IXO Facility Science Team Meeting
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Observatory Systems

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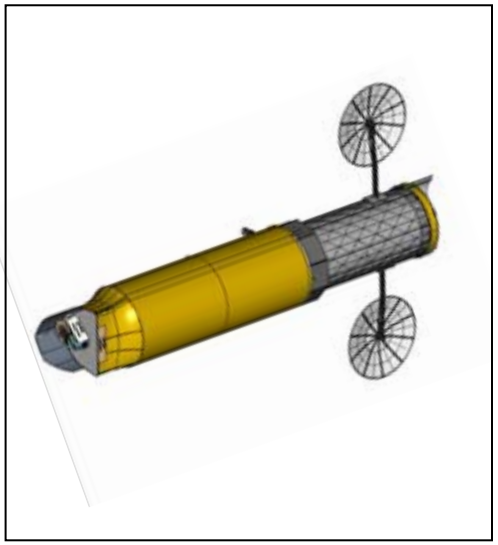
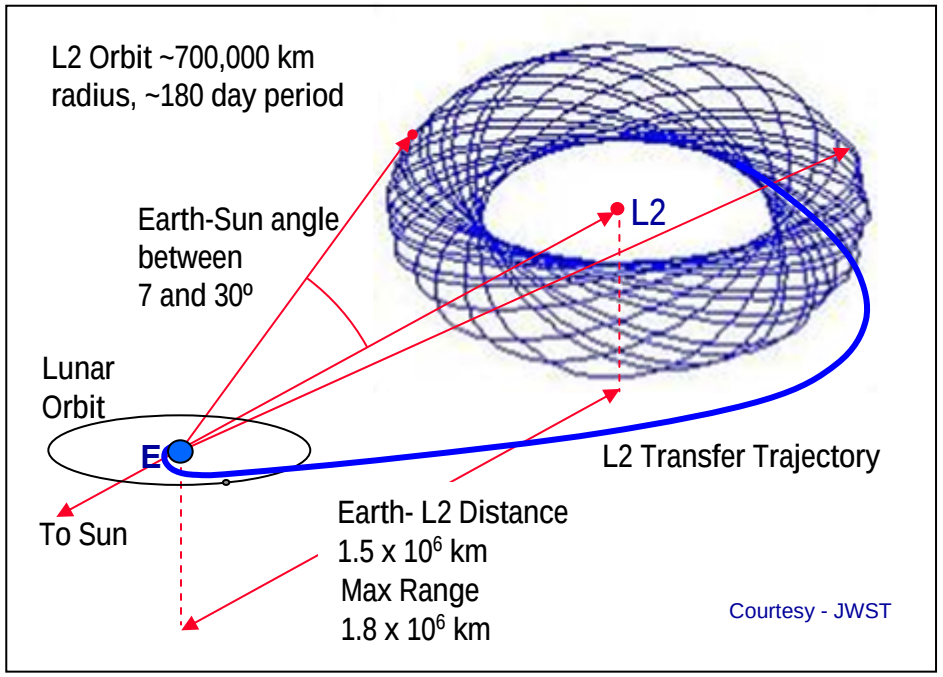
Outline

- Mission Configuration
  - Launch and Orbit
  - Timeline
  - Observation and Pointing
- Observatory Configuration
  - Subsystems Highlights
  - Resource Summary

