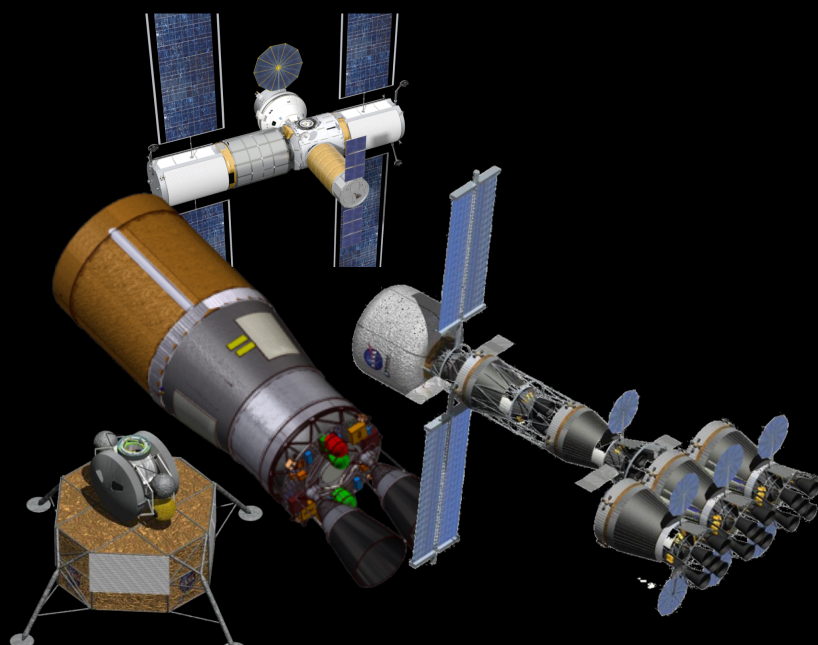
MSFC
Advanced
Concepts

Agenda

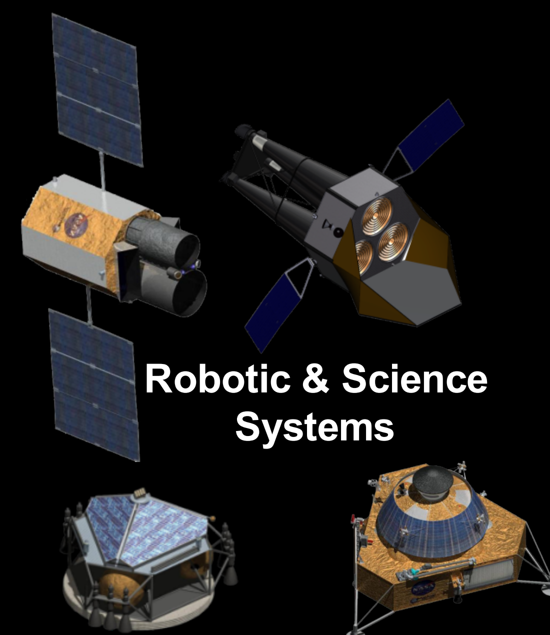
MSFC Advanced Concepts Office Overview	➢ Jack Mulqueen / MSFC Advanced Concepts Office Space Systems Team Lead
X-Ray Surveyor 2015 Conceptual Design Study Review	➢ Andrew Schnell / MSFC X-Ray Surveyor Study Lead

MSFC Advanced Concepts

We Are An Office Within the MSFC Engineering Directorate Specializing In Pre-Phase A & Phase A Concept Definition Studies For Space Exploration Systems



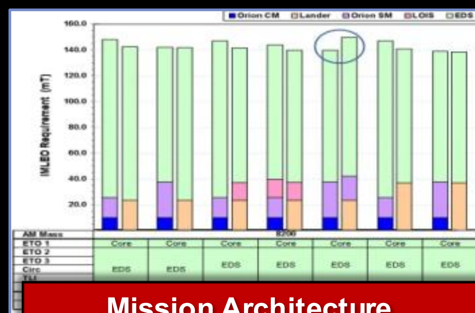
Human Exploration Systems



MSFC **Advanced Concepts**

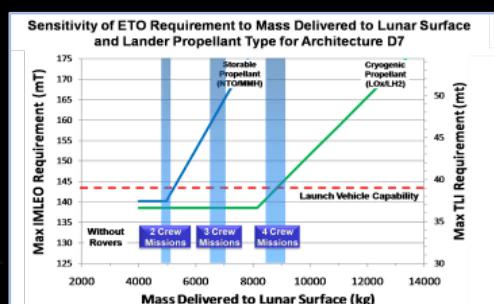
We Utilize Multi-Disciplined Teams Within the Office to Provide Fully Integrated Assessments of Missions and Their Elements

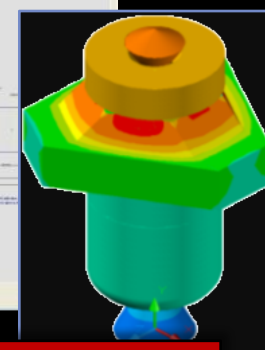
Integrated Systems Analysis Capability

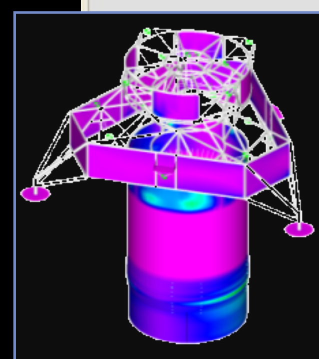


Mission Architecture Assessments

Mission Analysis







Subsystem Design & Analysis

Advanced Concepts Design Center

Collaborative design & analysis environment with discipline experts

MSFC Advanced Concepts Office Design Process

Planning

Initiate Customer Collaboration
Initiate Study Planning

Select Team Members
Develop Schedule
Allocate Resources
Develop Project NGOs
Develop Study GR&A

Customer Review

Mission Design

Develop Mission Requirements
Perform Parametric Analysis

Launch Vehicle Selection
Orbit Selection
DV Budget
Preliminary Sizing
Establish Maneuver Propellants
Develop Mission GR&A

Subsystem Design

Develop Subsystem Requirements
Perform Subsystem Analysis

Develop Subsystem GR&A
Perform Subsystem Design & Analysis
Analyze Trades
Generate Master Equipment List (MEL)
Identify Risks & Opportunities

Documentation

Document Study Findings

Generate Mission Analysis Documentation
Generate Subsystem Analysis Documentation
Perform Management & Customer Reviews
Publish Results Per Customer Request

National Aeronautics and Space Administration

X-Ray Surveyor
2015 Conceptual Design Study

Final Version

July 2015

MSFC Advanced Concepts

www.nasa.gov

Table of Contents

STUDY OVERVIEW

Andrew Schnell (ED04)

Study Participants

Study Lead	**Andrew Schnell (ED04)**
Study Lead *Emeritus*	**Randy Hopkins (ED04)**
Mission Analysis	Dan Thomas (ED04)
	Randy Hopkins (ED04)
Configuration	Mike Baysinger (ED04)
Propulsion	Dan Thomas (ED04)
Power	Leo Fabisinski (ED04)
C&DH	Ben Neighbors (ES12)
Communications	Ben Neighbors (ES12)
GN&C	Robert Kinsey (ASC)
Thermal Analysis	Andrew Schnell (ED04)
Structural Analysis	Jay Garcia (ED04)
Mechanisms	Alex Few (ES21)
Environments	Joe Minow (EV44)
Cost	Spencer Hill (CS50)

Science **Jessica Gaskin (ZP12)**

Martin Weisskopf (ZP12)

Simon Bandler (GSFC)	Priyamvada Natarajan (Yale)
Mark Bautz (MIT)	Steve O'Dell (ZP12)
Dave Burrows (PSU)	Robert Petre (GSFC)
Abe Falcone (PSU)	Andrew Ptak (GSFC)
Fiona Harrison (CalTech)	Brian Ramsey (ZP12)
Ralf Heilmann (MIT)	Paul Reid (SAO)
Sebastian Heinz (UWM)	Dan Schwartz (SAO)
Caroline Kilbourne (GSFC)	Harvey Tananbaum (SAO)
Chryssa Kouveliotou (GWU)	Leisa Townsley (PSU)
Ralph Kraft (SAO)	Alexey Vikhlinin (SAO)
Andrey Kravtsov (U-Chicago)	
Randall (McEntaffer) U-Iowa)	

Reason for the Study

January 2015:
Whitepaper lists several science missions, one of which is an X-Ray Surveyor mission, proposed at the Roadmap

Planning for the 2020 Decadal Survey
An Astrophysics Division White Paper

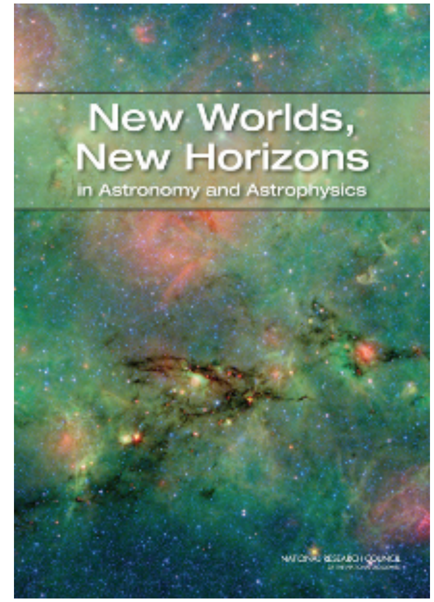
POC: Paul Hertz, Astrophysics Division Director (paul.hertz@nasa.gov)
January 4, 2015

Background

The next Decadal Survey in Astronomy and Astrophysics will be conducted by the National Research Council (NRC) in response to a charge set by NASA and NSF, and possibly DOE. Nominally this survey will be carried out in the years 2018-2020.

One of the important tasks of the 2020 Decadal Survey will be to prioritize large missions to follow JWST (the highest priority large space mission of the 2000 Decadal Survey) and WFIRST (the highest priority large space mission of the 2010 Decadal Survey). To enable this prioritization, NASA will provide information on several candidate large mission concepts for consideration by the 2020 Decadal Survey Committee.

- Habitable-Exoplanet Imaging Mission – 2010 Decadal Survey
- UV/Optical/IR Surveyor – 2010 Decadal Survey and Visionary Roadmap; science case assumes successful JWST and WFIRST missions
- X-ray Surveyor – Visionary Roadmap; science case assumes successful ESA Athena (2010 Decadal Survey) mission

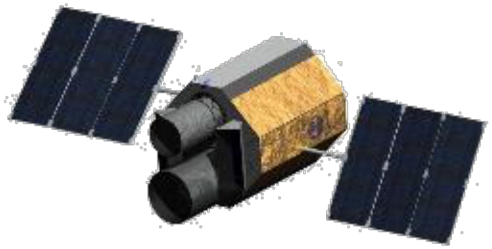


ASTRO2020 Decadal Survey

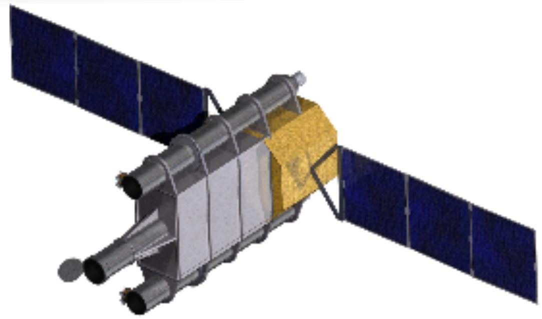
Spring 2015:
Mission Concept Study

Fall 2015:
Paul Hertz assigns each of the missions to a NASA Center for a more detailed study in order to provide input into the 2020 Decadal Survey.

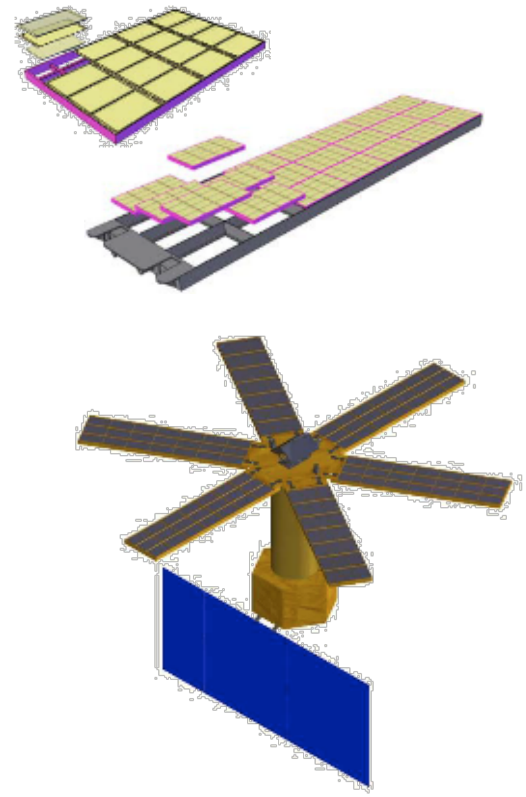
ED04 Experience With X-Ray Observatory Conceptual Design



Xenia (2009)

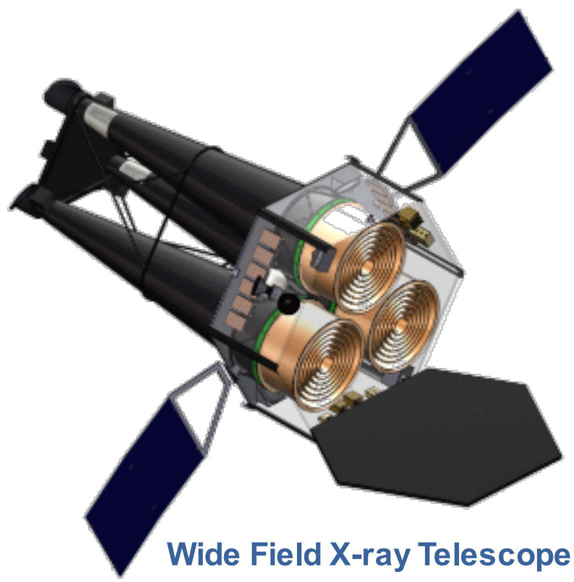


Solar Advanced X-ray Spectral Imaging
(SAXSI, 2012)



Large Observatory For x-ray Timing
(LOFT, 2012)
(Collimator thermal and structural analysis)

Advanced X-ray Timing Array
(AXTAR, 2010)



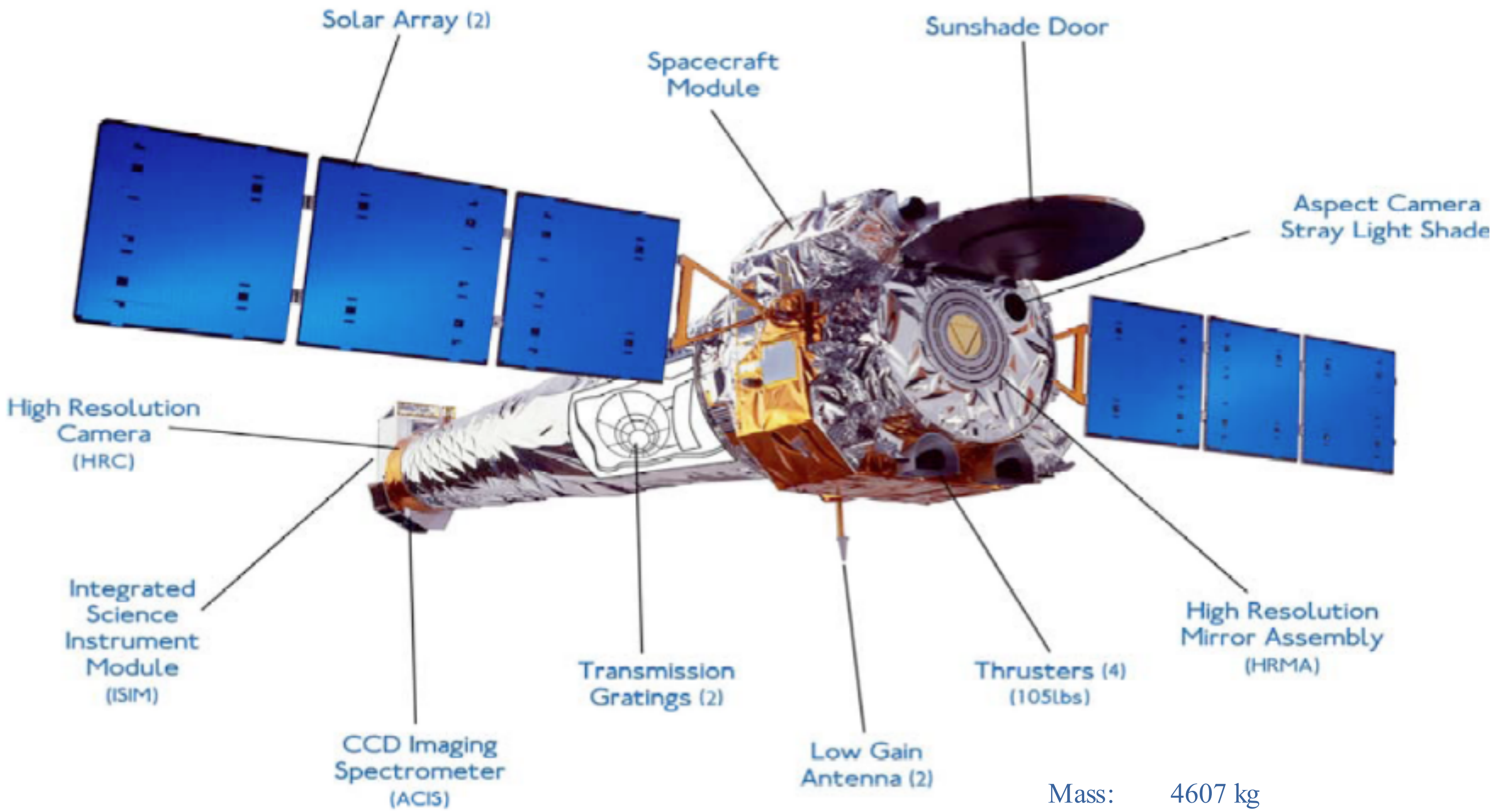
Wide Field X-ray Telescope
(WFXT, 2012)

