

SNAP

Small Next-generation Atmospheric Probe

Challenges of Measuring Atmospheric Composition of Giant Planets

Sensors and Instrumentation Webinar Series
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Hampton University

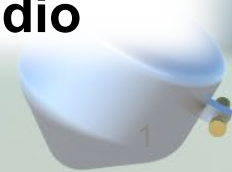
Study Team (All)

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(31 Team Members total)

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**Mission Designed at
NASA Langley Research Center Engineering Design Studio**



Selected Proposals

Venus

Christophe Sotin, NASA's Jet Propulsion Laboratory, Pasadena, California: Cupid's Arrow

Valeria Cottini, University of Maryland, College Park: CubeSat UV Experiment (CUVE)

Moon

Suzanne Romaine, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts: CubeSat X-ray Telescope (CubeX)

Timothy Stubbs, NASA Goddard Space Flight Center, Greenbelt, Maryland: Bi-sat Observations of the Lunar Atmosphere above Swirls (BOLAS)

Asteroids

Jeffrey Plescia, Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland: Asteroid Probe Experiment (APEX),

Benton Clark, Lockheed Martin Space Systems Company, Littleton, Colorado: CubeSat Asteroid Encounters for Science and Reconnaissance (CAESAR)

Mars

David Minton, Purdue University, West Lafayette, Indiana: Chariot to the Moons of Mars

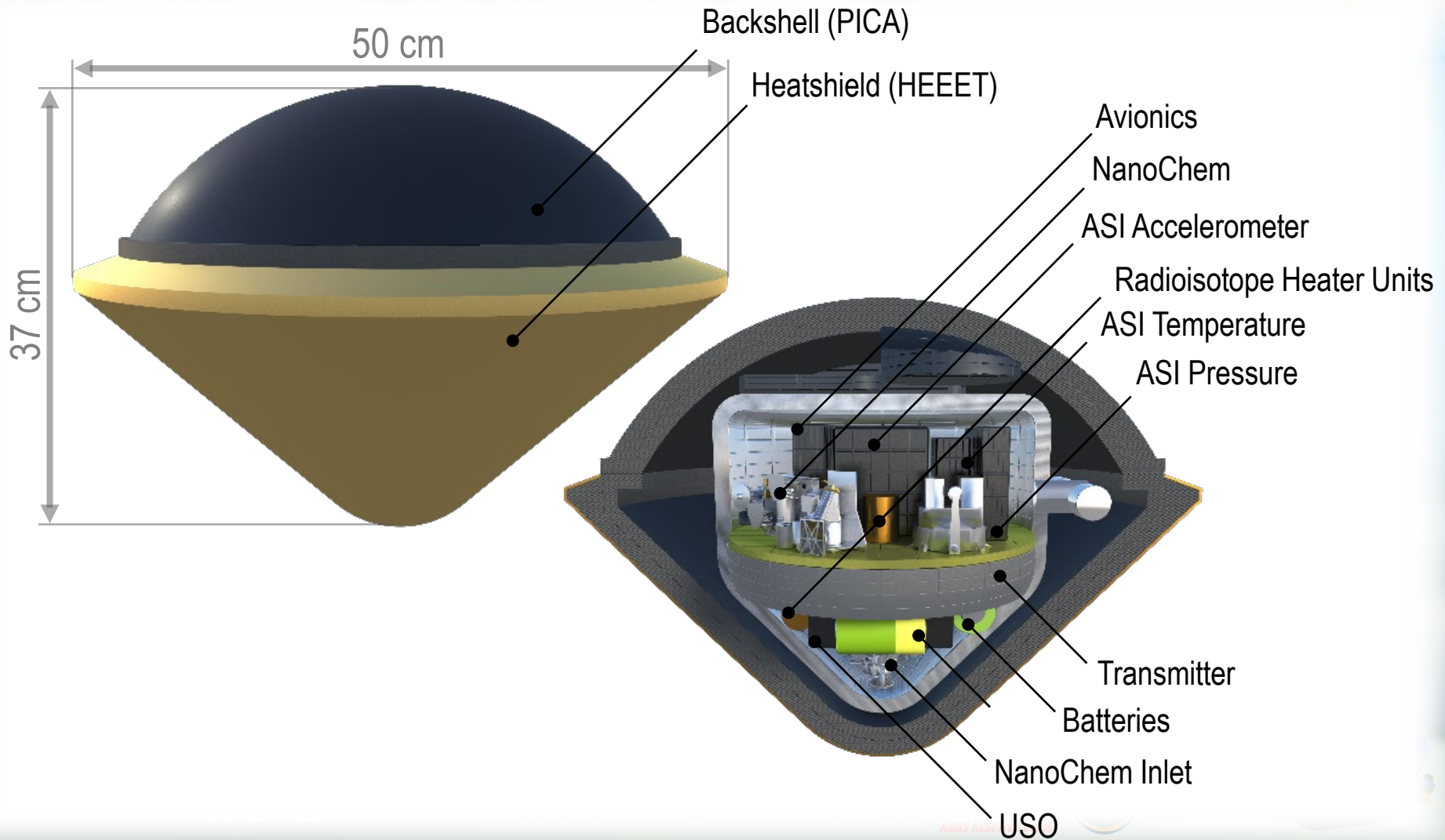
Anthony Colaprete, NASA Ames Research Center, Moffett Field, California: Aeolus

Icy Bodies and Outer Planets

Kunio Sayanagi, Hampton University, Virginia: Small Next-generation Atmospheric Probe (SNAP)

Robert Ebert, Southwest Research Institute, San Antonio, Texas: Jupiter Magnetospheric boundary Explorer (JUMPER)

SNAP Hardware Configuration



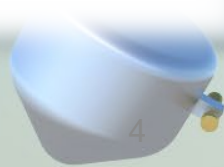
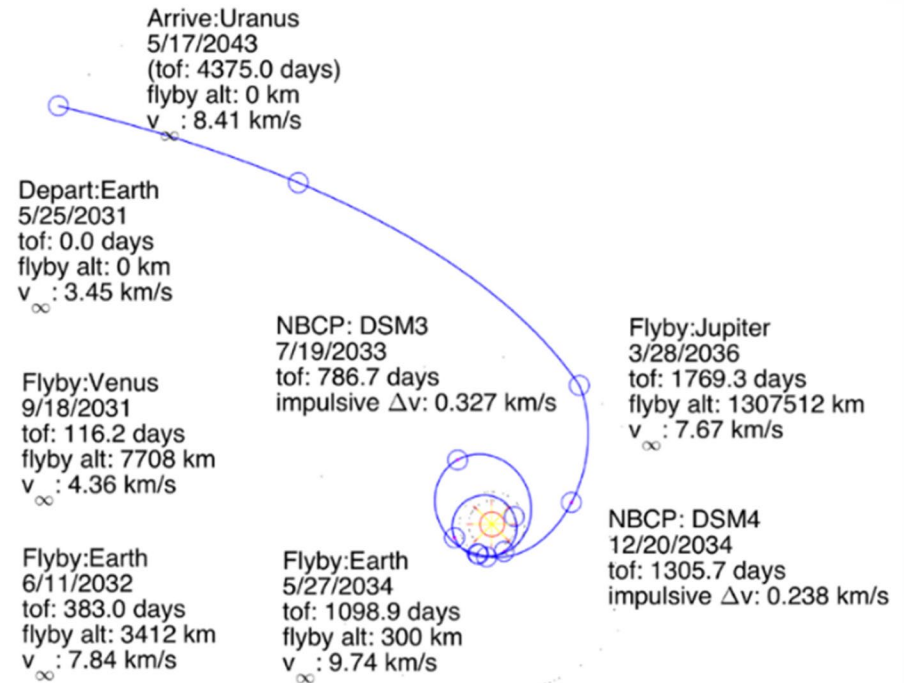
Baseline Carrier Mission

Venus-Earth-Earth-Jupiter-Uranus Trajectory

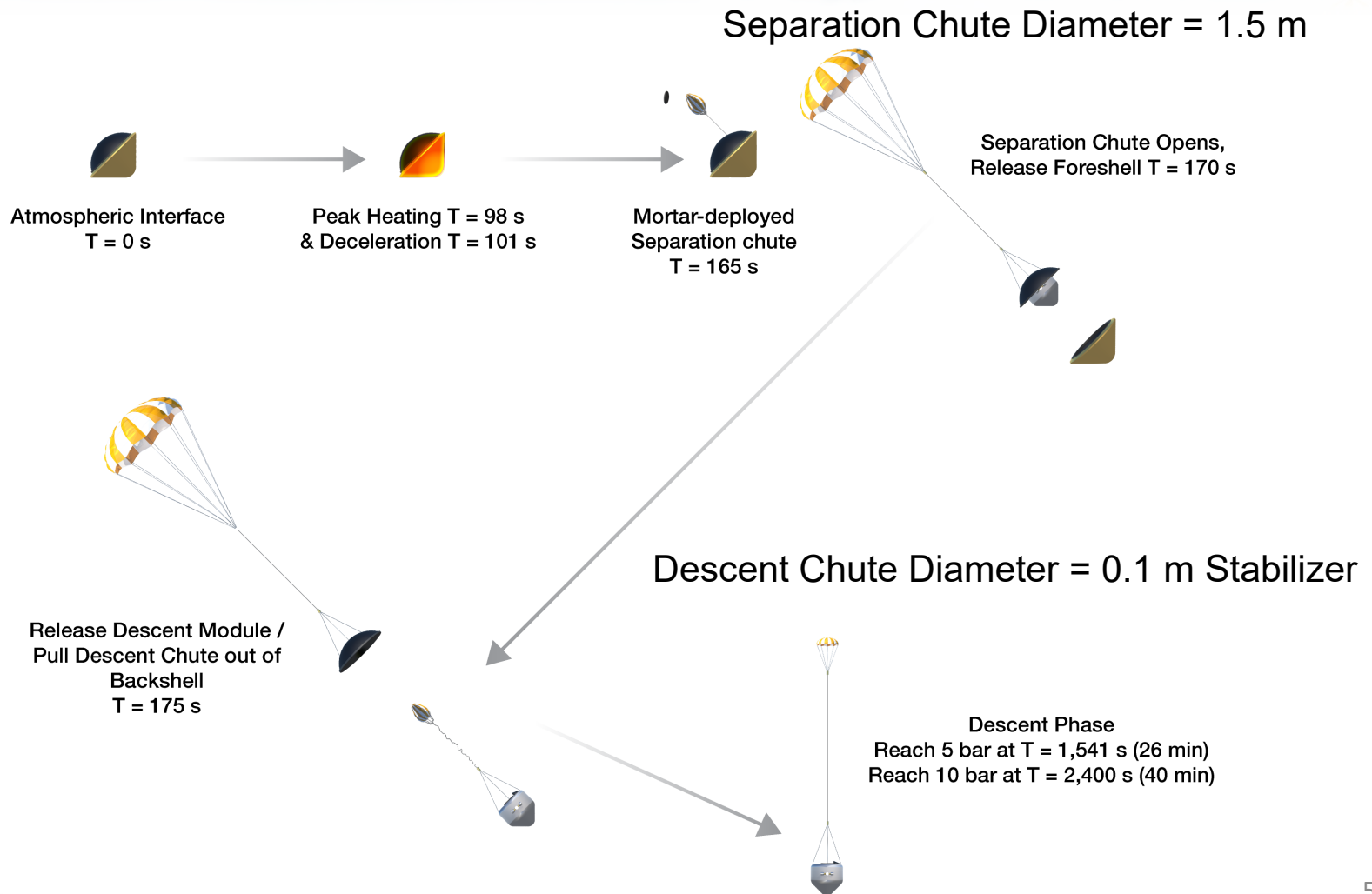
- Launch: 5/25/31, VEEJ gravity-assists + Two DSMs
- Launch Vehicle: Atlas V541, ~4450 kg $C_3 = 11.9 \text{ km}^2/\text{s}^2$
- 12-year cruise to UOI

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



Atmospheric Entry & Descent





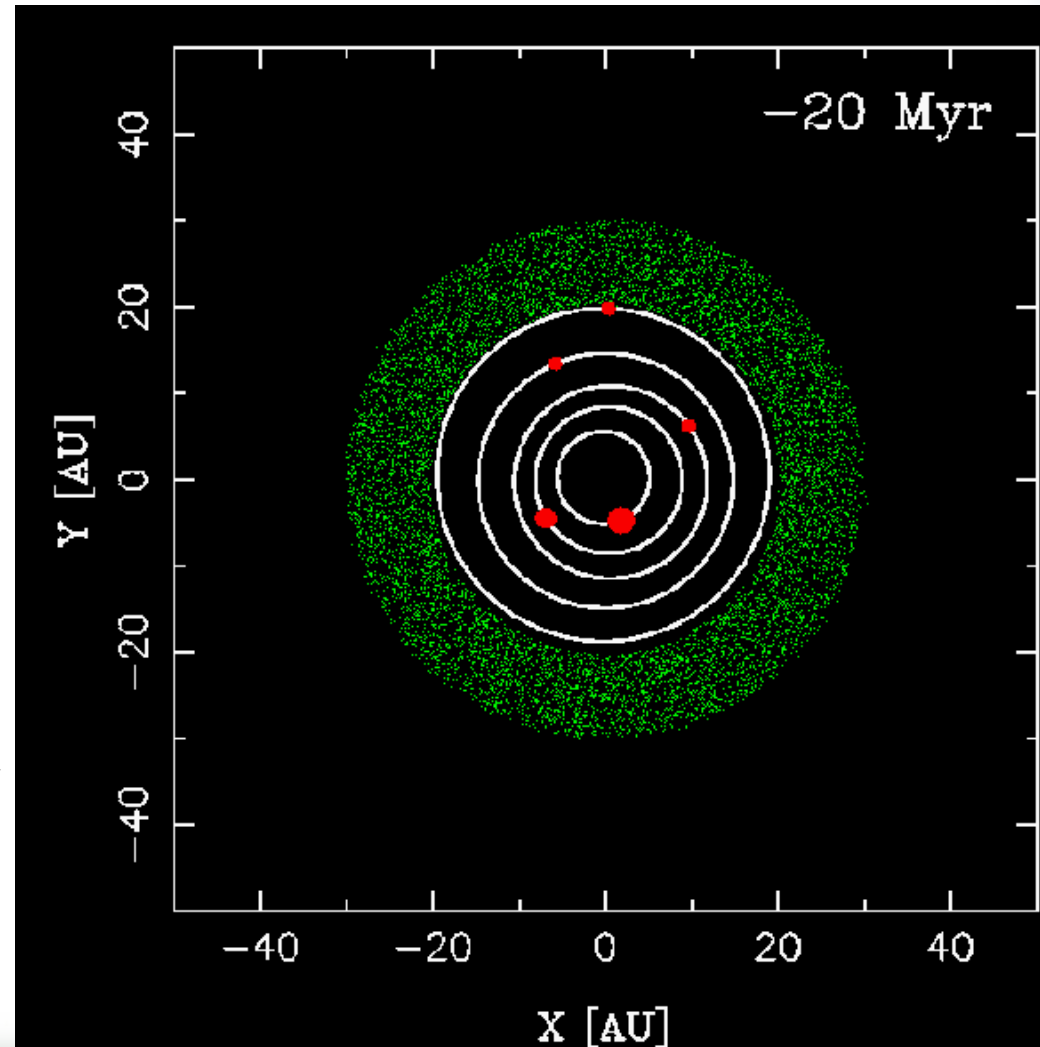
Why Send Probes to Uranus?

