

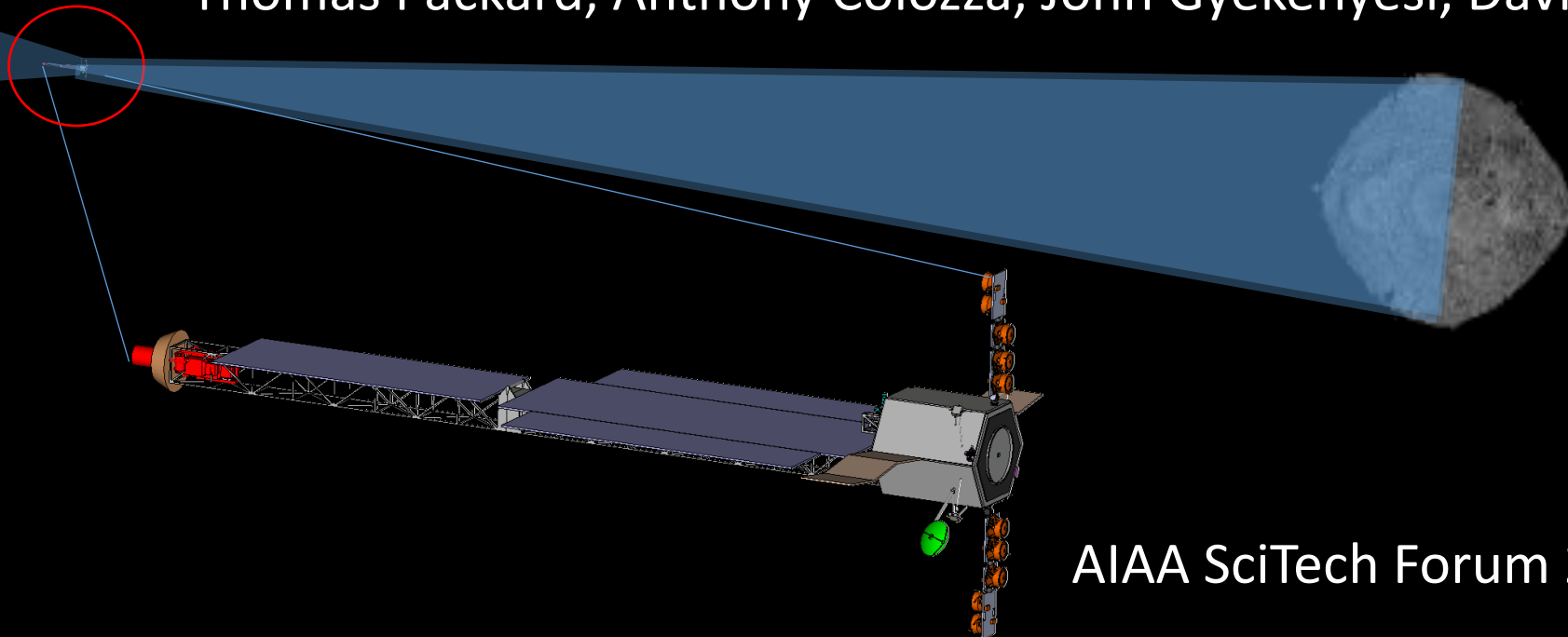


# *Nuclear Electric Propulsion Planetary Defense Interceptor*

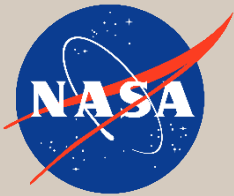
Steven Oleson, Elizabeth Turnbull, Steven McCarty, Lee Mason, Mackenzie Lykins,  
Brandon Klefman, Brent Faller, Benjamin Wozniak, Geoffrey Landis, W. Peter  
Simon, Ryan McDonough, Natalie Weckesser – NASA

James Fittje -SAIC

Thomas Packard, Anthony Colozza, John Gyekenyesi, David Smith – HX5



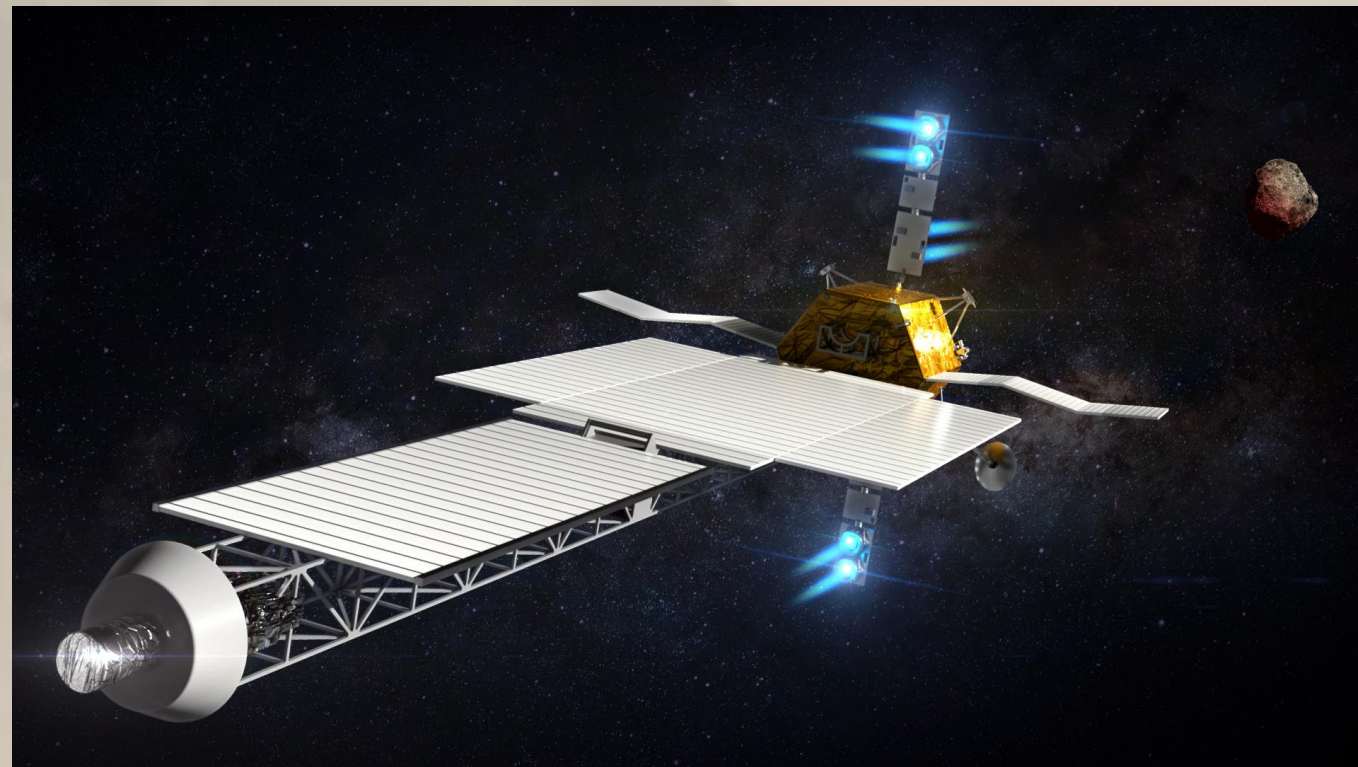
AIAA SciTech Forum 2026 – Orlando, FL

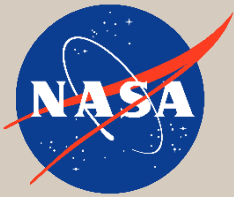


# Team



- Customer Team: Andy Presby, George Williams, Douglas Burns, Peter Ma, Christopher Garrett, Timothy Duquette
- Other Team Study advisors: Stephen Edwards, Matthew Duchek
- Lead: Steve Oleson
- Systems Integration: Betsy Turnbull
- Mission Design: Steve McCarty, David Smith
- Configuration: Tom Packard
- Science: Geoff Landis, John Brophy
- Attitude Determination and Control: Brent Faller, Ben Wozniak
- Command and Data Handling: W. Peter Simon
- Communications and Tracking: Katelyn Crockett, Ryan McDonough, Michael Marsden
- Power Systems: Lee Mason, Mackenzie Lykins, Brandon Klefman
- Thermal Control: Tony Colozza
- Propulsion: Jim Fittje, Robert Thomas, Dave Jacobson, Dave Manzella
- Structures and Mechanisms: John Gyekenyesi
- Cost Estimating: Natalie Weckesser, Amelia Marino





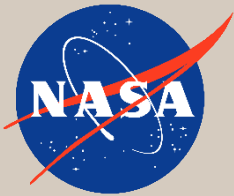
# Design Purpose



- Purpose:
  - *Develop a Nuclear Electric Propulsion (NEP) conceptual vehicle design for Planetary Defense*
  - *Object class defined by 2025 Planetary Defense Sample Mission (see below)*
- Scope
  - *Focus on the NEP and deflection design*
  - *Utilize large of volume of work using solar electric propulsion (SEP) Ion Beam Deflection by Brophy and others*
- Class A/B, Single Fault Tolerant
- FOMs: Size of Asteroid deflected, Time to launch, Robustness, Cost

## Sample Problem

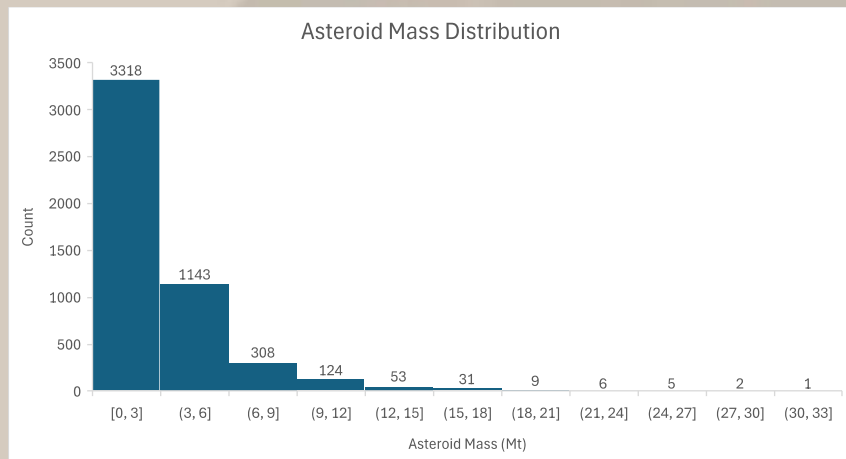
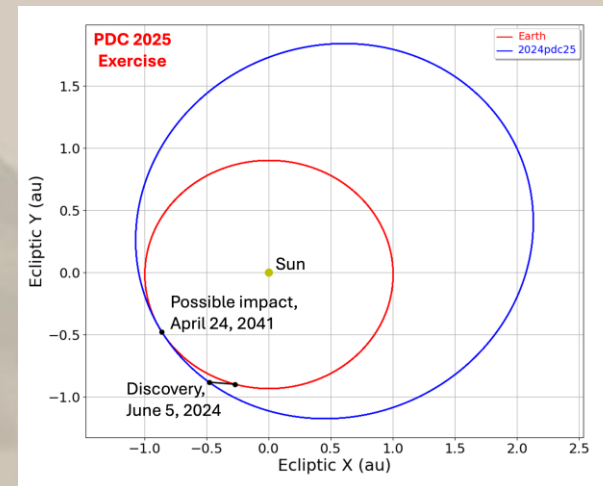
- Set by IAA Planetary Defense Conference 2025
- Will utilize an NEP vehicle and trade deflection techniques
  - Ion beam deflection, gravity tractor, laser ablation....
- Two pieces of the problem : Delivery to co-orbit and deflecting the asteroid
- Spacecraft starting points from previous Compass work



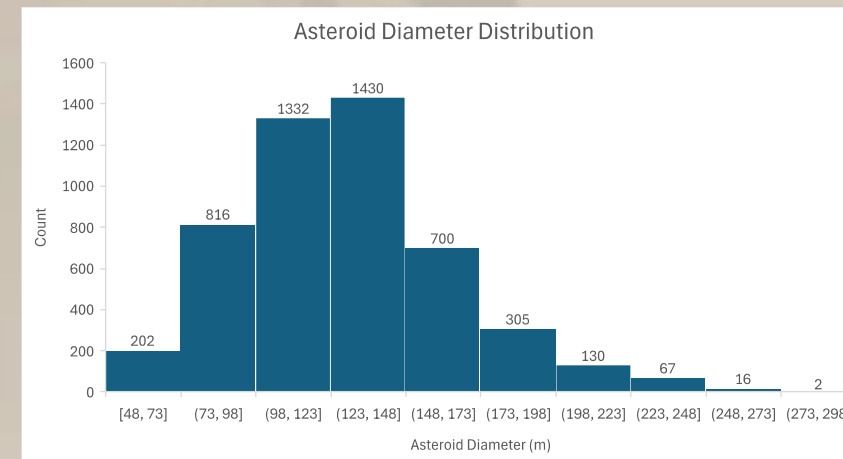
# Asteroid Characteristics



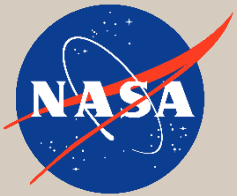
- Mission requirements are tightly coupled with asteroid mass
- What asteroid mass do we need to design to?
- 2024 PDC25 physical properties are uncertain:



