Lynx Mission Concept Overview

Winter Face-to-Face

Houston, TX

January 25, 2018

National Aeronautics and Space Administration
www.nasa.gov

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Study Team

Role	Name	Organization
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Power	Leo Fabisinski	MSFC / ED04
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Thermal	Steve Sutherlin	MSFC / ED04
Mechanisms	Justin Rowe	MSFC/ED04
GNC	Alex Dominguez	MSFC/EV41
Cost Analysis	Spencer Hill Robbie Holcombe	MSFC / CS50 MSFC / CS50

Overview and Objectives (1)

- Customer
  - Jessica Gaskin; Smithsonian Astrophysical Observatory (SAO); Science and Technology Definition Team (STDT)
- Purpose

  Our goal is to assist in the creation of a design concept for an X-Ray Telescope that will compete for funding during the 2020 Decadal Survey

  - Phase 1 (Feb-Mar 2017)
    - Payload-Independent Studies
    - End: April 2017 F2F
  - Phase 2 (Apr-Sep 2017) Payload-Specific Concept Study for Lynx
    - End: Management review in October 2017
  - **Phase 2B (Nov-Jan 2018)**
    - **Began: MEL/PEL scrub on November 6th, 2017**
    - **Ends: Customer Review at 2018 Winter F2F on January 25th, 2018**

Overview and Objectives (2)

- There are currently four different Lynx Observatory Configurations resulting from the combination of different gratings designs with the upper and lower-bound optics masses:
  - Heavy Optics + Off-Plane Gratings
  - Heavy Optics + Critical Angle Transmission Gratings
  - Light Optics + Off-Plane Gratings
  - Light Optics + Critical Angle Transmission Gratings

- The optics lower mass bound (Light Optics) is 1394 kg (with MGA).
- The optics upper mass bound (Heavy Optics) is 2818 kg (with MGA).

Study Products

- Phase 1
  - Payload-Independent Studies
- Phase 2
  - Spacecraft conceptual design
    - CAD, MEL, PEL
  - Identification of any mission and spacecraft requirements that are driving the design/cost to a much more complex/expensive solution
  - List of any spacecraft technologies needing development for the mission
  - Recommendations for future work / next iteration
  - Cost estimate
- Phase 2B
  - Updated **MEL, Power Schedule, and Cost Estimate** for "Heavy" configuration incorporating outcomes from the following activities:
    - Nov 6^{th} 2018 MEL/PEL Scrub
    - Subsystem-Level comparison with International X-ray Observatory (IXO)
  - First-cut Cost Estimate for "Light" configuration
  - Recommendations for future work/next iteration

Phase 2B and 2018 Schedule

Task	Dates	FY18											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Design Update 1	**Oct 1 – Jan 17**												
MEL / PEL Scrub	Oct 1 – Nov 24												
IXO Comparison & Updates	Nov 27 – Jan 17												
Internal Chart Review	Jan 10												
External Chart Review	Jan 17												
Update Cost Analysis	**Nov 6 – Jan 23**												
Review Cost Ground Rules	Jan 9												
Cost Analysis Internal Review	Jan 17												
Final Cost Analysis Adjustments	Jan 23												
GSFC IDL (HDXI)	**Jan 17-19**												
Lynx Face-to-Face Meeting	**Jan 25-26**												
Design Update 2	**Feb 19 – Jun 8**												
Light Mirror Optics (MSFC)	Feb 19 – Mar 16							Two-week extension if ACO does Optical Assembl					
Optical Assembly (SAO) ?	Mar 5 – Apr 27												
ISIM (MSFC)	May 14 – Jun 8												
Design Update 3	**Jul 16 – Sep 14**												
Optics Update (SAO)	Jul TBD												
Optical Assembly (SAO)	Jul 16 – Aug 10												
Science Team TIM (MSFC)	Aug 6												
Spacecraft Design (MSFC)	Aug 6 – Sep 14												
Cost Analysis	**Jul 16 – Sep 21**												
Documentation	**Aug 20 – Sep 28**												

Note: Past January, schedule is a *Draft*.

GR&A – General

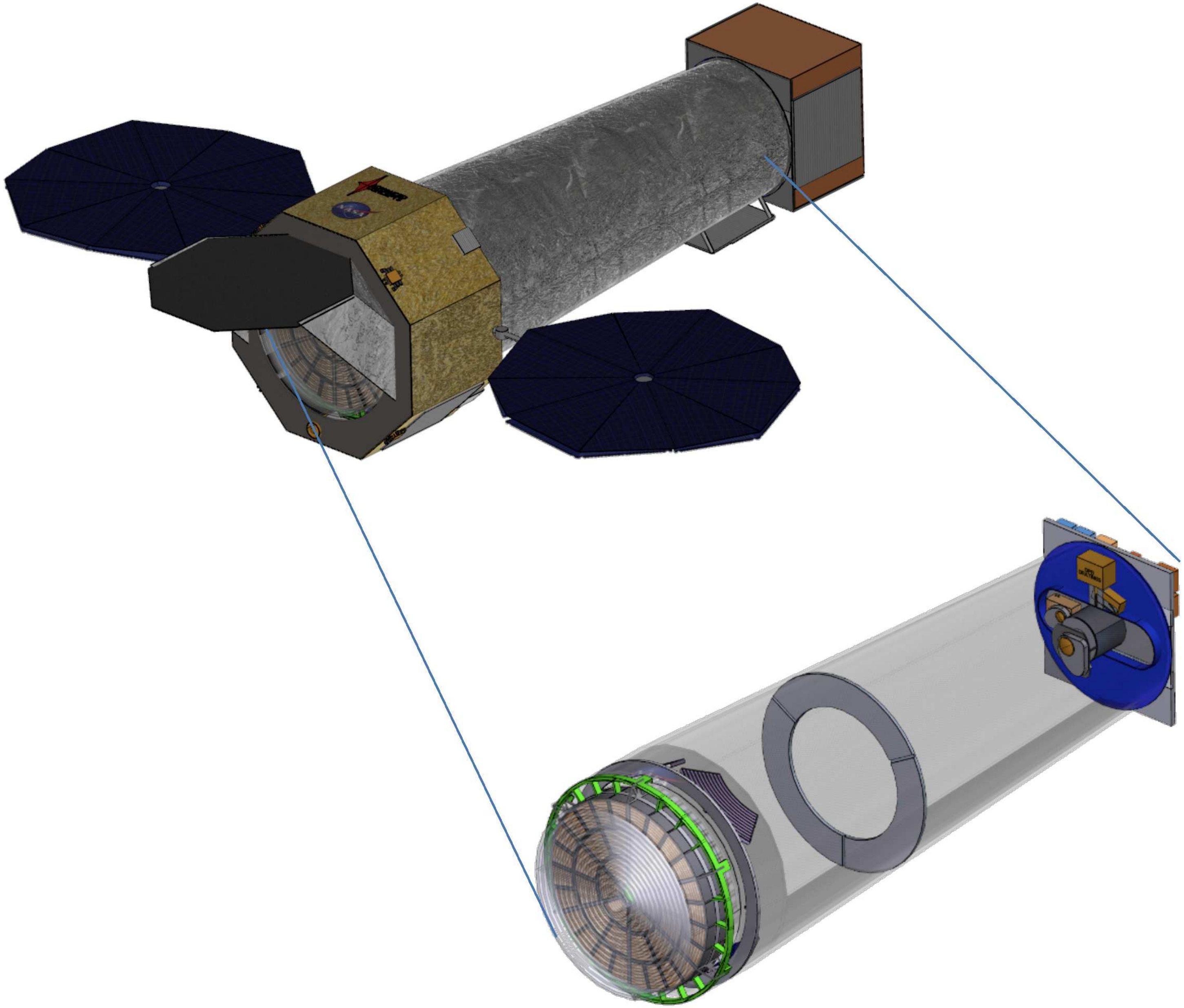
Property	Value
Mission	X-Ray Telescope
Approximate Launch Date	2036
Destination	SE-L2
Mission Duration	Five years, with 20 years of consumables
Maximum Time from Launch to Solar Array Deploy	1.7 hours*
Risk Class	Class B
Servicing interval	Assume no servicing
Fault Tolerance	Single Fault
Configuration	'Similar' to Chandra (Forward spacecraft bus encircling optics system. Aft instrument module)
Instrument Location	Movable gratings aft of mirror. Aft instrument module with stationary gratings readout. HDXI and Microcalorimeter translate to and from focal point.
Payload Envelope	Per LSP guidelines for 2030 time frame
Mass allocation	Per LSP guidelines for 2030 time frame

* **Note: Solar Arrays are assumed to deploy following Earth Departure Burn, which will take place after one revolution in LEO parking orbit (~90 minutes) [See Mission Analysis Charts]**

