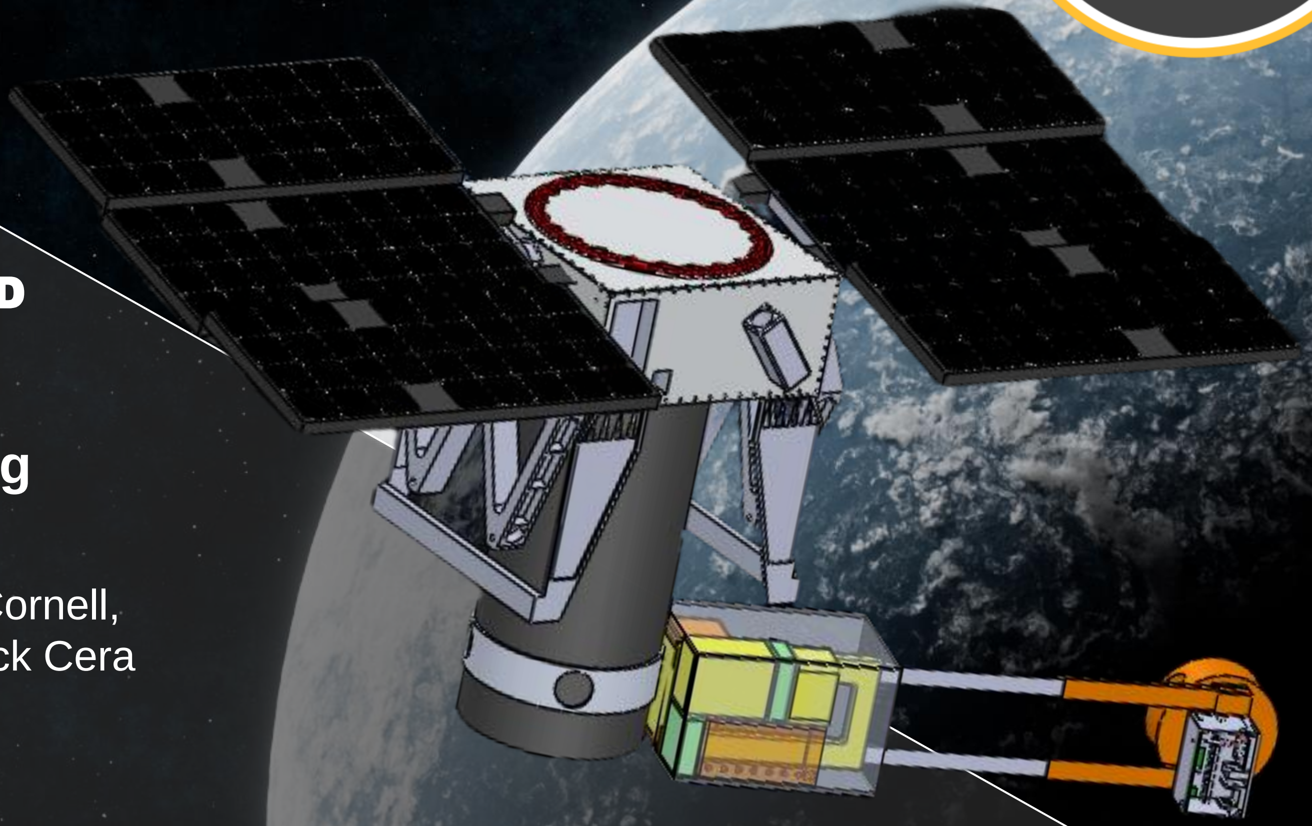
PennState College of Engineering | AEROSPACE ENGINEERING | COSMIC

WATCHDOG

AUTONOMOUS CONCENTRATED ENERGY SOLUTIONS (ACES)



COSMIC Capstone Challenge: Final Briefing

Students: Melik C. Demirel, Joseph W. Healy, Kiara N. Cornell, George S. Harmon, Denver Nazareth, Claire L. Shaw, Nick Cera

Advisors: Dr. Sara Lego, Dr. Sharad Sharan (PSU)

Mentor: Edward Tate (CTO, Virtus Solis Technologies)

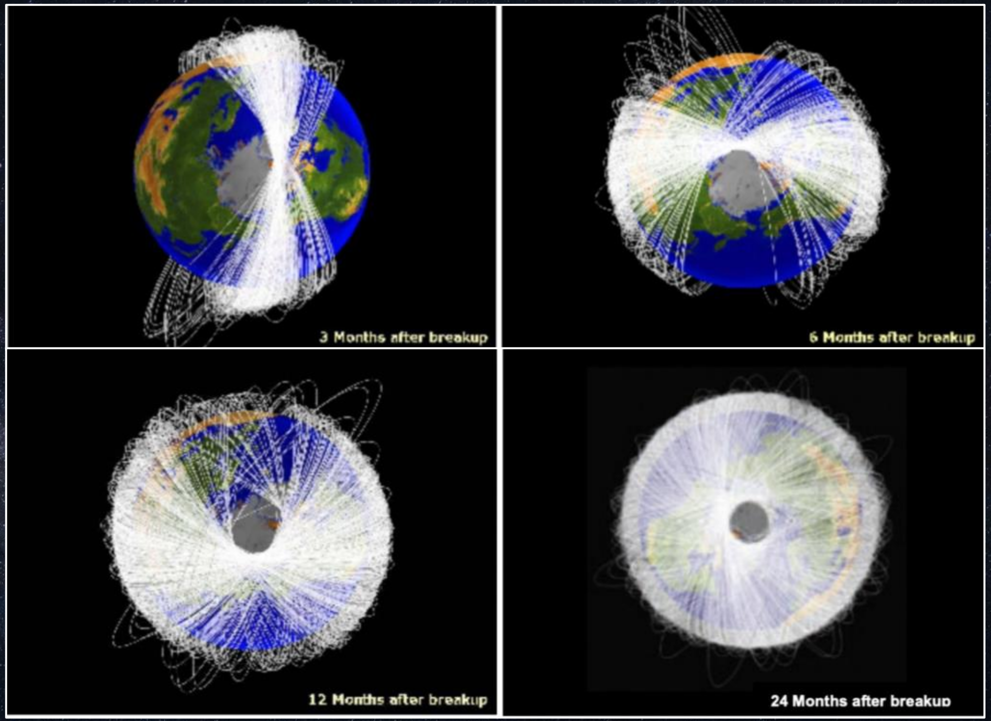
16 April, 2025

Executive Summary

Watchdog Mission – Autonomous Concentrated Energy Solutions (ACES)

- *Need:* As humanity expands its presence in space, so will the quantity of debris in low Earth orbit (LEO). To promote spacecraft sustainability, debris must be removed.
- *Capability:* Long range energy transmission-a laser to push debris into suborbital trajectories
- *Solution:* A laser can ablate a small amount of mass from a debris particle, and the resultant momentum change can alter its trajectory
- *Status:* ACES has developed a hypothetical mission that could explore the proposed capability. If successfully demonstrated, this technology could drastically improve the lifespan of satellites in LEO.

Fengyun-1C Incident

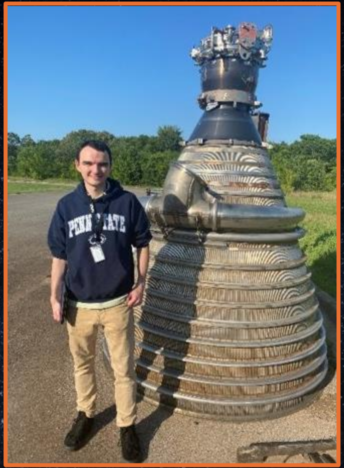


Pulliam W., "Catcher's Mitt Final Report," Defense Advanced Research Projects Agency, retrieved 4 December 2024.

Team

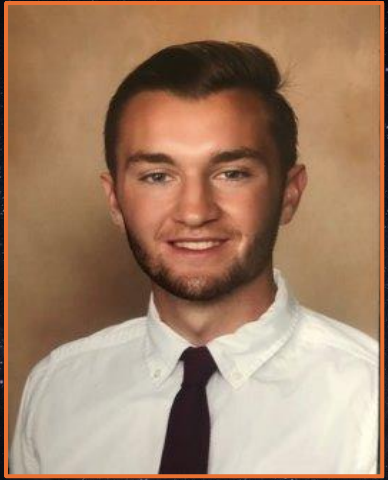
Meet the Team

Kiara Cornell



Joe Healy

Melik Demirel



Nick Cera

George Harmon

Claire Shaw

Denver Nazareth

2.4 Systems Engineering Milestones

Milestones across 9 months of the project

Semester 1 – Initial Research and Concept Development

August
- Project Begins

September
- Team organized
- **Project manager selected**
- Background ISAM research
- **Capability Chosen**

October
- Project Scoping
- Functional Analysis
- **Top-Level Requirements**
- CONOPS Development

November
- **Trade studies for concept down select**
- System Requirements Review (SRR)
- Subsystem requirements

December
- C3 Midpoint Showcase

Semester 2 – Subsystem Research, Design, and Analysis

January
- Initial analysis plan developed
- Subsystem roles assigned

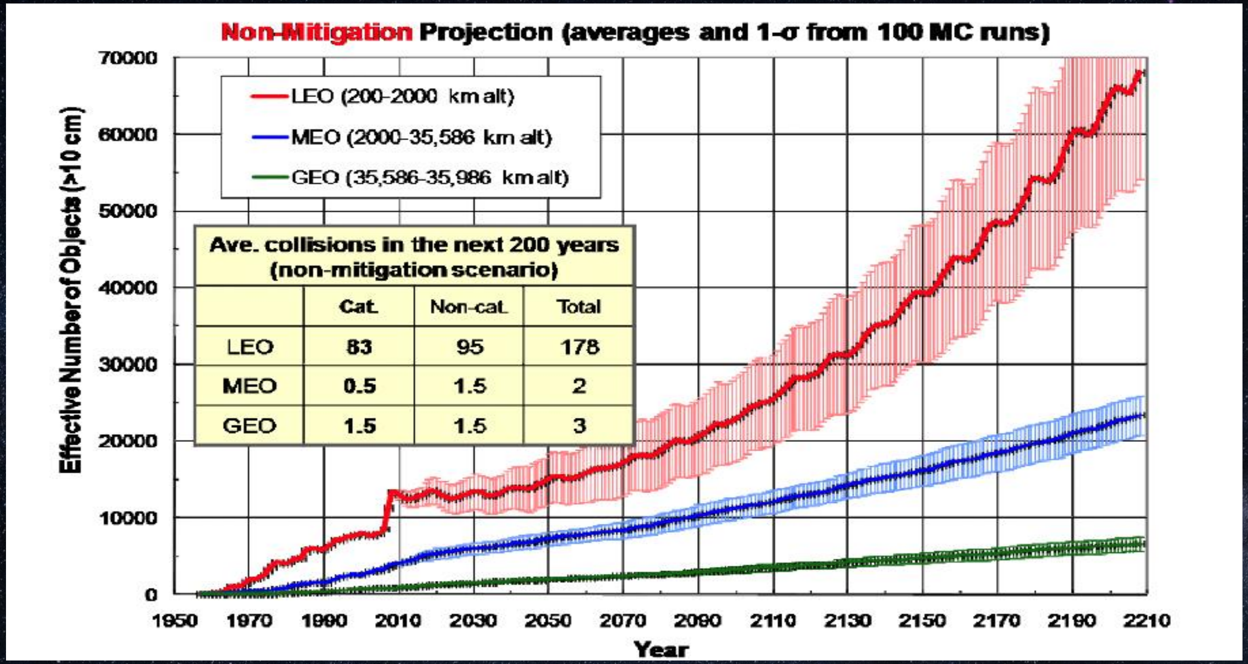
February
- Subsystem design work
- Concept further developed

March
- **Conceptual design finalized**
- Midterm concept design review (CDR)

April
- C3 Competition Brief-out
- **PDR Development**
- Final technical paper
- Design Showcase Poster Session

Background Research

Need for debris mitigation – debris is expected to increase



Pulliam W., "Catcher's Mitt Final Report," Defense Advanced Research Projects Agency, retrieved 4 December 2024.

		Satellite / Constellation Type		
		Small (Government)	*Medium (Commercial)*	*Large (Commercial)*
No Debris	*Mean Lifetime (years)*	5.7	9	12
	Replenishment Cost ($Billion)	20.1	16.9	7.9
Fatal Impacts Only	*Mean Lifetime (years) & Percent Reduction (2010-2040)*	5.5 – 5.6 2.3 – 2.1%	8.5 – 8.6 5.0 – 4.6%	11.5 – 11.6 5.7 – 5.1%
	Replenishment Cost ($Billion)	20.4 (2% increase)	17.7 (5% increase)	8.6 (8% increase)
All Impacts	*Mean Lifetime (years) & Percent Reduction (2010-2040)*	5.4 – 5.5 4.4 – 3.4%	8.2 – 8.3 8.9 – 7.6%	10.6 – 11.2 13.1 – 8.3%
	Replenishment Cost ($Billion)	20.8 (4% increase)	18.4 (9% increase)	9.1 (15% increase)

Debris Size	Mass (g) aluminum sphere	Kinetic Energy (J)	Equiv. TNT (kg)	Similar in Energy to	Quantity	Currently Trackable?
1 mm	0.0014	71	0.0003	Pitched baseball	Tens of millions	No
3 mm	0.038	1910	0.008	Bullets	Millions	No
1 cm	1.41	70700	0.3	Falling anvil	Hundreds of thousands	No
5 cm	176.7	8840000	37	Hit by bus	Tens of thousands	Mostly not
10 cm	1413.7	70700000	300	Large bomb	Tens of thousands	Mostly yes
> 10 cm	1400 – 500,000,000	< 10^13	< 3,000,000	Very large bomb	Thousands	Cataloged

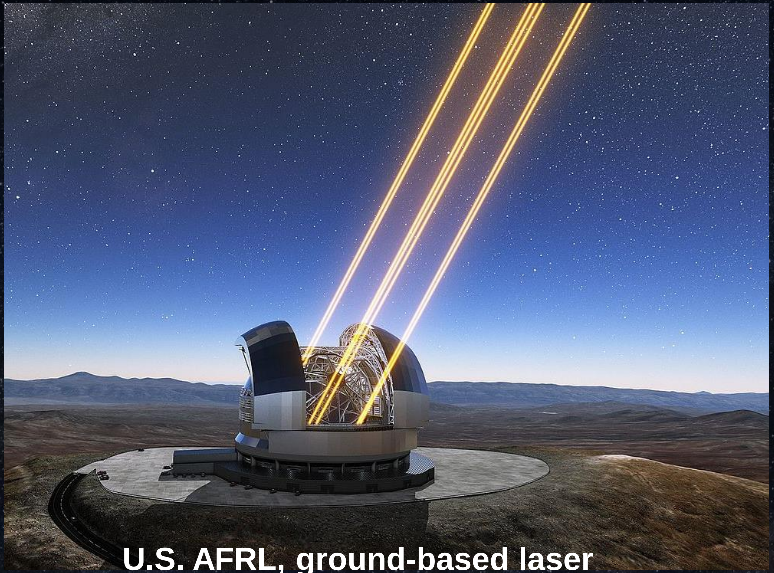
"Space Debris 101," Aerospace Corporation, 2024, retrieved 4 December 2024.

To fulfill the ISAM goal of increasing the longevity of satellites, there needs to be a way to reduce space debris in LEO

Background Research

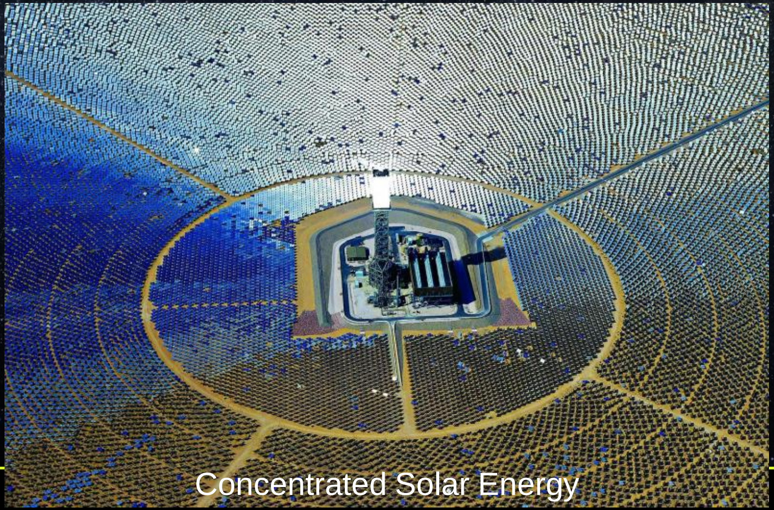
Possible solution - lasers for microdebris removal

"Ground-Based Lasers Could Push Space Debris off Collision-Course Orbits," Universe Today, retrieved 4 December 2024. https://www.universetoday.com/150896/ground-based-lasers-could-push-space-debris-off-collision-course-orbits/

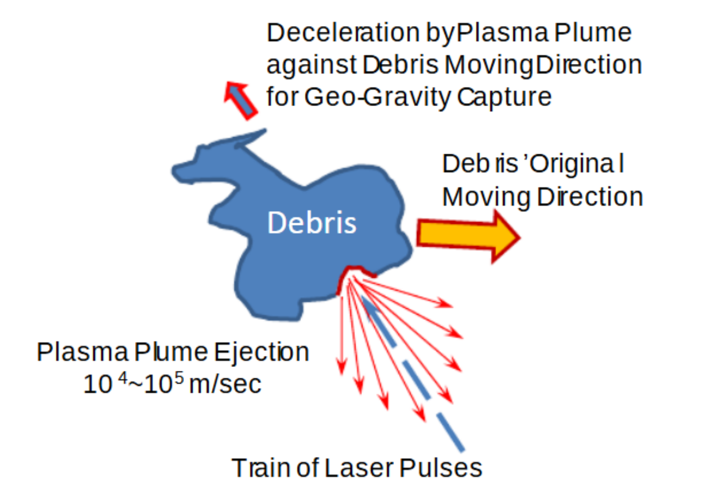


U.S. AFRL, ground-based laser

Extreme Tech, retrieved 4 December 2024. https://i.extremetech.com/imagery/content-types/01JLmTUzzGW4OUsDv4sFq67/hero-image.fit_lim.v1678673063.jpg



Concentrated Solar Energy

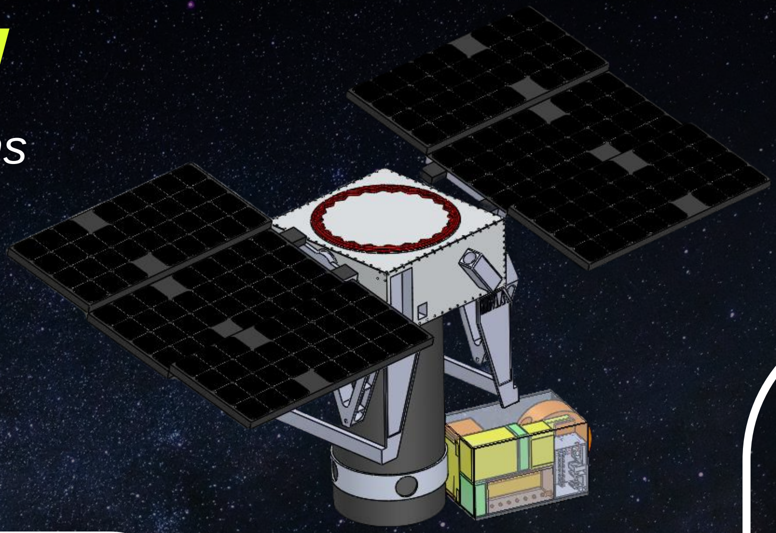


Choi, S. H., Pappa, R. S., "Assessment Study of Small Size Space Debris Removal by Orbit-Stationed Laser Satellites", Recent Patents on Space Technology 2, pp. 116-122, 2012

- Research into methods for active debris removal
- Lasers can be used for long distance and high coverage

Mission Overview

Mission Statement and Operations



Mission

Watchdog

Capability

Optical power transmission shall be used to satisfy the ISAM initiative for defense against micro debris particles in space.