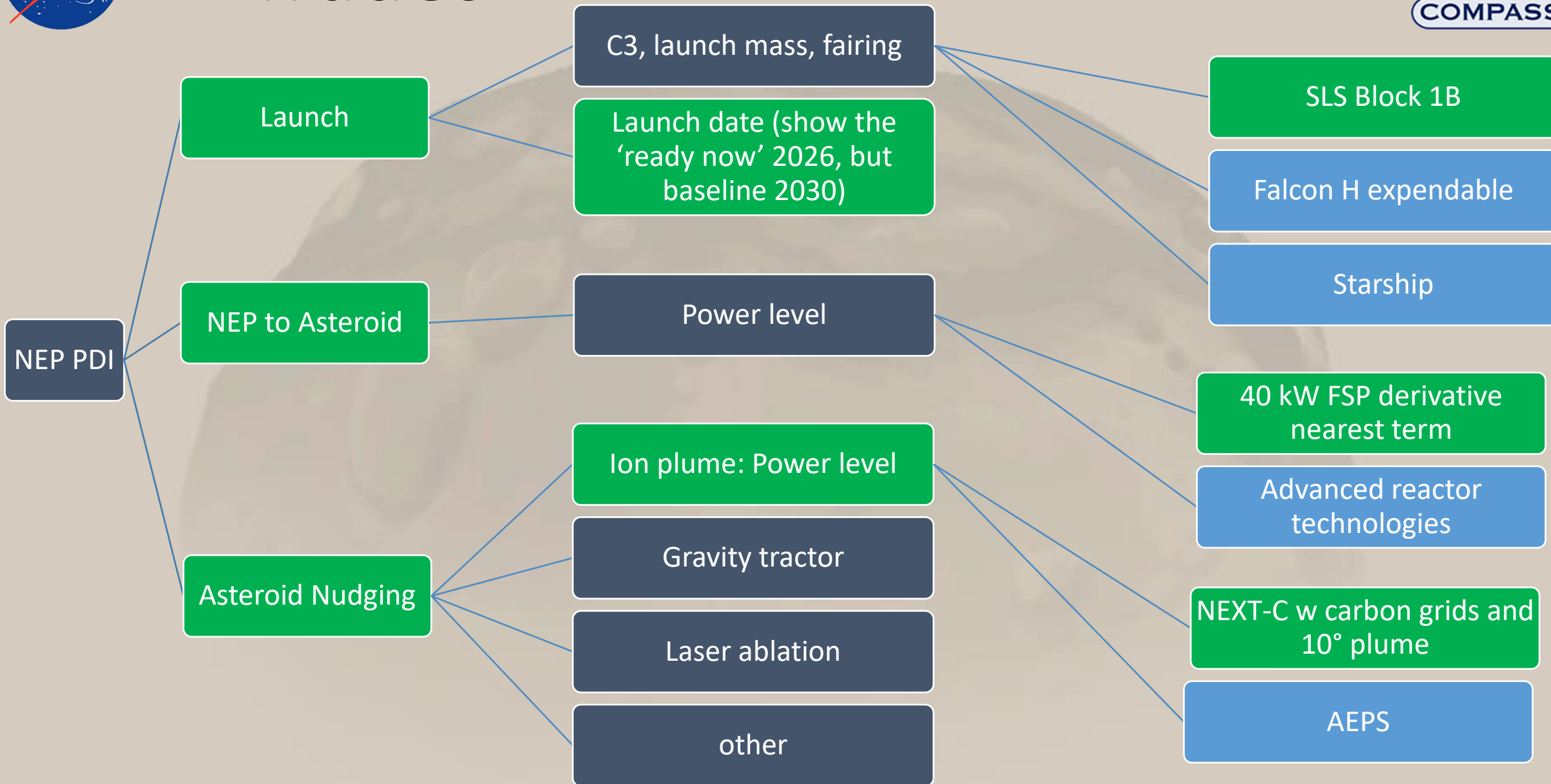
Mass Stats (Mt)	
min	0.12
max	31.38
mean	3.08
median	2.21
90th	6.35
99th	15.37
99.9th	25.45

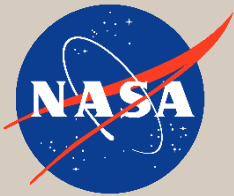


source: <https://cneos.jpl.nasa.gov/pd/cs/pdc25/>



# Trades





# Ion Beam Deflection Calculation

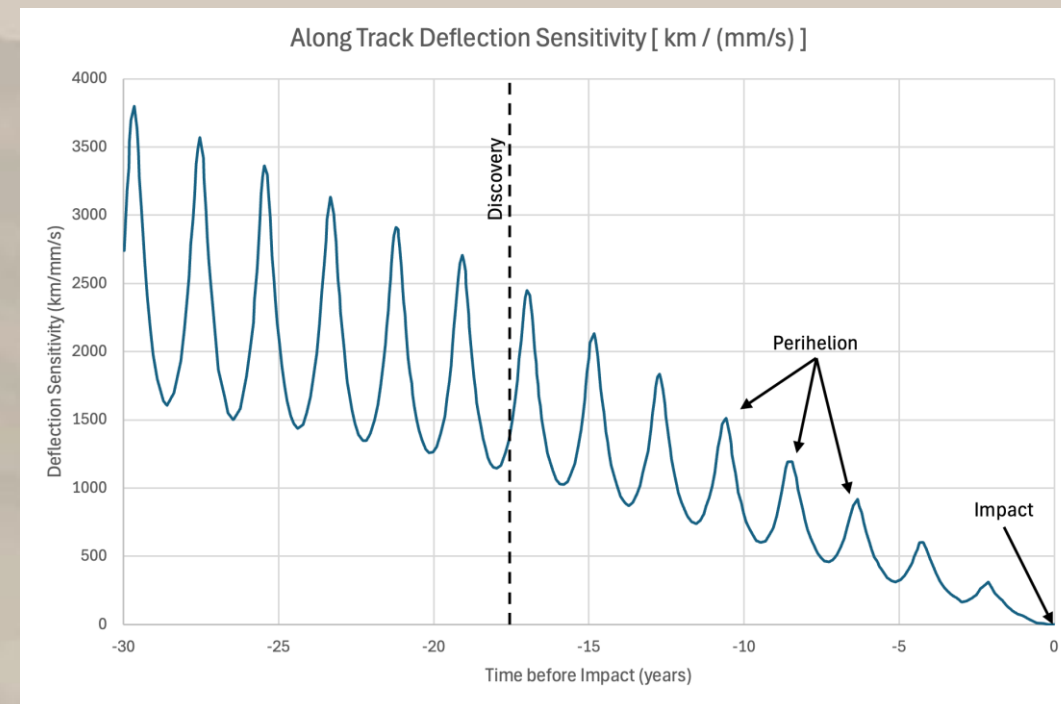


- Assume along track deflection only, since it's most efficient

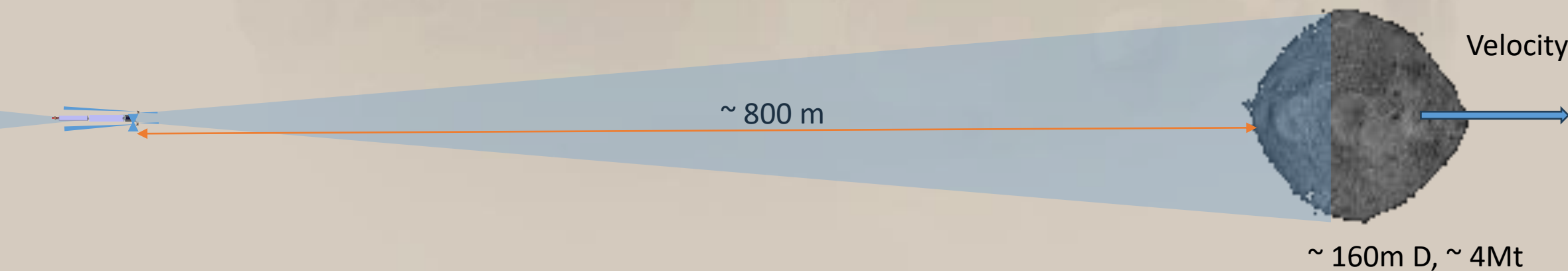
$$deflection = a_{asteroid} * \int_{T_0}^{T_f} Sensivity$$

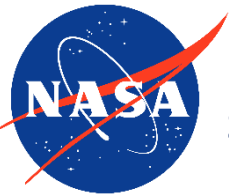
$$a_{asteroid} = \frac{T * \eta * DC}{M_{asteroid}}$$

- $a_{asteroid}$  = IBD acceleration
- $T$  = IBD thrust
- $\eta$  = effectivity of IBD momentum transfer
- $DC$  = IBD duty cycle
- $M_{asteroid}$  = asteroid mass



source: <https://cneos.jpl.nasa.gov/nda/nda.html>





2033 Rendezvous with Asteroid

# Concept of Operations Diagram



~ 2.5 Years NEP  
Propelled to co-orbit with Asteroid

Evaluate Asteroid Attributes (~1 month)

Reactor deployment / Commissioning

$C_3 \sim 37 \text{ km}^2/\text{s}^2$

DSN

Earth

Using ~535 mN of ion beams  
Nudge Asteroid along velocity vector for ~ 7 years, change its orbit sufficiently to miss Earth

Ka Band Communications and Data Downlink of Asteroid divert Progress and up to date images

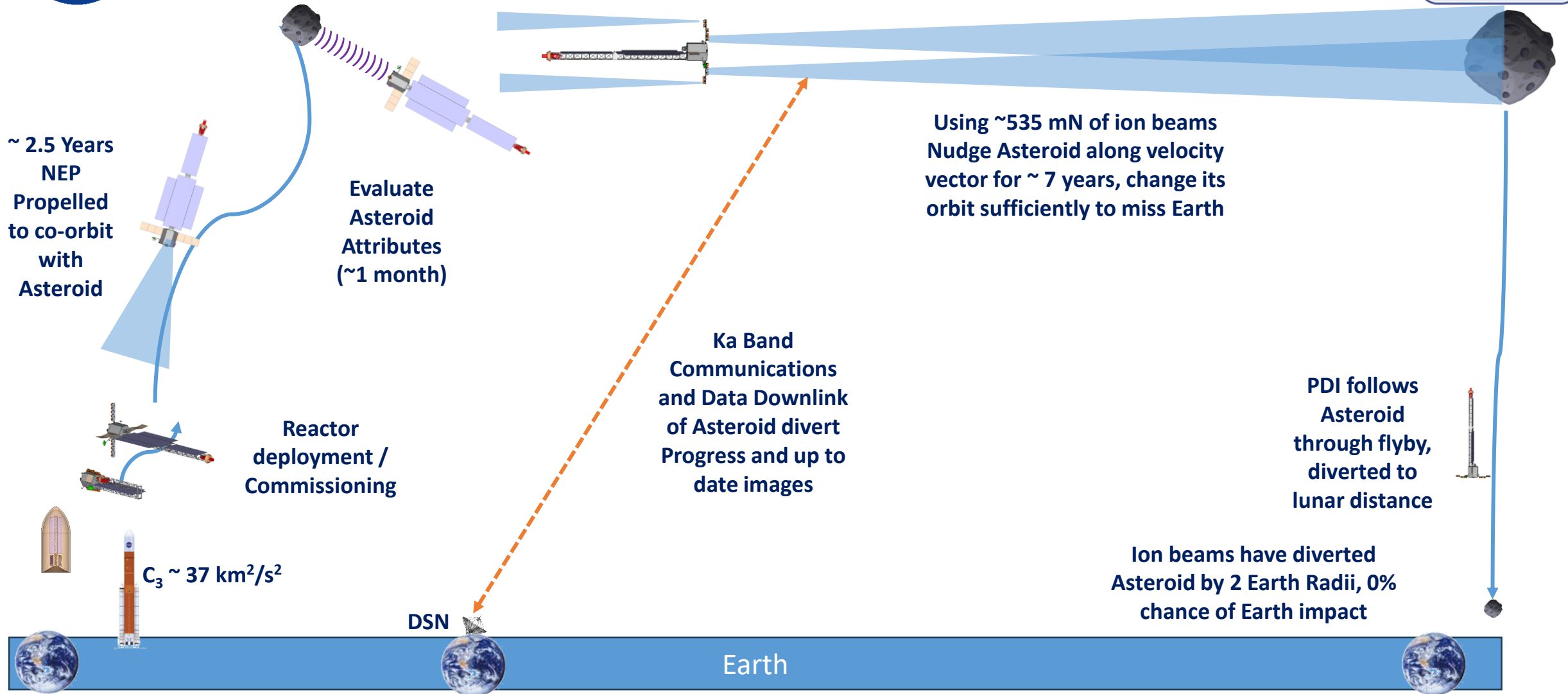
PDI follows Asteroid through flyby, diverted to lunar distance

