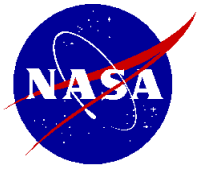
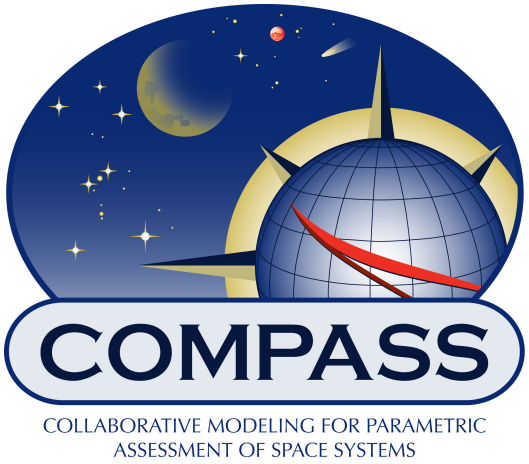


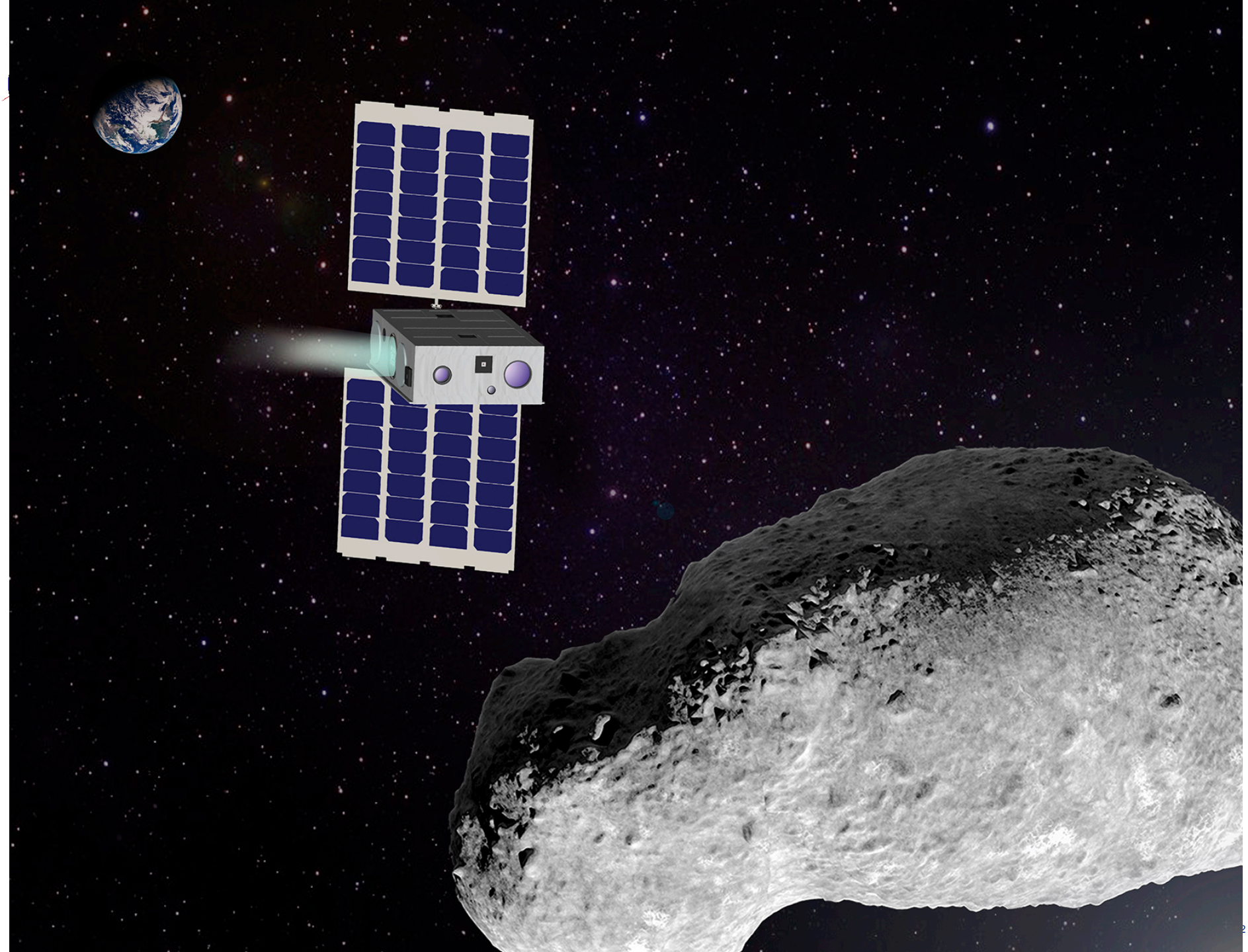





# Cubesat for Asteroid Exploration

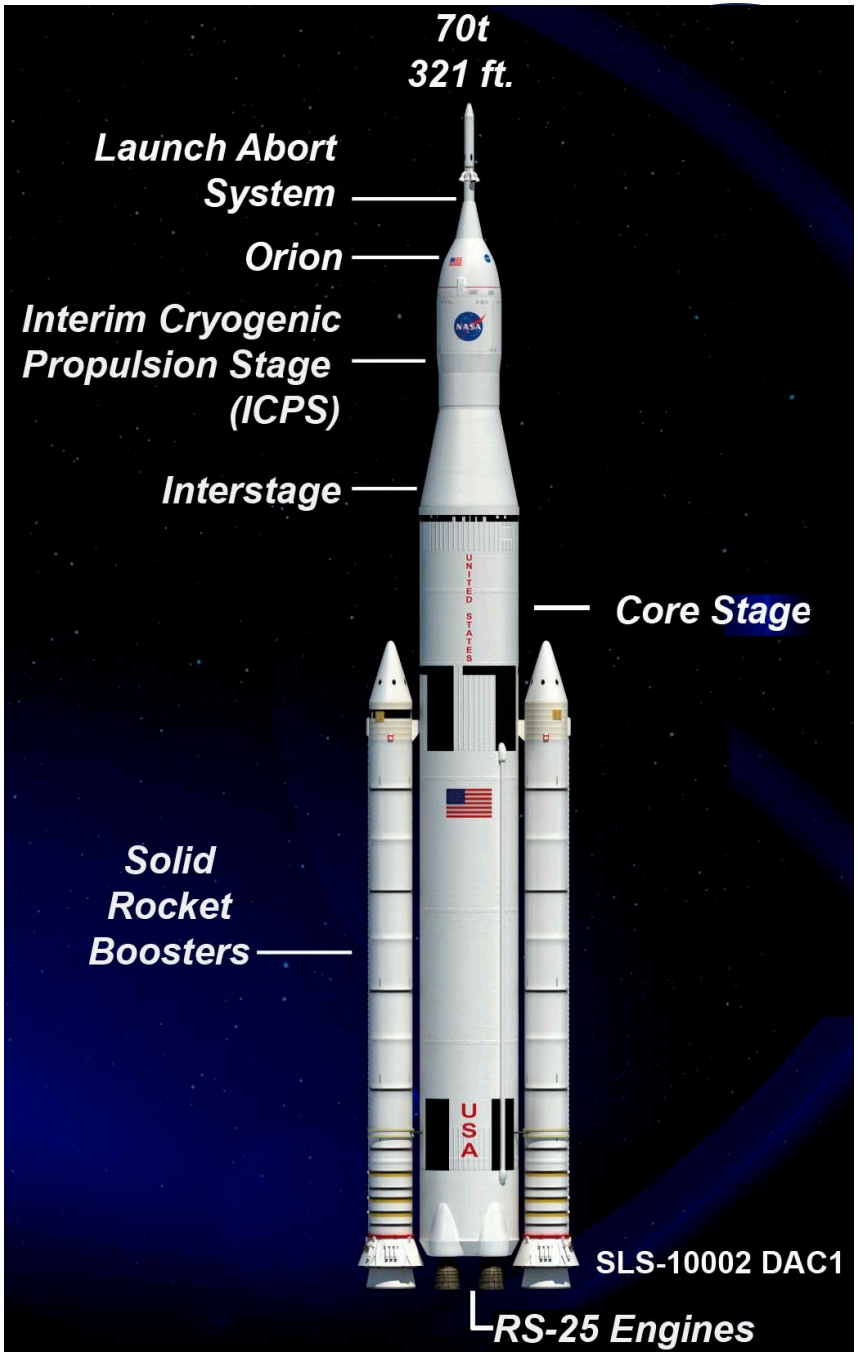
Geoffrey A. Landis
NASA Glenn Research Center

*COMPASS Team at NASA Glenn:*
Steve Oleson, Melissa McGuire, Aloysius Hepp, James Stegeman, Mike Bur, Laura Burke, Michael Martini, Jim Fittje, Lisa Kohout, James Fincannon, and Tom Packard
*Collaborating Institutions:*
Busek (propulsion); COSMIAC (spacecraft integration); Case Western (Ralph Harvey, Asteroid Science lead); Planetary Science Institute (Asteroid Science)



