# Titan Sample Return Using In Situ Propellants

# NIAC Phase I Study Status

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# Team

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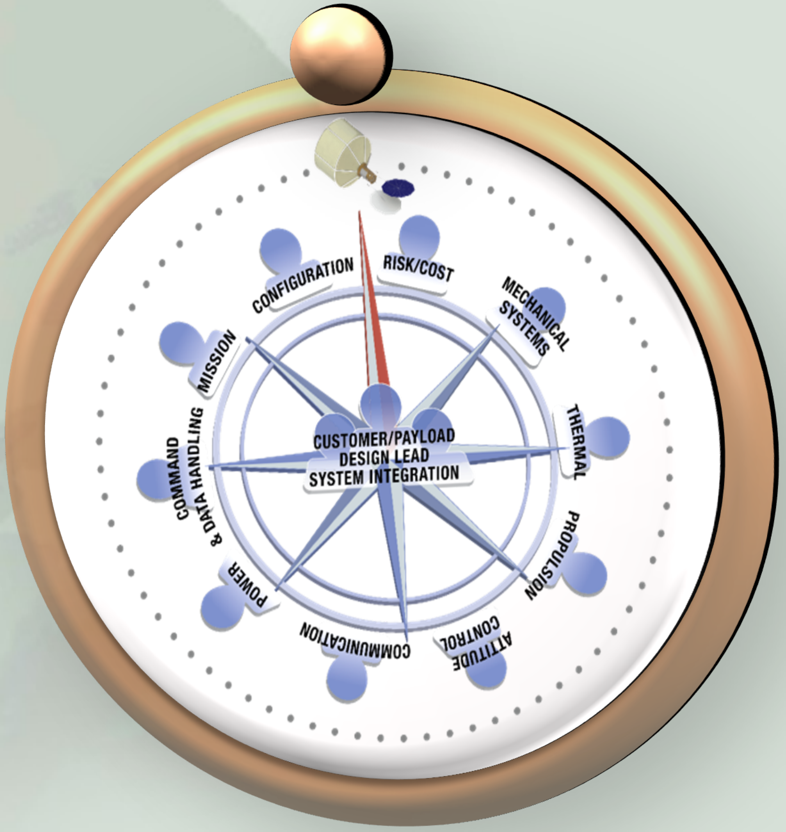


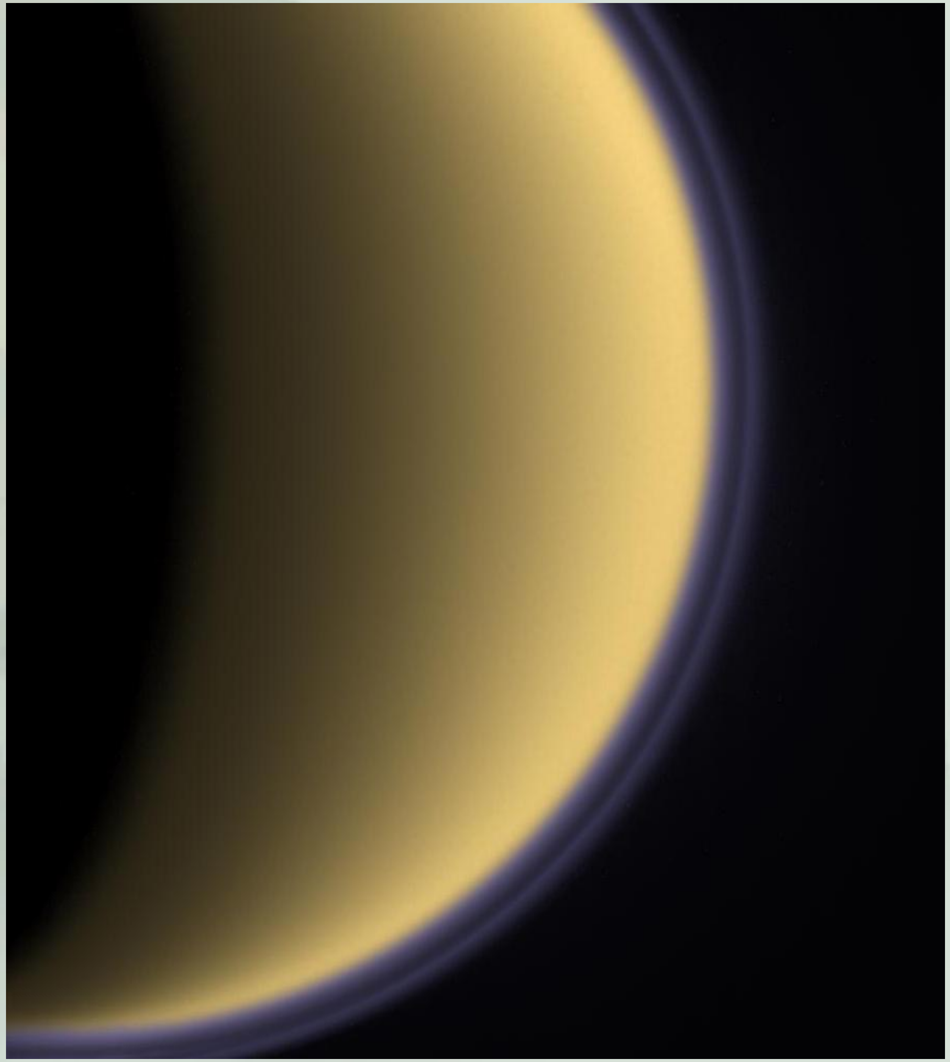
# Saturn and Titan

We would like to acknowledge and thank the members of the NASA Glenn COMPASS team for their many contributions to this mission design

# Titan– a world with atmosphere and oceans

- Titan is only moon in the solar system to have a dense atmosphere (1.5 times the atmospheric pressure of Earth), and has a surface that is rich in organic molecules.

That hazy yellow orange color of the nearly opaque atmosphere is a fog of organic particle aerosols: on Earth we would call this *photochemical smog*



Titan as viewed by the Cassini orbiter, showing the orange haze of the atmosphere, as well as the forward-scattering of blue light. Image courtesy NASA/JPL

# Huygens Lander: surface image

- Image from the surface of Titan by Huygens Lander

- Right: same image, with enhanced contrast and color

For a sense of scale: the rounded pebbles are a few inches across

Surface of Titan viewed from the Huygens probe. The orange color is due to organic tholins. Image courtesy ESA/NASA

# Tholins: building blocks of life?

- Titan is a high priority target for astrobiology. It is a world with a surface and atmosphere rich in the complex organic compounds known as tholins. A detailed understanding of the nature of these complex compounds will require an analysis using a full laboratory on Earth.
- Because of its value to understanding the organic compounds of the outer solar system which may be the primordial building-blocks of life, return of samples from Titan to laboratories on Earth will be the primary goal of this mission.

What we need: Titan Sample Return mission!

Surface of Titan viewed from the Huygens probe. The orange color is due to organic tholins. Image courtesy ESA/NASA

# Titan Launch Vehicle

Can we fuel a rocket to launch from the surface of Titan using rocket propellant we make on Titan?

