Cryogenic Hydrogen Oxygen Propulsion System for Planetary Science Missions

GSFC: Shuvo Mustafi, Lloyd Purves, Conor Nixon
MSFC: Alber Douglawi, Ali Hedayat, Steven Simpson

Cryogenic Hydrogen Oxygen Propulsion System (CHOPS)

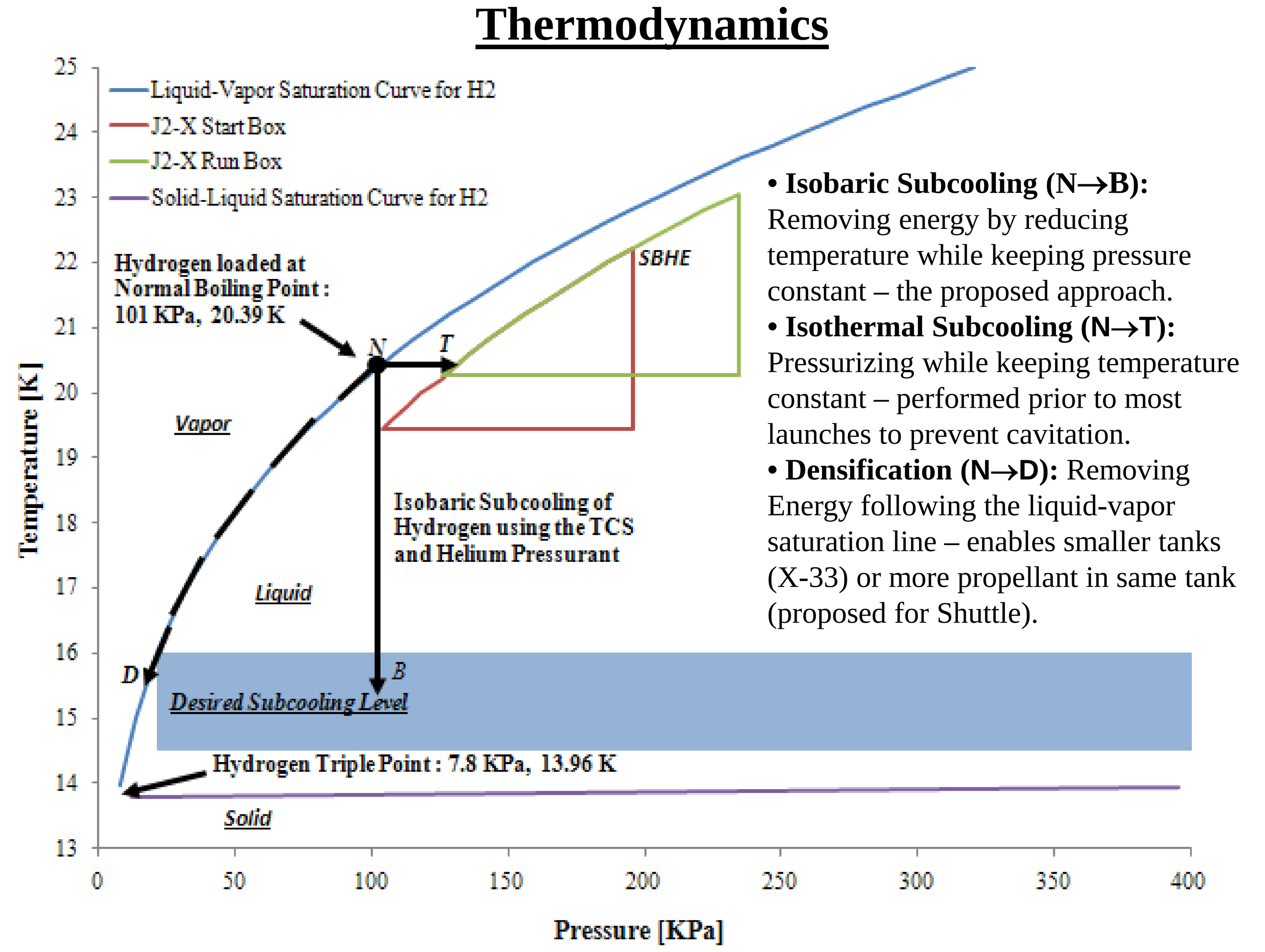
$$m_{Propellant} = m_{Dry}\left[e^{\{\Delta V/(g I_{sp})\}} - 1\right]$$