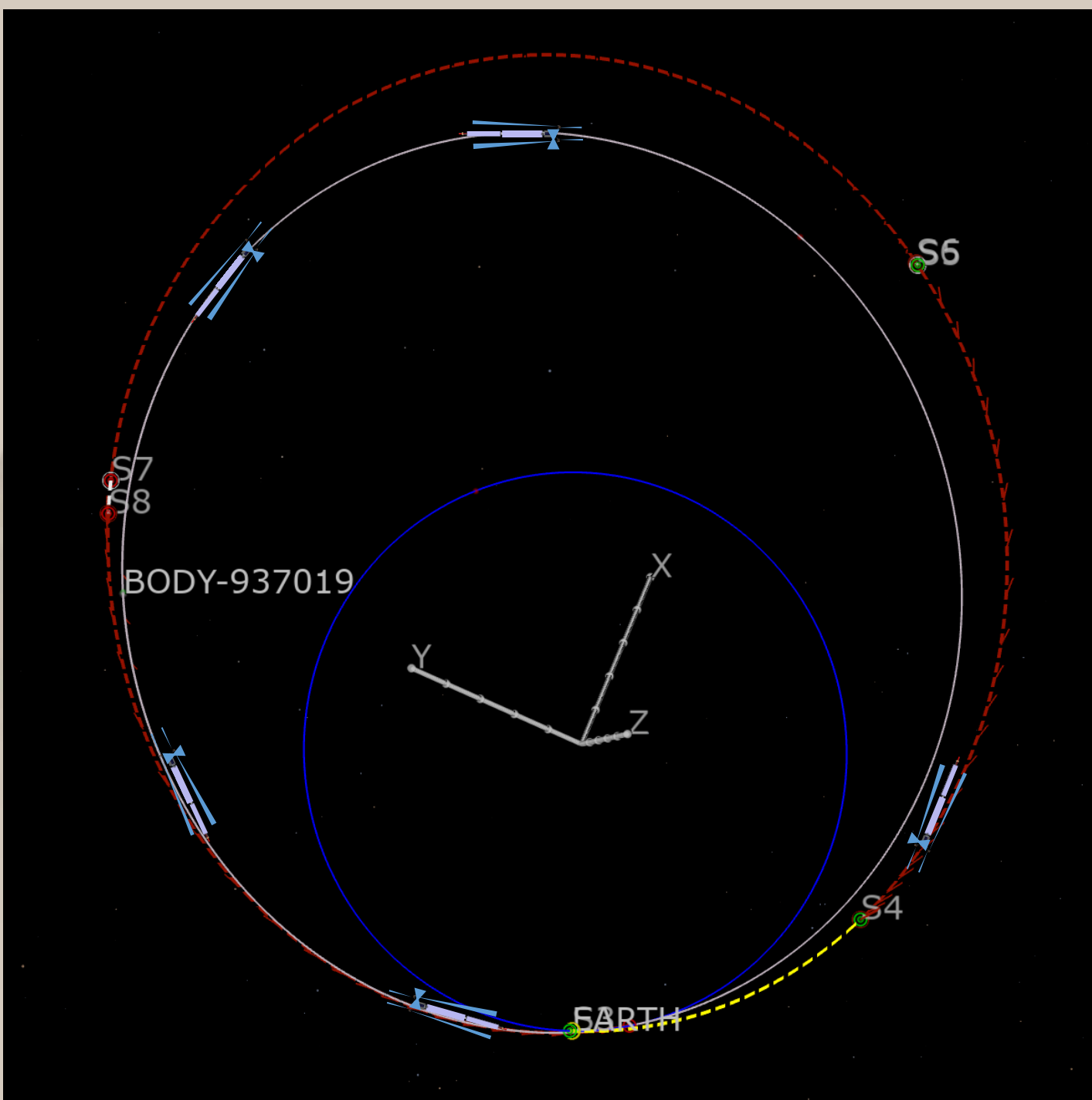
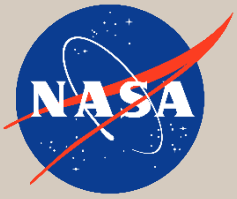
Ion beams have diverted Asteroid by 2 Earth Radii, 0% chance of Earth impact

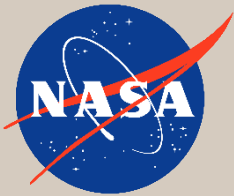
Lift-off 2030

SLS Block 1B

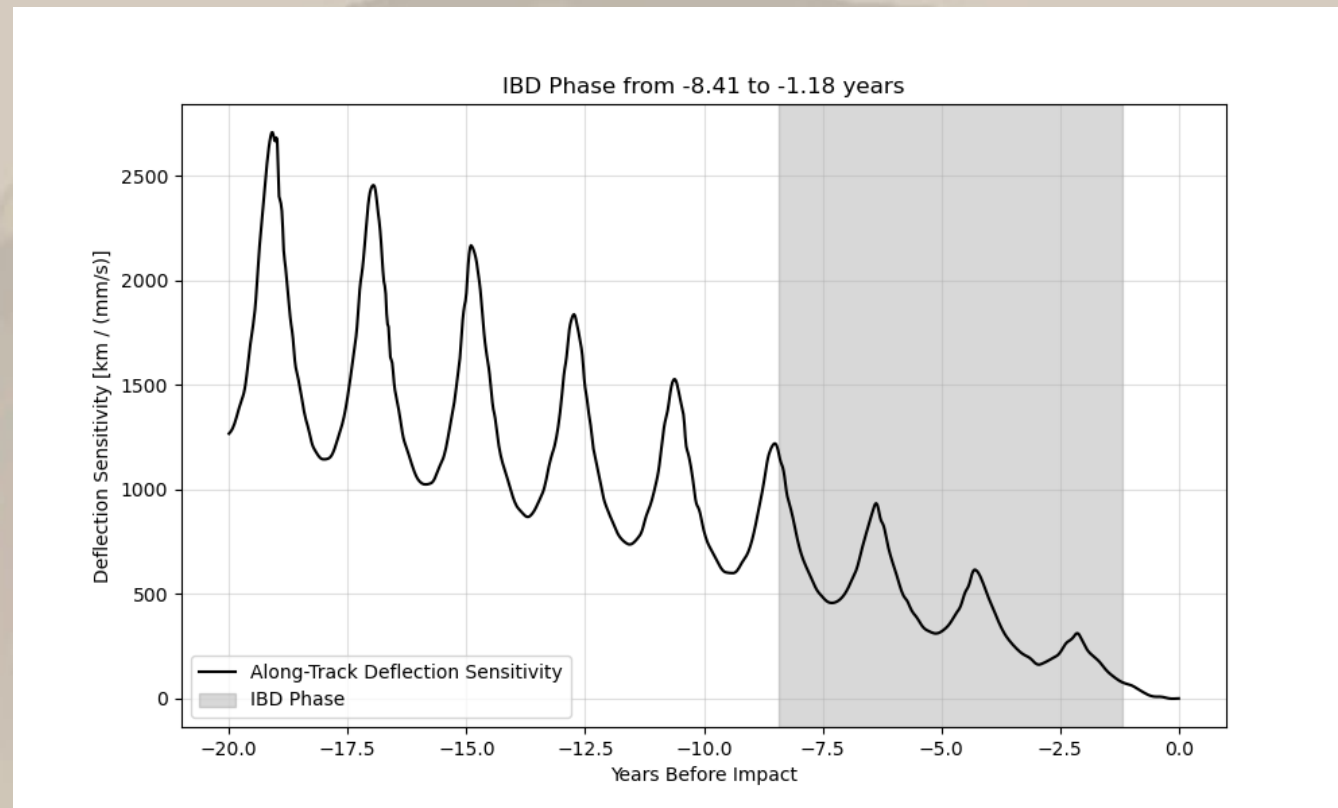
Earth Fly-by 2041



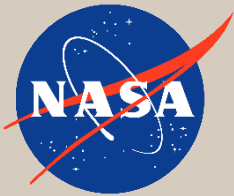




# Deflection Plot



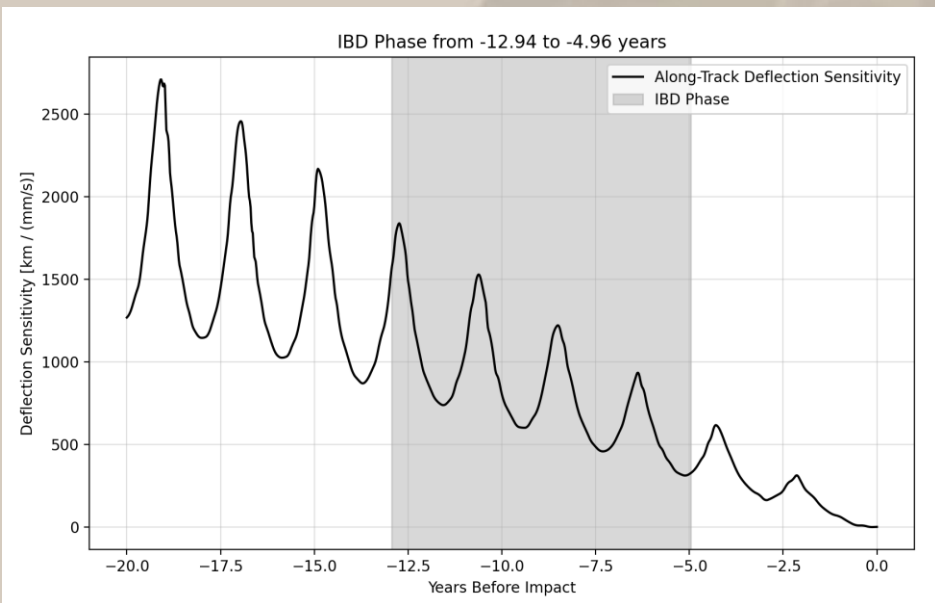
- Option to deflect the spacecraft post asteroid deflection:
  - The sensitivity 1 year before close approach is  $\sim 60$  km/(mm/s)
  - To deflect the *spacecraft* by 400,000 km requires  $\sim 7$  m/s (along track) ( $\sim 2$  kg propellant)



# Alternative Case (earlier 2026 launch)

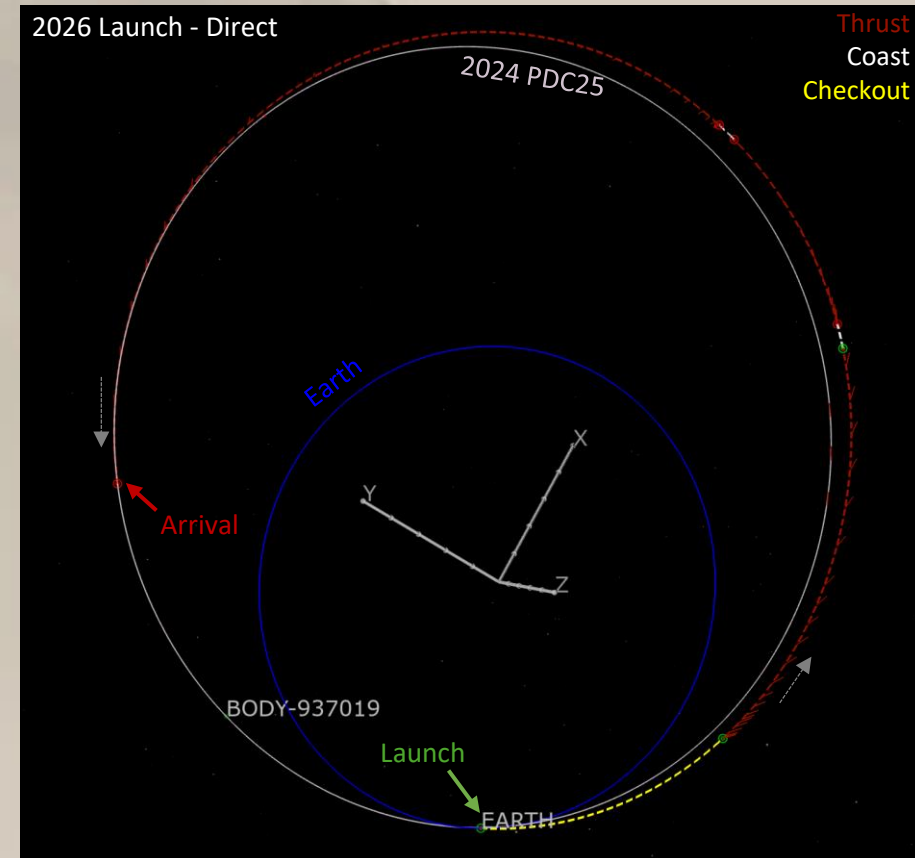


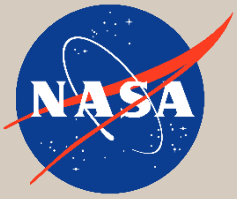
- What if we could launch in 2026?
  - Feasible asteroid mass increases from 4.0 to 8.5 Mt (94.5<sup>th</sup> percentile)