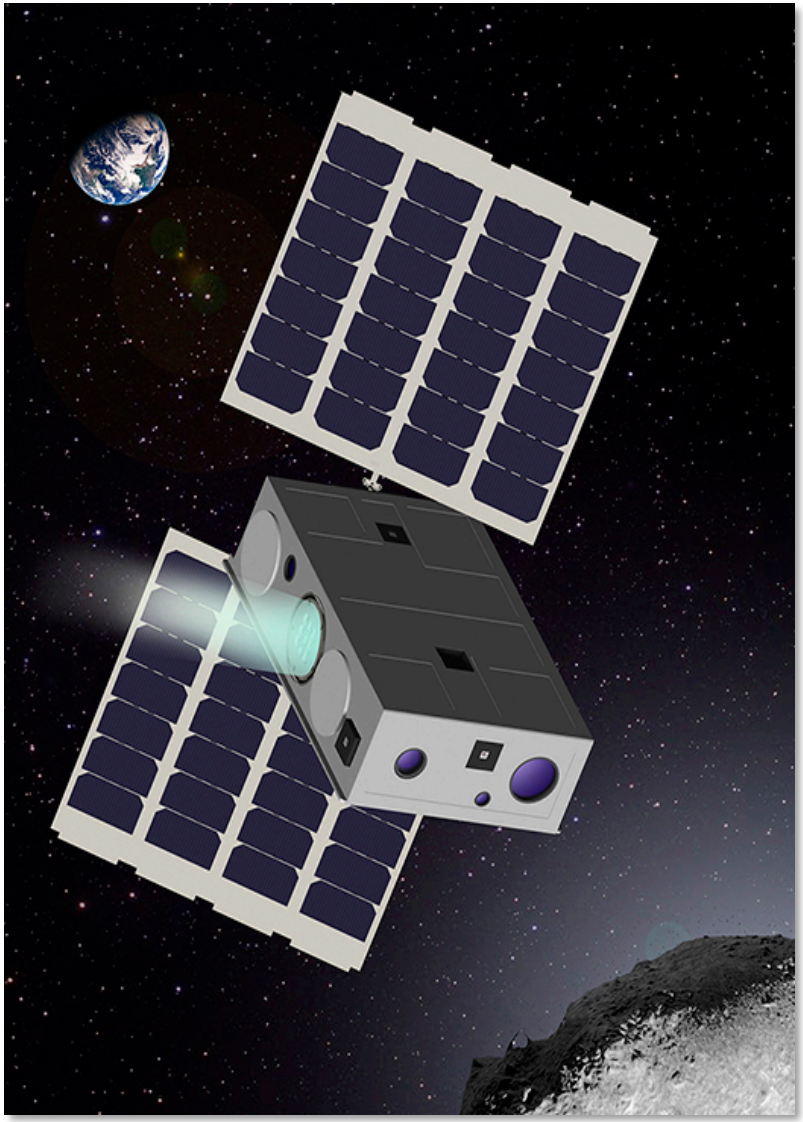
## Background:

- 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

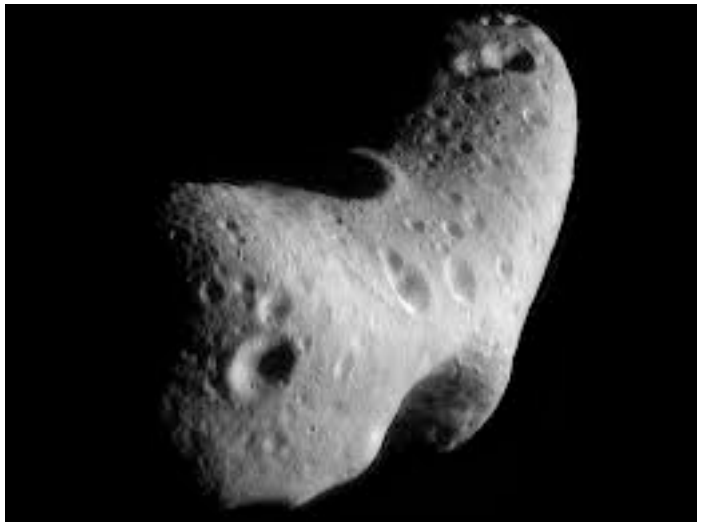
- 12874 close approaches by asteroids were analyzed
- List narrowed down:
  - nearest approach no earlier than 2019 (>1 year after launch date)
  - Nearest approach no later than 2020.
- **2001 GP2 was chosen as a target.**
  - From visual magnitude, estimate* ~18-meter diameter.

- 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

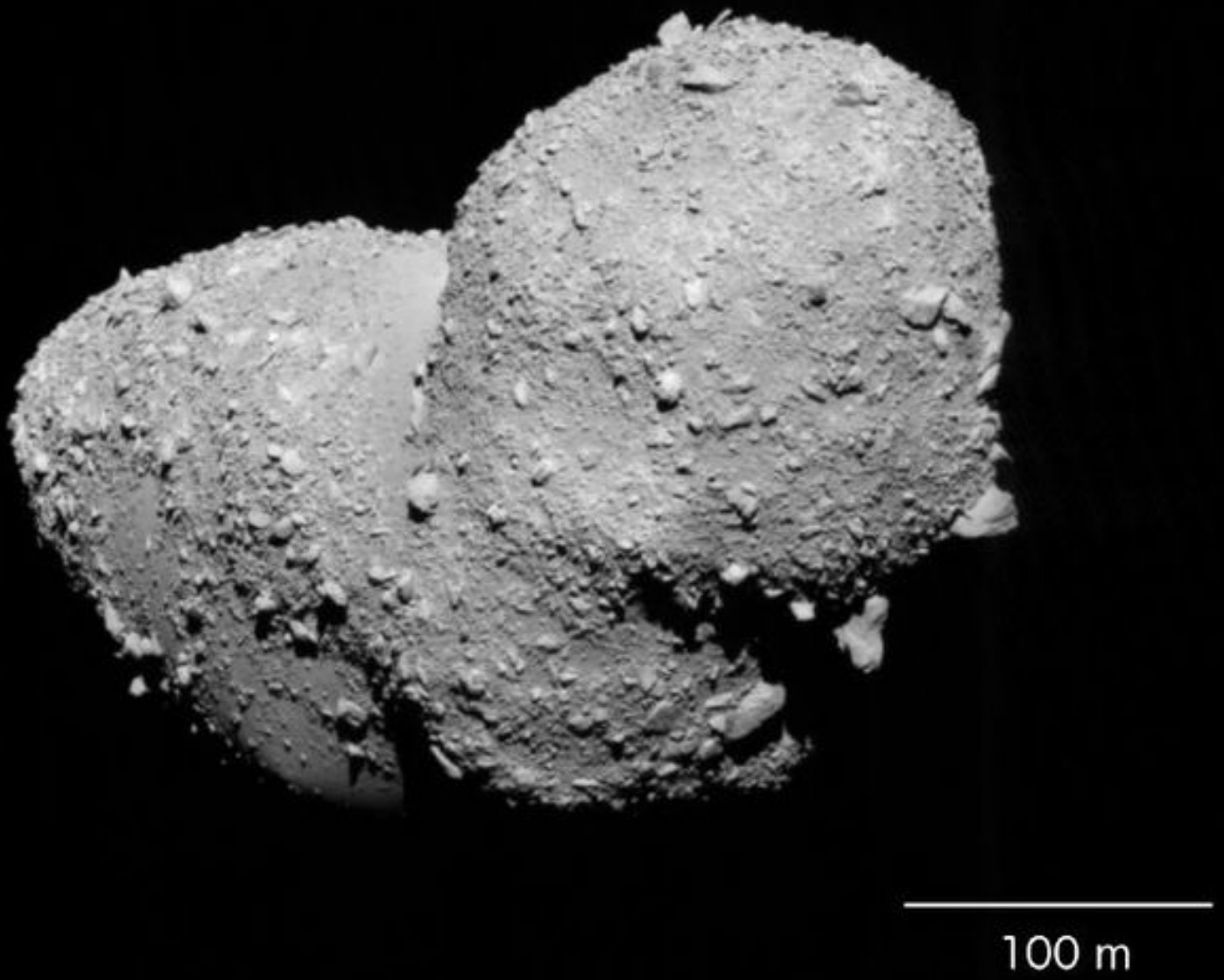
- Closest pass: Oct 3, 2020
- Closest approach at 0.5 to 4.3 time Lunar distance
- (~100,000 to 1 million miles)
  - Further observations will decrease uncertainty
- V relative: 2.37 km/sec



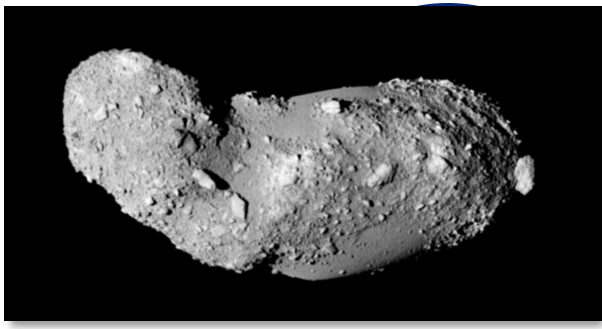
Near Earth asteroid Eros (viewed by the NEAR spacecraft)

# Itokawa: the smallest asteroid ever visited by a spacecraft

viewed by the Hayabusa spacecraft



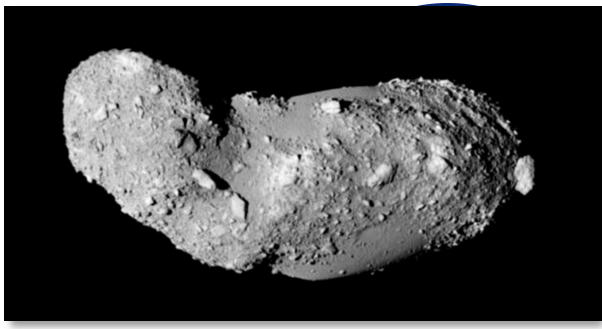
# What makes Asteroid 2001 GP2 Interesting?



