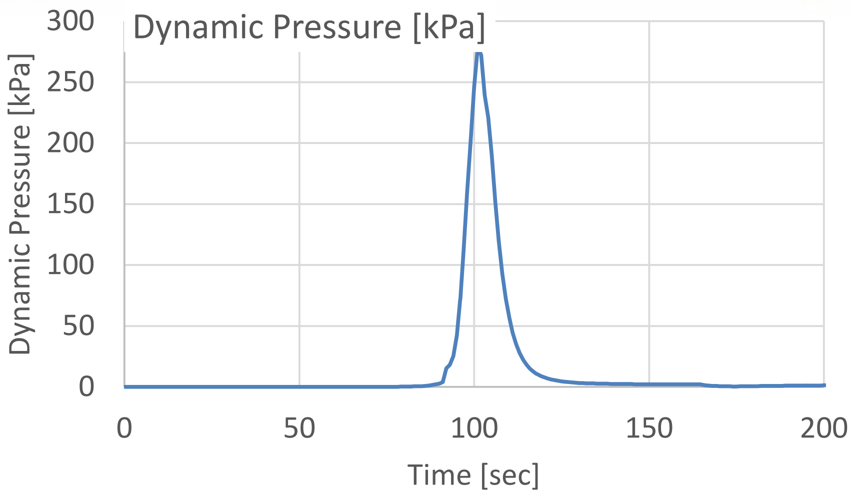


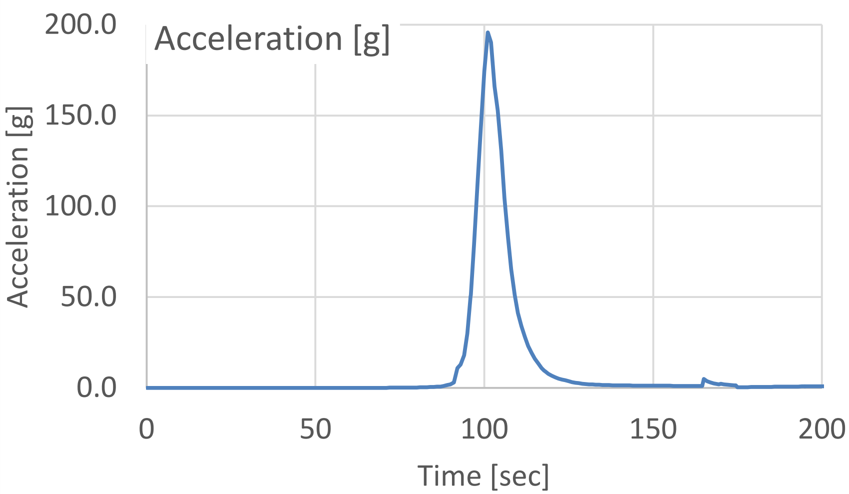
# Atmospheric Entry & Descent

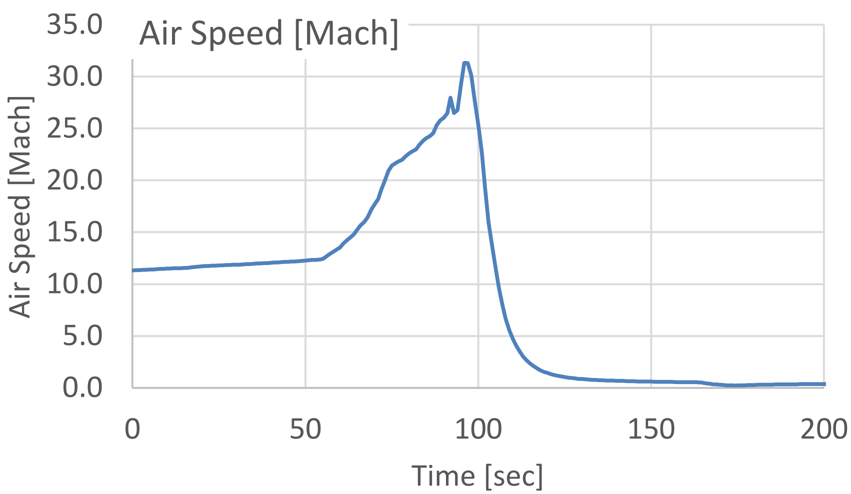


# Entry & Descent Analysis



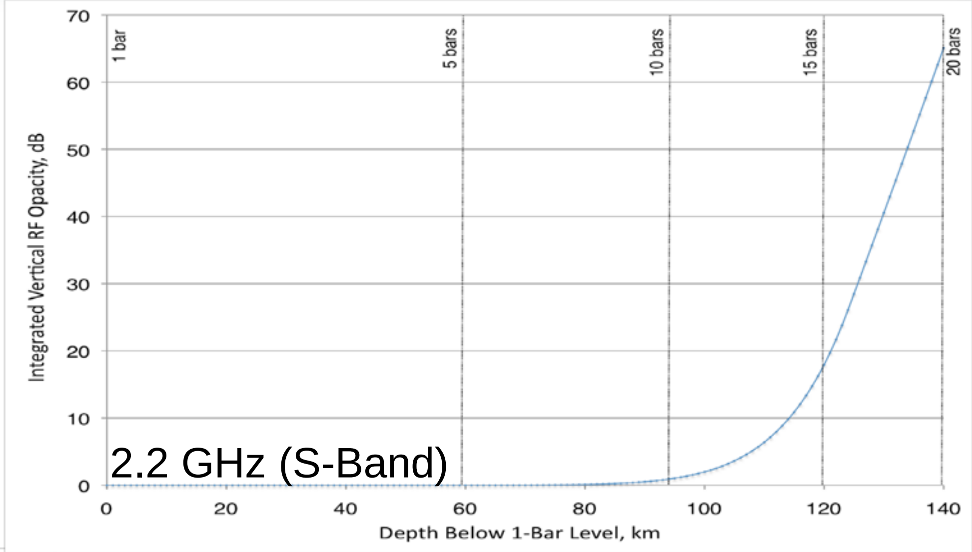



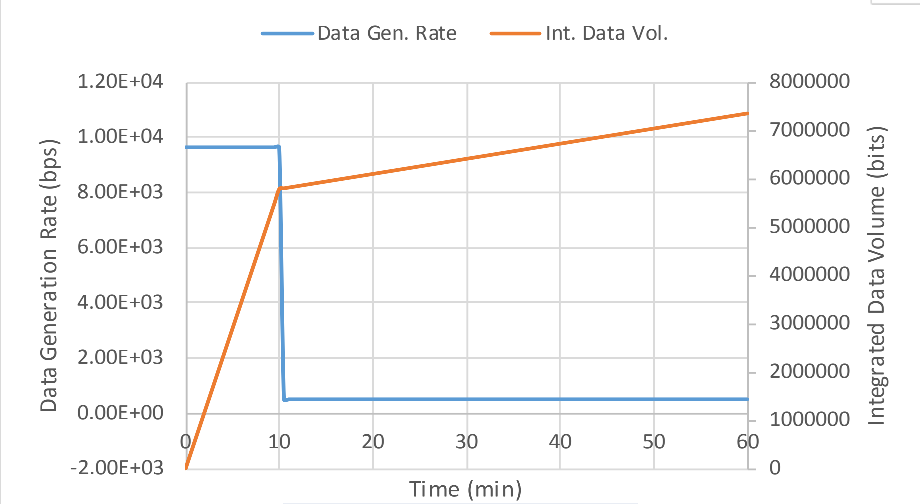