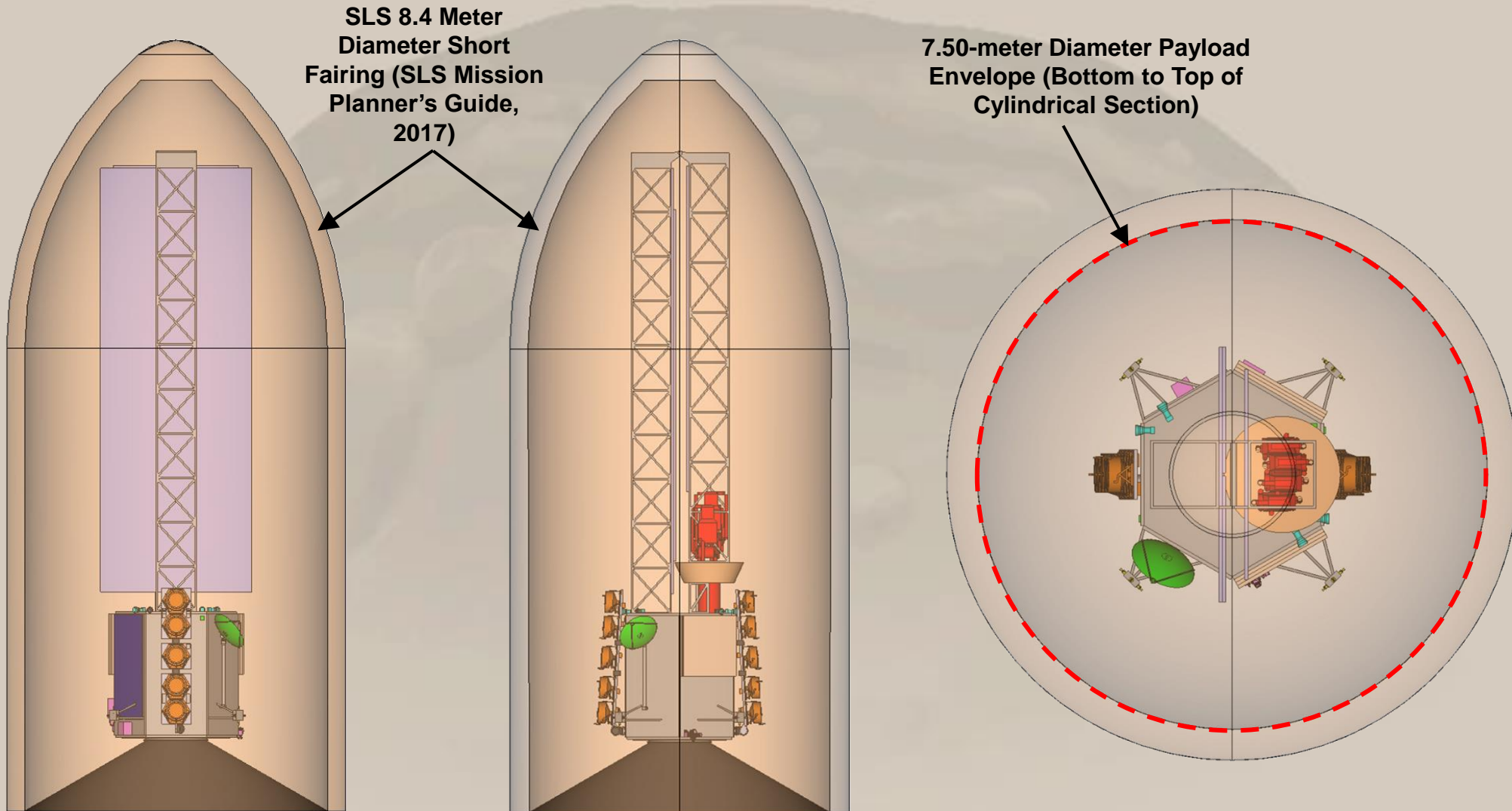
Xenon Capacity Limited

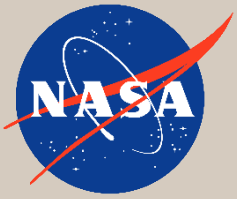
	Case 1 (2026)
Launch Date	4/15/26
Dry Mass (kg)	11,152
<b>Asteroid Mass (Mt)</b>	<b>8.5</b>
<b>Asteroid Percentile</b>	<b>94.5</b>
Launch Mass (kg)	19,496
Launch C3 (km <sup>2</sup> /s <sup>2</sup> )	36.9
Asteroid Arrival Mass (kg)	18,167
Transit Xe Used (kg)	1,328
Deflection Xe Used (kg)	6,543
Total Xe Used (kg)	7,871
Transit ΔV (m/s)	2,906
IBD Effective ΔV (m/s)	18,392
Transit Time (years)	1.93
Deflection Time (years)	8.0



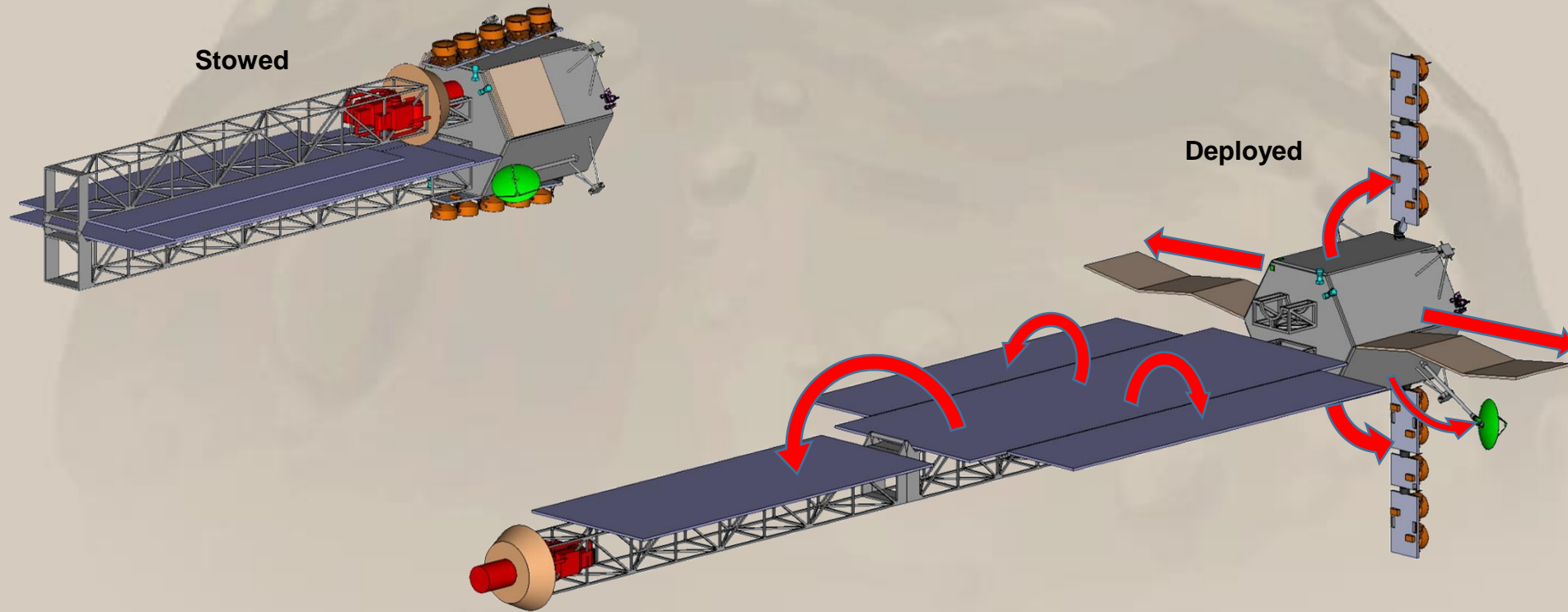


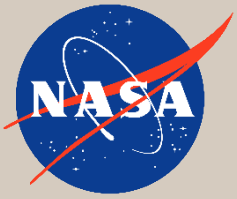
# NEP Planetary Defense Vehicle Inside the SLS 8.4m Diameter Short Fairing (Baseline)



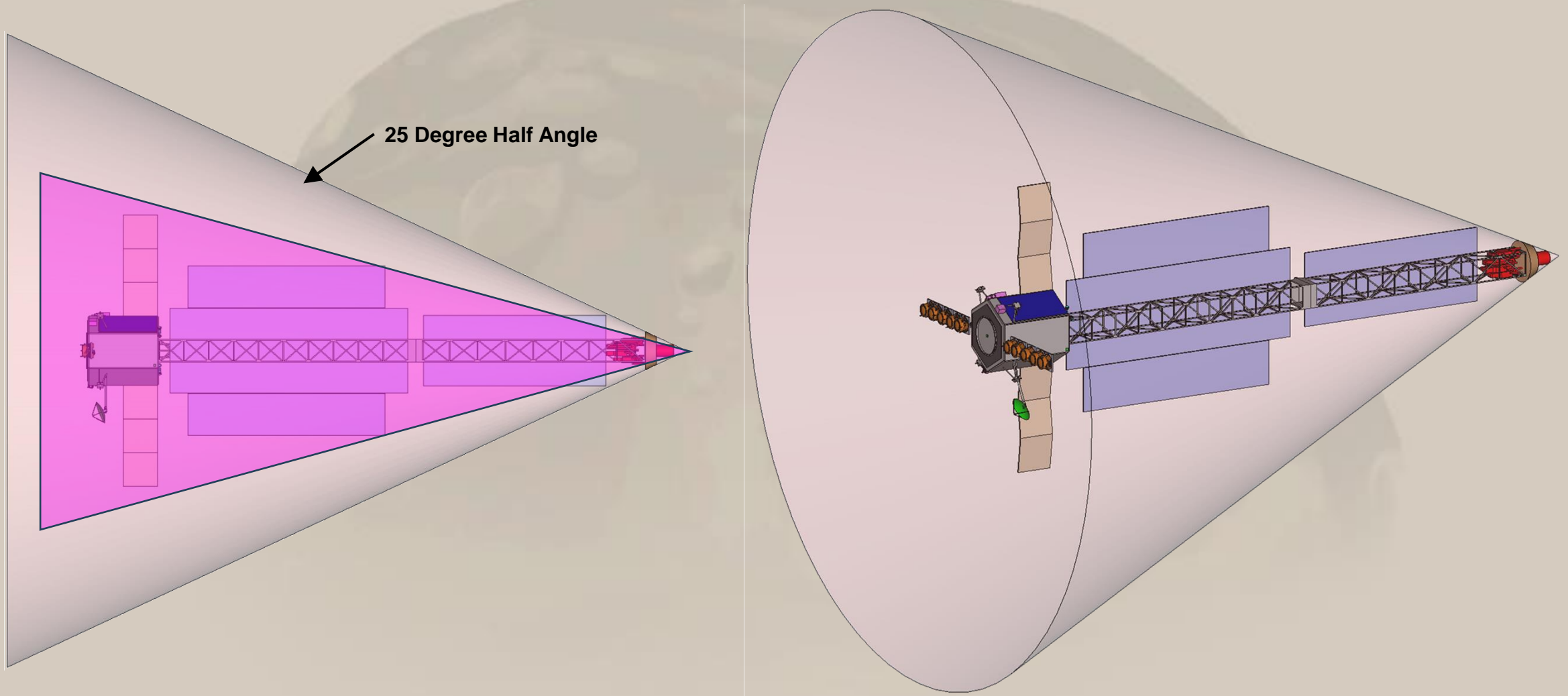


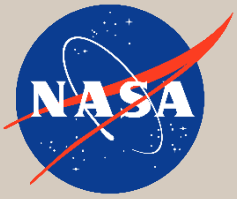
# NEP Planetary Defense Vehicle Deployment



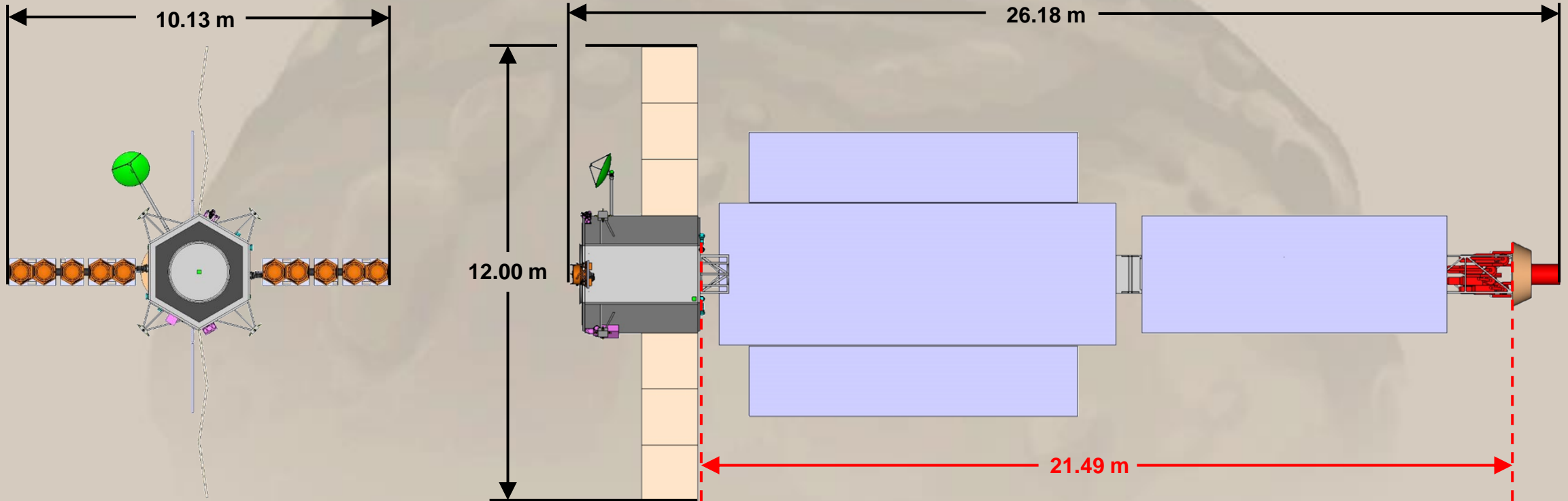


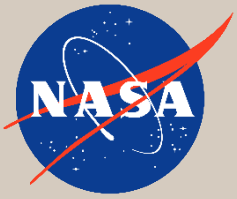
# NEP Planetary Defense Vehicle Reactor Shield Cone



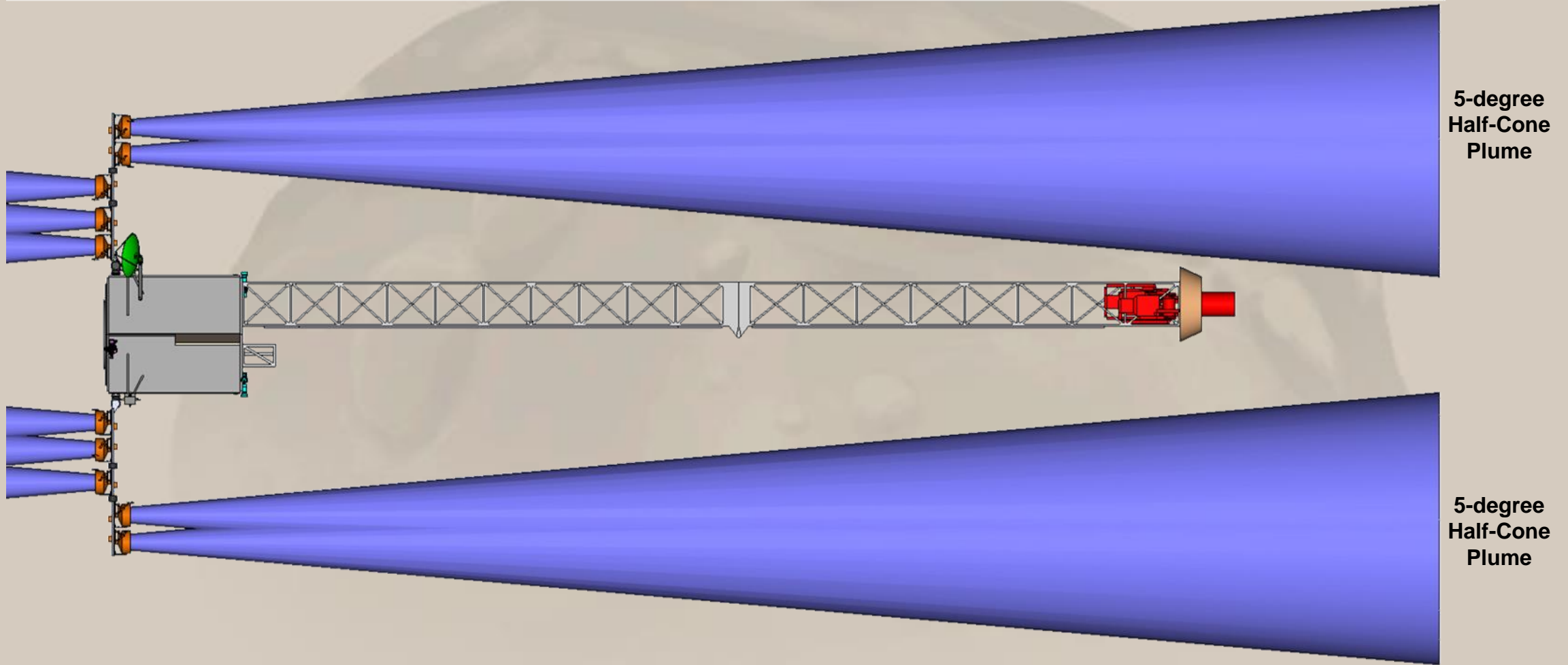


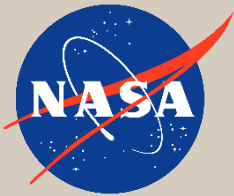
# NEP Planetary Defense Vehicle Deployed Dimensions