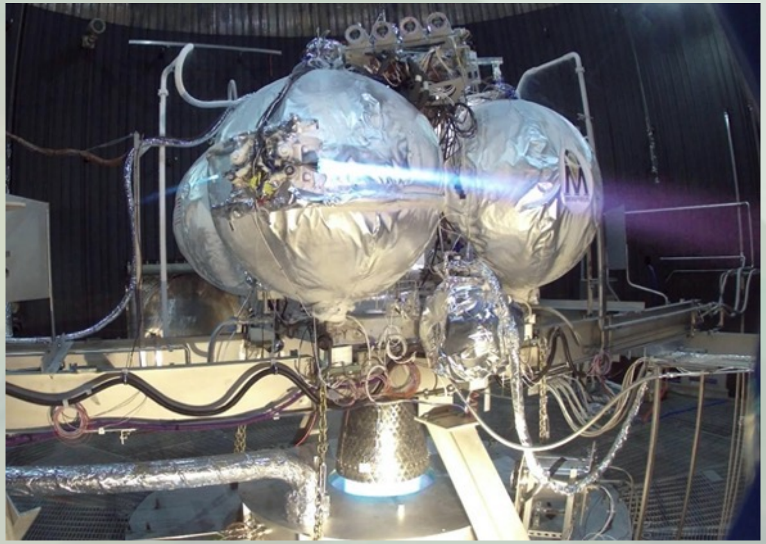
# Major Questions of the Study

1. *What resources does Titan have that we can use to make in-situ rocket propellants?*
2. *How do we gather and process the propellants – how much equipment, power, and time does it take?*
3. *How do we deliver a launch vehicle to the surface of Titan, and deploy it for launch?*
4. *How do we get to Titan and back to Earth?*
5. *How big of a system do we need to send – how much lighter is it than a mission that brings all of its propellant from Earth?*

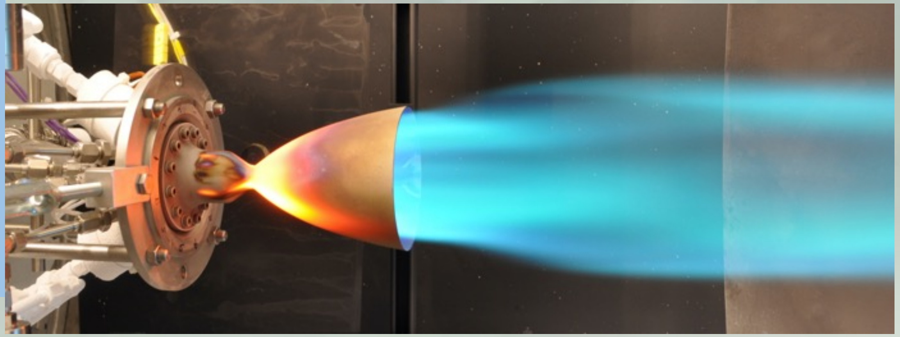
# Methane/LOX Propulsion

The Methane/liquid oxygen ("LOX") combination is very nearly the ideal rocket propellant.

- Specific impulse (Isp) of 325 seconds.
  - second only to liquid hydrogen among hydrocarbon-based rocket fuels
- Density of 0.44 kg/m$^3$. This is dense compared to hydrogen (0.071 kg/m$^3$), allowing for considerably smaller tanks
- The higher boiling point (111 K) eliminates need for cryogenic storage.



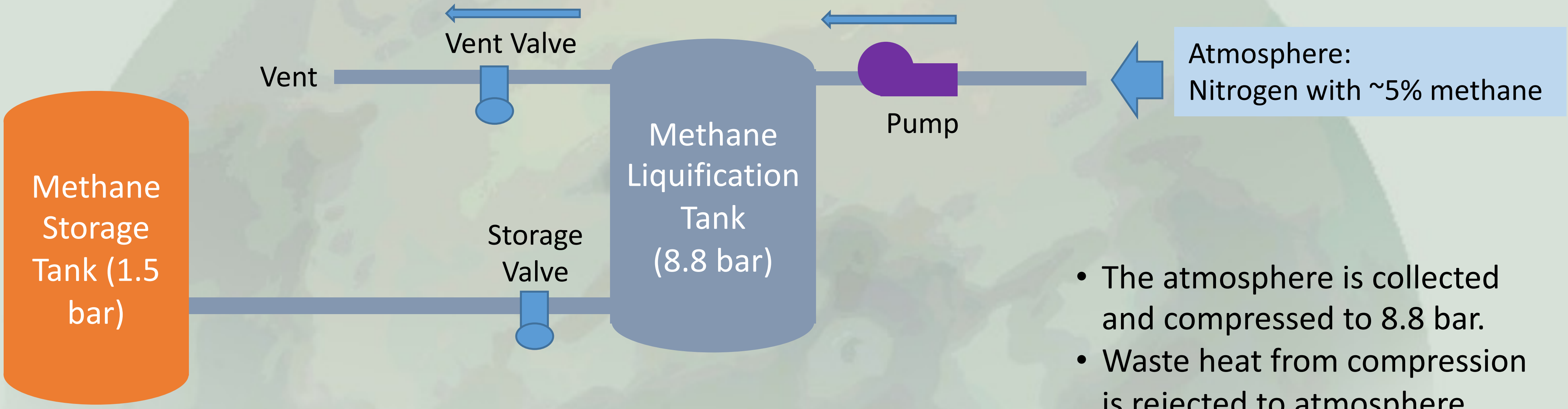
**Top**: Integrated hot-fire test of 12.5 kN (2800 lbf) LOX/methane engine at the Plum Brook ISP Thermal Vacuum Chamber



**Bottom**: uncooled small LOX/methane rocket engine being tested at NASA Glenn Altitude combustion stand

Citation: Robert L. Morehead, *et al.* "Vehicle-Level Oxygen/Methane Propulsion System Hotfire Demonstration at Thermal Vacuum Conditions." *53rd AIAA/SAE/ASEE Joint Propulsion Conference*. 2017.