Configuration Overview

Mike Baysinger

Configuration



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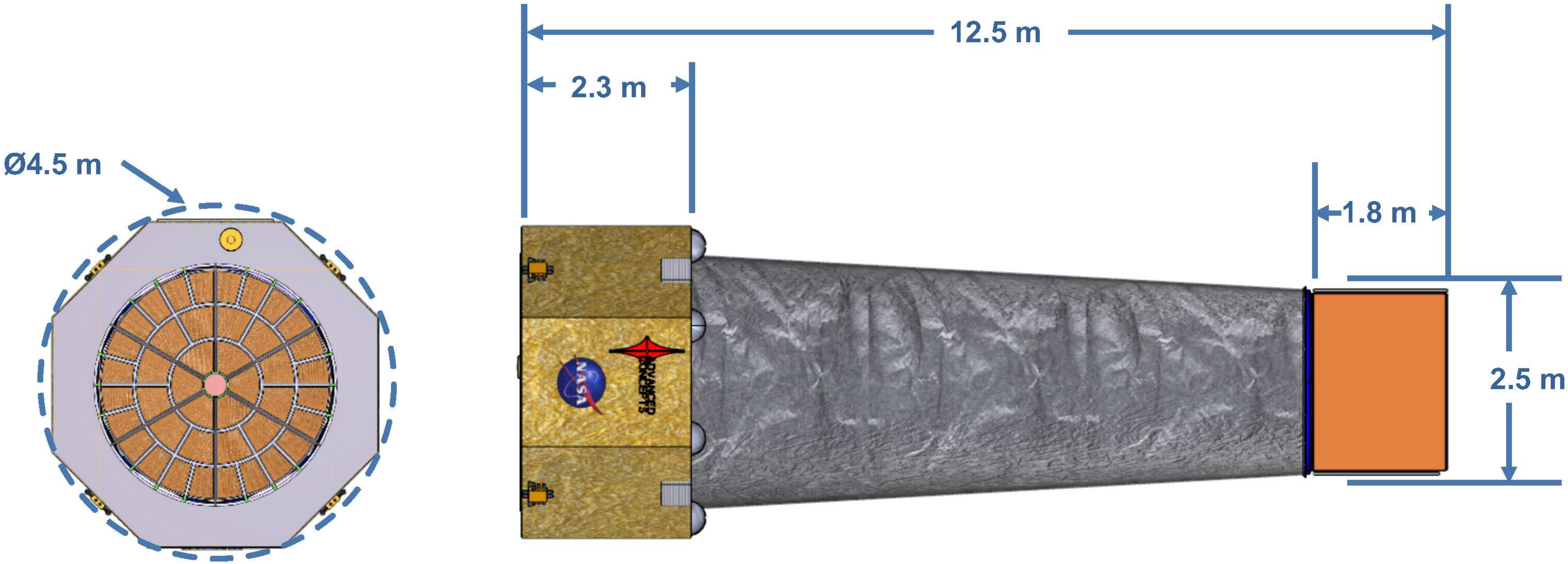

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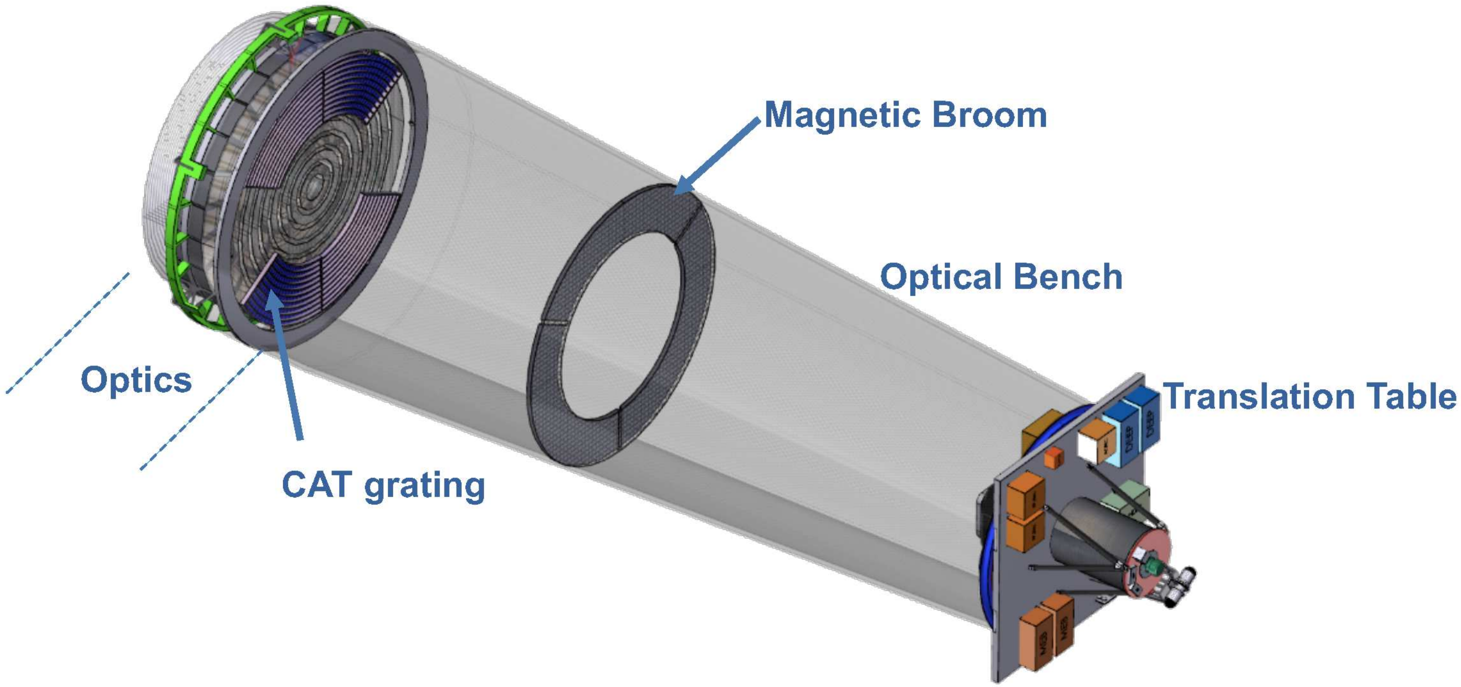