Mission Overview

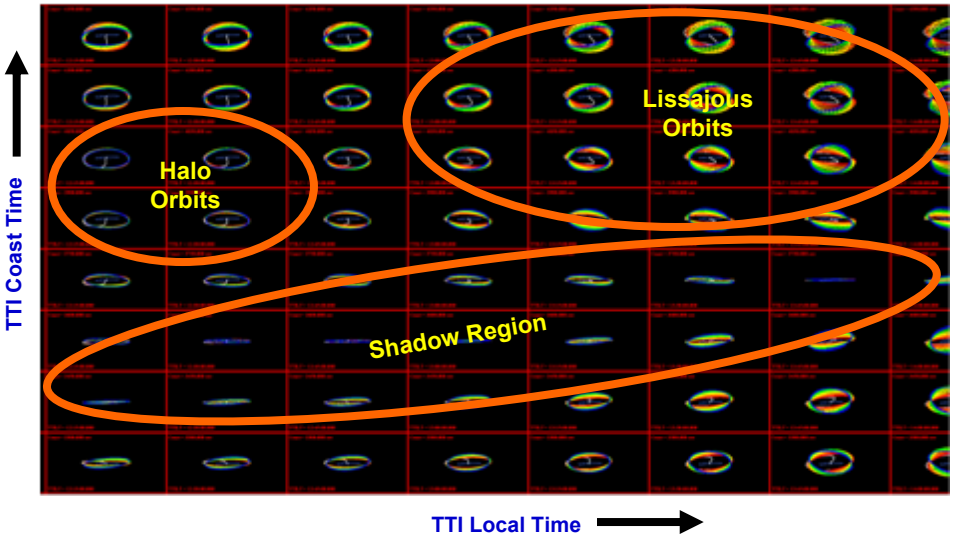
- **Single Mirror Configuration**
  - 3.3 m dia mirror with a 20 m focal length
  - Part of the metering structure is extensible (12.2m)
- **Mission Life and Sizing**
  - Class B Mission, no performance degradation w/ single point failure
  - Mission Life: 5 years required, 10 years goal, consumables sized for 10 years
- **Launch**
  - Launch on an Atlas V 551 medium fairing from KSC on 12/2020
  - Throw mass ~6342 kg (w/o Payload Attachment Fixture)
  - Direct launch into an L2 800,000 km semi-major axis "zero Insertion delta-v" halo orbit
  - 100 day cruise to L2
- **Mission Orbit**
  - At insertion, perform a maneuver to lower the Y amplitude to 700,000 km
  - Total Ionizing Dose (10 yrs): 27 kRad; severe Environment for Single Events Effects; micrometeoroid protection required





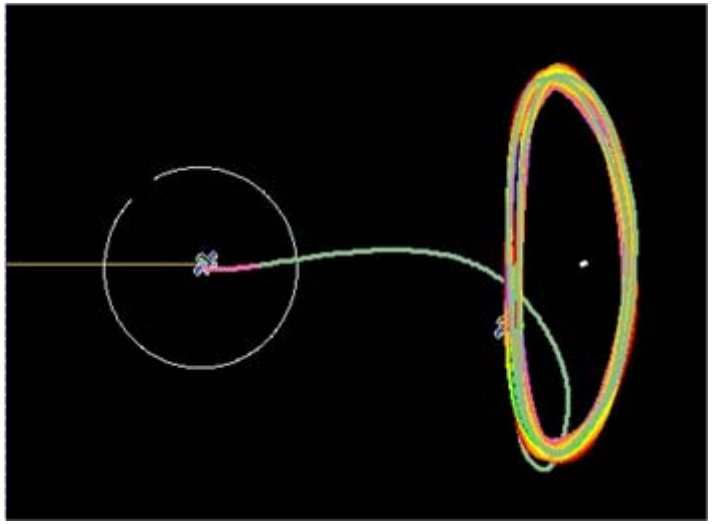
Orbit Considerations

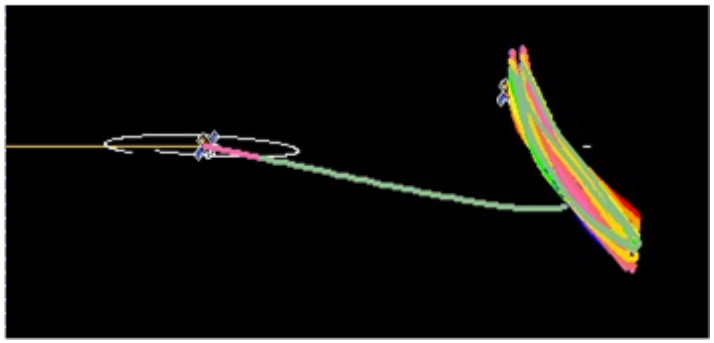
Courtesy Mark Beckman, JWST



- Orbit type varies as a function of launch time within a day
- The greater an L2 orbit's amplitude, the less insertion delta-v is required
- Insertion orbit selected to maximize launch opportunities
  - The size of the smallest achievable "zero-insertion-delta-v" orbit is a function of launch date
  - Frequent launch opportunities exist for "zero-insertion-delta-v" 800,000 km orbits (several opportunities every week)
  - ~1-2 launch opportunities per year for "zero-insertion-delta-v" 700,000 km orbits

