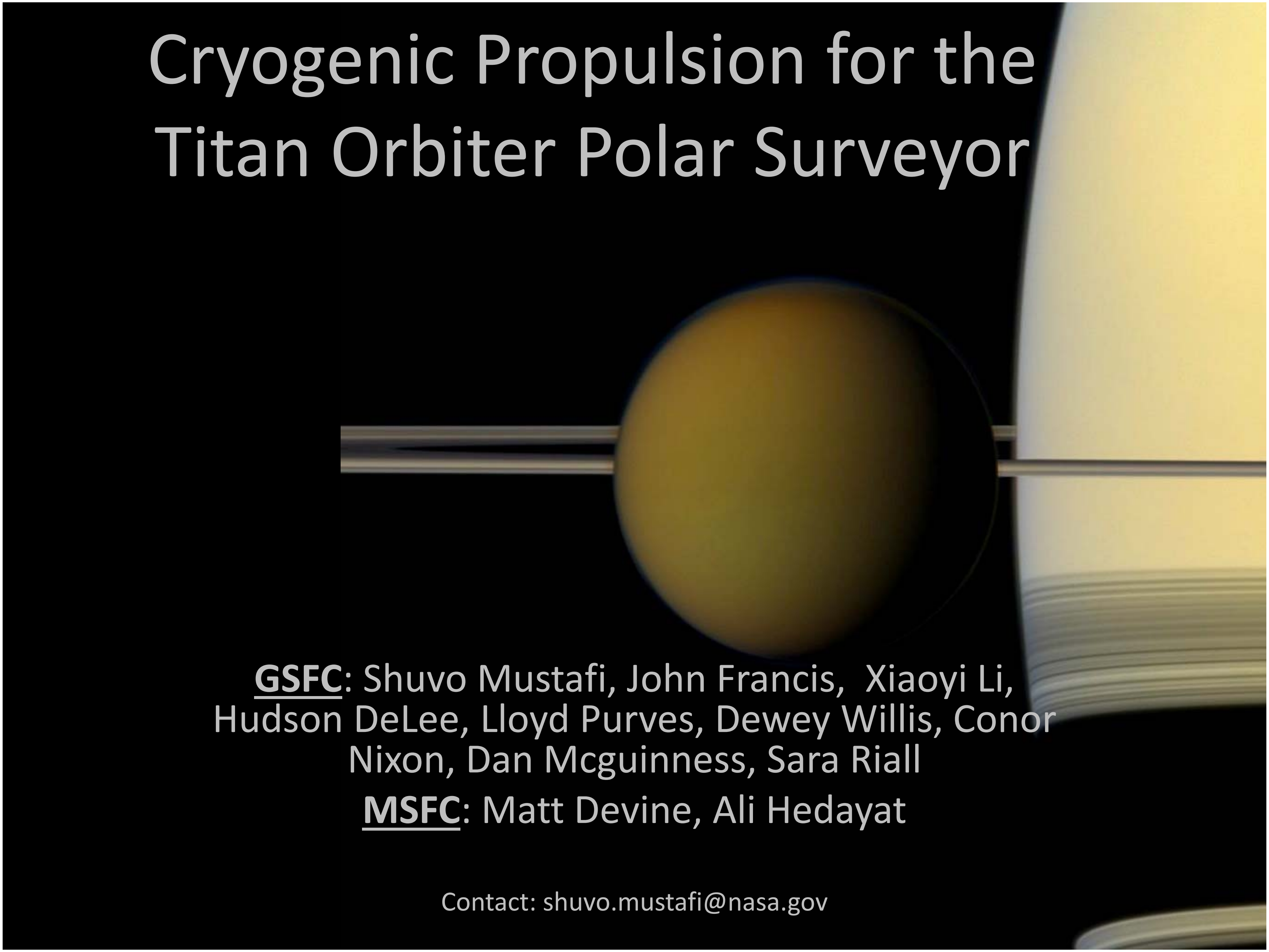

# Cryogenic Propulsion for the Titan Orbiter Polar Surveyor

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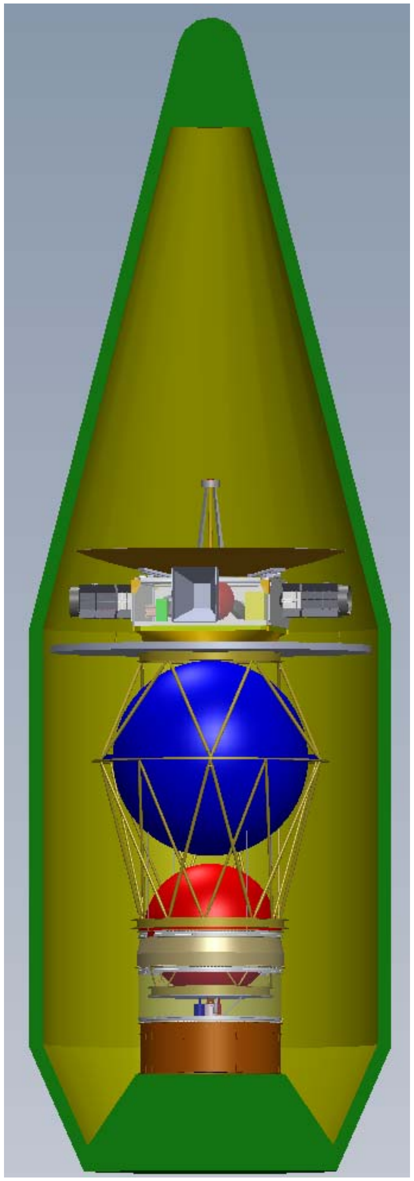
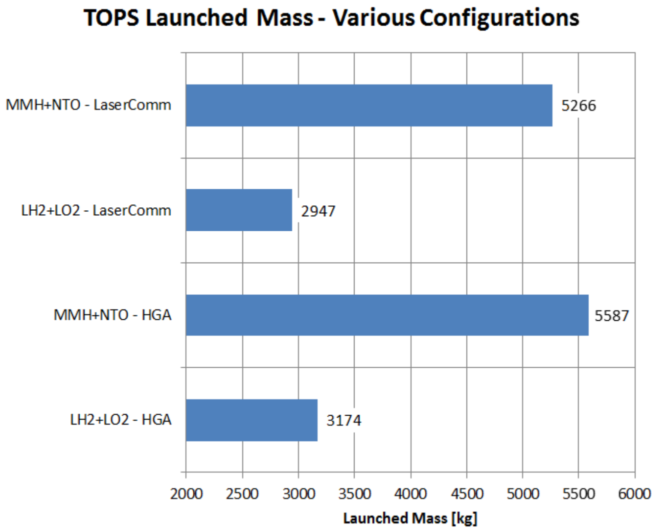
# Cryogenic Propulsion for Planetary Science Missions

- Why is liquid hydrogen (LH2) useful?
- LH2+LO2 Storage
- Subcooling Technique
  - Thermodynamic Cryogen Subcooler (TCS)
  - Launch Pad Cryocoolers
- Current Work
  - Missions of Interest: *Any mission that requires high ΔV and high delivered and high returned mass to and from planets, moons, asteroids, comets with lower spacecraft wet mass.*
  - *Examples:*
    - Titan Orbital Polar Surveyor (TOPS)
    - Europa or Enceladus Missions
    - Lunar Sample Return Mission
    - Comet and Asteroid Missions
  - Hardware: Subcooling using launchpad cryocooler demonstration
- Roadmap
- Summary