# Link Analysis

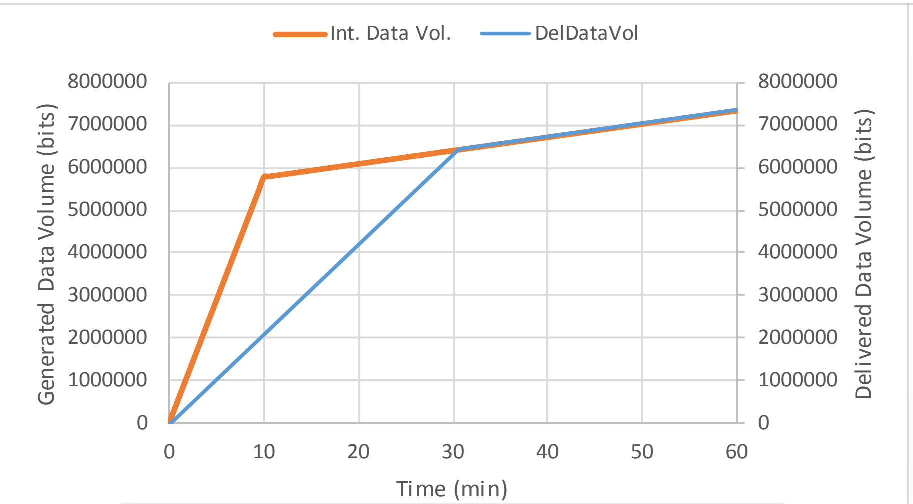
Link Analysis takes account of:

- Atmospheric Radio Absorption ($NH_3 + CH_4$)
- Attenuation through Link Range
- Transmitter/Receiver Antenna Gain
- Link Geometry
- Receiver Noise Model