- Baseline Orbit: 700,000 km "Y" semi-major axis L2 orbit

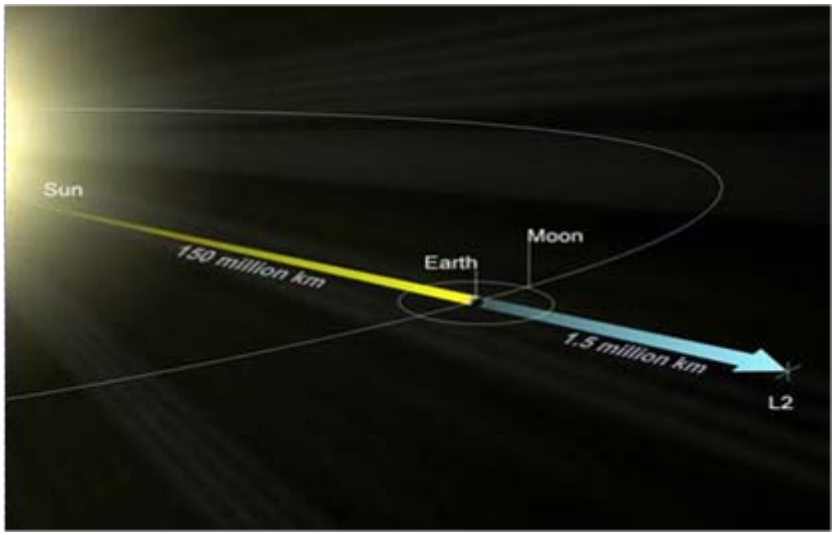




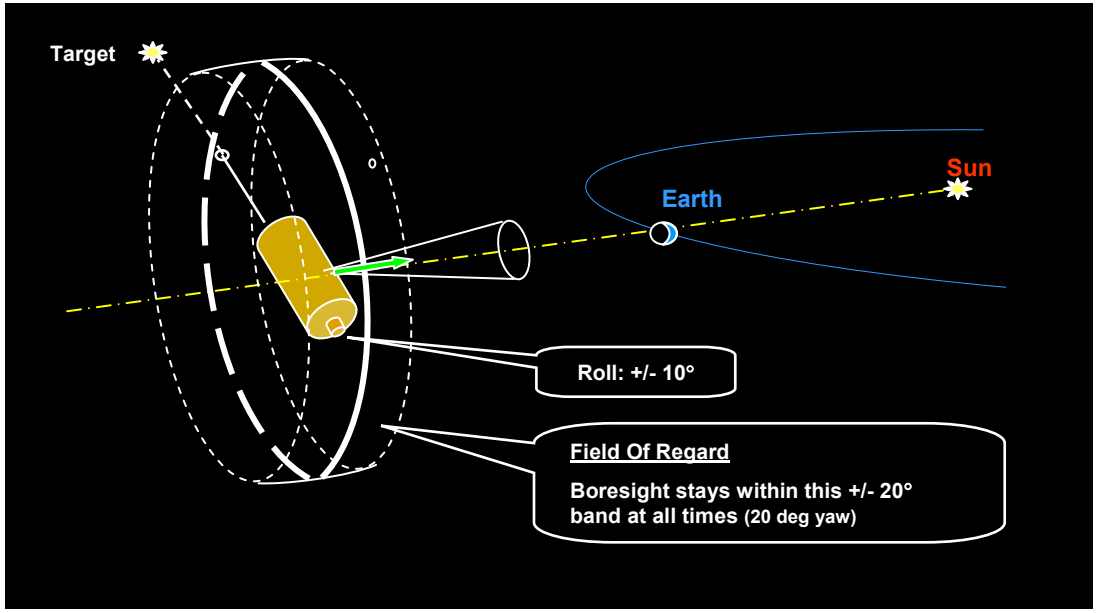
- Orbit mostly inside Earth's Magnetosheath
  - Lower low energy particle flux (solar wind)
- No Earth shadows during length of mission at L2
  - Potential of lunar penumbra at < 14% obscuration
- L2-Earth-SC Angle varies from 7° to 30° over 10 years