Where in the Solar System did Uranus Form?

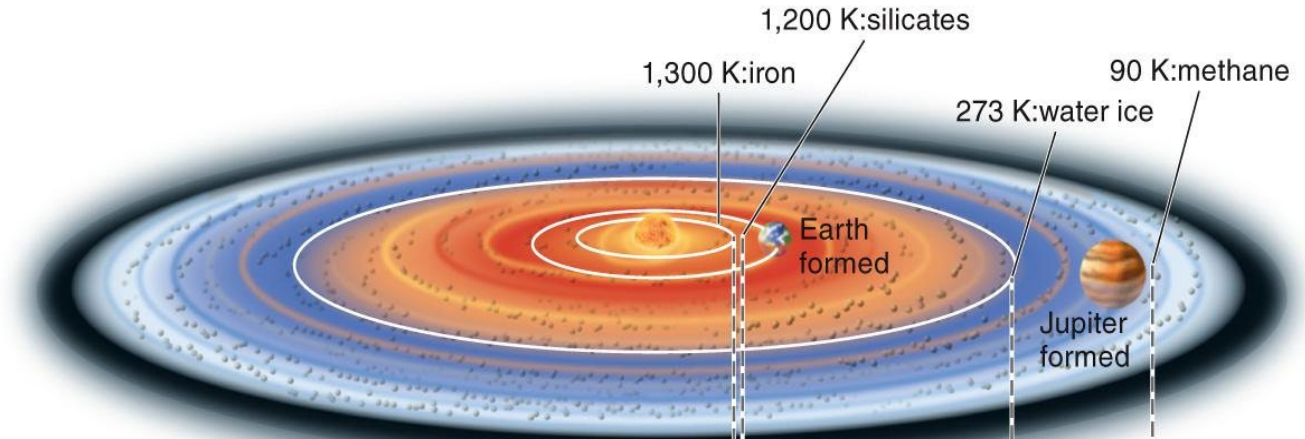
“Nice Model” of Solar
System Evolution

Jupiter and Saturn
pushed out Uranus
and Neptune, and
scattered many icy
left-over materials.

Did Uranus and
Neptune form closer
to the sun than they
are today?

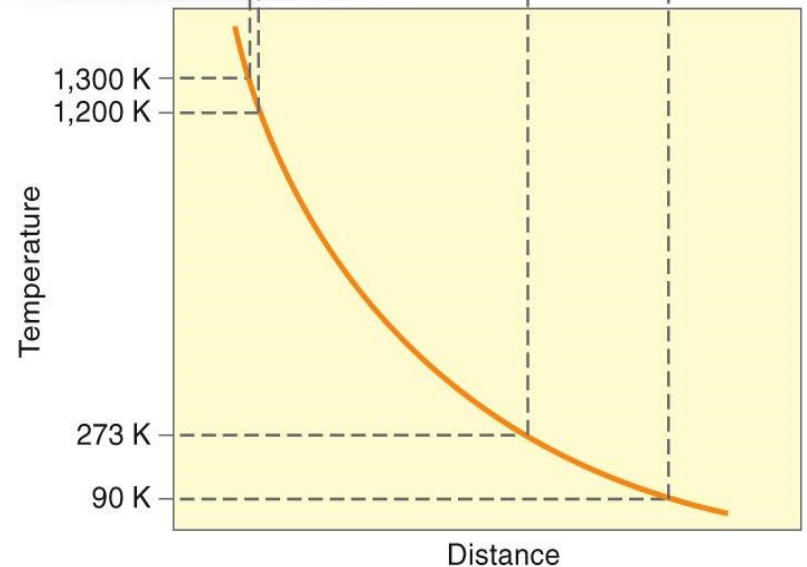


Planetary Formation and Atmospheric Composition

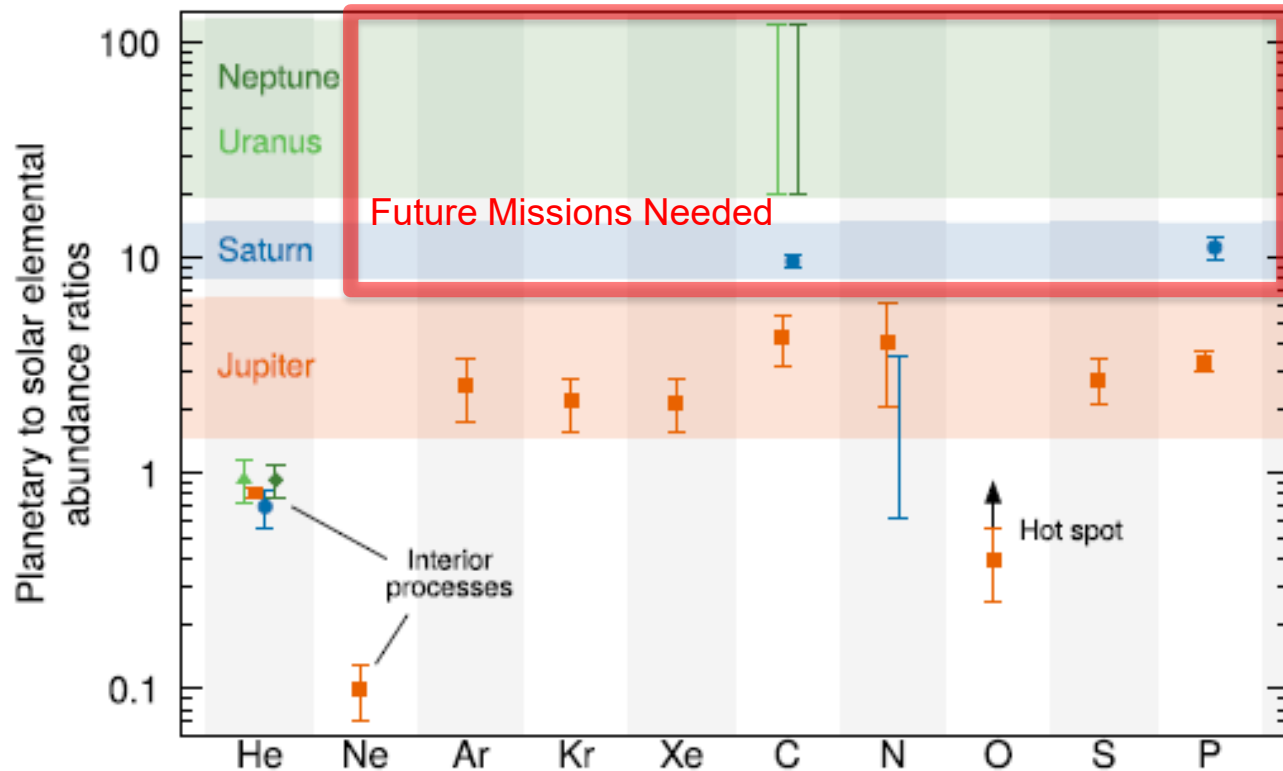


Planet that formed further from the sun collected:

- More volatile molecules
- More lighter elements
 - Isotopic Ratios
 - Noble Gas Abundance



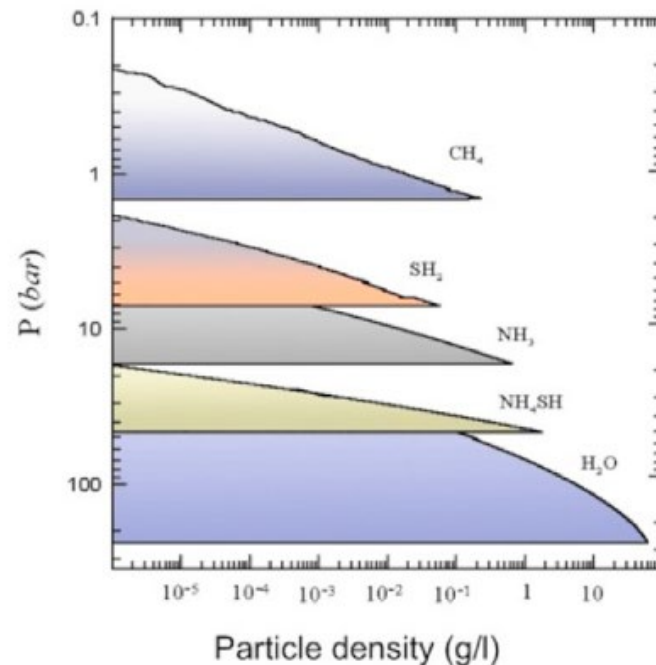
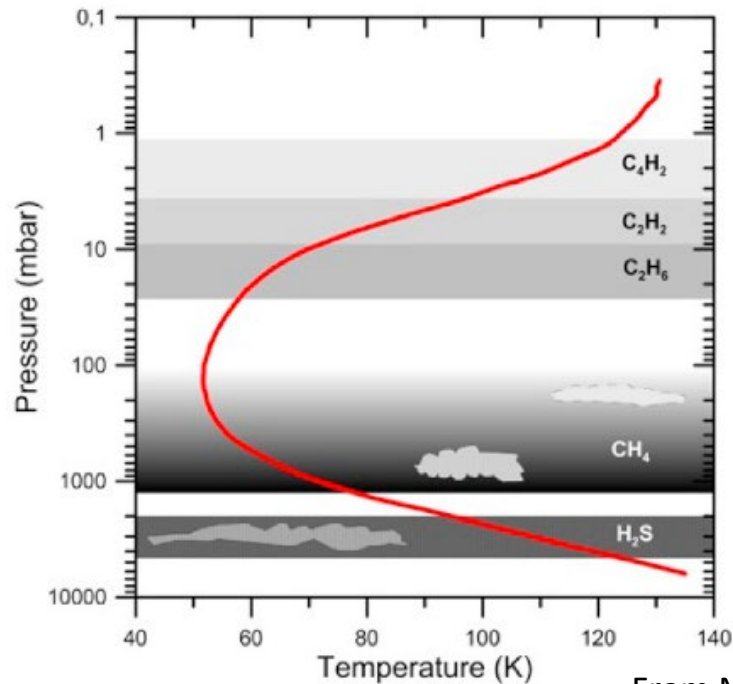
Missing Key: Noble Gas and Isotopic Ratios



From Mousis et al. (2018, *Planetary and Space Science*)

Noble Gas and Isotopic Ratios have not been measured at Saturn, Uranus and Neptune

How do clouds with 5 Condensibles Form Layers and Interact?

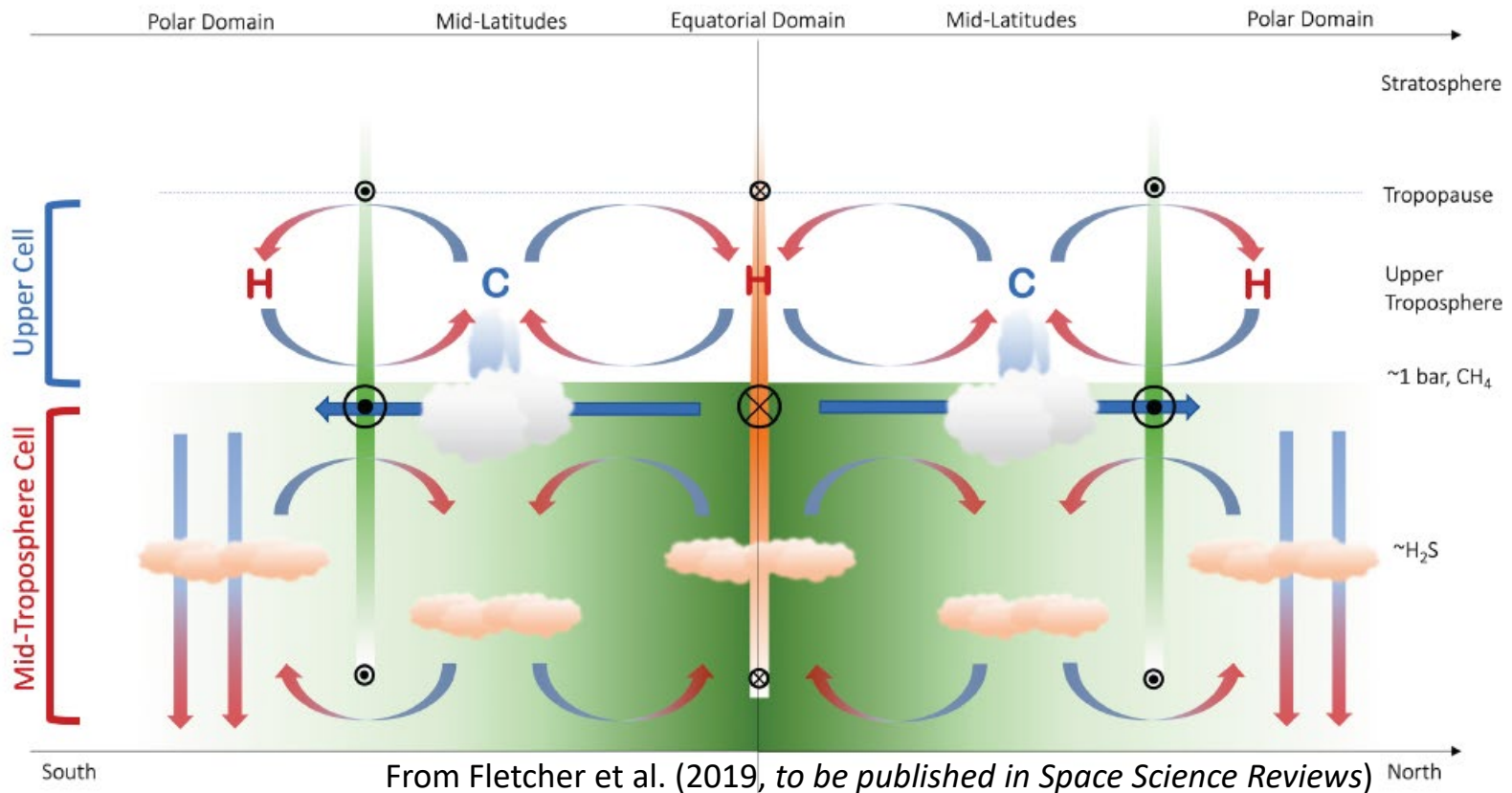


From Mousis et al. (2018, *Planetary and Space Science*)

There are 5 condensable species on Uranus:
 CH_4 , SH_2 , NH_3 , NH_4SH , H_2O

Earth has one (H_2O)!