Data Generation



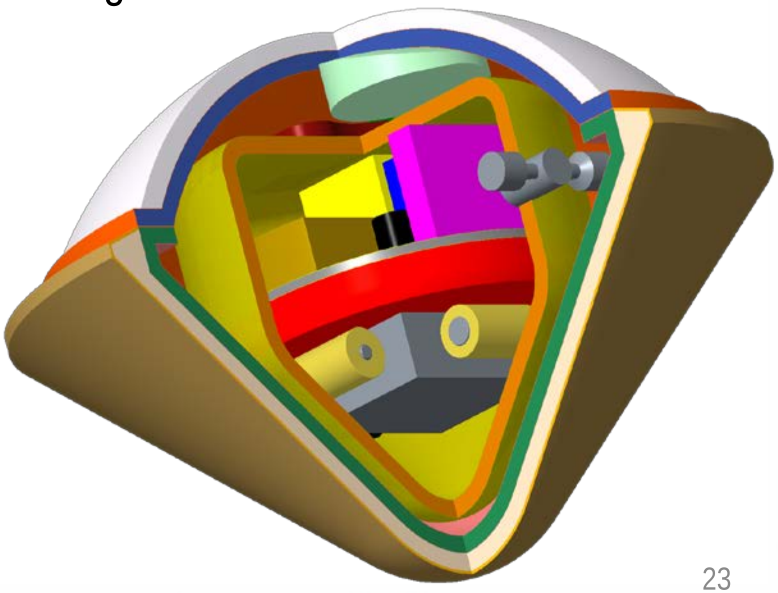

3500 bps Data Rate Worst-case

# Baseline SNAP Design Summary

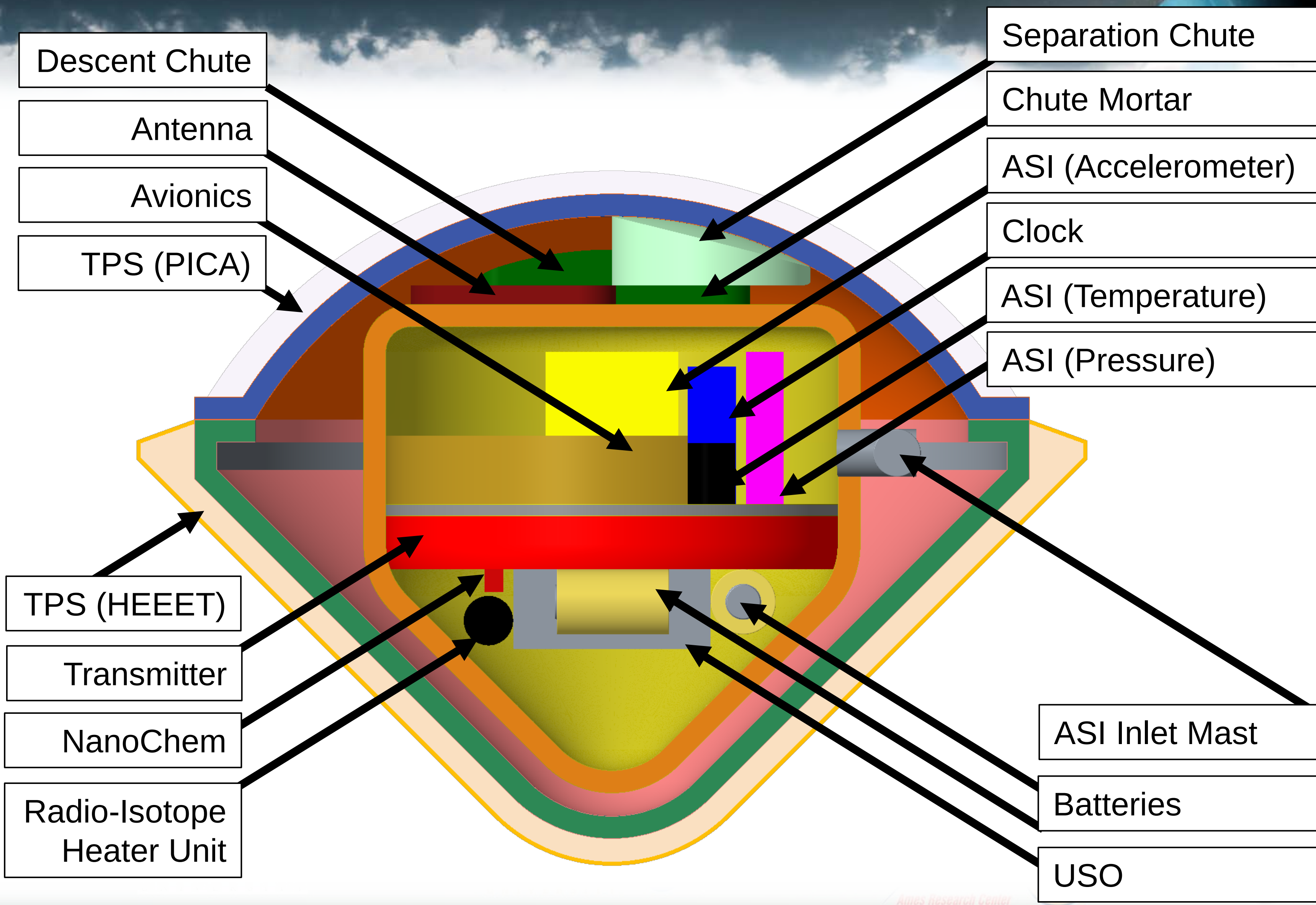
- 0.5 m diameter, 30-kg, 45° sphere-cone heat shield
- SNAP is released ~30 days before entry (from ~142-day orbiter orbit)
- After PP, SNAP enters prograde with EFPA between -40° and -45° and V = 22.4 km/s
- SNAP enters on the day side of Uranus
- Orbiter-SNAP separation 36000–13000 km during mission (~40-mins contact time)
    - Short distance range enables sufficient data rate
- Deceleration and aerothermal conditions all well within design limits
- Fore-body TPS = HEEET; Aft-body TPS = PICA