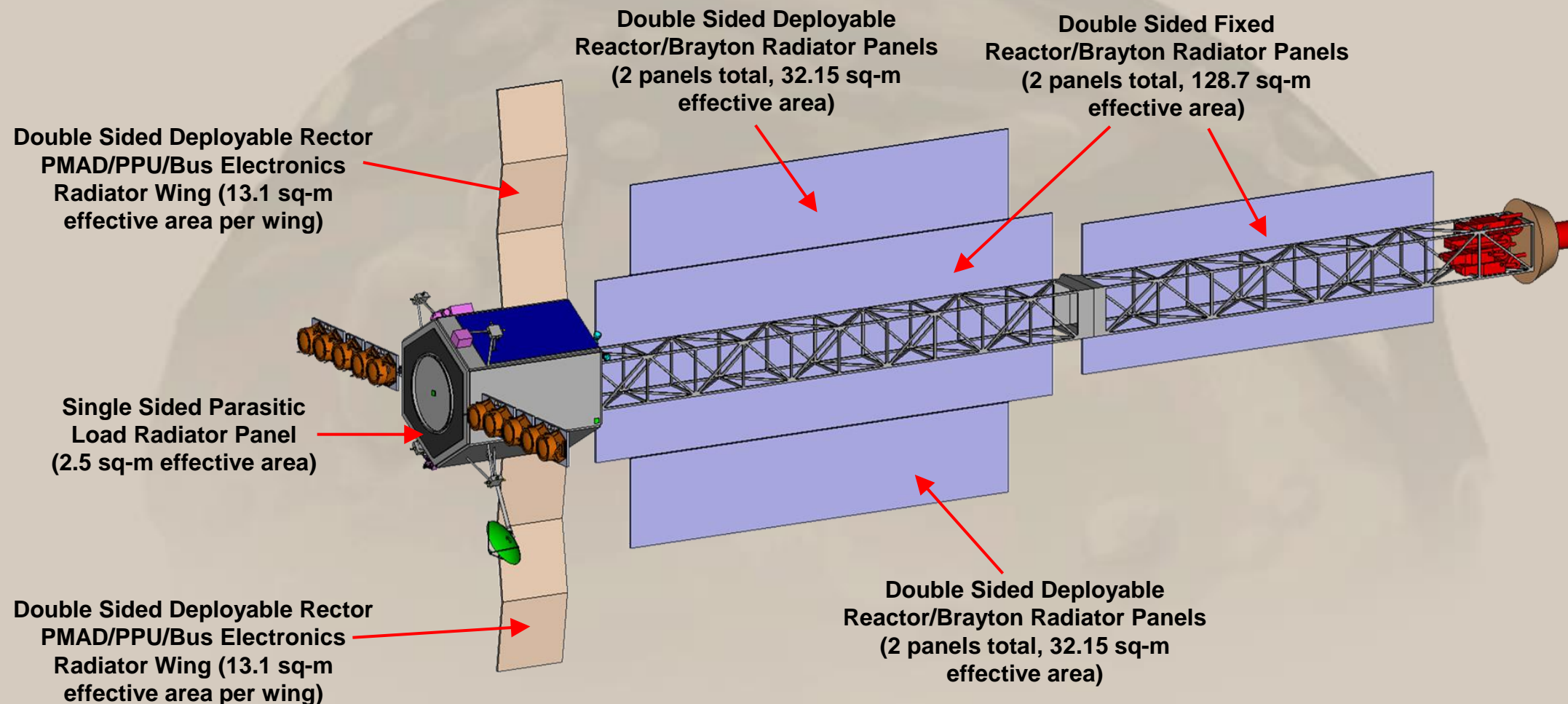


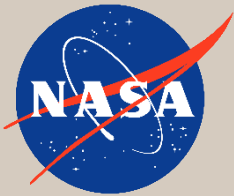
# NEP Planetary Defense Vehicle Thruster Plumes



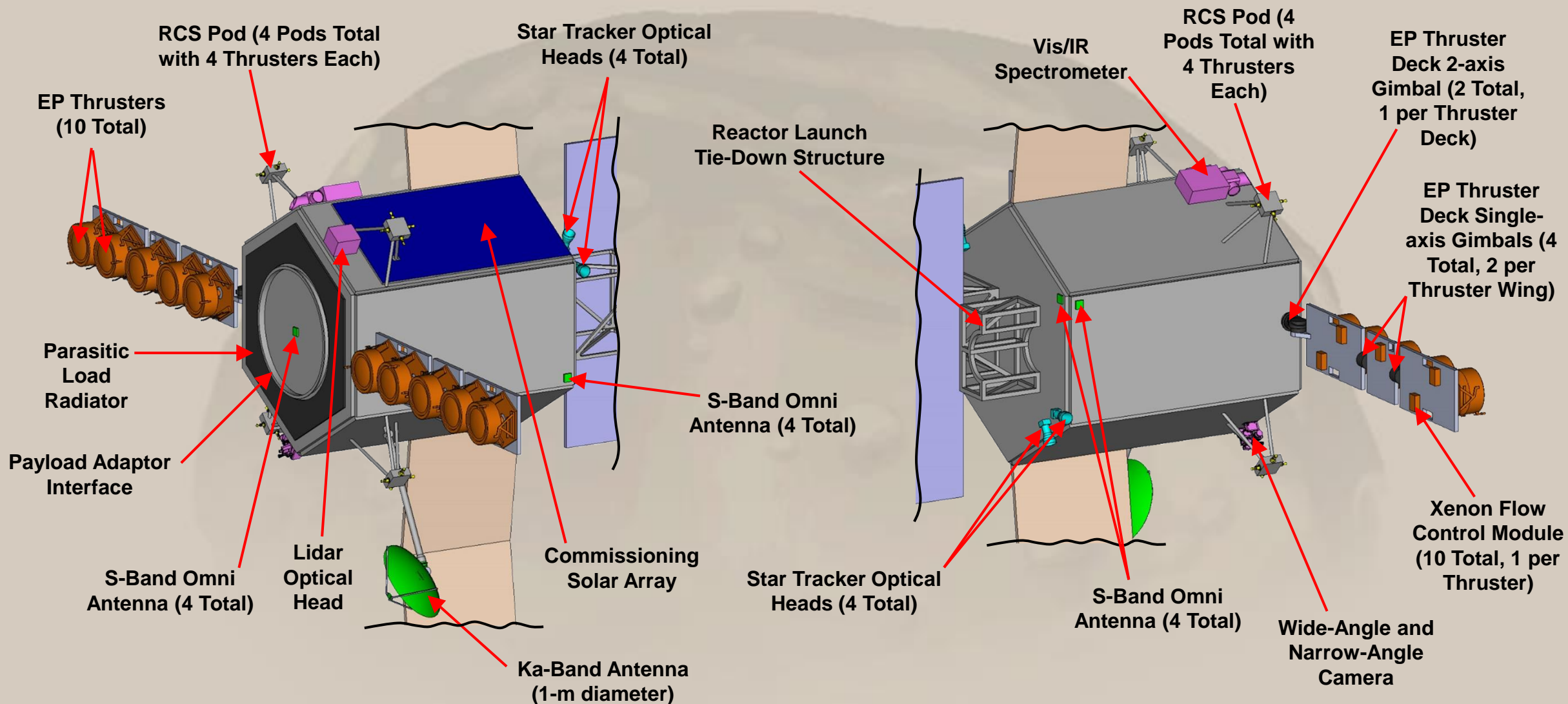


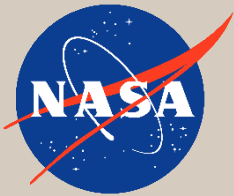
# NEP Planetary Defense Vehicle Radiators





# NEP Planetary Defense Vehicle External Bus Components

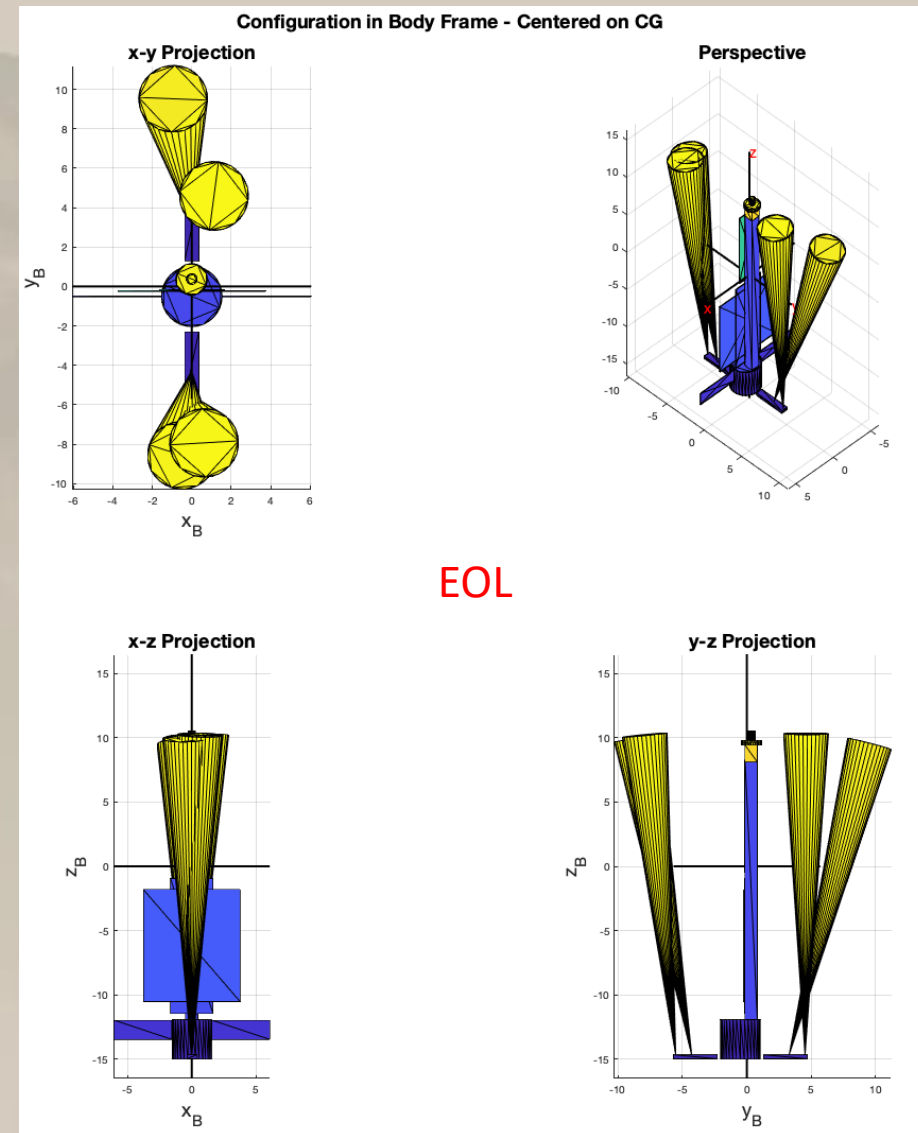


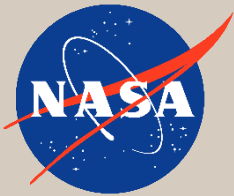


# Station-Keeping Gimbaling



- Strategy selected to maintain a fixed distance from the asteroid along the asteroid velocity vector involves gimbaling all 8 active EP thrusters
  - Goal is to maximize the amount of ions impacting the asteroid. This means the aft pointing thrusters are limited to  $1^\circ$  of off-pointing (about 12m beam off-pointing at asteroid)
  - Constrained such that torque and force on the vehicle due to EP thrust is net zero
  - Forward facing EP thrusters constrained to point ion beams away from vehicle
- Could also: throttle forward pointing thrusters, use pallet gimbals, slow spin about z axis, etc. Lots of options here