Study Products

- X-Ray Surveyor spacecraft conceptual design
- 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

DESIGN APPROACH

Design Would Follow Chandra: Similar X-Ray Observatory



Mass:	4607 kg
	121 kg unused reserve
Power:	2900 W actual at launch
	1350 used
	2100 W EOL spec (5 yr)
	2000 actual (14 yr)
	1100 used

Design Approach

- Custom bus design
- Optimize all subsystems based on analysis from the discipline experts using appropriate tools
  - Makes the cost estimate more straightforward – if we modified an existing bus, determining the cost of modifications could be difficult

Margin Philosophy	
Spacecraft subsystems mass	30%
Payload mass	30%
Spacecraft power	30%
Payload power	30%
Cost	See Cost section

General Mission Requirements

Requirement	Requirement (Goal)	
Launch Year	2030	
Spacecraft Lifetime	5 years	
Consumables	20 years	
Orbit	SE-L2 or Chandra-type	
Risk Class	B (assumed for baseline design). (as defined by NASA NPR-8705.4, *Risk Classification for NASA Payloads*.)	
Pointing	Radial	Roll (boresight)
Accuracy	30 arcsec	study output (see GN&C)
Knowledge (Derived requirement)	4 arcsec (p/y) RMS 99%	study output (see GN&C)
Stability	1/6 arcsec per 1 sec	study output (see GN&C)
Dithering	Lissajous figure, up tp +/- 30" amplitude with 8 bits resolution; periods 100 to 1000 seconds subject to derived rate constraint; arbitrary phase (8 bits: amplitude, rate and phase are to be independently commanded in yaw and pitch.*	

* Rationale is to allow calibration to be averaged over a set of pixels, instead of calibrating every single pixel individually, AND to allow filling in what might be small gaps between elements in a focal plane array.

General Mission Requirements

Requirement	Requirement (Goal)
Slew rates for normal observing (and #/day)	90 deg/30 minutes**
Slew rates for TOO* (and #/day)	1 TOO per week. Slew rates same as above.
Continuous observation time	100000 s**
Downlink frequency	1 – 3 downlinks per day
Data downlink volume per day	240 Gbits (flexible, want to save cost; are there breakpoints?)
Data storage requirement	Sufficient for 48 hours of data
Data processing/compression	Assume that instruments provide data processing/compression. Spacecraft only provides storage for data to be downlinked.
Avoidance angles	
Sun	45 degrees; but the rest of the sky must be accessible (this may affect the solar array articulation mechanisms)
Other	na (We aren't doing a sky coverage analysis, so only the sun avoidance angle will affect the design to first order)
Door operation	Once open, does not need to close again.

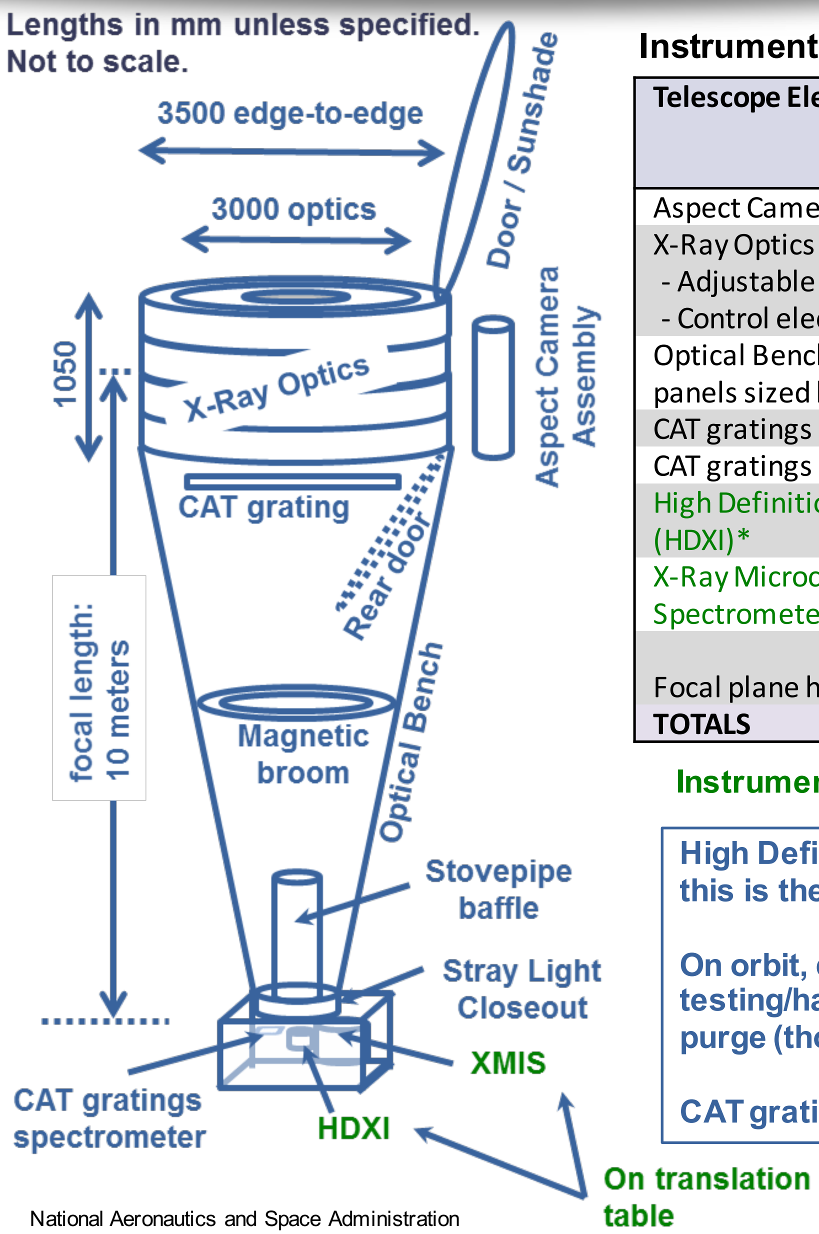
* Target of Opportunity: an unscheduled observation of interest, such as a sudden X-ray emission from an interstellar or intergalactic source.

** Not a primary driver for design; can pause observation for momentum unloading if necessary.

General Configuration and Instrument Data

- Design team knew that the configuration would be closely related to Chandra
  - X-Ray Surveyor has larger optics, heavier science instruments
  - Length, width, and general configuration would be about the same as Chandra
- Telescope elements, in order of front to back:
  - X-ray optics with front door (sunshade) and rear door
  - CAT grating
  - Optical bench (which includes magnetic broom and stovepipe baffle)
  - Science instrument module
- Science instrument module
  - CAT gratings spectrometer
  - High Definition X-ray Imager (HDXI, on translation table)
  - X-Ray Microcalorimeter Imaging Spectrometer (XMIS, on translation table)

General Layout of Telescope Elements (No Spacecraft)



Instrument and telescope element summary table, NO MARGINS.

Telescope Element	Mass (kg)	Power (W) by Mission Phase		<== Science ==>	
		Launch	Transfer	X-Cal op	X-Cal stdby
Aspect Camera	42.8	0	0	14	14
X-Ray Optics Assembly	1200	0	0	1250	1250
- Adjustable optics	included	0	0	10	10
- Control electronics	included	0	0	30	30
Optical Bench Assembly (w/ cone panels sized by ACO)	763	0	0	200	200
CAT gratings (w/o mech)	34	0	0	0	0
CAT gratings spectrometer	61.4	0	0	67	67
High Definition X-Ray Imager (HDXI)*	36	0	0	64.4	64.4
X-Ray Microcalorimeter Imaging Spectrometer (XMIS)*	397.2	0	542	1476	742
Focal plane heaters	study output	0	0	0	250
TOTALS	**2534**	**0**	**542**	**3111**	**2627**

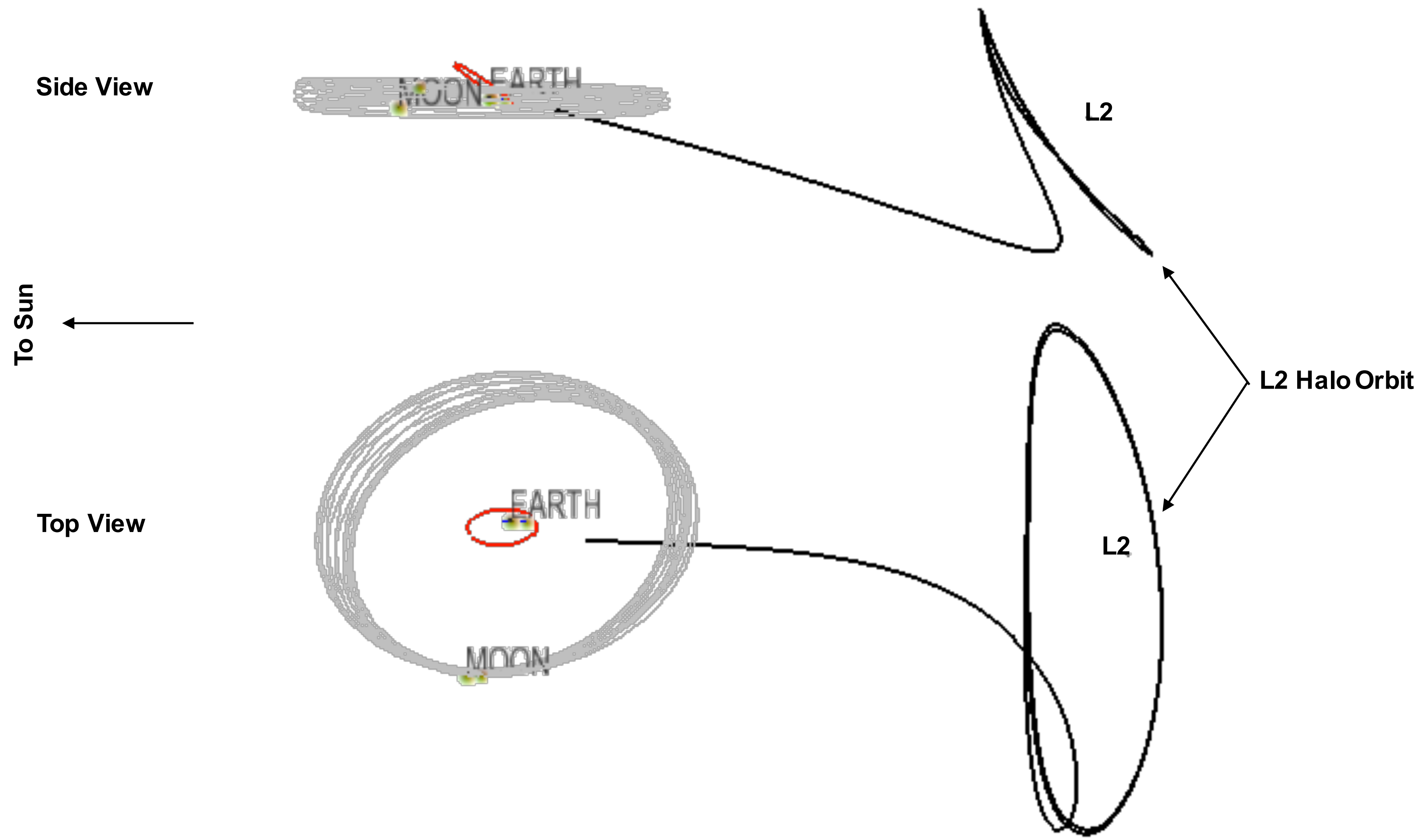
Instruments on translation table = 434.6 kg

High Definition X-Ray Imager (HDXI) is at focus during launch; if there is a failure this is the instrument that needs to be in the focal plane.

On orbit, doors open once and remain open. Doors must open/close during testing/handling. When closed, doors must hold a positive pressure for the nitrogen purge (though they *can* leak).

CAT gratings must move in and out of the optical path.

Baseline Orbit Options



Halo orbit about Sun-Earth L2 provides stable thermal environment. Selected for this Session.

MISSION ANALYSIS

Dan Thomas (ED04)
Randy Hopkins (ED04)

Methodology

- Mission orbit: Sun-Earth L2
- Launch on Atlas V 551
- Use JWST post-launch ΔVs
  - Add 5% “tax” for attitude and control during the maneuvers
  - Add another 10% for margin
- For second iteration, assume that the initial post-launch mass is 6185 kg
- All propulsion events performed using a monoprop/hydrazine system

ΔVs and propellants

Maneuver	mass (kg)	Mnvr ΔV (m/s)	ACS Tax %	Margin %	Total ΔV (m/s)	isp (s)	mp (kg)
Post-launch & MCCs	6185.0	66.5	5%	10%	76.8	228	208.9
Station Keeping (20 yrs)	5976.1	48.6	5%	10%	56.1	218	154.8
Momentum Unloading (20 yrs)	5976.1	29	0	10%	31.9	218	88.5
Disposal Burn	5732.8	1	0	10%	1.1	218	2.9

- Resulting maneuver propellant: 455.1 kg

Launch Vehicle Selection and Performance Estimates

Performance for Chandra-type orbit is from NASA Launch Services (NLS).
Performance for L2 transfer orbit is from NLS website.

Source -->	NLS quote		NLS website
Orbit type -->	**Elliptical Chandra-type**		**SE-L2 transfer**
Altitude or C3 -->	**16000 x 133000 km**		**C3 = -0.7 km2/s2**
Burn profile -->	2-burn	**3-burn**	**185 km parking orbit**
Atlas V 521	3355	**3305**	**4250**
Atlas V 531	3995	**3950**	**5005**
Atlas V 551	TBD	**4585**	**6185**
Falcon 9 (v1.1)	not requested	**not requested**	**3715**

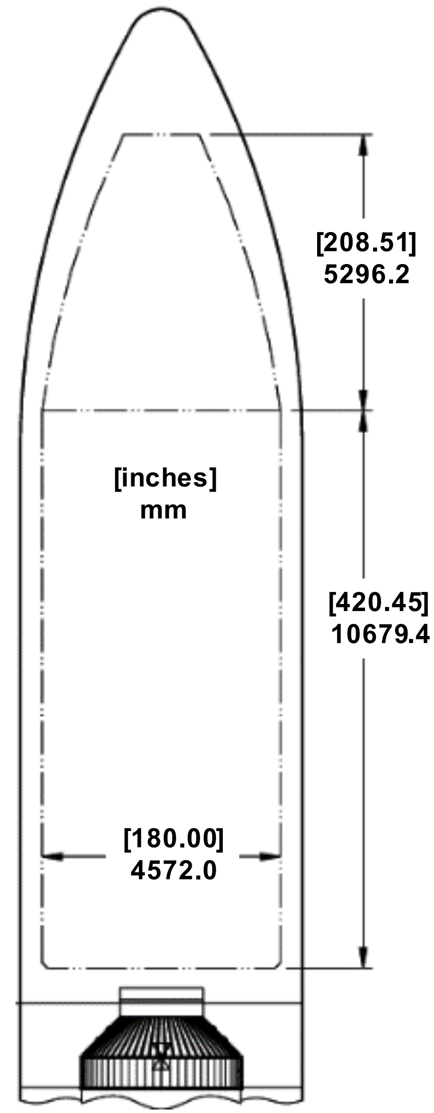
max

Ascent timeline for Chandra-type orbit was provided by NLS, and is included in the backup section but not included here since the performance to that orbit is inadequate for this mission.