Entry Conditions of SNAP

| Parameter | Values |
|---|---|
| Peak Heat Rate, W/cm$^2$ | 3250–3750 |
| Stagnation Pressure, bar | 2.75–3.75 |
| Heat Load, J/cm$^2$ | 29227–34515 |
| Peak Inertial Load, Earth G's | 196–270 |



# Baseline Hardware Configuration



# Probe Mass Summary

| Component | Mass [kg] | Subtotal Mass |
|---|---|---|
| Foreshell TPS (HEEET) + Structure | 5.74 | |
| Aftshell TPS (PICA) + Structure + Separation Mechanism | 4.15 | |
| Aeroshell Total | | 14.03 kg |
| Descent Module Structure | 2.1 | |
| Parachutes | 0.4 | |
| Science Instruments | 4 | |
| Engineering Subsystems | 4.2 | |
| Descent Module Total | | 9.85 kg |
| **Atmospheric Entry Mass Total** | | **23.88 kg** |
| **Mass Margin (25%)** | | **6.12 kg** |
| **Total Probe Mass** | | **30 kg** |

# Probe Power Summary

| Sub-system/ Instruments | Power |
|---|---|
| *Ultra-Stable Oscillator* | 3.2 W |
| *ASI* | 5.7 W |
| *Nano-Chem Sensor* | 0.1 W |
| Avionics | 4 W |
| Radio Transmitter | 50 W |
| Accelerometers | 0.1 W |
| Total | 63.1 W |

In left, we assume use of x3 RHUs.

Battery-powered heaters are also possible.

After probe release until atmo. entry
→ SNAP needs 3W of heating.
For 30-day "coast"…
Li-Ion (current, 145 Wh/kg) = 21 kg
Li-Ion (future, 400 Wh/kg) = 7.5 kg
Li/CFx (639 Wh/kg) = 4.7kg

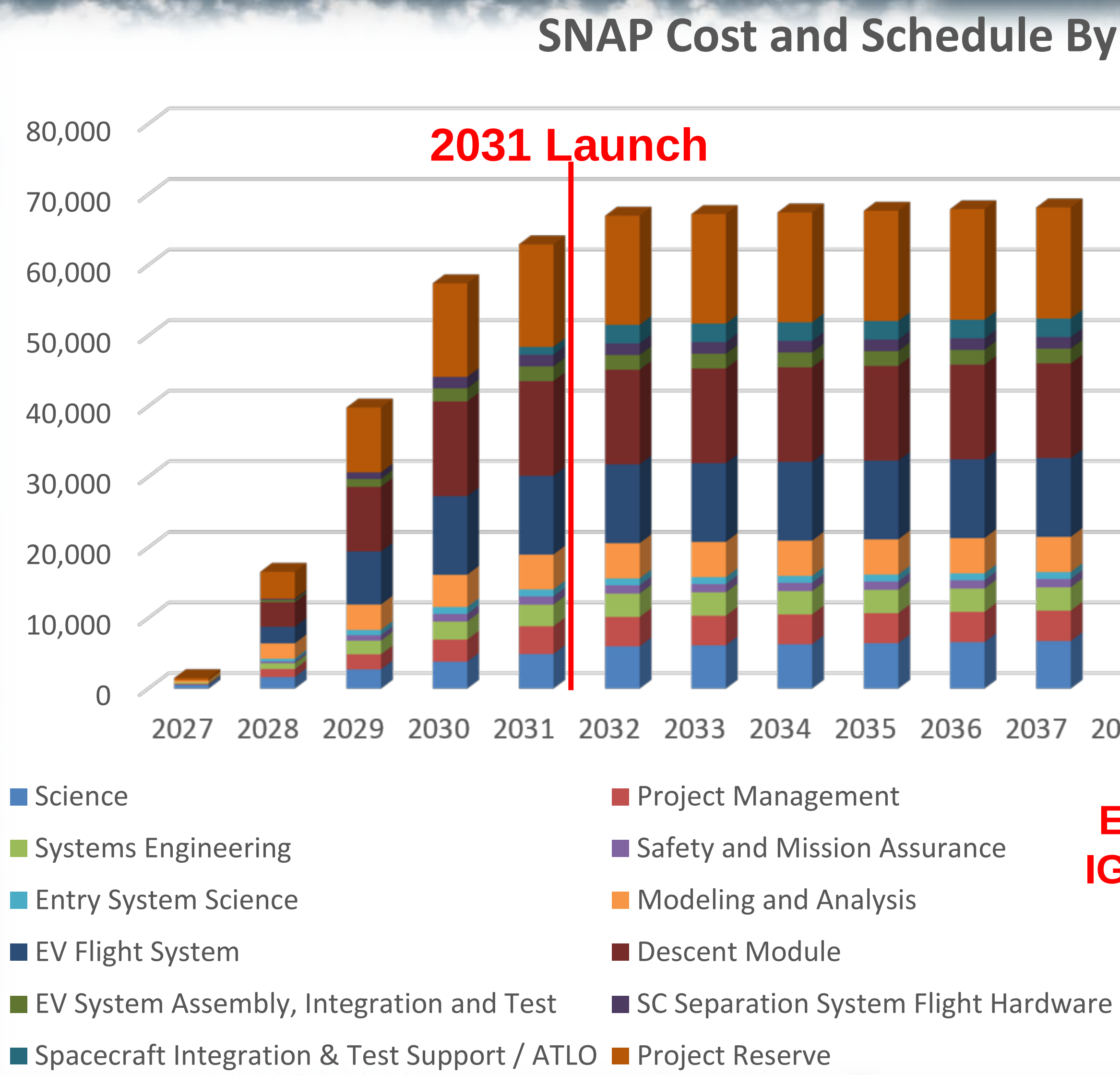
| Phase | Energy Requirement, Wh | Battery Mass, kg | Number of Batteries |
|---|---|---|---|
| SNAP Mission | 164 | 0.257 | 3 |