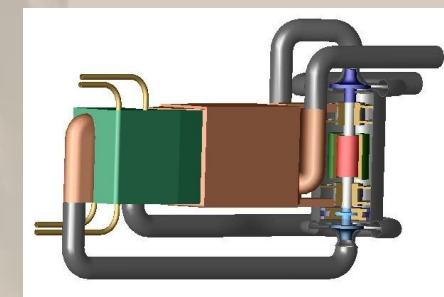
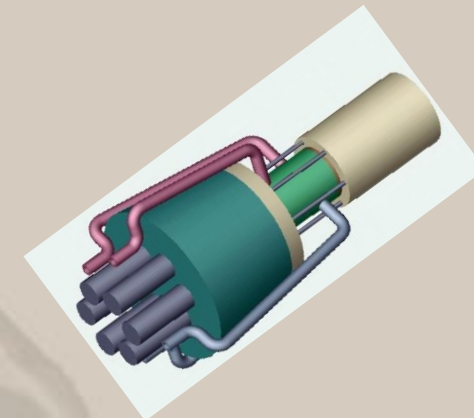


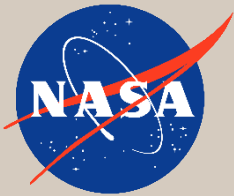
# 44 kW NEP Power System



## PDI nuclear power concept is heavily derived from FSP Govt. Reference Design

- 19.75% HALEU moderated reactor
  - UN fuel, YH moderator, Na heat pipes, 1100K reactor supply temperature, 10 yr full-power design life
- LiH/W shadow shield
  - $10^{11}$  n/cm<sup>2</sup>, 25 krad at 25m separation, 25 deg half angle (~5 Mrad at 2m power conversion)
- Four independent power strings
  - (PCS, HRS, PMAD) at 25% each; first fault results in no less than 75% power
- HeXe Brayton power conversion
  - four 12.7 kW converters, 1100K TIT, 390K CIT, 95% recuperator, 248 kWt thermal input, 21% conv efficiency, 24 kg/kWe conv sp mass
- Pumped H<sub>2</sub>O heat rejection
  - composite radiators with embedded Ti/H<sub>2</sub>O heat pipes, 192 kWt rejected, 504K T<sub>in</sub>, 379K T<sub>out</sub>, 0.09 kg/s per loop, 10% area margin, 193 m<sup>2</sup> total, 4.9 kg/m<sup>2</sup>
- 240Vac/2 kHz/3Ø
  - alternator output converted to 120 Vdc at bus, 25m AC cabling, 90% efficiency, 323K/17.5 m<sup>2</sup> PMAD radiator, 950K/2.5 m<sup>2</sup> PLR, 17 kg/kWe

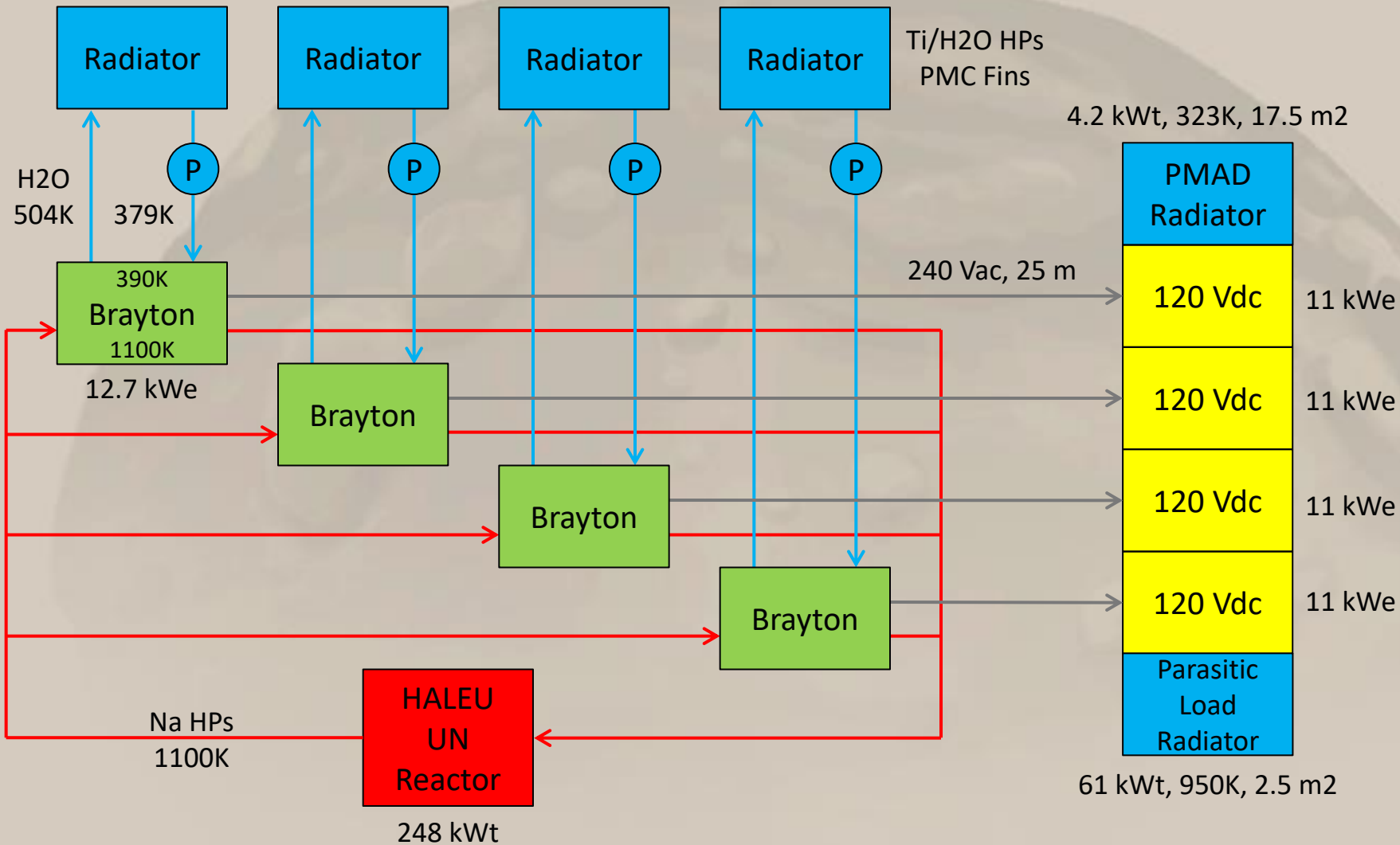


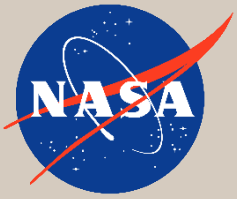


# NEP Power System Schematic

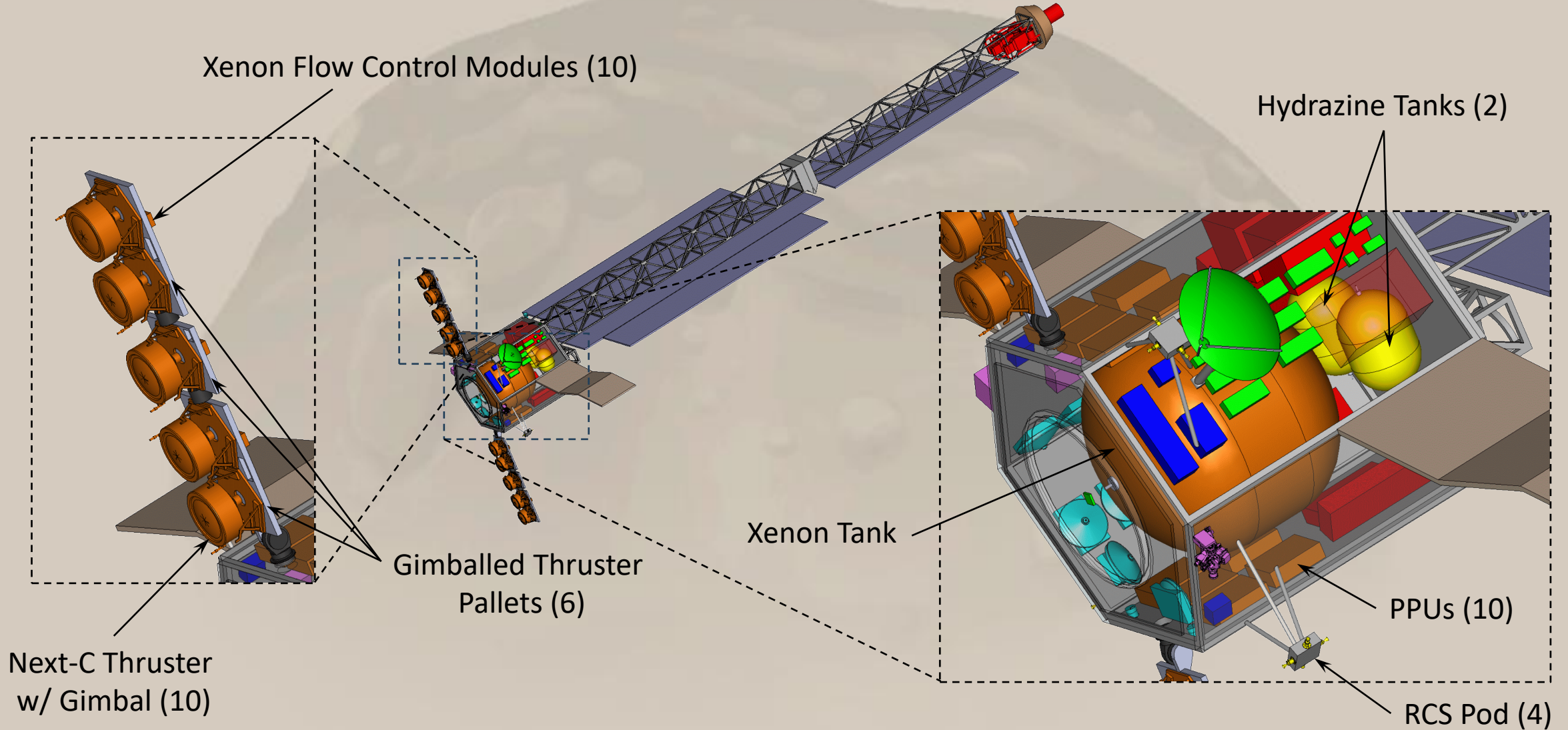


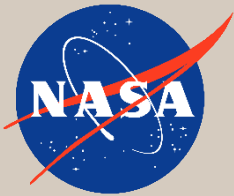
48 kWt, 414K, 48 m<sup>2</sup>





# Propulsion System Configuration





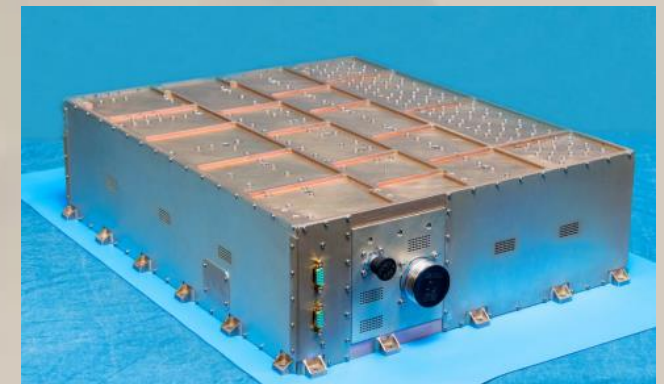
# EP System Overview



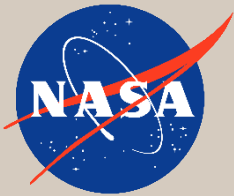
- Ten NEXT-C Thrusters in 8+2 Configuration w/o Cross-Strapping
  - ON-going CIF: Demonstration of an Ultra-Low Divergence Angle Gridded Ion Thruster
    - Demonstrating plume divergence angles sufficiently small to enable the ion beam deflection approach ( $< 5^\circ$ ).
    - Incorporate flat, carbon-based optics on a NEXT-C ion thruster
    - Experimentally characterize the plume divergence angle at relevant conditions and compare to SOA
- Mounted on Two Wings, each w/ Three Independently Gimballed Panels
- Dual Isolatable Feed Lines Across Gimbals for Redundancy
- NEXT-C Thrusters Mounted to Panels via Individual Gimbals
  - Three Strut Attachment to S/C Panel
  - Provides Thruster Retention in Launch Position
  - +/- 19 Degrees in X-Axis, +/- 17 Degrees in Y-Axis
- Single Xenon Flow Controller Mounted on Panel w/ Thruster
- Single 4,384 l Supercritical Xenon Storage Tank
- Thrusters Operated at Nominal 4,200 s Isp, 4.5 kW
- Single 95% Efficient PPU per Thruster
  - Operates from 120V S/C Bus Power
  - Provides DCIU Functionality to Flow Controller