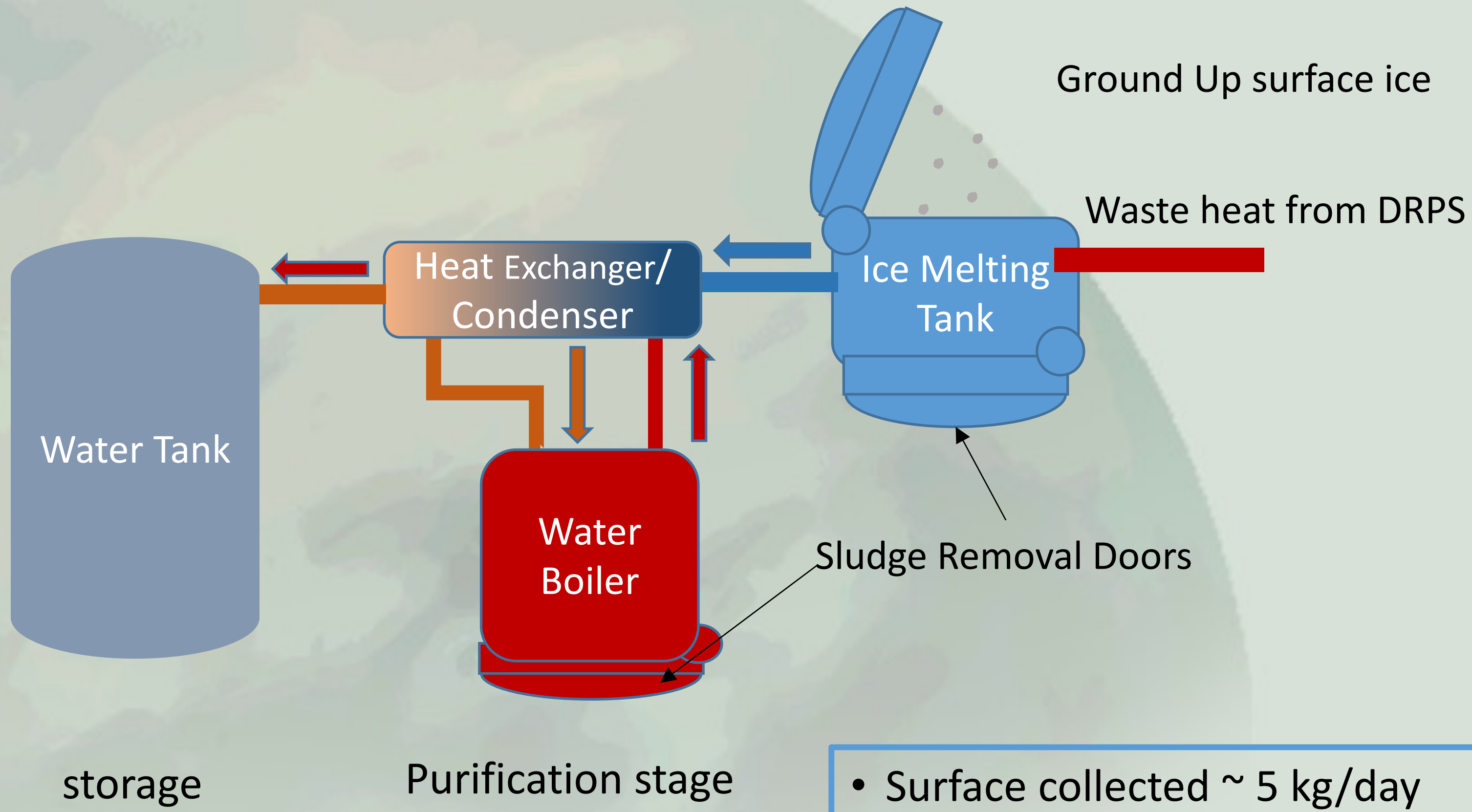
# Methane Production




- The atmosphere is collected and compressed to 8.8 bar.
- Waste heat from compression is rejected to atmosphere