Operations

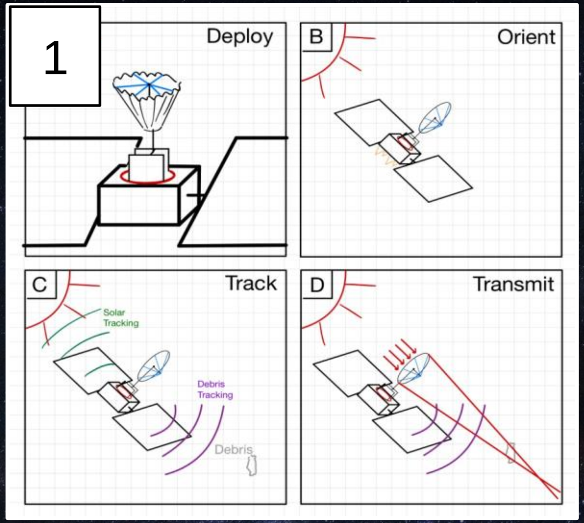
1. **Acquiring, tracking, and actively monitoring a debris target to redirect**
2. **Reorienting the optical transmission device, detectors, and the bus**
3. **Delivering Optical Power, move debris via ablation**

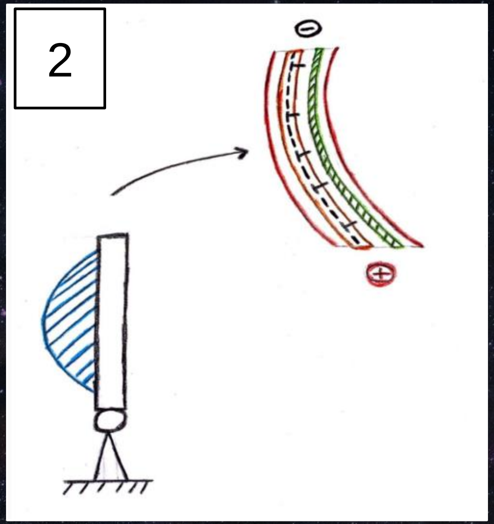
3.1 Innovative Concepts

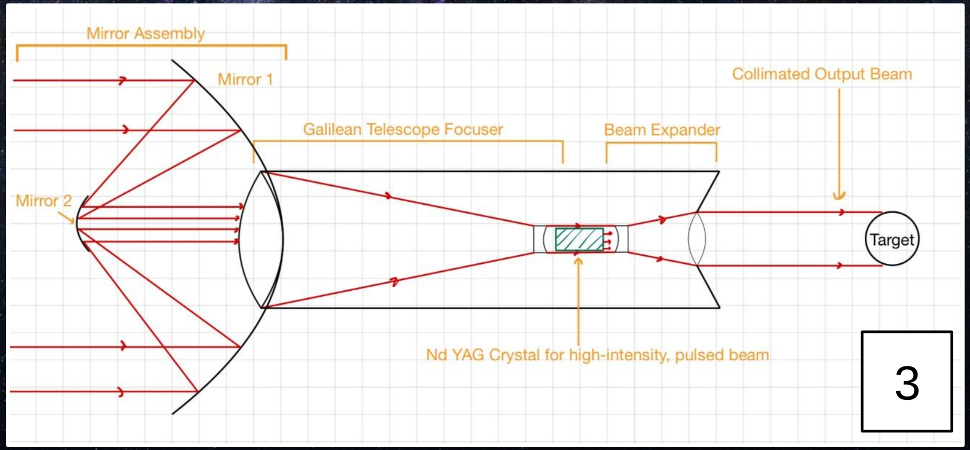
3 Main Concepts generated during CONOPS

- Initially, the plan was to use solar light to generate a laser, but this was changed in the final concept to an on-board laser
- The Solar Pumped Laser was chosen through trade studies

1. Unfolding Lens – inspired by NASA Starshade
2. Flexible Gimballed Lens – piezoelectric material
3. Solar Pumped Laser – Nd:YAG used to generate beam







3.1 Innovative Concepts

Down select Trade Study

Description			Concepts		
Category	**Criteria**	**Weight**	**Unfolding Lens**	**Flexible Lens**	**Solar Pumped Laser**
Performance	Max Estimated Power Output	15%	3	1	3
Performance	Precision	20%	1	2	3
Performance	Scale	20%	1	2	2
Performance	Energy Input from Satellite	10%	3	2	1
Complexity	Moving Parts	10%	2	1	3
Reliability	Lifespan	10%	2	1	2
Risk	Technology Readiness (TRL)	10%	3	1	2
Cost	R&D Cost	5%	3	1	2
TOTAL:		100%	**2.00**	**1.50**	**2.35**

Score	1	2	3	Units or Description
Max Estimated Power Output	< 30	$30 - 50$	> 50	Estimated output Power of Laser [KW]
Precision	3	4	5	Degrees of Freedom
Scale	≥ 8	$5 - 8$	< 5	Maximum Lens Diameter [ft]
Energy Required	$\geq 0.67P_s$	$0.33P_s - 0.67P_s$	$< 0.33P_s$	Fraction of satellite's producible power, $P_s = 444\text{W}$
Moving Parts	≥ 4	$2 - 4$	≤ 2	Number of moving assemblies
Lifespan	< 20	$20 - 40$	> 40	Expected years of operation
Technology Readiness (TRL)	$1 - 3$	$4 - 6$	$7 - 9$	TRL level of lowest TRL component
R&D Cost	> 10	$5 - 10$	< 5	Cost in Millions of USD [$M]

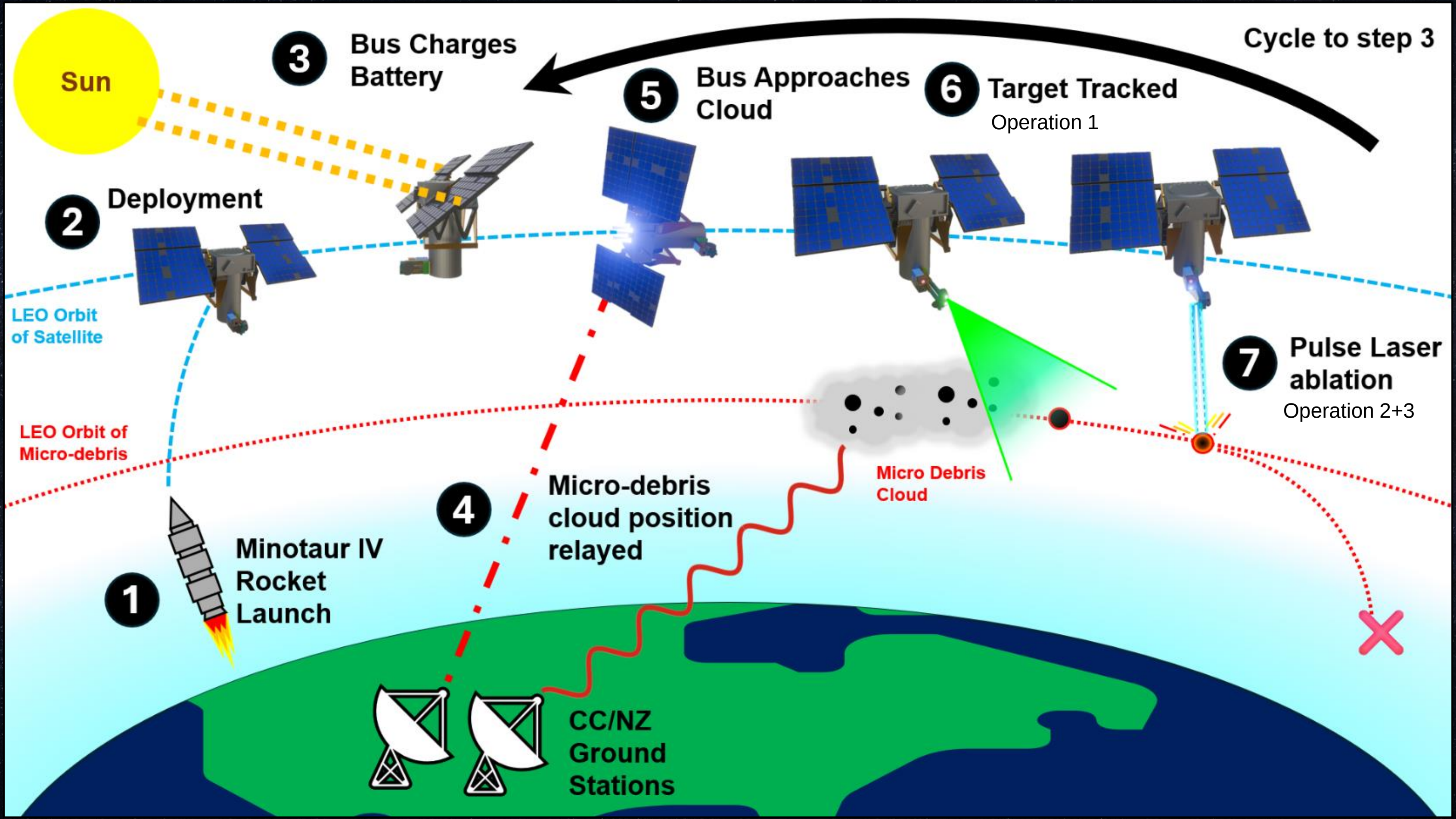
2.2 Storyboard of Complete Operation

Macro-Level Mission Architecture

- Launch epoch:
  15 April 2025, 15:00:00 UTC
- The spacecraft performs each stage autonomously
- Commands from the ground station for guidance toward micro debris concentration
- The spacecraft will deorbit after 5 years of operation

Nominal Orbit Parameters

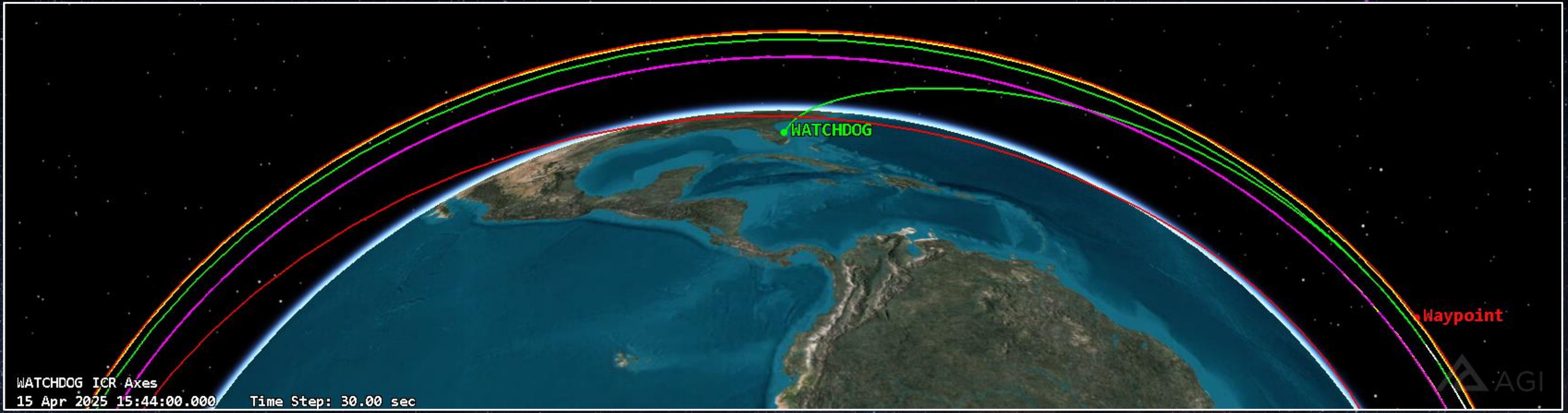
Semimajor Axis	7228 km
Eccentricity	0
Argument of Perigee	0 deg
RAAN	260 deg
Inclination	28.5 deg
Orbital Period	102 minutes



2.2 Storyboard of Complete Operation (2)

Orbital Procedures

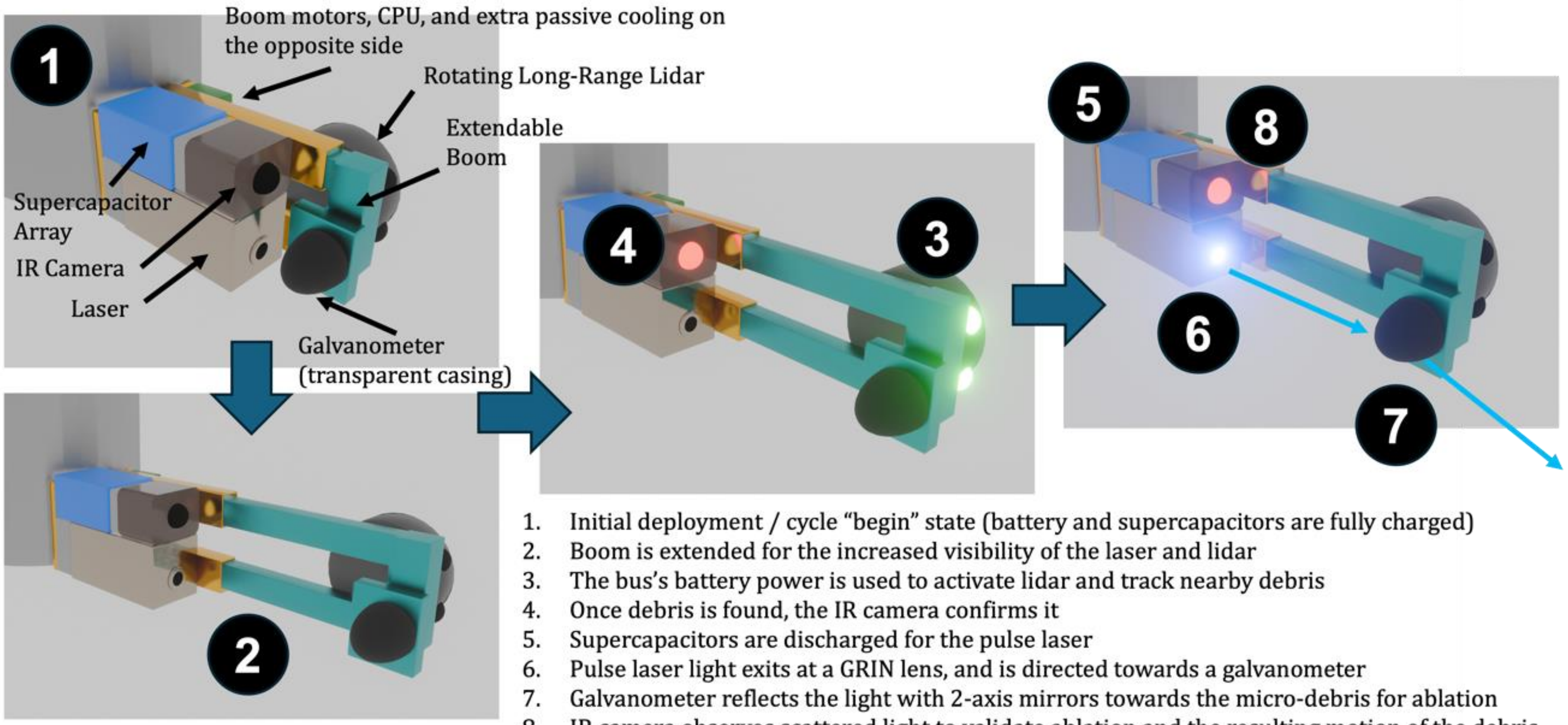
- **Expanding on Step 5:** Impulsive Hohmann transfers are used to move the spacecraft into “Waypoint” orbits where debris is most prevalent



Event	Δv (m/s)
Estimated Rendezvous Δv (2x Hohmann Transfers)	200
4 Total Rendezvous:	800
Orbit Sustaining (5 years)	0.5
End of Life Deorbit	240
Attitude Adjustment (10% prop. Mass)	82
TOTAL:	1122