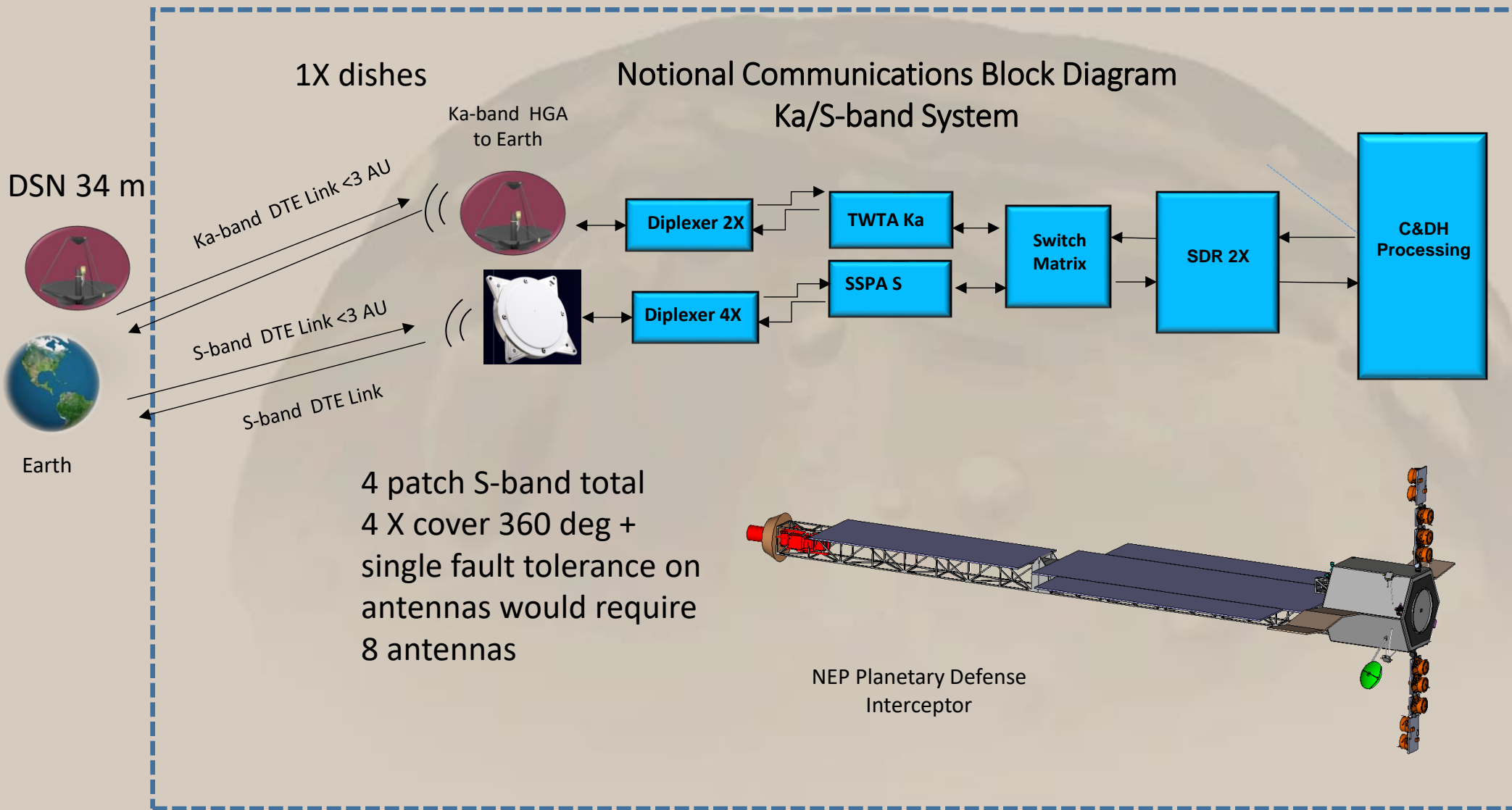
NEXT-C Thermal-Vacuum Testing



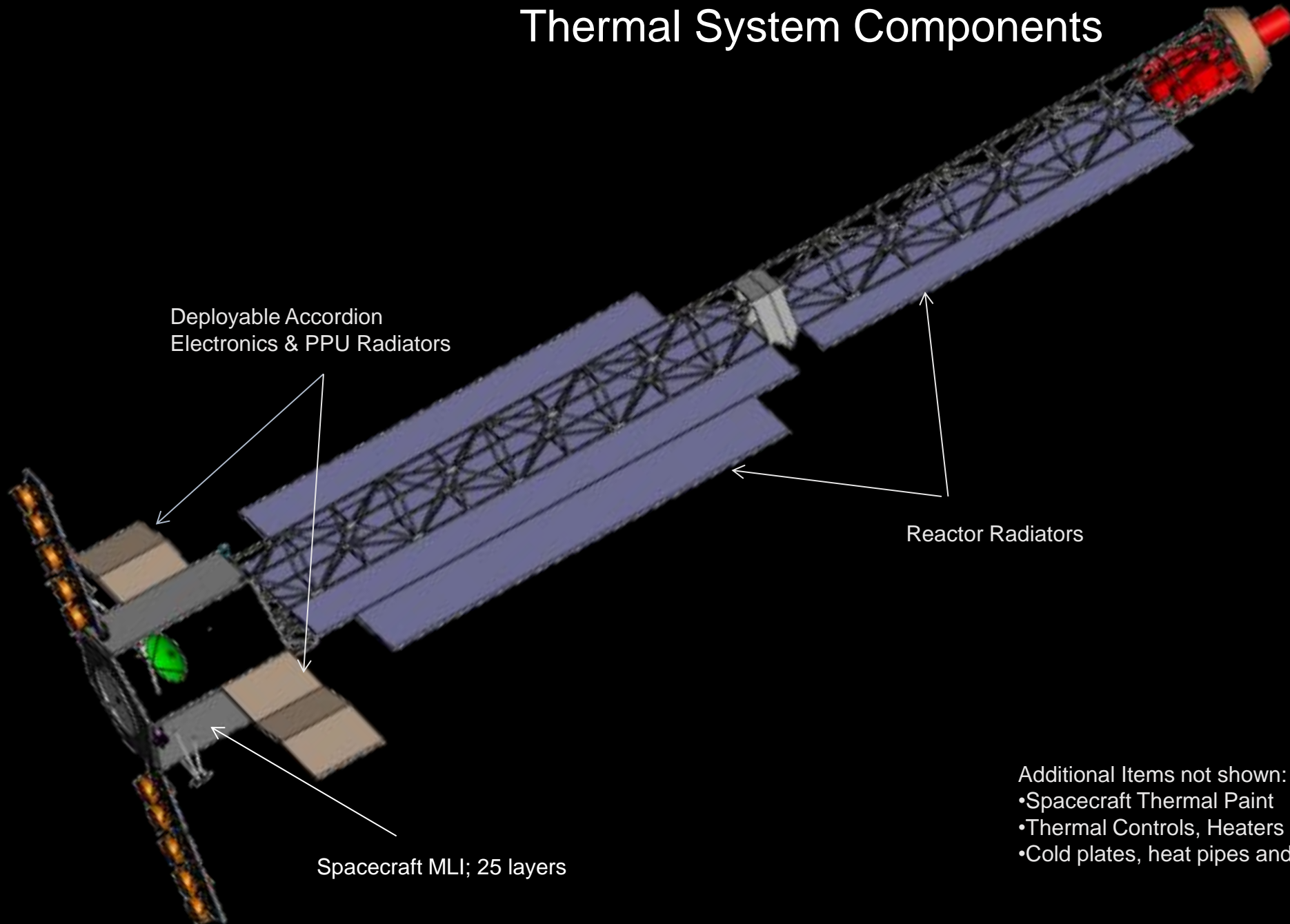
NEXT-C Power Processing Unit (PPU)



# Communications



# Thermal System Components

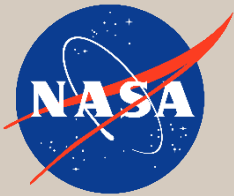


Deployable Accordion  
Electronics & PPU Radiators

Reactor Radiators

Spacecraft MLI; 25 layers

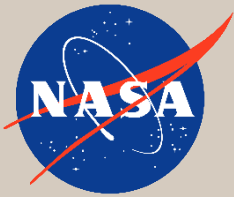
- Additional Items not shown:
- Spacecraft Thermal Paint
  - Thermal Controls, Heaters & Sensors
  - Cold plates, heat pipes and heaters



# Lessons Learned



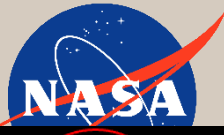
- Use of a nuclear power source for an ion beam deflection of an asteroid provides another option for planetary defense
  - The constant power of a nuclear source (compared to solar) provides a constant thrust an operationally simpler approach to ion beam deflection
- Re-use of the FSP 40 kW reactor technology provides a viable power source for planetary defense
- The tighter ion beam using carbon optics
  - Maximizes the beam on target while minimizing gravity impacts and providing safer proximity operations (target is further away)
  - Allows for thrusting along the reactor boom and not impinging on the radiators
- The ~40 kW NEP has sufficient thrust to nudge a 4 Mt asteroid which captures over 75% of the potential objects in the sample problem
- Launching earlier notably improves the potential object capture since the NEP PDI will be able to nudge the asteroid earlier and allow phasing to have a bigger impact
- By using 8 modified NEXT thrusters a throughput of over nearly 8t is possible (~ 1000 kg per NEXT thruster)
- A look at switching to HEU or Advanced Reactor technologies was performed and were found to save approximately the same mass on the vehicle design. Neither had a significant impact on the performance of the PDI.



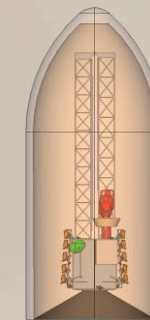
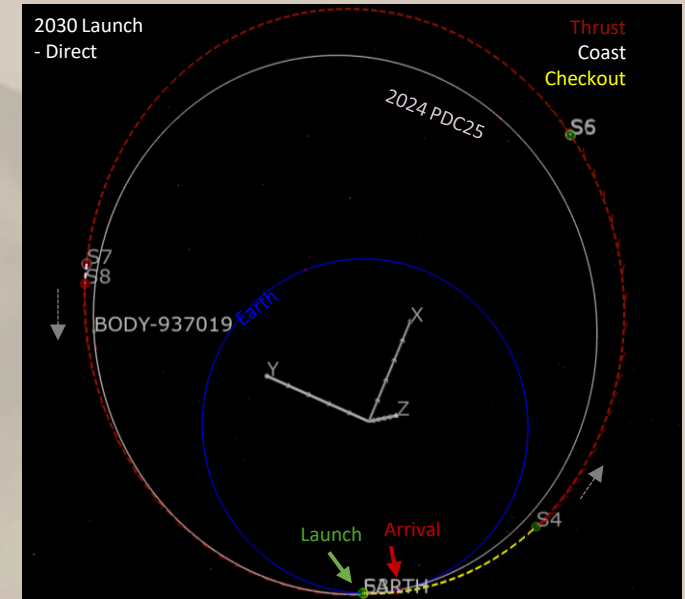
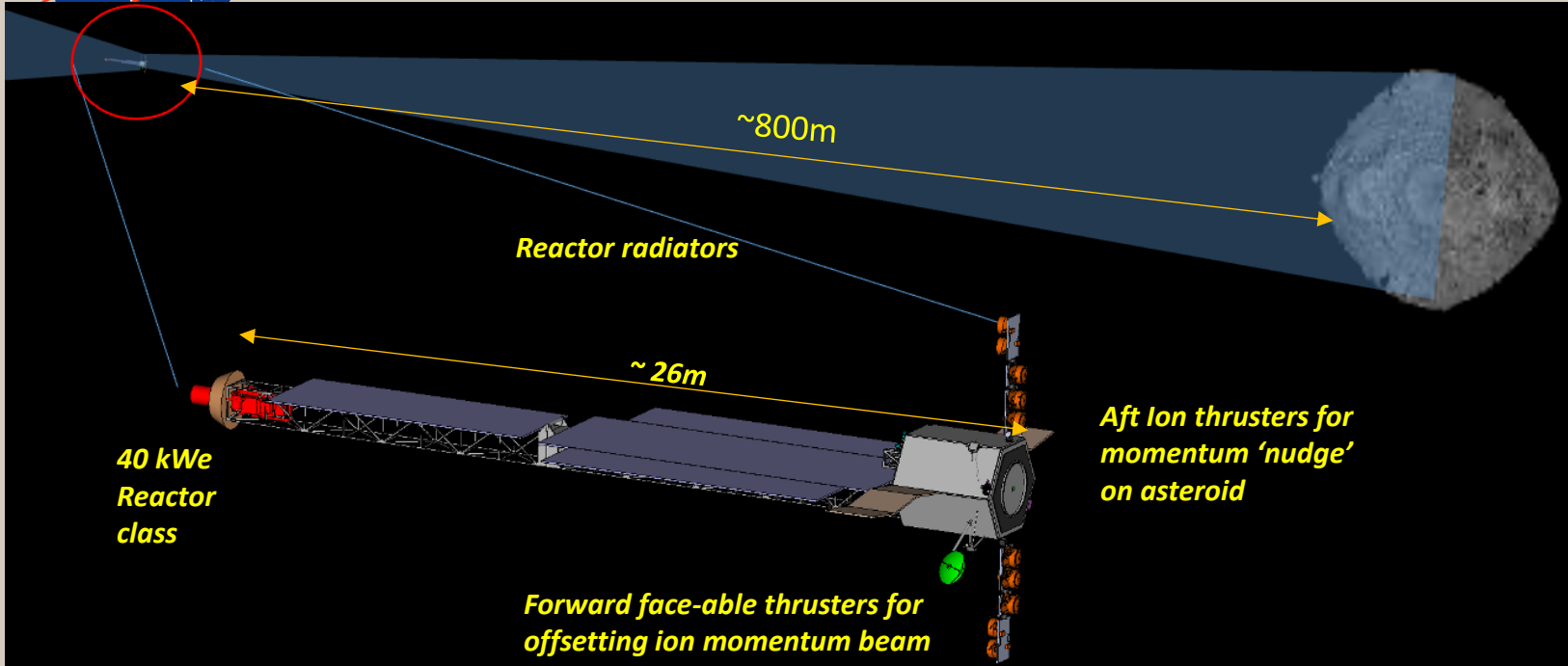
# Next Steps



- Evaluate an equivalent solar powered ion beam deflection vehicle which would compare technologies, availability, and cost
- Investigate how multiple NEP PDI vehicles could simultaneously nudge an asteroid
- Investigate how higher and lower power NEP vehicles perform vs asteroid size and orbit
- Investigate how commercial launchers could be used in lieu of SLS
- Investigate other PPU options that optimize use with Braytons