# Mass Impact on Carrier Mission by Addition of SNAP

- SNAP margined mass = 30 kg.
- Requires additional mass to baseline Uranus mission:
  - Probe Support Systems on the Orbiter
  - Propellant on the Orbiter

| Systems/ Subsystem | Mass, kg | Margined Mass, kg | Margin |
|---|---|---|---|
| Probe Support Systems Total | 4 | 5.3 | 30% |
| Spin ejection device | 3 | 4 | |
| Harness/ umbilicals | 1 | 1.3 | |
| SNAP Mass | 23.88 | 30 | 25% |
| Orbiter SNAP Support Propellant | 30 | 36 | 30% |
| Total Mass Addition to Carrier Mission | 58 | 72.3 | |

# Cost Analysis




**Est. SNAP Cost = 74.8M (FY18$)**
**IGSDT Arch. #5 Cost = 2B (FY15)**

**$75M = 4% Δcost to enable a multi-probe mission**

# Technology Needs

- Instrument/Sensor Technology

  NanoChem is TRL = 4 today (Under Dev. at Ames)
- Thermal Protection System:

  HEEET is needed for low density (Under Dev. at Ames)
- Power - Batteries:

  Low-temp., High Specific Energy Batteries alleviate need for RHUs
- Electronics:

  Low-survival temp will reduces heater power needs

# Study Components

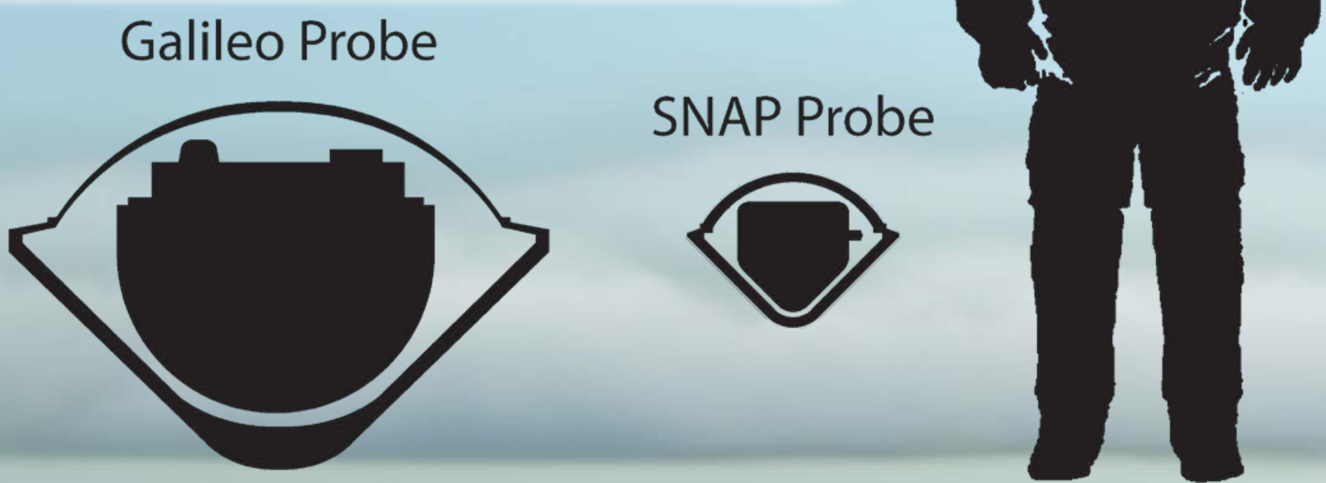
## Add SNAP as a <u>Second Probe</u> to a Future Uranus *Orbiter with Probe mission*