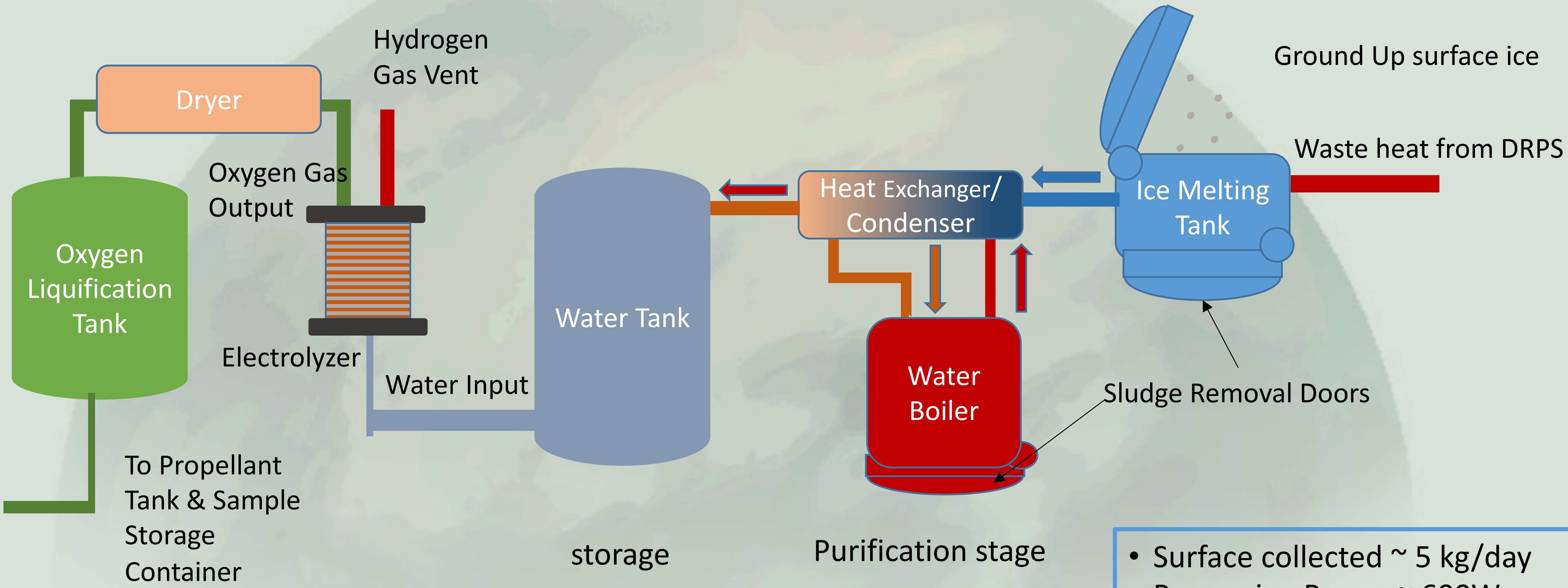
- Processing Power ~ 100W

# Water Production Process




- Surface collected ~ 5 kg/day
- Processing Power ~ 600W

# Water Electrolysis Process

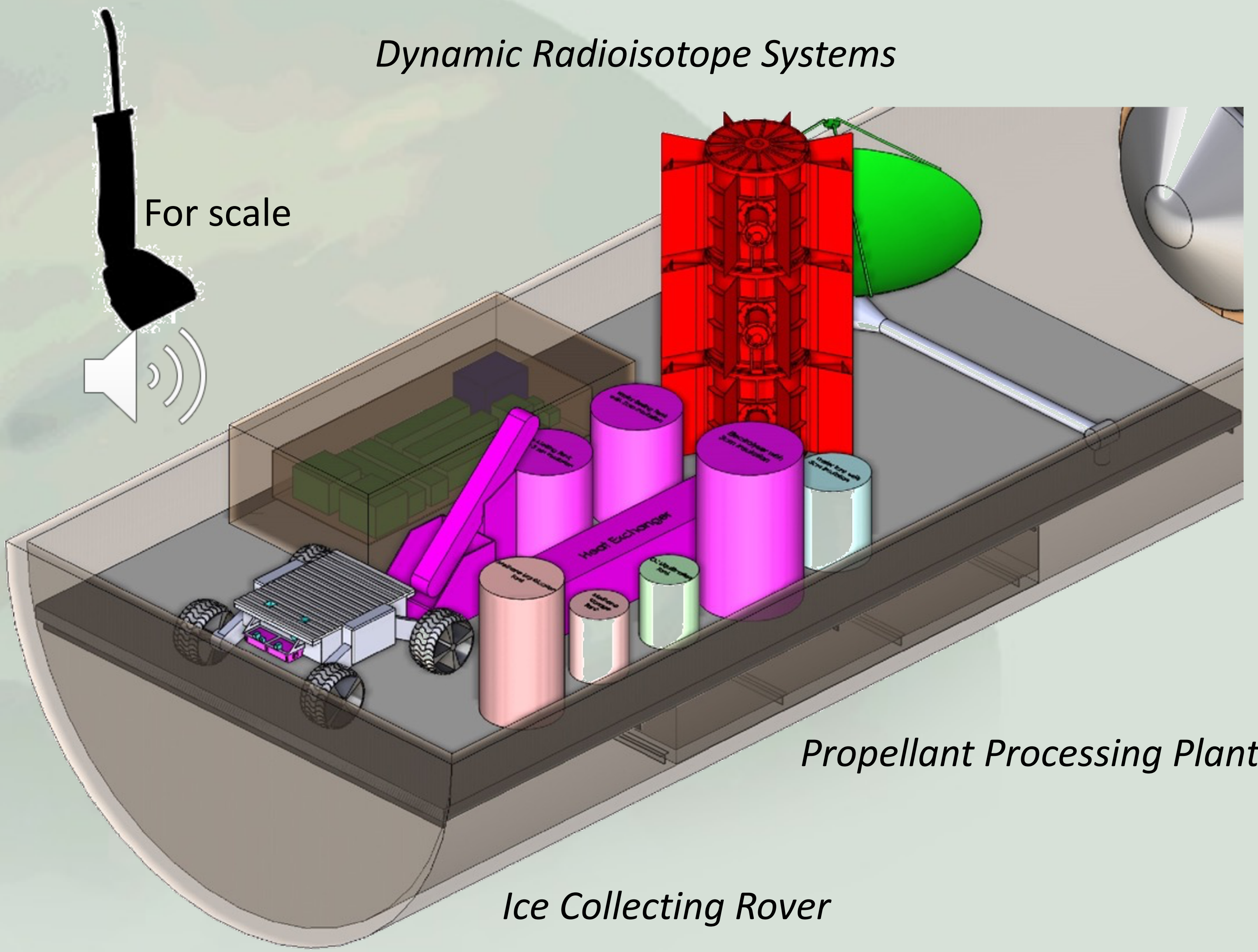



- Surface collected ~ 5 kg/day
- Processing Power ~ 600W

**Electrolysis stage**

# The Propellant Plant

- Processing: ~ 3000 kg of Bipropellant production
  - Fuel: Liquid Methane distilled from atmosphere (5%)
  - Oxidizer: Water Ice collected from the surface, melted, purified, electrolyzed to oxygen, cooled by 94K atmosphere to Liquid Oxygen (LOX)
- Rechargable small rover with grinder/vacuum to gather ~ 5kg of materials /day
- Power: Three, ~300We Dynamic Radioisotope Power Systems
  - Processes ~ 2kg of LOX and LCH4 per day
  - Also provides power to control/comms and waste heat to assist in Ice processing and warming avionics
- Balance of Plant: command and x-band comms direct to earth
- **About 3 years to gather and produce propellants with 1000 We power**



# Storage of Cryogenic propellants

**Titan environment:**
Average surface temperature: **90.6 K**
Maximum temperature: 93.6 K
Atmospheric pressure: 146.7 kPa (1.45 atm)
Gravity: 1.35 m/s$^2$ (0.138 $g_{Earth}$)

Cryogenic storage is simple for both methane and oxygen:

- The maximum measured surface temperature 93.6 K is well below methane's boiling point of 111.5 K.
- At 1 bar pressure above ambient, Oxygen remains liquid up to 100 K, a comfortable margin above the highest temperature measured on Titan.