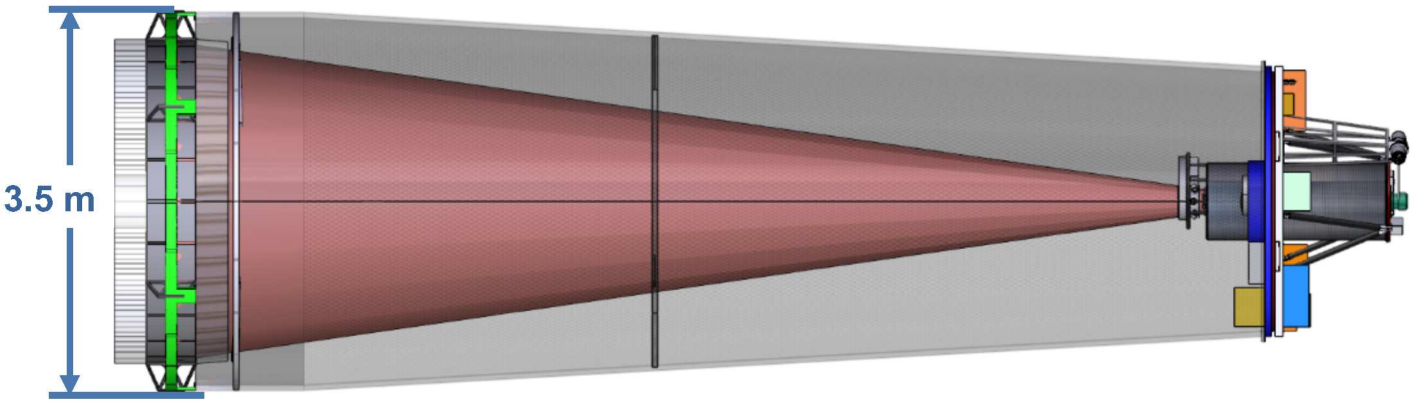

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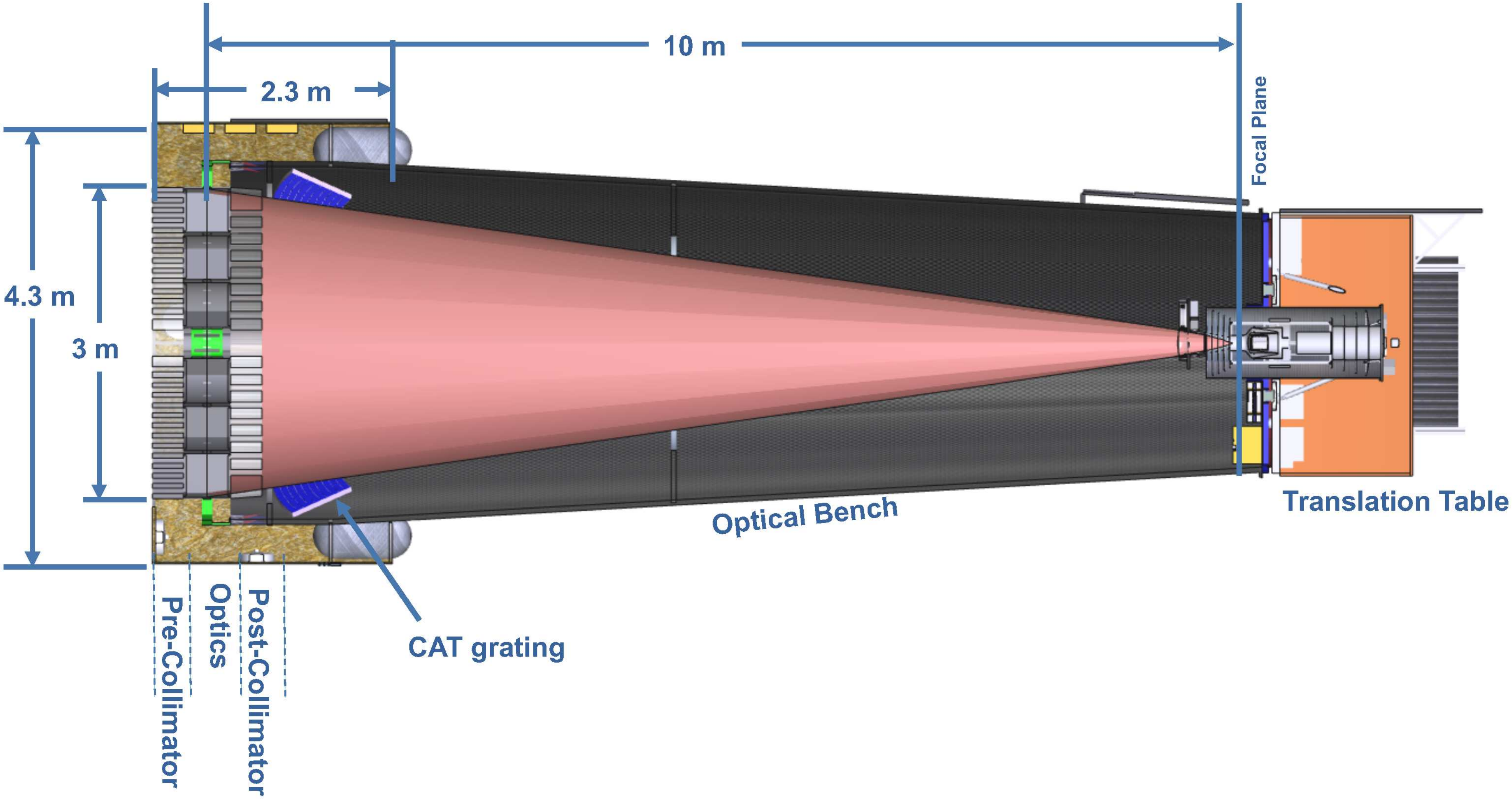

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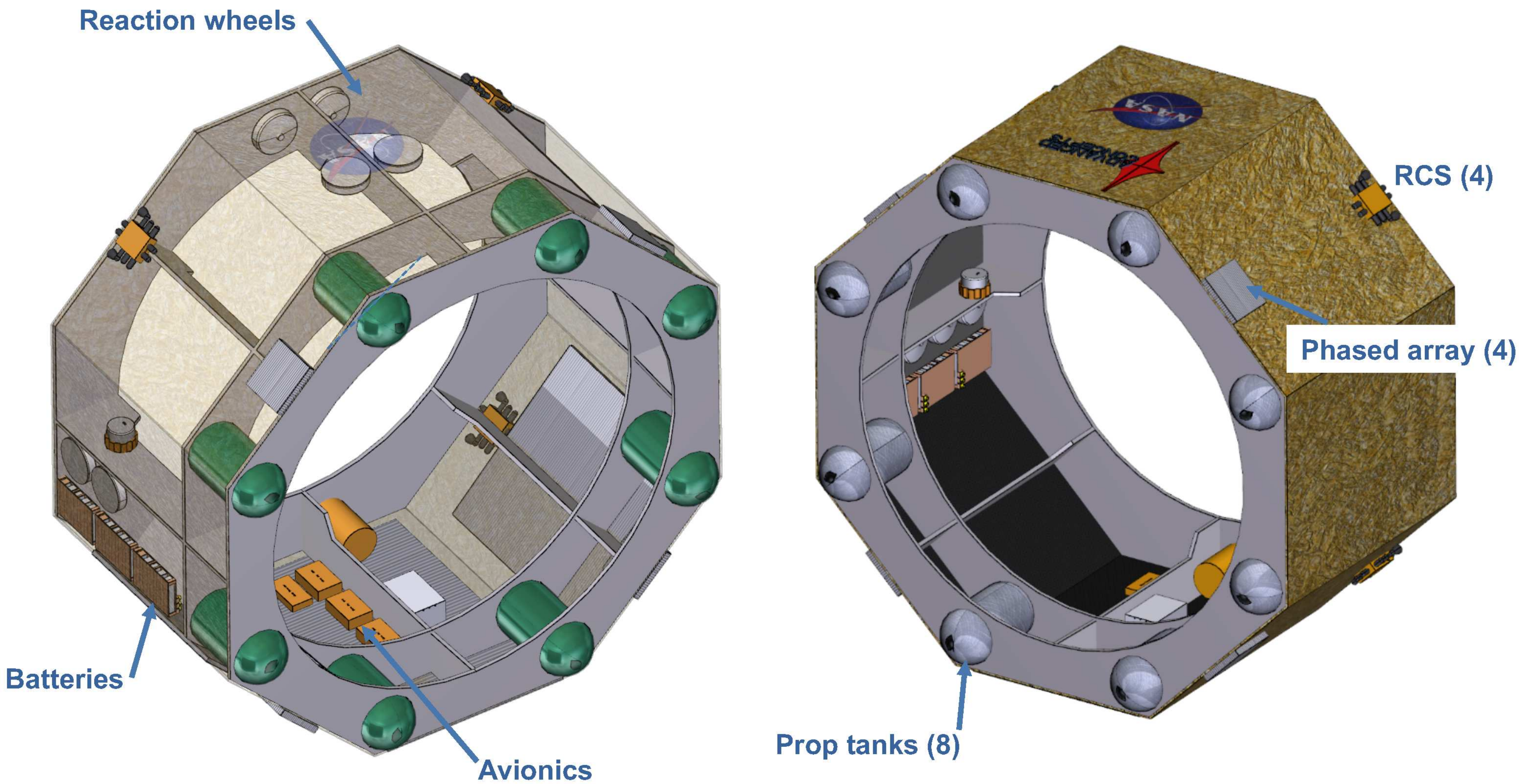