- Science Objectives*
- Top-Level Design Assumption (Pick Baseline Mission)*
- Interplanetary Trajectories*
- Dual-Probe delivery options*
- Atmospheric Characterization*
- Atmospheric Entry and Descent Analysis*
- Con-Ops*
- Link Analysis*
- Instrument Technologies*
- Mechanical Design*
- Thermal Analysis
- Power*
- CDH + Electronics
- Risk
- Cost*

*** Items Included in this Presentation**

# SNAP Design Summary

**Dual-Probe Trajectory Solutions Found**
**SNAP Mass: 30 kg (Instrument Mass = 4 kg)**
**Total Data Return = 7.3 Mbit**
**Total Mass Addition to Carrier Mission: 72.3 kg**
**Total Estimated Cost: 74.8M (FY18$)**
**Enabling Technologies: NanoChem & HEEET**
**Enhancing Technologies: Better Batteries**
**SNAP: Enable Future Multi-Probe Missions**

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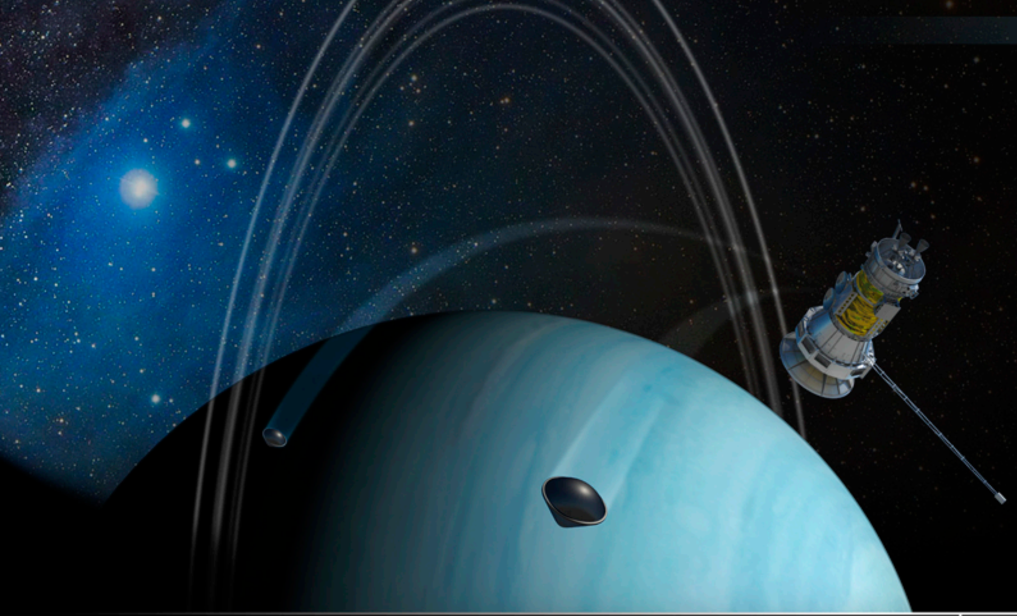
# SNAP

Small Next-generation Atmospheric Probe

Planetary Science deep Space SmallSat Studies



## Team Members/Institutions


| | |
|---|---|
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| Robert A. Dillman | NASA Langley Research Center |
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| Amy A. Simon | NASA Goddard Space Flight Center |
| Michael H. Wong | University of California, Berkeley |
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Supported by: NASA Langley Research Center Engineering Design Studio

## Science Objectives:

*Tier-1 Objectives*: Determine spatial differences of the following atmospheric properties from the Main Probe entry site:

1. Vertical distribution of cloud-forming molecules
2. Thermal stratification
3. Wind speed as a function of depth

*Tier-2 Objectives*: Augment Main Probe Science Objectives:

4. Measure abundances of the noble gases (He, Ne, Ar)
5. Measure isotopic ratios of H, C, N, and S

## Mission Overview:

*Baseline Mission Configuration:*

Add SNAP to Uranus Orbiter and Probe Mission
Orbiter delivers Main Probe and SNAP to Uranus

*Baseline Spacecraft Configuration:*

Mass: 30 kg
Probe Diameter: 50 cm
Probe Power: Primary Batteries
Heatshield Material: HEEET

*Notional Payload:*

NanoChem: Detect cloud-forming molecules
Atmospheric Structure Instrument: Measure thermal profile
Ultrastable Oscillator: Atmospheric Dynamics