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)

# What makes Asteroid 2001 GP2 Interesting?



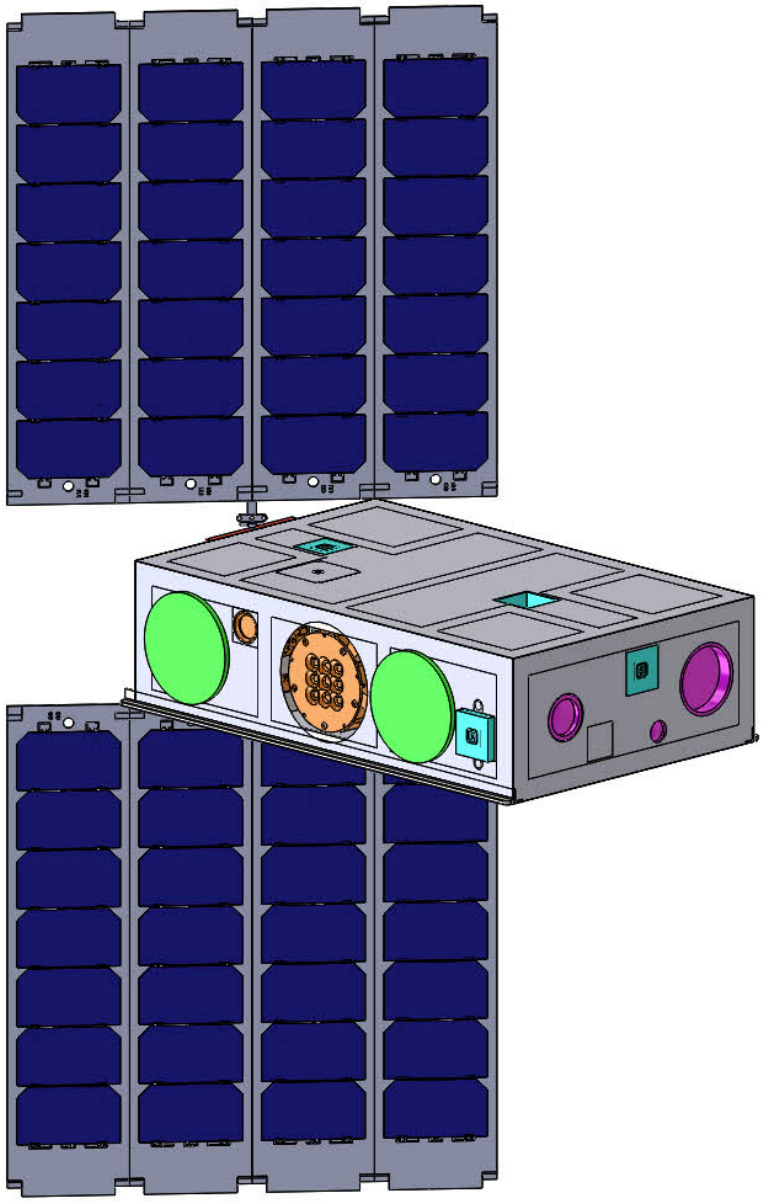
Asteroid Itokawa

- Asteroids this tiny have never been visited by spacecraft
  - Recent modeling suggests YORP-induced spin-ups can disaggregate bodies smaller than 150 m in size.
  - 2001–GP2 sits significantly below this model's threshold for stability:
    - Will it be an Itokawa-like body with a blocks and finer grained material, or a single cohesive block?
    - Will it be tumbling chaotically or spinning?
    - What history is evident or implied?

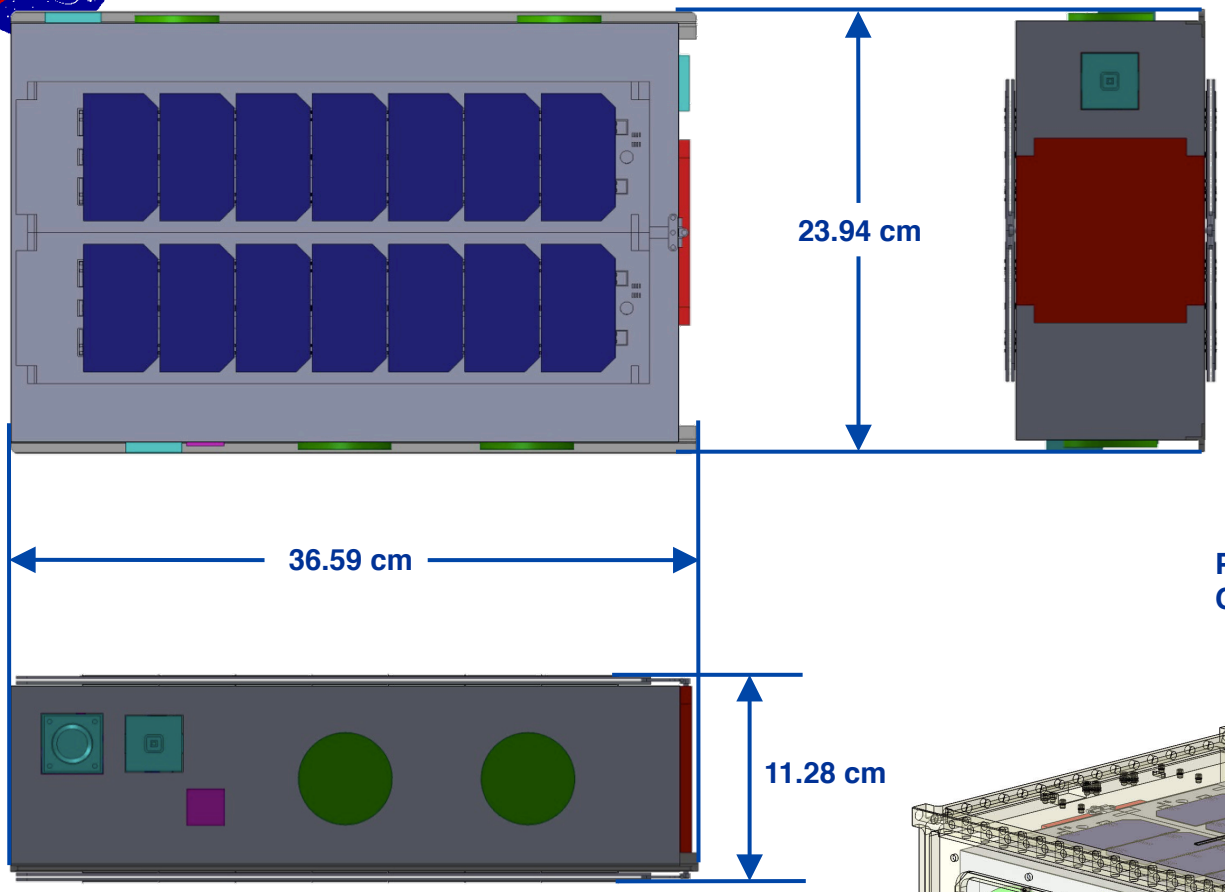
Representative of a whole class of objects that are numerous and interesting, but have never been observed up close

## DAVID (Diminutive Asteroid Visitor using Ion Drive)

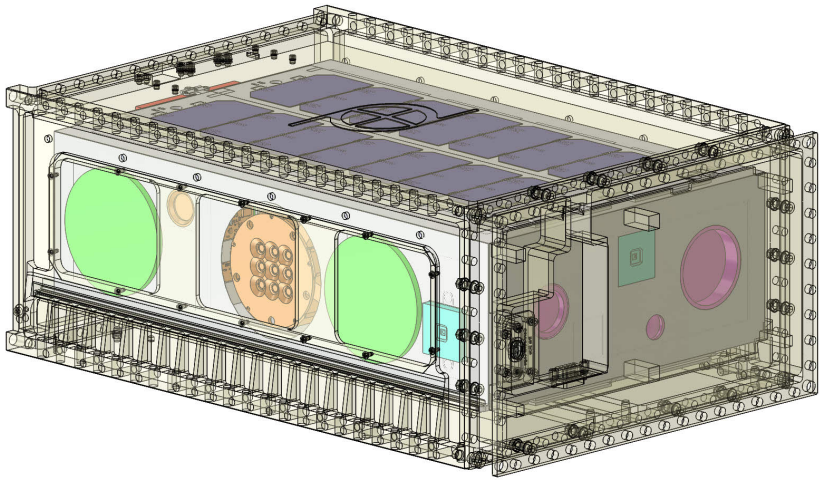
- 6-U cubesat
- Mass limit 12 kg
- Design must include margin on all systems