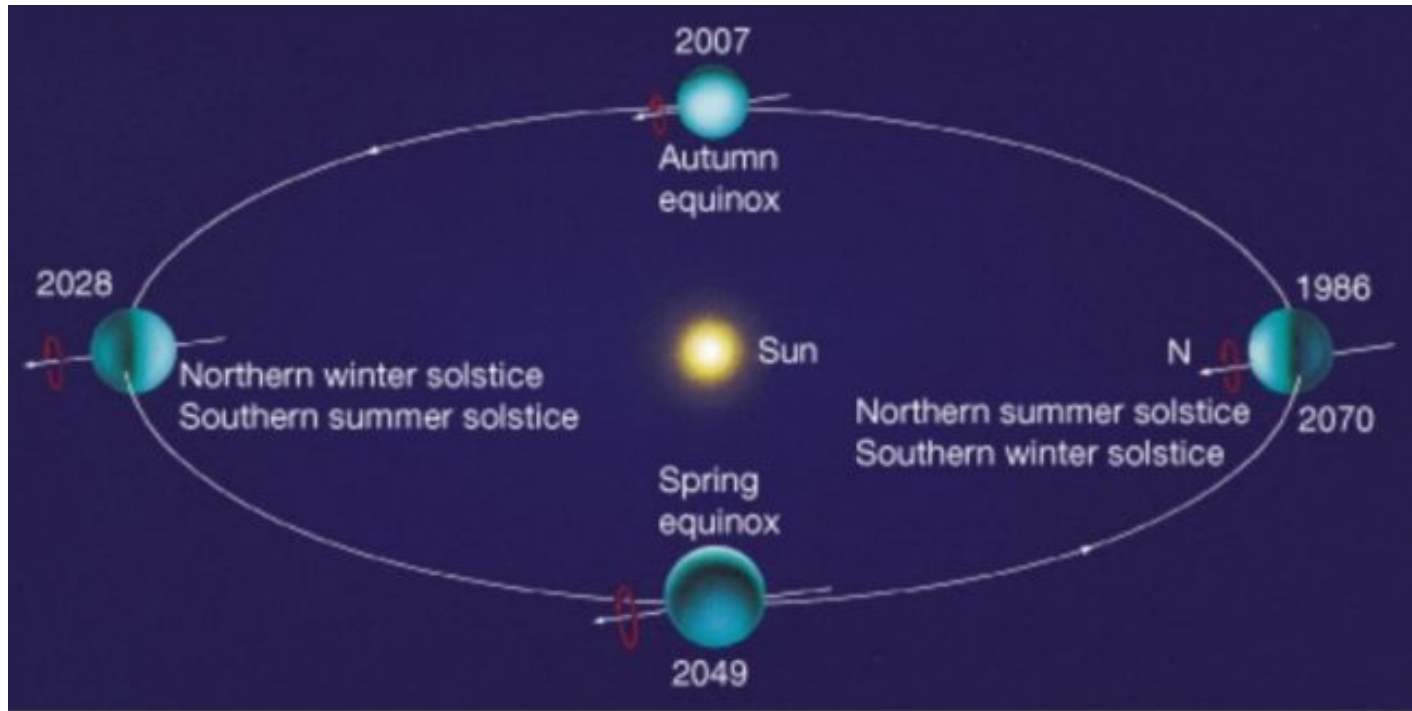
How does the Atmosphere Circulate on Uranus?



Hypothesized stacked “Hadley”-like Circulation

→ How does the circulation evolve with season?

How does seasonal forcing affect Atmospheric Circulation?



Public-domain figure

Review: Probe Scientific Objectives

Atmos. Composition - Formation and Evolution

- Noble Gas
- Isotopic Ratios

Thermal Structure and Energy Balance

- Temperature vs. Pressure
- Radiative Flux

Role of Clouds/Haze/Aerosols

- Composition & Light Scattering Properties of Aerosols
- Vertical Distribution of Aerosols and Vapors

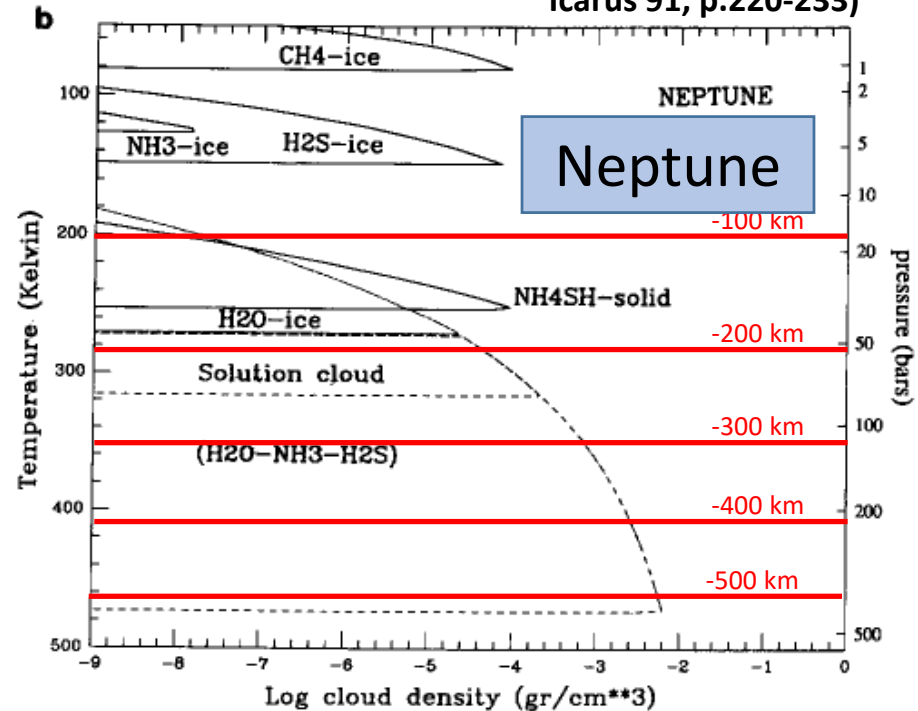
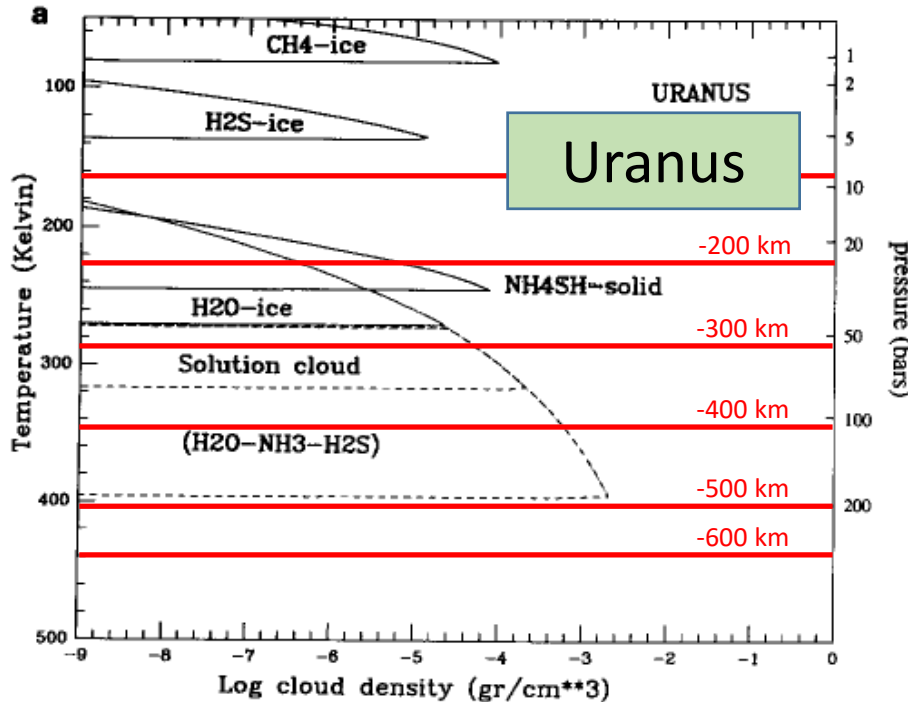
Atmospheric Dynamics

- Zonal Circulation
- Meridional Circulation
- Vertical Mixing of Disequilibrium Species

Design Decision #1: How deep do probe(s) need to reach?

Predicted Altitudes and Densities of clouds in Uranus and Neptune

de Pater et al. (1991
Icarus 91, p.220-233)

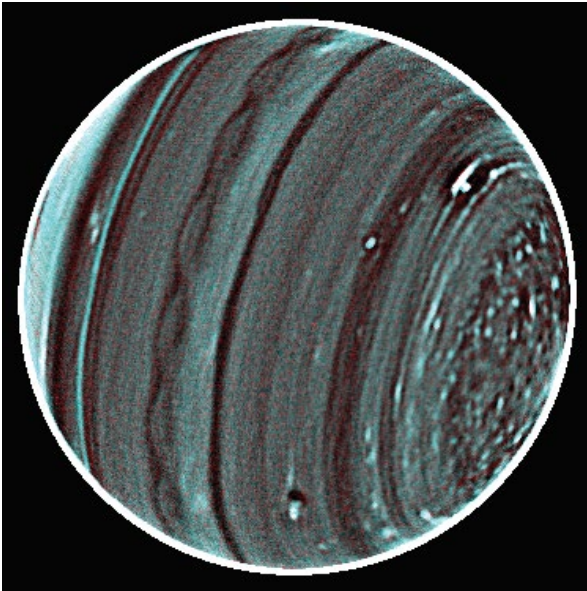


Sampling CH4-ice and H2S-ice clouds is possible with 10-bar probes, <100 km below 1-bar.
Sampling H2O-ice requires ~50-bar, 200-300 km below 1-bar.
Reaching below all clouds requires descent to 200-500 bar pressure, >500km below 1-bar.

Design Decision #2: Which Latitude(s)? How many probes?

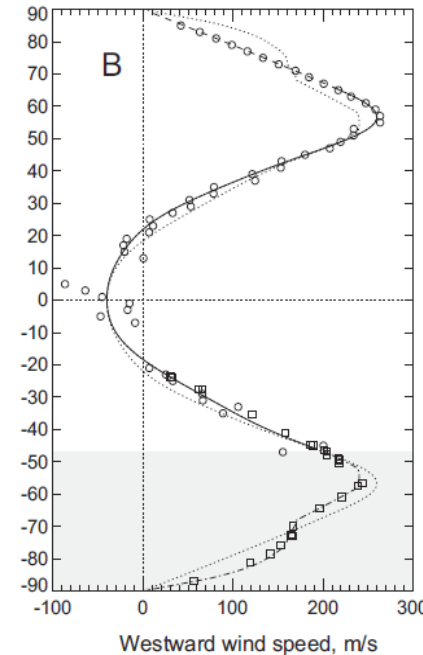
Example: Cloud bands and circulation on Uranus

Cloud Bands

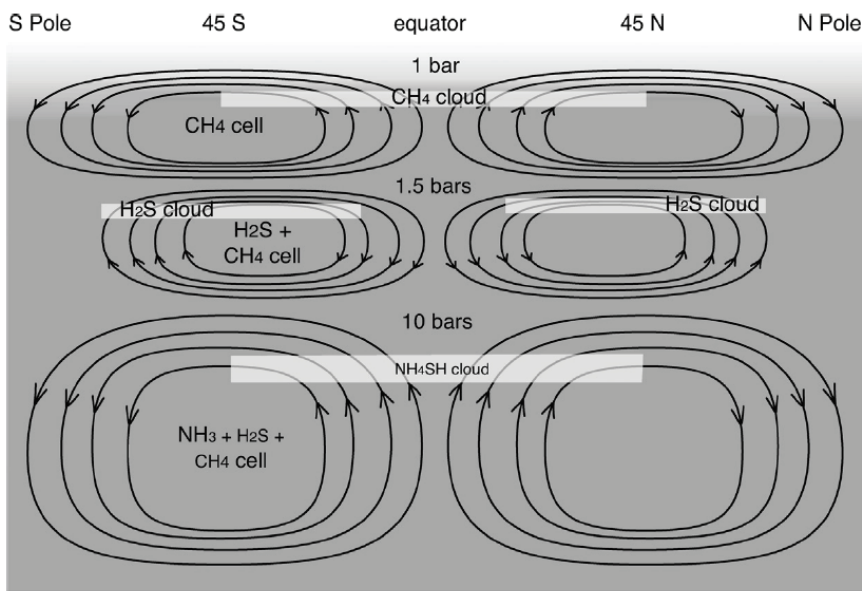


Sromovsky et al. (2015 Icarus 258, p.192-223)

Wind Bands



Meridional Circulation (Hypothesized)



Sromovsky et al. (2014 Icarus 258, p.137-155)

Which cloud band(s) should we target?
Where do we best sample the zonal wind?

How do we best test meridional circulation?
What's the effect of Seasonal forcing?