# BACK UP SLIDES

# Mission Design Center

**Engineering Design Studio (EDS), NASA Langley Research Center**

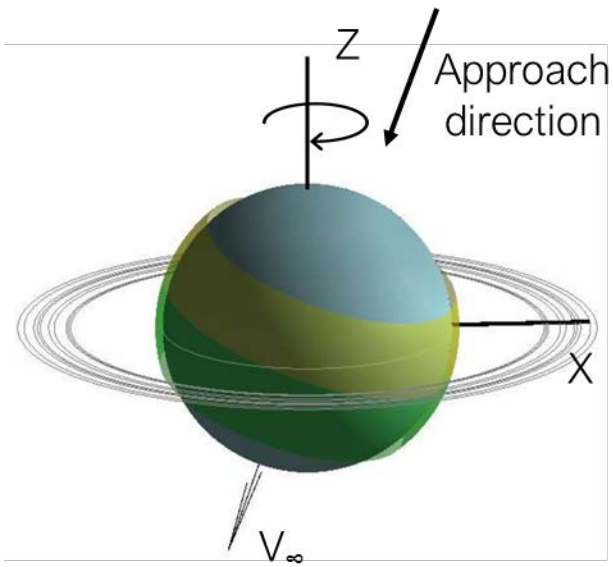
- Support PI-led Mission Design & Proposal Development
- Concurrent Engineering Design Capability in Dedicated Room
- Access Strengths of NASA Langley Research Center
  - Atmos. Entry, Descent & Landing
  - Remote-Sensing Measurements
  - Atmospheric In-Situ Measurements
  - Aeronautics
- Proposal Development Support
  - Blue/Red Team Reviews
  - Strength, Weakness, Opportunities, Threats (SWOT) Analysis
  - Mission Cost Analysis
  - Proposal/Project Budget Development
  - Graphics Design

*NASA LaRC Engineering Design Studio*

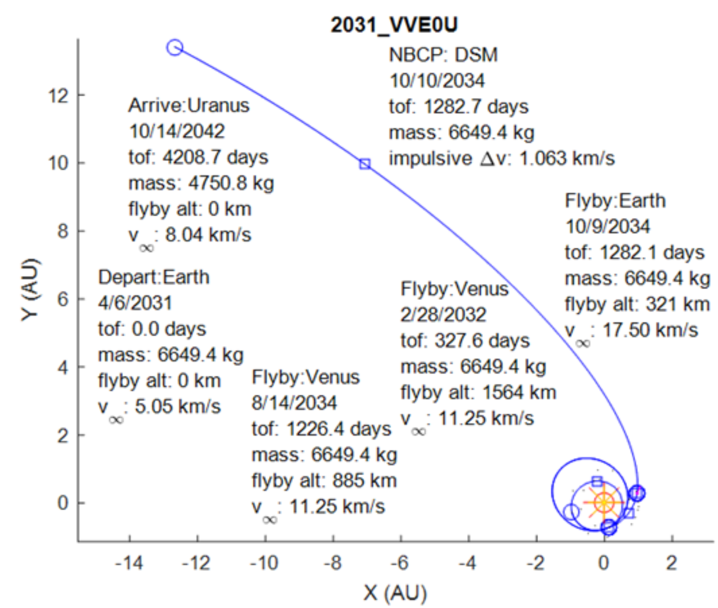
# Alternate Interplanetary Trajectories

- Dual probe delivery possible for multiple trajectory options
- SNAP mission concept is applicable to many interplanetary trajectories

| Launch date | Launch Vehicle | Flyby Sequence | Launch $C_3$ ($km^2/s^2$) | IP TOF (yrs) | DSM (m/s) | Arrival Mass (kg) | UOI $\Delta$V (m/s) | Arrival $V_\infty$ (km/s) | Arrival Decl., deg | Mass in Orbit (kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| 4/6/2031 | Delta IV Heavy | Earth-VVE-Uranus | 25.5 | 11.5 | 1063 | 4751 | 1580 | 8.04 | 71° | 1885 |