Mission Timeline

- Launch (L) at T0
  - Instruments and Cryo completely deenergized, Spacecraft power in Launch Mode (low power)
  - Launch Vehicle (LV) First Stage is ballistic (falls into ocean)
- Transfer Trajectory Insertion (TTI) at L + 25 to 120 minutes
  - Performed by LV Second Stage
- LV Separation: TTI + 5 minutes
  - LV 2nd stage Collision and Contamination Avoidance Maneuver
  - LV separation, Observatory in Acquisition Mode; acquire Sun-positive nominal attitude
  - Need live RF Comm w/ ground (have TDRSS capability)
- Deploy Solar Arrays & High Gain Antenna
- Spacecraft full power on
  - Some portions of Payload on, Cryo off
- Commence Observatory Checkout
- ELV Dispersion Corrections at TTI + 24 hours
- Deploy Metering Structure
- Commence Instrument Aliveness Checks
- Observatory Outgas
  - At least 2 weeks
- First Mid-Course Correction: TTI + 16 days
- Instrument internal background measurement
- Jettison / Open Flight Mirror Assembly Covers, turn Cryo on
- Open Instrument Covers and Gate Valves
- Calibrate w/ Celestial Targets
- Second Mid-Course Correction: TTI + 60 days
- L2 Orbit Insertion (L2OI) / Y-Amplitude Lowering Maneuver: ~ TTI + 100 days
- Science Ops
  - Downlink data (while observing, 30 minutes a day)
  - Repoint as required
  - Momentum Unloading Burns and L2 Stationkeeping burns during slews
  - Switch Instrument Mode every 2 weeks to 1 month
- EOM Disposal: L + 10 years +++ …
  - Delta-v < 1 m/s to driftaway trajectory, optional (not required)