Ascent timeline for SE-L2 estimated from data available in *Atlas V Launch Services Users Guide*. Eclipse time from JWST publications and ATLAST. Estimates are worst case, and assume eclipse occurs immediately after Earth departure burn.

	SE-L2 transfer	
Ascent/departure phase	**Duration**	**Source**
Launch to parking orbit insertion	30	Users Guide
Coast in parking orbit	90	Orbital period
Departure burn	6	Calculations
Coast to spacecraft separation	3	Users Guide
TOTAL TIME TO SEPARATION	**129 minutes**	
Eclipse period*	180	JWST/ATLAST
TOTAL ELAPSED TIME to SUNLIGHT	**309 minutes**	

*** NOTE: restricting launch window to two periods per year can eliminate this eclipse.**



5m long shroud

Estimated Acceleration During Earth Departure Maneuver

- Can solar arrays be deployed while in parking orbit?
  - Limited to approximately 2g's thrust acceleration
- Estimated maximum acceleration during the Earth departure burn, Atlas V 551 configuration
  - Use Centaur single engine configuration
    - Inert mass of 2138 kg, Max thrust of 99,200 N
    - Calculated using observatory masses of 3000, 4500, and 6000 kg
  - Results tabulated below
    - Does not include adapter, which would lower the maximum acceleration slightly

Observatory Mass (kg)	Max Acceleration (g's)	Centaur Thrust (N)	Centaur Inert Mass (kg)
3000	1.97	99200	2138
4500	1.52	99200	2138
6000	1.24	99200	2138

If observatory mass greater than 3000 kg, accelerations during departure are less than 2g's.

RADIATION ENVIRONMENTS

Joe Minow (EV44)

Ground Rules and Assumptions

Category	Value
Mission duration	5 years primary science, extendable to 20 years
Candidate orbits	
Operation orbit 1: "Chandra like" elliptical orbit	6,000 km x 133,000 km (altitude) x 28.7 deg inclination AOP 275 deg
Environments	Trapped electron, proton in Earth's magnetosphere
	Single extreme solar particle event ("flare") per decade magnetic shielding reduces flux within magnetosphere
	Solar minimum GCR magnetic shielding reduces flux within magnetosphere
Operation orbit 2: Sun-Earth L2	Interplanetary, 1 AU
Environments	Single extreme solar particle event ("flare") per decade 1 AU without magnetic shielding
	Solar minimum GCR 1 AU without magnetic shielding

Effects environments:

- **Cumulative total ionizing dose over period of time as a function of depth in shielding**
- **Extreme flux environment for single event effect rates**

Approach and Tools

- Utilize standard integrated space environment and radiation modeling tools accepted by NASA and aerospace industry for initial look at radiation environments

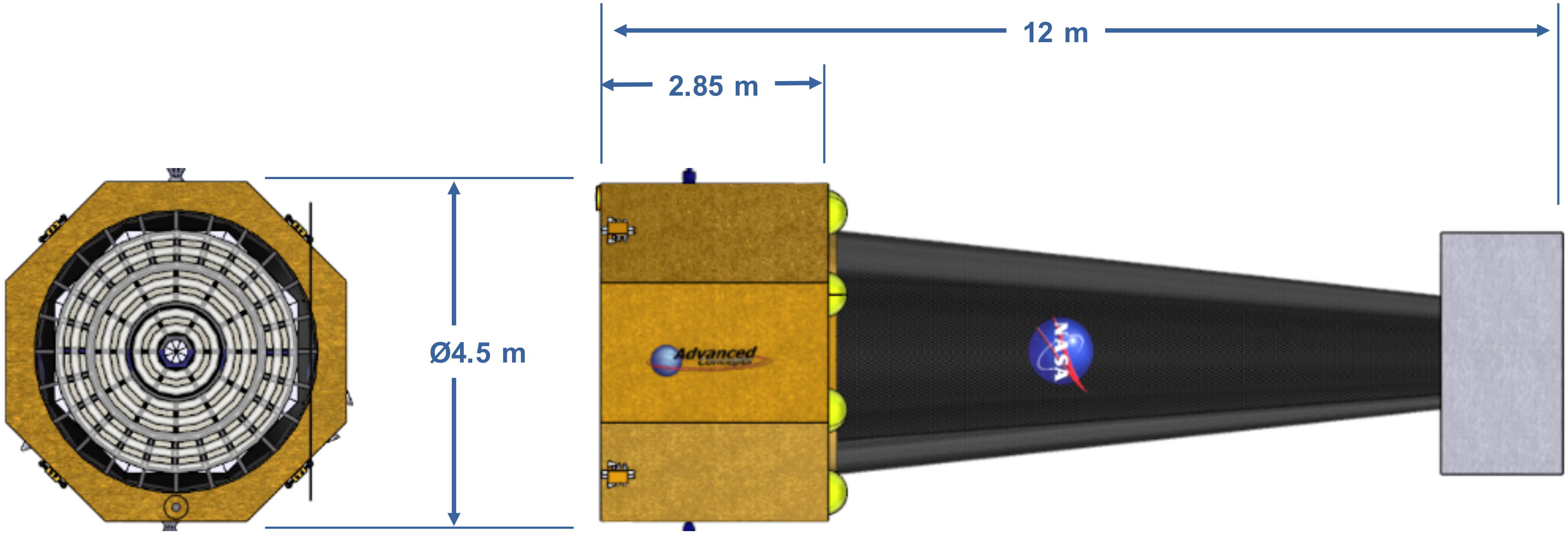
- Total ionizing dose:
  - The Space Environment Information System (SPENVIS)
  - Dose accumulated with time, consider 5 year primary mission with 5 year increments for extended mission to 20 years

- Single event effects:
  - Cosmic Ray Effects in Microelectronics (CREME) 1996
  - Single event effects are rate driven, consider extreme and worst case rates during solar particle event and background GCR rates

OBSERVATORY CONFIGURATION

Mike Baysinger (ED04)

Configuration



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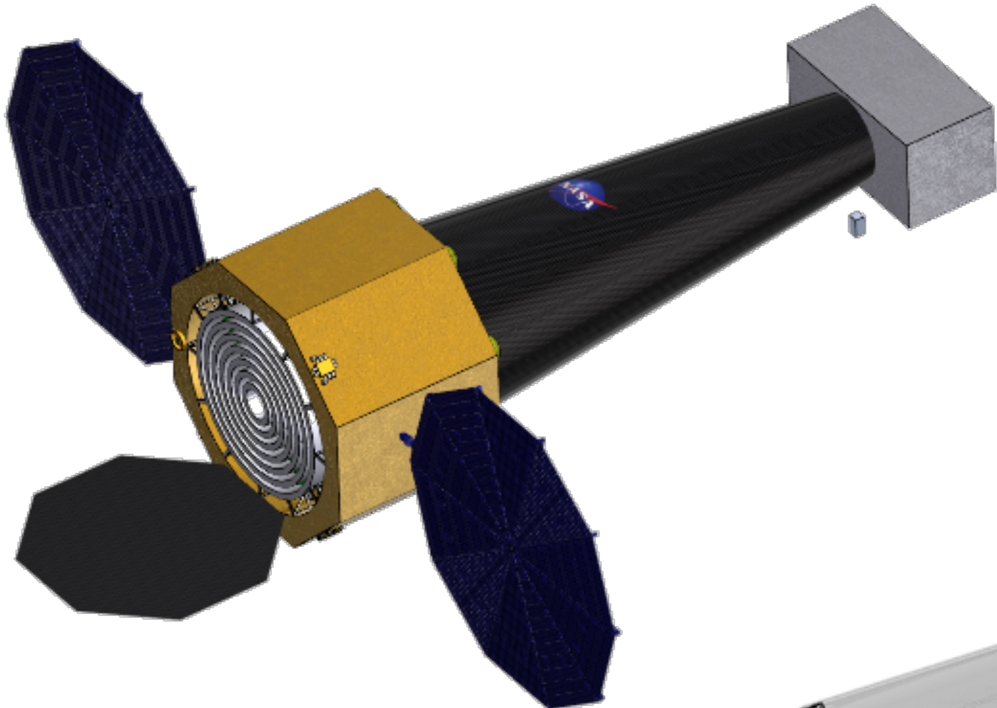

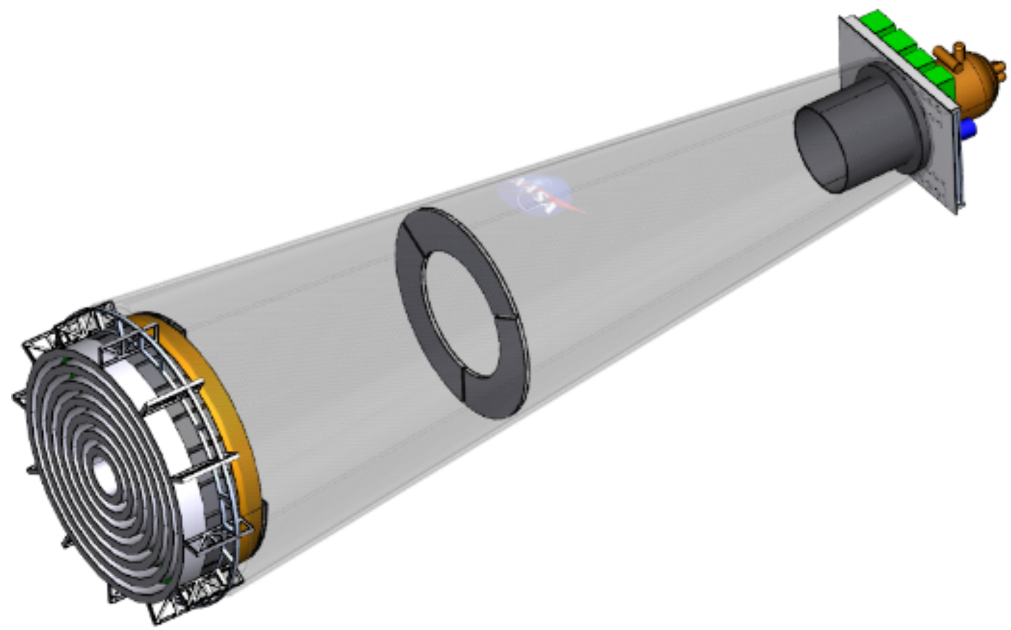

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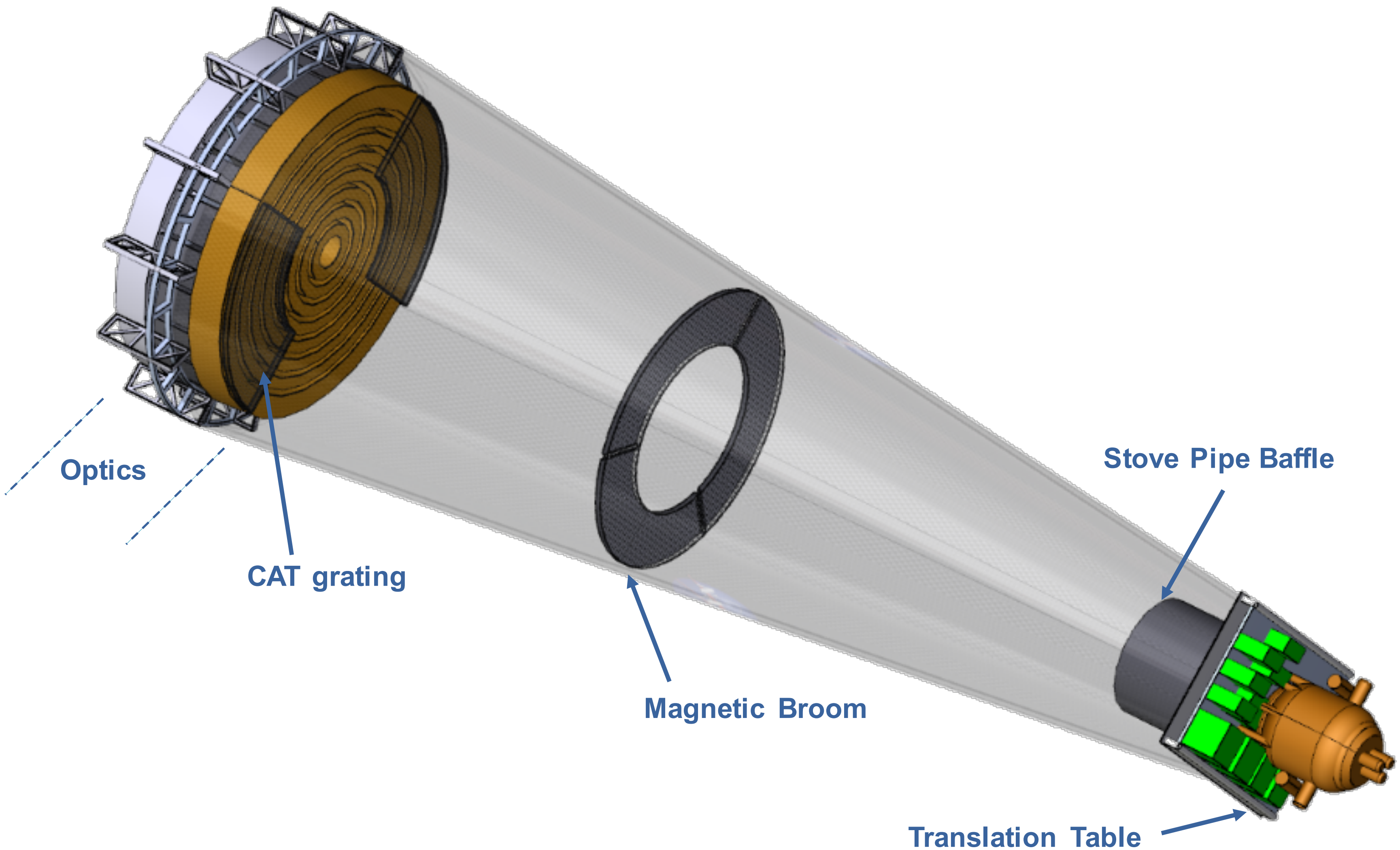