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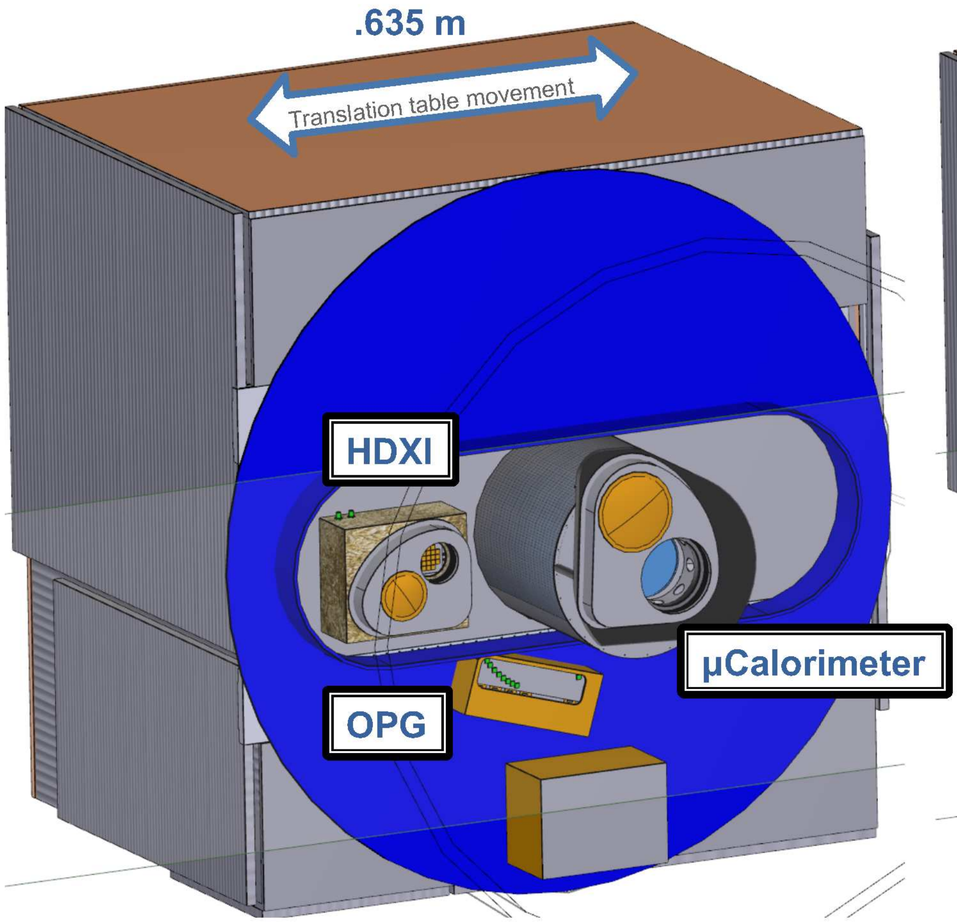
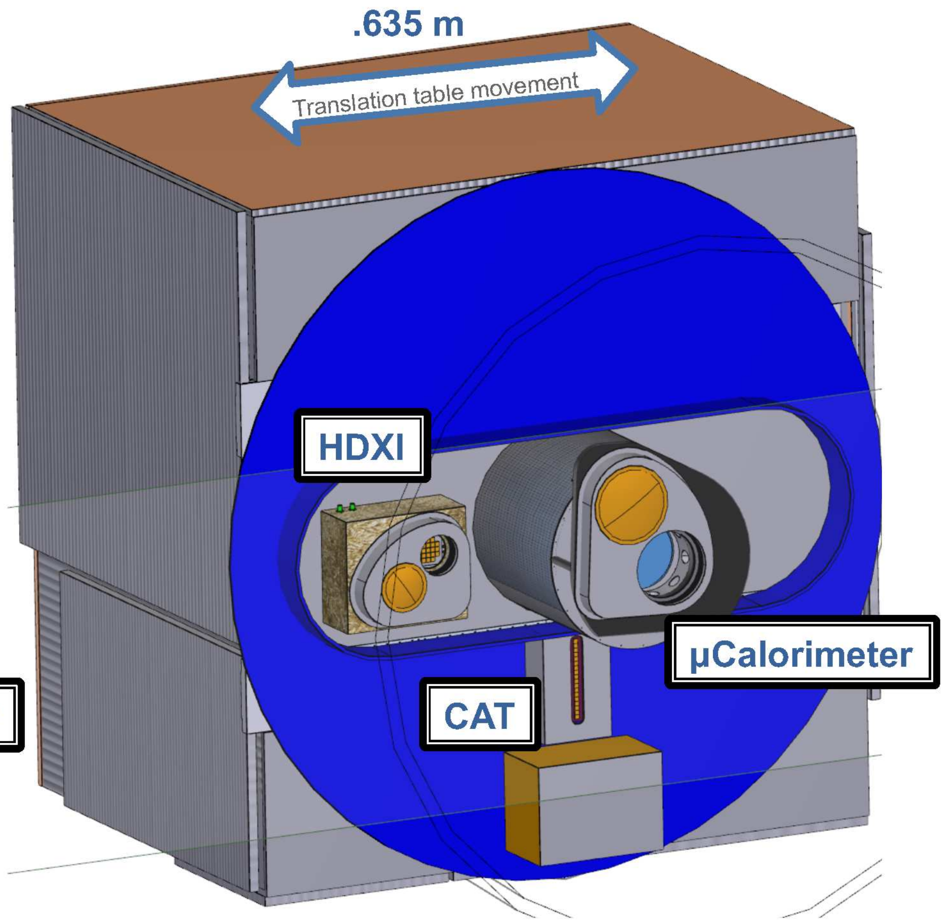
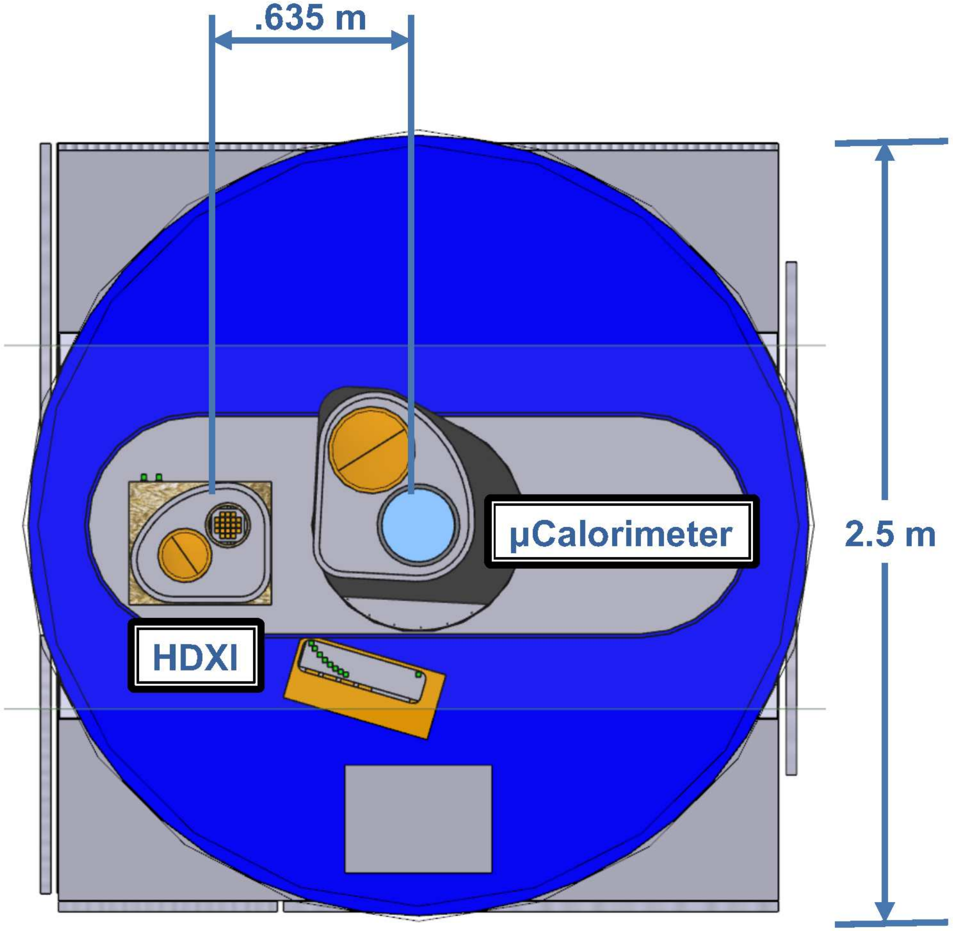