Some quantities are Homogeneous

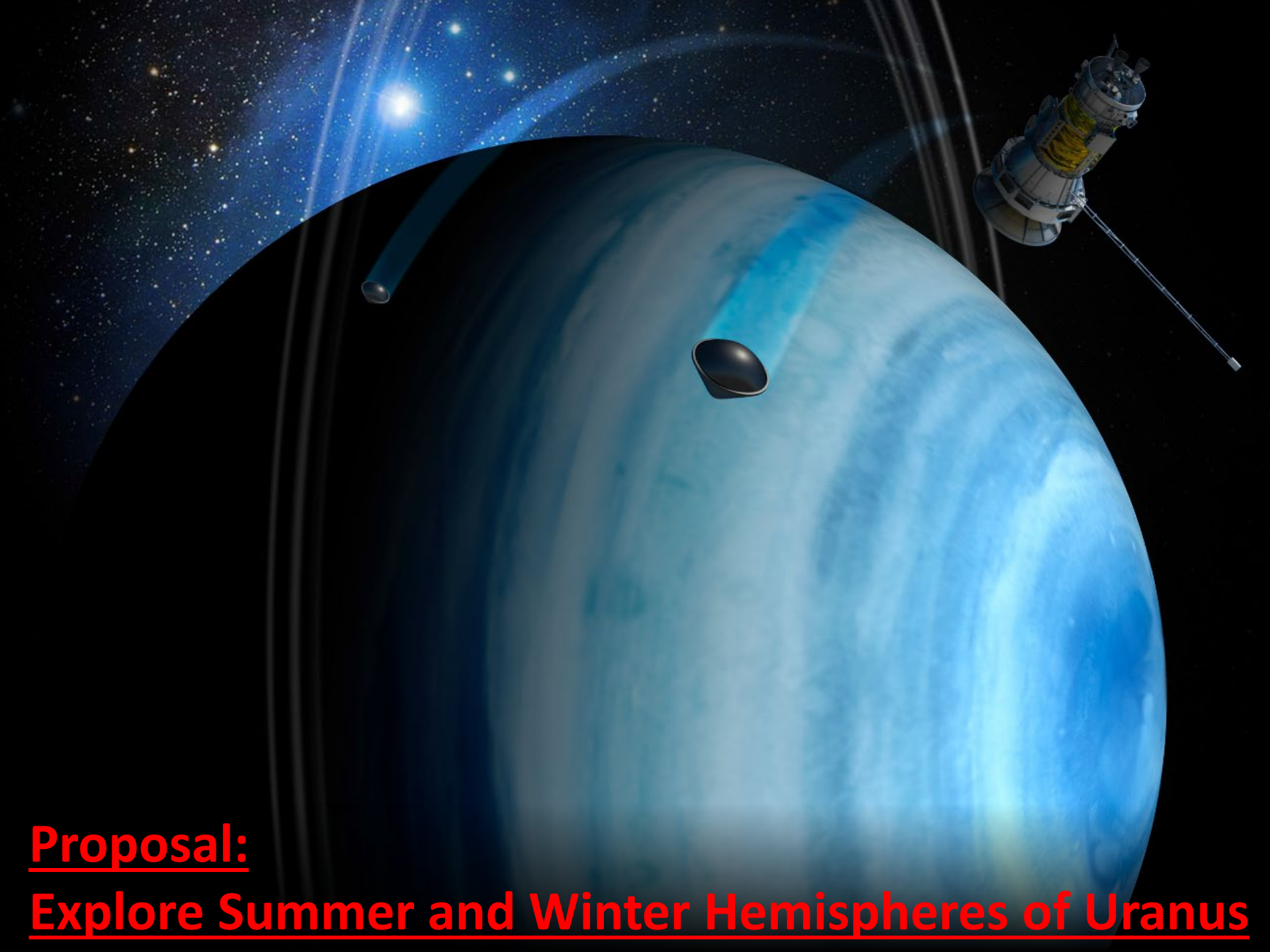
Observable	Spatial Variation
Noble Gas Abundance	Spatially Homogeneous
Isotopic Ratios	
Volatile Molecule Abundance	Spatially Variable
Cloud/Haze/Aerosol Properties	
Disequilibrium Species Concentration	
Temperature vs. Pressure/Density	
Radiative Flux	
Horizontal Wind Speed	
Probe Descent Speed+Accel.	
Local Turbulence	

Spatially Homogeneous quantities do not need to be measured at multiple entry locations.

Review: Instruments

Red Letters = Usual Suspects

Observable	Instruments
Noble Gas Abundance	Mass Spec , He Detector, Noble Gas Sensor
Isotopic Ratios	Mass Spec , Tunable Laser Spectrometer (TLS)
Volatile Molecule Abundance	Mass Spec , TLS, Vapor Sensor
Cloud/Haze/Aerosol Properties	Nephelometer
Disequilib. Species Concentration	Ortho-Para Sensor, Vapor Sensor
Temperature vs. Pressure/Density	Atmospheric Structure Instrument (ASI)
Radiative Flux	Net Flux Radiometer
Horizontal Wind Speed	USO/Doppler Wind Experiment
Probe Descent Speed+Accel.	ASI



Proposal:

Explore Summer and Winter Hemispheres of Uranus

Multi-Probe Missions

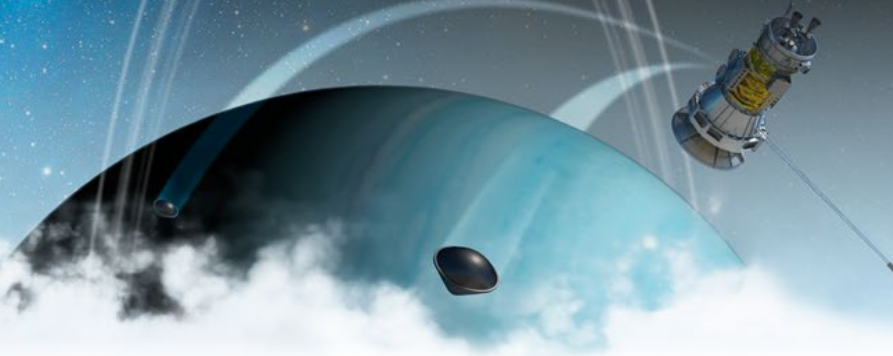
Enable Future Multi-Probe Planetary Missions:

- Advocated by 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

SNAP

Small Next-generation Atmospheric Probe



Multi-Probe Science Objectives

Multi-Probe Shared Objectives:

Determine spatial variability in atmospheric properties:

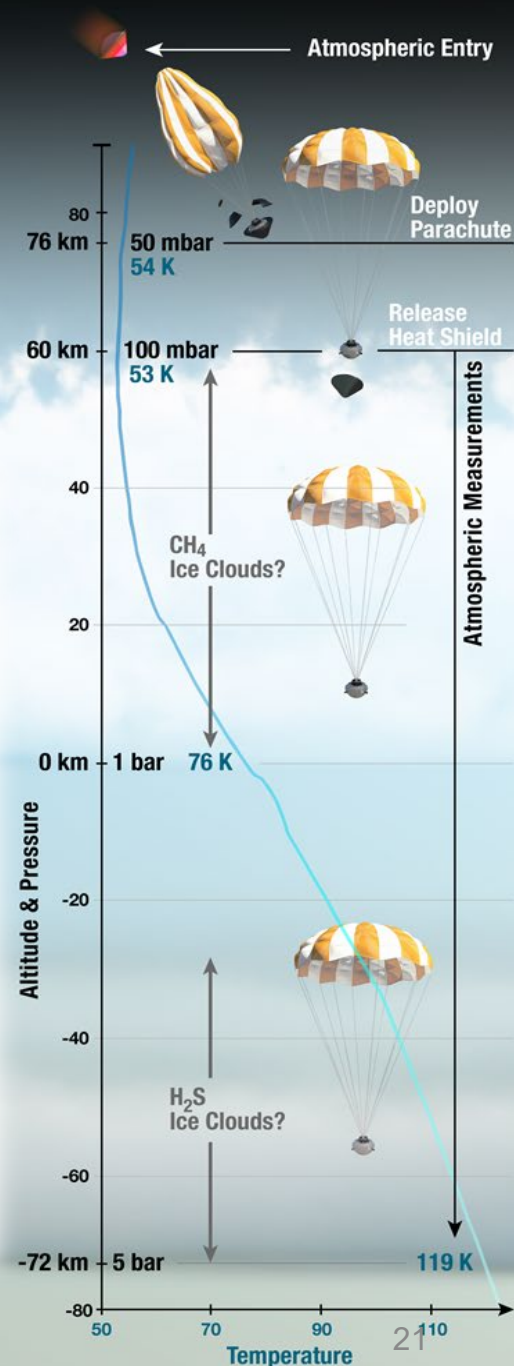
- Vertical distribution of cloud-forming molecules
- Thermal stratification and static stability
- Atmospheric dynamics as a function of depth

Proposal: Probe Summer and Winter Hemispheres

Main Probe-only Objectives:

Determine Bulk Composition:

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

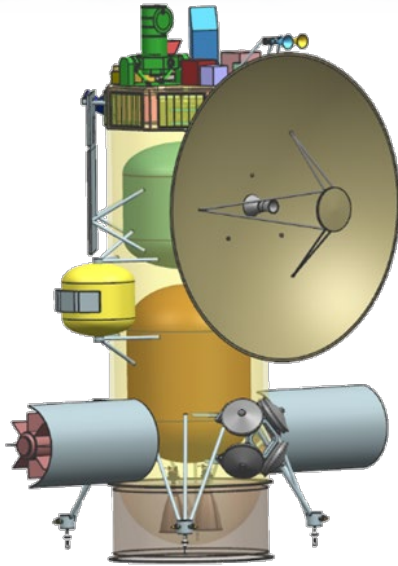


Mission Design Assumptions

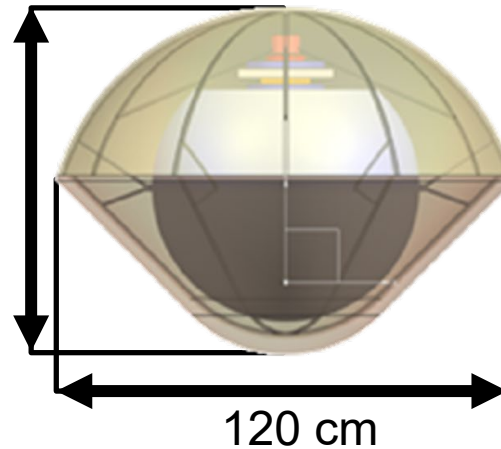
1. Baseline Carrier Mission: Uranus Orbiter with Probe Mission Architecture #5 by Ice Giants Flagship SDT:
 - 1913 kg Uranus Orbiter
 - All-chemical Propulsion (no SEP)
 - 50 kg Science Payload on Orbiter
 - 321 kg Probe (= Primary Probe = PP)
2. Add SNAP as a Second Probe
3. Deliver PP and SNAP at Uranus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

Notional Uranus Mission in 2030s

From Ice Giant SDT Study



91 cm



120 cm

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

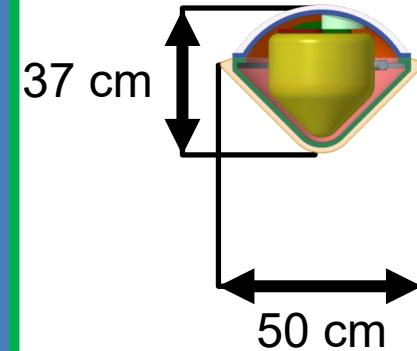
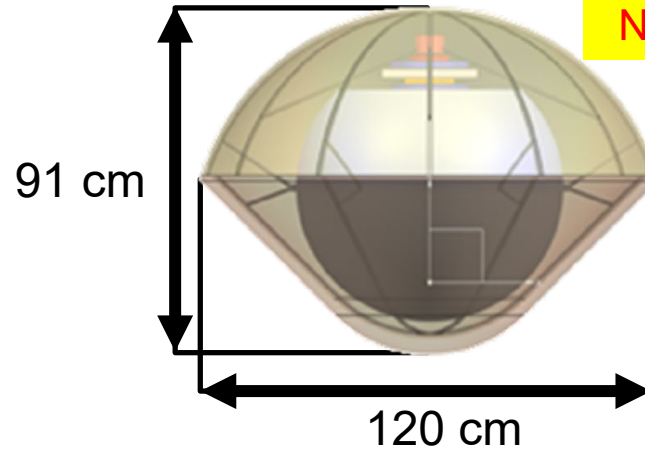
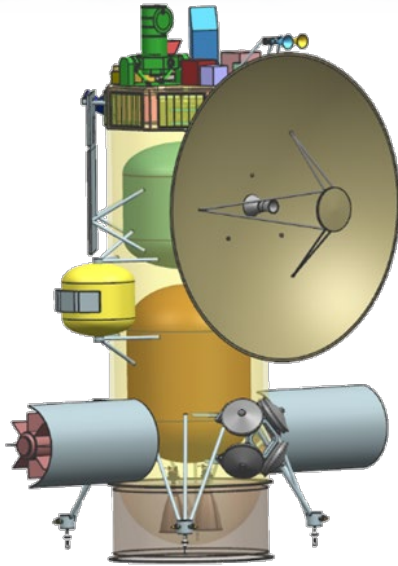
*10-bar is requirement for hardware operation for margin, science objective is to reach 5-bar.

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°

SNAP

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

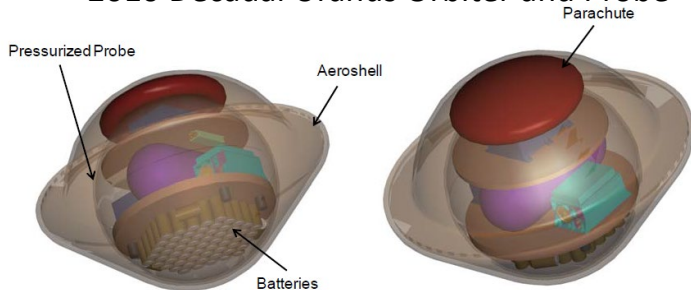
Baseline Orbiter and Probe: Ice Giant SDT Architecture #5

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

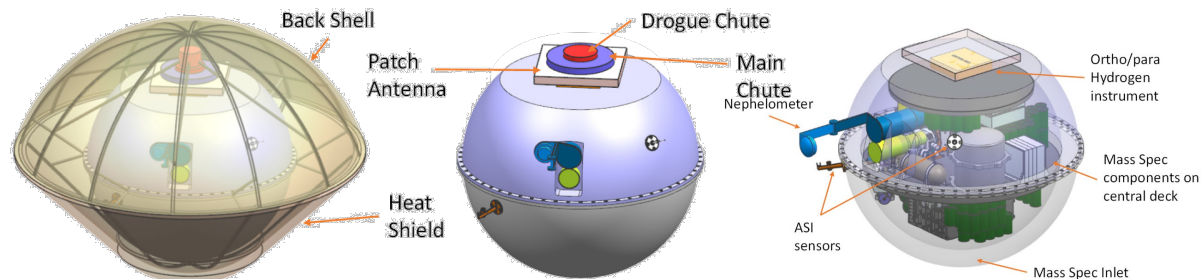
Probe Design Comparison

- Design Considerations:
 - Instruments
 - Usual Suspects: Mass Spec, ASI, USO ...
 - **Mass Spec has large impact on probe mass.**
 - Entry Latitude & Depth
- Design Comparisons
 - Galileo Probe
 - Huygens
 - 2010 Decadal Uranus Orbiter and Probe
 - 2010 Decadal Saturn Probe
 - 2017 Ice Giant SDT Study
 - SNAP