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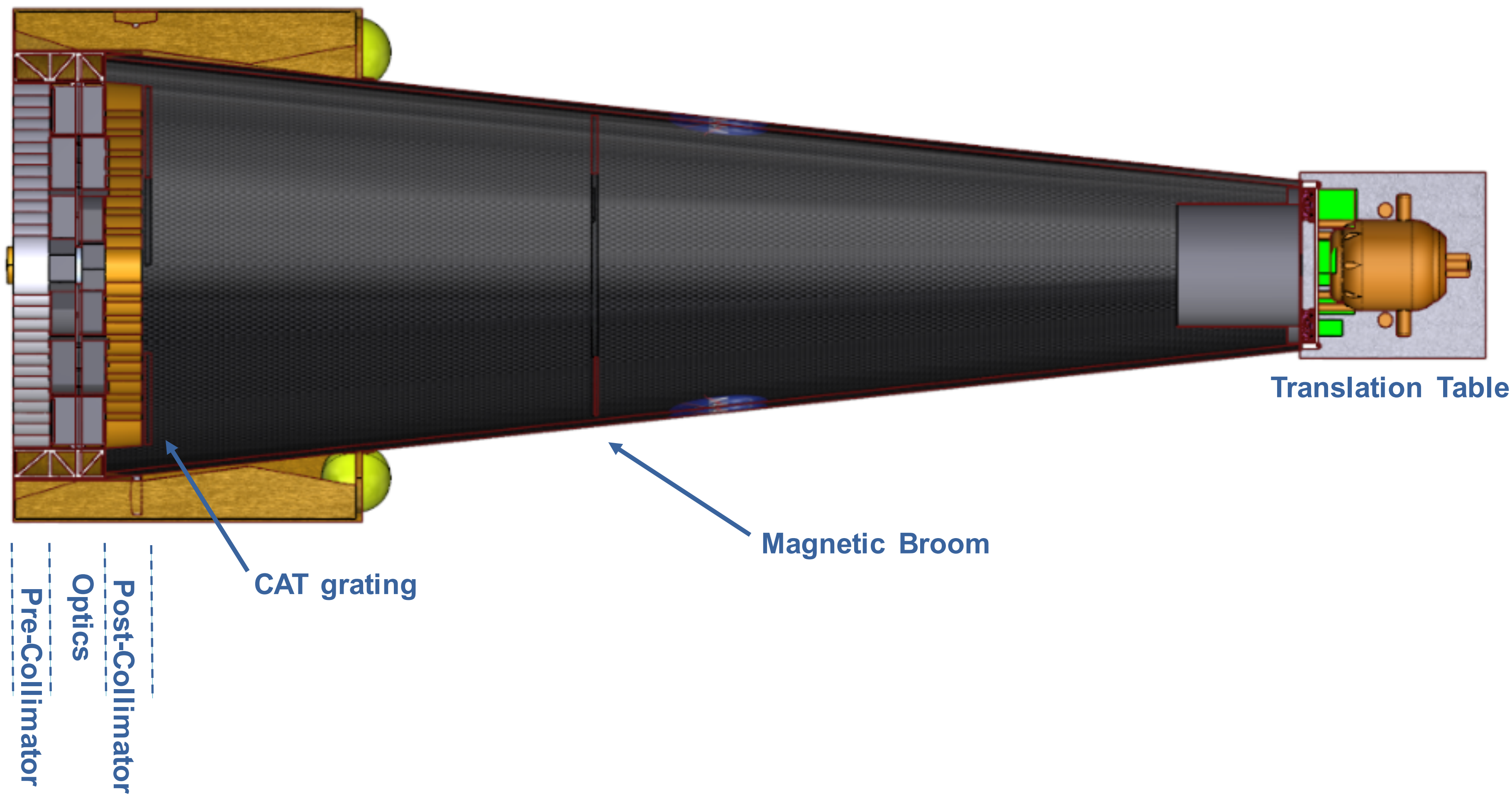

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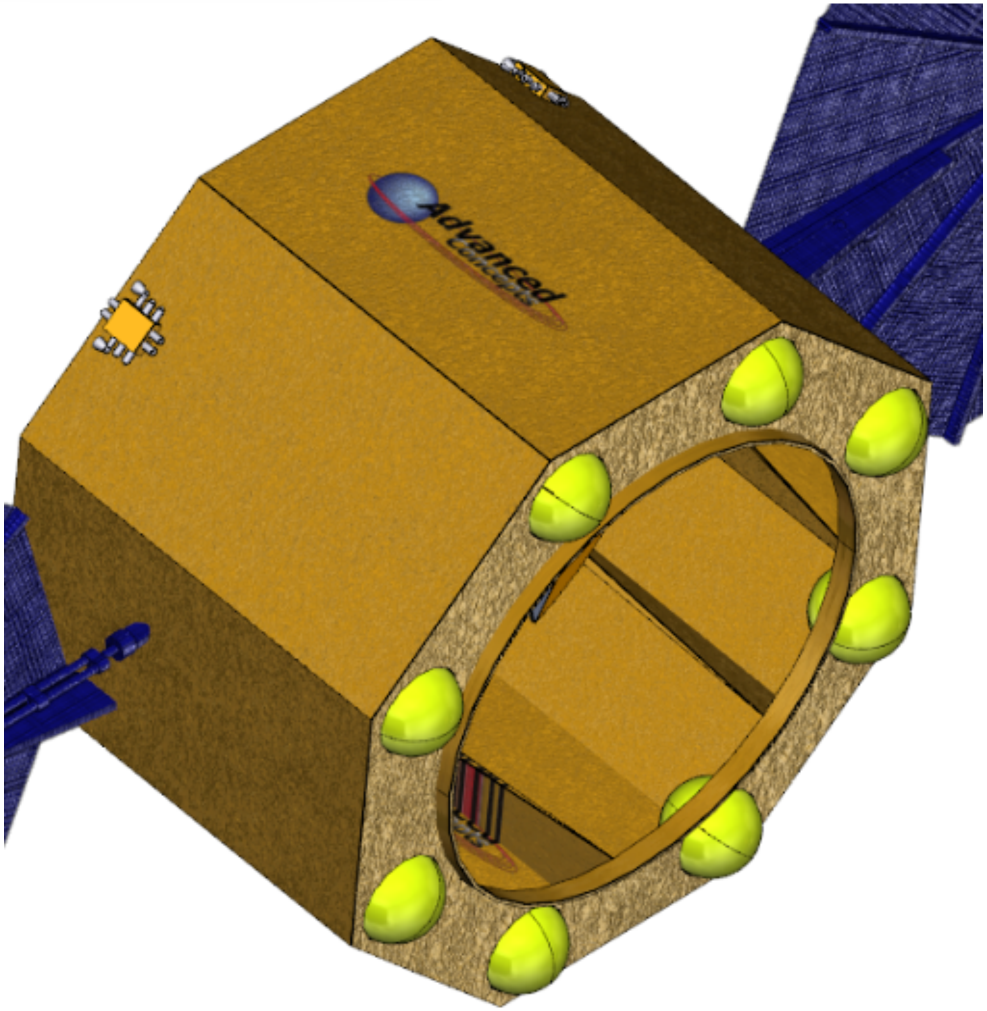
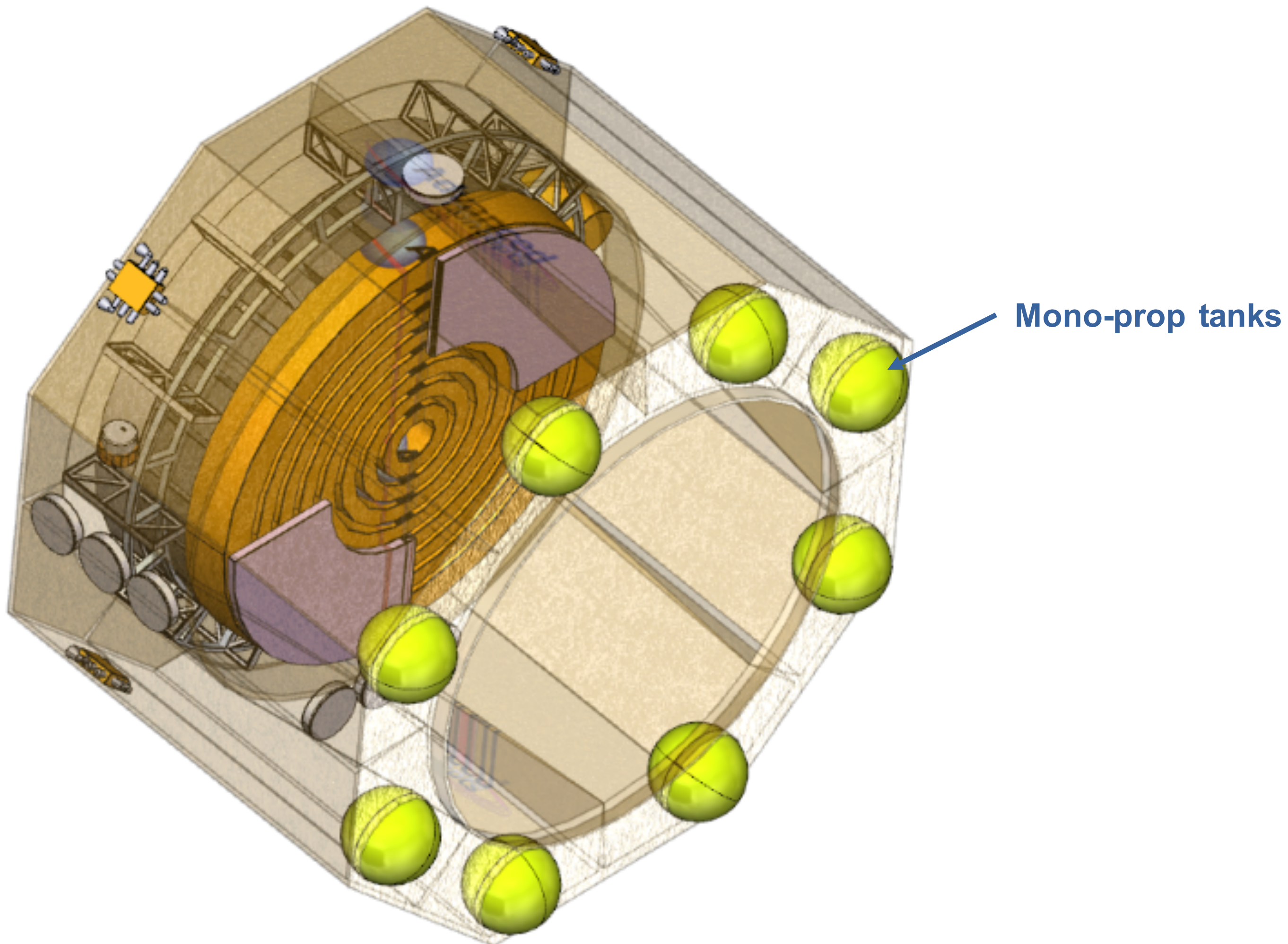
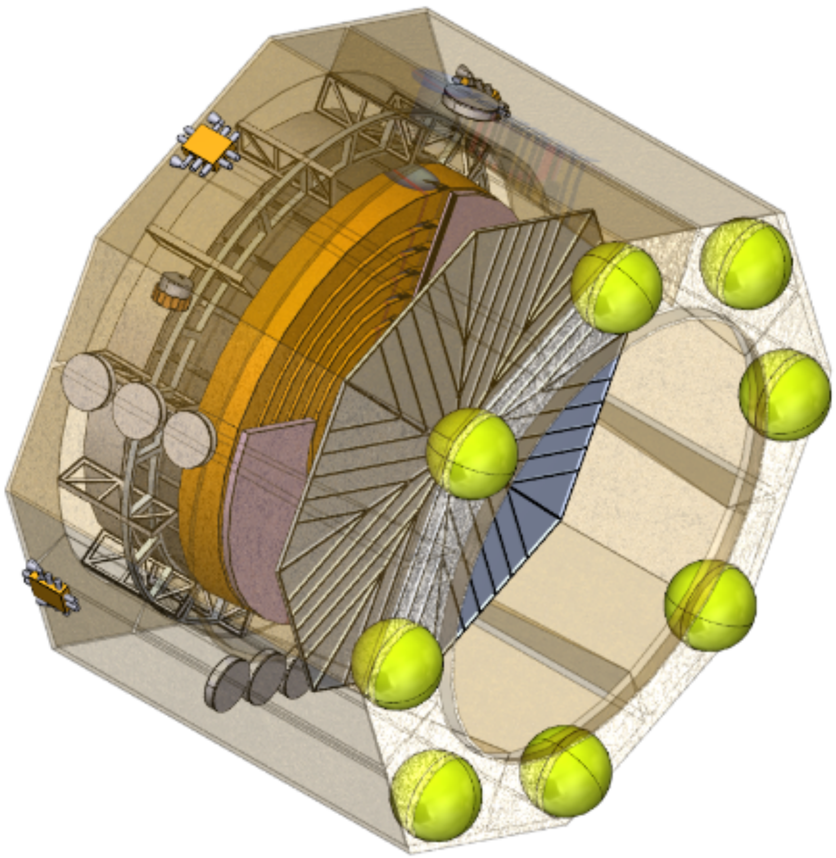


Spacecraft Bus

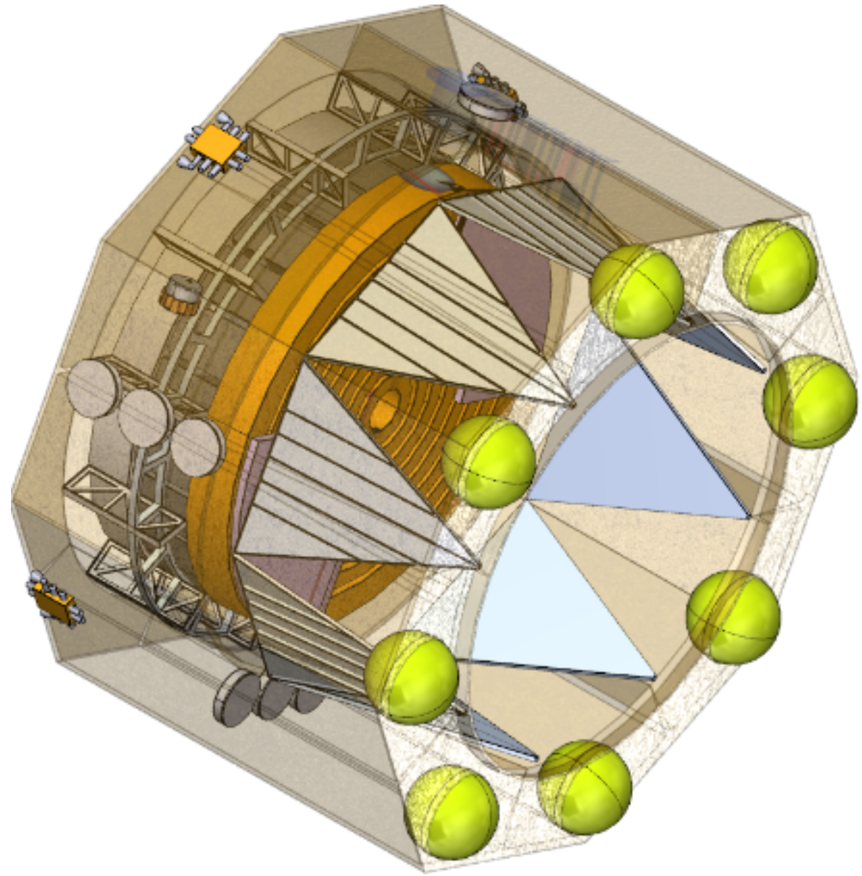
Configuration



Configuration

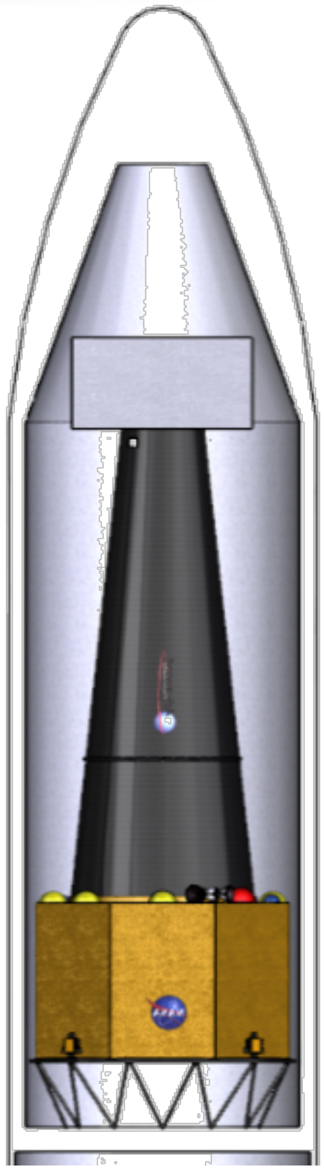


Aft door closed



Aft door open

Configuration



AtlasV 5m Long Shroud

MASS SUMMARY

Andrew Schnell (ED04)

Post Phase 2 Mass Summary

X-Ray Surveyor		Basic Mass (kg)	Contingency (%)	Contingency (kg)	Predicted Mass (kg)
1.0	Structures	795.60	30%	238.68	1034.28
2.0	Propulsion	127.26	30%	38.18	165.43
3.0	Thermal	38.00	30%	11.40	49.40
4.0	Avionics	97.64	30%	29.29	126.93
5.0	GN&C	156.76	30%	47.03	203.79
6.0	Power	426.00	33%	140.40	566.40
7.0	Science Instrument Module (Translation Table)	201.00	30%	60.30	261.30
	Dry Mass	*1842.26*	*30%*	*552.68*	*2394.93*
8.0	Non-Propellant Fluids	32.08	0%	0.00	32.08
9.0	Telescope	1840.90	30%	552.27	2393.17
10.0	Science Instruments	520.80	30%	156.24	677.04
	Inert Mass	*2393.78*		*708.51*	*3102.29*
	Propellant	*494.90*			*494.90*
	Vehicle Mass	**4730.94**		**1261.19**	**5992.13**

