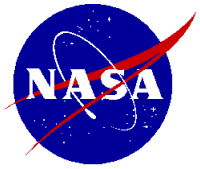

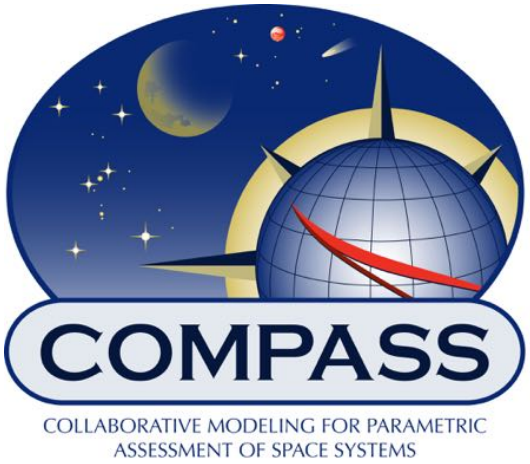

A Cubesat for Asteroid Exploration

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COMPASS Team at NASA Glenn:
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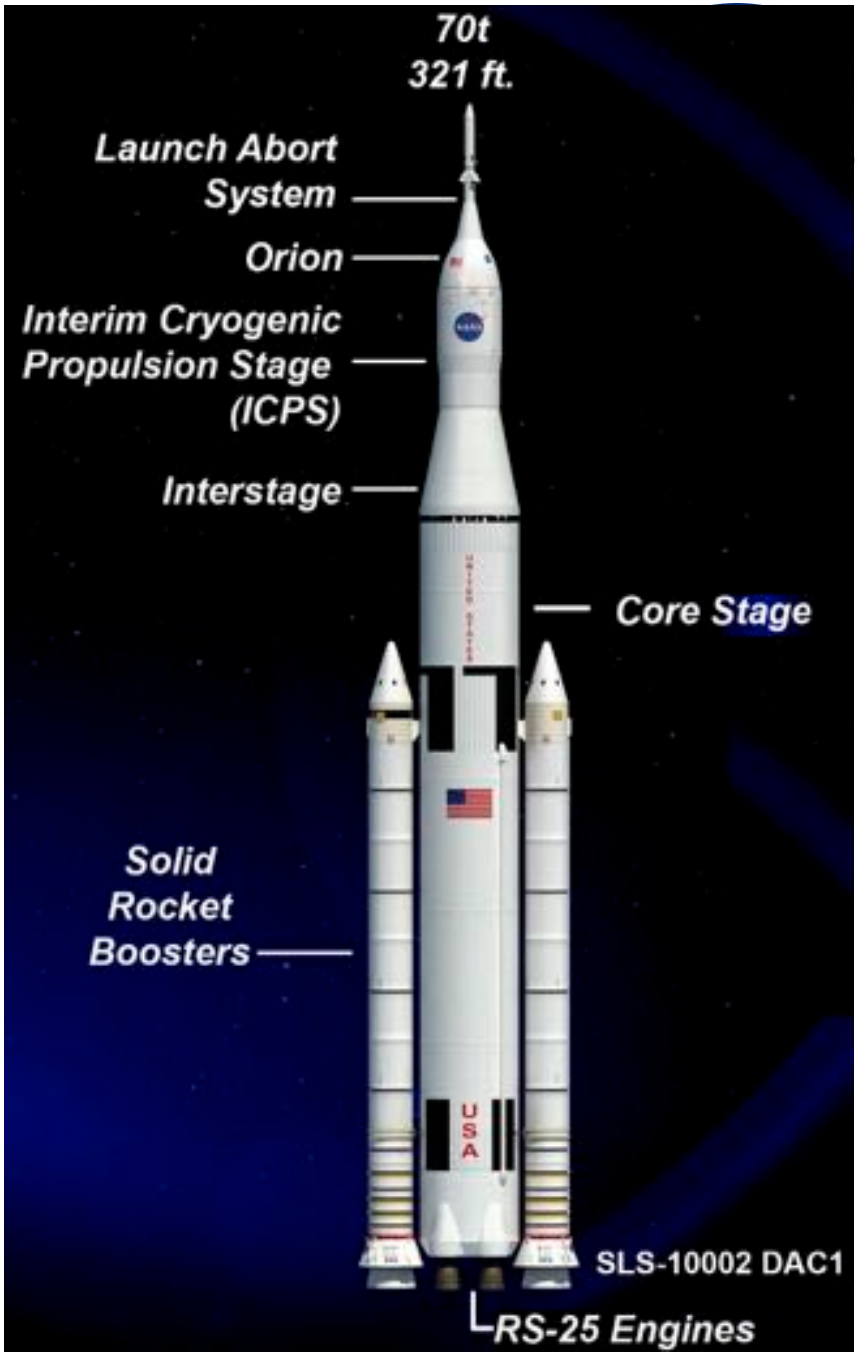
Collaborating Institutions:
Busek (propulsion); COSMIAC (spacecraft integration); Case Western (Ralph Harvey, Asteroid Science lead); Planetary Science Institute (Asteroid Science)

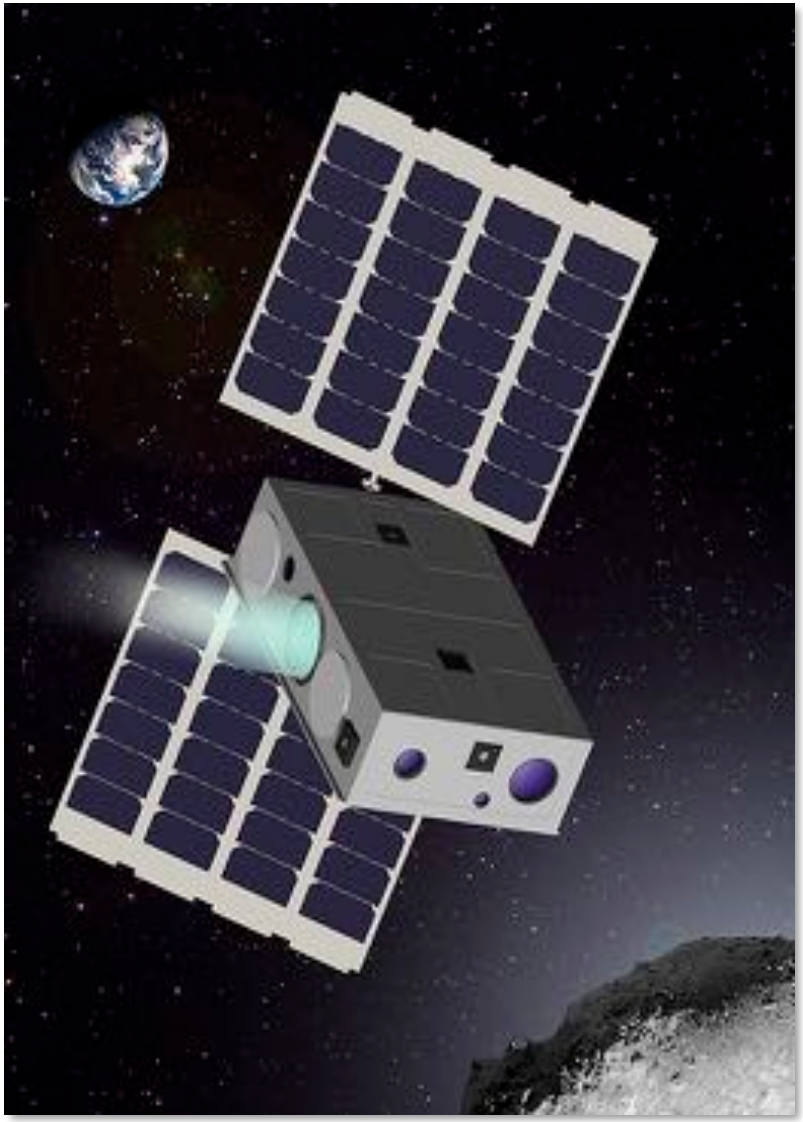
Background:

- Purpose:
  - a cubesat design for SLS launch opportunity for EM-1
  - EM-1 launch (2018) to a lunar free return trajectory.
  - A small ΔV before lunar fly-by can adjust the escape trajectory to C3 =0 (co-orbital to Earth)
- Mission: **visit an asteroid**



Highly Constrained Project:

- **Size** constrained:
  - 6U
  - about the size of a large shoebox
- **Mass** constrained
  - 12 kg total mass
  - including 1.3 kg assumed growth
- **Propulsion** constrained
  - no energetic components
- **Cost** constrained
  - $5.6 million dollar cost cap
  - about $5 million after subtracting required cost reserves
  - (does not include launch)



Choice of Target

- 12874 close approaches by asteroids were analyzed
- List narrowed down:
  - nearest approach no earlier than 2019 (>1 year after launch date)
  - Nearest approach no later than 2020.
- **2001 GP2 was chosen as a target.**
  - From visual magnitude, estimate* ~18-meter diameter.