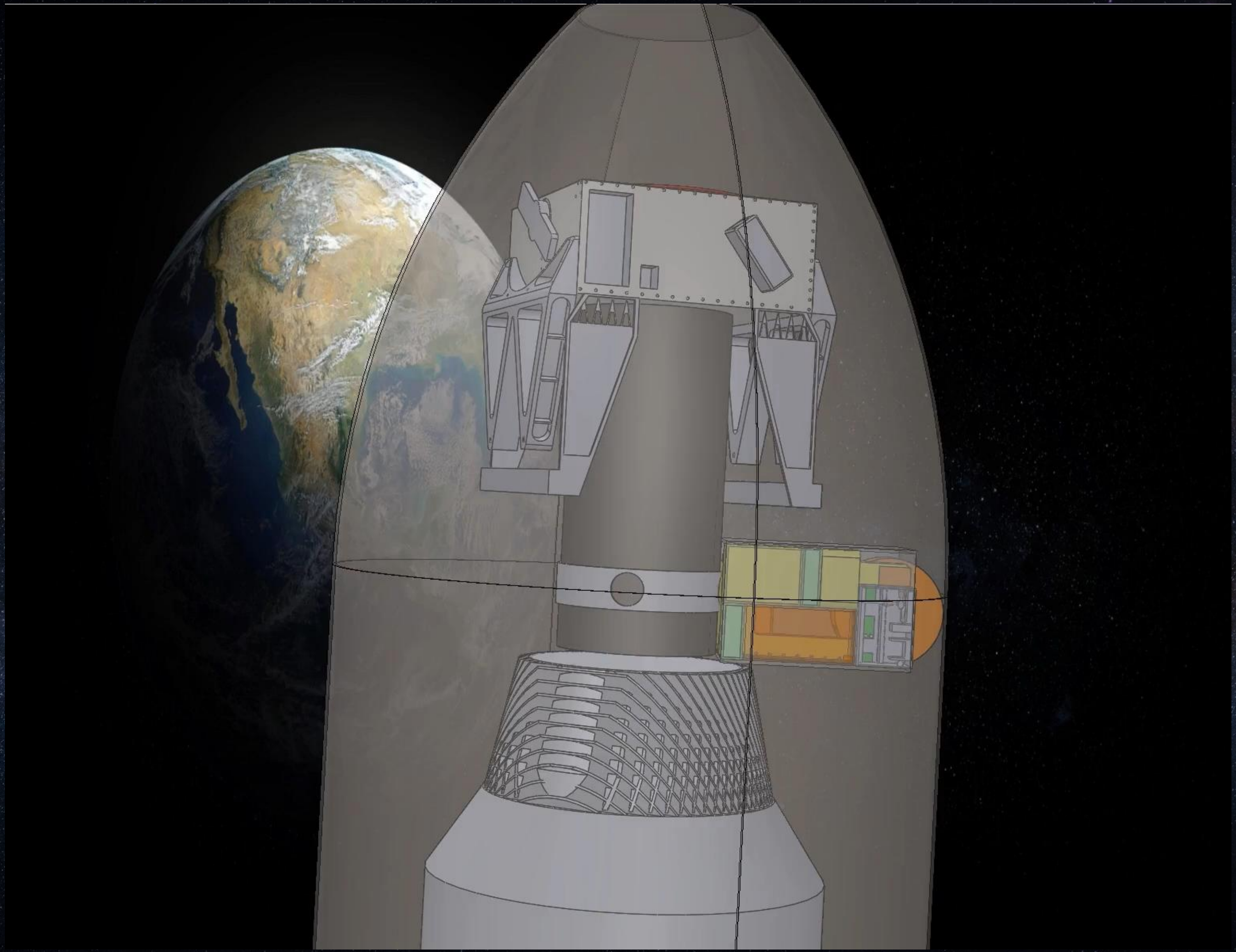
2.1 Animation of Key Operating Sequence

Functional steps of the payload



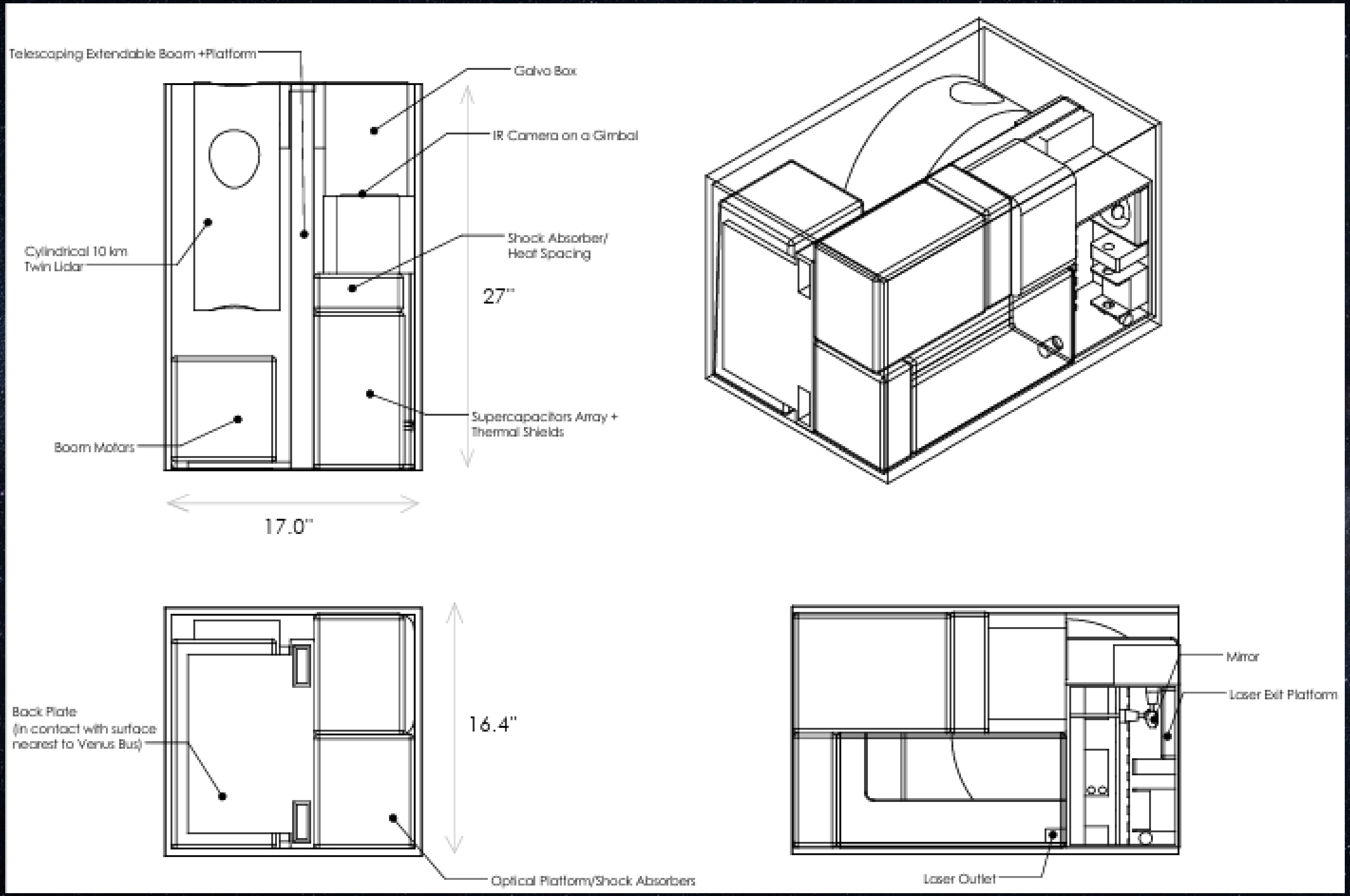
1. Initial deployment / cycle “begin” state (battery and supercapacitors are fully charged)
2. Boom is extended for the increased visibility of the laser and lidar
3. The bus’s battery power is used to activate lidar and track nearby debris
4. Once debris is found, the IR camera confirms it
5. Supercapacitors are discharged for the pulse laser
6. Pulse laser light exits at a GRIN lens, and is directed towards a galvanometer
7. Galvanometer reflects the light with 2-axis mirrors towards the micro-debris for ablation
8. IR camera observes scattered light to validate ablation and the resulting motion of the debris

2.1 Animation



Payload Overview

Payload 3 View Drawing with Components, Mass Budget

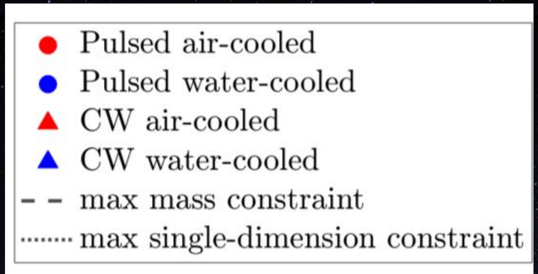


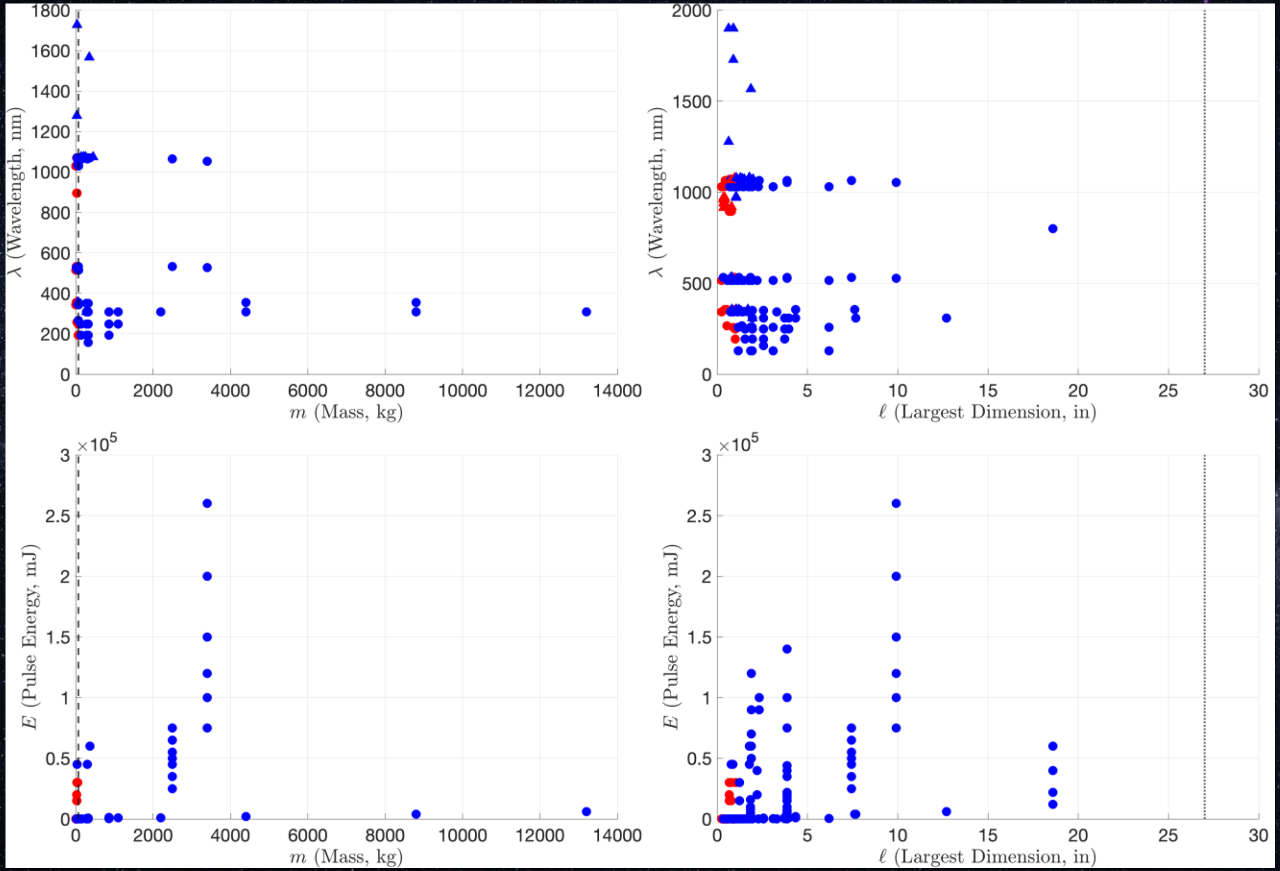
No.	Part Name	Description	#
1	Payload Box	An aluminum 1060 container for the 17''x16.4''x27'' payload	1
2	Boom Motor	Rotational motor for boom	1
3	Boom	Translatable extension	1
4	Cylindrical Lidar	Debris tracker	1
5	IR Camera	Camera for debris detection	1
6	Superconductors Array w/ Thermal Shields	Power transmitter	1
7	Shock Absorbers	Force dampeners	2
8	CPU	Payload computer	1
9	Galvanometer	Laser positioner	1
10	Laser	Debris ablation tool	1

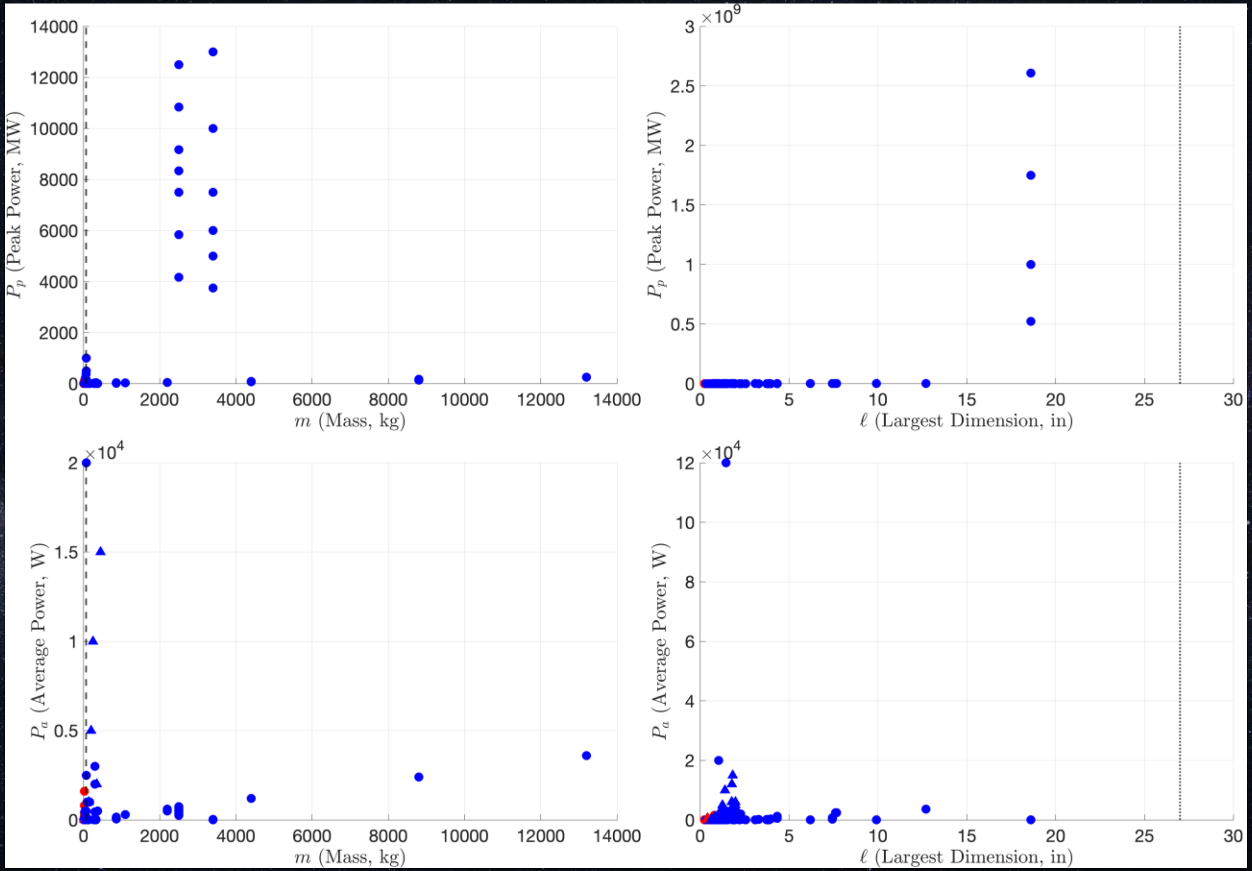
Payload Mass Budget	
Component	Mass (kg)
Laser	2.0
Tracking Sensors	30.0
Power	1.0
Thermal	10.0
Structures	10.0
GNC+C&DH	1.5
20% Margin	54.5
Payload Total:	65.4