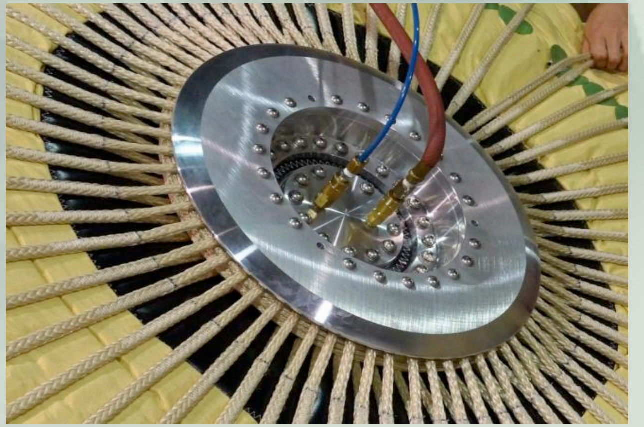
By a fortunate coincidence, the temperature and pressure at the surface of Titan is ideally suited to allow cryogenic propellants to be stored in liquid form without refrigeration.

- But the **volume** of propellant is large

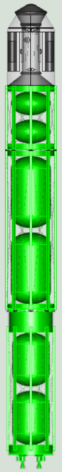
# Inflatable Tanks

- Being Investigated at NASA JSC
- Tank Design Consists of a Thin Polymer Bladder, Longitudinal Load Carrying Tendons, and Polar Bulkheads
- Materials Currently Being Evaluated for Cryogenic Applications
- Tanks can Fold Down Flat for Transport
- Designs for Equatorial Skirt Accommodation and Cylindrical Form Factor Being Evaluated
- Tank Mass Very Competitive with Ti-Alloy for Same Volume and MOP (Potential 30-50% Mass Savings)
- Allows for Deployable Launcher Structure
- Use in Current Design Requires Flexible Propellant and Pressurant Lines

Inflatable Test Tanks

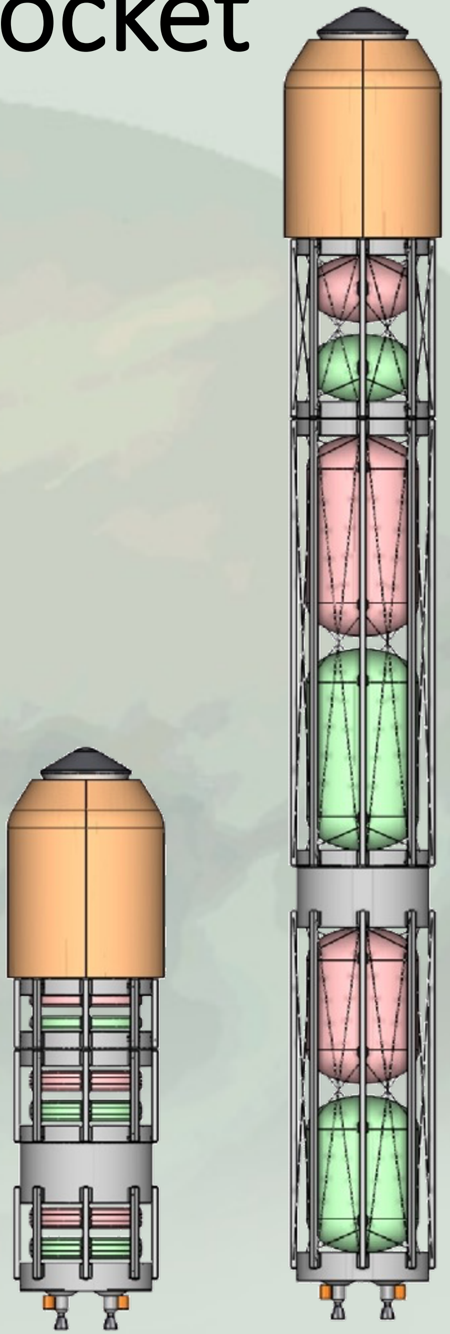


Polar Bulkhead w/ Plumbing Elements

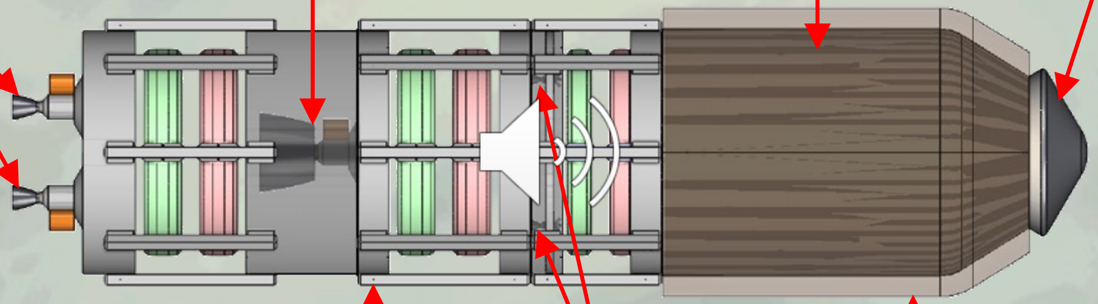


# The Titan Deployable Rocket

- Three inflatable tank/extendable stages
  - Inflatable tanks and feed lines
  - Sliding booms and cable stiffeners
  - Deployed vehicle only sees 1 g max during ascent, and only 1/7g on surface with minimal wind loads
- Each stage tanks inflated and filled with LOX/LCH4 during 3 year production
- 1st Stage to 30 km
- 2nd to insert third and return vehicle to titan orbit (1000 km)
- 3rd stage to push return S/C home (with Saturn/Titan gravity assists)