- Fly-by and Rendezvous missions analyzed
- From escape, ΔV of ~400 m/s needed for May 2020 fly-by.
  - October 2020 fly-by was just outside the window of the solicitation
- ΔV ~2000 m/s needed to achieve a rendezvous.

*depending on asteroid albedo

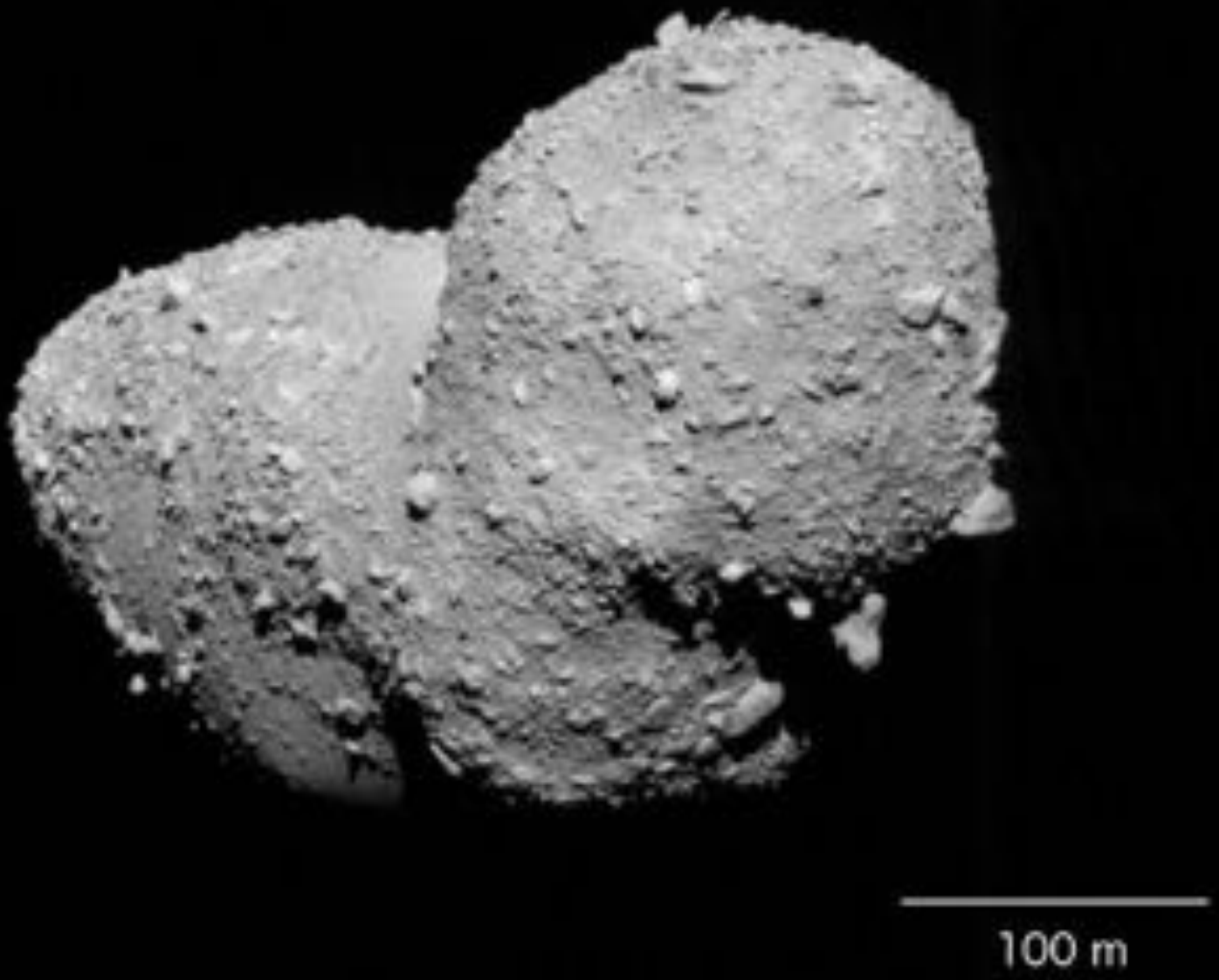
Asteroid 2001 GP2 Earth Fly-by

- Closest pass: Oct 3, 2020
- Closest approach at 0.5 to 4.3 time Lunar distance
- (~100,000 to 1 million miles)
  - Further observations will decrease uncertainty
- V relative: 2.37 km/sec

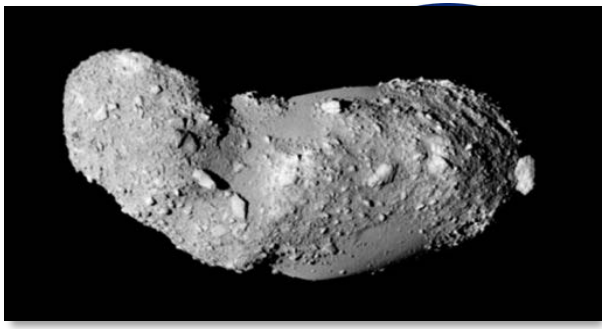
Near Earth asteroid Eros (viewed by the NEAR spacecraft)

Itokawa: the smallest asteroid ever visited by a spacecraft

viewed by the Hayabusa spacecraft



What makes Asteroid 2001 GP2 Interesting?

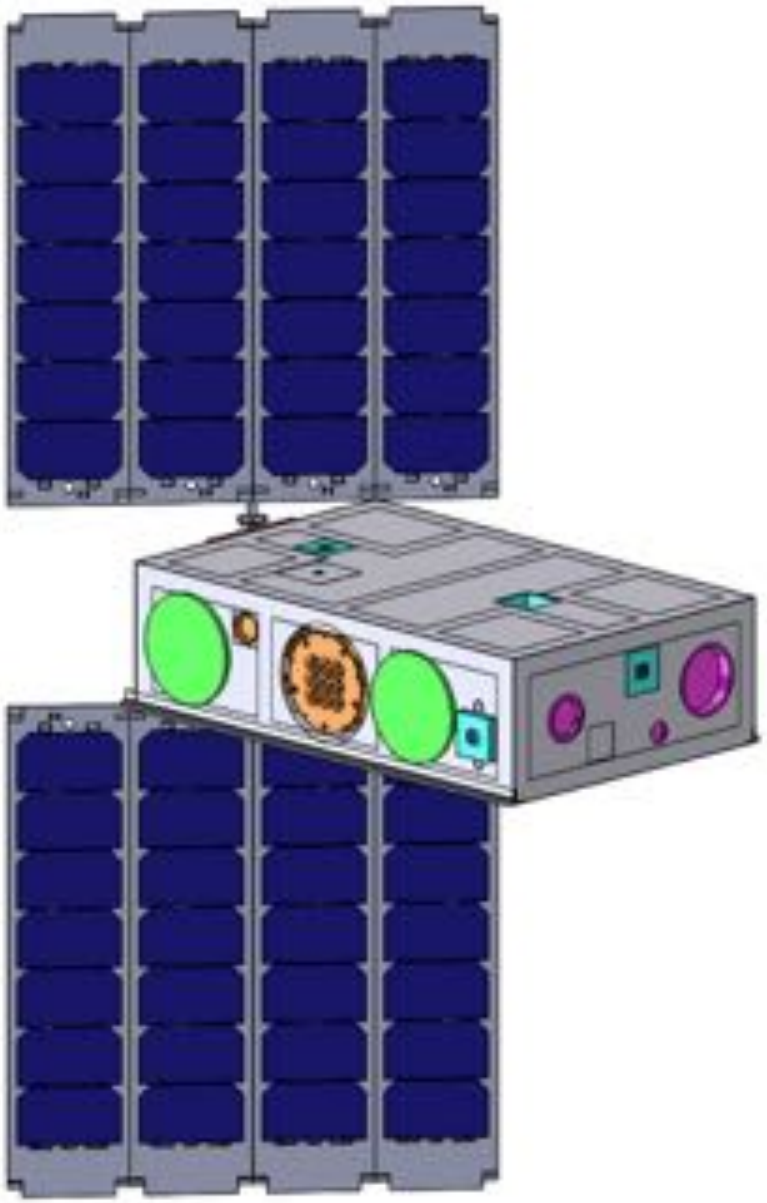


Asteroid Itokawa

- 10-20 meters in diameter
  - **Two orders of magnitude** smaller than any other asteroid ever visited
  - Typical of “city killer” impact threats (much more frequent than extinction-level threats)