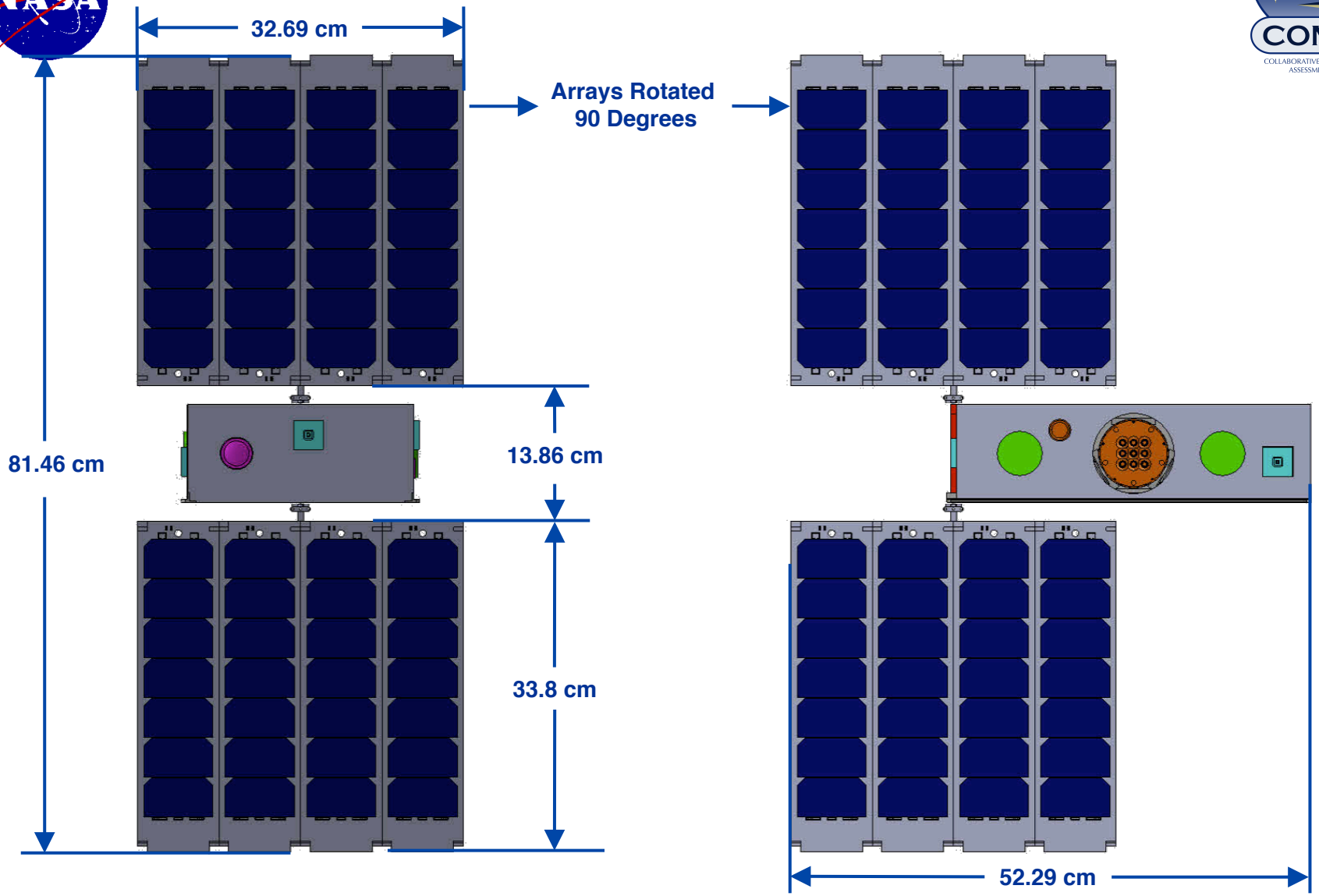
# Size



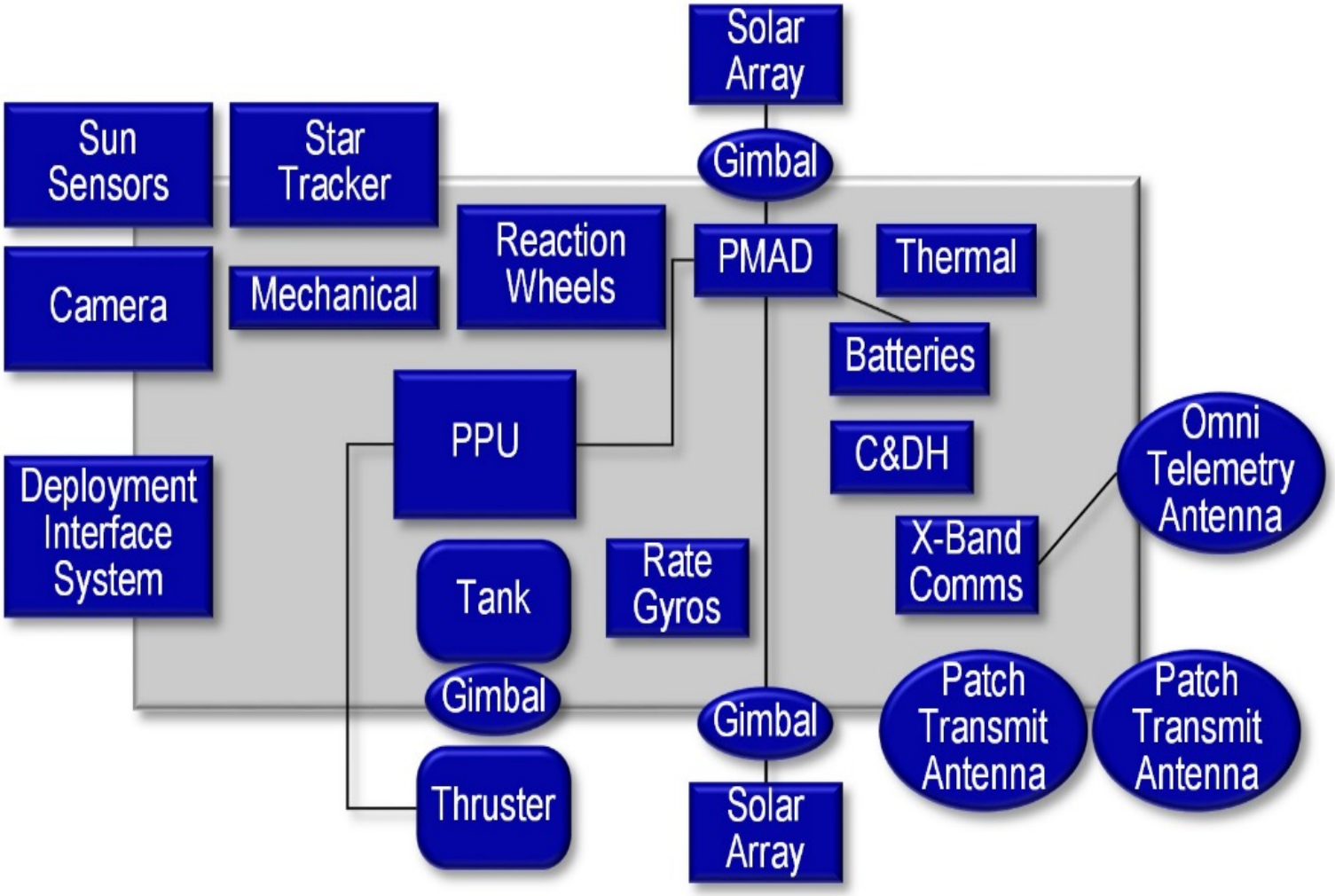

**Planetary Systems Corporation**
**Canisterized Satellite Dispenser**



# SLS 6U Cubesat Deployed Dimensions



# System Schematic

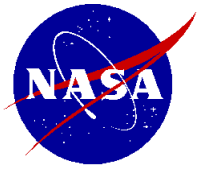


# Propulsion Trade Off

**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

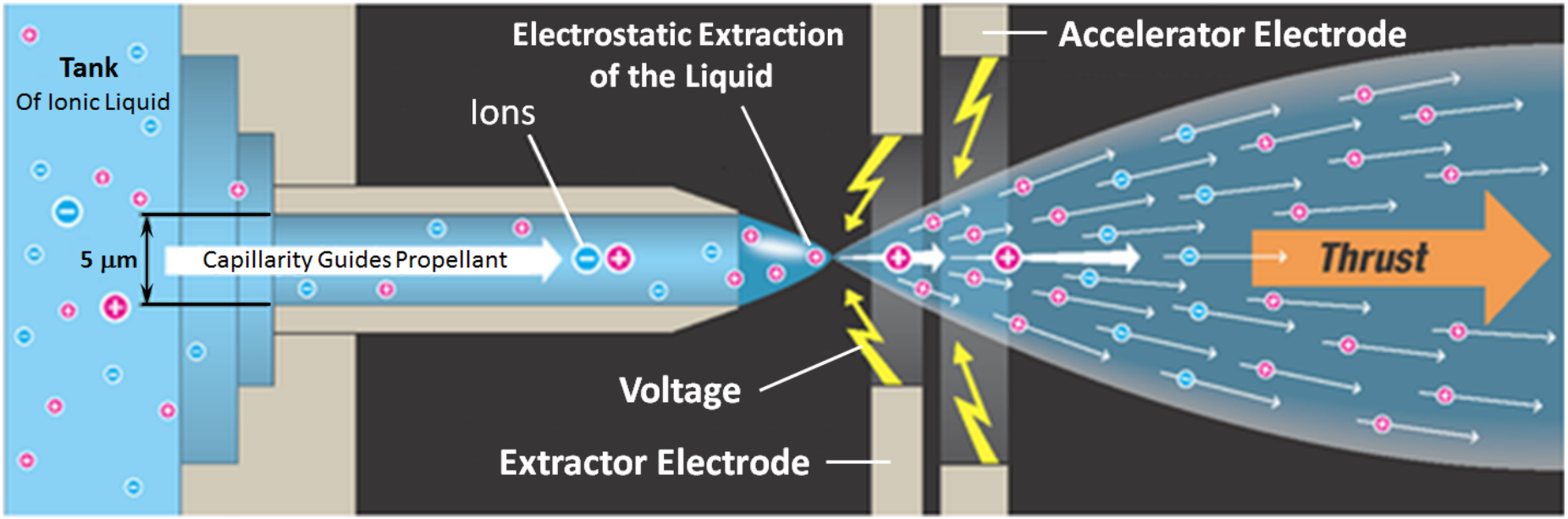


# Propulsion Choice


- Trade-off study included many propulsion systems
- The Hall thruster has the greatest base of experience in operation in space, but the cases analyzed exceeded the initial mass allowance of 12 kg, as did the Xe ion thruster.
- A case with two 10-W PUC (Propulsion Unit for Cubesats) electrospray thrusters also exceeded the mass allowance, but a revised case where this was reduced to lower power and a single thruster was run, which met the requirements.
- **Single PUC electrospray thruster chosen for baseline design**