OPG Option

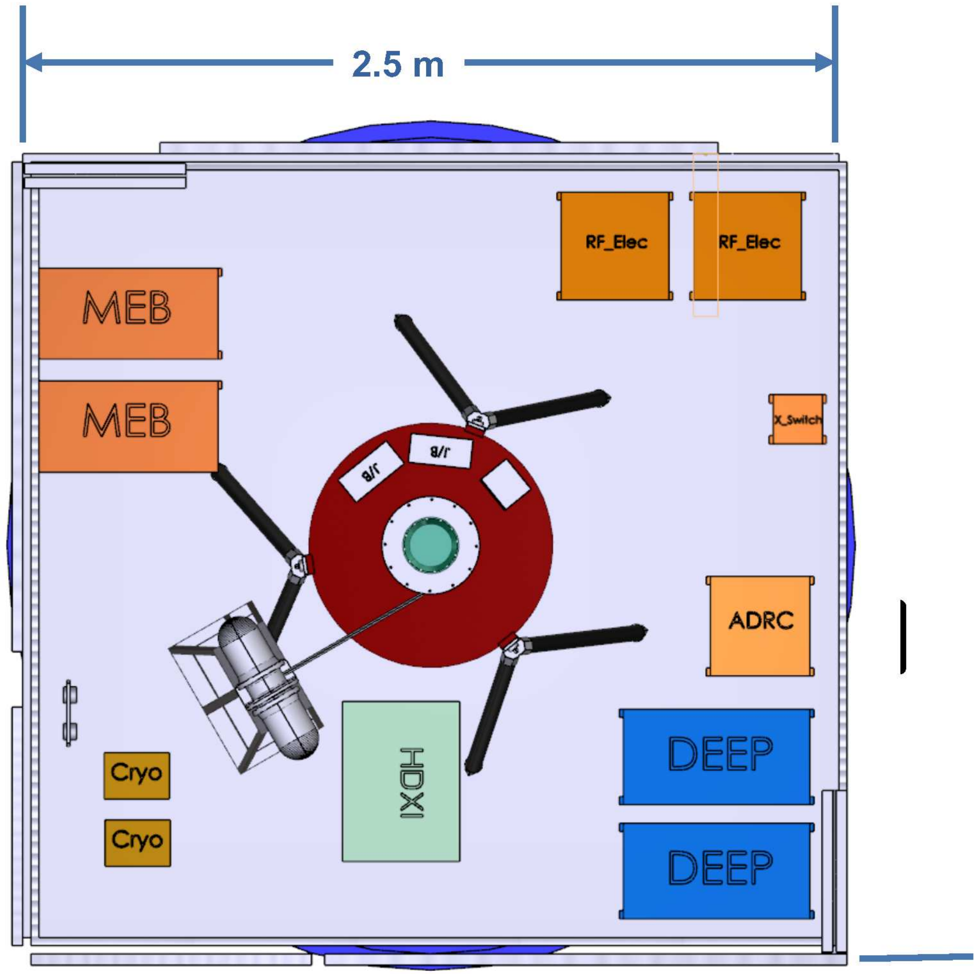


CAT Option

Configuration



Optical bench closeout



Translation Table

Heavy Configuration Mass Analysis

ADVANCED CONCEPTS

Mass Delta from Previous Studies

(Source: LYNX_MEL_2018-01-08c, Heavy w/ XGS-OPG)

	Phase 2 Predicted Mass (kg)	Phase 2B Predicted Mass (kg)	Delta (%)	Percentage of Total (%)
Structures	1177.2	1021.07	-13%	13%
Propulsion	140.5	138.534	-1%	2%
Thermal	368.8	292.03	-21%	4%
Avionics	237.69	237.69	0%	3%
GNC	321.84	232.3	-28%	3%
Electrical Power System	1261.2	437.38	-65%	6%
ISIM	249.3	275.34	10%	4%
Optical Bench Assembly	3539.6	3440.44	-3%	44%
Microcalorimeter	830	779.68	-6%	10%
HDXI	87	87.27	0%	1%
XGS-CAT	221.02	221.02	0%	3%
Non-Propellant Fluids	84.1	53.3	-37%	1%
Propellant	661.4	445.9	-33%	6%
Spacecraft Adapter	96	95.99	0%	1%
TOTAL	9138	7757.944	-15%	100%

Mass Analysis Takeaways

- Spacecraft subsystem mass decreases from the Phase 2 study iteration can be attributed to refinement of requirements and MGAs
  - All – Reviewed all MGAs to align with AIAA Depletion Schedule
  - Structures - Thinned optical bench structure while adding stiffener rings
  - Thermal - Baselined IXO-like approach of heat pipes vs optical bench heaters *
  - Power - Reduced survival power time requirement from 90 to 60 minutes
  - Delta V Budget/Propulsion Wet Mass - Reduced Delta-V budget, momentum unloading propellant requirement, and overall vehicle mass
  - GNC - Reduced number of reaction wheels form 8 to 6 (similar to Chandra)

*** Heat pipe mass is currently an estimate based on IXO and needs to be refined (expected to increase). A trade of heat pipe mass versus required power system mass for optical bench heaters is pending.**

Mass Analysis Takeaways

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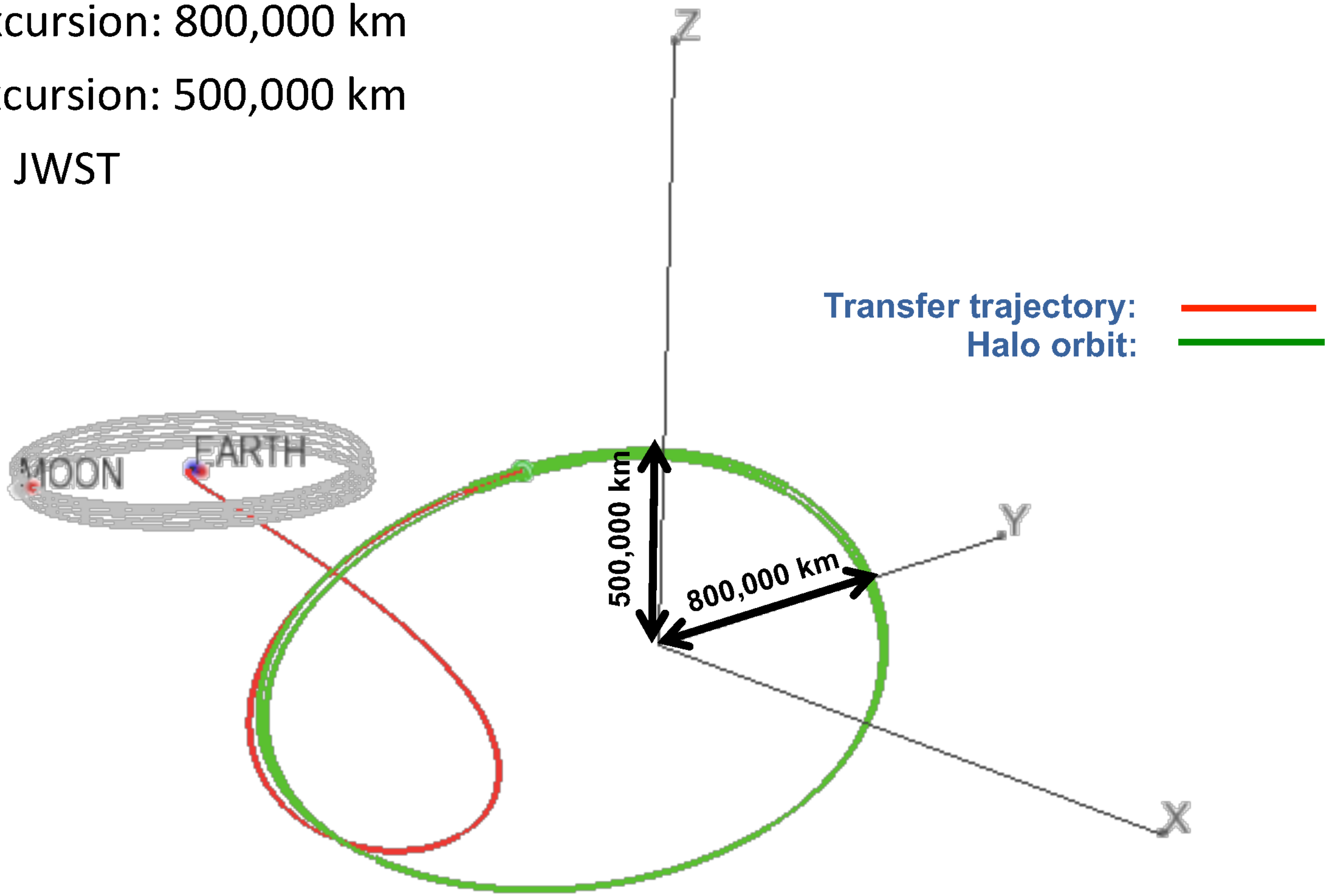
Mission Analysis

Randy Hopkins

SE-L2 Chosen as Baseline Orbit

- Sun-Earth L2 Halo
  - Direct orbit (no lunar gravity assist), 0 insertion (just start station-keeping)
  - Max Y-excursion: 800,000 km
  - Max Z-excursion: 500,000 km
  - Based on JWST



Delta-V Budget: SE-L2

Event/Maneuver	Start Date	MET (Days)	C3 (km2/s2)	Delta-V (m/s)	ACS Tax (%)	Margin (%)	Total (m/s)	NOTES
SE-L2								
Launch C3	12/1/36	0.0	-0.70					
Despin	12/1/36	0.0		5	0%	0%	5.00	ACO estimate
Launch Window	12/1/36	0.0		10	5%	0%	10.50	IXO value
Post-TTI correction (Dispersions)	12/2/36	1.0		20	5%	0%	21.00	IXO value + 5% ACS tax
MCC-1	12/6/36	5.0		7.5	5%	0%	7.88	JWST value + 5% ACS tax; already includes margin
MCC-2	1/5/37	35.0		5	5%	0%	5.25	JWST value + 5% ACS tax; already includes margin
Other (Contingency)	1/30/37	64.0		5	5%	0%	5.25	JWST value + 5% ACS tax; already includes margin
Station-keeping (20 years)	3/15/37	104.0		48.6	5%	10%	56.13	From GNC
Momentum unloading (20 years)	3/15/37	104.0		12.27	0%	0%	12.27	Derived value based on GN&C prop estimate
Disposal	12/1/56	7305.0		1	5%	0%	1.05	IXO value + 5% ACS tax
TOTALS				**114.4**			**124.33**	

Most values are based on JWST and IXO, and are assumed to already include margin.