Representative of a whole class of objects that are numerous and interesting, but have never been observed up close

DAVID (Diminutive Asteroid Visitor using Ion Drive)



- 6-U cubesat
- Mass limit 12 kg
- Design must include margin on all systems

Propulsion Trade Off

Mission is mass and volume constrained

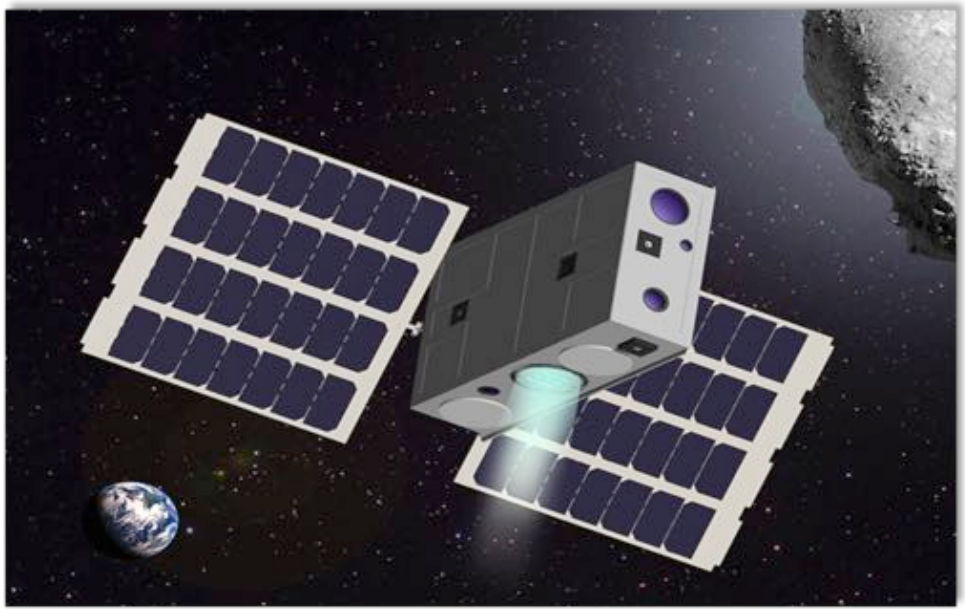
Electric propulsion systems:

- High Specific Impulse: Low propellant use, high power requirement
  - If Isp is too high, the power system mass dominates the system
- Low Specific Impulse: High propellant use, low power requirement
  - If Isp is too low, the propellant mass dominates the system

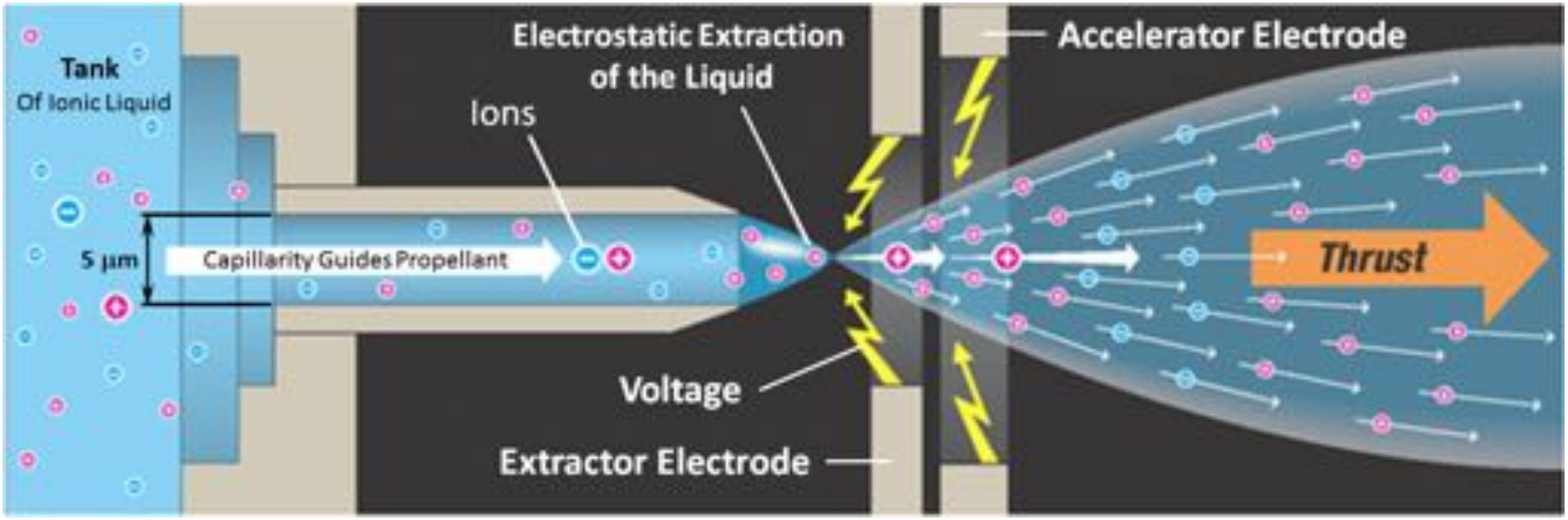
Propulsion Choice

- Trade-off study included many propulsion systems
- **Single PUC electrospray thruster chosen for baseline design**

- Rendezvous case requires higher Isp and larger solar array
  - ion engine needed for ΔV ~2000 m/s