# Launch Vehicle Stowed



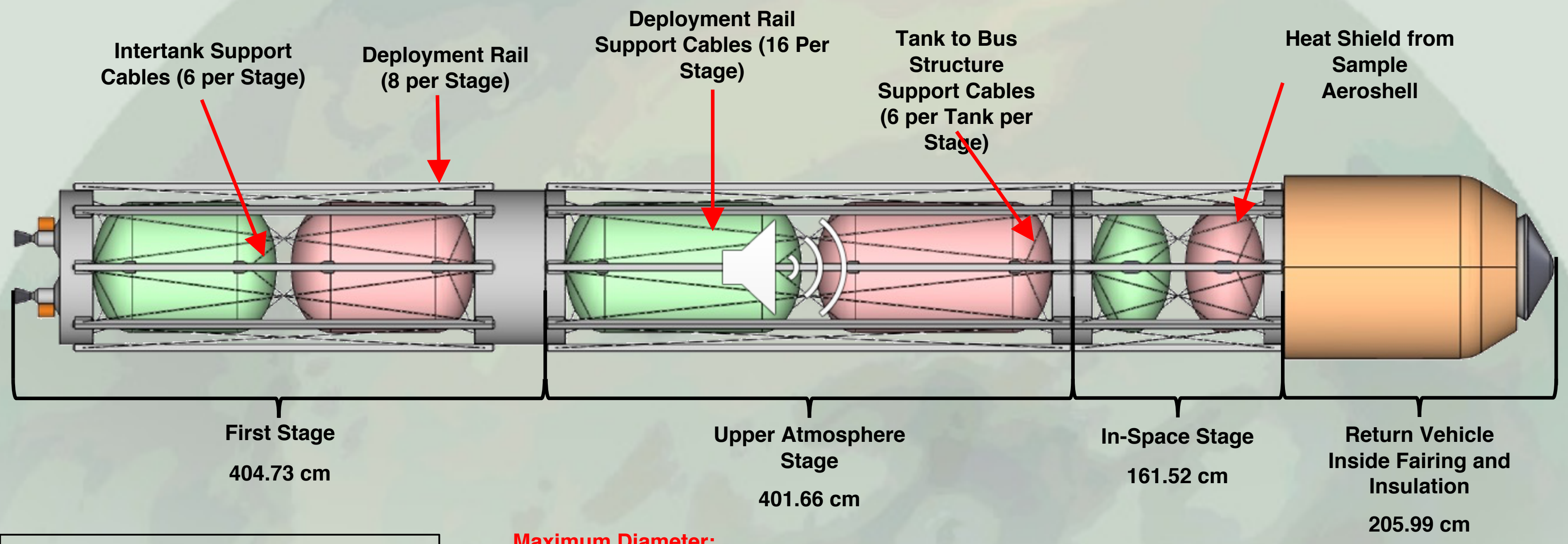

Stowed Inflatable Methane Tanks
Stowed Inflatable LOX Tanks

**Maximum Diameter:** 140 cm (Insulation on Fairing)

**Overall Stowed Length:** 520.59 cm

Configuration modeling by Tom Packard, NASA Glenn

# Launch Vehicle Fully Deployed



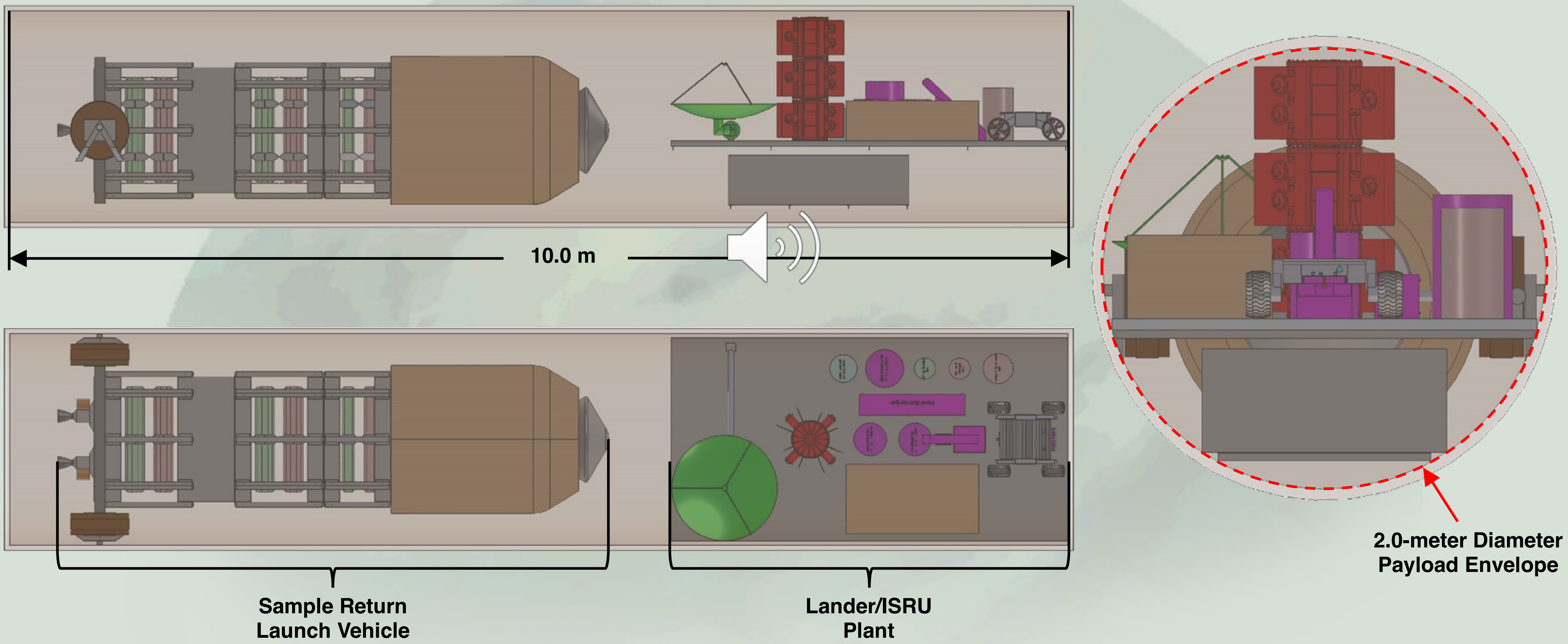

Filled Inflatable Methane Tanks
Filled Inflatable LOX Tanks

**Maximum Diameter:** 140 cm (Insulation on Fairing)

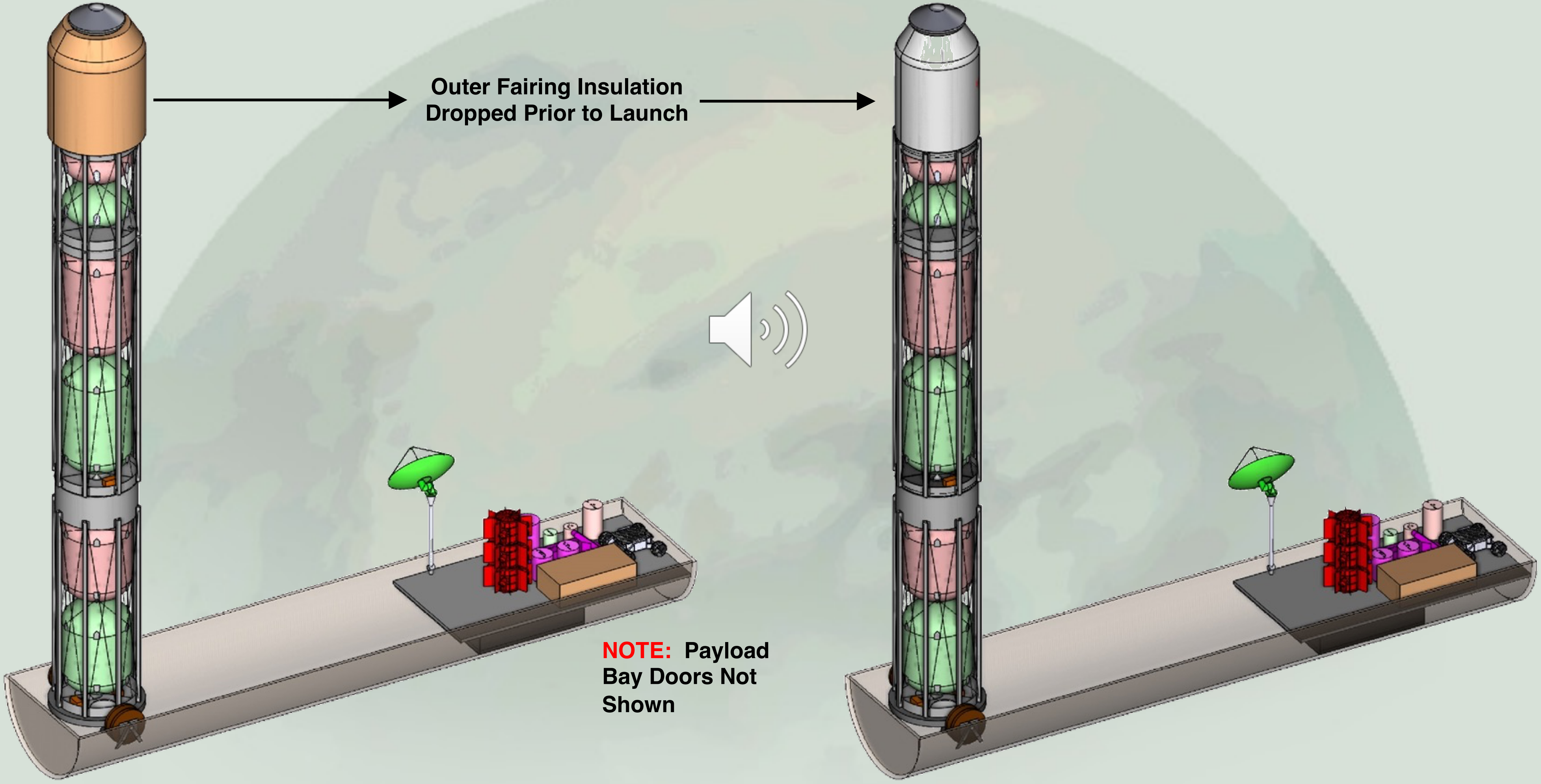
**Overall Deployed Length:** 1173.91 cm

Configuration modeling by Tom Packard, NASA Glenn

# Mission Elements Inside a Representative Lifting Body Payload Bay (1/2)

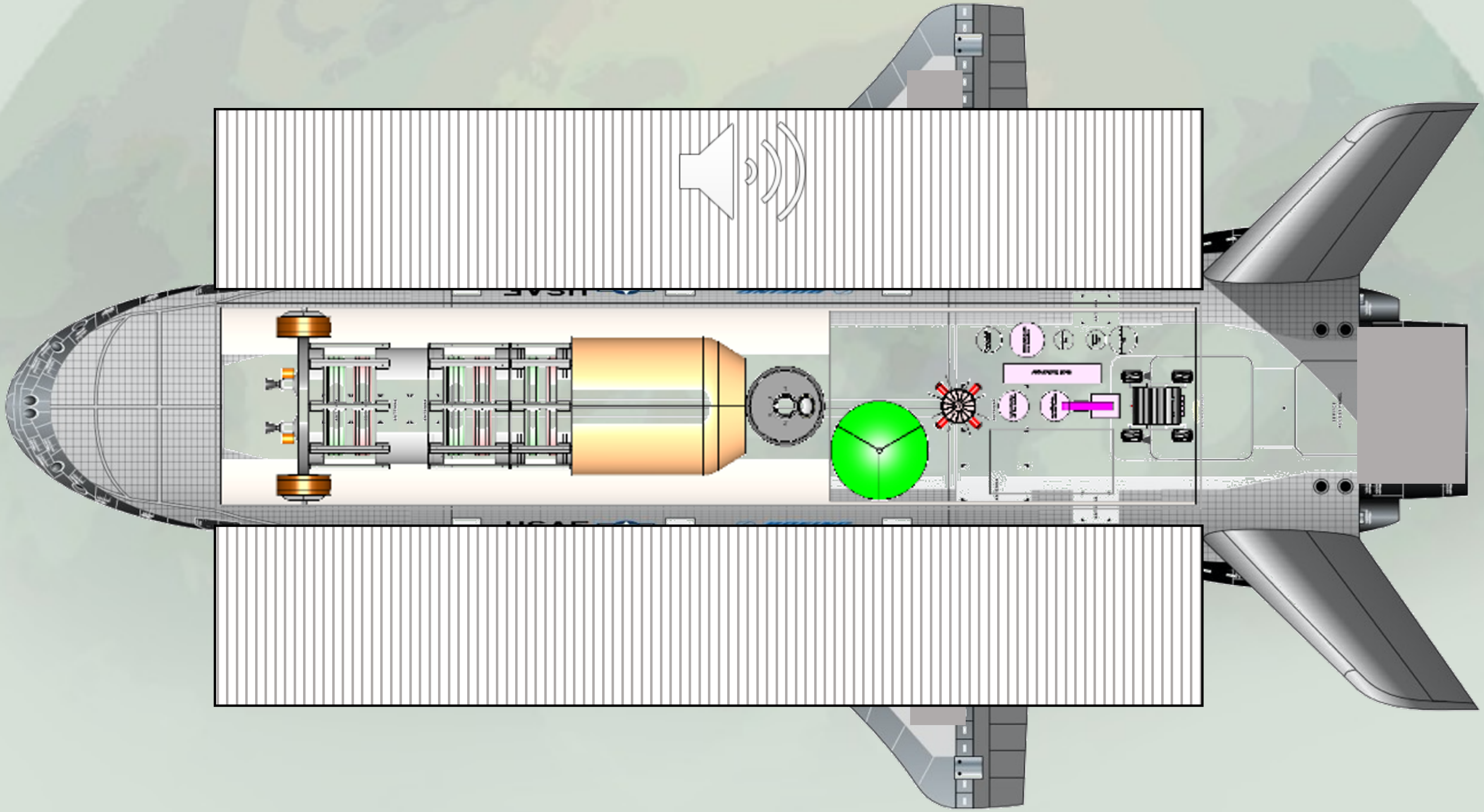


# Mission Elements with Deployed Launch Vehicle Elevated

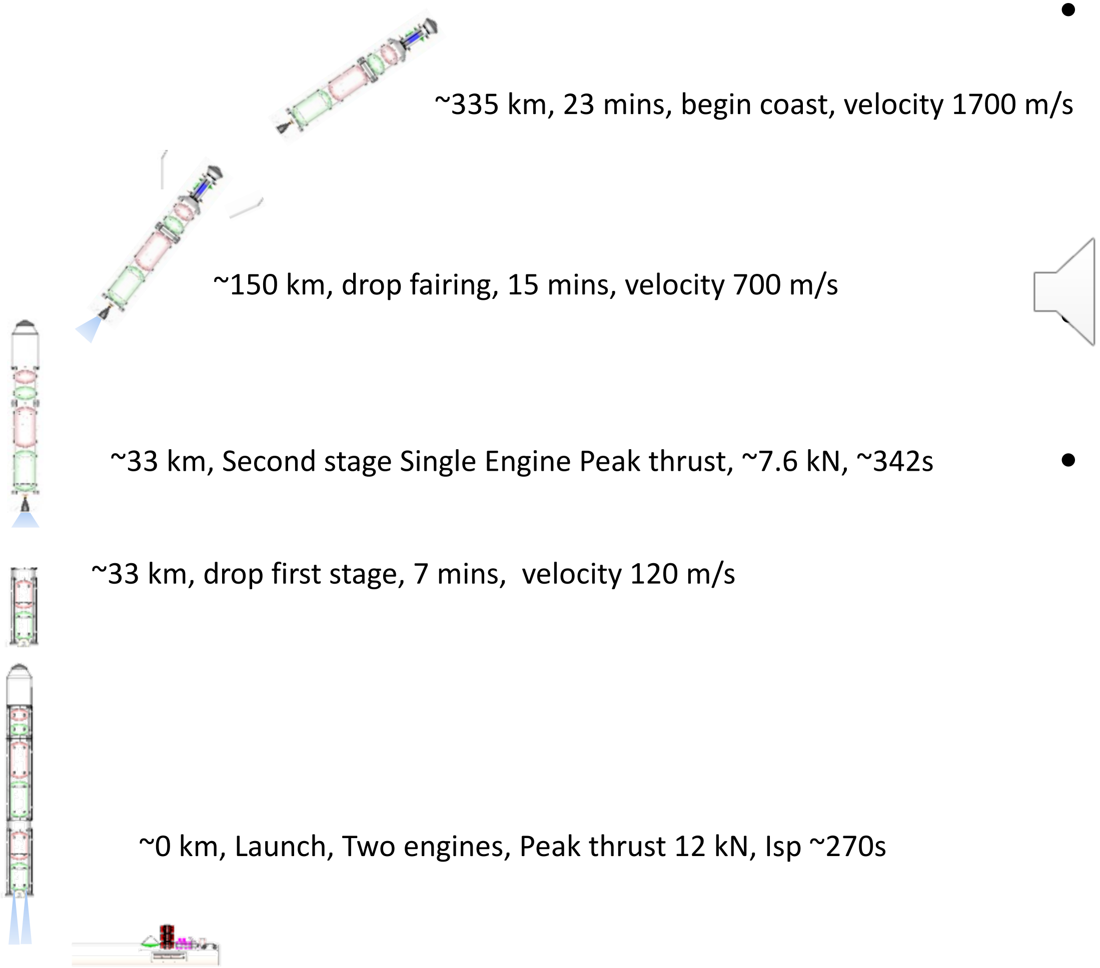