# Why LH2+LO2 vs Hypergols (MMH+NTO)



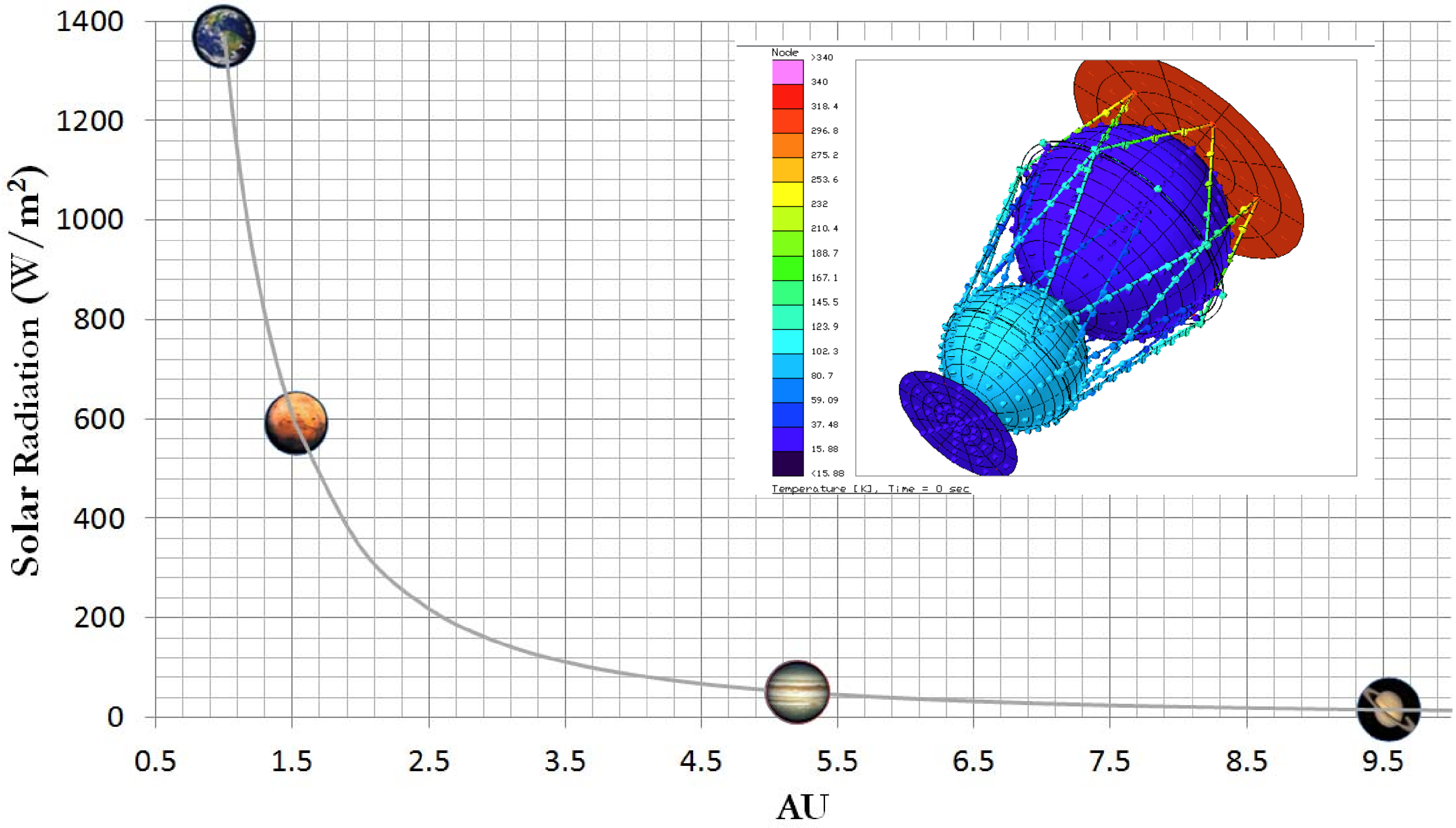
- LH2+LO2 provides the highest specific impulse of any practical chemical propulsion system.
- **For the TOPS Mission this means a 44% reduction in launched mass. This mission can be completed using an Atlas Launch Vehicle using LH2+LO2 but not with MMH+NTO.**
- **LH2+LO2 can enable missions that deliver/recover substantially larger masses to/from the target destinations, or launch the mission on smaller and cheaper launch vehicles, or both.**
- **LH2+LO2 can be also be used to reach the surfaces of atmosphere less planetary bodies without exposing the target bodies to hazardous and toxic hypergols, *eg. Europa or Enceladus***
- **If required the LH2+LO2 could also provide an alternative to heavier batteries with the use of fuel cells, *eg. shadowed regions of the moon.***