Electrospray Thruster



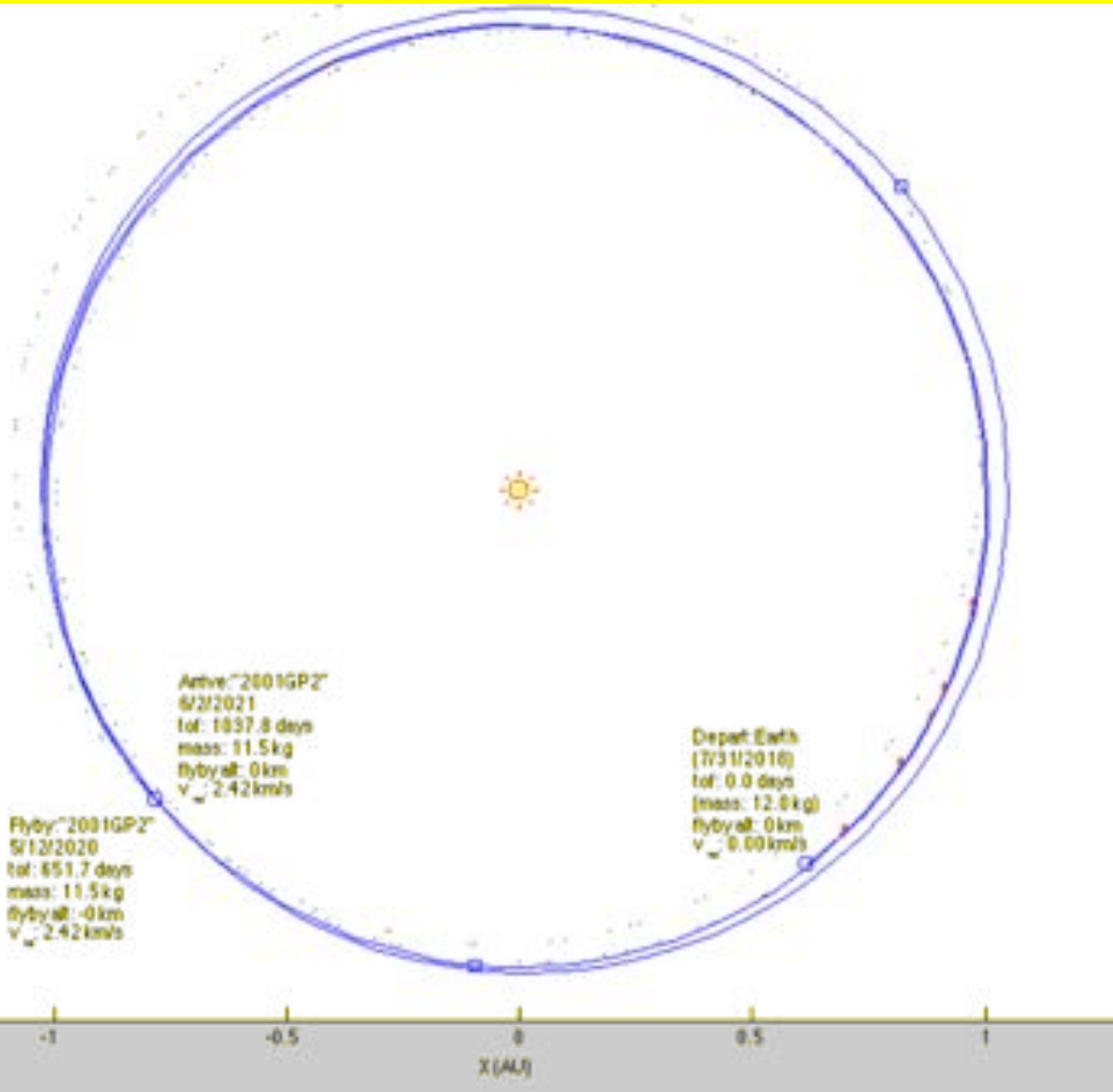
Propellant:
high density ionic liquid

LISA Pathfinder Thruster Integration

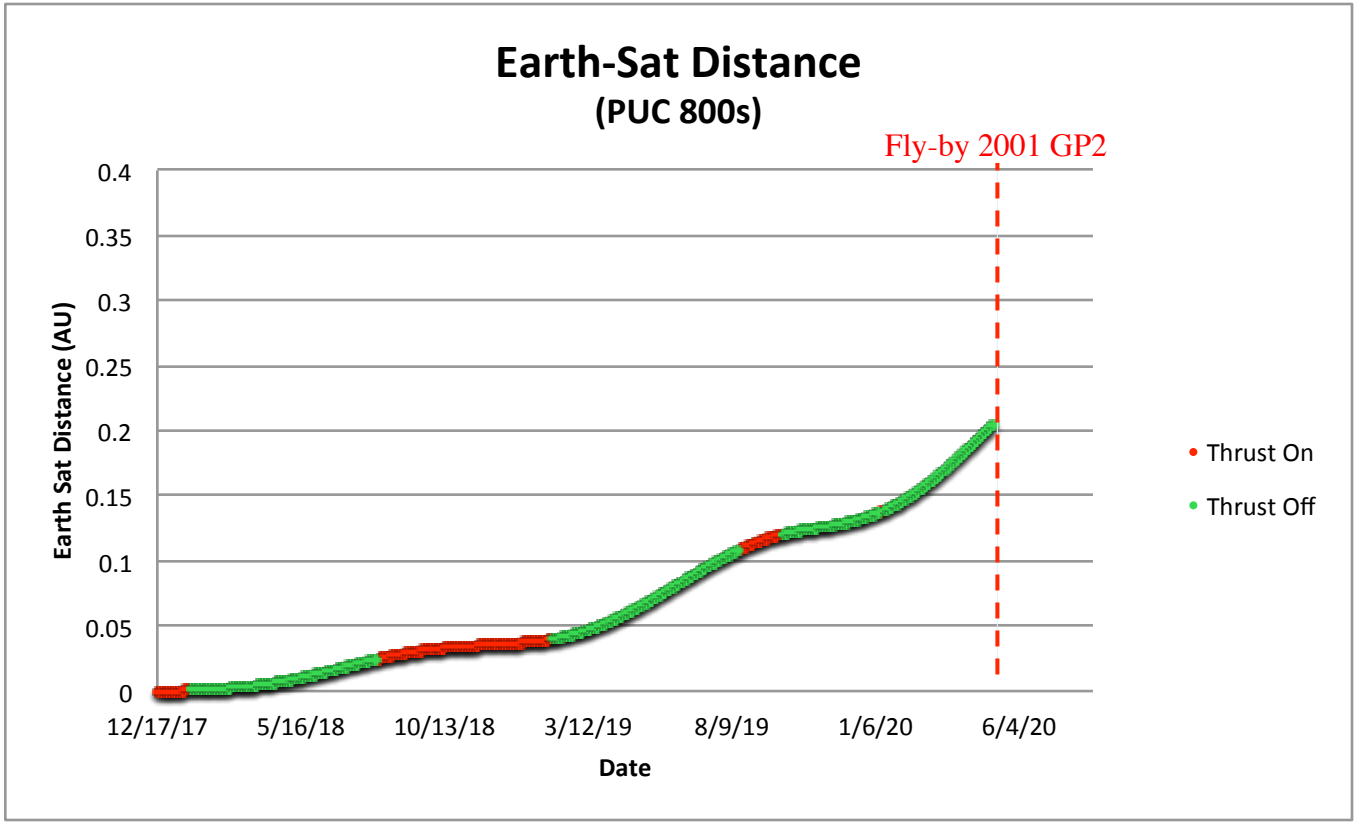
- Mechanical Simplicity: No Moving Parts
- Small Volume, Mass, and Power
- NASA ST7 Technology Flight Development

2001 GP2 Interplanetary Trajectory mid-2018 Launch (Double Fly-by)

- Colloid (Electrospray) Thruster Parameters:
  - Power to thruster = 9W
  - Isp = 800s
  - Efficiency = 31%
  - Duty Cycle = 90%
- Trajectory Assumptions:
  - Double Fly-by of 2001 GP2
  - Constant 9W to thruster
  - SLS Launch Date: 7/31/2018
    - 4 days, 10 m/s to correct for worst-case SLS injection
  - Spacecraft Wet mass = 12 kg
- Trajectory Details:
  - Delta-V = 365 m/s
  - Required Prop Mass = 0.546 kg
  - TOF = 1037.8 days
  - Total Thrusting Time = 75 days