$$I_{sp,LH2+LO2} = 420s - 460s$$

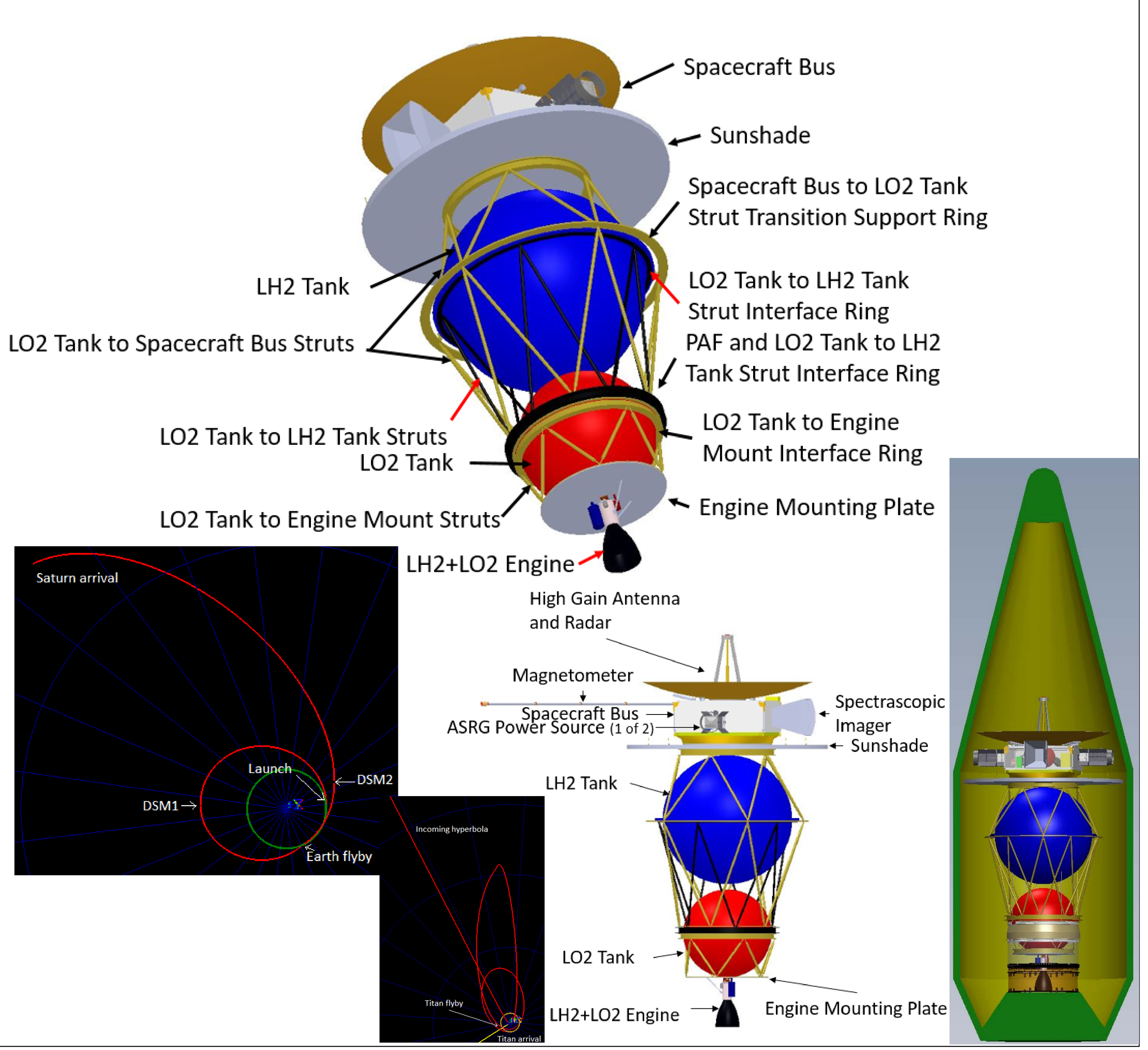
$$I_{sp,MMH+NTO} = 310s - 329s$$

- Liquid Hydrogen (LH2) and Liquid Oxygen (LO2) provide the highest specific impulse of any practical chemical propulsion system. → Highest payload mass fraction.
- New storage technologies: advanced MLI, pre-launch subcooling, advanced spacecraft design allows passive storage of cryogenic propellants for multi-year planetary missions
- **Mission Design Laboratory (MDL) study of a representative mission to Titan: Titan Orbiter Polar Surveyor (TOPS).**