Payload Overview

Selecting a Laser System



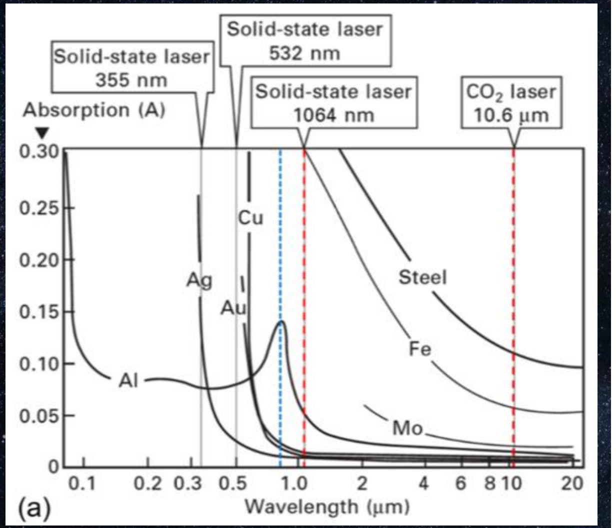




More work needed for finding ideal laser wavelength and power

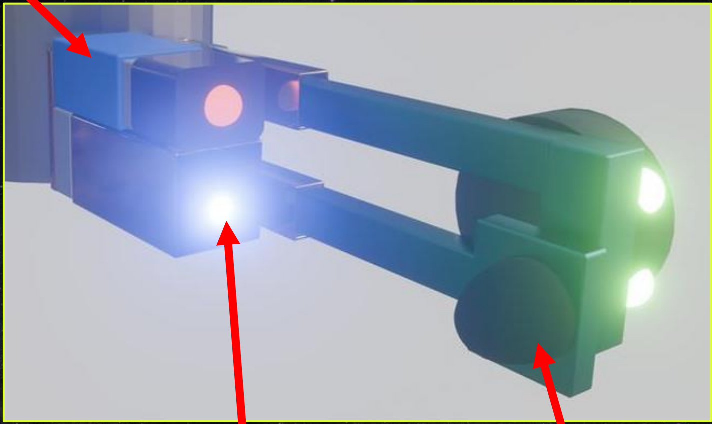
Payload Overview

Chosen Laser System



SPECIFICATIONS	FLARE NX 1030-1.0-2	FLARE NX 515-0.6-2	FLARE NX 343-0.2-2
Wavelength (nm)	1030 ±1	515 ±0.5	343 ±0.5
Pulse Energy[1] (μJ)	>500	>300	>100
Pulse Energy Variation ptp (%)		<±5	
Pulse Repetition Rate (Hz)		up to 2000	
Pulse Width (ns)	1.5 ±0.2	1.3 ±0.2	1.0 ±0.2
Spatial Mode		TEM_{00}	
M^2 (Beam Quality)		<1.2	
Beam Waist Diameter at $1/e^2$ (μm)	490 ±35	360 ±35	300 ±30
Beam Waist Location[2] (mm)	140 ±15	200 ±30	190 ±30
Beam Symmetry (%)	>90	>90	>85
Static Alignment Tolerances Beam Position (mm) Beam Angle (mrad)		 <±1 <±1	
Polarization		>100:1, vertical ±5°	
Warm-up Time to Stand By (s)		<150	
Base Plate Operating Temperature		15 to 35°C (59 to 95°F)	
Ambient Temperature Operating Storage		 15 to 40°C (59 to 104°F) -20 to +50°C (-4 to 122°F)	
Laser Head Heat Dissipation[3] (W)		≤40	
Relative Humidity (%) (non-condensing)		≤80	
Dimensions (L x W x H) Laser Head Controller		 155.6 x 93.5 x 38.25 mm (6.13 x 3.68 x 1.5 in.) 160 x 130 x 45 mm (6.3 x 5.12 x 1.77 in.)	
Weight Laser Head Controller		 ~1.25 kg (2.75 lbs.) ~0.75 kg (1.65 lbs.)	
Controller Cable Length		1 m (3.28 ft.)	
Operating Voltage[4] (VDC)		24 ±2	

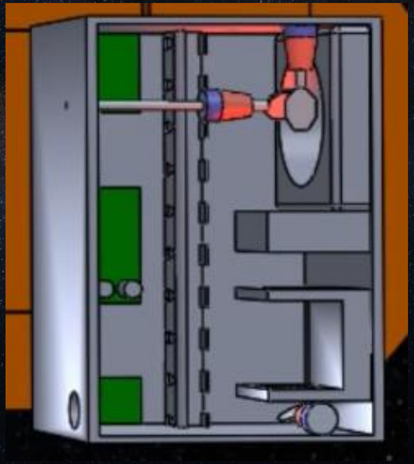
Capacitor Bank



Laser

Galvo

“FLARE NX”, Coherent Corp.

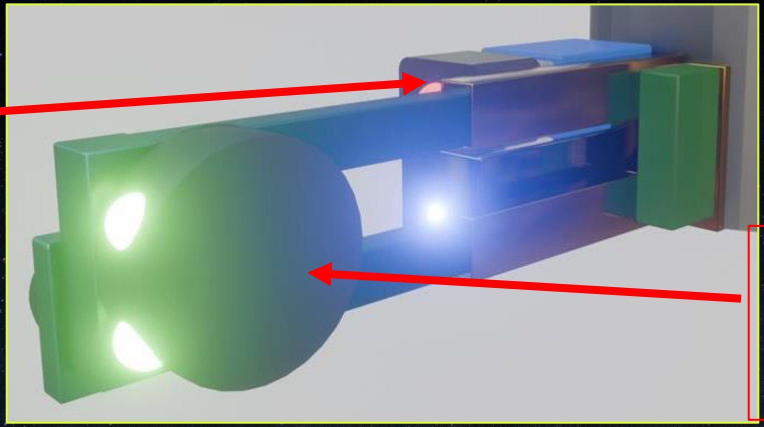


Bunaziv, I., Akselsen, O. M., Ren, X., Nyhus, B., and Eriksson, M., “Laser Beam and Laser-Arc Hybrid Welding of Aluminium Alloys,” Metals, Vol. 11, No. 7, 2021, Article 1150. doi:10.3390/met11081150

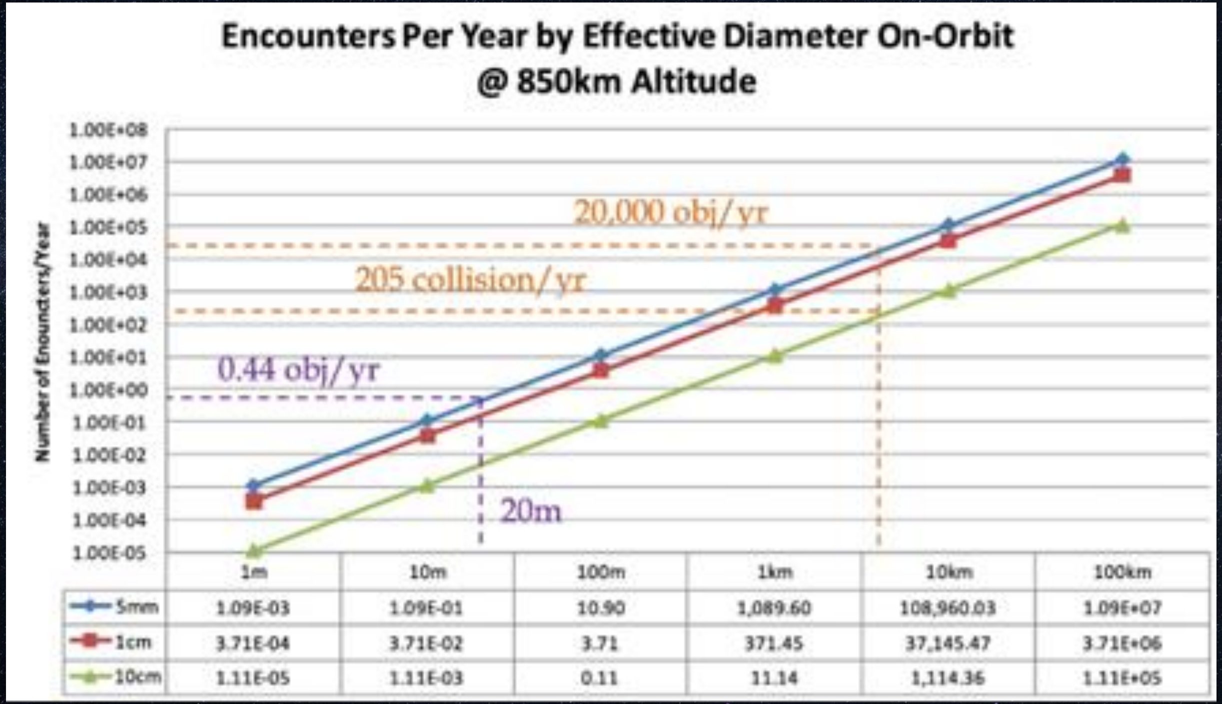
Payload Overview

Selecting a Tracker System

IR Camera



Twin Fan Sweep LIDAR



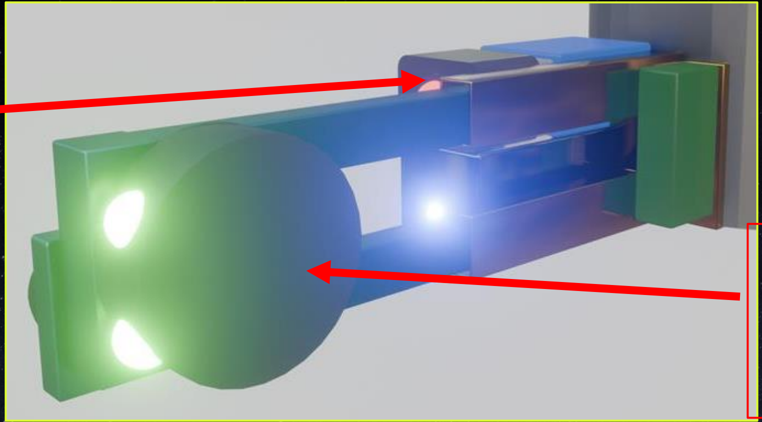
Pulliam W., "Catcher's Mitt Final Report," Defense Advanced Research Projects Agency, retrieved 4 December 2024.

Average microdebris for the study is 10 cm and made of aluminum. The detector must be 10km-100km.

Payload Overview

Chosen Tracker System

IR Camera



Twin Fan Sweep LIDAR

Tracker Trade Study

	Criteria (Label)	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	Total
	Weights	*15%*	*10%*	*2%*	*15%*	*5%*	*2%*	*1%*	*5%*	*1%*	*5%*	*5%*	*5%*	*5%*	*10%*	*5%*	*5%*	*2%*	*2%*	*100%*
Lidar	*Doppler*	3	2	2	2	2	3	3	3	2	3	2	3	2	2	3	3	2	2	81%
	Frequency Modulated Continuous Wave (FMCW)	3	3	1	3	2	2	3	3	2	2	2	2	1	2	3	3	2	3	84%
	Flash	2	2	1	2	2	2	3	3	2	2	2	2	1	2	3	3	3	2	70%
	Twin Fan Sweep	3	3	1	3	2	2	3	3	2	2	2	2	1	3	3	3	2	2	86%
	Multispectral	3	3	1	3	2	2	3	2	2	2	2	2	1	2	3	3	2	3	82%
	Hyperspectral	3	3	1	3	1	2	3	2	1	1	1	1	1	2	3	3	1	3	74%
	Polarmetric	2	2	2	2	2	2	3	3	2	2	2	2	2	2	3	3	2	2	72%
Radar	*Phased Array*	3	3	2	2	2	1	3	3	2	3	2	3	2	3	3	3	2	2	86%
	Doppler	3	2	2	2	2	2	3	3	2	3	2	3	2	3	3	3	2	2	84%
	Sythentic Aperture (SAR)	3	2	2	2	2	2	3	3	2	3	2	3	2	2	3	3	1	3	80%
	Inverse Synthetic Aperture (ISAR)	3	2	2	2	2	2	3	3	2	3	2	3	2	2	3	3	1	3	80%
	Passive	2	1	3	1	1	1	3	2	3	2	3	2	3	3	3	2	2	1	65%
	BiStatic/Multistatic	3	2	2	2	2	2	3	3	2	3	2	3	2	3	3	3	2	2	84%
Infrared Camera	*Shortwave Infrared (SWIR)*	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	69%
	Midwave Infrared (MWIR)	2	2	1	2	2	2	3	3	2	2	2	2	1	2	2	2	2	2	66%
	Longwave Infrared (LWIR)	2	2	1	2	2	2	3	3	2	2	2	2	1	2	2	2	2	2	66%
Other Camera	*Passive / Visible Optical*	2	2	2	2	2	2	3	3	2	2	2	2	3	2	1	1	2	1	66%
	Polarimetric	2	2	2	2	2	2	3	3	2	2	2	2	2	2	1	1	2	2	65%
	Stereoscopic	2	2	2	2	2	2	3	3	2	2	2	2	3	2	2	1	2	2	69%

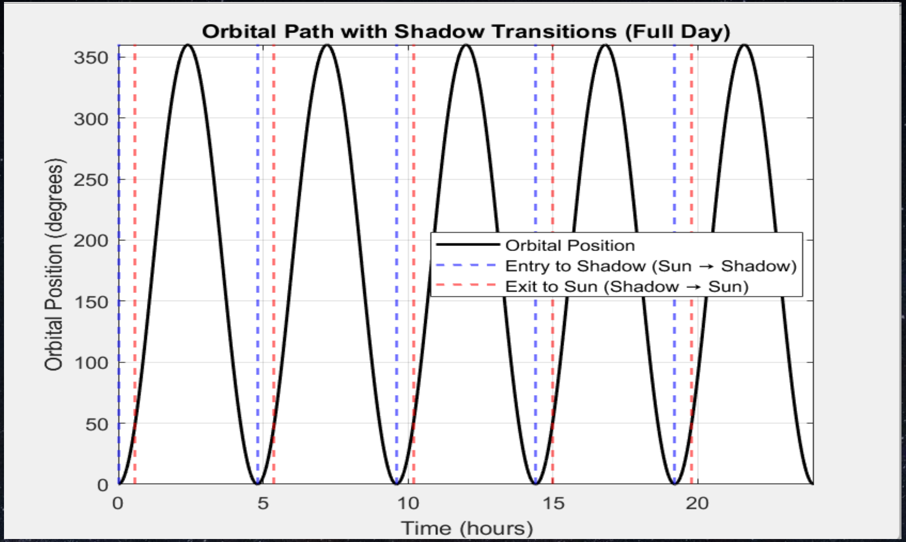
Label	Score	1	2	3	Units	Description
T1	*Range*	< 10	10 – 50	> 50	km	-
T2	*Precision*	> 10	1 – 10	< 1	% Error	Error in the data output from true values
T3	*Required Power*	> 500	500 – 250	< 250	W	Power required by device
T4	*Detection Size*	> 10	10 – 1	< 1	cm	Size of microdebris
T5	*Average Size*	> 4000	4000 – 100	< 100	in^3	Size of device
T6	*Average Mass*	> 50	50 – 10	< 10	kg	Mass of device
T7	*Lifespan*	< 3	3 – 5	> 5	Years	-
T8	*TRL*	< 4	4 – 6	> 6	TRL	-
T9	*Cost*	> 5	5 – 1	< 1	$Million	-
T10	*Robustness*	No Protection	Moderately Hardened	Hardened	Radiation Hardness	How resilient is it to space weather?
T11	*Data Rate*	> 10	1 – 10	< 1	Gbps	Onboard processing / bandwidth needed
T12	*Duty Cycle*	< 30	30 – 70	> 70	Percent	Continuous operation capability
T13	*Cooling*	Active	Passive	None	Cooling	-
T14	*Field of View*	< 10	10 – 60	> 60	°	-
T15	*Autonomy (Information processing)*	Computer Vision	Filtering Processing	Basic Math	-	How much help do you need / can it process all the data on its own easily? Does it need AI?
T16	*Low-light performance*	Low	Medium	High	Performance	Low = Requires direct illumination, Medium = Limited low-light capability, High = Fully functional in total darkness
T17	*Frame rate*	< 1	1 – 10	> 10	FPS	What is the rate at which it checks for change?
T18	*Amount of information extracted*	1	2	≥ 3	Sets	1 = position; 2 = position + velocity; 3 = position + velocity + thermal; etc.

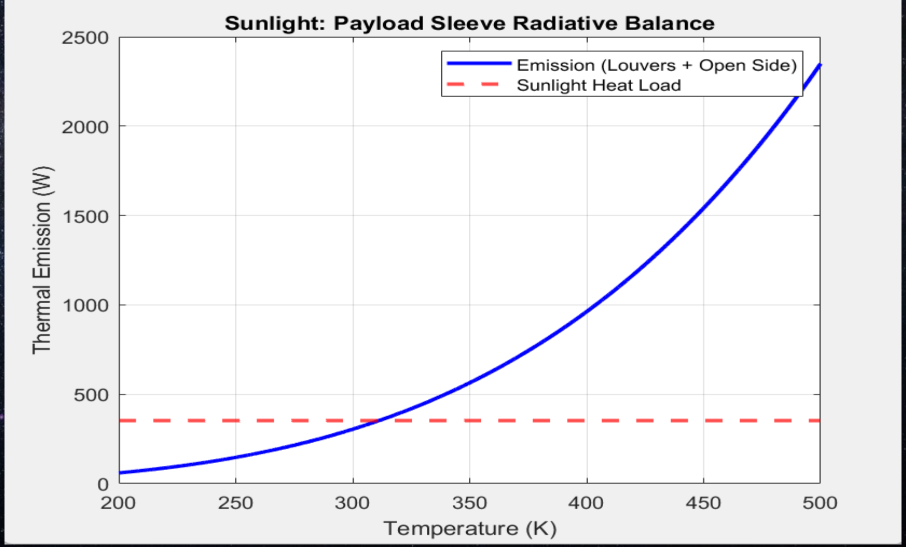
Payload Overview

Thermal System (1)

- Eclipse times used to determine time spent in sun and heat generation from the sun. The power used in the payload determines the internal heat generation
  - Total heat into the system = Sun + Internal = 122.5 W + 230.5 W = 353W
- One side of the payload is completely open to radiate to space (.18 square meters) with louvers on two of the other side (.6 square meters). Combined radiating area of .78 square meters

- *This* radiating of heat combined with the incoming heat load from the sun results in an equilibrium temperature of the system to come out to 38.1 Celsius (311.3 K, where the blue curve intersects the red line in the bottom graph)
  - In order to get the operating temperature a more ideal 20 Celsius, about 75.4 Watts needs to be dedicated to active cooling