# Propellant Plant and Rocket Delivery

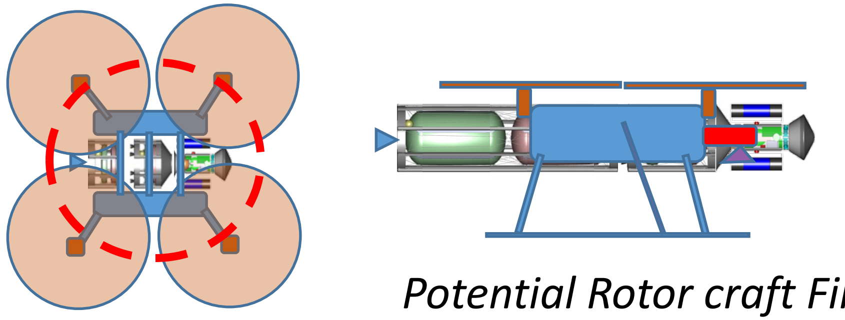
Notional High L/D Lifting body:
sized from X-37C design



# Launch To Titan Orbit

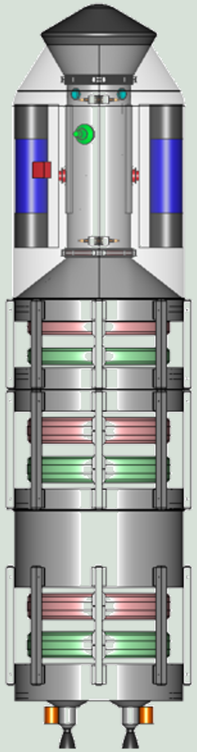




- *The Good news: Titan Gravity only ~ 1/7$^{th}$ of Earth*
- *The Bad news: Density of the atmosphere is >5X of earth and goes up >4X higher!*
  - *Causes large drag impact on rocket –*
  - *Need to use a skinny rocket or Fly up above thick atmosphere*
- *Phase 1 Solution: Skinny rocket*
  - *Total ΔV: ~4 km/s but includes Drag loss ~1 km/s*
- *Further Work for Phase 2:*
  - *Consider air launch (to eliminate 1stage), use lift*
  - Estimates show that required ISRU propellant mass and production time halved!