Thermodynamics



Titan Orbiter Polar Surveyor (TOPS) – Representative Mission

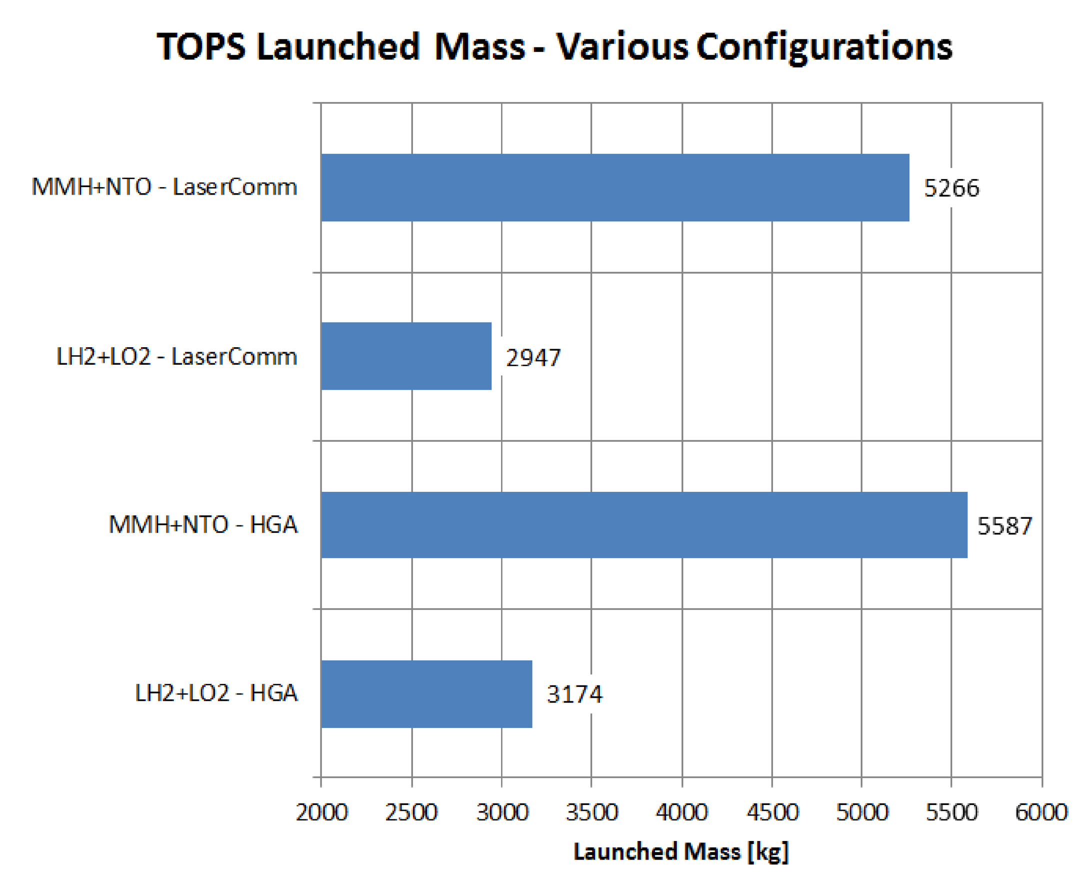


Mission Design Parameters

- Mission Duration: 10.5+ years
- Cryogenic Propellant Storage Mission: 8.5+ Years
- Launch in 2022
  - Jupiter not available for gravity assist
- ΔV = 5887 m/s
- 7 Engine Burns
  - Shortest Burn = 2.2 min.
  - Longest Burn = 56 min.
- Launch on an existing Atlas Launch Vehicle
- Science Payload Mass = 53.3 kg
- Non-Main Propulsion Dry Mass = 595.1 kg
- No Active Cooling during Mission

Mission Design Study Results

- TOPS that is propelled by LH2+LO2 saves 43% in launched mass over TOPS that is propelled by MMH+NTO
- TOPS (with the 25% dry mass contingency) can be launched on an Atlas V 551 with a 8% launch mass margin and with more margin on Falcon Heavy and SLS
- This mission does not close on any Atlas V vehicle if a standard hypergolic propulsion option is used.
- A LH2+LO2 cryogenic propelled TOPS mission could fit comfortably as a New Frontiers mission and mission closes without a Jovian gravity assist.
- Confirmed the basic viability and value of the LH2+LO2 cryo propulsion system.
- Provided a much better understanding of how to incorporate this kind of LH2+LO2 cryo propulsion into an actual mission.
- Generated a number of promising approaches for how the cryo propulsion could be further improved in terms of I_{sp}, mass, envelope, thermal control, and required electrical power.
- Efforts are underway to further reduce the TOPS expected dry mass to fit in even smaller launch vehicles without science reduction.