2010 Decadal Uranus Orbiter and Probe



2017 Ice Giant SDT Study



Probe Mass Comparison

Missions	Atmos. Entry Mass	Entry Sys.	Descent Module				
	CBE +Conting. +Margin	Aeroshell + Chutes (TPS Material)	Instruments	Inst. Mass	Mass Spec Mass	Non-MS Inst. Mass	Battery
Galileo Probe	335 kg	219 kg 65% (Carbon Phenolic)	MS, ASI, USO, HAD, Neph, NFR, Lightning, Energetic Particles	35 kg (10%)	13.2 kg	21.8 kg	7.5 kg (Li-SO ₂ , 2.2%)
Huygens	318 kg	118 kg 37% (AQ60)	GCMS, ASI, USO, DISR, Surface Sci.	48 kg (15%)	17.2 kg (+6 kg pyrolizer)	24.2 kg	13 kg ? (Li-SO ₂ , 4%)
2010 Uranus Study	127.1 kg	40.8 kg 46% (Carbon Phenolic)	MS, ASI, Neph, USO	17.1 kg (13%)	9.2 kg	7.9 kg	11.3 kg (Li-SOCl ₂ , 9%)
2010 Saturn Probe Study	216.4 kg	120.9 kg 56% (Carbon Phenolic)	MS, ASI	10.5 kg (5%)	9.2 kg	1.2 kg	5.0 kg (Li-SOCl ₂ , 4%)
2017 IG SDT	320.7 kg	147.0 kg 46% (HEEET)	GCMS, ASI, Neph, Ortho-Para	32.5 kg (10%)	17.4 kg	15.1 kg	17.1 kg (Li-Ion, 5.3%)
2019 SNAP	30 kg	14.8 kg 49% (HEEET)	NanoChem, ASI, USO	6.6 kg (22%)	(No Mass Spec)	6.6 kg	0.34 kg (Li-CFx, 1.1%)

Probe Mass Comparison

Missions	Atmos. Entry Mass	Entry Sys.	Descent Module				
	CBE +Conting. +Margin	Aeroshell + Chutes (TPS Material)	Instruments	Inst. Mass	Mass Spec Mass	Non-MS Inst. Mass	Battery
Galileo Probe							7.5 kg (Li-SO ₂ , 2.2%)
Huygens							13 kg ? (Li-SO ₂ , 4%)
2010 Uranus Study							11.3 kg (Li-SOCl ₂ , 9%)
2010 Saturn Probe Study							5.0 kg (Li-SOCl ₂ , 4%)
2017 IG SDT	320.7 kg	147.0 kg 46% (HEEET)	GCMS, ASI, Neph, Ortho-Para	32.5 kg (10%)	17.4 kg	15.1 kg	17.1 kg (Li-Ion, 5.3%)
2019 SNAP	30 kg	14.8 kg 49% (HEEET)	NanoChem, ASI, USO	6.6 kg (22%)	(No Mass Spec)	6.6 kg	0.34 kg (Li-CFx, 1.1 %)

Mass Spec Design Trade should be an important component of future mission studies.

Atmospheric Gas Composition Instruments

Instrument Type	Pro	Con
Mass Spectrometer Heritage: Galileo, Huygens, Curiosity SAM ...	Sensitive to Noble Gas Sensitive to Isotopic Ratio Can search for unexpected molecules	Massive (usually >10 kg) due to vacuum plumbing requirement High Mass Resolution required to break degeneracy in mass
Tunable Laser Spectrometer Heritage: Curiosity SAM	High-sensitivity Isotopic Ratio Measurements	Massive due to vacuum plumbing needs Can search only for predicted species (One laser channel per species) Not sensitive to Noble Gas
Helium Abundance Detector Heritage: Galileo	Low-mass, Low-power Sensitive to Helium	Sensitive only to Helium
Vapor Sensor Heritage: ISS Cabin Environmental Monitor	Low-mass, Low-power Does not require vacuum plumbing	Can search only for predicted species (One sensor head per species, can pack >100 sensors) Not sensitive to noble gas Does not distinguish isotopes

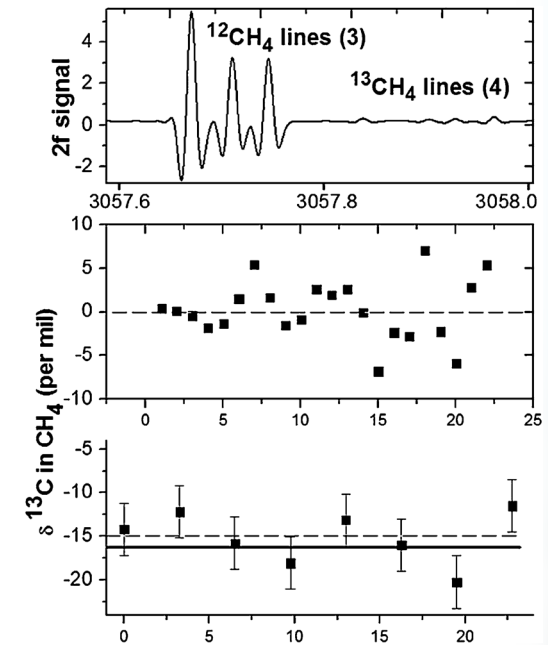
A little bit about Tunable Laser Spectrometer (TLS)

- Shoot a tunable laser through gas sample
- Scan wavelength around an absorption line
- (Usually) One tunable laser required for one target gas molecule

Table 10 TLS measurement capability

Channel	Wavelength	Scan name	15 minute predicted capability
1-IC laser	3.3 μm	Methane	to 0.3 ppbv $\delta^{13}\text{C}$ to 2 per mil
2-Near IR laser	2.785 μm	Carbon dioxide	to 0.2 ppmv in CO_2 and H_2O $\delta^{13}\text{C}$ to 2 per mil $\delta^{18}\text{O}$ to 3 per mil $\delta^{17}\text{O}$ to 5 per mil
	2.783 μm	Water	H_2O to 0.1 ppmv δD to 2 per mil $\delta^{18}\text{O}$ to 3 per mil $\delta^{17}\text{O}$ to 5 per mil

Example: Mars Curiosity SAM instrument (Mahaffy et al. 2012)

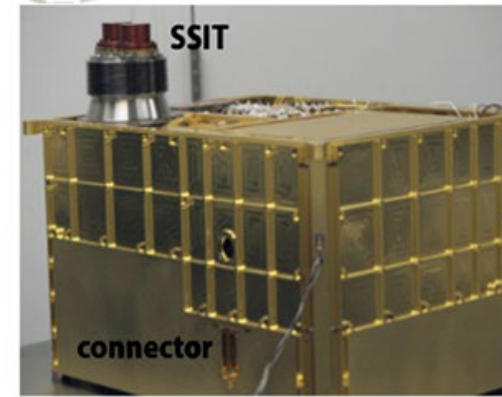
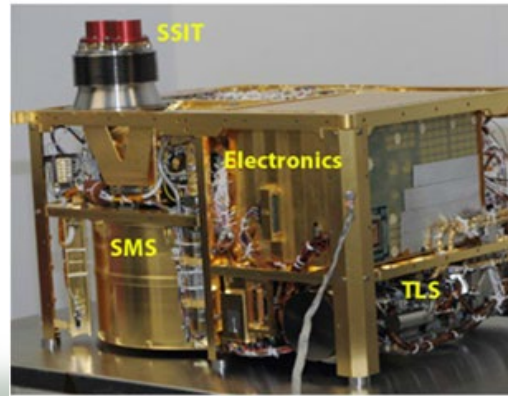
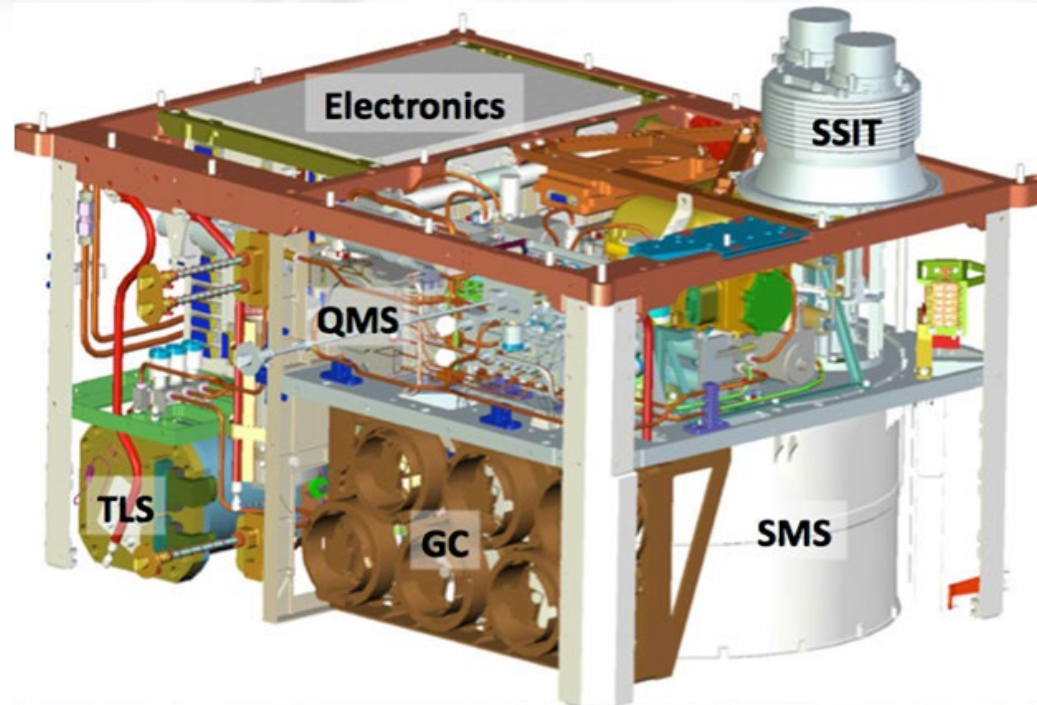


Mars Curiosity SAM: State-of-the-Art Atmospheric Composition Instrument

Curiosity Sample Analysis at Mars (SAM):

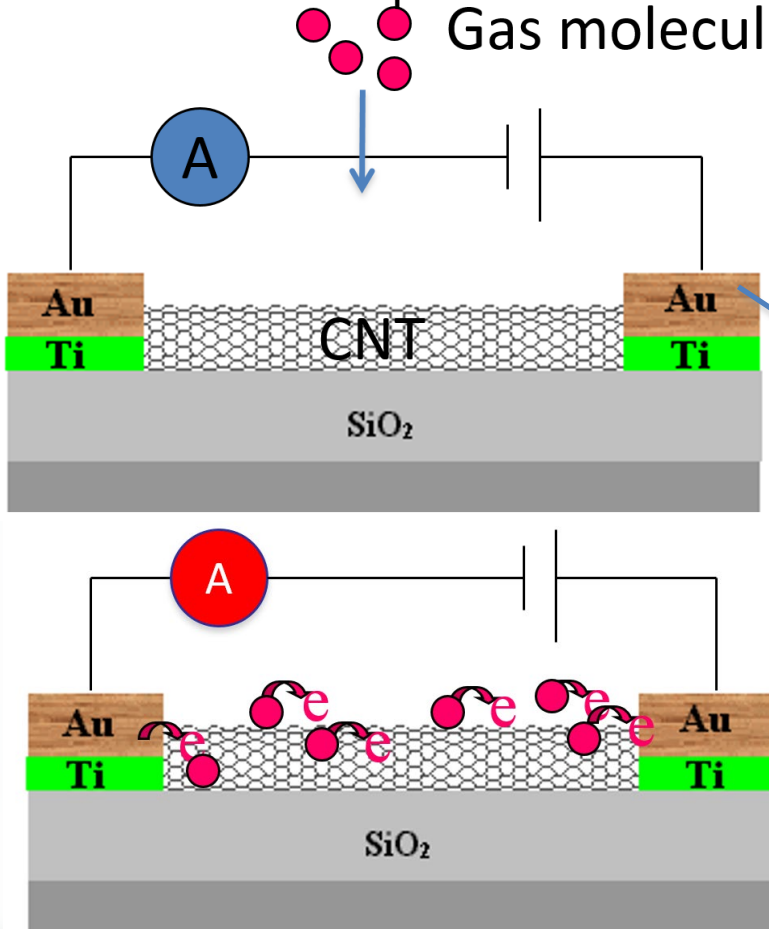
- Combination of:
 - Quadrupole Mass Spec.
 - Gas Chromatograph
 - Tunable Laser Spec.
 - Solid Sample Inlet Tube
 - Solid Manipulation System
- 40 kg instrument mass
- Curiosity's Total Inst Mass = 75 kg
- SAM was >50% of total instr mass
- Curiosity total mass = 899 kg

Mars Curiosity SAM instrument
(Mahaffy et al. 2012)



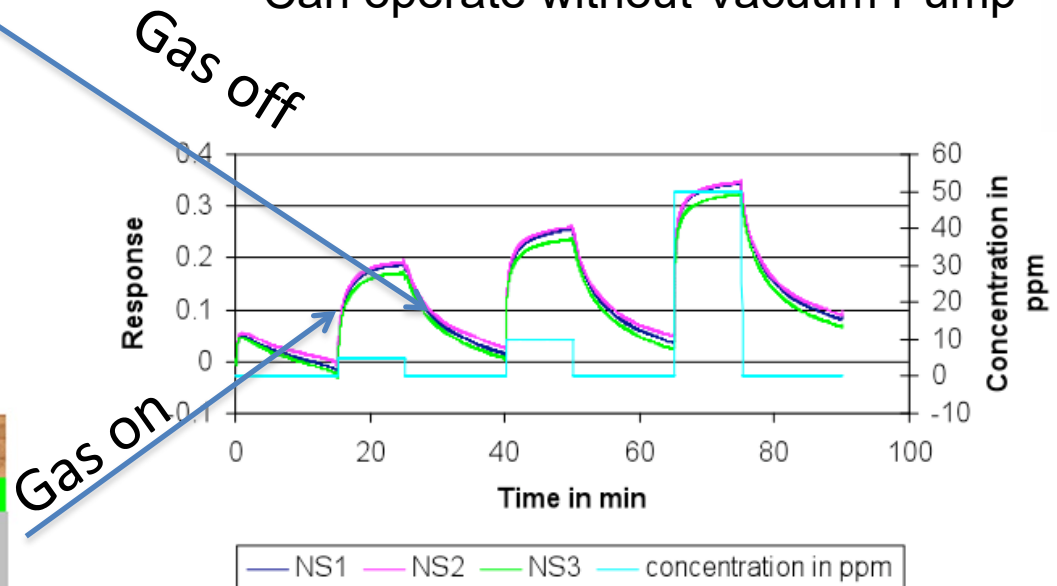
NanoChem Vapor Sensor: How it works

- Measures Changes in Resistivity in response to vapor concentration
- Sensor Heads can be arrayed up to 16 x16 grid on a single chip
- Under Development at NASA Ames (PI: Jing Li)



NanoChem Advantages:

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

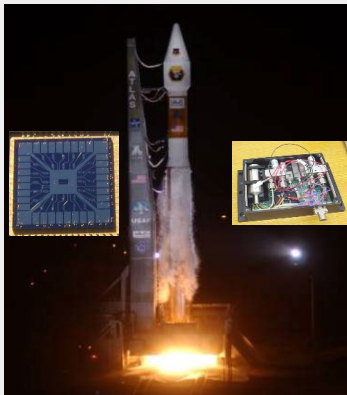


NanoChem response to ammonia

NanoChem: TRL = 4 Today

Launched and Operated in Space

Navy MidSTAR-1
satellite in 2007



Environmental
Monitoring on ISS



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 ₂ O ₂	3.7 ppm in air

Sensitivity demonstrated for:

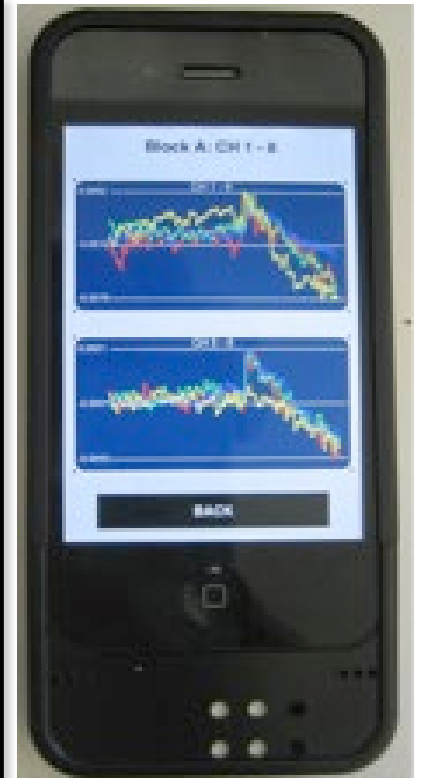
- ... CH₄, H₂O, and NH₃, among others
- ... in Mars and Earth conditions

Need to

- ...develop sensitivities for H₂S
- ... demo in Giant Planet Conditions

NanoChem Commercialization

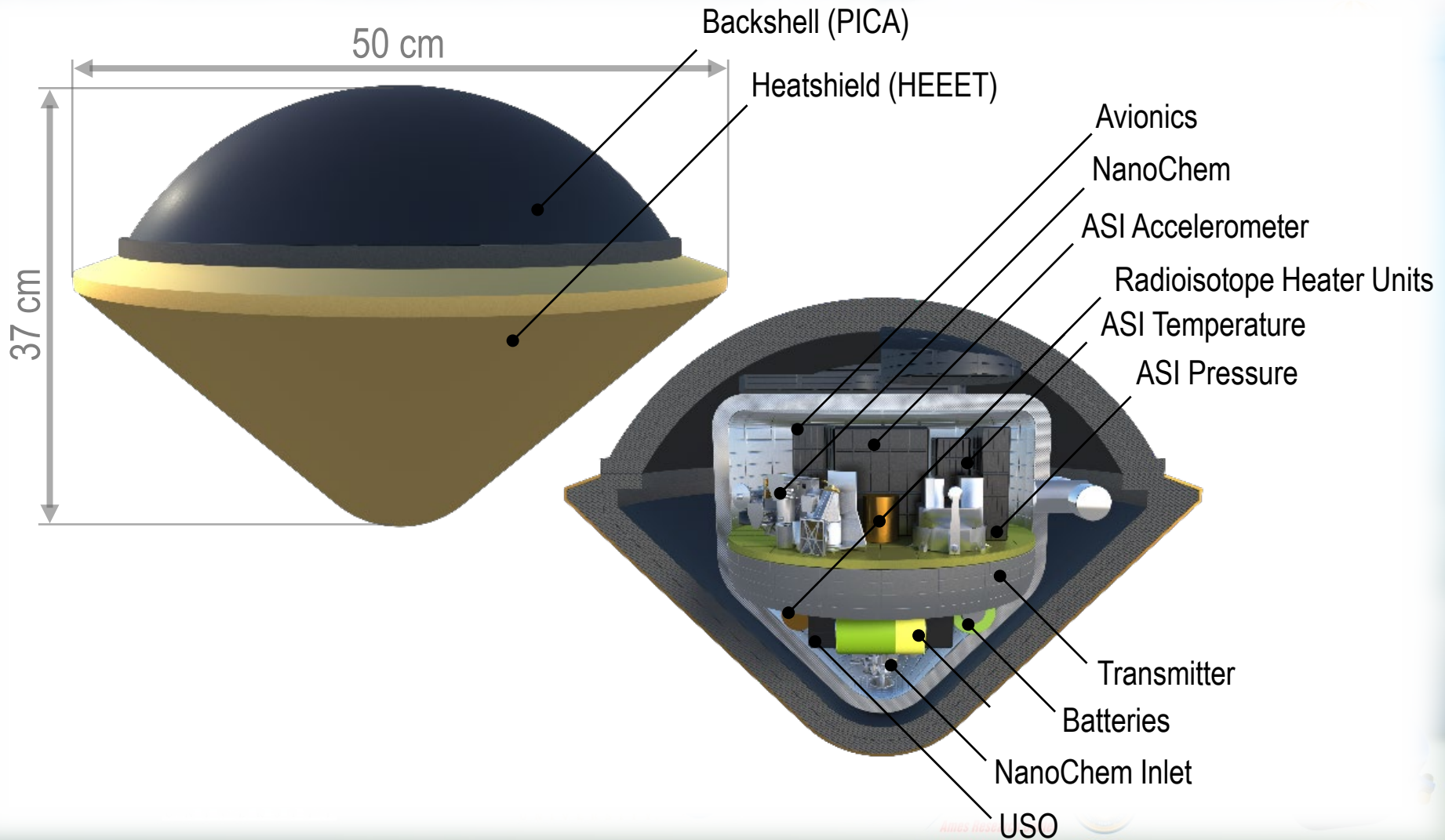
- Development at NASA Ames
PI: Jing Li
- A/D on NanoChem Attachment
- Power from Phone (~mW)
- Processing on the Phone
- High sensitivity – ppb to ppm
- Data Transmission through Cellular Network



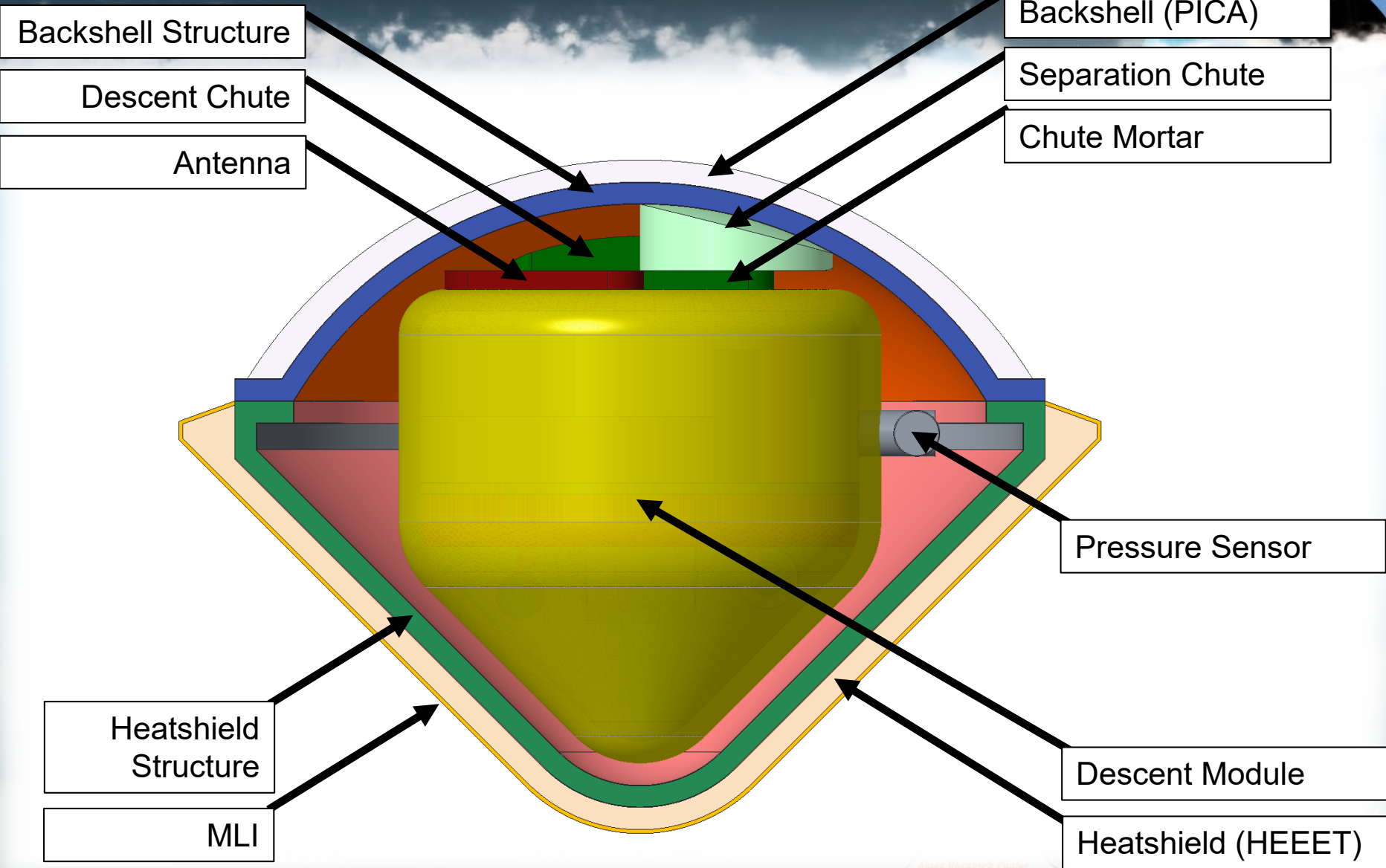
Science Instruments

Instrument	Measurement	Mass	Power	SNAP Data Return
NanoChem	Atmospheric Composition	1.0 kg	1 W	0.6 Mbit
Atmospheric Structure Instrument	Pressure Temperature Acceleration	1.3 kg	5 W	4.5 Mbit
Ultra-Stable Oscillator	Doppler Wind Experiment	1.7 kg	3 W	0.03 Mbit (Housekeeping Only)
Total		4 kg	9 W	5.1 Mbit

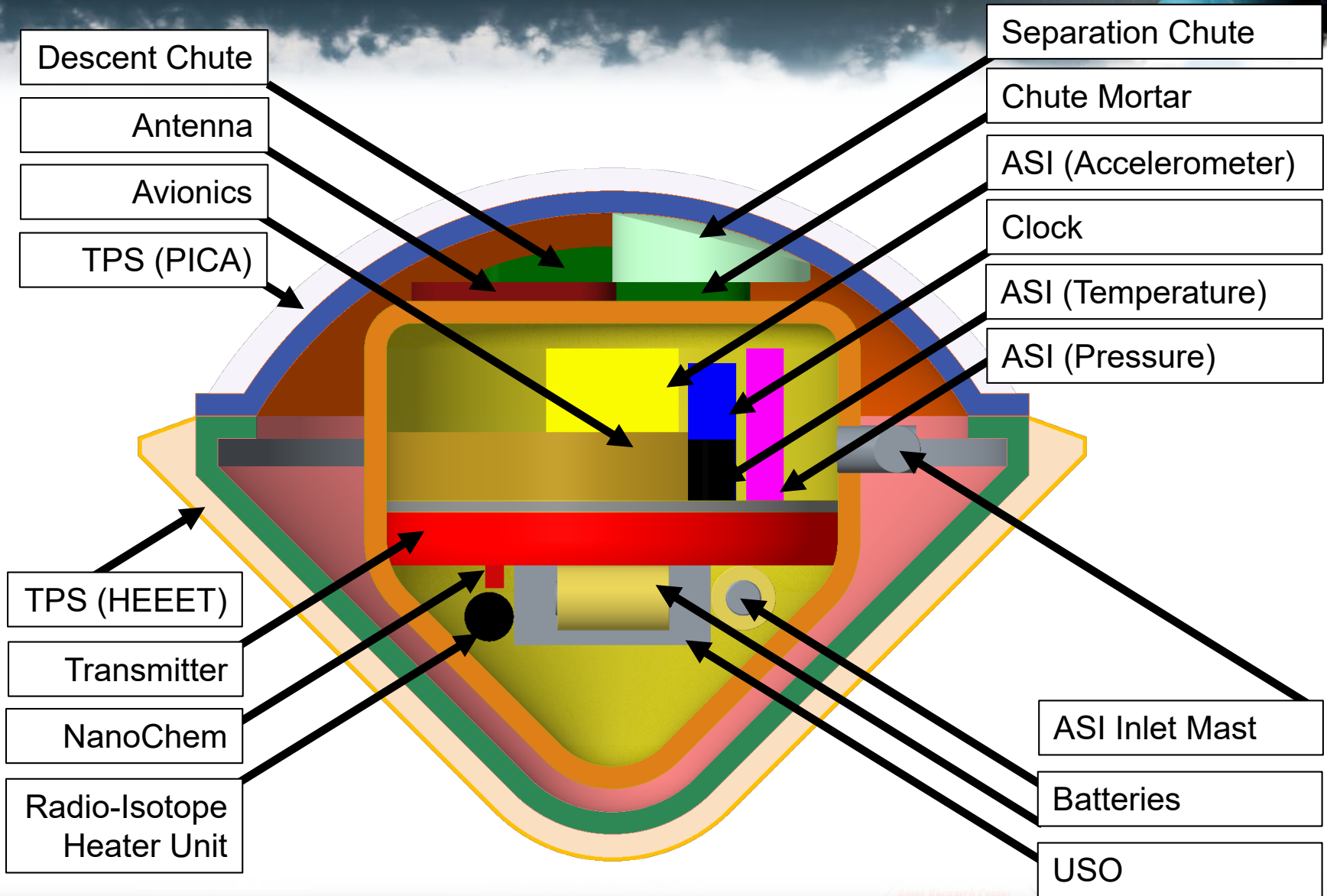
Baseline Hardware Configuration



Baseline Hardware Configuration



Baseline Hardware Configuration



Probe Mass Summary

Subsystem	CBE (kg)	+30% MGA (kg)	+15% Margin (kg)
Forebody TPS (HEEET)	3.7	4.9	5.6
Forebody Structure	2.0	2.6	3.0
Backshell TPS (PICA)	0.7	0.8	1.0
Backshell Structure	1.4	1.8	2.1
Separation Parachute & Mortar	1.3	1.7	1.9
Separation System	0.8	1.0	1.2
Aeroshell Total	9.9	12.9	14.8
Descent Module Structure	1.4	1.8	2.1
Descent Parachute	0.4	0.6	0.6
Science Instruments	4.4	5.7	6.6
Engineering Systems	3.93	5.1	5.9
Descent Module Total	10.2	13.2	15.2
Total Mass Entry Mass	20.1	26.1	30.0

SNAP Design Summary

Dual-Probe Trajectory Solutions Found
SNAP Mass: **30 kg (Instrument Mass = 4 kg)**
Total Data Return = **5.1 Mbit**
Total Mass Addition to Carrier Mission: **77 kg**
Total Estimated Cost: **79.5M (FY18\$)**
SNAP: **Enable Future Multi-Probe Missions**

Galileo Probe



SNAP Probe



Review: Probe Scientific Objectives

Atmos. Composition - Formation and Evolution

- Noble Gas
- Isotopic Ratios

Thermal Structure and Energy Balance

- Temperature vs. Pressure
- Radiative Flux

Role of Clouds/Haze/Aerosols

- Composition & Light Scattering Properties of Aerosols
- Vertical Distribution of Aerosols and Vapors

Atmospheric Dynamics

- Zonal Circulation
- Meridional Circulation
- Vertical Mixing of Disequilibrium Species

Review: Instruments

Red Letters = Usual Suspects

Observable	Instruments
Noble Gas Abundance	Mass Spec , He Detector, Noble Gas Sensor
Isotopic Ratios	Mass Spec , TLS
Volatile Molecule Abundance	Mass Spec , TLS, Vapor Sensor
Cloud/Haze/Aerosol Properties	Nephelometer
Disequilib. Species Concentration	Ortho-Para Sensor, Vapor Sensor
Temperature vs. Pressure/Density	ASI
Radiative Flux	Net Flux Radiometer
Horizontal Wind Speed	USO/Doppler Wind Experiment
Probe Descent Speed+Accel.	ASI

Take Home Message

Atmospheric Composition Instruments are the Primary Driver for Total Mass of an Atmospheric Entry Probe

Current State-of-the-Art:

- Mass Spectrometer + TLS combination (e.g. Curiosity SAM)

Current Needs:

- Reduce Mass and Power of Gas Composition Instruments

Next generation:

- Miniaturized Mass Spectrometer?
- TLS without Harriot Cell? (e.g. LaRC's Diode Laser Hygrometer)
- Vapor Sensors?