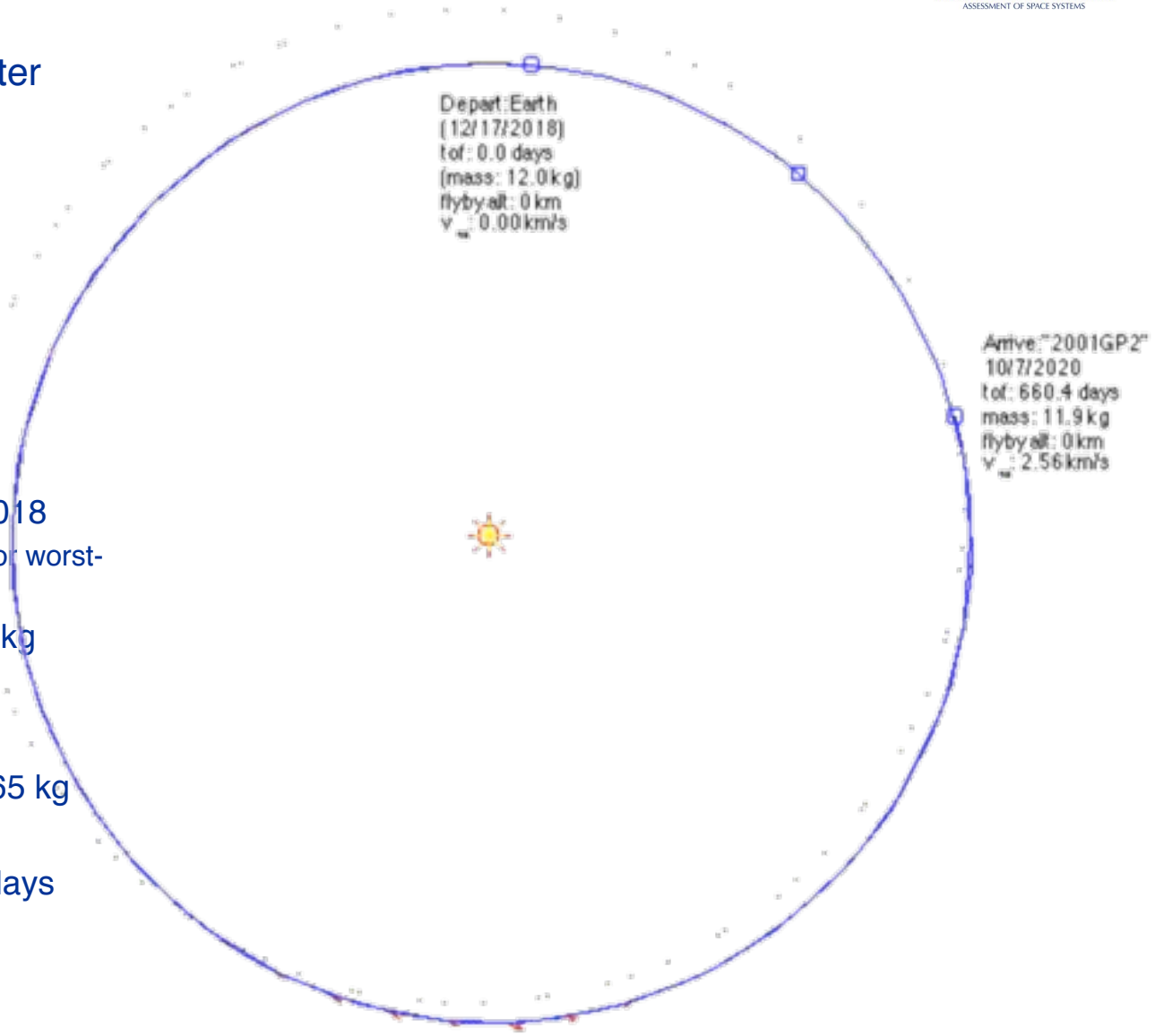


2001 GP2 Interplanetary Trajectory

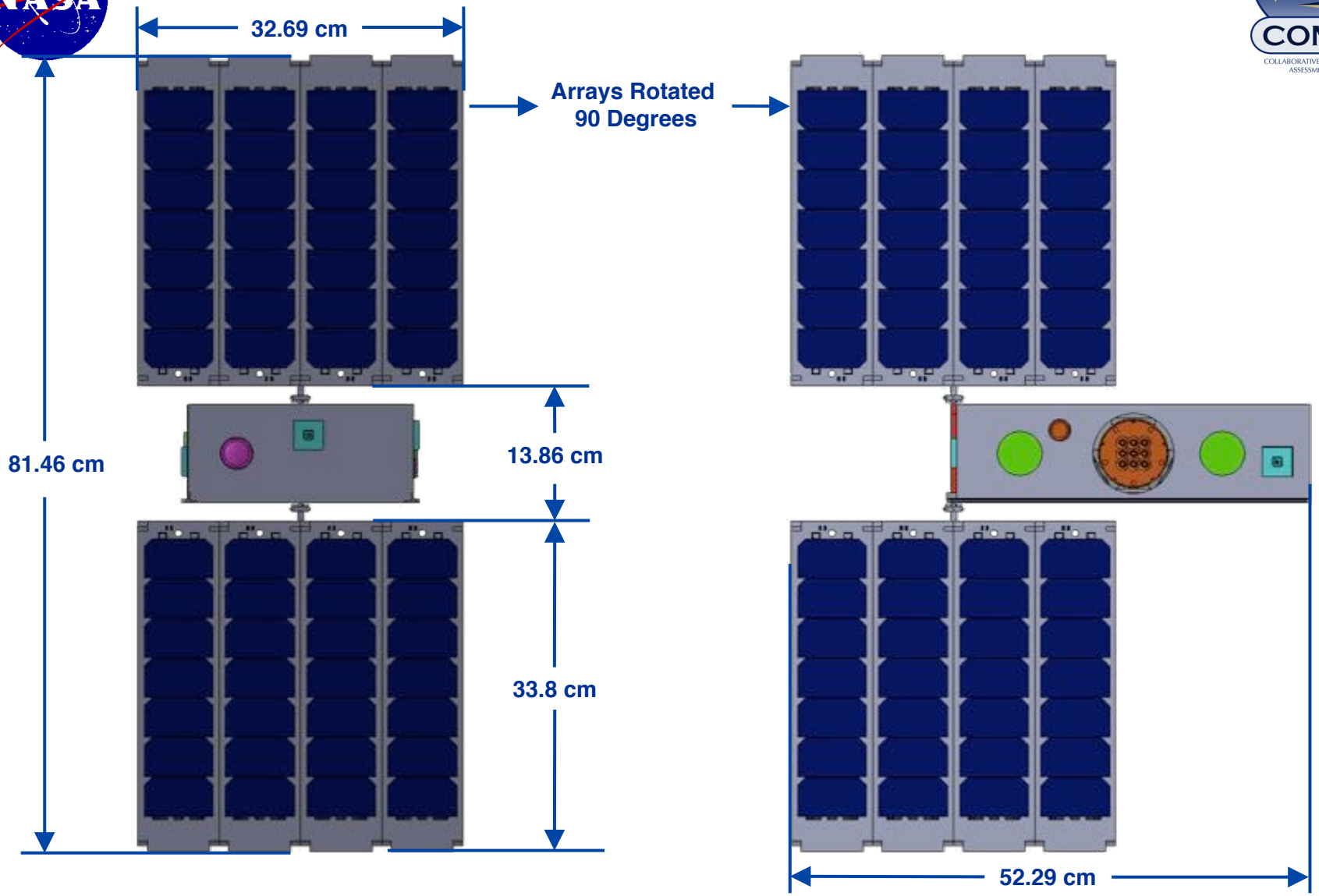


2001 GP2 Interplanetary Trajectory
2018 Launch (October Fly-by)

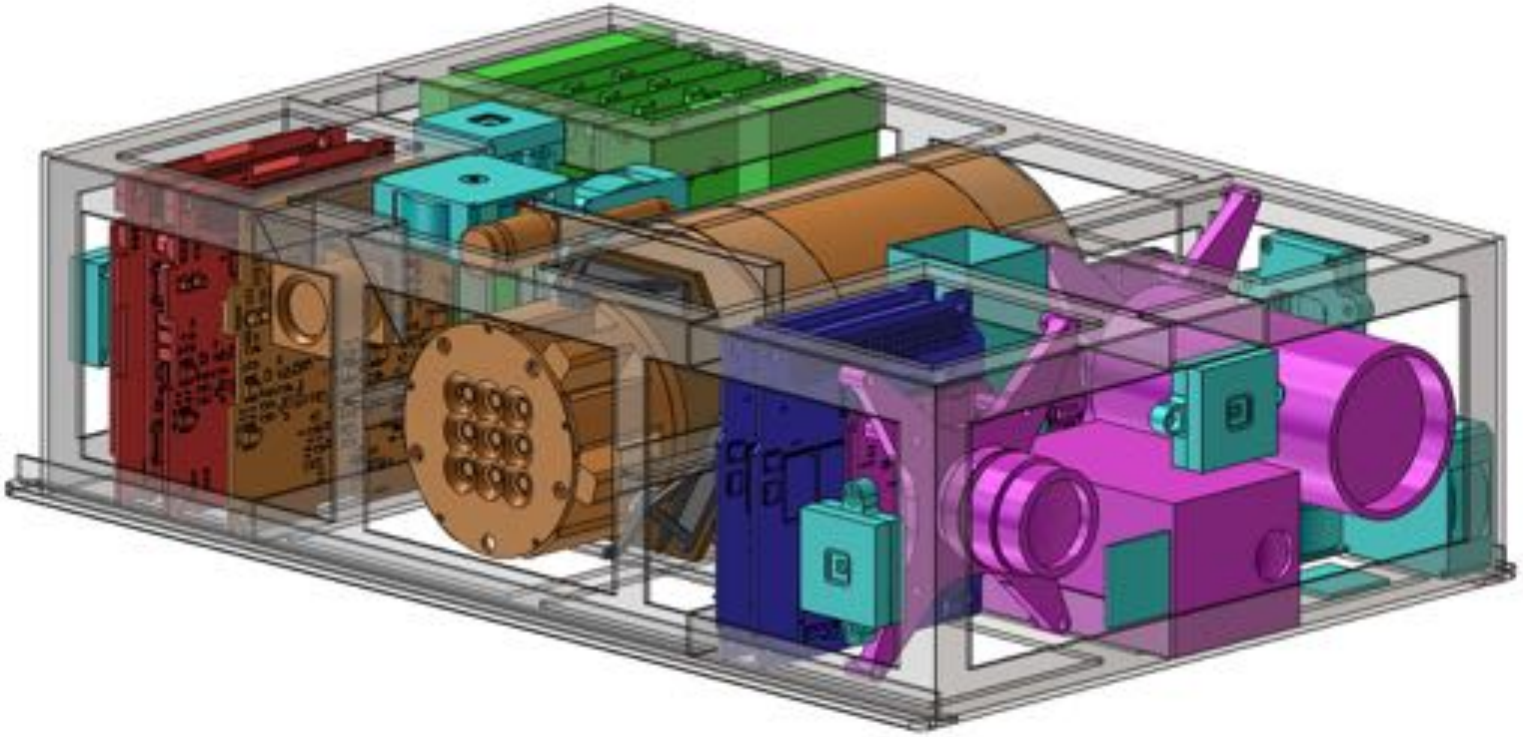
- Colloid (Electrospray) Thruster Parameters:
  - Power to thruster = 9W
  - Isp = 800s
  - Efficiency = 31%
  - Duty Cycle = 90%
- Trajectory Assumptions:
  - Fly-by of 2001 GP2
  - Constant 9W to thruster
  - SLS Launch Date: 12/17/2018
    - 4 days, 10 m/s to correct for worst-case SLS injection
  - Spacecraft Wet mass = 12 kg
- Trajectory Details:
  - **Delta-V = 43 m/s**
  - Required Prop Mass = 0.065 kg
  - TOF = 660 days
  - Total Thrusting Time = 57 days



SLS 6U Cubesat Deployed Dimensions

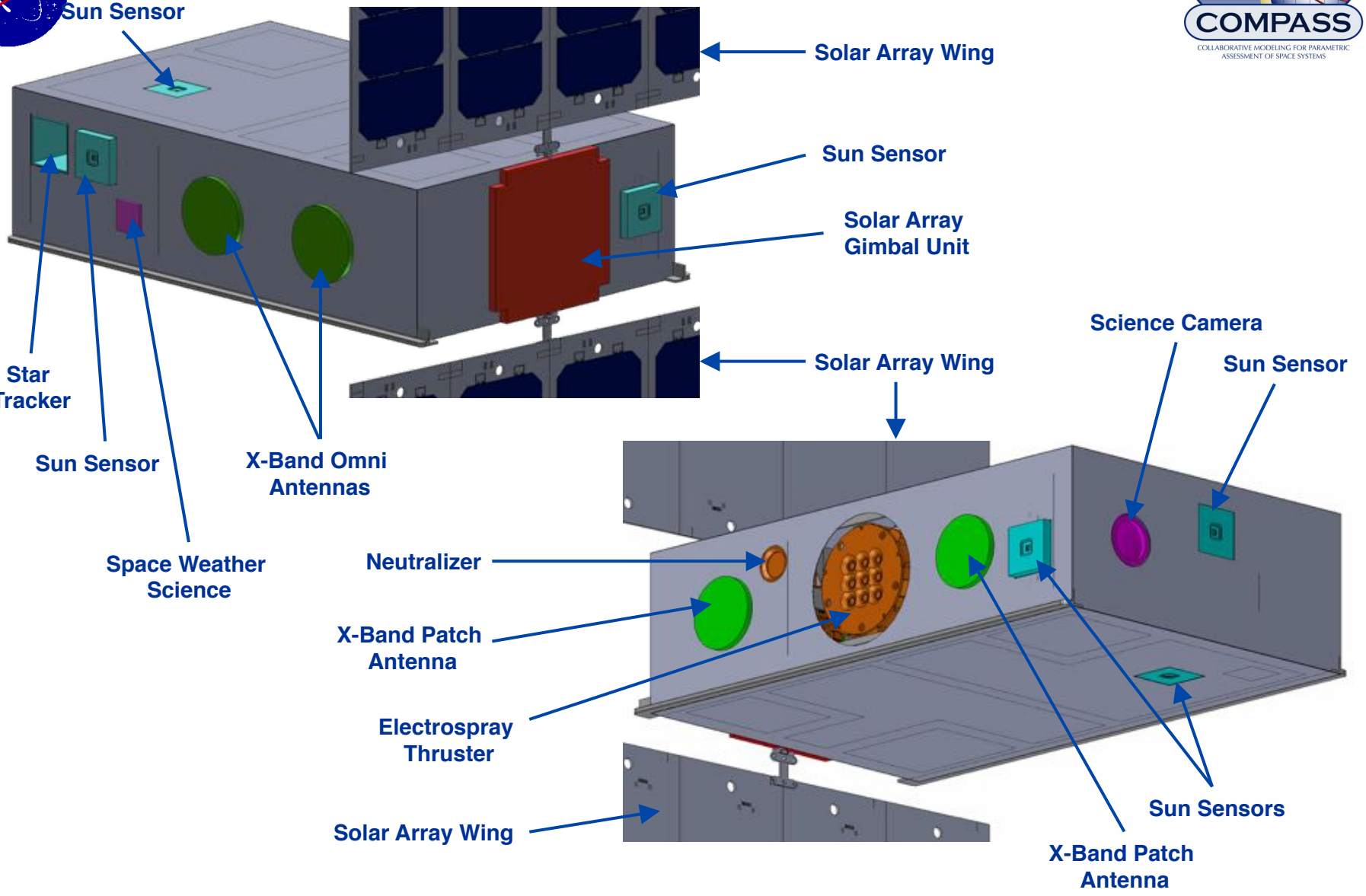


Instruments



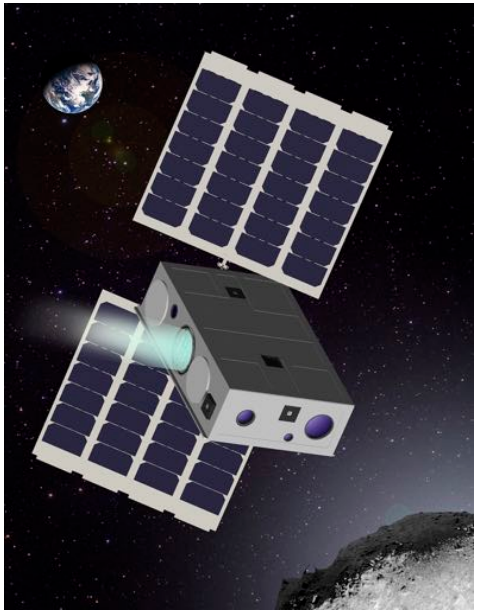