# TOPS Launch Vehicle Performance

| | LH2+LO2 - HGA | MMH+NTO - HGA | LH2+LO2 - LaserComm | MMH+NTO - LaserComm |
|---|---|---|---|---|
| Total Delta - V | 5887 | 5887 | 5887 | 5887 |
| Dry Mass - Nominal [Kg] | 739 | 878 | 739 | 878 |
| Dry Mass - With Variable Dry Mass Contingency [Kg] | 880 | 1053 | 880 | 1053 |
| Launch Mass with Variable Dry Mass Contingency [Kg] | 3174 | 5587 | 2947 | 5266 |
| AV 431 - Separated Launch Limit [Kg] | 2827 | 2827 | 2827 | 2827 |
| AV 431 - Separated Launch Mass Margin [%] | -11 | -49 | -4 | -46 |
| AV 541 - Separated Launch Limit [Kg] | 3105 | 3105 | 3105 | 3105 |
| AV 541 - Separated Launch Mass Margin [%] | -2 | -44 | 5 | -41 |
| AV 551 - Separated Launch Limit [Kg] | 3430 | 3430 | 3430 | 3430 |
| AV 551 - Separated Launch Mass Margin [%] | 8 | -39 | 16 | -35 |

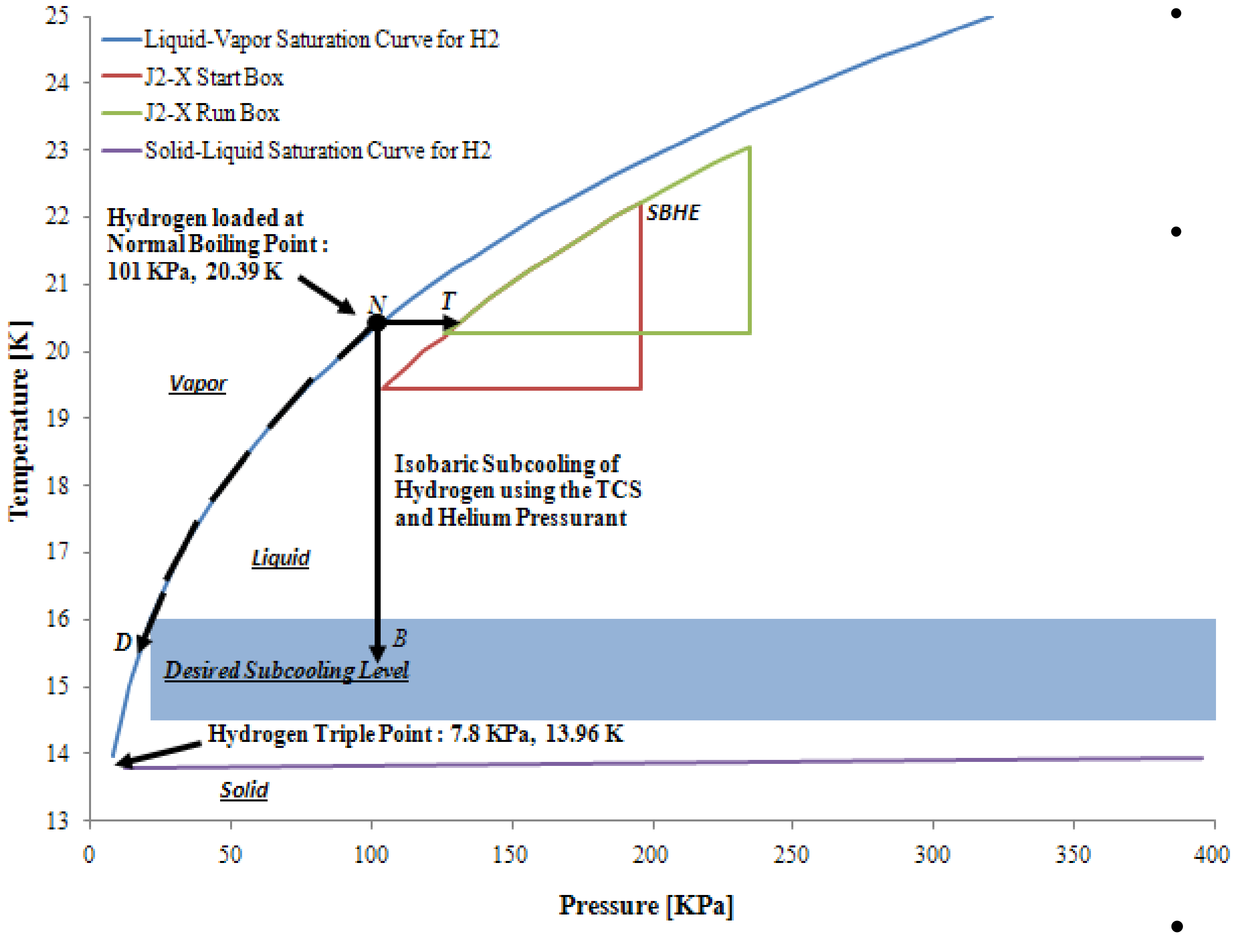
Includes a 25% Dry Mass Margin

# LH2+LO2 Storage



Combination of Smart Cryogenic Design with Subcooling and Lowering Solar Flux (artificially and naturally) allows long term storage of LH2+LO2 for Planetary Science propulsion