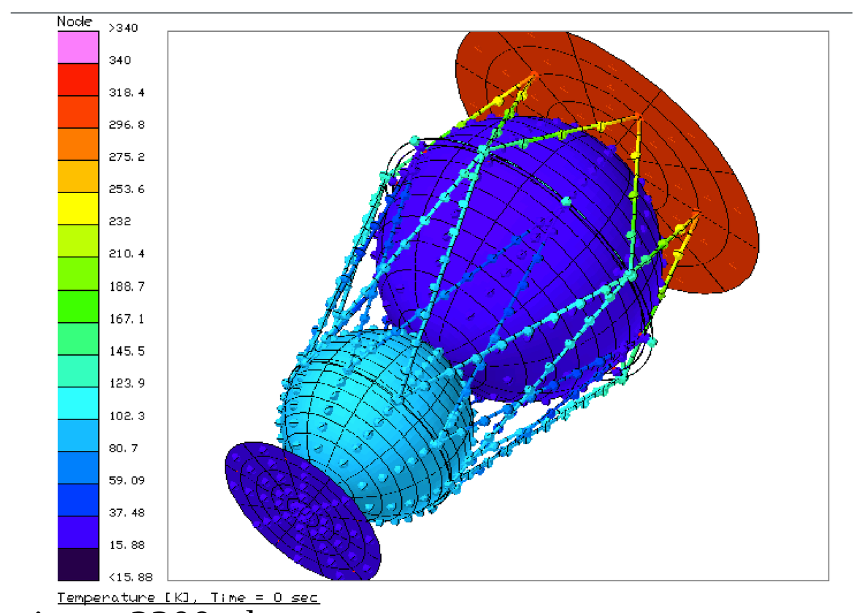


Parametric Launch Mass Savings for using LH2+LO2 Vs MMH+NTO (MEV) [kg]

	ΔV [m/s]		
Non-Main Propulsion Dry Mass (CBE) [kg]	**2500**	**5000**	**7500**
250	118	843	3,664
500	255	1,469	6,251
1000	529	2,721	11,425