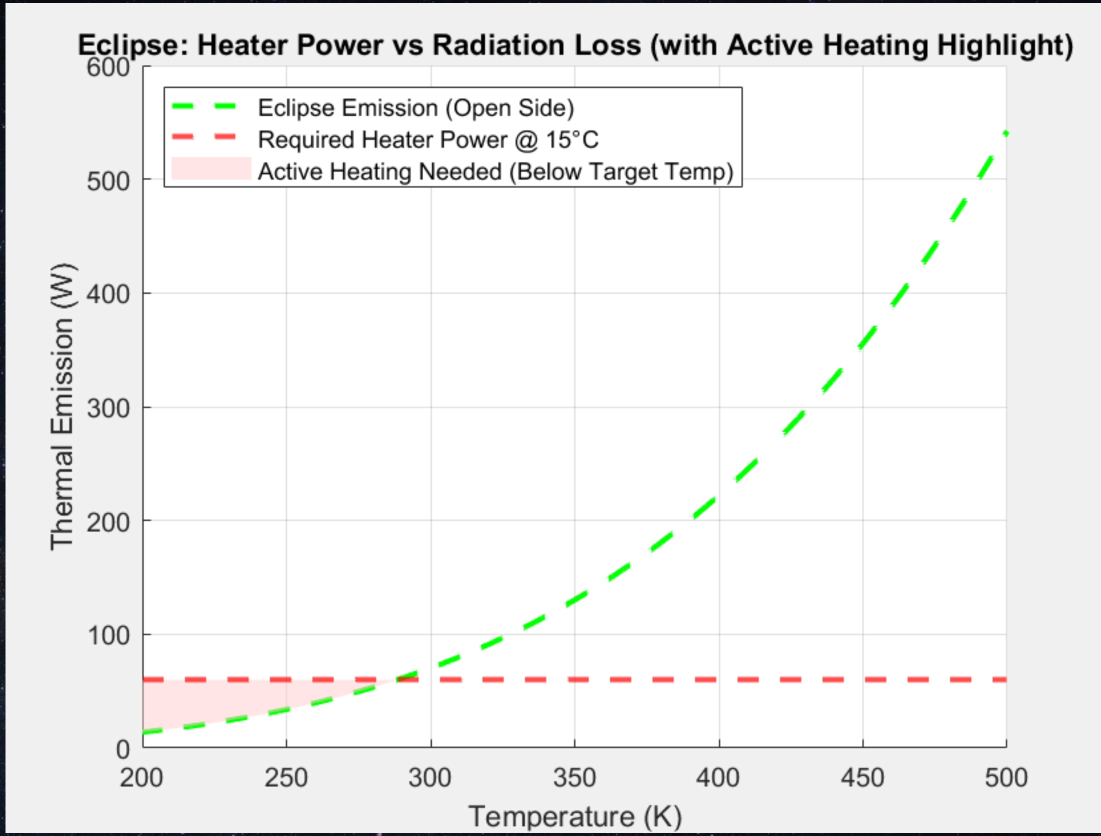




Payload Overview

Thermal System (2)

- Next was to worry about thermal loading in eclipse.
- The payload isn't operating during eclipse, so the only internal heating would come from active heating.
- The equilibrium temperature before active heating was found to be roughly –73 Celsius meaning active heating is needed
- The target temperature was set to be 15 Celsius (288.15 K) in the Stefan-Boltzmann Law to find a heating power of 59.81 Watts required
- This is the only power being drawn to the payload at this time leaving plenty of energy to be used for heating, comms, propulsion, etc. for the satellite
- The graph shows where our emission curve intersects the heating power to show the heating power needed for the desired temp



Payload Overview

Power System

- A company called Eaglepicher Technologies makes the chosen space-rated Li-ion battery. 8 of these are used in one battery module to get the following specs:
- This battery module is stored on the bus and charges 12 supercapacitors
- The supercapacitors are configured in a such a way to get the following specs:
- Using a DC-DC boost converter accounting for thermal losses and inefficiencies, allows the battery module to charge the supercapacitors in around 20 minutes.
- The laser is then fired using the supercapacitors and another boost converter.
- All of these values were found using general equations for batteries and capacitors in parallel/series

Only the laser draws power from the supercapacitors

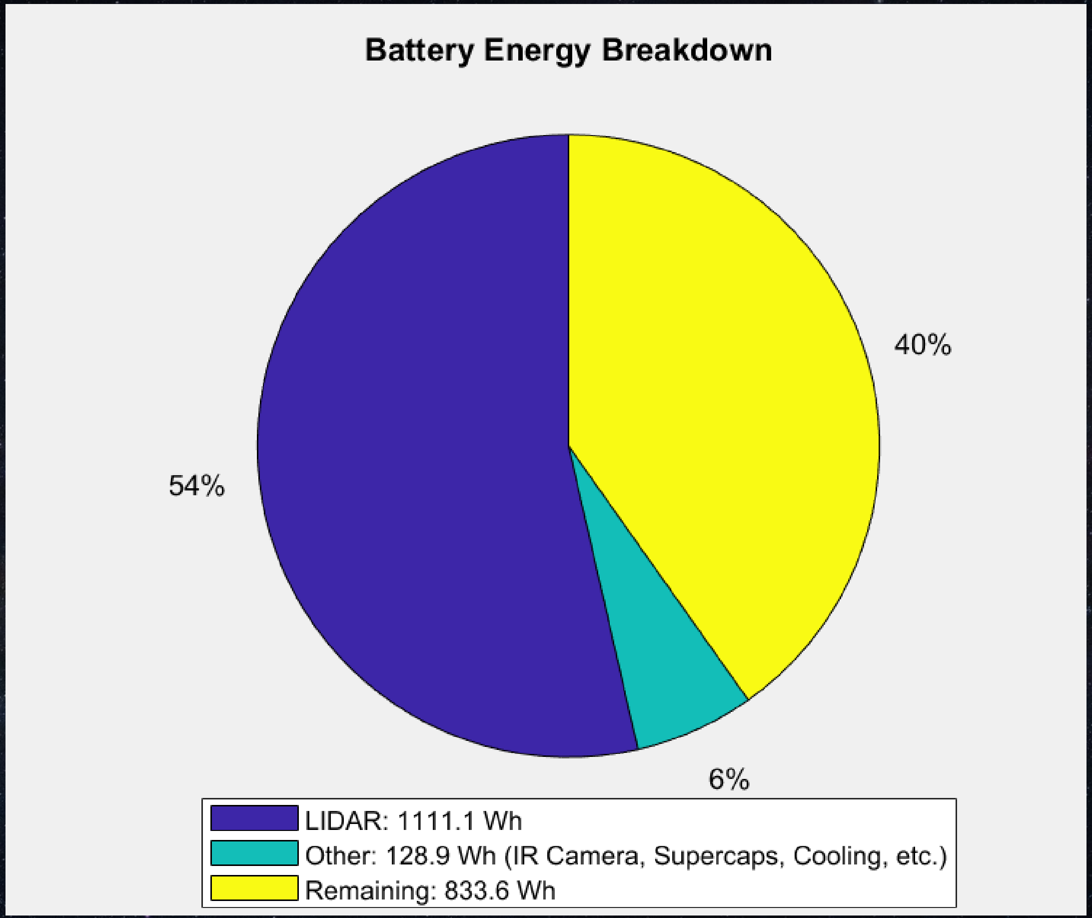
Battery Module	
Parameter	**Value**
Capacity	288 Ah
Energy	2073.6 Wh
Voltage	7.2 V
Weight	16.792 kg
Charge Current Limit	144 A
Discharge Current Limit	288 A
Operating Temp. Range	10°C to 30°C
Storage Temp. Range	-5°C to 5°C

Supercapacitors	
Parameter	**Value**
Capacitance	133.33 F
Voltage	9 V
Energy	1.5 Wh, 5400 J
Operating Temp. Range	-40°C to 65°C

Payload Overview

Power System (2)

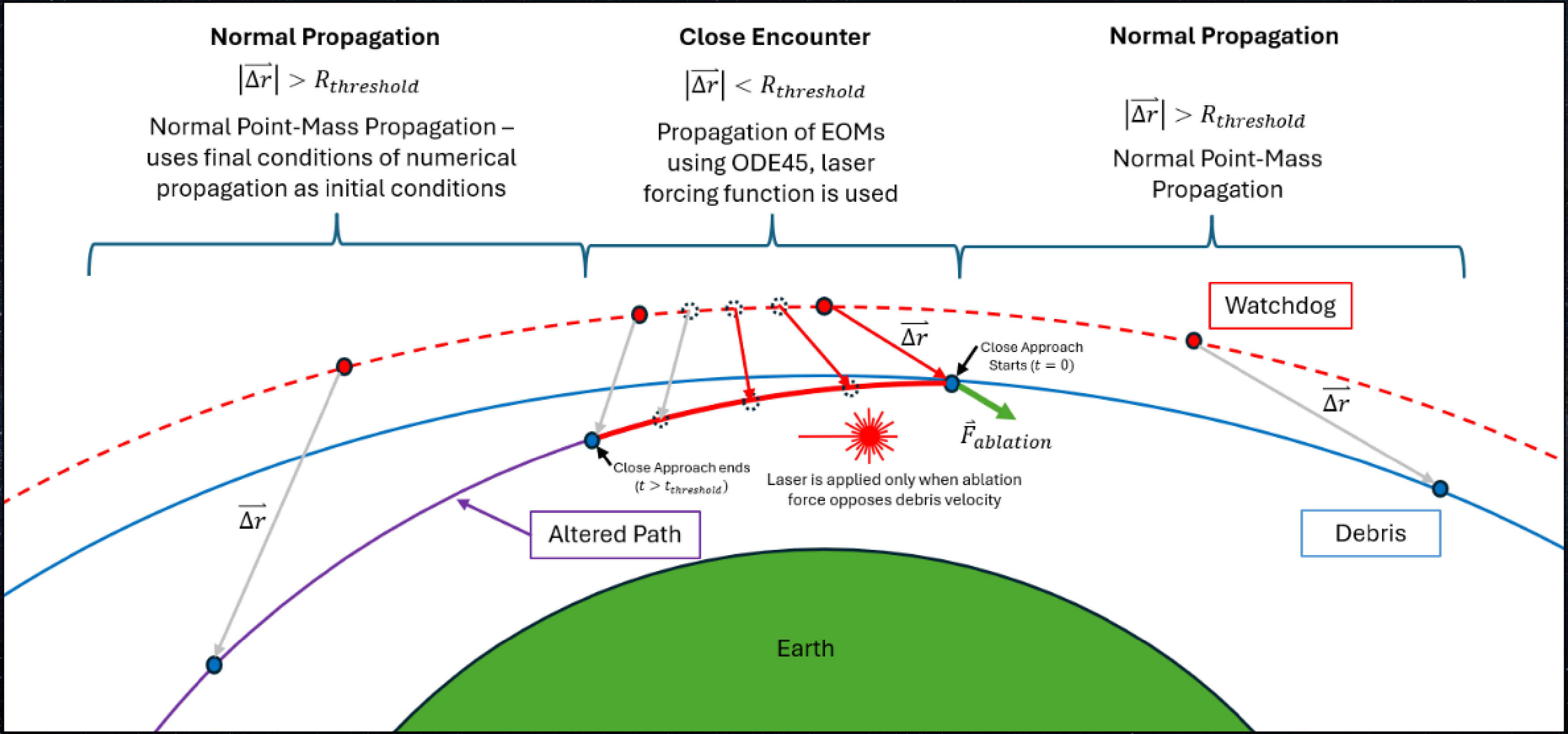
- The laser can activate for around 60 seconds of continuous fire before supercapacitors need recharged
- LIDAR
  - requires 1000 Watts
  - activated for one hour at a time to ensure sufficient debris tracking,
  - 1111.1 Wh to achieve this
- Infrared camera
  - Active while the lidar is active
  - Requires 25 Watts
  - 25 Wh to achieve this
- Galvo box and boom motors power use is negligible
- Most of the satellite's subsystems are inactive during payload operation, so 40% power is enough to power the bus payload activation occurs



Payload Overview

Physical Simulation - Methodology

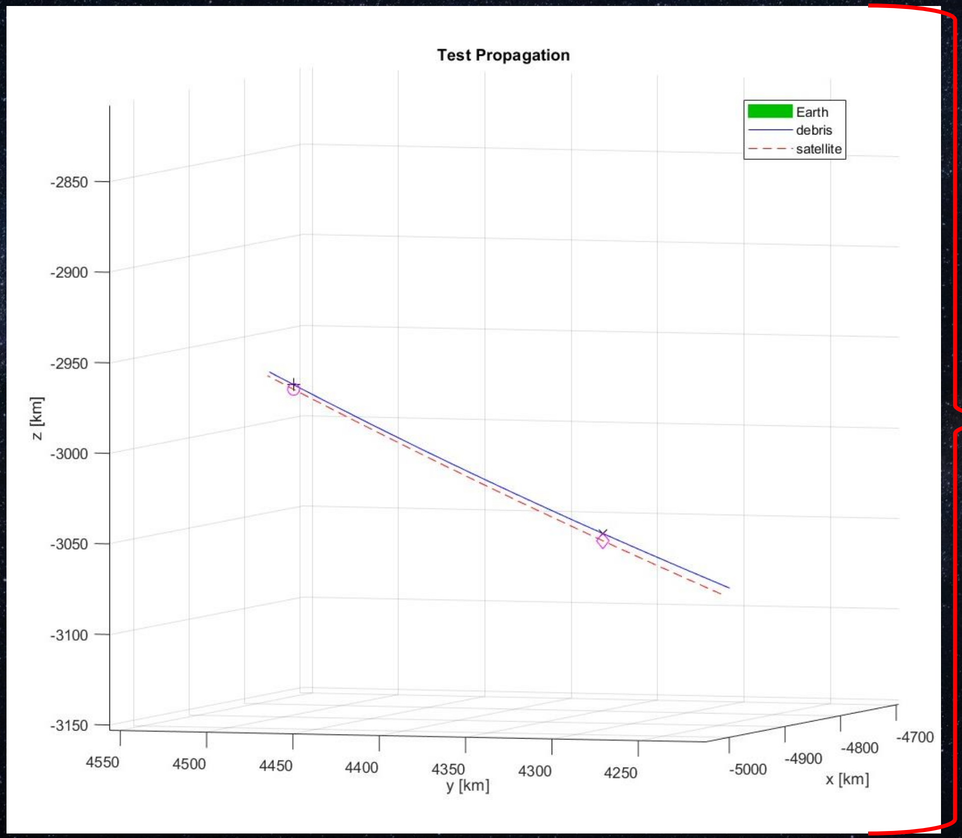
- The model combines analytical and numerical propagations to simulate the effect of micro-debris ablation

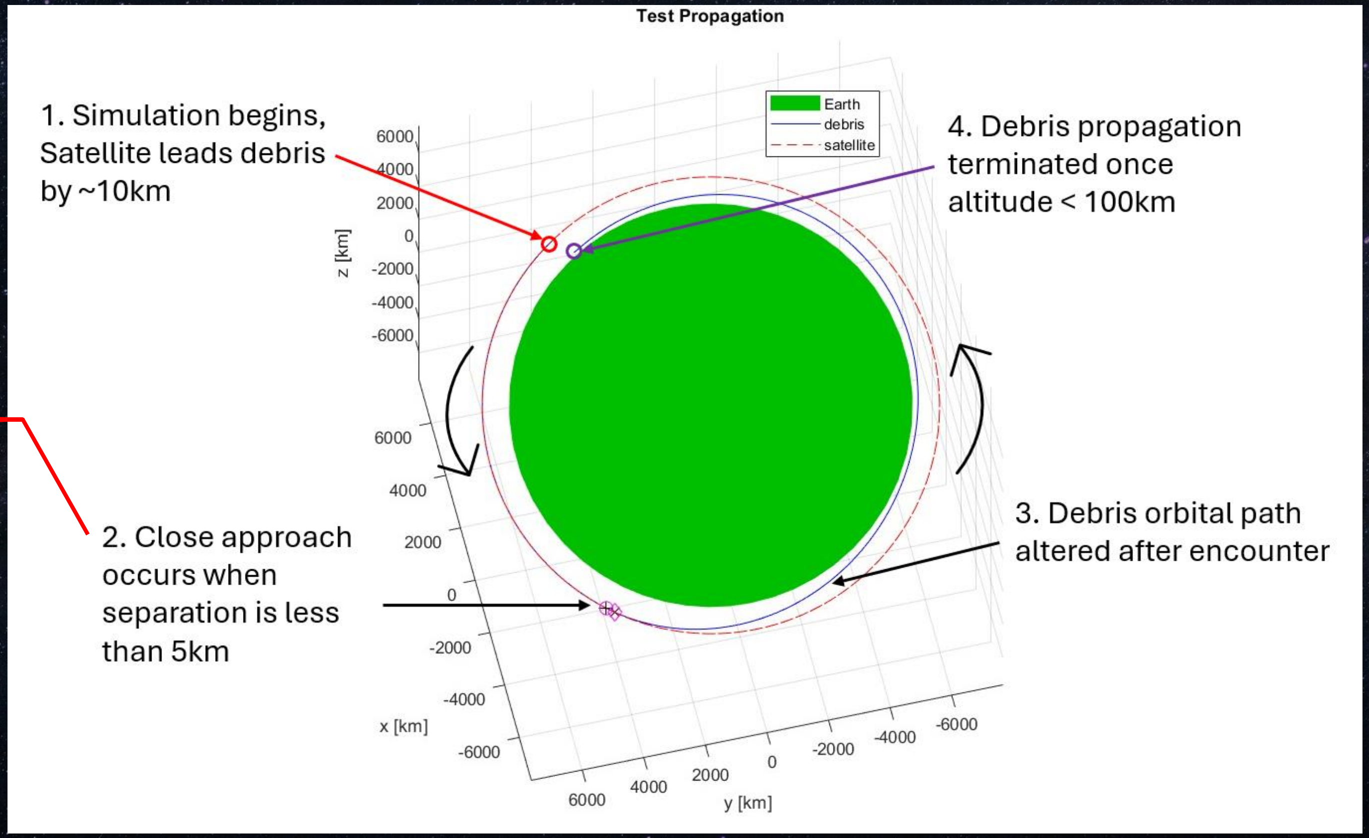


Payload Overview

Physical Simulation – MATLAB Simulation

- The model combines analytical and numerical propagations to simulate the effect of micro-debris ablation





Simulation uses 3mg/100J ablation rate, 100g initial debris mass, average laser power of 1.3kW, 40 second encounter

1.5 Risks

Three Most Prominent Risks with Watchdog

Risk	Pre-Mitigation	Post-Mitigation
1. Lasering a non-debris target	• Without sufficient checking, the payload could laser objects that are not debris (C1)	• Inclusion of an IR camera capable of distinguishing between debris and other objects (D4)
2. Pushing debris onto trajectories other than sub-orbital	• If the laser were to ablate any particle found, it may push it in a direction that does not assist in deorbiting (B3)	• Tracking system must verify the trajectory of the target before lasering to ensure it will move against its velocity (D3)
3. Regulatory risk with high-powered lasers in space	• Some parties may not be comfortable with a debris-clearing satellite near operational satellites (C2)	• Communicate with satellite hosts operating near Watchdog to ensure there are no conflictions (C4)