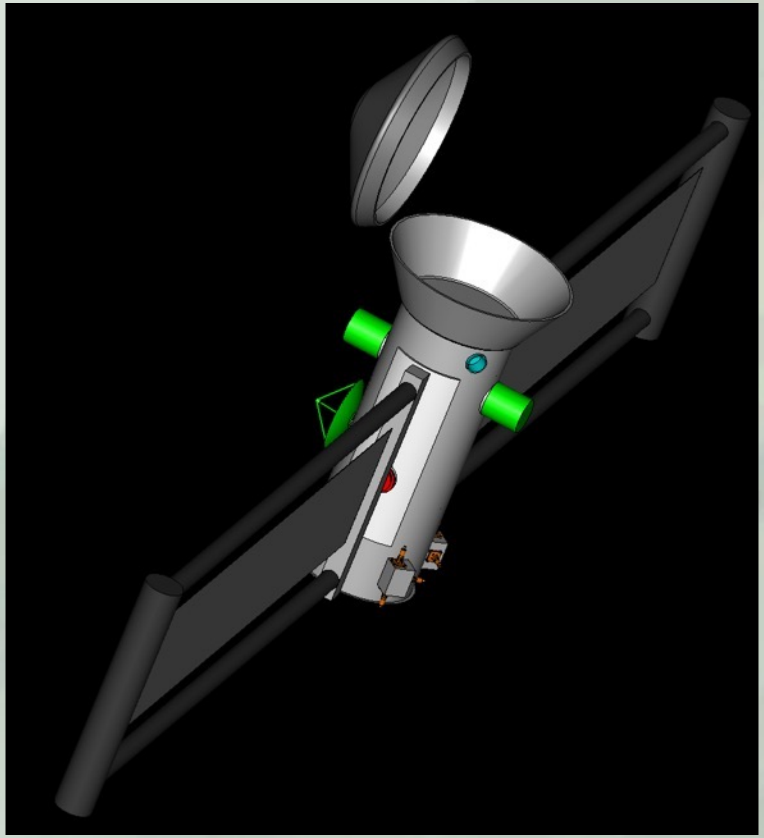


*Potential Rotor craft First Stage*

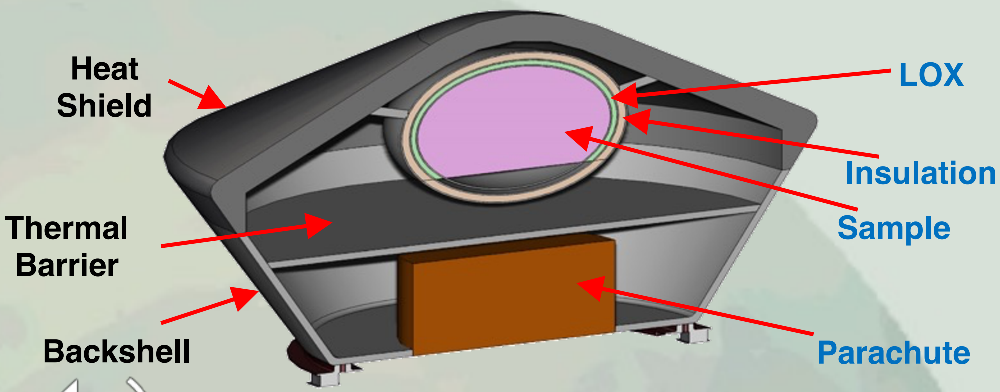
# Return vehicle



Return Stowed in Compressed Launcher



Deployed Return with Aeroshell Open to Cool Sample

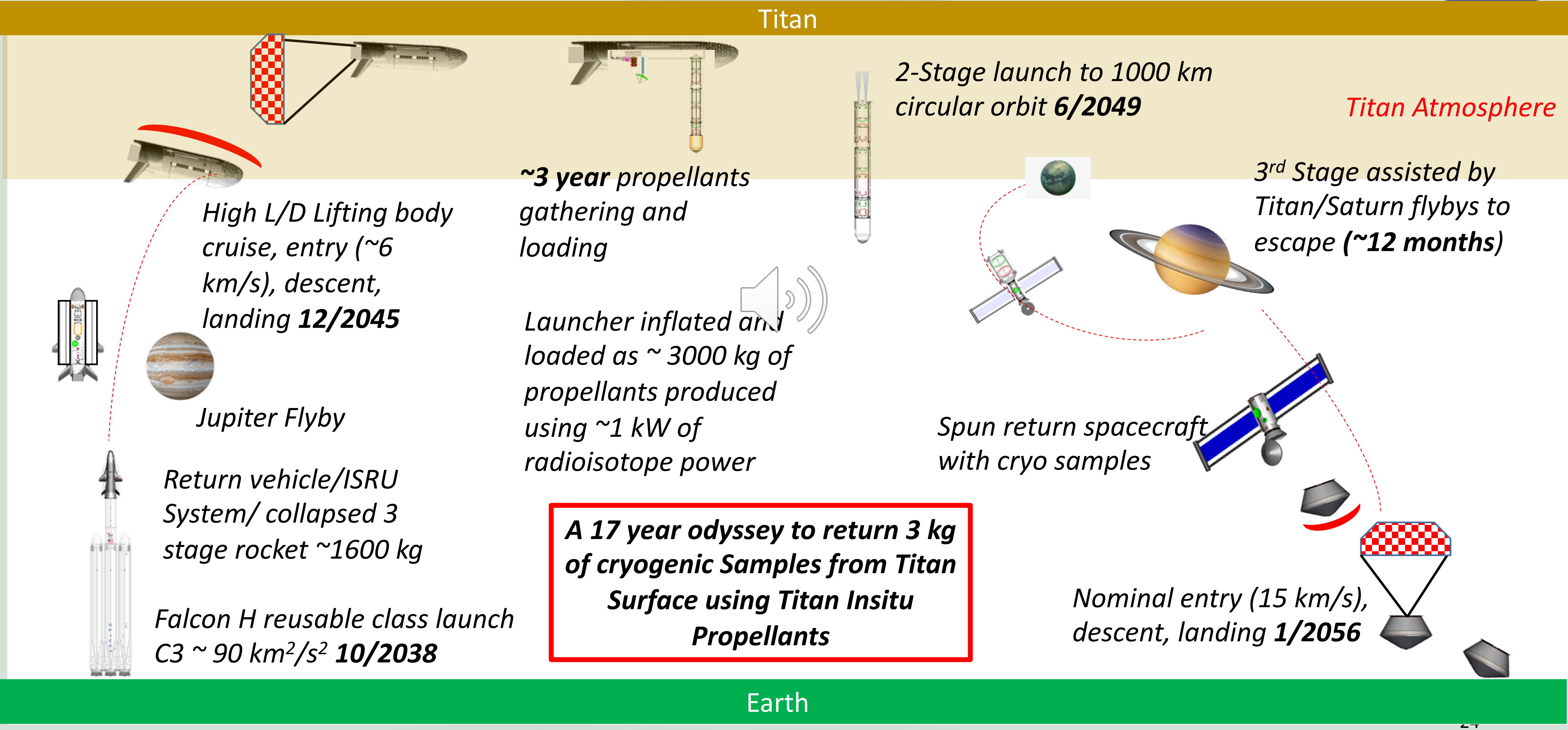



Stardust

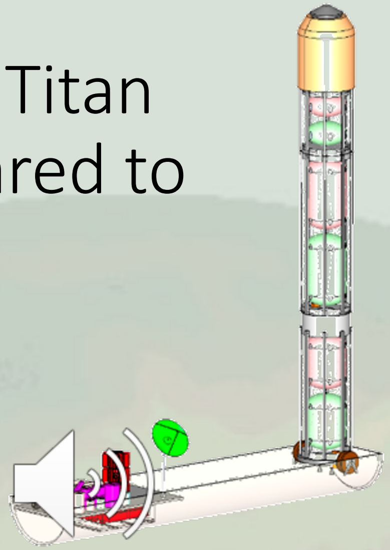
Design is based on the Stardust heat shield and entry vehicle design

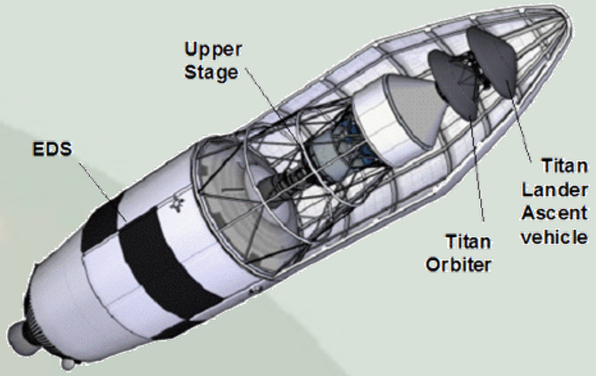
Configuration modeling by Tom Packard, NASA Glenn

# Overall Mission Conops



# Advantages/Challenges of Titan ISRU Sample Return Compared to Bringing Propellants






| Parameter | ISRU Propellant Approach: NIAC, Oleson, Landis, Lorenz (2021) | Bring Propellants: TITAN SAMPLE RETURN MISSION CONCEPT B. B. Donahue, JANNAF 2010 |
|---|---|---|
| Mass (less EDL systems) | ~1900 kg | ~9000 kg |
| Launcher | Falcon H | SLS |
| Time (round trip) | 17 yr | 13 yr |
| Power | ~1000 We Radioisotope Power Systems | ~100 We |
| Critical Technologies | Deployable cryogenic tanks/rocket, Gathering Ice/atmospheric methane, LOX/LCH4 processing | Orbiter Aerocapture, orbit rendezvous/docking in Titan orbit |

***Almost 80% reduction in mass at the expense of an additional 3-4 years of propellant gathering/production time and 900We of added radioisotope power***