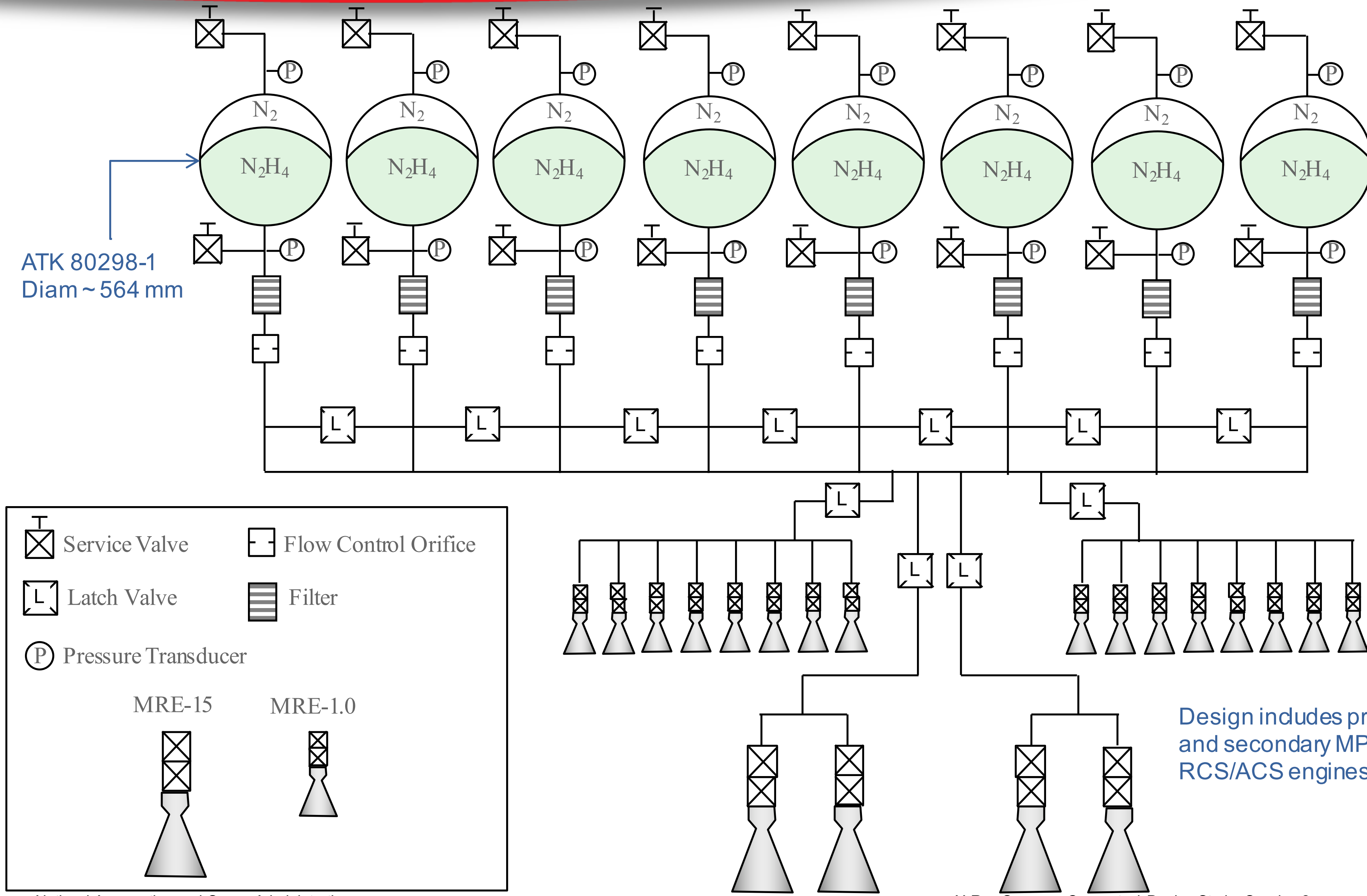
PROPULSION

Dan Thomas (ED04)

Methodology

- Designed monoprop blowdown system
  - Fuel = Hydrazine
  - Pressurant = Gaseous Nitrogen
- Maneuver Propellant
  - Hydrazine = 494.9 kg (includes 8.75 % extra to fill COTS tank)
- Engines
  - Main Engines: Northrop Grumman MRE-15
    - Thrust = 86 N at 27.6 bar (400 psia), 66 N at 19.0 bar (275 psia)
    - Isp = 228 s at 19.0 bar
  - RCS/ACS Engines: Northrop Grumman MRE-1.0
    - Thrust = 5.0 N at 27.6 bar, 3.4 N at 19.0 bar
    - Isp = 218 s at 19.0 bar
- Mass estimated using flight-qualified components
  - Rough estimate made for feed lines and mounts/fittings

Propulsion System Schematic



Design includes primary and secondary MPS and RCS/ACS engines

GUIDANCE NAVIGATION & CONTROL

Dr. Bob Kinsey, Senior Project Leader
The Aerospace Corporation, Civil and Commercial Operations

Ground Rules and Assumptions

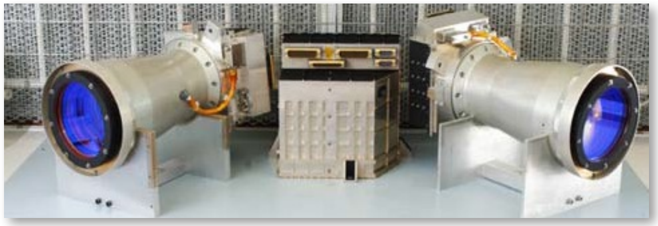
Category	Value	
Continuous Observation Time	100000 seconds (can be interrupted for momentum unloading if necessary)[1]	
Slew Requirements	90 degrees in 30 minutes (soft requirement that does not drive the design)[2]	
Pointing	Radial	Roll (boresight)
Accuracy	30 arcsec (3 sigma)	30 arcsec or better
Knowledge[3]	4 arcsec (pitch/yaw) RMS 99%	4 arcsec or better
Stability[4]	±1/6 arcsec per sec, per axis (3 sigma)	1/6 arcsec per sec or better
Dithering	Lissajous figure, up to +/- 30" amplitude with 8 bits resolution; periods 100 to 1000 seconds subject to derived rate constraint; arbitrary phase (8 bits: amplitude, rate and phase are to be independently commanded in yaw and pitch).	
Fault tolerance	Single-fault tolerant reaction wheel configuration	

[1] Suggested 6 for 8 wheel configuration provides capability to go for > 100,000 seconds without unloading.
[2] Suggested wheel configuration can support 27.6 minutes with 9.6% margin on wheel momentum capability or 35.8 minutes with 30.5% margin, for the worst slew axis.
[3] Driven by ground reconstruction of pointing; looser knowledge could be adequate to support pointing accuracy.
[4] A 100,000-second observation interval is made up of many short measurements, so short-term stability is the key.

Sensor and Actuator Info (1 of 3)

- Sensors
  - IMU: 3x Honeywell Miniature Inertial Measurement Unit (MIMU)
    - Uses GG1320 Ring Laser Gyro (RLG)
    - Range: +/- 375 deg/sec; Bias <= ±0.005 arcsec/sec (1 sigma)
    - Align the three IMUs so that no two gyro axes are aligned.
    - Operate two IMUs (6 gyros) at a time, so that gyro failure can be identified in real-time in software.

  - Star Tracker: Ball Aerospace HAST
    - ±0.2 arcsec per axis (1 sigma) while tracking at rates up to 1 degree/second[1]
      - RSS of random, spatial, and boresight errors
    - >94% success rate over 7 years
    - Derived from Chandra's Aspect Camera



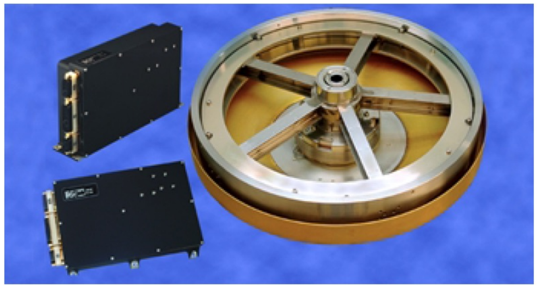
Performance Characteristics	
Random	0.110 arcsec 1 σ
Spatial	0.140 arcsec 1 σ
Boresight	0.100 arcsec 1 σ

  - Adcole Coarse Sun Sensors 2x
    - 2 Pi steradian FOV, accurate to a few degrees
  - Adcole Fine Sun Sensors 2x
    - Limited FOV (e.g., 64 x 64 degrees), accurate to a small fraction of a degree
  - Fiducial System (part of the Instrument) for knowledge of HAST relative to Telescope
    - Typically includes one or more lasers and a number of corner reflectors

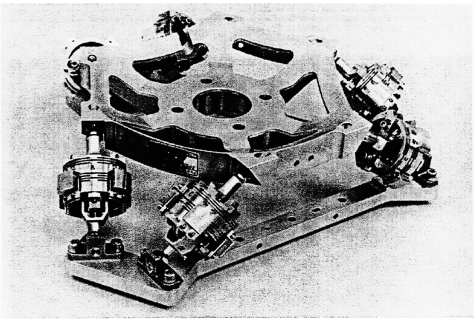
[1] Dan Michaels, James Speed, "New Ball Aerospace star tracker achieves high tracking accuracy for a moving star field," Acquisition, Tracking, and Pointing XVIII, edited by Michael K. Masten, Larry A. Stockum, Proceedings of SPIE Vol. 5430 (SPIE, Bellingham, WA, 2004) · 0277-786X/04/$15 · doi: 10.1117/12.549107, Downloaded From: http://proceedings.spiedigitallibrary.org/ on 06/17/2015

Sensor and Actuator Info (2 of 3)

- Actuators
  - Reaction Wheels: Rockwell Collins Teldix RDR 68-3
    - Each Wheel: Torque 0.075 Nm, Mom. Storage 68 Nms
    - 8 wheels in "pyramid" configuration; 6 of 8 in operation at a time
      - Cant angle and pyramid orientation can be optimized for more or less capability in any given axis
      - 338 Nms capability for pitch and yaw (perpendicular to boresight): axes with larger inertias, and slew axis will be in the pitch/yaw plane.
      - 106 Nms capability for roll (twist about boresight)



  - Reaction Wheel Vibration Isolation[1, 2]
    - One isolator per wheel; < 2 kg per isolator.
    - Northrop Grumman heritage design used on Chandra and JWST
      - Designed specifically for Teldix RDR 68 wheel
      - Could be modified for a different wheel with comparable mass if the Teldix wheel is not available for this mission
    - Does not require launch locks

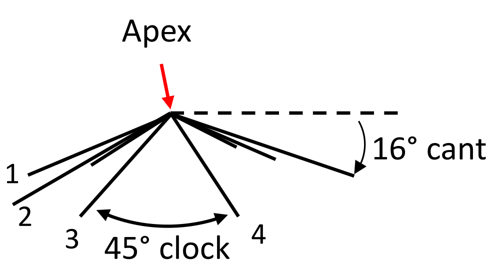


[1] Karl J. Pendergast, Christopher J. Schauwecker, "Use of a passive reaction wheel jitter isolation system to meet the Advanced X-ray Astrophysics Facility imaging performance requirements," SPIE Conference on Space Telescopes and Instruments V • Kona. Hawaii • March 1998, SPIE Vol. 3356 • 0277-786X/98, pp. 1078-1094.

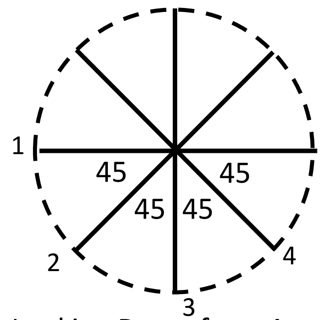
[2] Dr. Reem Hejal, Northrop Grumman, Dynamacist for Chandra, phone call on 19 June 2015.

Sensor and Actuator Info (3 of 3)

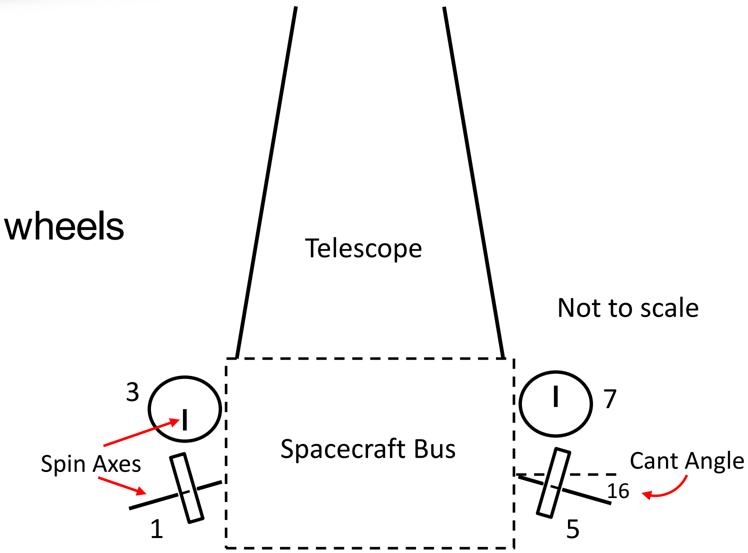
- Wheel Pyramid
  - Pairs of opposite wheels shown to the right
  - Spin axis cant angle ~16 degrees for each wheel
  - Spin axis clock angle of 45 degrees between adjacent wheels



3D View of Spin Axes

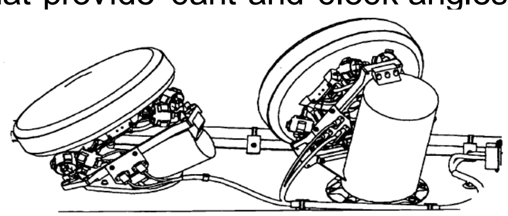


Looking Down from Apex

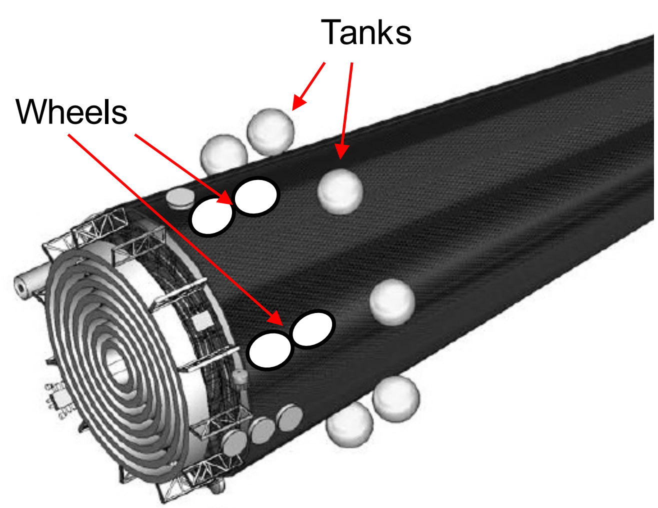


Opposite Pairs of Wheels

- Locations on the vehicle
  - Similar concept used for Chandra
  - Wheel pair at each of four locations
    - 90 degrees around barrel between pairs
  - Isolators mounted to standoffs that provide cant and clock angles.