RISK ASSESSMENT MATRIX				
Severity/Probability	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)				
Probable (B)			2.	
Occasional (C)	1.	3.		3.
Remote (D)			2.	1.
Improbable (E)				

1.5 Risks (and Costs)

Costs analyzed using Aerospace Corp. SSCM19 Software – Base Cost Breakdown

- Most of the technologies (Laser, Tracker, Thermal) are low TRL (likely 3-4)
- This mission may require preceding ones to demonstrate in-space operation of these technologies
- To account for the low TRL in the project, the cost estimation factors in greater cost distributions
  - +100%, -0% for C&DH, Thermal, and Power, to account for possible developments necessary for these subsystems
  - Methodology is that TRL needs to nearly double for technology in these subsystems, hence the cost may be double.
- Most likely cost of $51,683K
- Mean cost of $60,378K

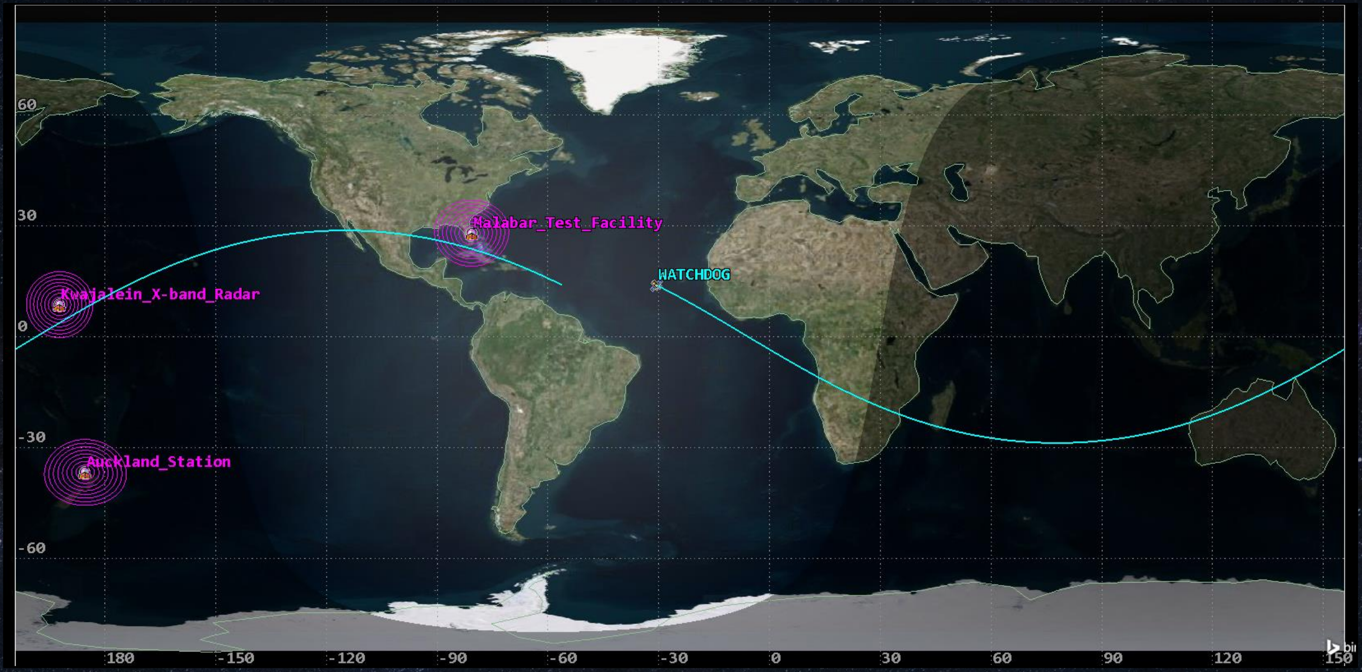
	Percentages		Distribution Points			Estimate (FY25$K)	
	Low	High	Low	Most Likely	High	Mean	Std Dev
Spacecraft Bus Subsystems							
Power	0%	100%	5,456	5,456	10,912	**7,274**	3,016
Structure			4,135	4,135	4,135	**4,135**	1,848
ADCS	0%	100%	4,201	4,201	8,402	**5,601**	2,231
Propulsion			2,089	2,089	2,089	**2,089**	932
TT&C/C&DH	0%	100%	14,194	14,194	28,387	**18,925**	7,505
Thermal	0%	100%	2,235	2,235	4,469	**2,980**	1,405
Spacecraft Bus			**32,309**	**32,309**	**58,394**	**41,004**	**11,633**
ATLO			9,920	9,920	9,920	**9,920**	4,087
PM/SE			9,454	9,454	9,454	**9,454**	5,077
S/C Development & First Unit			**51,683**	**51,683**	**77,769**	**60,378**	**13,840**

Note: Factoring in overhead for bus systems unit cost

2.3 Data Handling and Comms

Ground Stations

- The Space Fence radar, located in the Marshall Islands will be used for debris detection
  - This will guide the spacecraft towards orbits where debris are most likely
  - NOT used for communications
- Ground Stations:
  - Malabar Transmitter Annex (Cape Canaveral)
  - Awarua Ground Station (New Zealand)
  - Two stations located near the highest latitudinal inclination of the orbit, which allows for multiple accesses each day.
  - Both work in S-band transmission, inclination allows for access about 12 times per day, average access of about 12 minutes



2.3 Data Handling and Comms (2)

Downlink and Uplink Budgets

- The communications subsystem is sized to use a standard all-metal patch antenna, used on the S-band frequency, provided by Blue Canyon Technologies
- An uplink and downlink budget was developed, which defines link margins expected for the given setup
- Analysis using access times generated in STK
  - For an upper-bound estimation of data transmitted on a single pass to be 100MB, the data rate is 12.1 Mbps

Downlink Budget

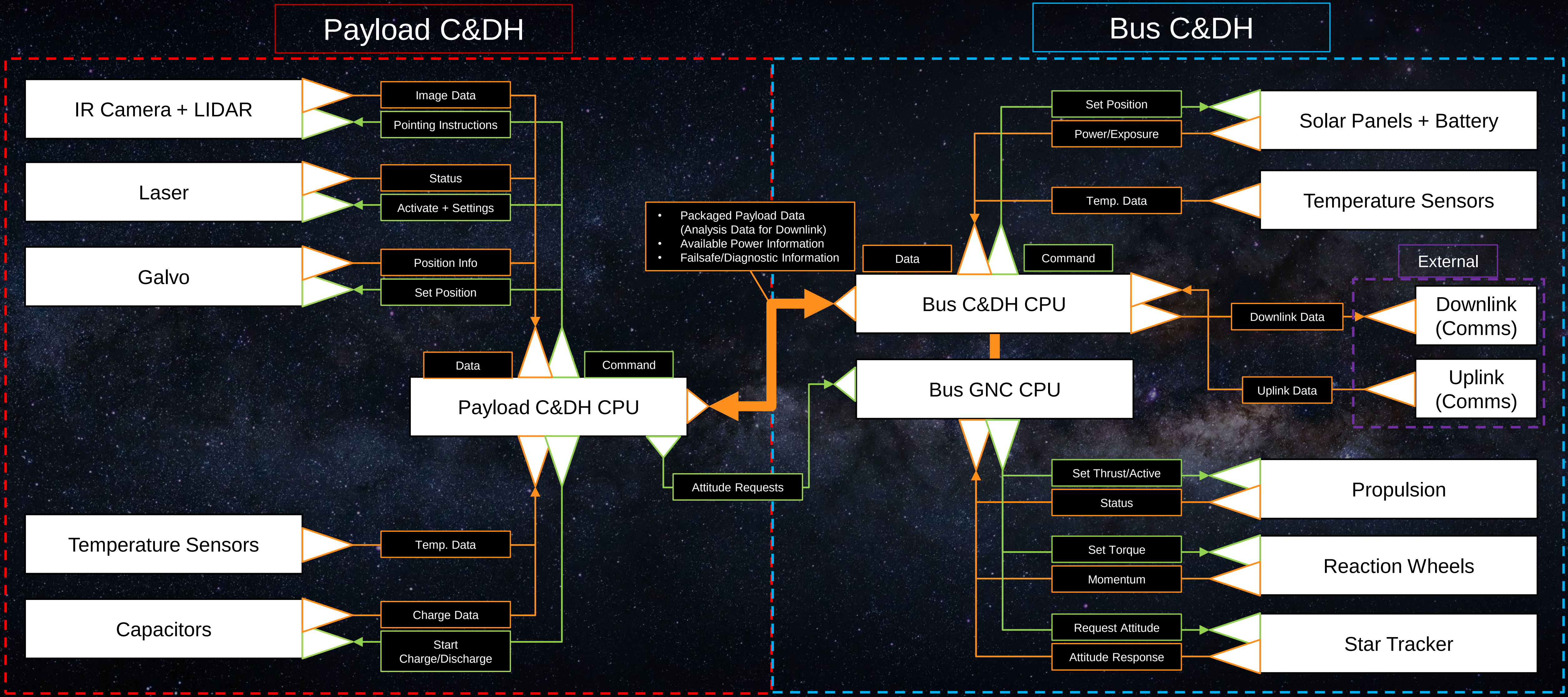
Transmitter (BC S-Band All Metal Patch Antenna)	Frequency	2.50	GHz
	Antenna Power (W)	7000	mW
	Diameter	0.0838	m
	Pointing Error	140	deg
	Antenna Power (dB)	8.45	dBW
	Line Loss	-1.0	dB
	Peak Gain	4.3	dB
	Pointing Loss	-23.4	dB
	Transmit Gain	-19.1	dB
	Net Gain	-11.7	dB
Reciever (NZ Station)	Diameter	11	m
	Pointing Error	0.07	deg
	Peak Gain	46.6	dB
	Pointing Loss	-0.1	dB
	Net Gain	46.5	dB
Other	Path Length (max)	1000	km
	Space Loss	-160.4	dB
	Bit Error Rate	1.0E-05	
	Modulation	BPSK, R-1/2 Viterbi	
	E_b/N_0 Reqd.	10.9	dB
	Imp. Loss	-2.0	dB
	Prop./Polarization Loss	-0.03	dB
	Data Rate	12.1	Mbps
	Noise Temp.	135	
	Downlink Margin:	4.4	dB

Uplink Budget

Transmitter (NZ Station)	Frequency	2.65	GHz
	Antenna Power (W)	500	W
	Diameter	11	m
	Pointing Error	0.07	deg
	Antenna Power (dB)	27.0	dBW
	Line Loss	-1.0	dB
	Peak Gain	47.1	dB
	Pointing Loss	-0.1	dB
	Transmit Gain	47.0	dB
	Net Gain	73.0	dB
Receiver (BC S-Band All Metal Patch Antenna)	Diameter	0.0838	m
	Pointing Error	140	deg
	Peak Gain	4.74	dB
	Pointing Loss	-26.3	dB
	Net Gain	-21.6	dB
Other	Path Length (max)	1000	km
	Space Loss	-160.9	dB
	Bit Error Rate	1.0E-05	
	Modulation	BPSK, R-1/2 Viterbi	
	E_b/N_0 Reqd.	4.5	dB
	Imp. Loss	-2.0	dB
	Prop./Polarization Loss	-0.03	dB
	Data Rate	120	kbps
	Noise Temp.	135	
	Uplink Margin:	40.5	dB

2.3 Data Handling and Comms (3)

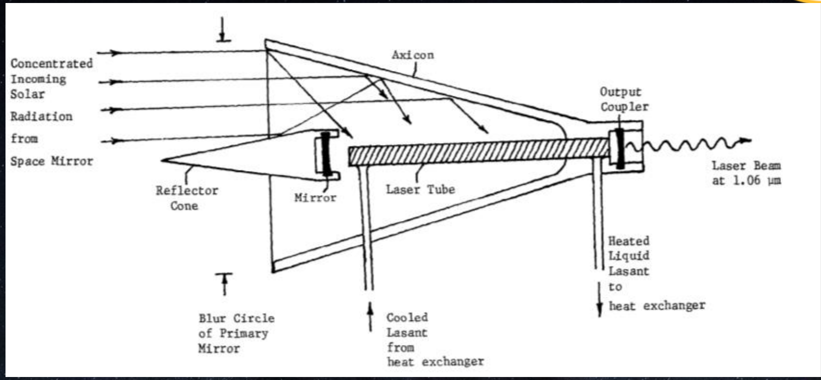
Flow of Data Illustrated



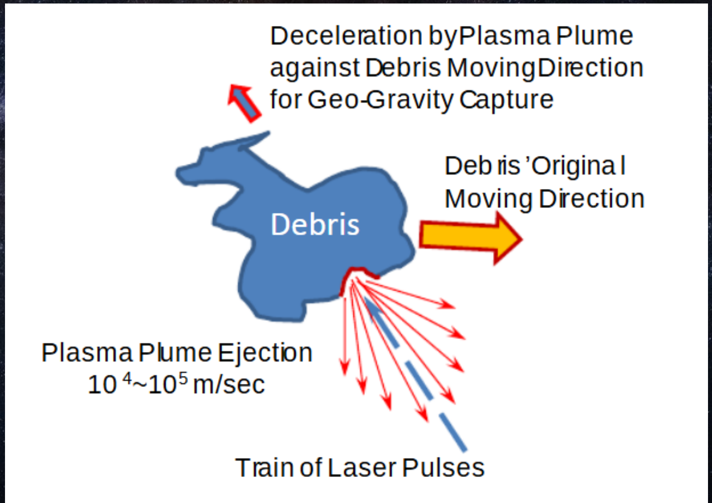
3.3 Biggest Challenges Encountered

Three challenges and their approach

- 1. Technical challenge proving that debris could be pushed into desired trajectories
  - The orbital MATLAB simulation was developed to show the effect of an encounter with debris
- 2. Technical challenge developing a laser system that could be pumped by solar light
  - Eventually, this idea was avoided to avoid complexity and feasibility risks
  - This has challenges both in materials and logistical implementation
- 3. Technical challenge of modeling ablation for the desired particle
  - A paper was found that discusses using lasers to redirect debris. We used this data to have an ablation rate that was approximately proportional to the laser power.
  - Still unknown how wavelengths and pulse frequency will affect this rate



Kurzweg, U.H., "Analysis of a 10 Megawatt Space-Based Solar-Pumped Liquid Neodymium Laser System," NASA CR 3774 c.1 Grant NAGI-135, January 1984, retrieved 4 December 2024. https://ntrs.nasa.gov/api/citations/19840008476/downloads/19840008476.pdf

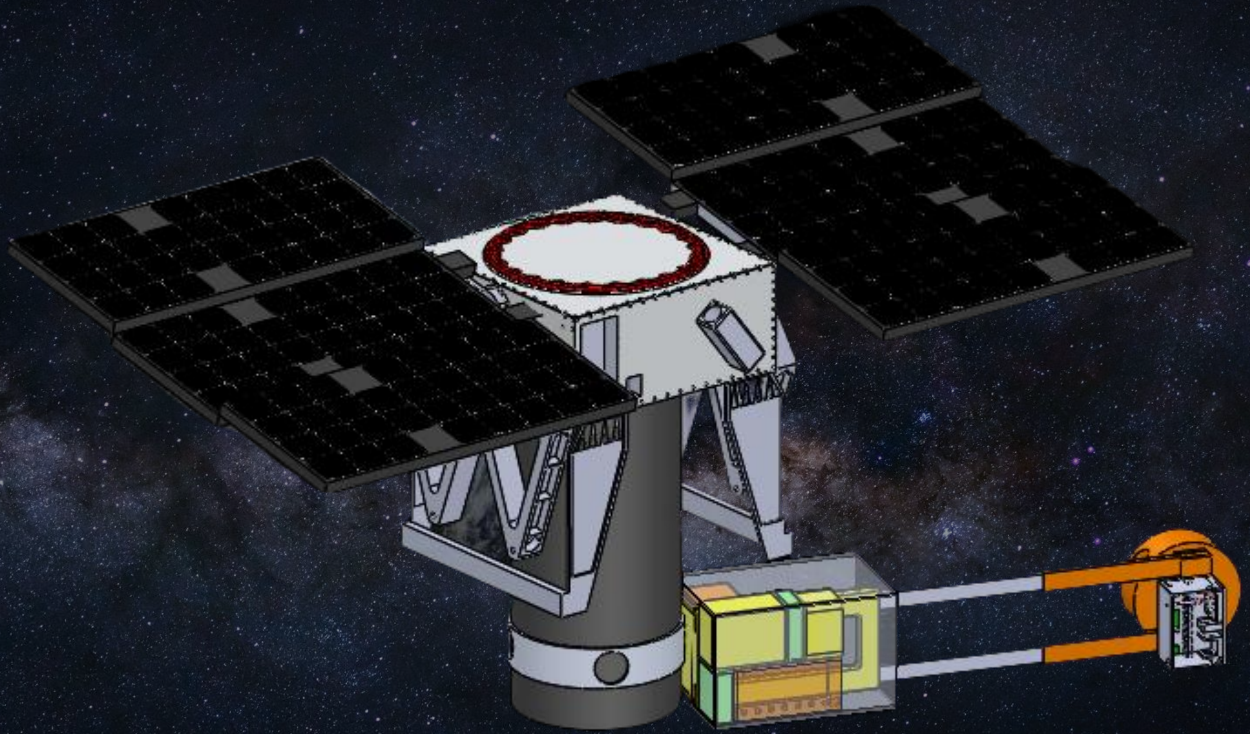


Choi, S. H., Pappa, R. S., "Assessment Study of Small Size Space Debris Removal by Orbit-Stationed Laser Satellites", Recent Patents on Space Technology 2, pp. 116-122, 2012