However, 10% margin is still added to the JWST stationkeeping estimate since the configuration of JWST and Lynx vary considerably.

Mission Elapsed Time (MET) values are approximate.

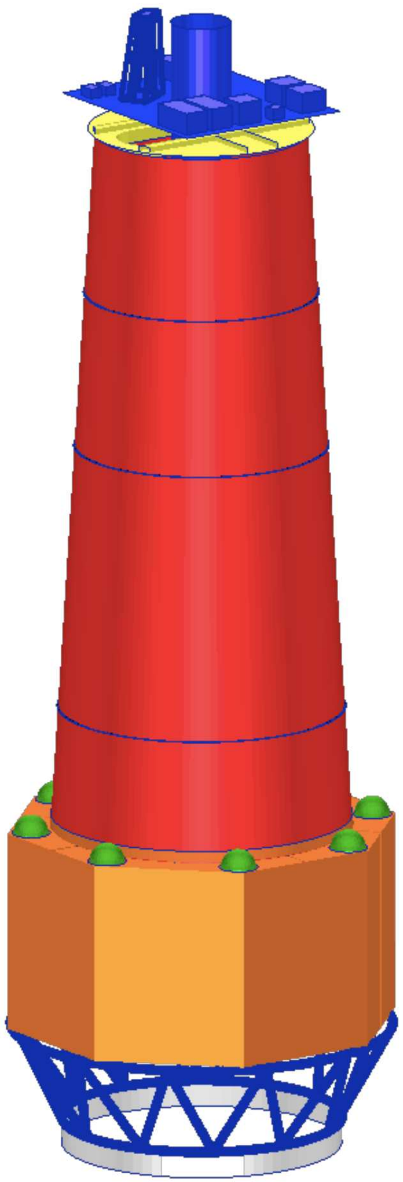
Structures

Jay C. Garcia

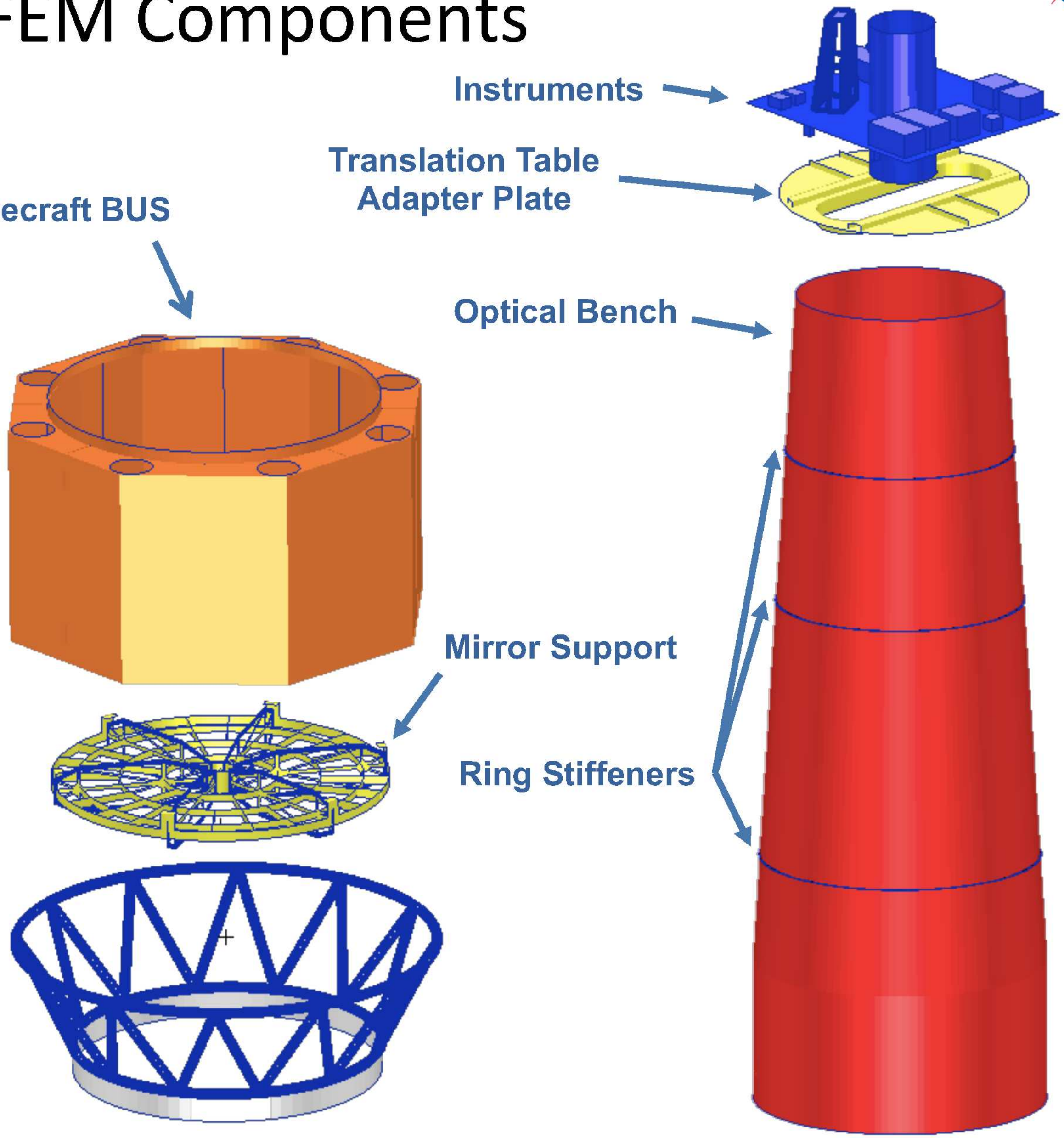
LYNX Structures Model Description

- Spacecraft BUS constructed using Aluminum 2219
- Optical Bench structure assumes M46J High Modulus composite construction
  - Added three ring stiffeners to the optical bench in order to reduce mass and add stiffness
- Translation Table to Optical Bench interface plate assumes Aluminum 2219 construction
- Tanks are assumed to be rigid with mass based on element volume and mass density
- Instrument mounting plate and instruments are assumed to be rigid with correct mass
- Launch Adapter assumes Aluminum 2219 truss tube construction
- Mirror support structure included in model to provide a load path definition between the Optical Bench and BUS structures. Actual mirror support structural arrangement remains as forward work

LYNX Structures FEM Components



LYNX Assembly



Launch Adapter

Conclusions

- All structures meet or exceed strength requirements as defined in NASA STD-5001B
- First Lateral Constrained normal mode exceeds the current Launch Vehicle requirement of 8Hz
- Optical Bench first normal mode exceeds the target frequency of 30Hz (Frequency based on engineering judgement and typical launch vehicle stiffness requirements for payloads)

Thermal Control

Steven Sutherlin

National Aeronautics and Space Administration
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Heater Power Requirements