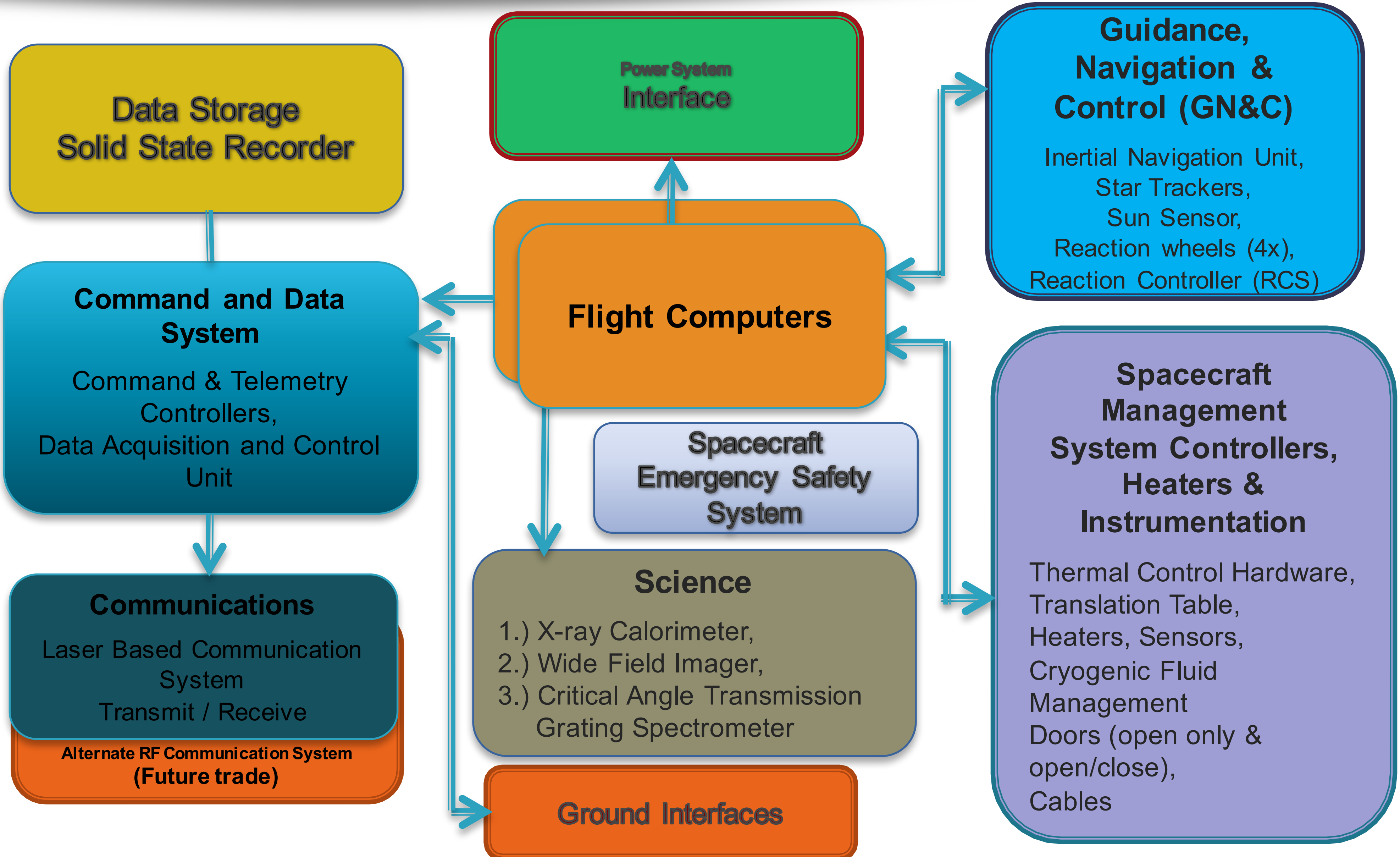
From reference 1 on the previous chart.



AVIONICS: C&DH AND COMMUNICATIONS

Ben Neighbors (ES12)

Architecture and Interfaces



Results

- No significant technology hurdles for avionics system
  - Opportunity for newly demonstrated technologies to be included in design with new technologies being flight proven prior to completion of design cycle.
  - Avionics and GN&C system components were identified to establish mass and power requirements to populate integrated system solution
  - Forward work identified to continue solution refinement and understanding.
- Redundancy management trade studies
  - Establishing redundancy management system and methodology for fail operational, fail safe-mode requires additional refinement and requirement derivation to understand improvements in system reliability.
  - Communication requirements in fail safe mode may drive system solutions between RF and laser based communication systems
    - Requirements to provide status of spacecraft faults or receive instructions for safe-mode recoveries will impact design complexities as it may require added redundancies for Communications and GN&C systems.

Recommendations for Future Work

- Develop more design specifics for Laser Based Communication System
  - Perform trade study between Laser and RF to further refine: mass, power, cost, availability, and reliability
- Refine redundancy methodology and risk management approach for system architecture.
- Continue system design parameters to define interface requirements and protocols
- Perform downlink analysis based on orbital mechanics and available ground stations and identify cost advantages from available solutions.

POWER SYSTEM

Leo Fabisinski

Ground Rules and Assumptions

Category	Value
Power subsystem required to provide power for all spacecraft elements + payload power.	Vehicle will provide capability to store, generate, manage/condition and distribute power to all subsystems and payloads on the vehicle
Maximum Battery Power Time	180 minutes
Bus voltage	120V / 28V Nominal.
Power during initial checkout / solar array deployment	Power will be provided to all attached architecture elements during initial checkout (1 hr) and solar array deployment if required. Full power will remain available during final orbit insertion.
Payload circuits	20 switched circuits provided to payload
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%

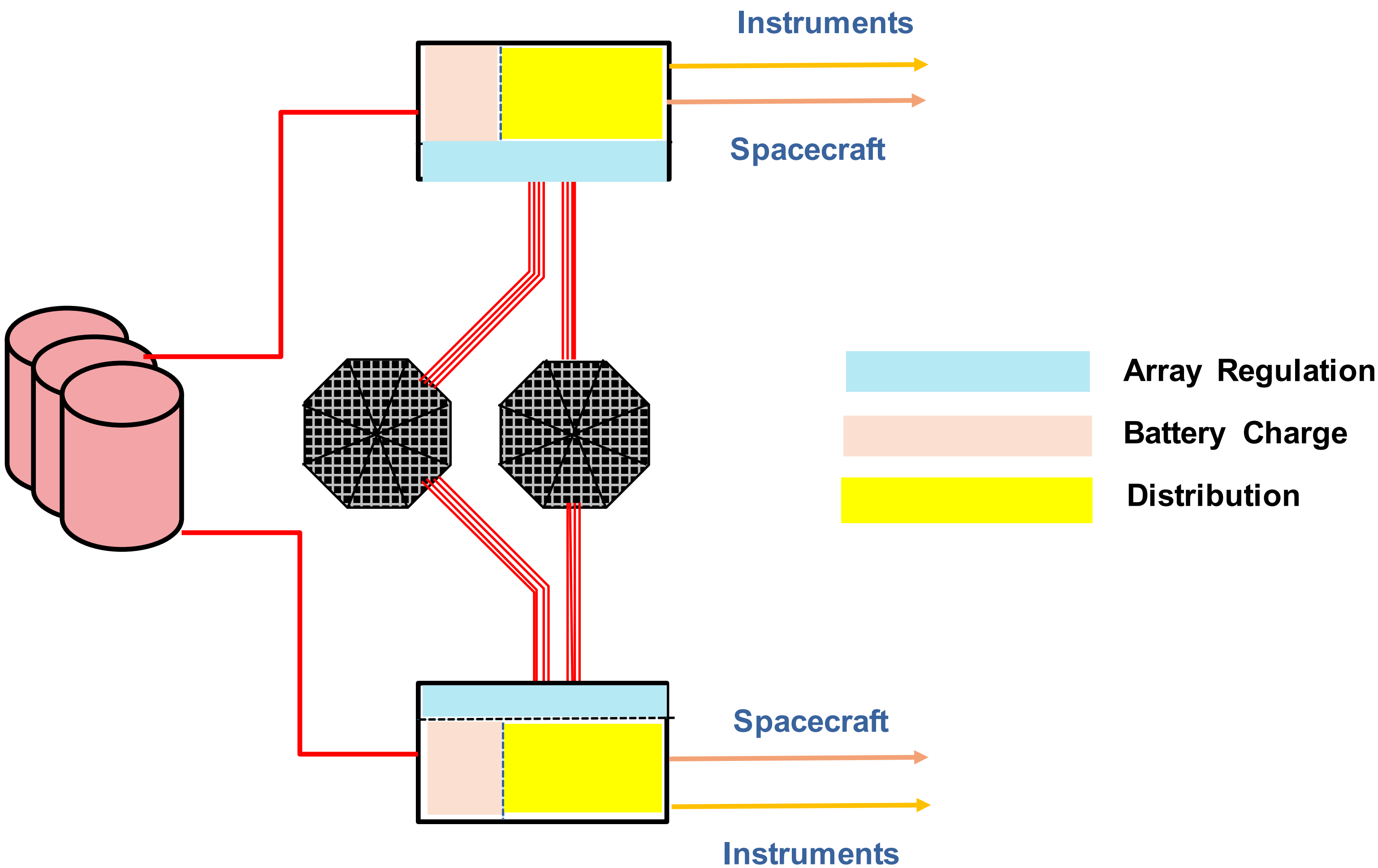
Approach and Tools

- Solar arrays are sized for 10 year full-power life. Will operate at reduced capacity for 20 years per GRA. UltraFlex array structure is sized for 2.5g loads to survive orbit insertion acceleration. Sizing is performed with physics-based design tools.
- Energy storage is sized to provide power for 180 minutes. This provides 3 hrs of battery power for servicing the arrays at a later time.
- Integrated power electronics (solar array regulation, battery charge control and power distribution) are sized using components designed for use in the Orion vehicle.
- Cabling and harness are sized with physics-based tools to achieve 2% power loss.

Power Required

Source	Standby	Science Op
Science	2627	3111
Avionics	532	532
Guidance, Navigation & Control	245	245
Thermal	50	50
Propulsion	364	0
Total Power	**3818**	**3938**
With 30% Design Margin	**4963**	**5119**

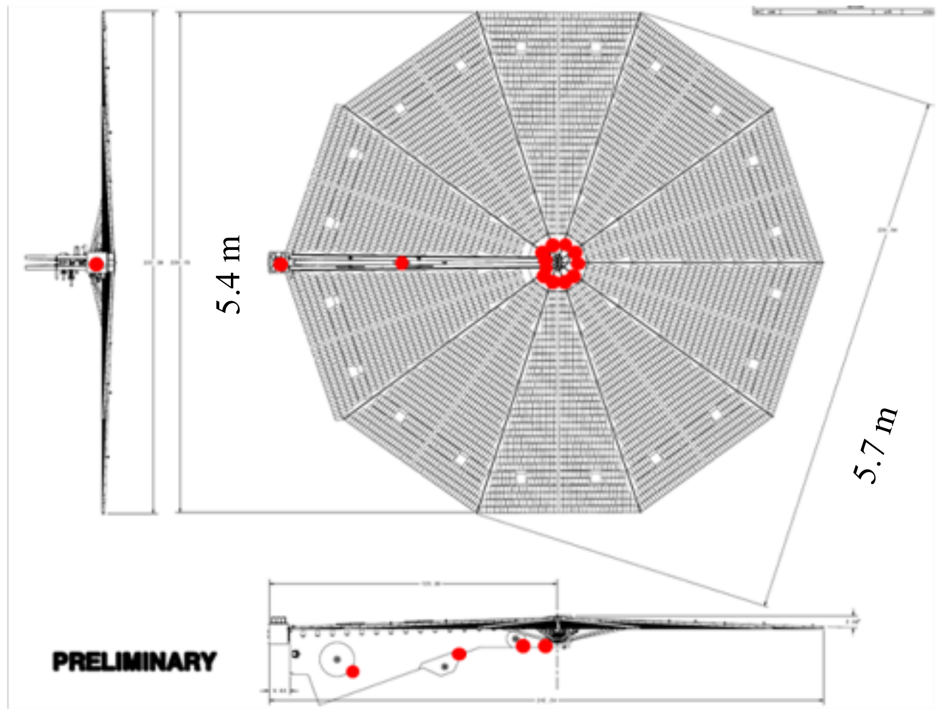
Schematic



Instruments
Spacecraft
Array Regulation
Battery Charge
Distribution
Spacecraft
Instruments

Solar Arrays

- **2 UltraFlex Array Wings**
- **Wing Diameter 5.7 m, Area 23.5 m^2 Each**
- **Total Power Generated (Both Wings EOL) 7,990 W**
- **73% Cell Coverage**
- **Sized to withstand 2.5g loads**



Power Electronics

- Integrated Power Electronics Approach based on original Orion Service Module Power System.

- Uses Orion power boards in 2 standard VME enclosures – fully redundant architecture allows either box to perform all power electronics functions.

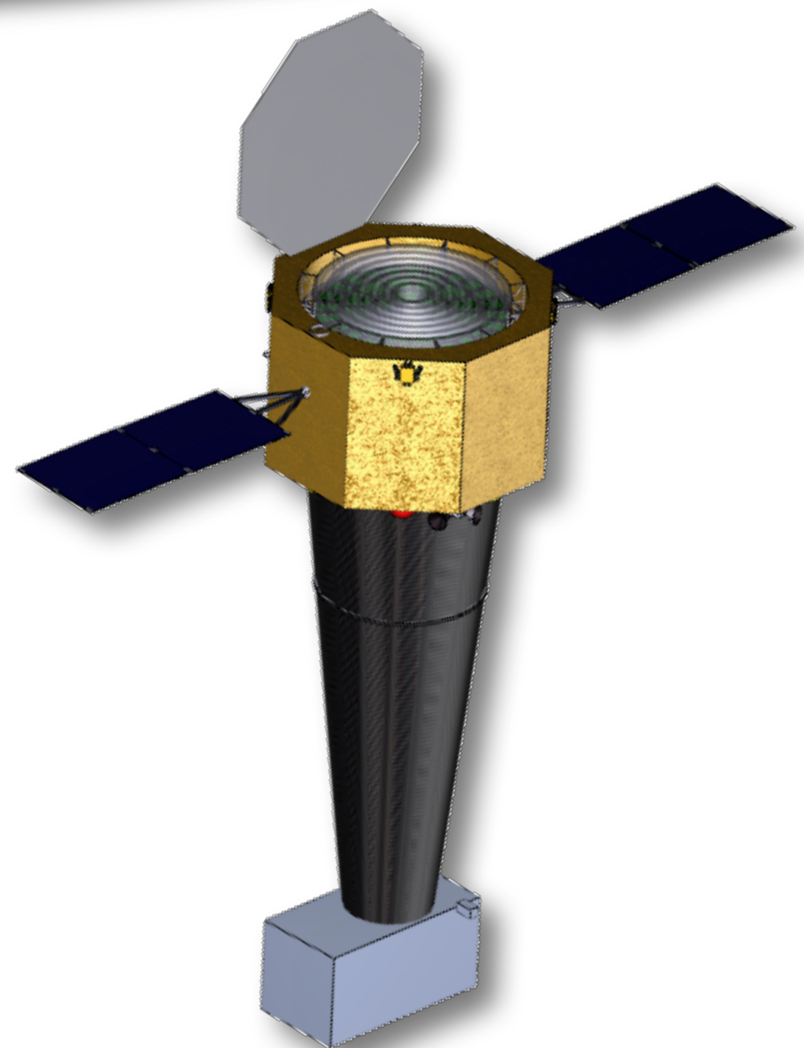
- Individual circuits may be either 120V or 28V. Harness sized for 28V to be conservative.