# NEP Planetary Defense Interceptor: Exec Summary

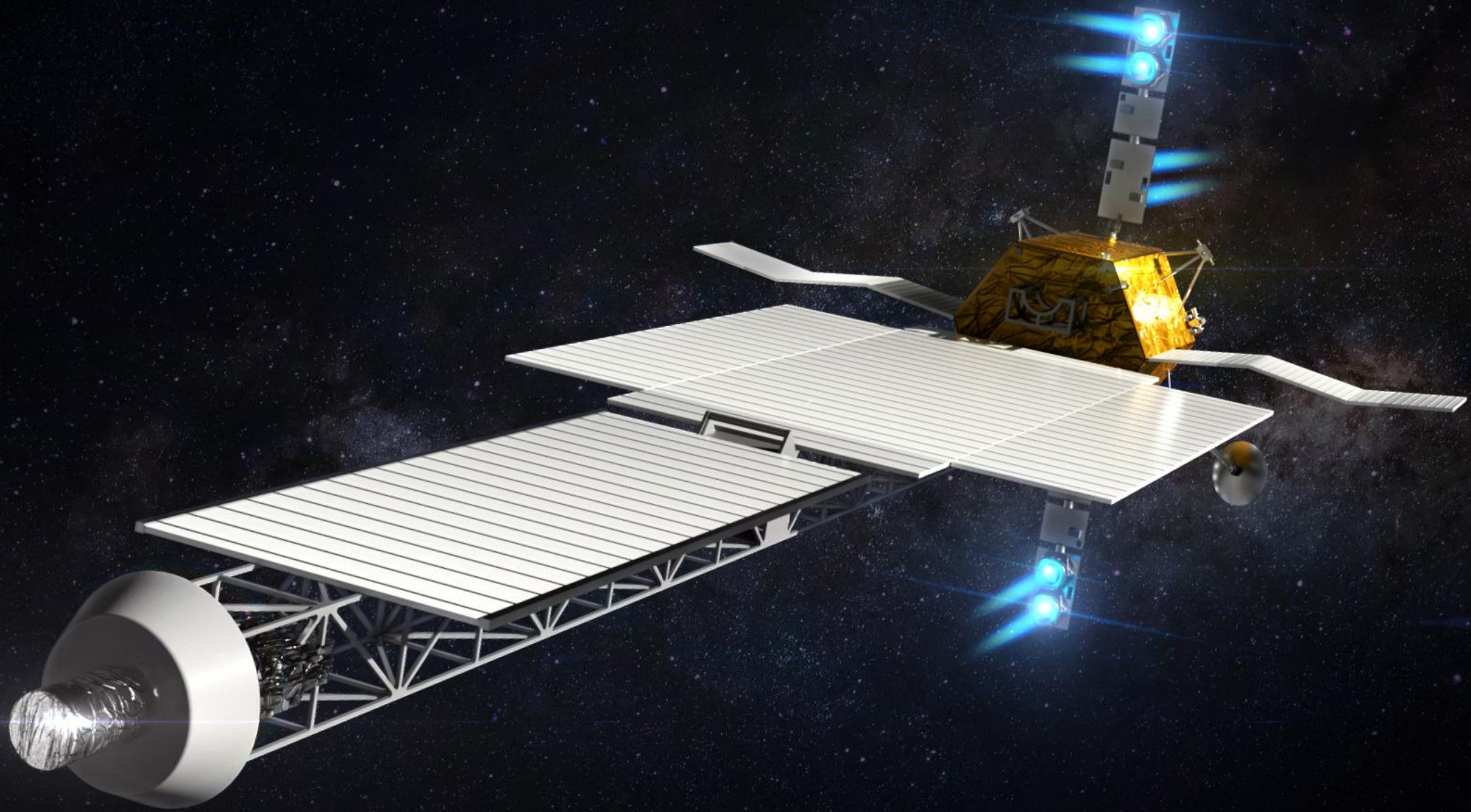


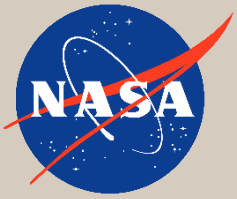
MEL Summary: Case 1_HALEU CD-2025-217		Spacecraft
Main Subsystems		Basic Mass (kg)
Science		46.3
Attitude Determination and Control		85.1
Command & Data Handling		106.3
Communications and Tracking		38.0
Electrical Power Subsystem		4371.0
Thermal Control (Non-Propellant)		1352.1
Propulsion (Chemical Hardware)		63.5
Propellant (Chemical)		162.8
Propulsion (EP Hardware)		1001.8
Propellant (EP)		8030.6
Structures and Mechanisms		824.8
<b>Element Total</b>		<b>16082.3</b>

LV Summary: Case 1_HALEU CD-2025-217	Single Launch
Architecture Details	All
Launch Vehicle	SLS 1B
Energy, C3	37.4
Performance (pre-margin)	21480
Margin (%)	10%
Performance (post-margin)	19332
Total Wet Mass w/% Growth	18819
Available LV Margin	512
Available LV Margin (%)	3%

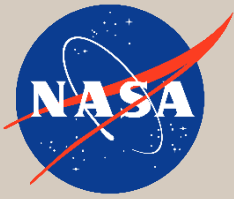
Element Dry Mass (no prop,consum)	7888.9
Element Propellant	8193.4
Element Mass Growth Allowance (Aggregate)	1553.8
<b>MGA Percentage</b>	<b>20%</b>
Predicted Mass (Basic + MGA)	9442.7
System Level Mass Margin	1183.3
System Level Growth Percentage	15%
Element Dry Mass (Basic+MGA+Margin)	10626.0
Element Inert Mass (Basic+MGA+Margin)	11157.2
<b>Total Wet Mass (Allowable Mass)</b>	<b>18819.4</b>

- Mission:** 40 kWe Class NEP Vehicle that uses 7 years of ion beam plumes to change the orbit of a sample 4 Megaton, 160 m diameter asteroid to avoid hitting the earth in 2041 (sample target asteroid 9th Planetary Defense Conference)
- Launch:** 2023, SLS Block 1B, short fairing, C<sub>3</sub> ~37.4 km<sup>2</sup>/s<sup>2</sup>
- Science:** WAC/NAC camera, IR spectrometer, LIDAR to maintain Asteroid separation and create detailed shape model
- Power:** 44 kWe HALEU Reactor based on NASA Fission Surface Power System (planned 2030), Four Brayton convertors, ~1.5 kW for Bus, 25 krad shield, 10 yr life
- Electric Propulsion:** 8+2 4.5 kWe (derated) NEXT-C Thrusters (modified for 10° plumes using carbon grids), ~8000 kg Xenon propellant Load, stored in single COPV 2 m tank
  - Single set point PPU (95%), Thruster Feed, Thruster
- Thermal:** Boom attached, deployable reactor radiators, deployable electronics/PPU radiators, MLI and Heaters
- Mechanical:** Hexagonal Bus, Jack-knife extendable reactor boom
- Communications, C&DH:** Ka-Band, 200 kbps Data rate from Asteroid, 1 m Antenna, 8 Tb non-volatile storage
- AD&C:** 4 Star Trackers, 2 IMUs, 6 reaction wheels, Hydrazine propulsion RCS





# Backups



# Final Assumptions and Results

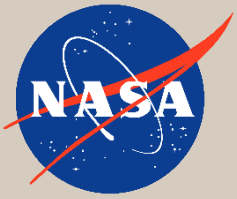


## Assumptions

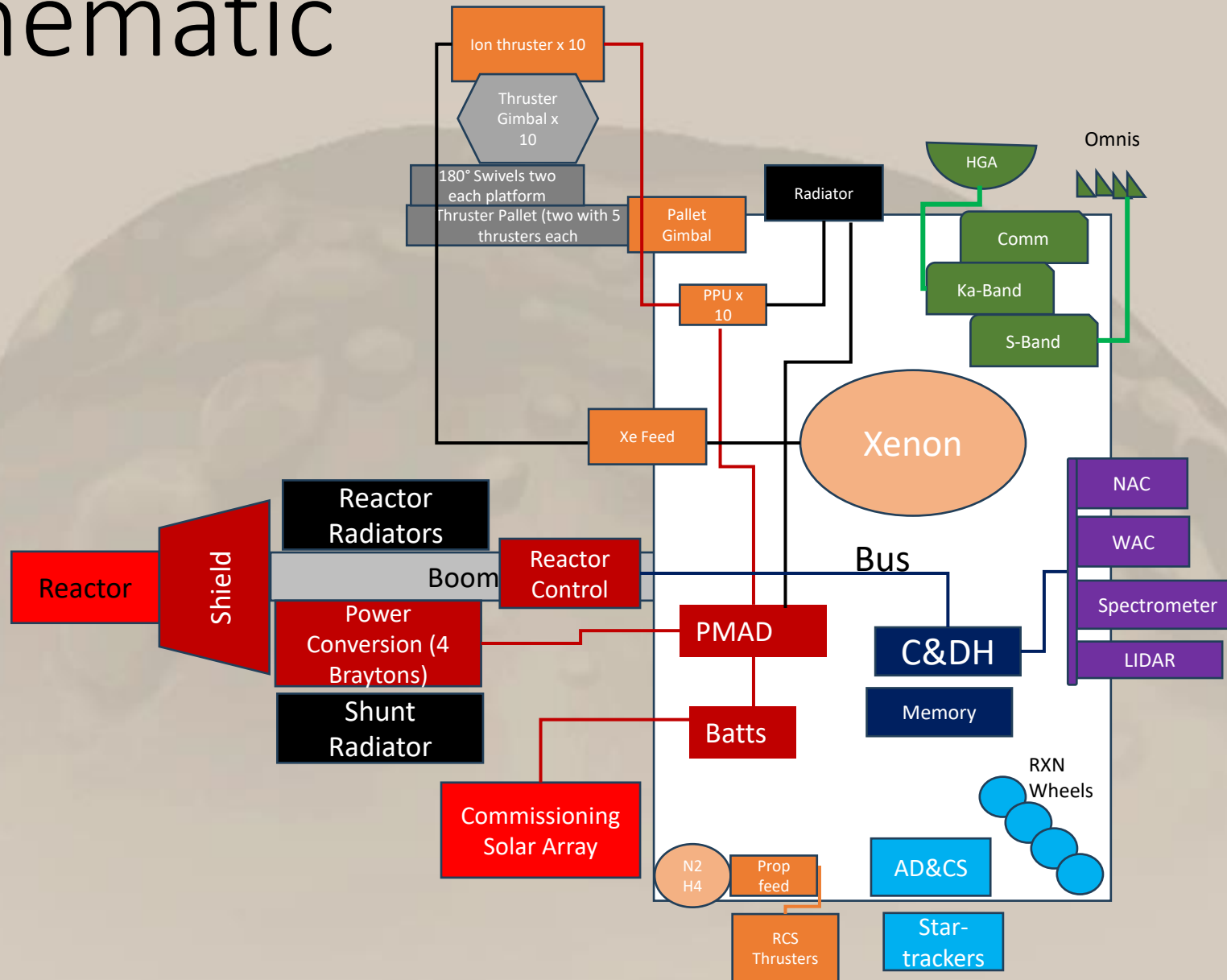
- **Launch:** SLS B1B | CCSFS
- **Dry Mass:**
  - Case 1: 11,152
  - Case 2: 10,338 (advanced reactor)
- **Electric Propulsion:**
  - Xe Margin: 6%
  - Duty Cycle (transit): 85%
  - Duty Cycle (IBD): 90%
  - NEXT-C Efficiency: 0.68
  - NEXT-C Isp: 4200s
- **Ion Beam Deflection:**
  - 95% momentum transfer efficiency
  - Along-track deflection
  - Required deflection:  $2.0 R_E$
- **Trajectory:**
  - 60-day post launch checkout coast
  - 30-day asteroid survey before IBD
  - IBD concludes NLT 100 days before nominal impact

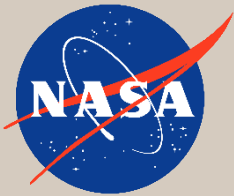
## Results

	Case 1	Case 2 (adv reactor)
Launch Date	4/13/30	4/12/30
Dry Mass (kg)	11,152	10,338
Asteroid Mass (Mt)	4.0	4.1
Asteroid Percentile	<b>77.3</b>	<b>78.3</b>
Launch Mass (kg)	19,317	18,581
Launch C3 (km <sup>2</sup> /s <sup>2</sup> )	37.4	39.5
Asteroid Arrival Mass (kg)	17,542	16,849
Transit Xe Used (kg)	1,775	1,732
Deflection Xe Used (kg)	5,928	6,044
Total Xe Used (kg)	7,703	7,776
Transit $\Delta V$ (m/s)	3,970	4,030
IBD Effective $\Delta V$ (m/s)	16,985	18,299
Transit Time (years)	2.49	2.43
Deflection Time (years)	7.23	7.37



# Schematic





# Science Instruments



## Floor

- Used for initial Asteroid characterization
- Only nav cams required during Ion beaming
  - **Wide Angle Camera (WAC)**
    - Size, shape and spin of asteroid
    - Spacecraft position relative to asteroid
  - **Narrow Angle Camera (NAC)**
    - Surface topography of asteroid
  - **Lidar**
    - Detailed shape model
    - High-precision distance to asteroid
  - Stereo imagers (navigation):
    - right now, assume we can use the WAC and NAC

## Desired (hopefully on a demo)

- Used to characterize the effect of the ion beam on the asteroid.
- Used during Ion beaming
  - **Vis/IR spectrometer**
    - Surface composition of asteroid
  - **Mass Spectrometer**
    - Measures composition of material sputtered by beam from the asteroid
  - **Plasma diagnostics**
    - Charge and magnetic fields of environment

## Mass and Power

Instrument package specs are based on existing flight instruments (Osiris-REX, Europa Clipper & Messenger)

- Wide Angle Camera and Narrow-Angle Camera
  - Based on MESSENGER Dual Imaging System (MDIS)
  - 7.9 kg, 10 W
- Lidar
  - Based on OSIRIS-REx Laser Altimeter (OLA)
  - 21.4 kg, 59 W
- Vis/IR spectrometer
  - Based on OSIRIS-REx Visible & Infrared Spectrometer (OVIRS)
  - 17.8 kg, 8.8 W
- **Mass Spectrometer**
  - Based on MASPEX instrument (Europa Clipper)
  - 8 kg
- **Plasma diagnostics**
  - (Mass and power are negligible)