Instrument	Field of view	Specification	Resolution
Wide-field camera	10.7° × 8.06°	3-megapixel color	42 cm at closest approach
Narrow-field camera	4.4° × 3.32°	3-megapixel color	17 cm at closest approach
V/NIR spectrometer	1°	400 to 1650 nm; 512 channels	8 nm (visible); 10 to 15 nm (IR)

SLS 6U Cubesat External Components



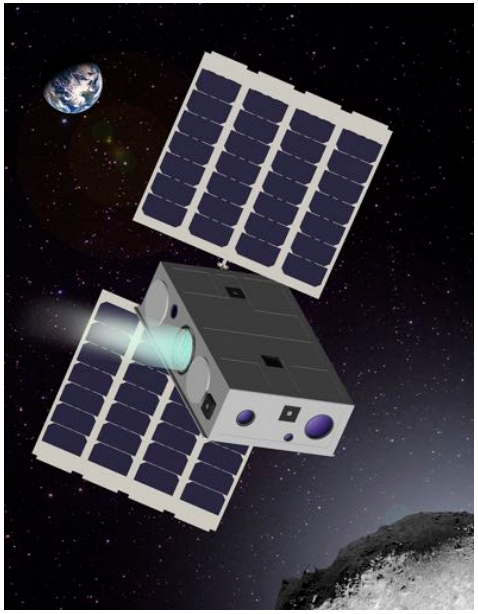
Status

- Proposal submitted to SIMPLEX solicitation, but not selected for the EM-1 Mission Opportunity
- Selected for a one-year technology development study
  - Asked by program office to focus work on maturing the instrumentation
- Continuing to working on the engineering design
- **Looking for a launch opportunity** to C3=0 in 2019 or early 2020



Where do we go if we find a launch, but miss the window for the Oct 2020 fly-by?