- Rendezvous case requires higher Isp and larger solar array
  - ion engine needed

# Electrospray Thruster

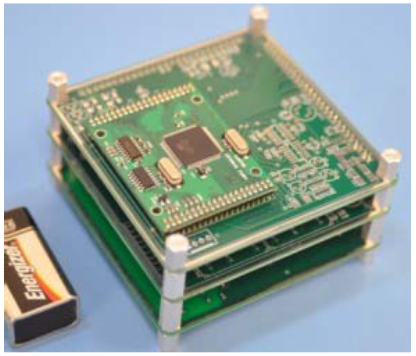



Propellant:
high density ionic liquid

# 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

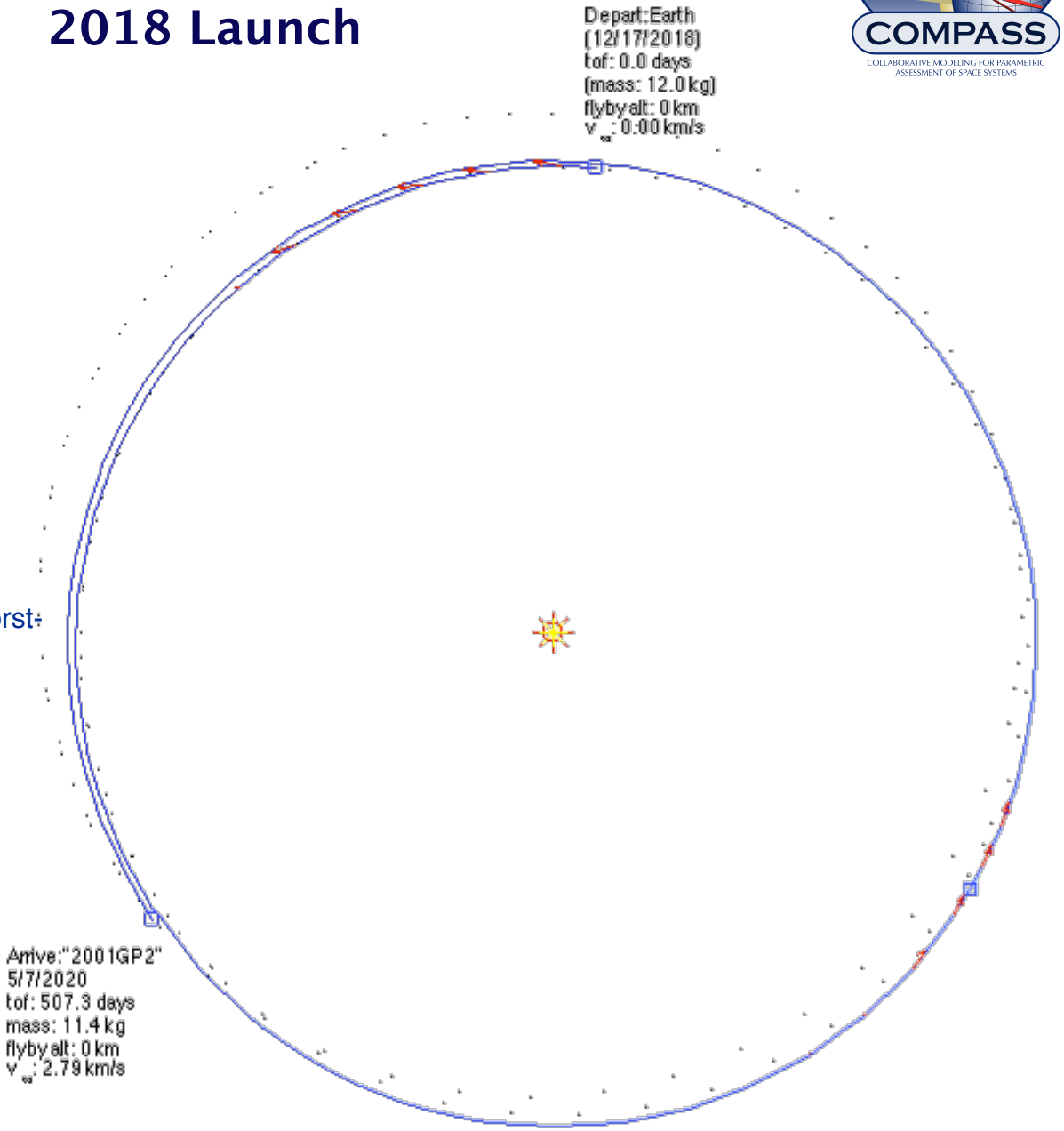


Integrated PPU/DCIU
(Engineering Model)

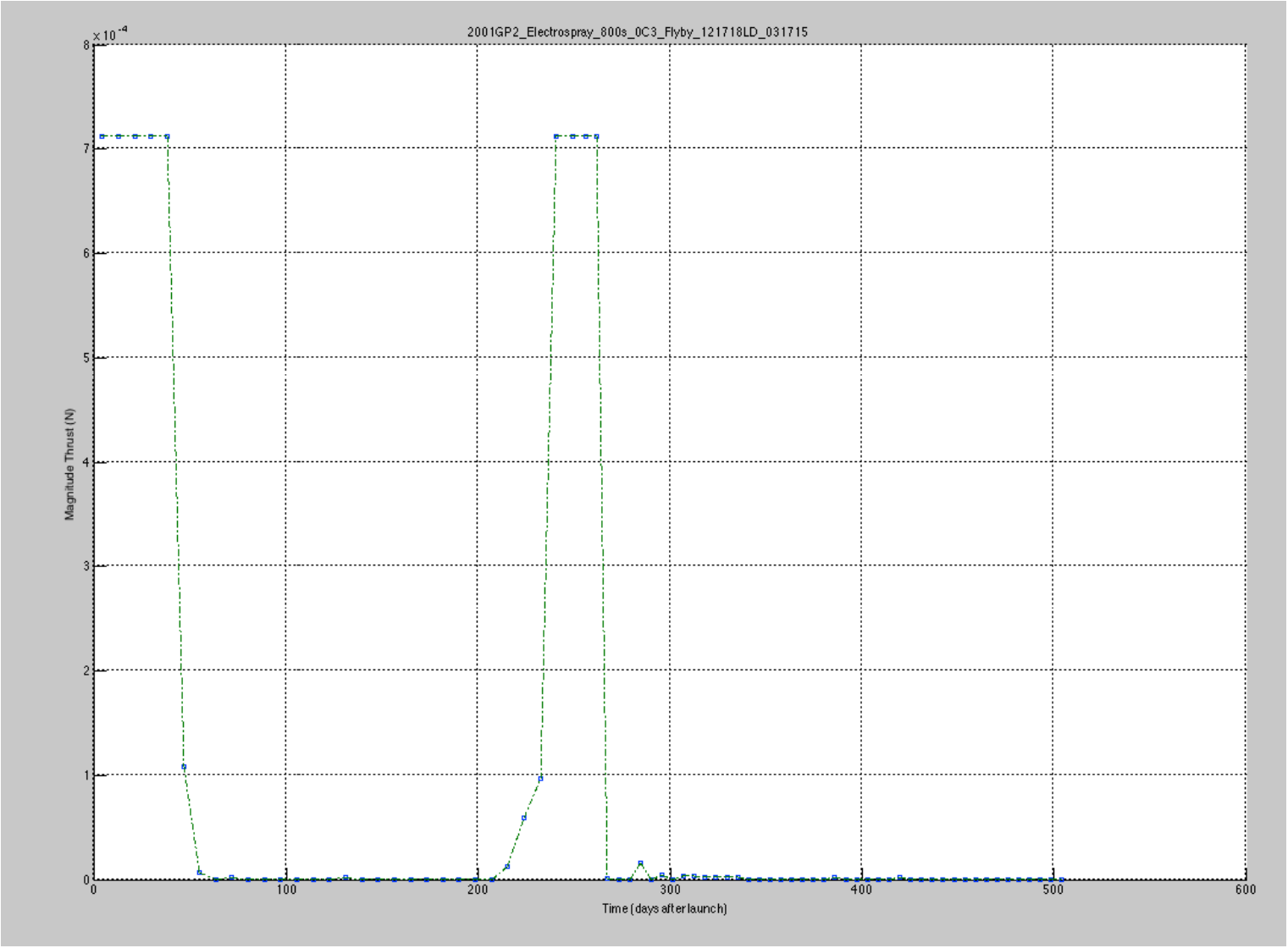
# LISA Pathfinder Thruster Integration

# 2001 GP2 Interplanetary Trajectory
# 2018 Launch

- 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 = 390 m/s**
  - Required Prop Mass = 0.58 kg
  - TOF = 507 days
  - Total Thrusting Time = 89 days