- Worst case: vehicle pointing directly anti-Sun

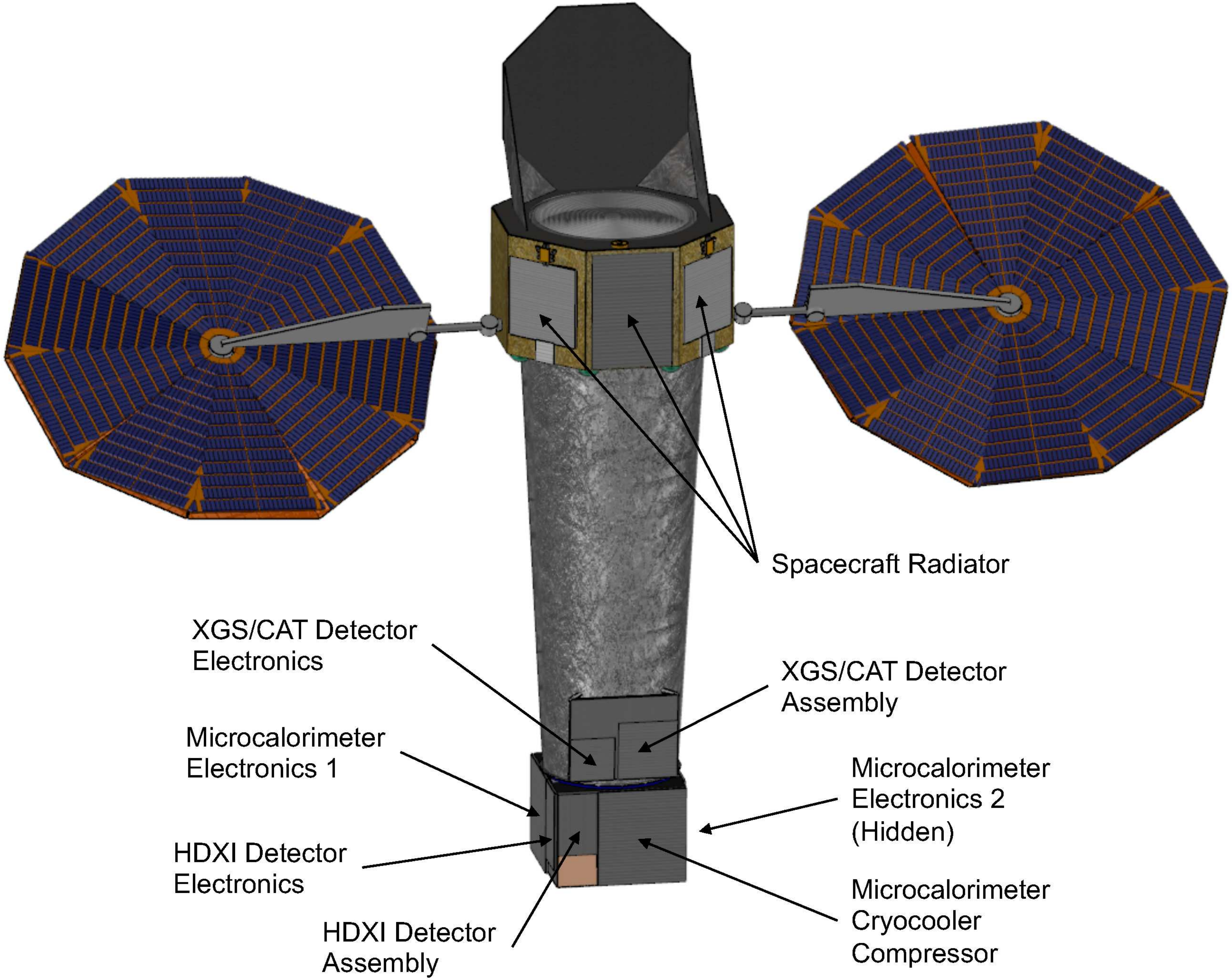
	Worst-case Heater Input Power (kW)	Comment
Optics heaters	1.2	
Optical Bench heaters	0.0	
Spacecraft heaters	0.1	
Translation Table heaters	0.0	<20 W
Propellant Tank heaters	0.0	<10 W
Total	1.3	

- The optics heater power was capped at 1200 W per input from the study office.
- ACO received direction from the study office to assume that the yet undefined optical bench thermal requirements for Lynx will be similar to those for IXO, justifying an IXO-like approach of using heat pipes to distribute solar heating across the optical bench in lieu of optical bench heaters, and thereby reducing power requirements. At this time, no analysis has been done to ascertain the feasibility of this approach for Lynx.
- A trade on Optical Bench insulation/heater/heat pipe mass vs power system mass is forward work.

OBA Temperature Control Trade

- Trade space contains passive and active options
  - Passive (Option 1) – multi-layer insulation (MLI) only
  - Passive (Option 2) – MLI with heat pipes
  - Active (Option 3) – MLI with electric heaters
- Passive options
  - Fine temperature control will not be possible
  - Temperature response will vary with Sun angle
  - May not be possible to satisfy all requirements in all cases
- Active option
  - Fine temperature control should be possible for any Sun angle
  - Power analyst advises that mass penalty for kilowatts of heater power would be on the order of tens of kilograms
- Good requirements are essential
  - Temperature – 10 K colder than optics (~283 K) was discussed last Fall
  - Temperature gradient – TBD
  - Minimum mass – has been emphasized often
- IXO-like passive concept (Option 2) has been selected
  - MLI with heat pipes
  - All passive option caveats apply
  - At this time, OBA heat pipe mass should be scaled by surface area from IXO FMS area containing heat pipes
- Tasks for Option 2 trade
  - Determine configuration of heat pipe network on OBA
  - Generate temperature results for selected MLI configurations at selected Sun angles
  - Evaluate and report temperature response and mass penalty for each case

LYNX Spacecraft and Instrument Radiators



Power

Leo Fabisinski

Ground Rules and Assumptions

Ground Rule / Assumption	Value
Power provision	Power System will store, generate, manage/condition and distribute power to all subsystems and payloads on the vehicle
Maximum Battery Power Time (Survival Power)	60 minutes*
Bus voltage	28V Nominal.
Power during initial checkout / solar array deployment	Power will be provided to all attached architecture elements during initial checkout (1.7 hr) and solar array deployment if required. Full power will remain available during final orbit insertion.
Overload protection will be provided	For all critical functions (should consider resettable fuses)
Fault tolerance	No single fault will allow the vehicle to enter mission critical failure mode
Ground reference	A common ground reference will be provided across all subsystems
Secondary battery charge/discharge efficiency	95%
Secondary battery max depth of discharge	60%

*Reduced from 90 minutes – Key driver for energy storage sizing.

A detailed Payload Power Schedule was developed to refine initial power system sizing results.

LYNX Power Budgets

Power Modes Key	
Launch	
Standby/Safe	
Nominal	

Lynx Flight Mode Power Budgets (W)

Source	Launch			Cruise			Safe Hold			Survival (Battery Power Only)		
	Estimated	Margin (%)	Predicted	Estimated	Margin (%)	Predicted	Estimated	Margin (%)	Predicted	Estimated	Margin (%)	Predicted
Payloads												
Microcalorimeter	10	40%	14	310	40%	434	310	40%	434	10	40%	14
HDXI	0		0	152	40%	213	5	40%	7	5	40%	7
XGS	0		0	136	40%	190	5	40%	7	5	40%	7
Mirror Heater	10		10	1200	13%	1356	1200	13%	1356	525	13%	593
Optical Bench Heaters	0		0	0		0	0		0	0	0%	0
Totals (Payloads)	**20**	**20.00%**	**24**	**1798**	**21.98%**	**2193**	**1520**	**18.68%**	**1804**	**545**	**13.99%**	**621**

Lynx Sciene Mode Power Budgets (W)

Source	Science Mode 1			Science Mode 2			Science Mode 3			Science Mode 4			"All ON" Science Mode		
	Estimated	Margin (%)	Predicted	Estimated	Margin (%)	Predicted	Estimated	Margin (%)	Predicted	Estimated	Margin (%)	Predicted	Estimated	Margin (%)	Predicted
Payloads															
Microcalorimeter	2995	40%	4193	310	40%	434	310	40%	434	2995	40%	4193	2995	40%	4193
HDXI	5	40%	7	152	40%	213	152	40%	213	5	40%	7	152	40%	213
XGS	136	40%	190.4	136	40%	190	5	40%	7	5	40%	7	136	40%	190
Mirror Heater	1200	13%	1356	1200	13%	1356	1200	13%	1356	1200	13%	1356	1200	13%	1356
Optical Bench Heaters	0	40%	0	0	40%	0	0	40%	0	0	40%	0	0	40%	0
Totals (Payloads)	**4336**	**32.53%**	**5746.4**	**1798**	**21.98%**	**2193**	**1667**	**20.56%**	**2010**	**4205**	**32.29%**	**5563**	**4483**	**32.77%**	**5952**

NOTES:

Description of Payload Modes

The Nominal Payload Modes table defines possible modes of science instrument operation for science. In each mode, an instrument is either fully on and draws

Science Modes:

MODE 1: Microcalorimeter and XGS are fully on, HDXI is in Standby. Mirror Heaters are on. WORST-CASE FOR POWER.

MODE 2: Microcalorimeter is in Standby. HDXI, XGS, and Mirror Heaters are on.

MODE 3: Microcalorimeter and XGS are in Standby, HDXI and Mirror Heaters are on.
(It is assumed that the Microcalorimeter and HDXI would never be on at the same time.)

MODE 4: Microcalorimeter is fully on, Mirror Heaters are on, HDXI and XGS are in Standby.

"ALL ON" MODE: All instruments at full power, plus mirror heaters. Rationale: Even when not "doing science," some instruments may require full power for calibration.

Additional Notes:

The format of this spreadsheet mirrors IXO_Sys_Def_Doc_Chapter_07_Subsystems chart 43.

See tabs for input on instrument standby powers.

Microcalormeter checkout operations begin after cruise day 21, but this additional mode is similar to the Science mode.

1See Design Margin Justification tab.