STRUCTURES

Jay Garcia (ED04)

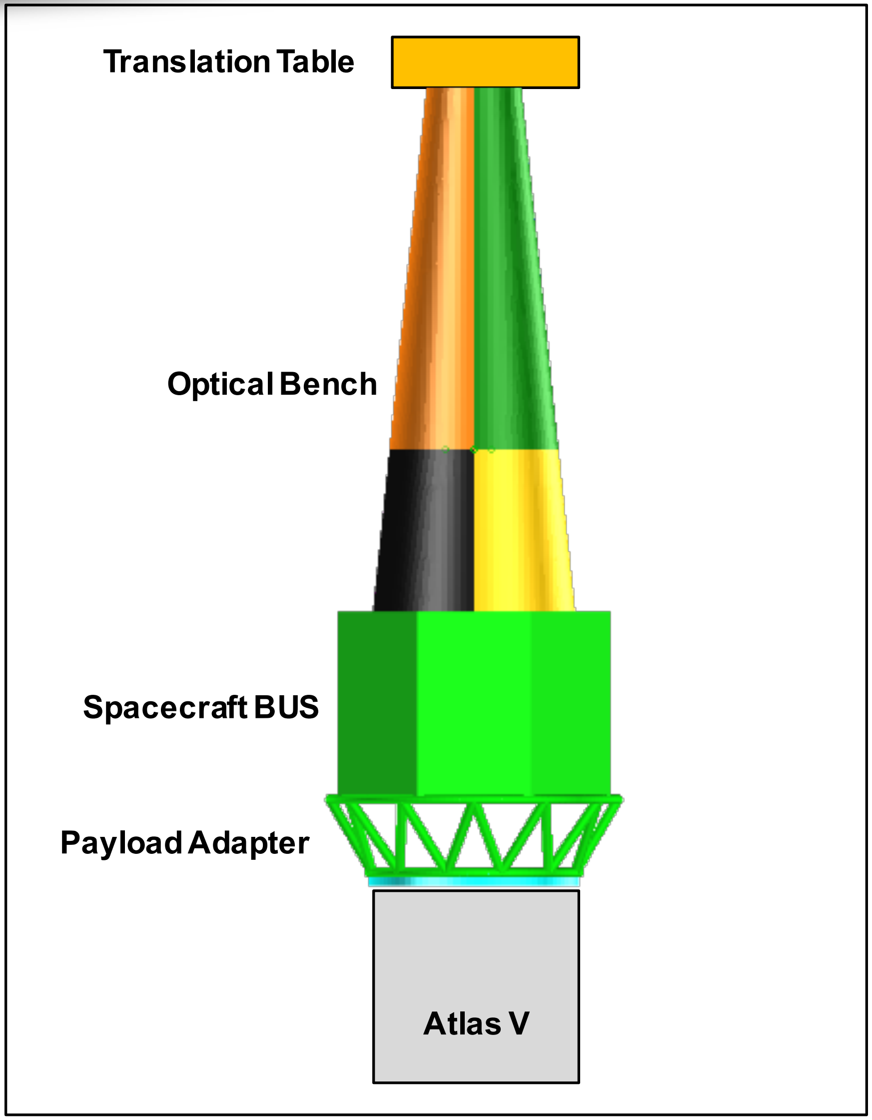
Introduction

- X-Ray Surveyor telescope Assembly
- Structural analysis performed to obtain mass estimates for the following:
  - Optical Bench composite conical tube
  - Spacecraft BUS
- Assume Optical bench is manufactured using carbon composite
- Subsystem mass for all sub-system mass in the Optical Bench and Spacecraft BUS are included in the finite element model
- Model loads are applied using model mass and inertial acceleration



Analysis Approach and Tools

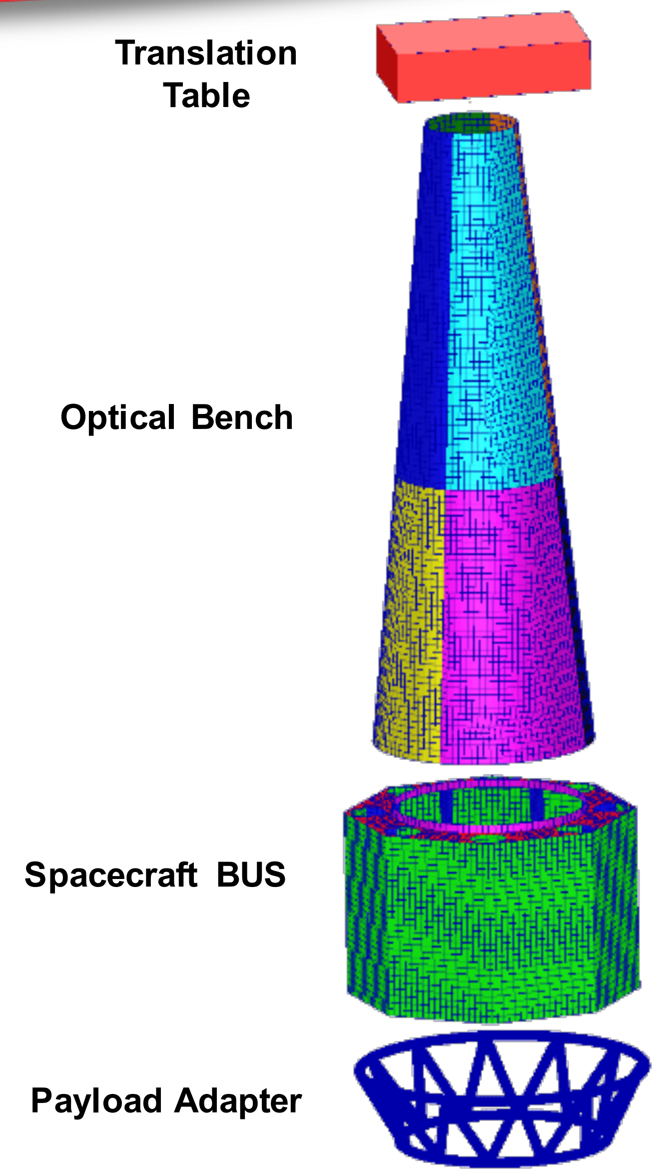
- Finite element model developed to size the Optical Bench, Spacecraft BUS, and Payload Adapter
- MSC Patran used to pre-process finite element model
- MSC Nastran / Hypersizer used to analyze / optimize the FEM
- Structural optimization accounts for strength and global stability



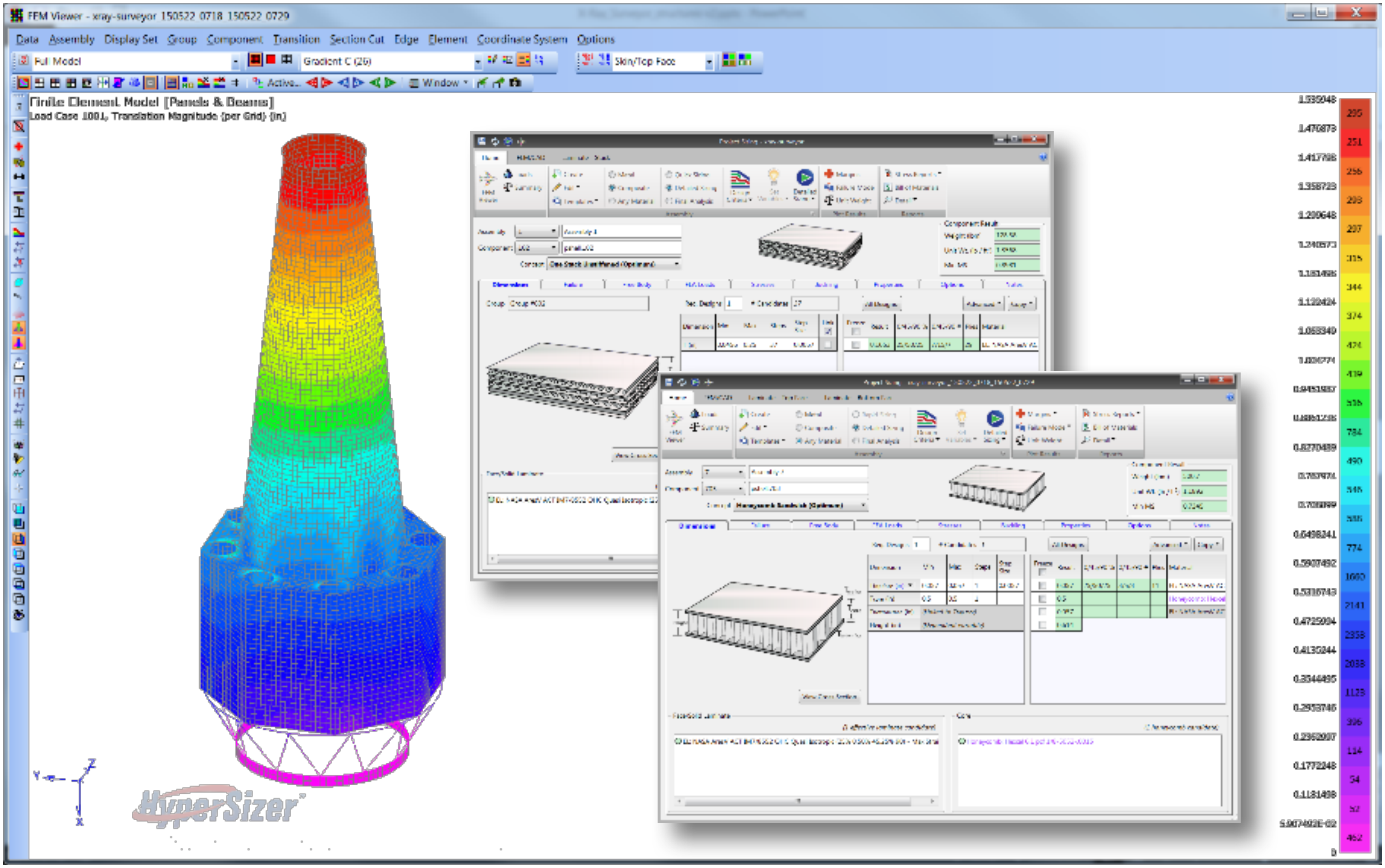
LAUNCH CONFIGURATION

FEA Model Description

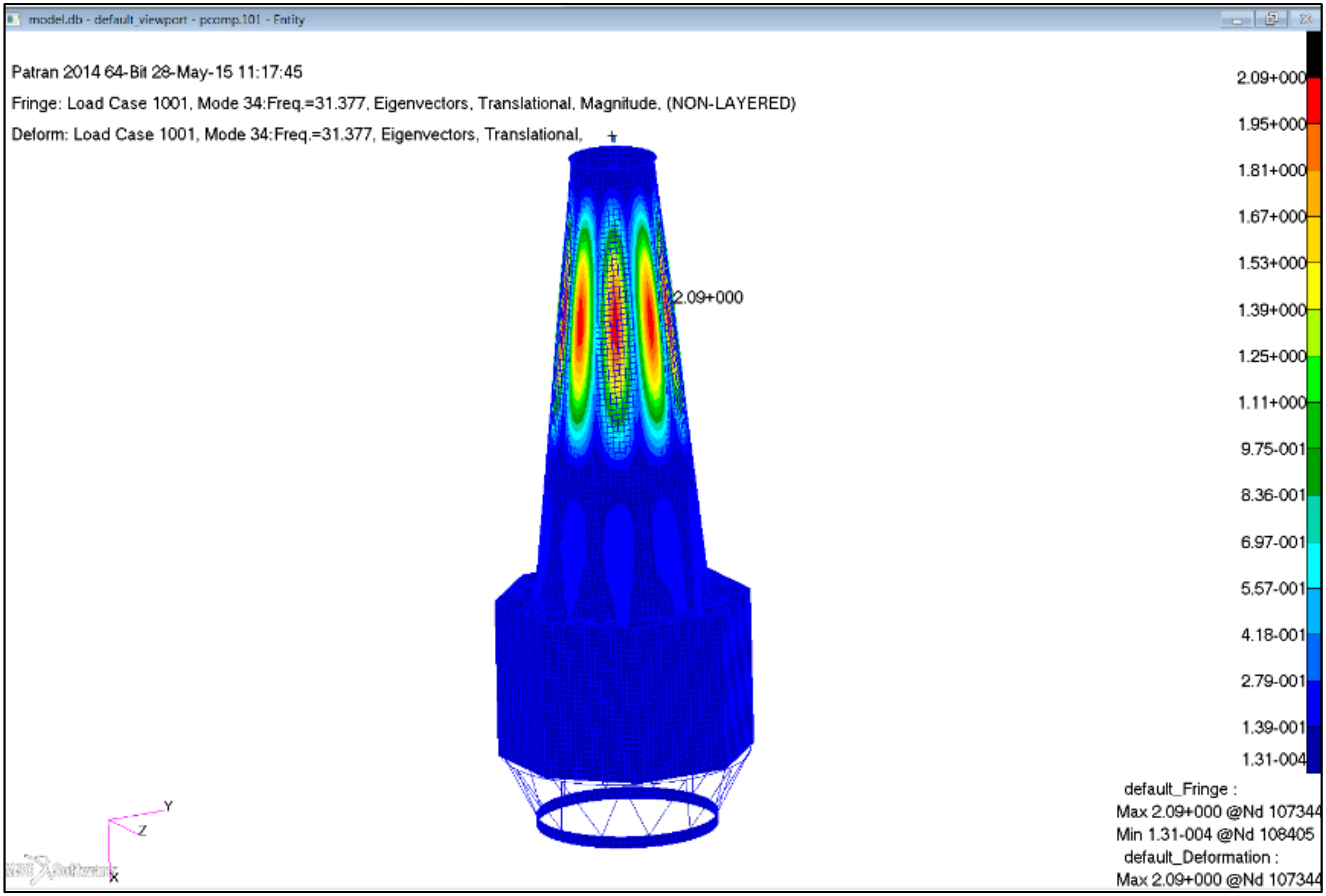
- FEA model comprised of components as shown
- Carbon composite shell elements used to represent the Optical Bench structure
- Spacecraft BUS fabricated using metallic and carbon composite materials
- Translation Table mass represented as a point mass connected to the Optical Bench using an MPC.



Hypersizer Design Software



Optical Bench
1st Natural Frequency (31 Hz)

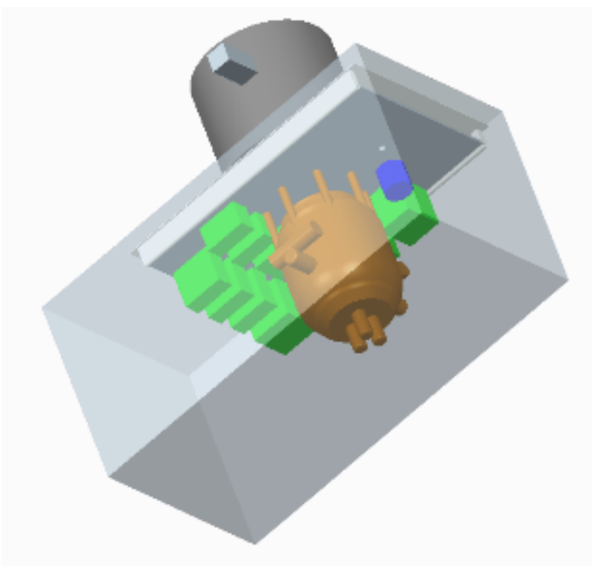


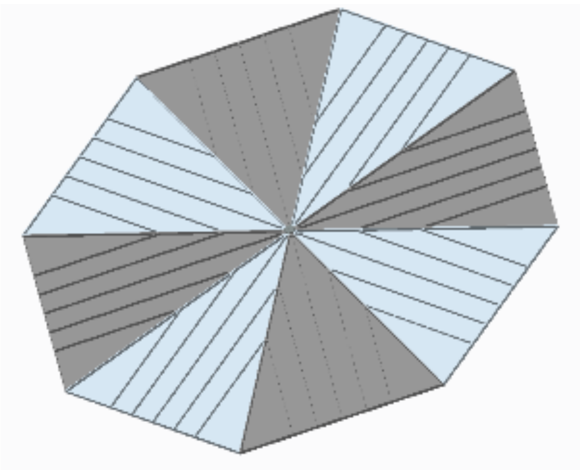
MECHANISMS

Alex Few

Mechanisms Studied

- Translation Table
  - Lateral Motion
  - Vertical Motion
- Inner Optics Door
- Outer Optics Door/Sunshade
- CAT Grating





Translation Table

- GR&A

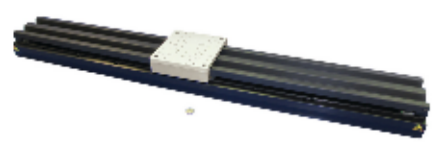
Category	Value
Instruments' focal plane location	WFI, X-Ray Calorimeter and CAT grating planes will be coplanar
CAT Grating Location	Not required on Translation Table
Horizontal translation accuracy	0.0002"
Vertical Translation distance	0.4"
X-Ray Calorimeter instrumentation locations	All instruments (coolers, power, etc) requiring to be less than 1 meter from Dewar Assembly will reside on the Translation Table
Enclosure	Translation Table, science, and supporting instruments will be fully enclosed
Launch Locks	Used until science is activated

Translation Table

- Approach and Tools
  - Direct Drive system (no power transfer via chains, belts, or gearing) is chosen due to extensive application in precision translation devices, accuracy, durability, and heritage success
  - Translating instruments are researched to verify that translation distance and, precision, and accuracy requirements could be mutually satisfied
  - If all requirements are satisfied by a commercial item, then it is assumed that the technology could be modified for flight
    - Vendors will produce specialty items to satisfy off gassing, loads, and reliability requirements
    - Price increase 10x to be expected
  - If no commercial item exists, then heritage flight hardware with similar application is examined and resized