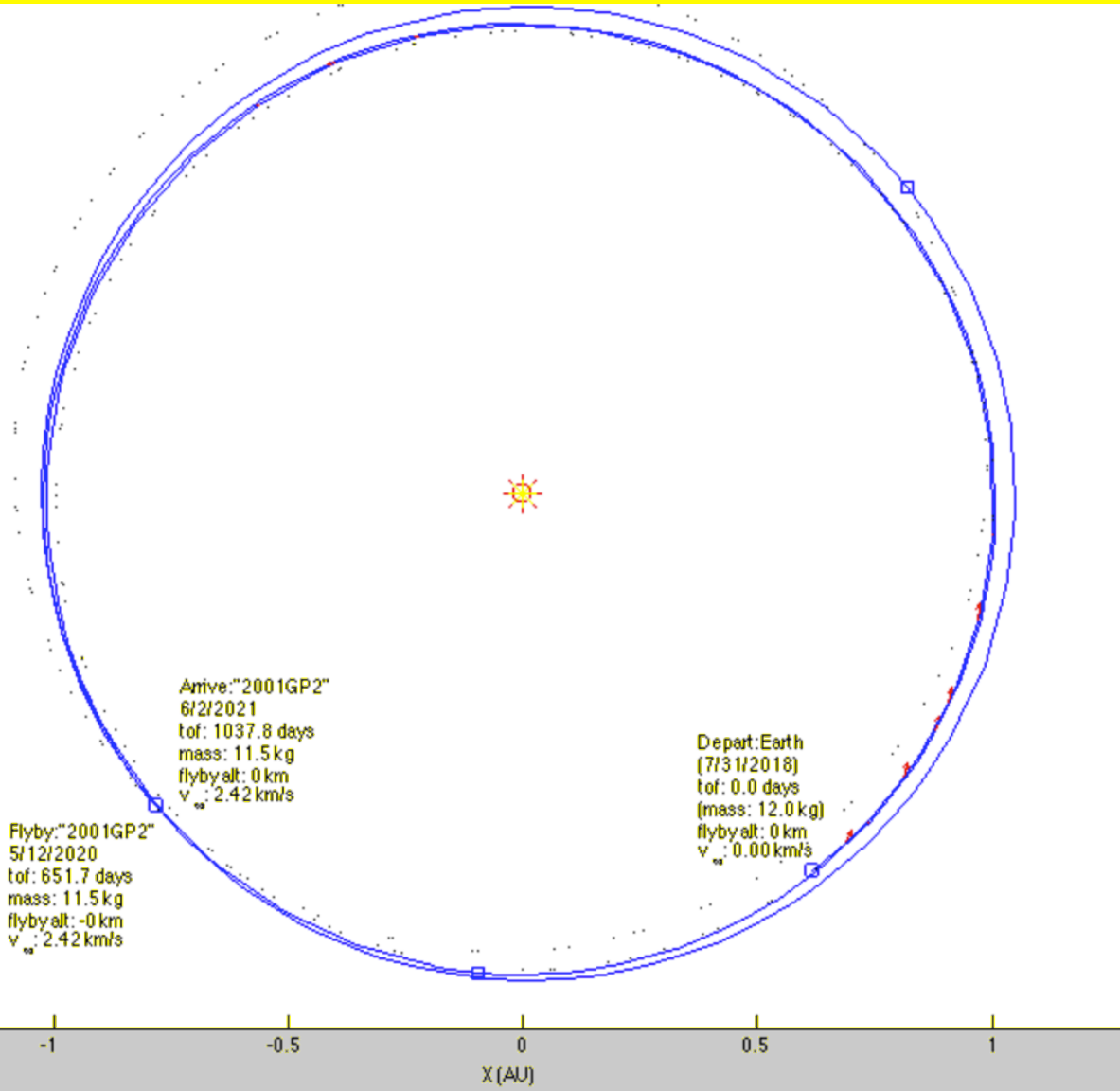


# 2018 Thrust Profile

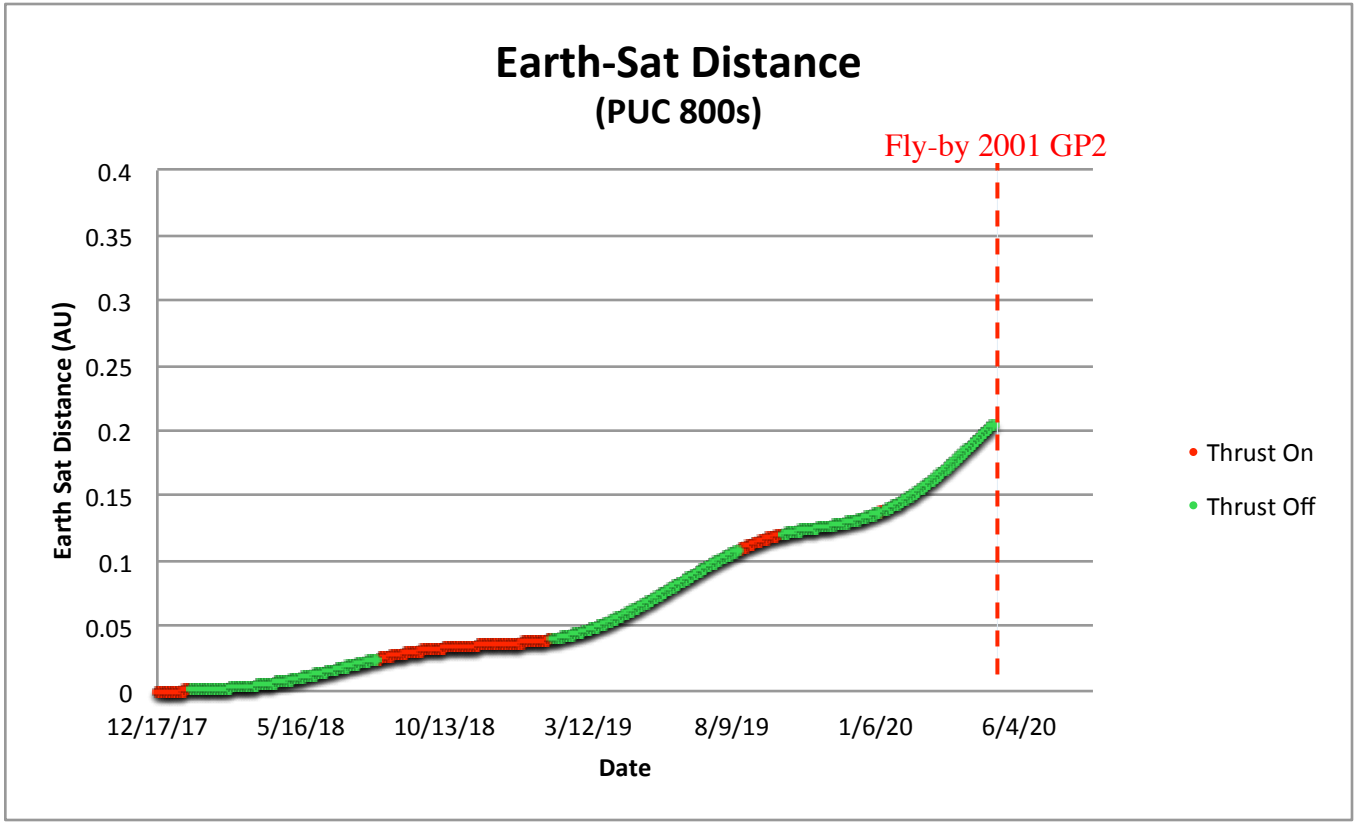


# 2001 GP2 Interplanetary Trajectory mid-2018 Launch (Double Fly-by)

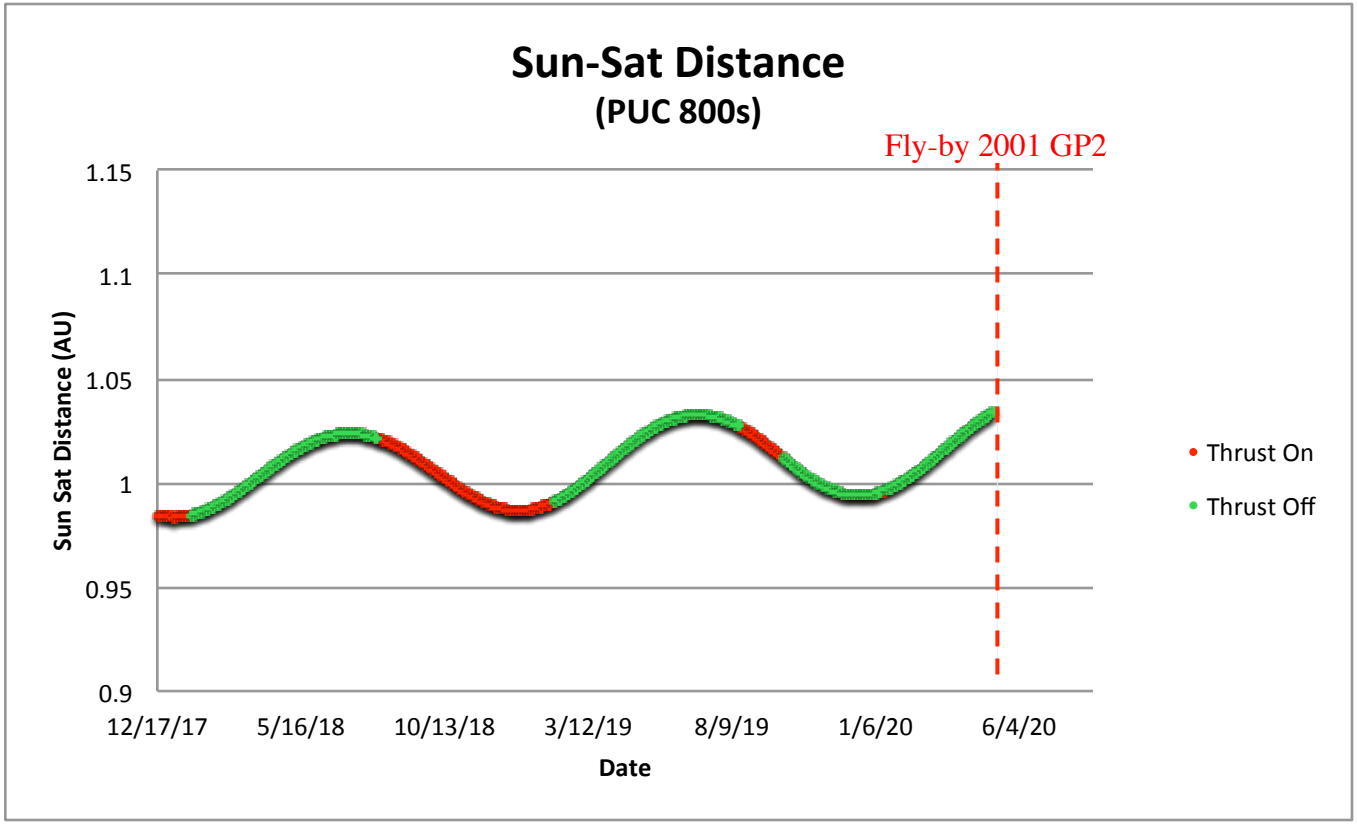
- Colloid (Electrospray) Thruster Parameters:
  - Power to thruster = 9W
  - Isp = 800s
  - Efficiency = 31%
  - Duty Cycle = 90%
- Trajectory Assumptions:
  - Double Fly-by of 2001 GP2
  - Constant 9W to thruster
  - SLS Launch Date: 7/31/2018
    - 4 days, 10 m/s to correct for worst-case SLS injection
  - 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