- Latest possible launch for 2020 fly-by is ~May 2020
- Asteroid 2011-CL50 has December 24 2020 fly-by
  - not quite as good, but almost
  - only slightly later
- If we miss that, 2010 UE51 has opportunity Dec. 2023
  - *Tiny* asteroid (~10 m class)
  - Farther away, but *much* slower fly-by speed
  - Possibility to do a rendezvous mission

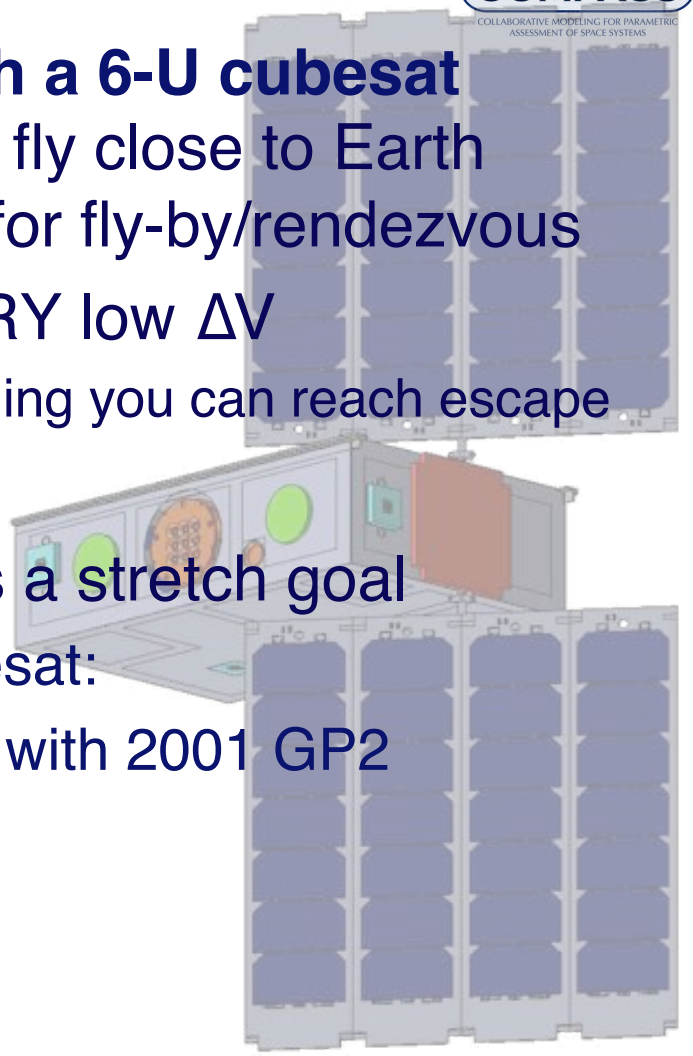


Conclusions

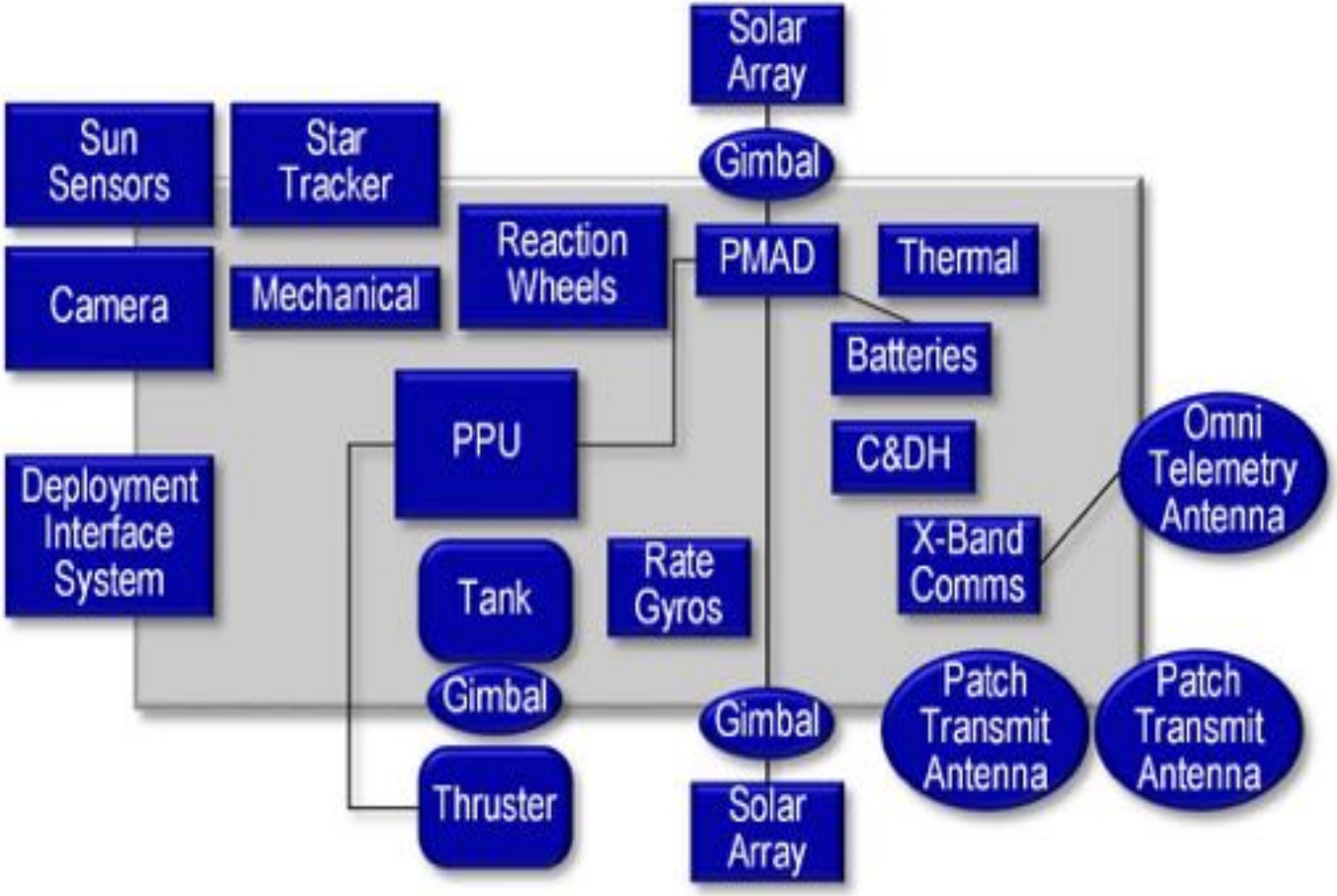
- **Asteroid mission is possible with a 6-U cubesat**
  Targeting near earth asteroids that fly close to Earth minimizes the propulsion required for fly-by/rendezvous
- Upcoming Oct 2020 fly-by has VERY low ΔV

*assuming you can reach escape

- Rendezvous mission is possible as a stretch goal
  - ΔV is very significant for a 6U cubesat:
  - ~2000 m/s needed for rendezvous with 2001 GP2