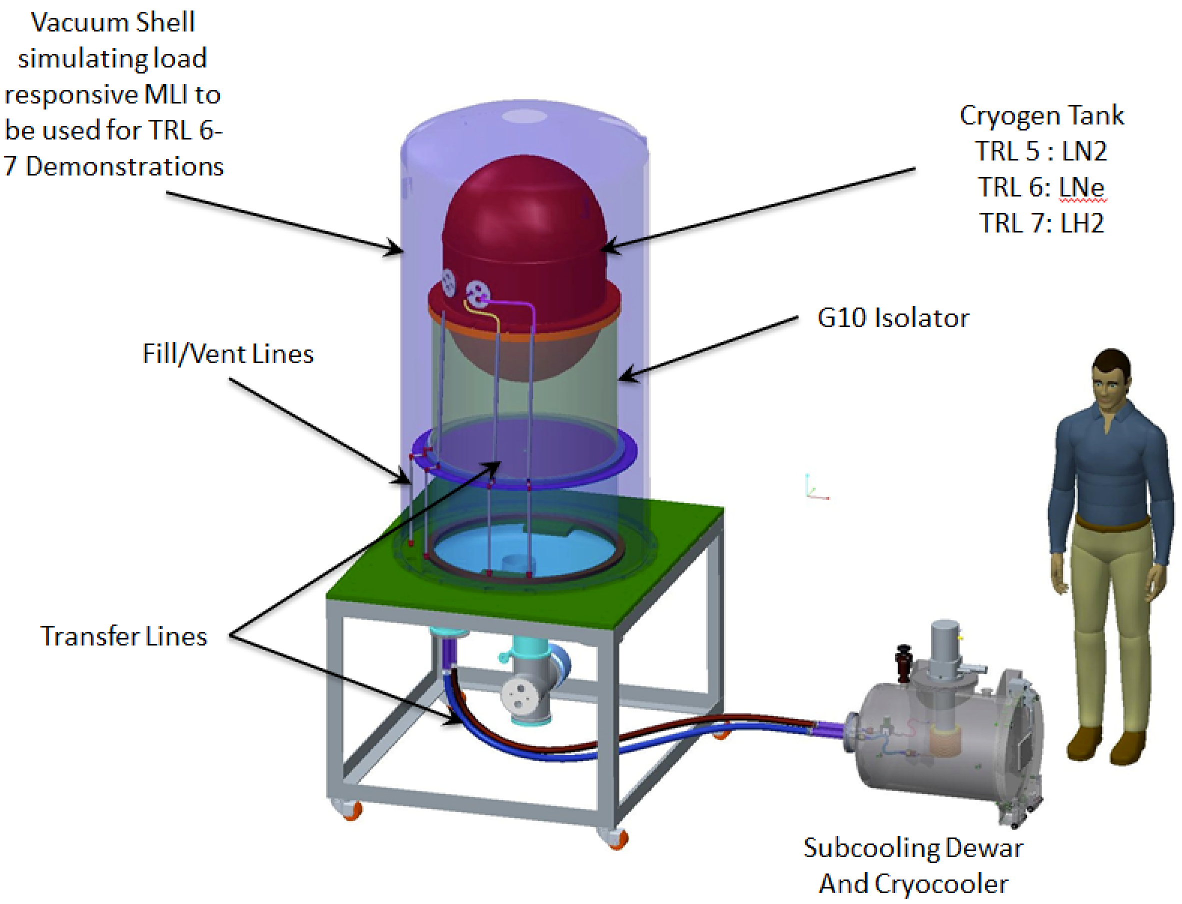
# Pre-Launch Isobaric Subcooling for Storage