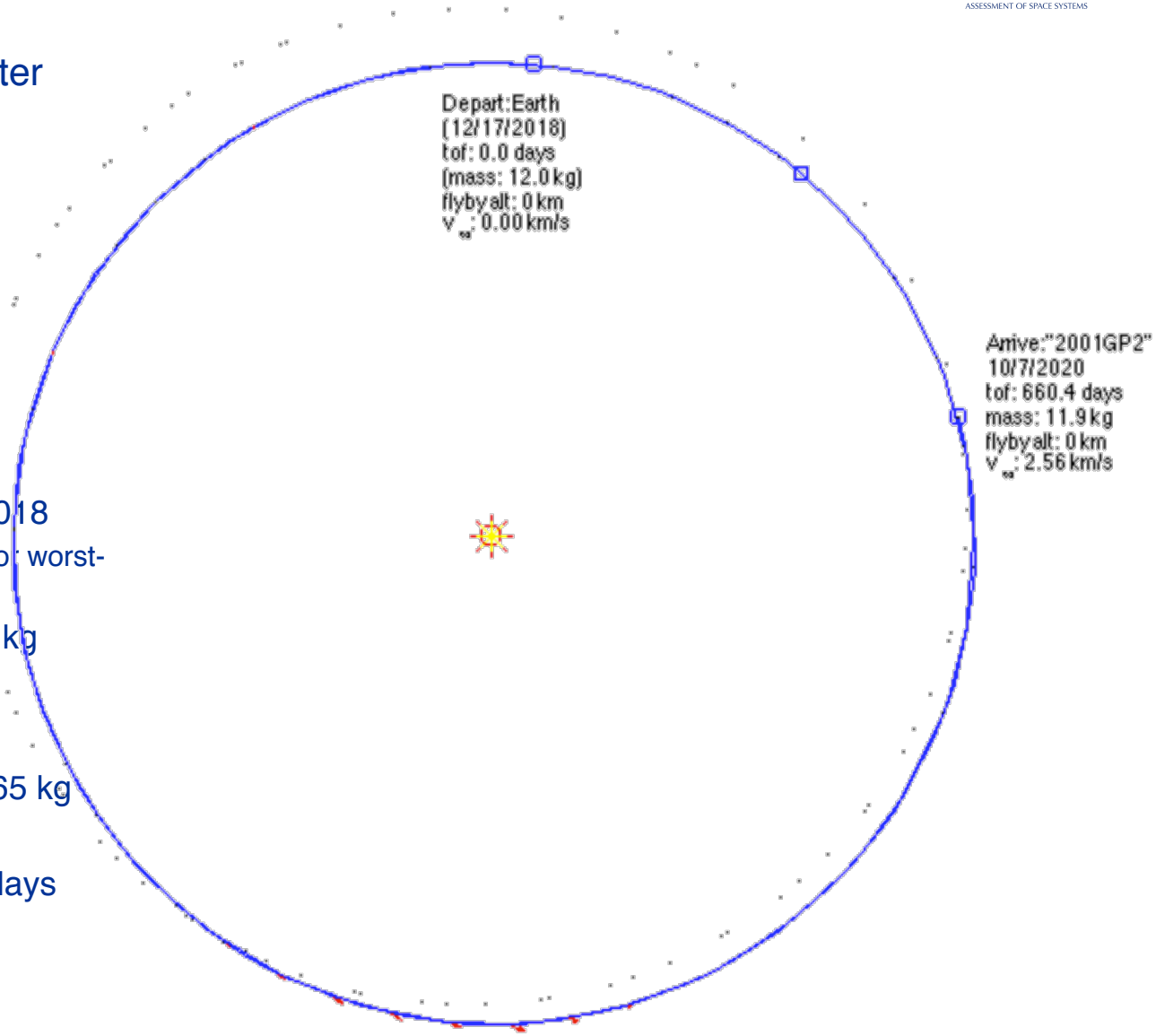


# 2001 GP2 Interplanetary Trajectory

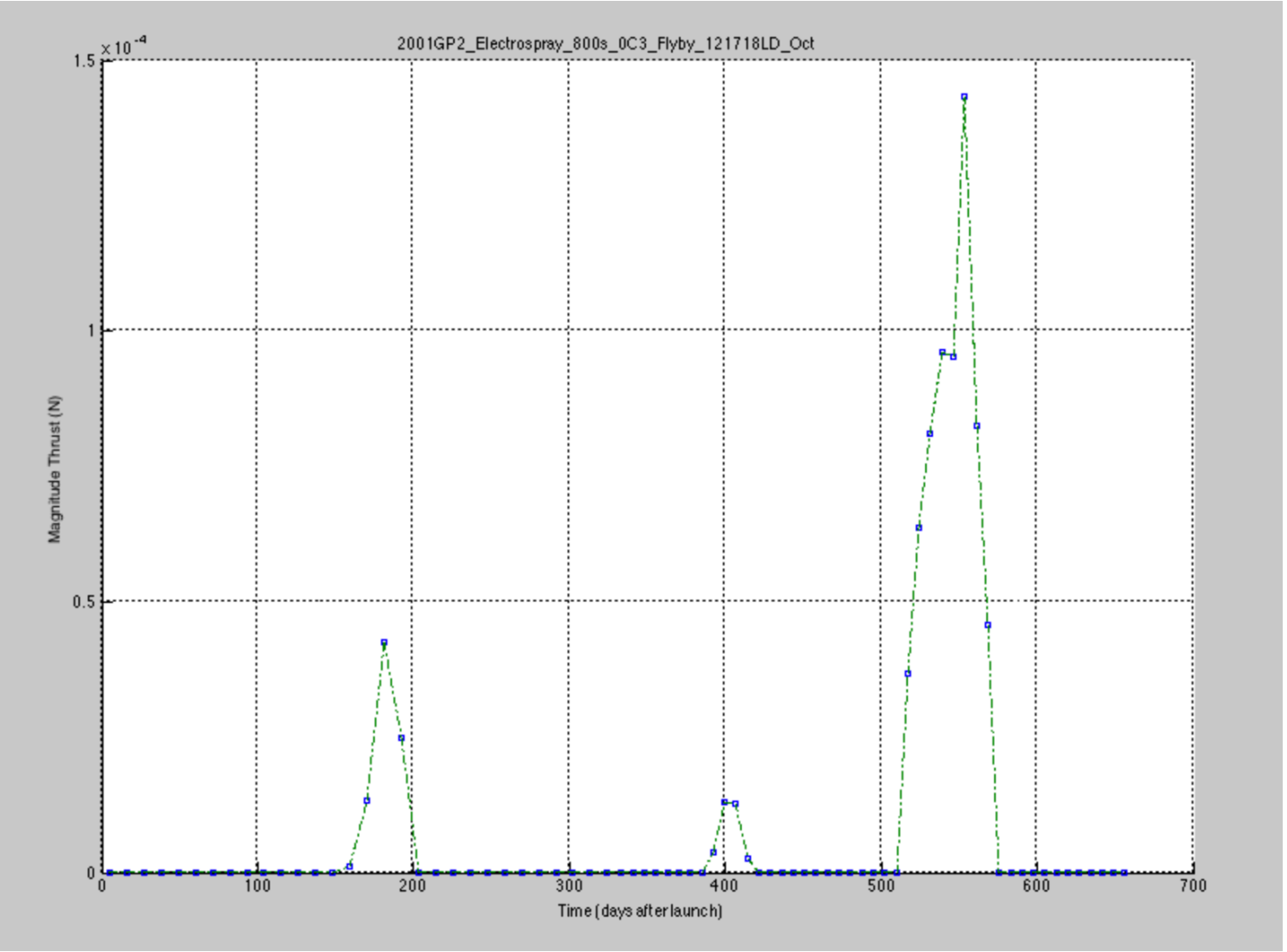


# 2001 GP2 Interplanetary Trajectory
# 2018 Launch (October Fly-by)

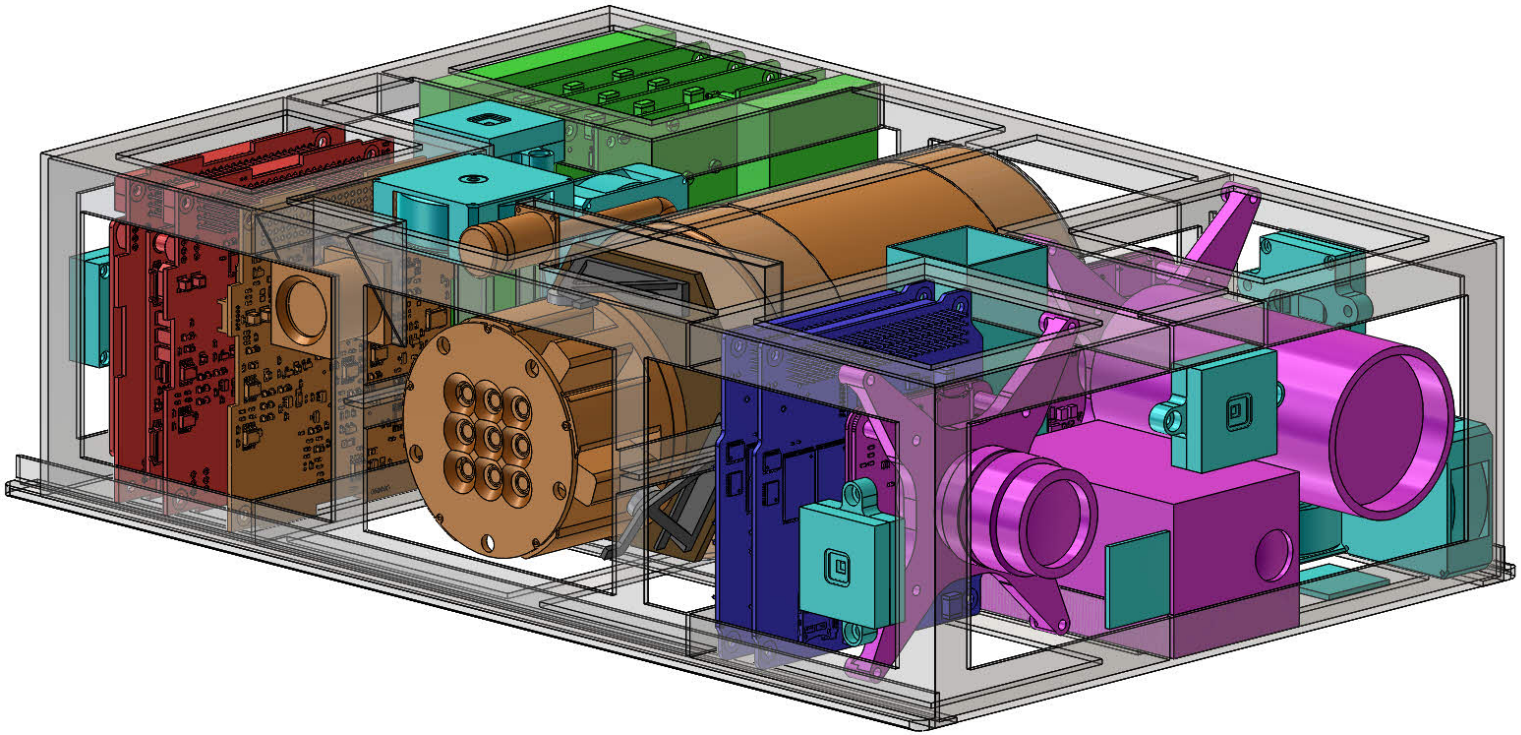
- Colloid (Electrospray) Thruster Parameters:
  - Power to thruster = 9W
  - Isp = 800s
  - Efficiency = 31%
  - Duty Cycle = 90%
- Trajectory Assumptions:
  - Fly-by of 2001 GP2
  - Constant 9W to thruster
  - SLS Launch Date: 12/17/2018
    - 4 days, 10 m/s to correct for worst-case SLS injection
  - 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



# 2018 Thrust Profile (October Fly-by)

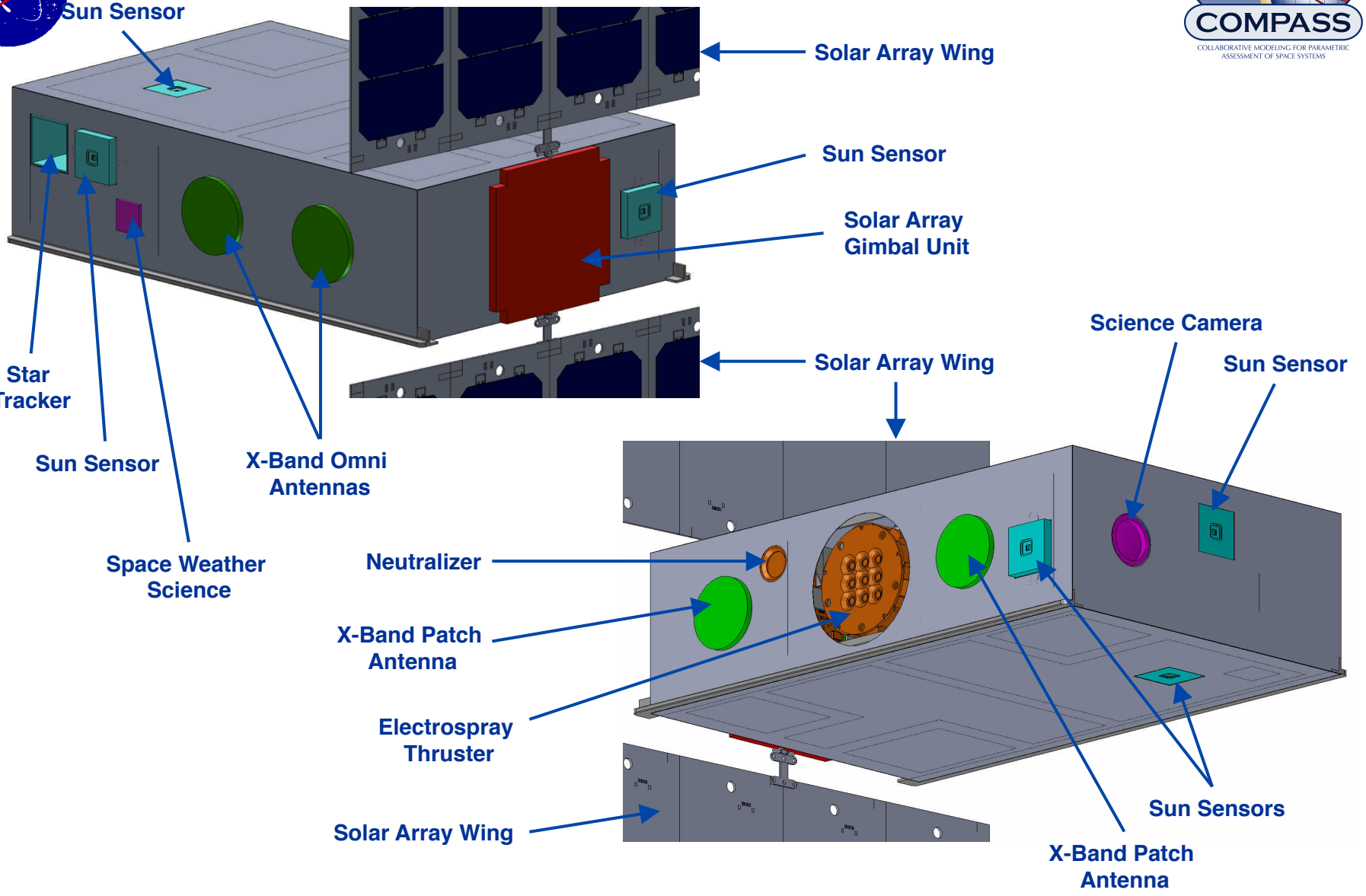