BACK UP SLIDES



Challenges of Multi-Probe Missions

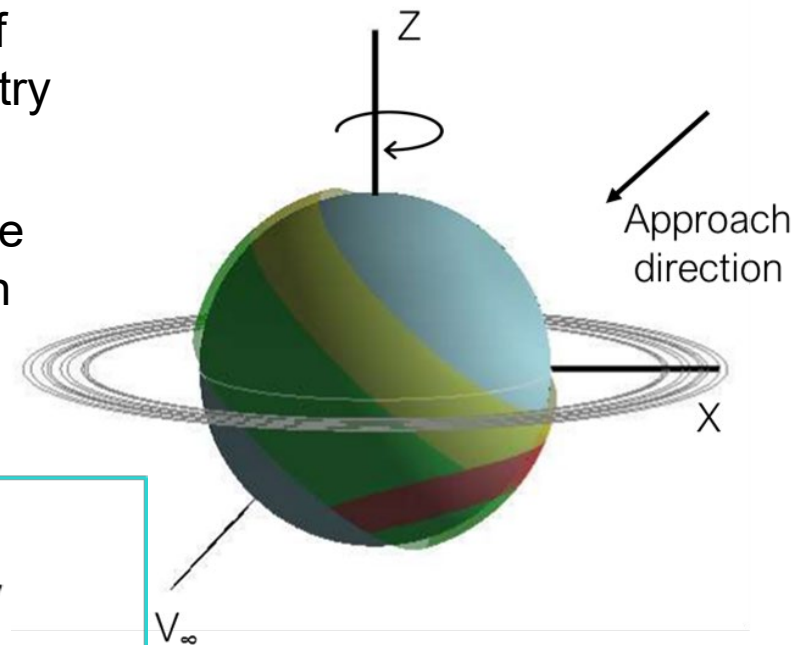
- Deliver Primary Probe and SNAP at two significantly different locations (**latitude**, longitude, time-of-day)
- During each probe's atmospheric descent:
 - Orbiter used to receive data from probe, relay to Earth
 - Orbiter must be within 30 degree comm. cone around zenith.
 - Each probe must reach at >5-bar while Orbiter is in 30-deg cone.

Uranus Entry Locations

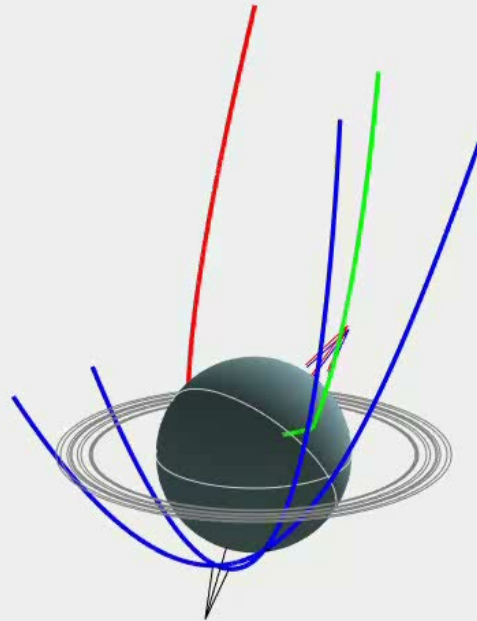
Accessibility of Entry Locations

- 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

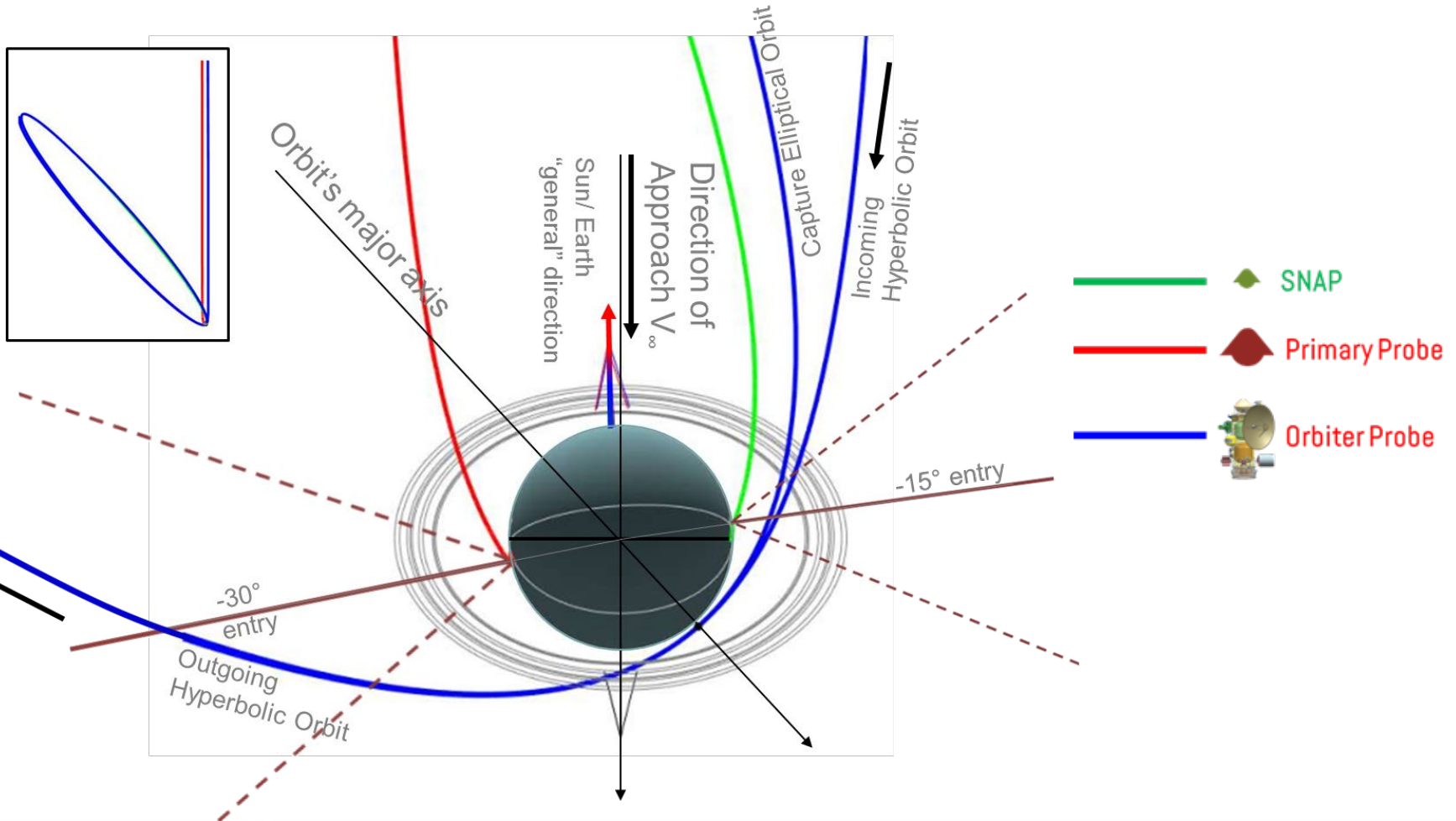


Dual Probe Delivery Trajectory



Dual-Probe Delivery Trajectories

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





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



Multi-Probe Missions

Enable Future Multi-Probe Planetary Missions:

- Advocated by National Academy 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

Interplanetary Trajectory Options

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

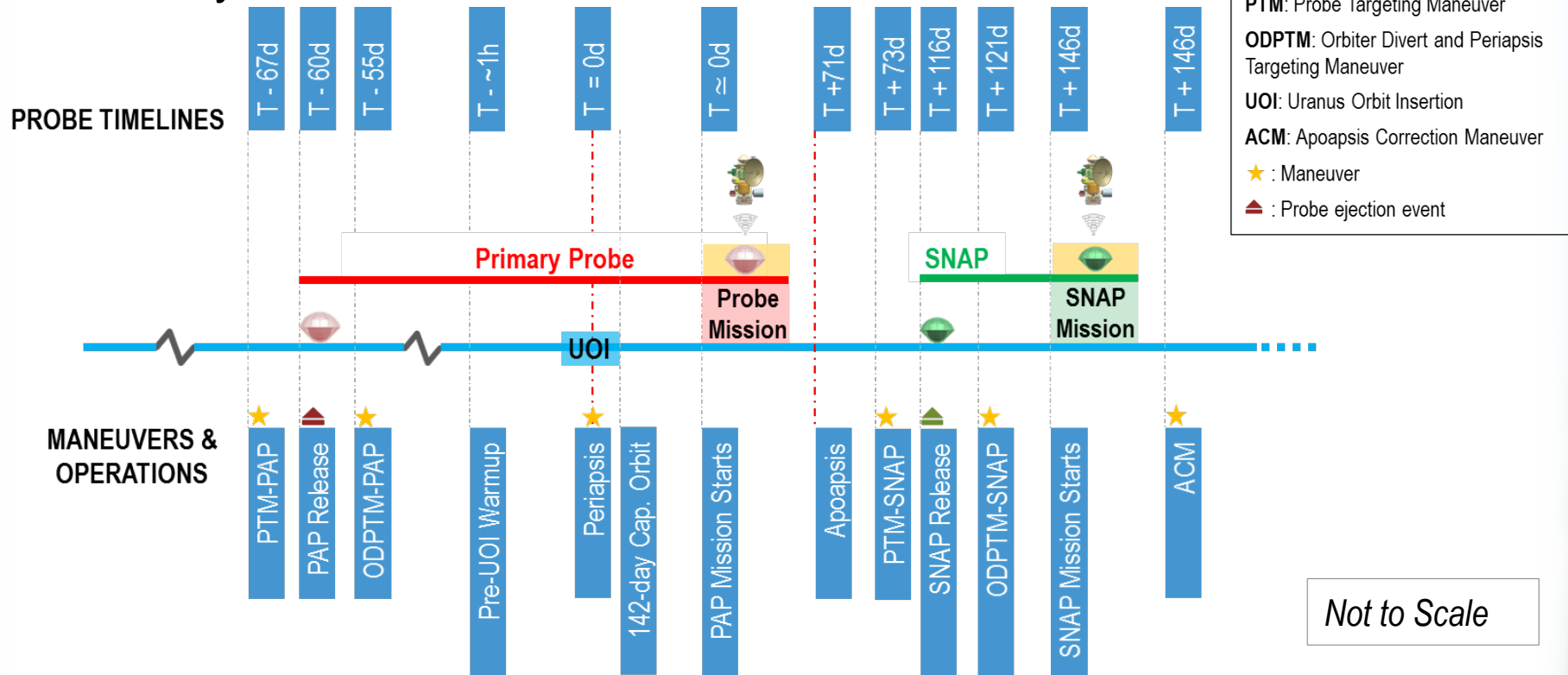
Launch Date	Launch Vehicle	Flyby Sequence	Launch C_3 (km^2/s^2)	Interplanetary Cruise (yrs)	DSM (m/s)	Arrival Mass (kg)	UOI ΔV (m/s)	Mass in Orbit (kg)
5/25/2031	Atlas V 541	Earth-VEEJ-Uranus	11.9	12	565	3582.5	1680	1850
7/18/2031	Delta IV Heavy	Earth-VEJ-Uranus	20.3	10.9	737	5265	2240	2393
4/6/2031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

Overall Mission ConOps

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





Impact on Carrier Mission

Trajectory:

- Release SNAP after Uranus Orbit Insertion

Hardware:

- Mounting & deployment hardware
- Pre-deployment power & data connections
- Orbiter propellant