3.2 Technology Gap Assessment

Greatest Tech Gaps within the Payload

- Laser System
  - The laser used for this mission must support output power on the scale of kilowatts
  - Some systems exist, but require large mass and volume, as well as cooling
  - While the team envisioned designing a laser for the mission, this proved to be too involved for this project
- Target Tracker
  - It was found that LIDAR would be the most suitable for this system
  - The mission would only be feasible if the tracker were accurate to several kilometers
  - Additionally, the power for this is not certain, and may not be feasible for a small sat
- Laser Thermal Management
  - Most thermal systems for a laser would include a pumped system transporting a coolant, which can be large
  - Cooling such as this has not been demonstrated in space



4.1 Paper

AIAA paper detailing design and analysis work

A 20-page paper has been prepared detailing the design and analysis work performed on this project

The paper is in AIAA formatting, and is intended to be submitted to the SciTech conference (Orlando, Jan 2026)

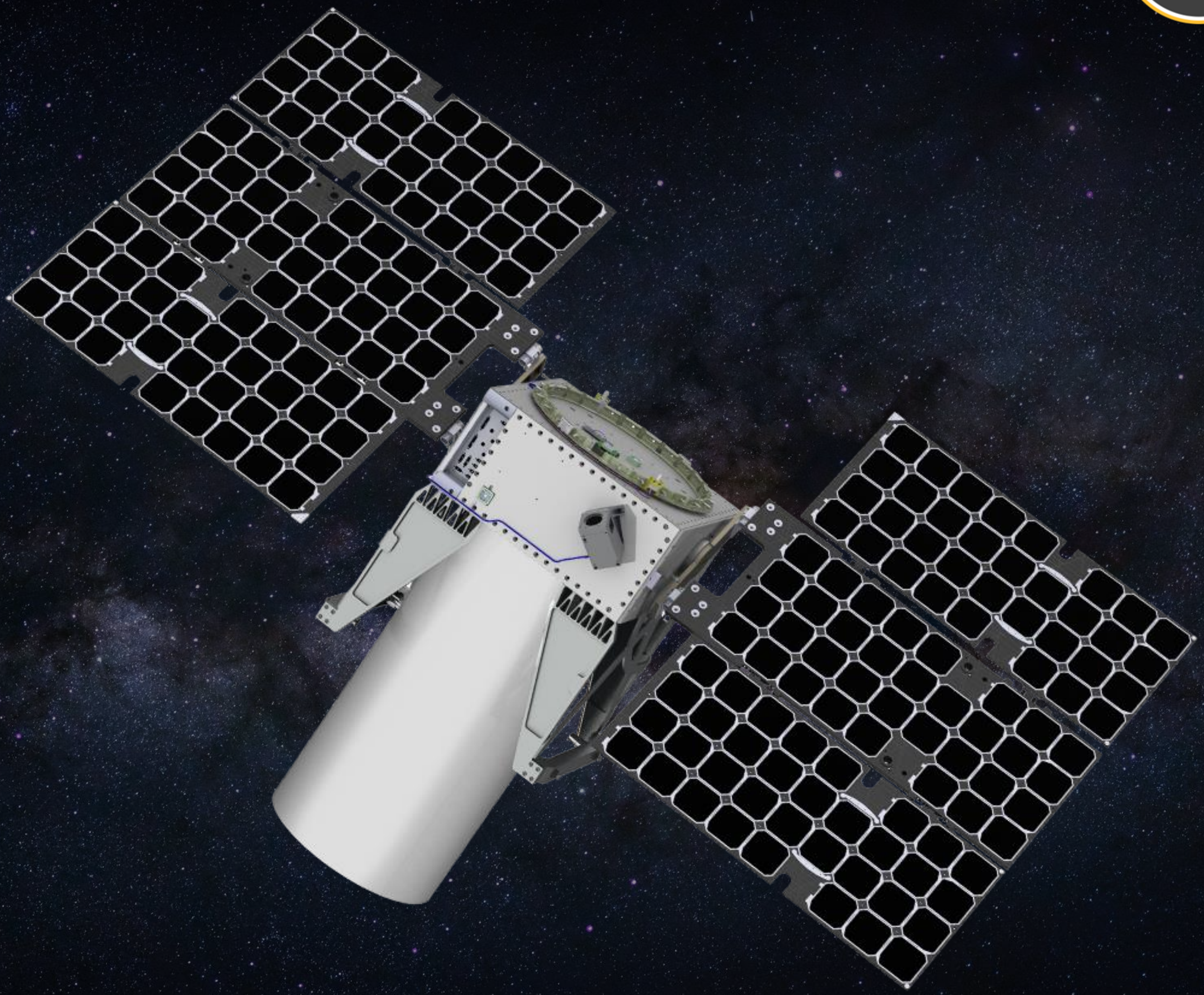
Alternatively, IEEE Aerospace Conference, SmallSat Conference, and AAS/AIAA Astrodynamics Specialist Conference are being considered

Abstract is 195 words, there are 15 references

1.6 Path to PDR

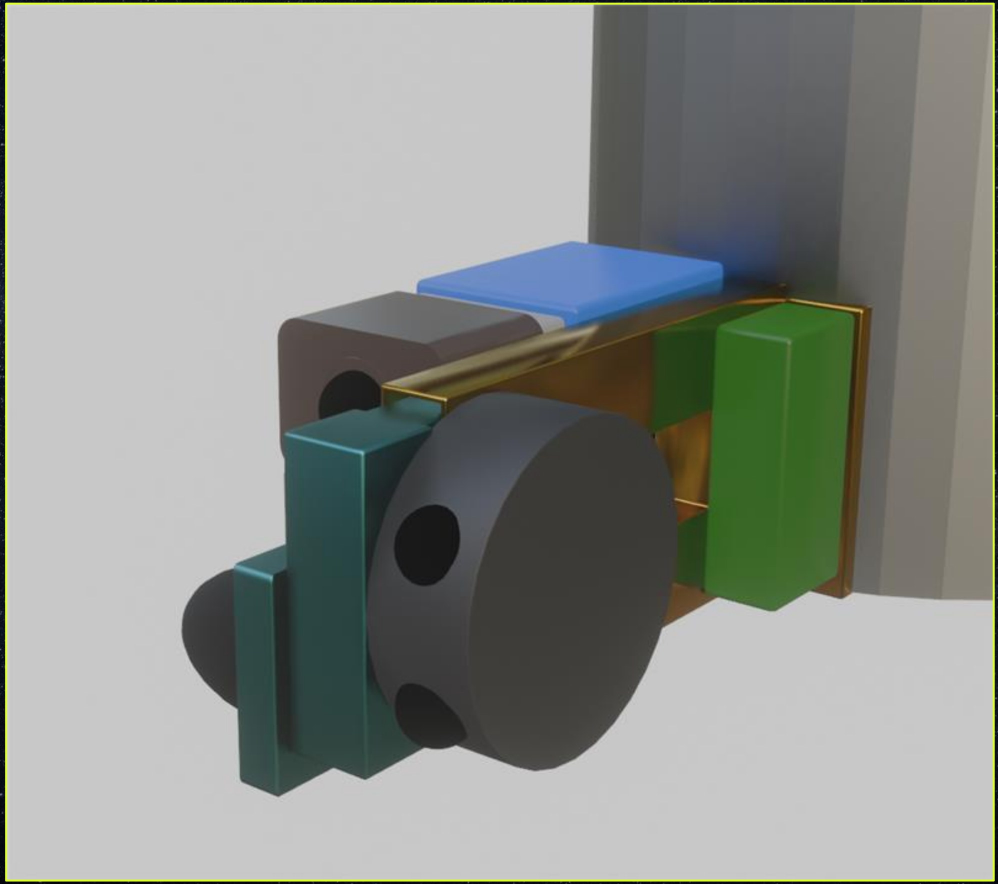
Venus X-Class Bus Integration Work

- So far, there is design verification for:
  - Propulsion, Power, and Thermal systems
- The next steps would include:
  - Determining detailed mass/inertia information about the bus to develop GNC models
  - Further develop C&DH systems to determine the size and processing power needed for on-board computers
  - Perform more in-depth studies of the physical characteristics of the spacecraft, such as structural and environmental loads during launch and operation



1.6 Path to PDR

Next steps for the payload design and integration



Build up the astrodynamics models to find optimal power and forces necessary to redirect debris

Experiment with laser ablation, develop ablation simulations that align close to reality

Design or select a laser capable of delivering optimal power at a specified wavelength/frequency

In-Space/Lab demo of some key technologies (Laser, Tracker) to raise TRL

Lessons Learned

Three important takeaways from the project

01

Take the technological fidelity of your ideas into account at the earliest phase of conceptualization

- The team realized later in development that some of the concepts were not highly demonstrated
- There were considerations of swapping to a technical demonstration to raise TRL, but decided not to move forward

02

Be sure to balance workload and time

- Be careful becoming too focused on one item or task
- Take care not to over-scope

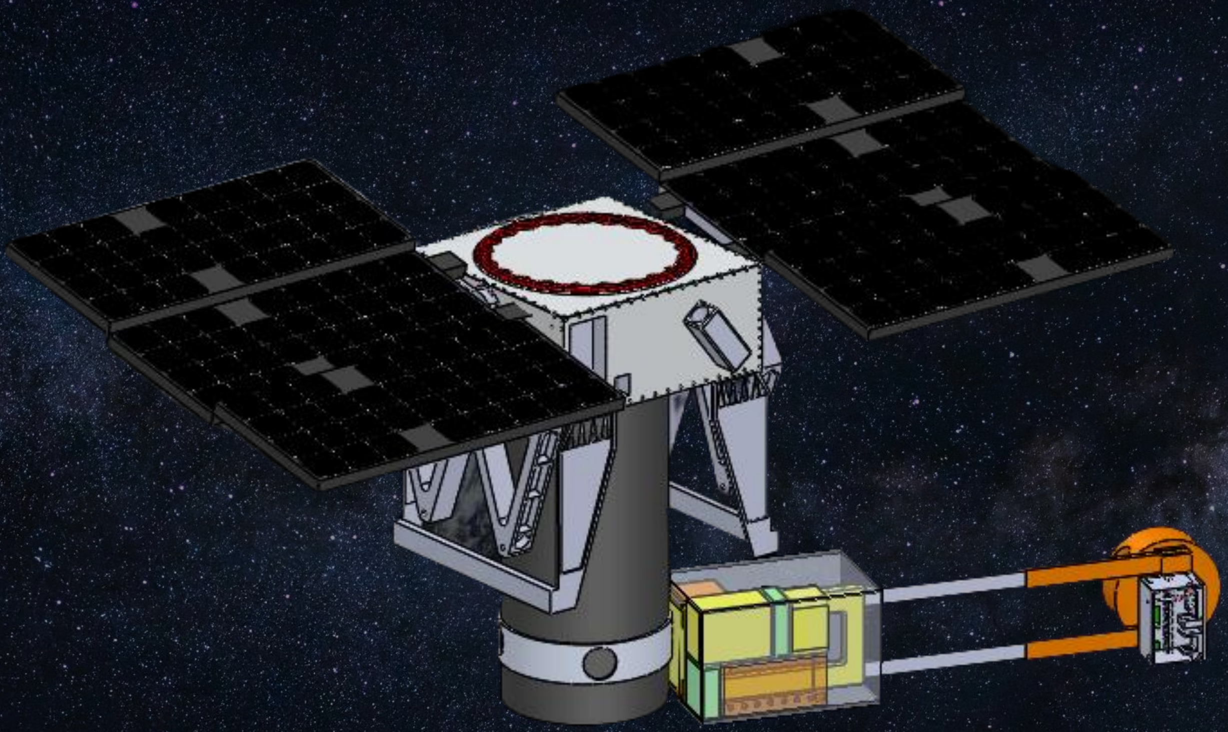
03

Be sure to do “back of the envelope” calculations as early as possible

- Use physical principals and models available to back up early concepts
- May help to play devil’s advocate in early discussion

Conclusion

Impact to ISAM and Innovation



Impact

- This work may become inspiration for future ISAM related space missions
- Raise awareness for the microdebris problem
- Call to action for research on lasers and debris tracking technology

Innovation

- The Watchdog mission aims to clear a large quantity of debris from long range
  - While some systems clear few large debris targets, Watchdog aims to clear many small ones

Questions?

ACES

PennState College of Engineering | AEROSPACE ENGINEERING

COSMIC

THE POWER OF COLLABORATION

Backup Slides

1.6 Risk (and Costs)

SSCM19 Cost Breakdown by Subsystem and Sublevel

	Non-Rec	Rec	Estimate (FY25$K) Total	Std Error	% of Sub-level	% of Sys-level
Spacecraft Bus Subsystems						
Power	2,151	3,305	**5,456**	2,046	16.9%	
Structure	2,155	1,980	**4,135**	1,848	12.8%	
ADCS	2,000	2,201	**4,201**	1,500	13.0%	
Propulsion	712	1,377	**2,089**	932	6.5%	
TT&C*	2,300	2,255	**4,554**	5,039	14.1%	
C&DH*	4,867	4,772	**9,639**		29.8%	
Thermal	1,161	1,073	**2,235**	977	6.9%	
Spacecraft Bus	**15,346**	**16,963**	**32,309**	**6,088**	**100%**	62.5%
IA&T*	3,311	3,881	**7,192**	4,087		13.9%
PM/SE	4,288	5,166	**9,454**	5,077		18.3%
LOOS*	0	2,728	**2,728**			5.3%
S/C Development & First Unit	**22,945**	**28,738**	**51,683**	**8,919**		**100%**

Trade Studies

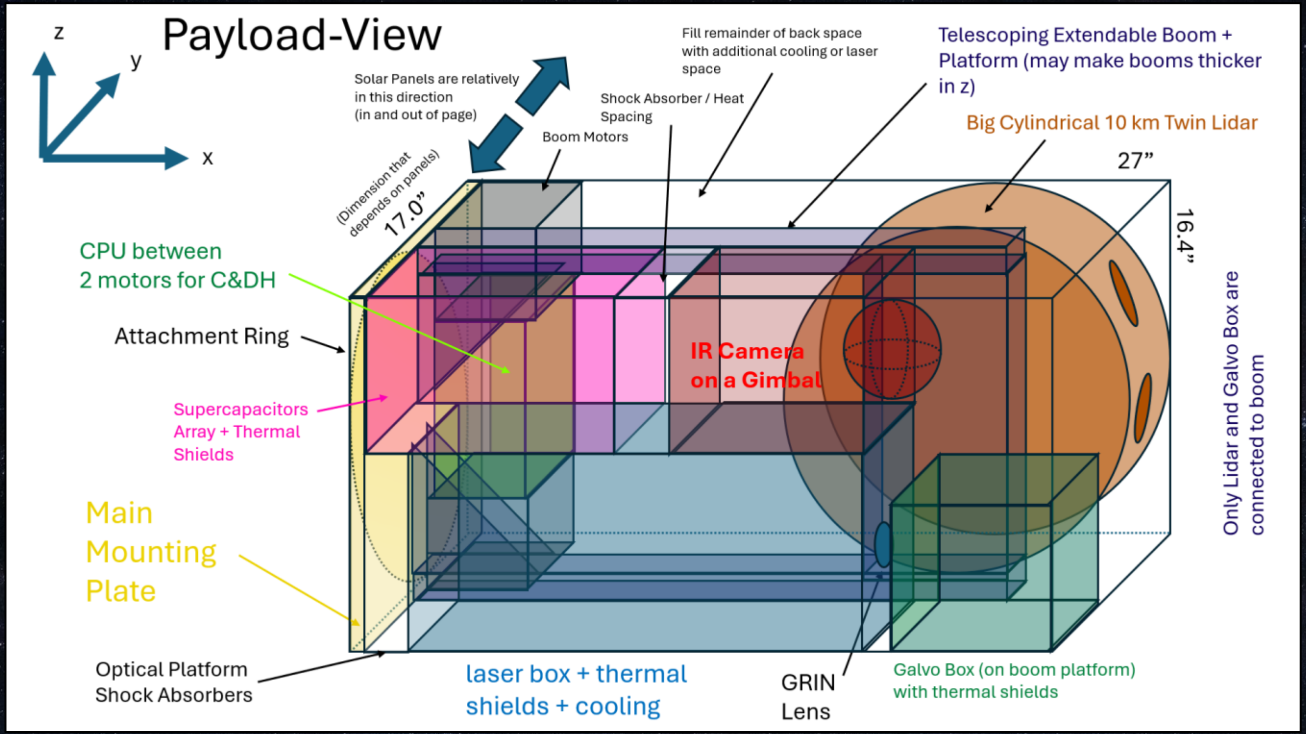
Launch Vehicle

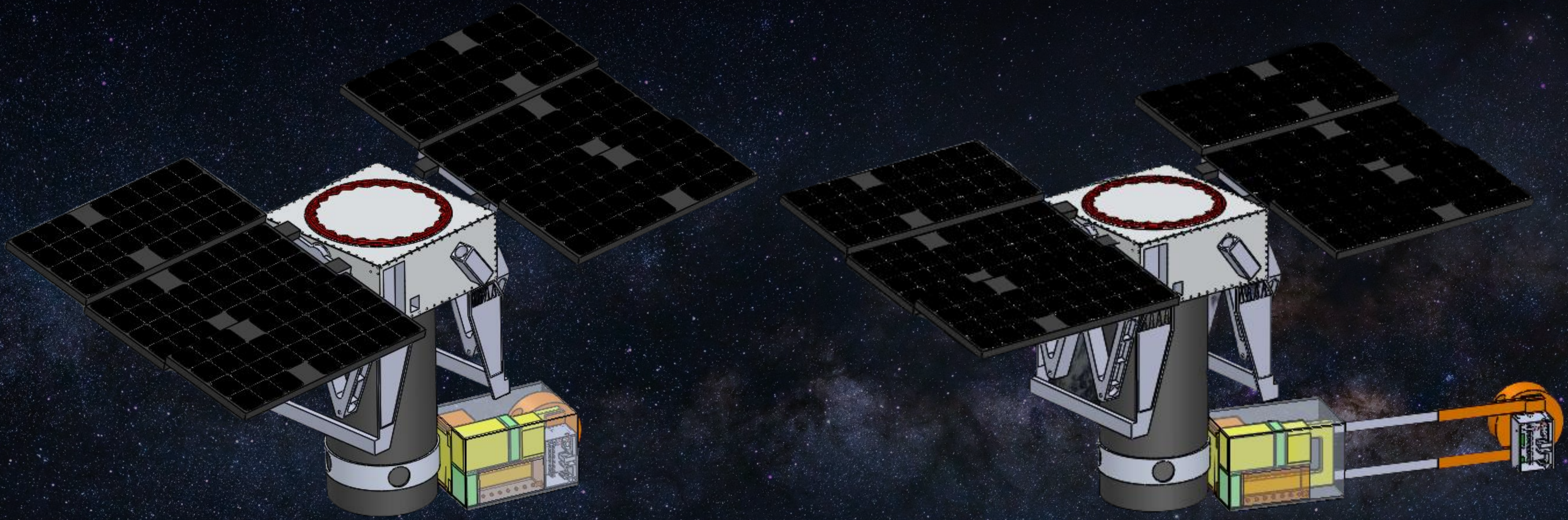
Launch Vehicles	Weight	Goal	Falcon 9	Atlas V	Ariane 5	Minotaur IV
Payload Mass to LEO	5	Max	50,265	41,560	10,000	3,825
Normalized Value			1	1	0.133	0
Reliability	45	Max	4.985	5	4.79	5
Normalized Value			0.929	1	0	1
Fairing Volume	5	Max	257.2	520.4	396.5	27.5
Normalized Value			0.466	1	0.749	0
Estimated Cost	45	Min	62	153	175	46
Normalized Value			0.876	0.171	0	1
Totals:	100		0.885	0.617	0.044	0.90