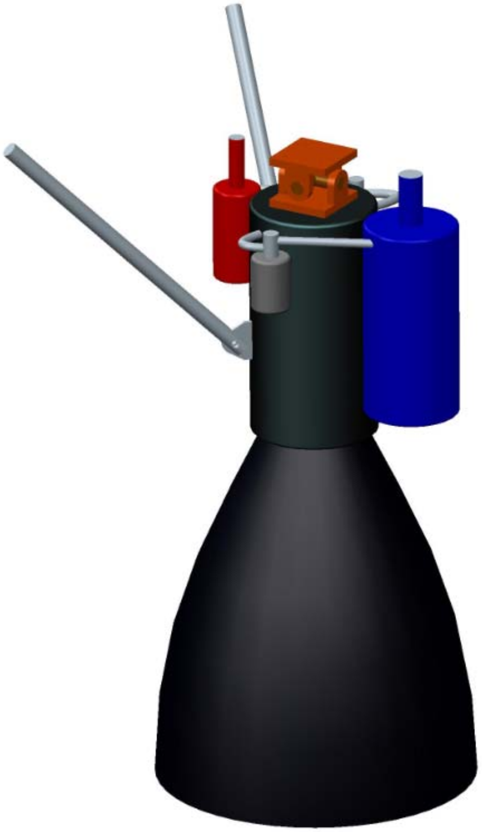
- RL-10s operated with densified hydrogen
- Other Engines would have to be qualified

- ***Objective:*** Delay venting of the cryogen as long as possible.
- **Fluid Conditioning**
  - Engine Start Box High End (SBHE)
  - Fluid at Normal Boiling Point (N)
  - Isobaric Subcooling (B)
    - Proposed fluid conditioning method
- **Physics**
  - Substantially lower heat flux in-space than in-atmosphere exploited or enhanced
    - Dominant in-space load < 0.25 W/m$^2$
    - Dominant in-atmosphere load >63 W/m$^2$
  - Available heat capacity of the stored cryogen - Unexploited
    - Heat Capacity from N to SBHE = 18.2 KJ/Kg
    - Heat Capacity from B (@ T=16 K) to SBHE = 55.0 KJ/Kg
  - Isobaric Subcooling to 16 K allows hydrogen to absorb ~ 3x the energy before venting has to be initiated => hold time before venting for isobaric subcooling is ~ 3x
- Pre-launch Subcooling using launch pad subcoolers or a thermodynamic cryogen subcooler

# Subcooling Demonstration

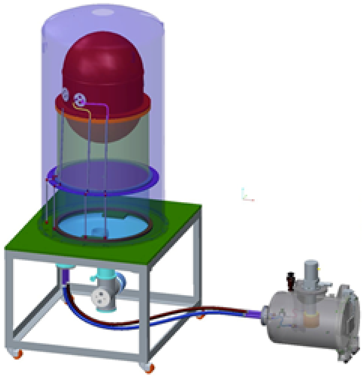


# 490 N LH2+LO2 Engine

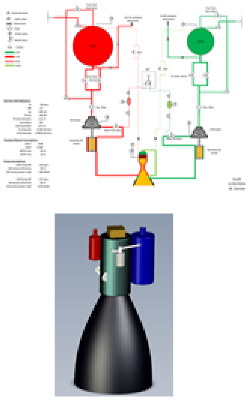


Joint GSFC+MSFC Development Effort

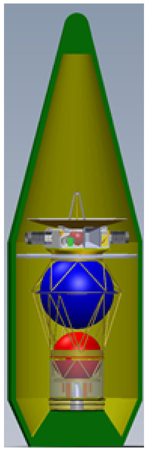
# Roadmap



2015: TRL 5



2017: TRL 6



2022: TRL 9

# Summary: Cryogenic Propulsion for Planetary Science Missions

- Cryogenic LH2+LO2 Propulsion provides high specific impulse chemical propulsion for planetary science exploration
- Provide high ΔV and high delivered and high returned mass to and from planets, moons, asteroids, comets with lower spacecraft wet mass.
- For the TOPS mission, subcooled LH2+LO2 reduces launched spacecraft mass by 43% and allows for launch on an Atlas launch vehicle. The same mission cannot be performed using a MMH+NTO propulsion and an Atlas launch vehicle.
- Subcooling cryogenic propellants on the launch pad enables multi-year storage of LH2+LO2 without adding launched mass for LH2+LO2 storage