CHOPS Storage Capabilities

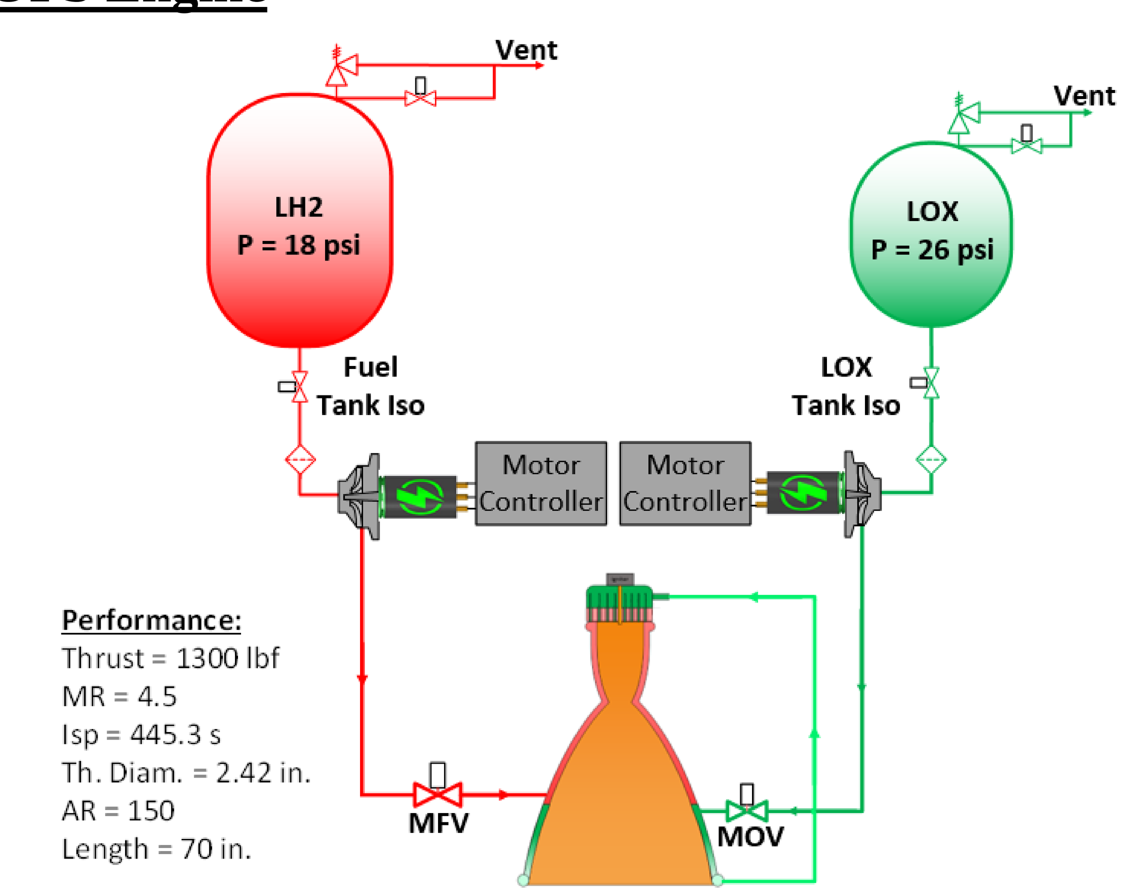
TOPS Mission Results



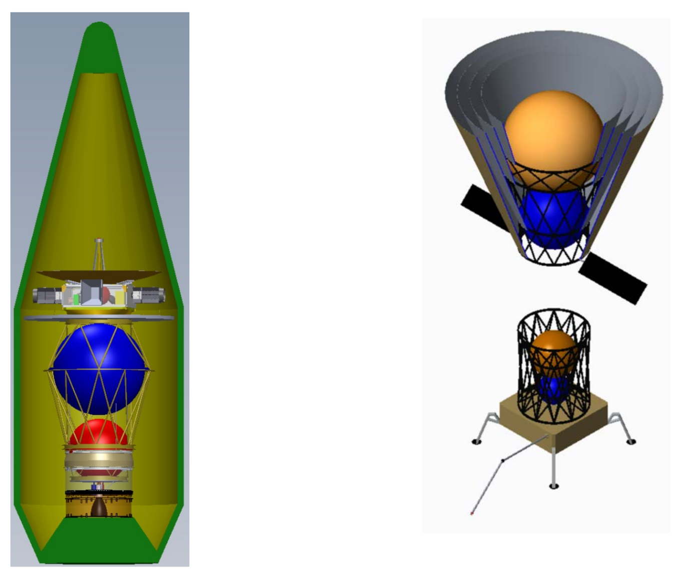
- Duration of Propellant Storage Mission >8.5+ Years
- LO2 Tank
  - Deep Space Nominal Heat Loss: 42 mW
  - No LO2 loss due to phase change
- LH2 Tank
  - Deep Space Nominal Heat Gain = 71 mW
  - -Maximum Heat Input During Burns = 191 W
  - -Duration of Longest Burn < 57 min.
  - -Minimal 10% loss of LH2 due to phase change
    - -Reduction by active cooling possible but unnecessary
- LH2+LO2 Launched Mass Savings over MMH+NTO for TOPS mission = 2300+ kg (43% launch mass reduction)

CHOPS Engine

- CHOPS engine uses BLDC motors to drive the propellant pumps.
- The motors are controlled using battery-powered inverters. The engine can be throttled through motor speed control.
- Electric cycle engines offer cost savings and simplicity when compared to traditional pump-fed engines and offer performance benefits when compared to pressure-fed systems.
- Power required is about 15 kW for both pumps combined. Rechargeable high energy density batteries are used during engine firing.
- Active Cooling Circuits for autogenous repressurization.
- Gimballed for Thrust Vector Control (TVC).



Future Work



CHOPS Missions being investigated by GSFC and MSFC

- Technology Demonstrations needed for CHOPS Storage and CHOPS Engines
- CHOPS for planetary science missions will significantly enable or enhance many planetary science missions with
  - Higher launch mass savings than all other practical conventional chemical propulsion systems
  - Lower potential for planetary contamination with water as the only propulsion product for all planetary science missions
  - Mission enabling for lander and sample return missions for planetary science targets without atmosphere
  - Opens up new opportunities to explore outer planets and their moons by orbiting, landing and/or sample return, potentially without the necessity of proper planetary alignments for gravity assists.
  - Increased science in the near term as well as providing a cost-effective, safe and clean technique for exploration of our solar system.

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Contact:
shuvo.mustafi@nasa.gov
301-286-7436