Payload	Nominal	andby/Sa	Launch
Microcal	2995	310	10
HDXI	152	5	0
XGS	136	5	0
Mirror Heater	1200	1200	10
Optical Bench	0	0	0
Total	4483	1520	20

Power Requirements

Source	Launch	Cruise	Science	Safe Hold	Survival
	(W)	(W)	(W)	(W)	(W)
Payloads					
Microcalorimeter	14	434	4193	434	14
HDXI	0	213	213	7	7
XGS	0	190	190	7	7
Mirror Heater	10	1356	1356	1356	593
Optical Bench Heaters	0	0	0	0	0
Totals (Payloads)	**24**	**2193**	**5952**	**1804**	**621**

Source	Launch	Cruise	Science	Safe Hold	Survival
	(W)	(W)	(W)	(W)	(W)
Spacecraft					
Avionics	0	1079.4	1079.4	1079.4	395
GN&C	0	420	420	420	0
Propulsion	0	509.6	509.6	509.6	0
Mechanisms	0	0	210	210	0
Thermal	140	140	140	140	140
Totals	**140**	**2149**	**2359**	**2359**	**535**

5952 + 2359 = 8311W (Max Power)

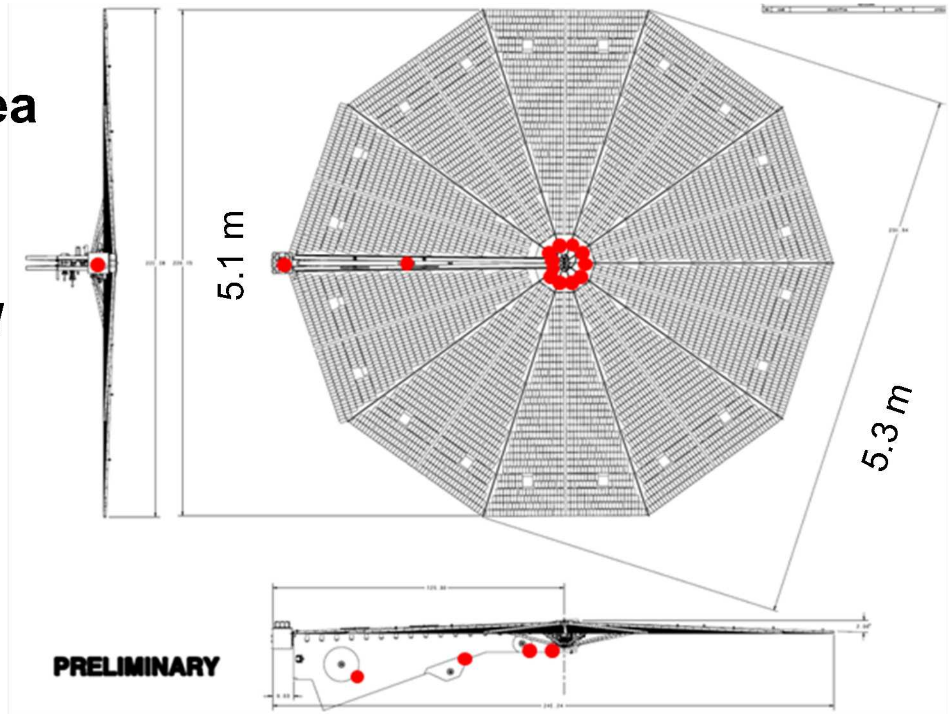
621 + 535 = 1156W (Battery Power for 1 Hour)

Solar Arrays

UltraFlex Arrays Chosen Over Body Mounted Arrays

- **Articulated UltraFlex Wings allow full sun pointing regardless of orientation**
- **8,311 W Peak Power Requirement requires 40+ m^2 pointed directly at the sun**

- **2 UltraFlex Array Wings**
- **Wing Diameter 5.3 m, Area 20.7 m^2 Each**
- **Total Power Generated (Both Wings EOL) 8,690 W**
- **83% Cell Coverage**



Energy Storage

- Requirement to supply Survival Power (1156 W) for 1 hour for initial checkout and service and for Launch Power (679 W) during launch sequence 1.7 hrs
- 28V Battery has 690 Whrs capacity and mass = 6.5kg.
- Requires 6 Batteries to meet requirement at 59% Depth of Discharge
- 1 extra battery carried for 1-fault tolerance

The number of batteries was reduced from 10 to 7, and the size and mass of each battery was reduced as well.

Propulsion

Tyrone Boswell

Overview

- Propulsion System:
  - Monopropellant blowdown system
    - Fuel = Hydrazine
    - Pressurant = Gaseous Nitrogen
- Maneuver assumed: SE-L2
- Engines
  - Main Engines: Northrop Grumman MRE-15
    - Thrust = 86 N at 400 psia; 66 N at 275 psia
    - Isp = 228 s at 275 psia
  - RCS/ACS Engines: Northrop Grumman MRE-1.0
    - Thrust = 5.0 N at 400 psia; 3.4 N at 275 psia
    - Isp = 218 s at 275 psia

Propulsion System Sizing

- The propulsion system was sized using the following assumptions:
  - Heavy CAT config: 6,438.87 kg (*dry mass only*)
  - Heavy OPG config: 6,533.86 kg (*dry mass only*)
  - Trajectory: SE-L2, Delta-V values →
  - Ullage volume = 59% CAT, 57% OPG
  - Residual propellant = 5%
  - Momentum unloading:
    - 20 years, 52.28 kg of propellant assumed (from GN&C)
  - I_{SP1} = 218 s, I_{SP2} = 215.2 s
    - According to NGAS data

Event/Maneuver	Total (m/s)
Launch C3	
Despin	5.00
Launch Window	10.50
Post-TTI correction (Dispersions)	21.00
MCC-1	7.88
MCC-2	5.25
Other (Contingency)	5.25
Station-keeping (20 years)	56.13
Momentum unloading (20 years)	12.27
Disposal	1.05
TOTALS	**124.33**

Sizing Summary

CAT				OPG		
Hydrazine mass	**440.2**	kg		Hydrazine mass	**445.9**	kg
Residual propellant	22.0	kg		Residual propellant	22.3	kg
GN2 mass	31.1	kg		GN2 mass	31.0	kg
Prop + GN2 volume	0.725	m^3		Prop + GN2 volume	0.724	m^3
Volume Per Tank	0.091	m^3		Volume Per Tank	0.091	m^3
Tank count	8.0	ct		Tank count	8.0	ct

Reduced from 661.4 kg

Light Configuration Mass Analysis

Preliminary Results

Mass Delta from Heavy Configuration

(Source: LYNX_MEL_2018-01-08c, Light w/ XGS-OPG)

- Accounts for lower-bound optics mass and preliminary structural analysis.

	Phase 2B Predicted Mass (kg) BASELINE	Phase 2B Predicted Mass (kg) Light Optics - Prelim.	Delta (%)	Percentage of Total (%)
Structures	1021.07	1006.84	-1%	16%
Propulsion	138.534	138.534	0%	2%
Thermal	292.03	292.03	0%	5%
Avionics	237.69	237.69	0%	4%
GNC	232.3	232.3	0%	4%
Electrical Power System	437.38	437.38	0%	7%
ISIM	275.34	275.34	0%	4%
Optical Bench Assembly	3440.44	2025.09	-41%	32%
Microcalorimeter	779.68	779.68	0%	12%
HDXI	87.27	87.27	0%	1%
XGS-CAT	221.02	221.02	0%	3%
Non-Propellant Fluids	53.3	53.3	0%	1%
Propellant	445.9	445.9	0%	7%
Spacecraft Adapter	95.99	95.99	0%	2%
TOTAL	7757.944	6328.364	-18%	100%

Mass Analysis Takeaways

- Preliminary initial structural analysis suggests that the effect of the reduction in optics mass on other observatory subsystem masses may be minimal.

- Additional subsystem analysis for this configuration is Forward Work.

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Forward Work Summary

Light Configuration Forward Work

- The change in the optics mass will propagate to affect the other observatory subsystem masses, however initial structural analysis suggests that the effect will be minimal.

- The following subsystem analysis work is planned for this configuration:
  - Update propellant mass estimate
  - Update mass properties model
  - Evaluate potential changes to GNC actuator sizing based on mass properties
  - Evaluate potential changes to power system based on potential changes to GNC
  - Update configuration if required

General Known Discrepancies and Forward Work

- Lack of Thermal Requirements Definition and Analysis
  - The thermal design presented is based on an assumption that yet undefined Lynx requirements will be similar to those for the International X-ray Observatory (IXO) and allow for a similar approach to optical bench temperature management. No analysis or trade studies have yet been carried out to support the feasibility of applying the IXO-like design to Lynx.
- Lack of Definition of Secondary Structures
  - Lack of internal interface definition results in a structural model that lacks secondary structure detail.
- Propulsion System Architecture
  - It is forward work to reassess the current propulsion system architecture and analyze differences/similarities between it and those used on Chandra and IXO.
- Guidance, Navigation, and Control Hardware
  - It is forward work to reassess the current GNC hardware and determine whether there are advantages to using alternative components.
- PEL and Power Schedule
  - PEL is in LYNX_MEL_2018-01-08c may not be aligned with current power schedule. Detailed investigation of spacecraft power schedule is forward work. Payload power schedule had several items TBR.