Observation Parameters



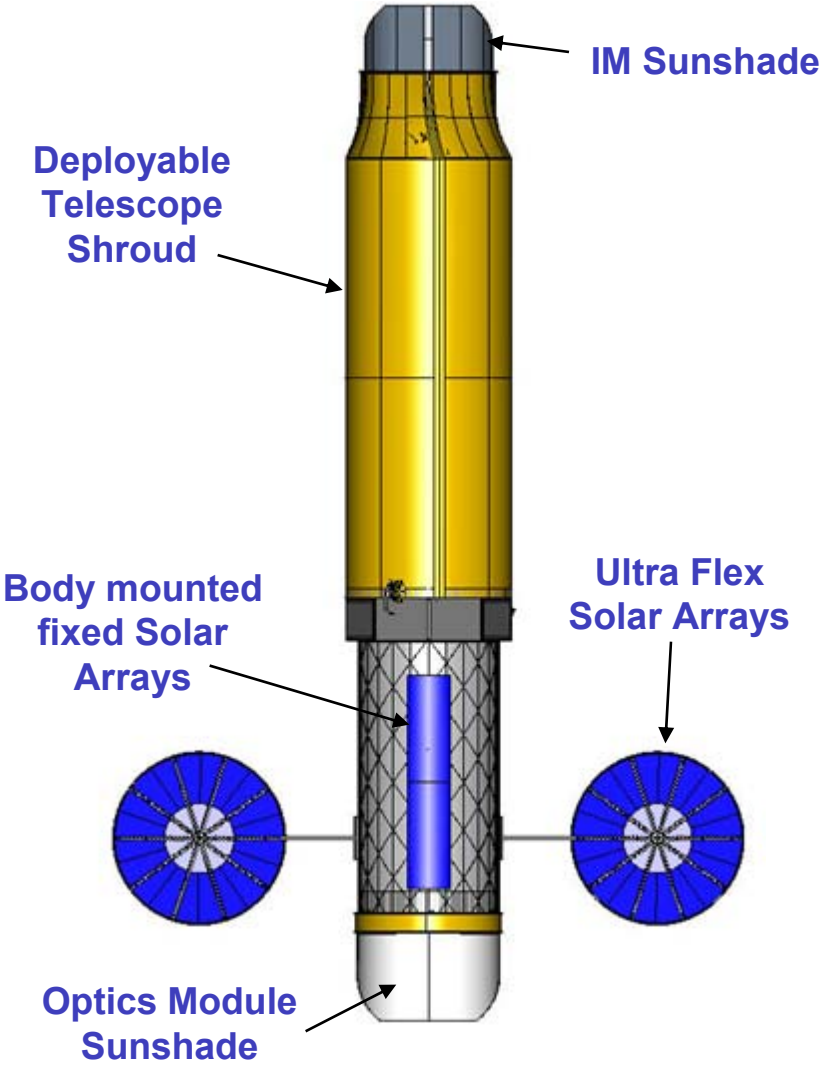
Field of Regard	▪ Pitch: +/- 20° off Sunline ▪ Yaw: +/- 180° ▪ Roll: +/- 10° (with a goal of 20°) off Sunline
Slew	▪ Average slew: 60 degrees in 60 minutes (goal value; negotiable, based on Reaction Wheel selection) ▪ Average # of slews per day: 2.5 during first year of mission, less later
Operational Efficiency	▪ ~85%, when averaged over the mission life
Timing accuracy	▪ Photon arrival tagged to UTC to ±100 μsec