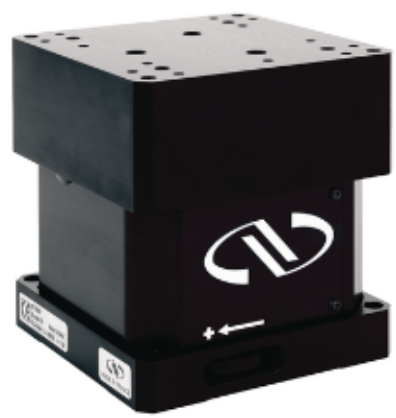
Translation Table

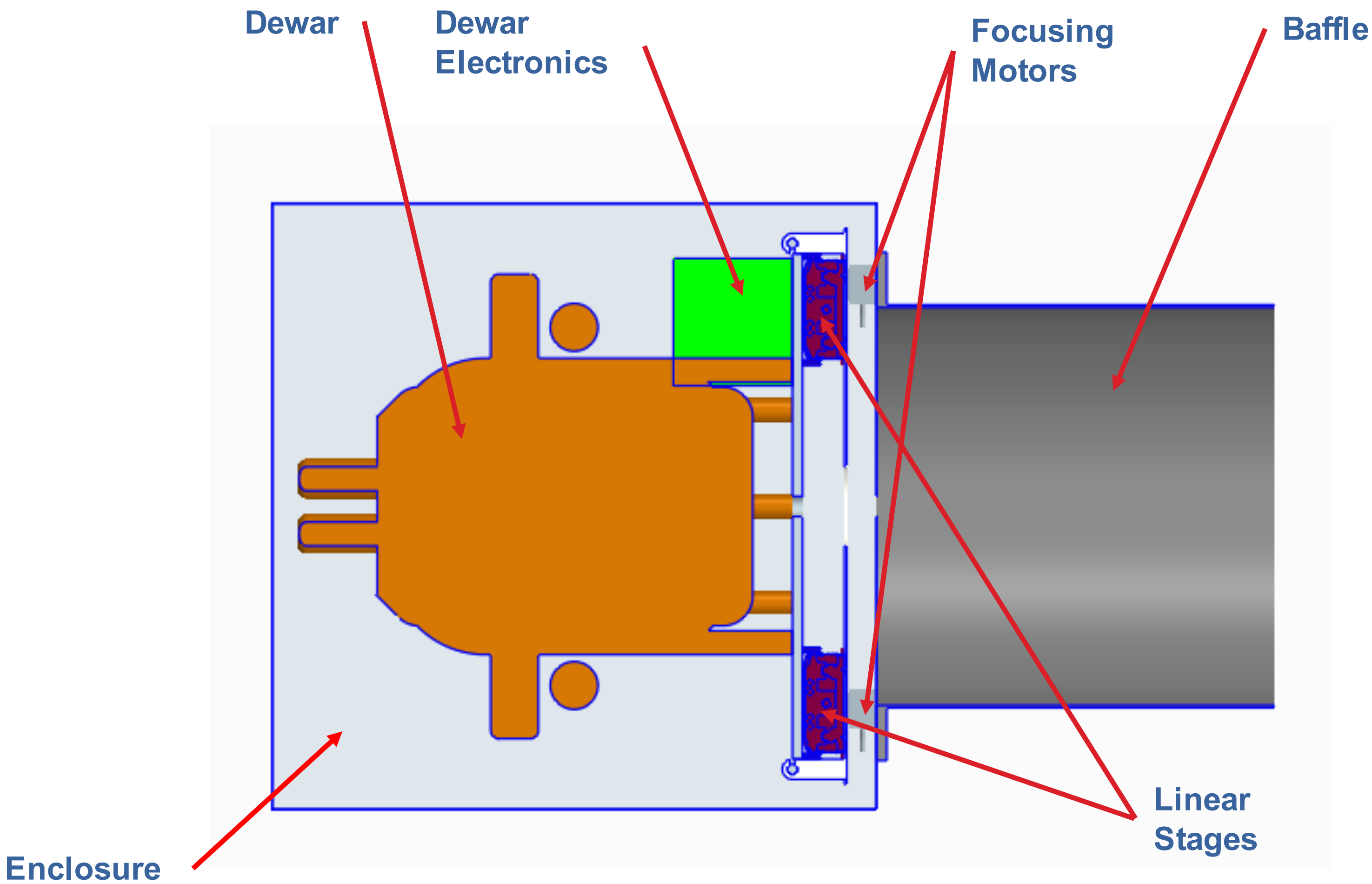
- Horizontal Translation Results
  - Direct Drive Linear Stage
    - These systems specialize in precision applications and are low-profile
    - Newport and Rockwell Industries produce applicable technologies with products within or near the accuracy and precision requirements
    - Launch locks will be required, unless product is modified for science mass under launch dynamic conditions
- Sizing Results
  - 750mm minimum translation required
  - 2 stages suggested due to table size
    - Reduce induced moments from acceleration
    - Redundancy
    - Commercial versions weigh about 30 kg



Translation Table

- Vertical Translation Results
  - Precision Vertical Stage
    - These systems are used in clean room or lab environments for optical applications
    - Meets translation and accuracy requirement
    - Commercial version uses roller bearings
    - Launch locks will be required, unless product is modified for science mass under launch dynamic conditions
    - Servos can be applied to commercial version
- Sizing Results
  - 1.2” (30 mm) translation
  - 4 stages suggested due to table size
    - Each commercial version weighs 3.3 kg
    - Each commercial version is 130 mm tall




Dewar
Dewar Electronics
Focusing Motors
Baffle
Linear Stages
Enclosure

Inner Optics Door

- GR&A

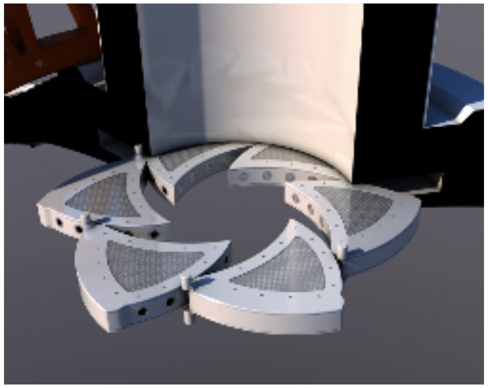
Category	Value
Service Life	Single use
Pressure	Pressure in Optics compartment, leakage allowed
Open/Closed position	Opened door must reside within optical bench and outside of optical path
Door position monitoring	Secondary monitoring device will be used (Chandra Heritage)
Material	Composite or Metallic

- Approach and Tools
  - The door must be over 3 meters in diameter, and support significant normal loads created by pressure gradient (for example, every 1000 Pa gradient will create a distributed normal load of about 8000 N or 1800 lbs)
  - Mechanisms and structure must either support this load or be fixed by separate locking mechanisms
  - Analysis showed that the door bulges out of plane about 1” at 2000 Pa and over 2” at 5000 Pa
  - Aluminum door is possible with optimization of stiffeners

Inner Optics Door

- Trades

Iris Door	Petalled Door
Low profile in direction parallel to optical path	More petals allow for lower profile in optical path
Requires much complex support structure, most likely extending outside of optical bench	Simper design
Limited application at this scale	Will require multiple mechanisms
	Will require door locks to support pressure



- Results
  - Octagonal door with petals
- Sizing Results
  - 8 equal-size petals with individual servos
  - 1/32”-1/16” thick with stiffeners
  - Door mass: ~80 kg
  - 8 single-use steppers and support structure: ~10 kg total

Outer Optics Door/Sunshade

- GR&A

Category	Value
Service Life	Single use
Pressure	Pressure in Optics compartment, leakage allowed
Open/Closed position	Opened door must open beyond optical path and serve as sunshade
Door position monitoring	Secondary monitoring device will be used (Chandra Heritage)
Material	Composite or Metallic

- Approach and Tools
  - Similar loads to Inner door to be expected
  - Mechanisms and structure must either support this load or be fixed by separate locking mechanisms
- Results
  - Stepper motors suggested
  - Reliable, well known technology
  - Higher holding torque than servo motor

CAT Grating

- GR&A

Category	Value
Operation range	Grating must swing into and out of optical path multiple times
Position during launch	Stowed
Accuracy and precision	Large alignment tolerances
Neighboring structure and mechanisms	Inner door will remain outside of operation range
Door position monitoring	Secondary monitoring device will be used (Chandra Heritage)
Grating size	4 Sections covering 3000 cm^2 (about half of optic area)

- Approach
  - Gratings appear to be moderately sized, and loose tolerances will allow for less precise motion
- Results
  - 4 Compact Linear Actuator
  - Moog, Schaeffer Magnetics Division

THERMAL CONTROL

Andrew Schnell (ED04)

Ground Rules and Assumptions

Category	Value
Spacecraft thermal control	Thermal control of the spacecraft shall utilize standard, flight-proven features such as MLI, selected surface finishes, foils and tapes; coupled and isolated mounting concepts; optical solar reflectors and radiators; resistance heaters, thermostats and controllers; and pumped fluid loops, cold plates, heat exchangers and fluid radiators.
Instrument compartment requirements	300 K +/- 10 K operating temperature and control
Environmental heat loads	Radiator sink temperature estimated at Earth/Sun L2 Solar flux at Earth/Sun L2: 1296 W/m2.
Science payload heat loads	Science payload is assumed thermally isolated from the spacecraft bus.

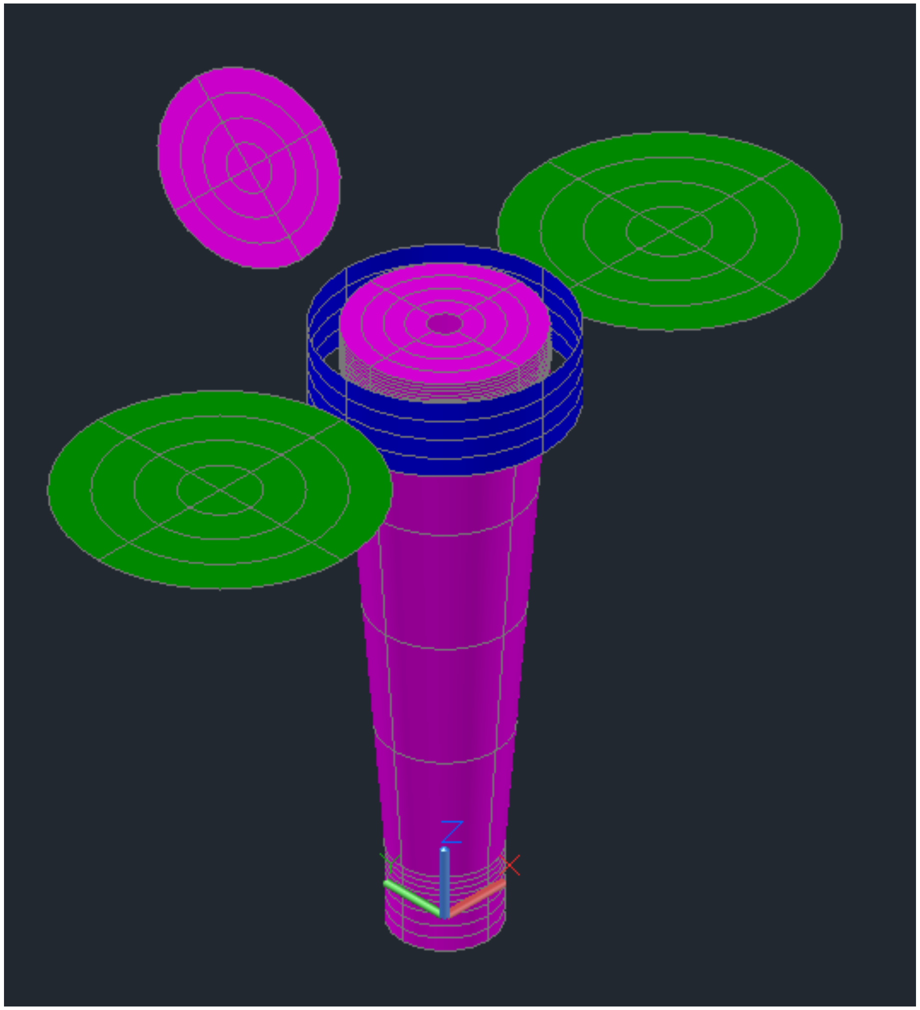
Approach and Tools

- Integrated spacecraft/telescope thermal model using Thermal Desktop

- Spacecraft Thermal Control
  - 10 layers multi-layer insulation (MLI) on external spacecraft shell
  - Low-absorptivity MLI outer layer
  - Heaters to maintain required temperature

- Avionics Heat Rejection
  - Heat rejection using conduction to structure via doublers
  - Heat rejection temperature: 265 K

Spacecraft Thermal Model



National Aeronautics and Space Administration

X-Ray Surveyor Design Study

Cost

June 22, 2015

www.nasa.gov

Spacecraft Costs (2015 $ in Millions)

Item	DDT&E	Flight Unit	Total
Subsystems	**471.5**	**152.7**	**624.2**
Structures & Mechanisms	149.6	20.1	169.7
Thermal Control	12.0	3.5	15.5
Electrical Power Subsystem	30.6	20.5	51.1
Command & Data Handling	43.0	13.7	56.7
Communication	14.9	5.0	19.9
Guidance & Navigation Control	72.3	35.6	107.9
Propulsion	15.3	8.7	24.0
Structural Instrument Module	38.0	6.9	44.9
Optical Bench Assembly	73.8	32.7	106.5
Aspect Camera	22.0	6.0	28.0
Systems	**274.8**	**63.1**	**337.9**
Integration Assembly & Checkout	22.6	14.6	37.2
Systems Test Operations	12.6		12.6
Ground Support Equipment	27.6		27.6
Systems Engineering & Integration	68.1	20.7	88.8
Program Management	93.3	27.8	121.1
Launch & On Orbit Support	50.6		50.6
Fee @ 10%	**74.6**	**21.6**	**96.2**
Program Support @ 10%	**82.1**	**23.7**	**105.8**
Vehicle Integration @ 5%	**45.2**	**13.1**	**58.2**
Reserves @ 35%	**331.9**	**96.0**	**427.8**
Total	**1,280.0**	**370.1**	**1,650.2**

Scientific Instrument Costs

2015 $ in Millions

Scientific Instruments	
X-Ray Optics Assembly	465.8
CAT X-Ray Grating Spectrometer	58.6
X-Ray Microcalorimeter Spectrometer	254.0
High Definition X-Ray Imager	46.6
Instrument Total	825.0
Payload Integration @ 5%	41.3
Total	**866.3**

Total Mission Costs

2015 $ in Millions

Scientific Instruments	866
Spacecraft	1,650
Launch Vehicle (Atlas 551)	240
Pre-Launch Ops, Planning & Support, Software Dev, Grants	196
Post-Launch Ops & Grants (5 yrs @ 70M per year	350
TOTAL	**3,302**

Study Status

Topic	Status	Reason
Design Status	Closed	GNC analysis complete. Current mass estimate does not exceed the mass limit for Atlas 551
Mission Requirements	Good	The current spacecraft design meets all mission requirements.
Launch Vehicle	Good	With 30% contingency, current observatory estimated mass (5992 kg) is 193 kg below maximum launch mass of Atlas 551 (6185 kg)
Technologies Needing Development	Good	The design team did not identify any technologies on the spacecraft that need development.
Discipline Status	Good	Analysis for bus completed through Phase 2. GNC design revised via collaboration with Aerospace Corporation

National Aeronautics and Space Administration

Potential
High-Level Design Tasks for 2016-17

MSFC Advanced Concepts

www.nasa.gov

Potential Trade Studies for FY16-17

- Orbit Trades
  - Sun-Earth L2, Chandra-like, Earth trailing, Lunar Reference Orbits, etc.
- Thermal Design Trades
  - Control concepts, heaters, thermistors, etc.
- Rapid Response Capability
  - Ability to communicate and respond to opportunities
- Attitude Control Trades
  - Instrument selection and sizing
- Avionics Trades
  - Safe modes, future communication system infrastructure, power trades
- Optical Bench Trades
  - Shorter/longer focal lengths, materials trades, affect on thermal control
- Mechanisms Trades
  - Sunshade deployment, focusing stages, instrument selection