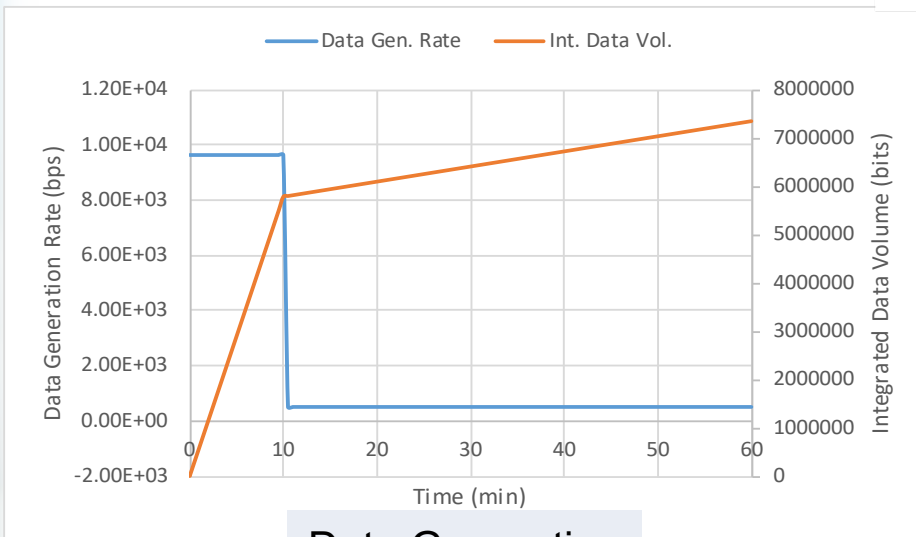
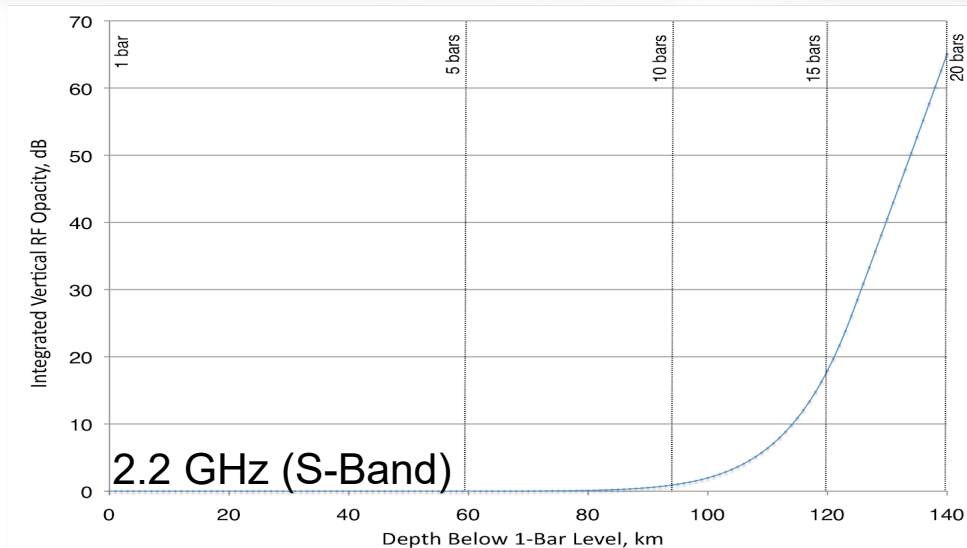
Software & operations:

- Accommodate second probe delivery and data relay

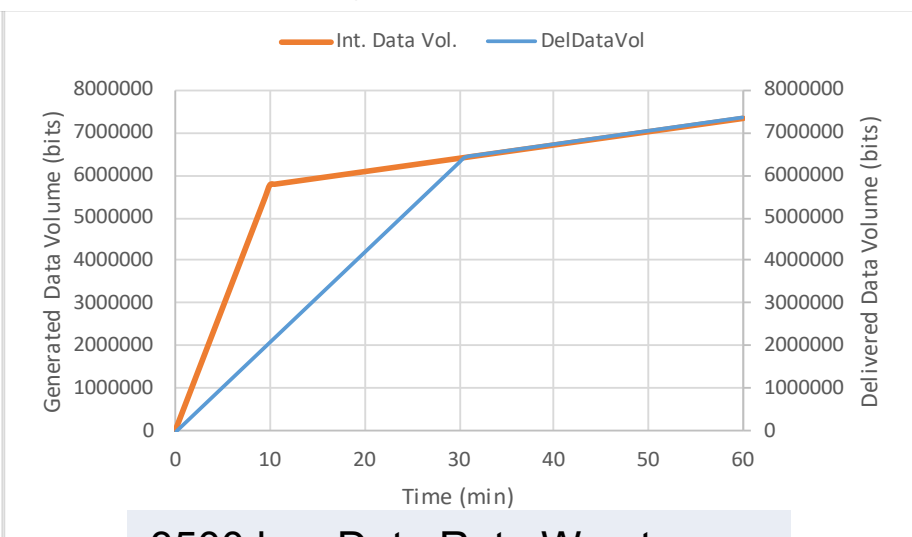
Link Analysis

Link Analysis takes account of:

- Atmospheric Radio Absorption
(NH₃ + CH₄)
- Attenuation through Link Range
- Transmitter/Receiver Antenna Gain
- Link Geometry
- Receiver Noise Model



Data Generation



3500 bps Data Rate Worst-case

Probe Mass Summary

Subsystem	CBE (kg)	+30% MGA (kg)	+13% Margin (kg)
Heatshield TPS (HEEET)	3.74	4.86	5.48
Heatshield Structure	2.0	2.6	2.9
Backshell TPS (PICA)	0.65	0.85	0.95
Backshell Structure	1.4	1.8	2.1
1st Parachute & Mortar	1.3	1.7	1.9
Separation System	0.8	1.0	1.2
Aeroshell total	9.9	12.9	14.5
Descent Structure	1.4	1.8	2.1
2nd Parachute	0.43	0.56	0.63
Science Instruments	3.85	5.0	5.6
Engineering Systems	4.9	6.4	7.2
Descent Module total	10.6	13.8	15.5
Total Entry Mass	20.5	26.6	30.0

SNAP Probe Power Summary

Sub-system/ Instruments	Power
<i>Ultra-Stable Oscillator</i>	3.2 W
<i>ASI</i>	5.7 W
<i>Nano-Chem Sensor</i>	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

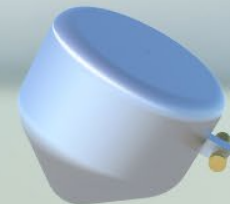
Mass Impact on Carrier Mission by Addition of SNAP

- 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	
Spin ejection device	3	4	30%
Harness/ umbilicals	1	1.3	
SNAP Mass	23.88	30	25%
Orbiter SNAP Support Propellant	30	36	30%
<u>Total Mass Addition to Carrier Mission</u>	<u>58</u>	<u>72.3</u>	

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 reduce heater power needs



Study Team (Science Team)

Kunio M. Sayanagi (PI)	Hampton University
Robert A. Dillman	NASA Langley Research Center
David H. Atkinson	Jet Propulsion Laboratory
Amy A. Simon	NASA Goddard Space Flight Center
Michael H. Wong	University of California, Berkeley
Thomas R. Spilker	Independent Consultant
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

SNAP

Small Next-generation Atmospheric Probe



HAMPTON
UNIVERSITY

Planetary Science deep Space SmallSat Studies

Team Members/Institutions

Kunio M. Sayanagi		Hampton University
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Drew Hope		NASA Langley Research Center
W. Chris Edwards		NASA Langley Research Center

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:

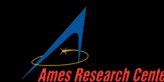
Mass: 30 kg
Probe Diameter: 50 cm
Probe Power: Primary Batteries
Heatshield Material: HEEET

Notional Payload:

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



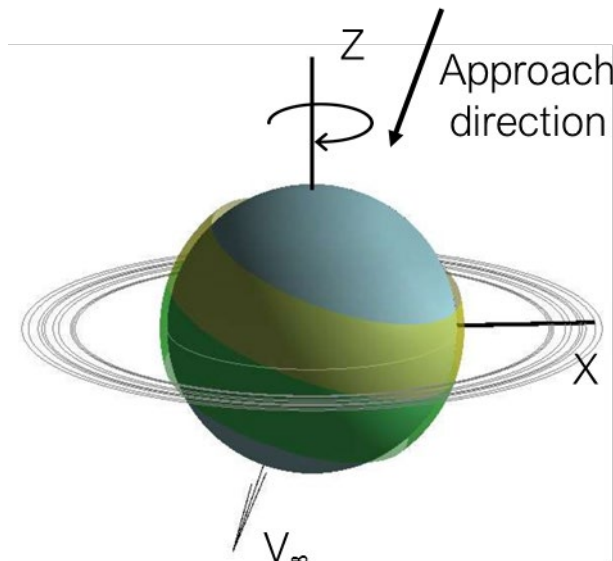
NASA Langley



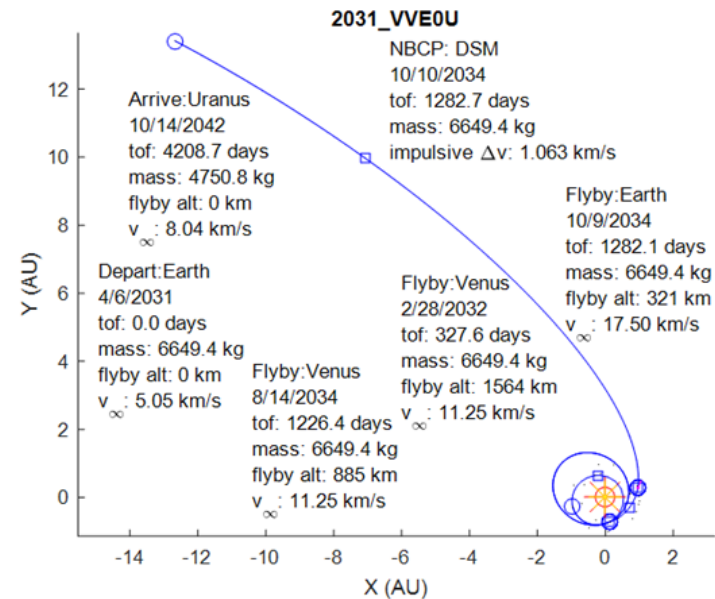
Alternate Interplanetary Trajectories

- 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 ΔV (m/s)	Arrival V_∞ (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

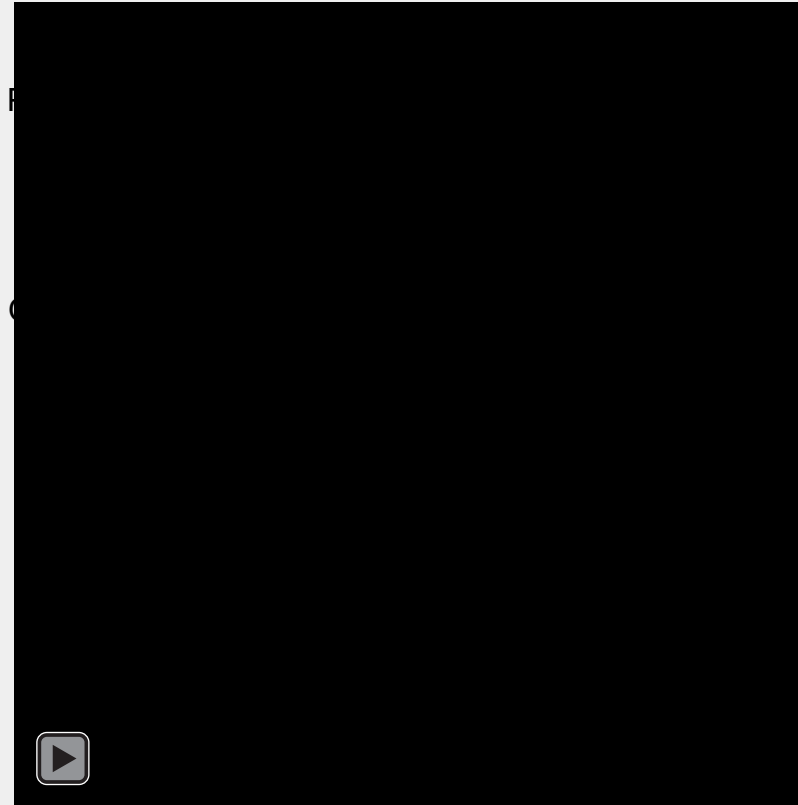


Accessibility of Entry Locations



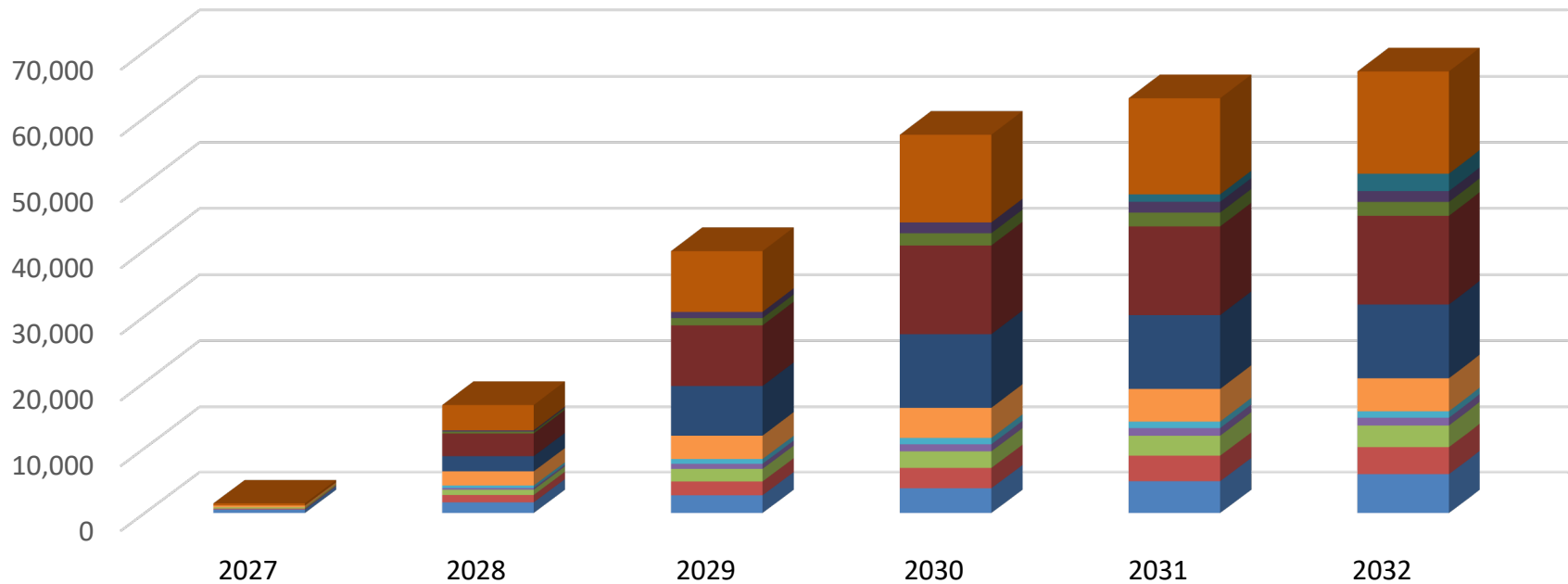
Concept-of-Operations: Dual-Probe Delivery

- 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

SNAP Cost Through Development



- Science
- Systems Engineering
- Entry System Science
- EV Flight System
- EV System Assembly, Integration and Test
- Spacecraft Integration & Test Support / ATLO
- Project Management
- Safety and Mission Assurance
- Modeling and Analysis
- Descent Module
- SC Separation System Flight Hardware
- Project Reserve