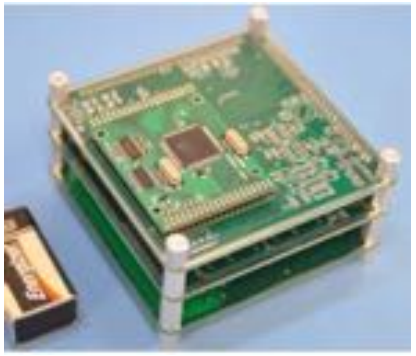
System Schematic



Busek Electrospray Thruster

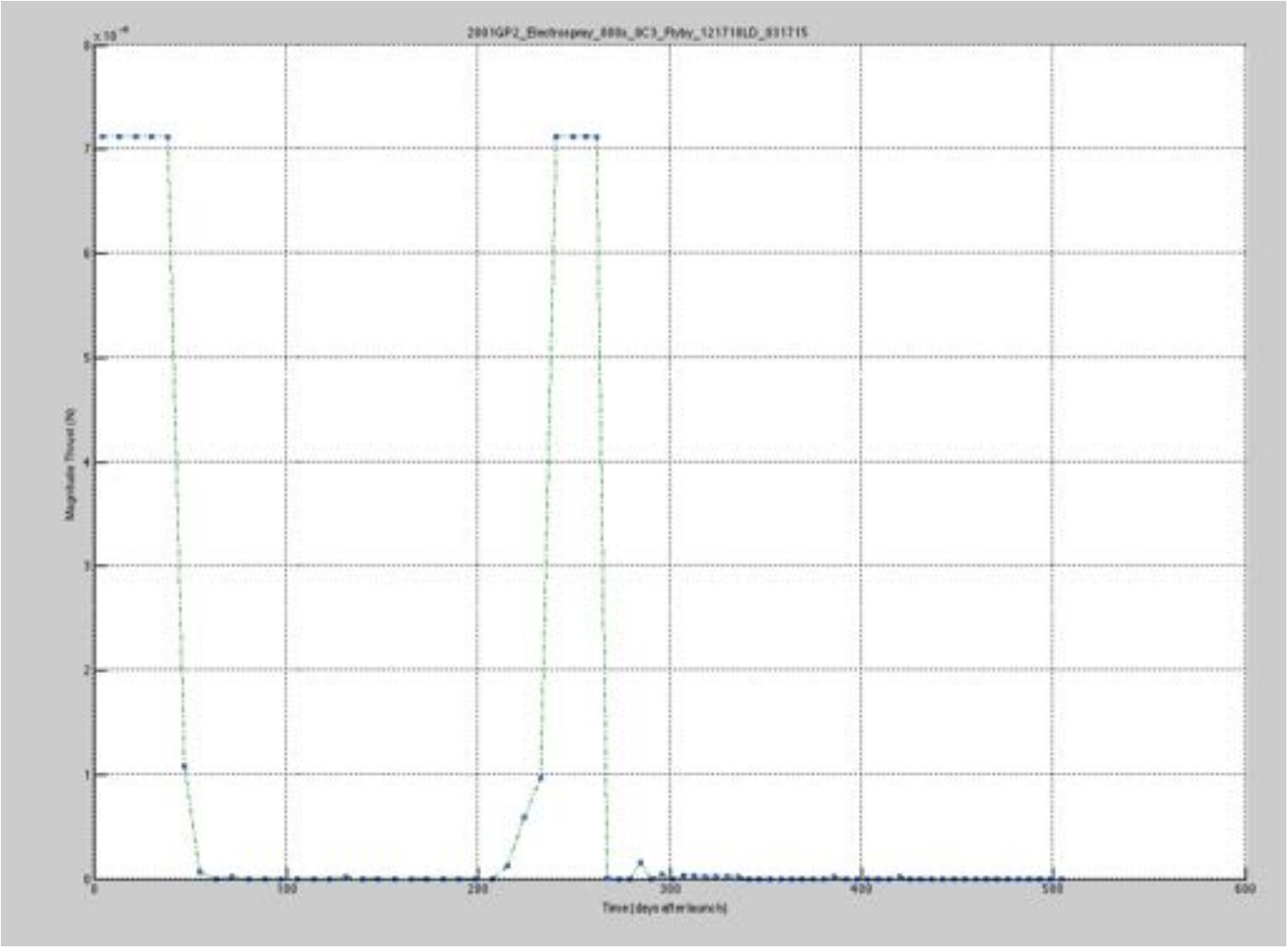
- Mechanical Simplicity: No Moving Parts
- Small Volume, Mass, and Power
- Leverages $20M NASA ST7 Technology Flight Development
- Leverages SBIR Work on Micro-Valves and Power Management
- Non-Volatile Propellant
- Multi-Emitter Design
- Lisa Pathfinder Flight Heritage
- Propellant Stored in Low Pressure Stainless Steel Bellows Tank
- Cold Ion Plume (No Hot Gas)
- Self Regulating Feed System
- Piezo-Actuated Isolation Micro-Valve

Busek Electrospray Thruster

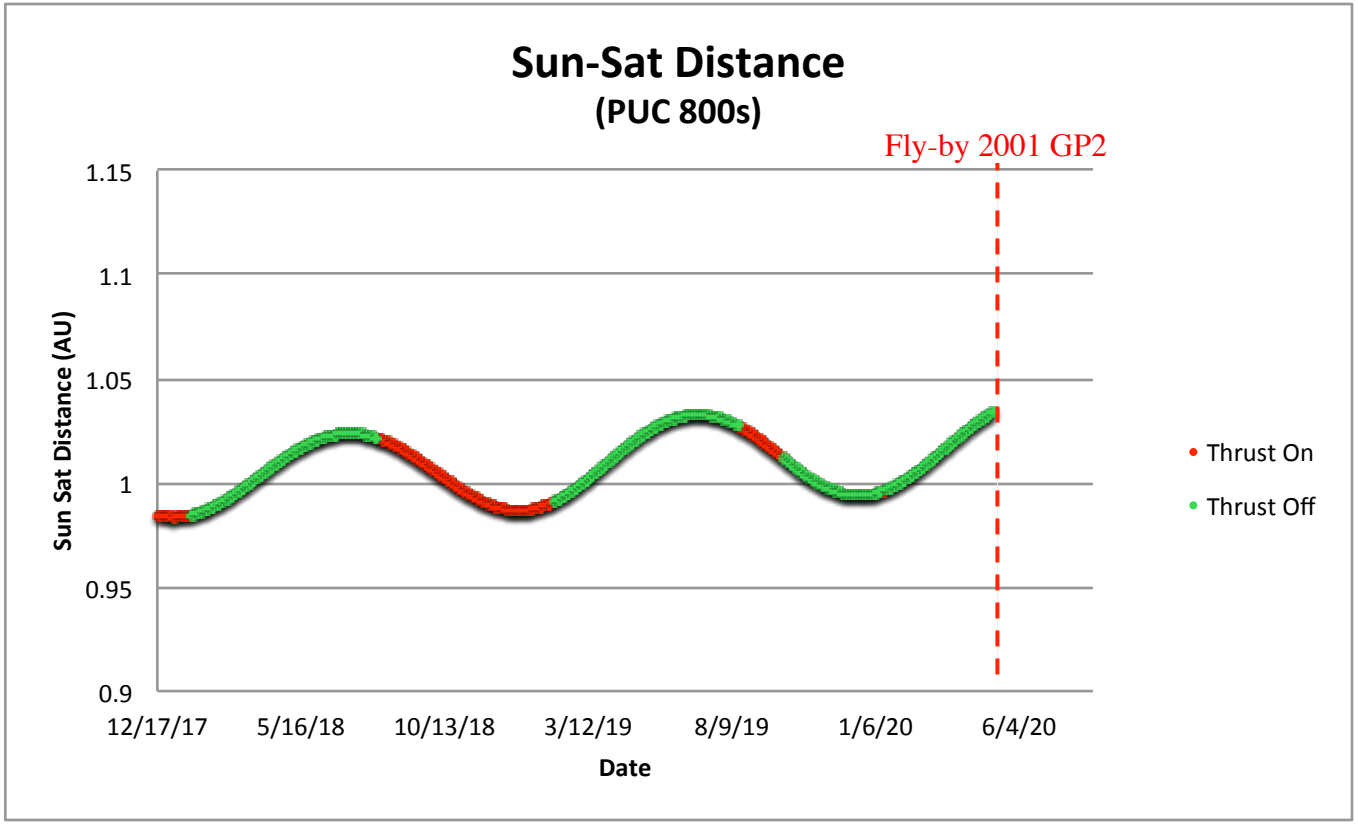


Integrated PPU/DCIU
(Engineering Model)

2018 Thrust Profile



2001 GP2 Interplanetary Trajectory



2018 Thrust Profile (October Fly-by)