# Instruments



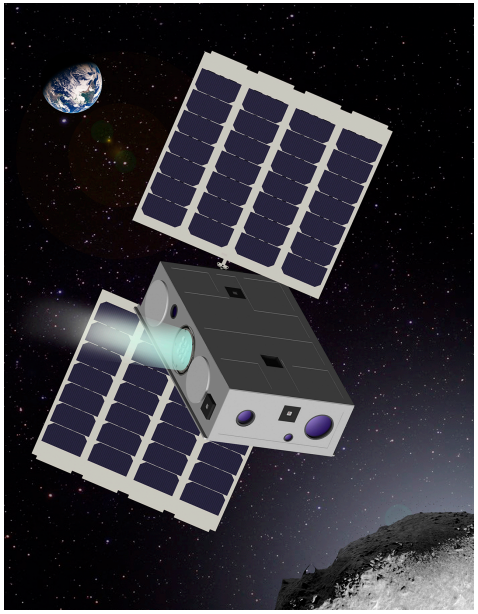
| Instrument | Field of view | Specification | Resolution |
|---|---|---|---|
| Wide-field camera | 10.7° × 8.06° | 3-megapixel color | 42 cm at closest approach |
| Narrow-field camera | 4.4° × 3.32° | 3-megapixel color | 17 cm at closest approach |
| V/NIR spectrometer | 1° | 400 to 1650 nm; 512 channels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

# SLS 6U Cubesat External Components



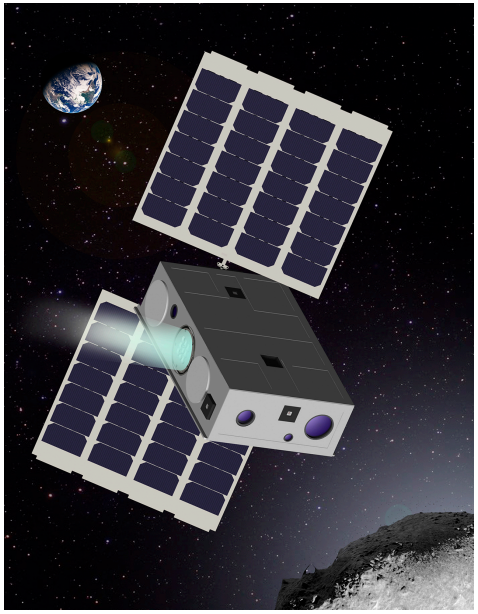
# Status

- Proposal submitted to SIMPLEX solicitation, but not selected for the EM-1 Mission Opportunity
- Proposal was rated highly, and 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