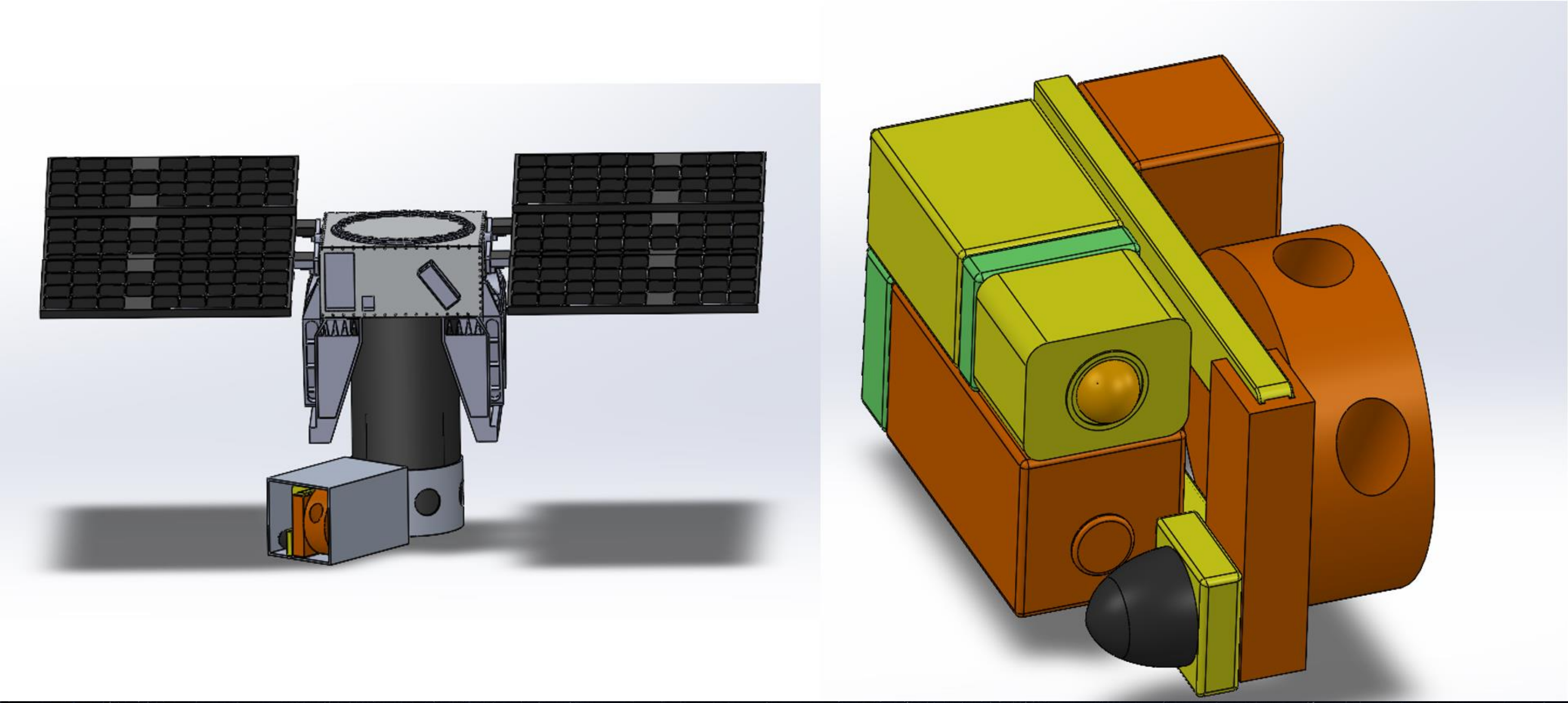
Other

Description	Δv (m/s)
Impulse 1 (Xfer)	39
Impulse 2 (circularize)	39
Hohmann Xfer (to 700km)	78
Impulse 3 (Xfer)	57
Impulse 4 (Circularize)	58
Hohmann Xfer (to Waypoint)	115
TOTAL TRANSFER:	193

Access Parameters	Approx. Data Per Pass	100	MB
	Approx. Access Time	12.5	minutes
	Estimated Initialize Time	2	minutes
Observation Parameters	η_{max}	58.5	deg
	λ_{max}	16.5	deg
	λ_{min} (est)	15	deg
	F	0.43	
	ρ	1.08	
	M	3	
	Est. Data Rate	12.05	Mbps

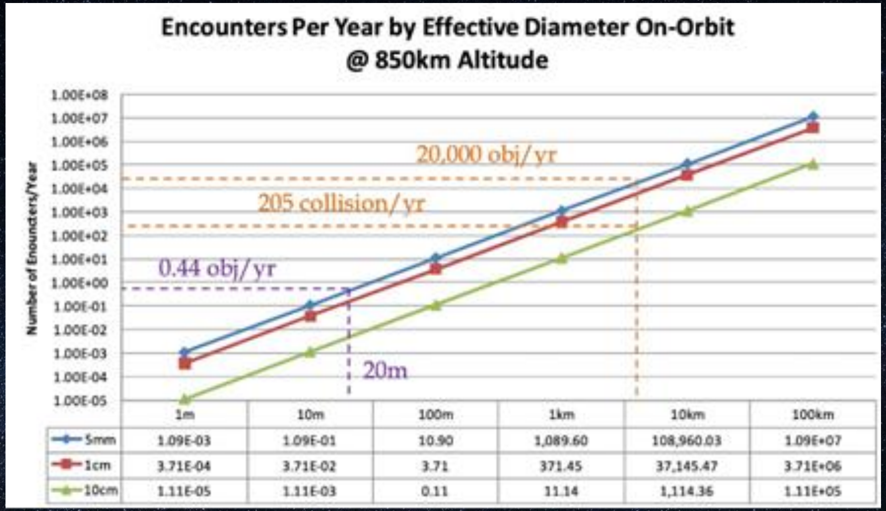






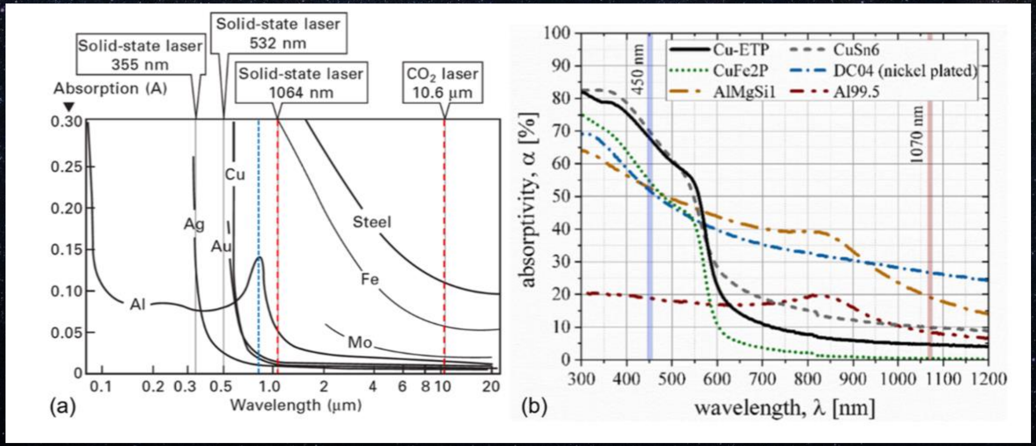
Payload Overview

Laser System

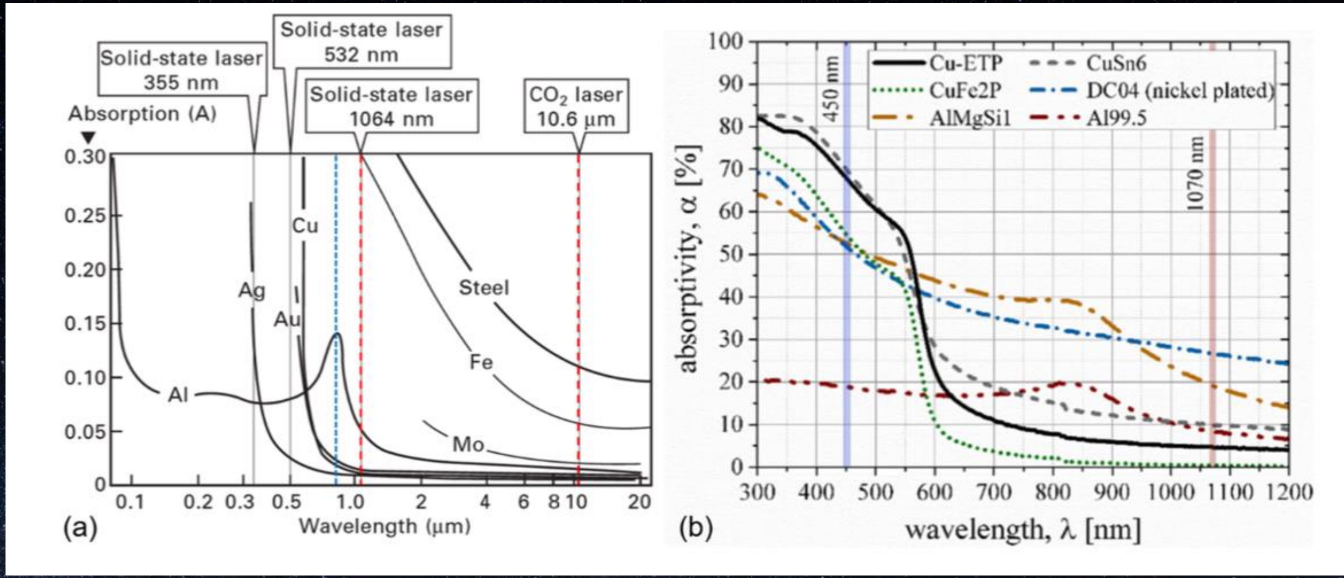


“FLARE NX”, Coherent Corp.

Pulliam W., "Catcher's Mitt Final Report," Defense Advanced Research Projects Agency, retrieved 4 December 2024.



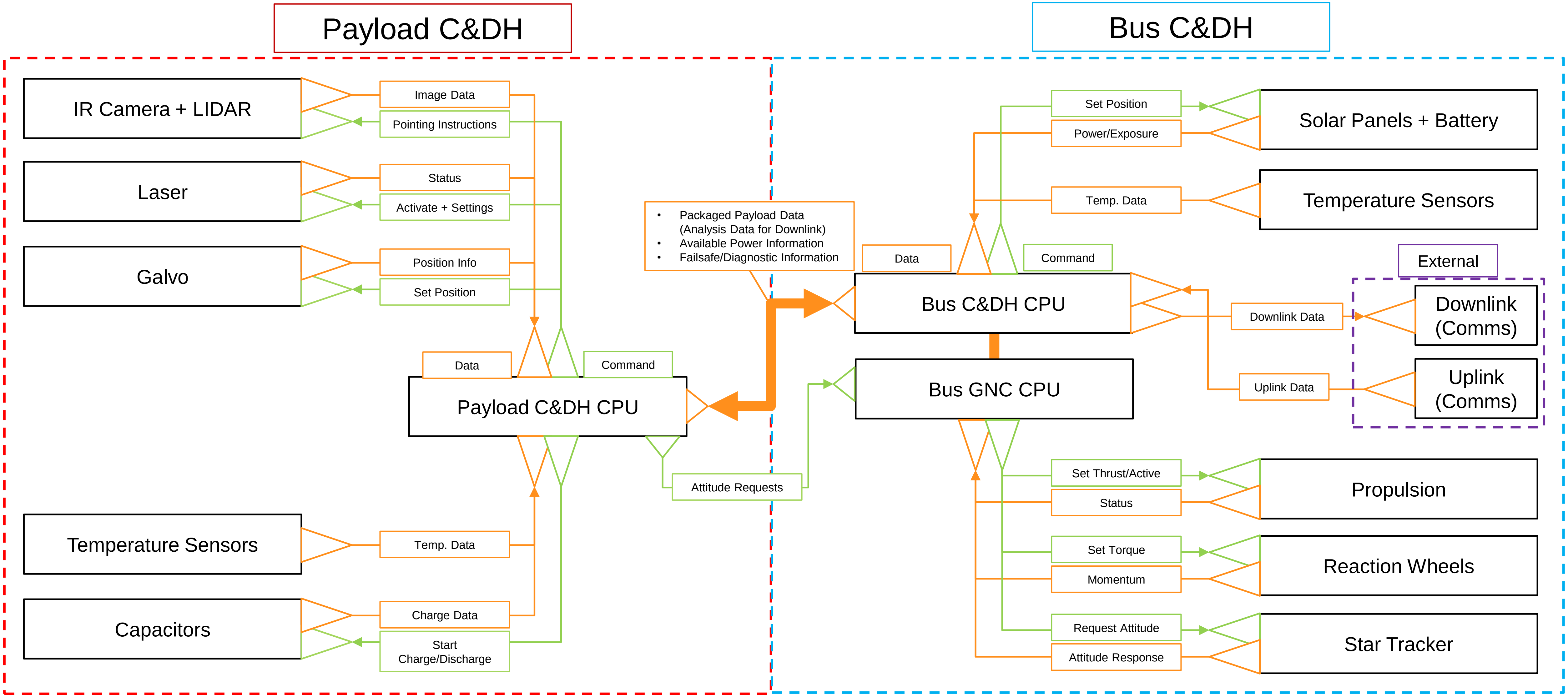
Bunaziv, I., Akselsen, O. M., Ren, X., Nyhus, B., and Eriksson, M., “Laser Beam and Laser-Arc Hybrid Welding of Aluminium Alloys,” Metals, Vol. 11, No. 7, 2021, Article 1150. doi:10.3390/met11081150



"FLARE NX", Coherent Corp.

SPECIFICATIONS	FLARE NX 1030-1.0-2	FLARE NX 515-0.6-2	FLARE NX 343-0.2-2
Wavelength (nm)	1030 ±1	515 ±0.5	343 ±0.5
Pulse Energy[1] (µJ)	>500	>300	>100
Pulse Energy Variation ptp (%)		<±5	
Pulse Repetition Rate (Hz)		up to 2000	
Pulse Width (ns)	1.5 ±0.2	1.3 ±0.2	1.0 ±0.2
Spatial Mode		TEM_{00}	
M^2 (Beam Quality)		<1.2	
Beam Waist Diameter at $1/e^2$ (µm)	490 ±35	360 ±35	300 ±30
Beam Waist Location[2] (mm)	140 ±15	200 ±30	190 ±30
Beam Symmetry (%)	>90	>90	>85
Static Alignment Tolerances Beam Position (mm) Beam Angle (mrad)		<±1 <±1	
Polarization		>100:1, vertical ±5°	
Warm-up Time to Stand By (s)		<150	
Base Plate Operating Temperature		15 to 35°C (59 to 95°F)	
Ambient Temperature Operating Storage		15 to 40°C (59 to 104°F) -20 to +50°C (-4 to 122°F)	
Laser Head Heat Dissipation[3] (W)		≤40	
Relative Humidity (%) (non-condensing)		≤80	
Dimensions (L x W x H) Laser Head Controller		155.6 x 93.5 x 38.25 mm (6.13 x 3.68 x 1.5 in.) 160 x 130 x 45 mm (6.3 x 5.12 x 1.77 in.)	
Weight Laser Head Controller		~1.25 kg (2.75 lbs.) ~0.75 kg (1.65 lbs.)	
Controller Cable Length		1 m (3.28 ft.)	
Operating Voltage[4] (VDC)		24 ±2	
Laser Control Electronics		Digital, OEM[4]	
Communication Interface		RS-232	

1 Pulse energy at 2000 Hz, maximum decrease over warranty period <10%.
2 The beam waist location is inside the laser head. Reference surface is the output window.
3 Baseplate temperature 30°C.
4 Power supply not included, PC required.



Payload C&DH
Bus C&DH
IR Camera + LIDAR
Image Data
Pointing Instructions
Laser
Status
Activate + Settings
Galvo
Position Info
Set Position
Data
Command
Payload C&DH CPU
Temperature Sensors
Temp. Data
Capacitors
Charge Data
Start Charge/Discharge
Attitude Requests
• Packaged Payload Data (Analysis Data for Downlink)
• Available Power Information
• Failsafe/Diagnostic Information
Set Position
Power/Exposure
Solar Panels + Battery
Temp. Data
Temperature Sensors
Data
Command
External
Bus C&DH CPU
Downlink Data
Downlink (Comms)
Uplink Data
Uplink (Comms)
Bus GNC CPU
Set Thrust/Active
Status
Propulsion
Set Torque
Momentum
Reaction Wheels
Request Attitude
Attitude Response
Star Tracker