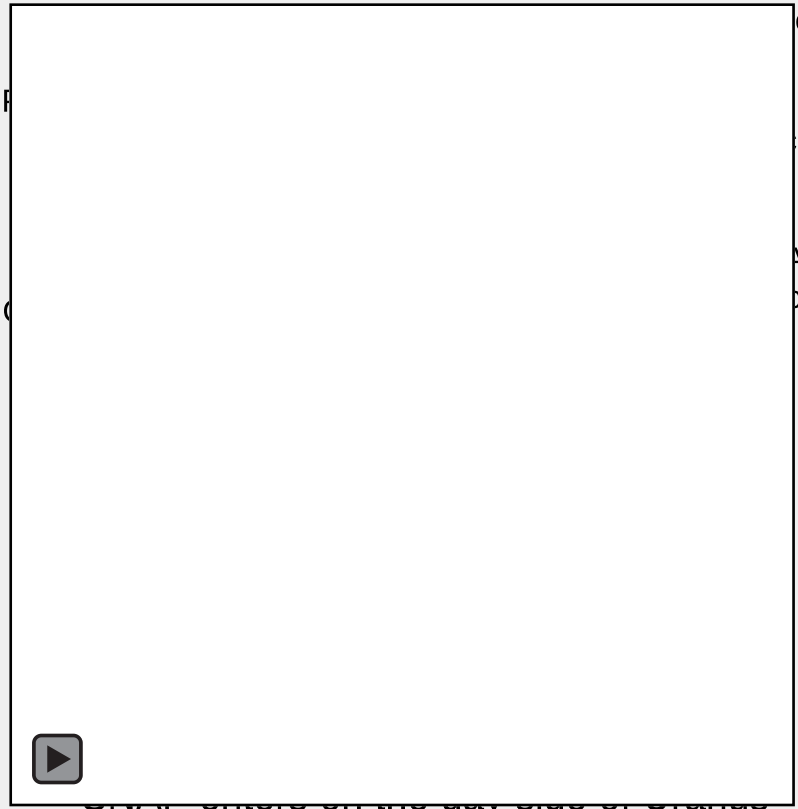


Accessibility of Entry Locations

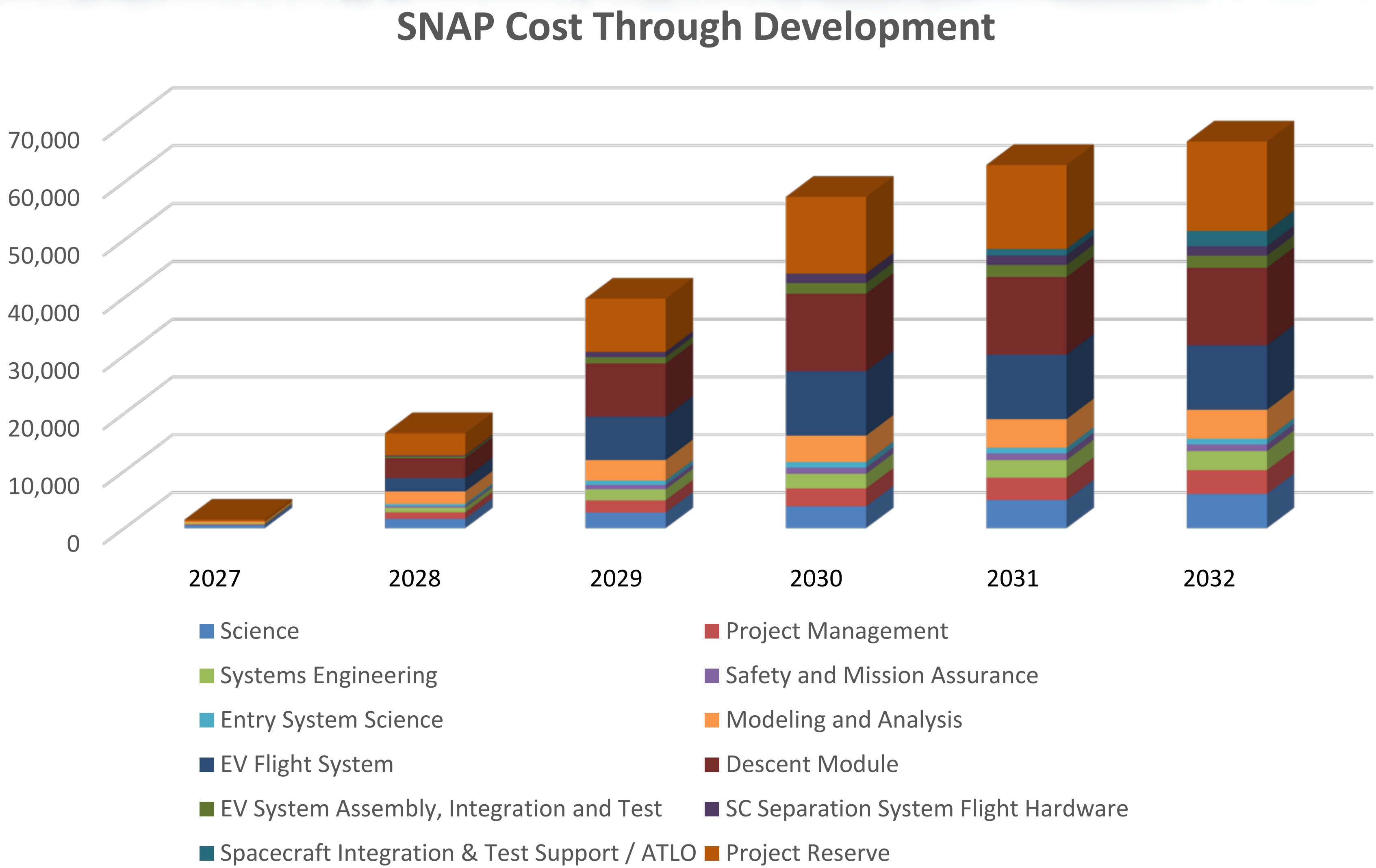


# Concept-of-Operations: Dual-Probe Delivery

- Shows hyperbolic approach trajectories of orbiter + SNAP (blue, right) and primary probe (red)
- Shows elliptical captured orbit of orbiter (blue, left) and elliptical trajectory of SNAP (green)
- 30° Margined HWHM beam cone is centered around the negative of planet-relative velocity vector of the probes as they undergo entry and descent
- Orange cone: Ongoing probe entry mission but no orbiter-probe contact
- Green cone: When orbiter is in contact with the probe



# Cost Analysis



# Baseline Hardware Configuration