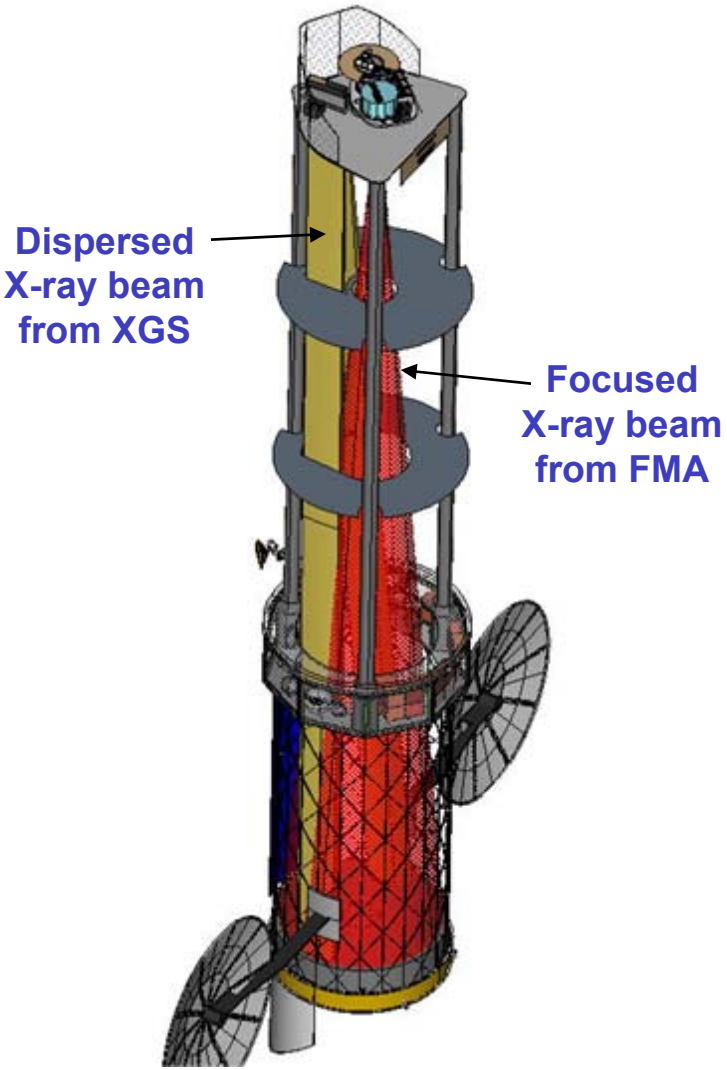
Pointing Parameters

Term	Definition	Parameters	Stat
Image Position Control	The absolute precision of placing and keeping an image on the Focal Plane Detector	• Pitch: 10 arcsec • Yaw: 10 arcsec • Roll: 30 arcsec	3σ
Image Position Reconstruction Knowledge (a.k.a.: "Aspect Reconstruction")	The absolute post-facto knowledge of a down-linked and processed (calibrated, reconstructed) image's position relative to the Truth	• Pitch and Yaw: 0.7 arcsec	HPD
Jitter (excluded from the Image Position Knowledge requirements)	Jitter effects encompass all high frequency errors above the bandwidth of the Control System and Monitoring System	• 200 milliarcsec over 200 msec	HPD

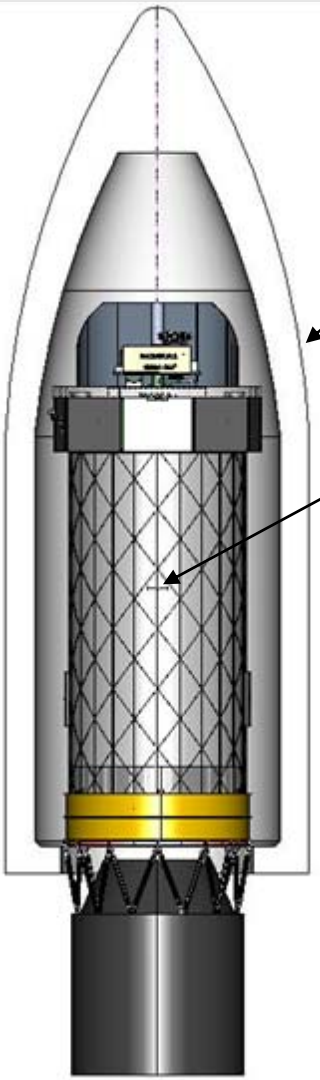
Switch between Mode 1 and 2 on average 2 times per month (based on use of XMS and WFI). Targets available for < 12 weeks per year based on ± 20 deg pitch field of regard.		Science Modes	
		Mode 1	Mode 2
Instrument Operations	Science	XMS, XGS	WFI, HXI, XGS
	Standby	WFI, HXI	XMS
Observation Duration	Average	10 hours	
	Minimum	30 minutes	
	Peak	48 hours	
Percent of time for each Mode		50%	50%

Observatory On-orbit Configuration



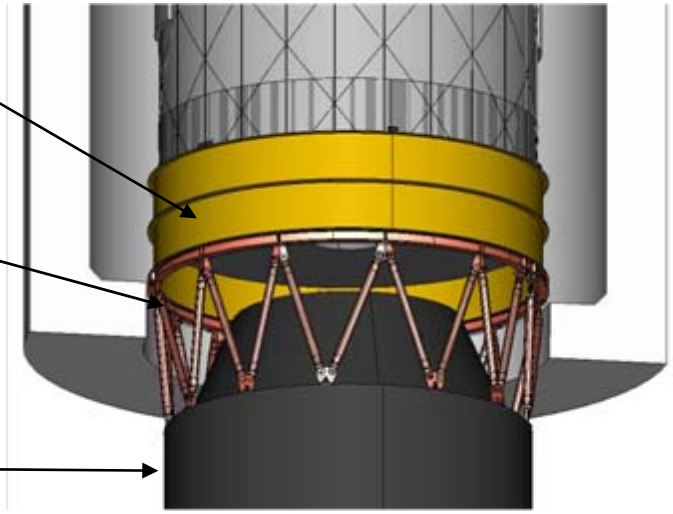


Launch Configuration



Atlas V (551) Medium Composite Fairing

Observatory in Stowed Configuration

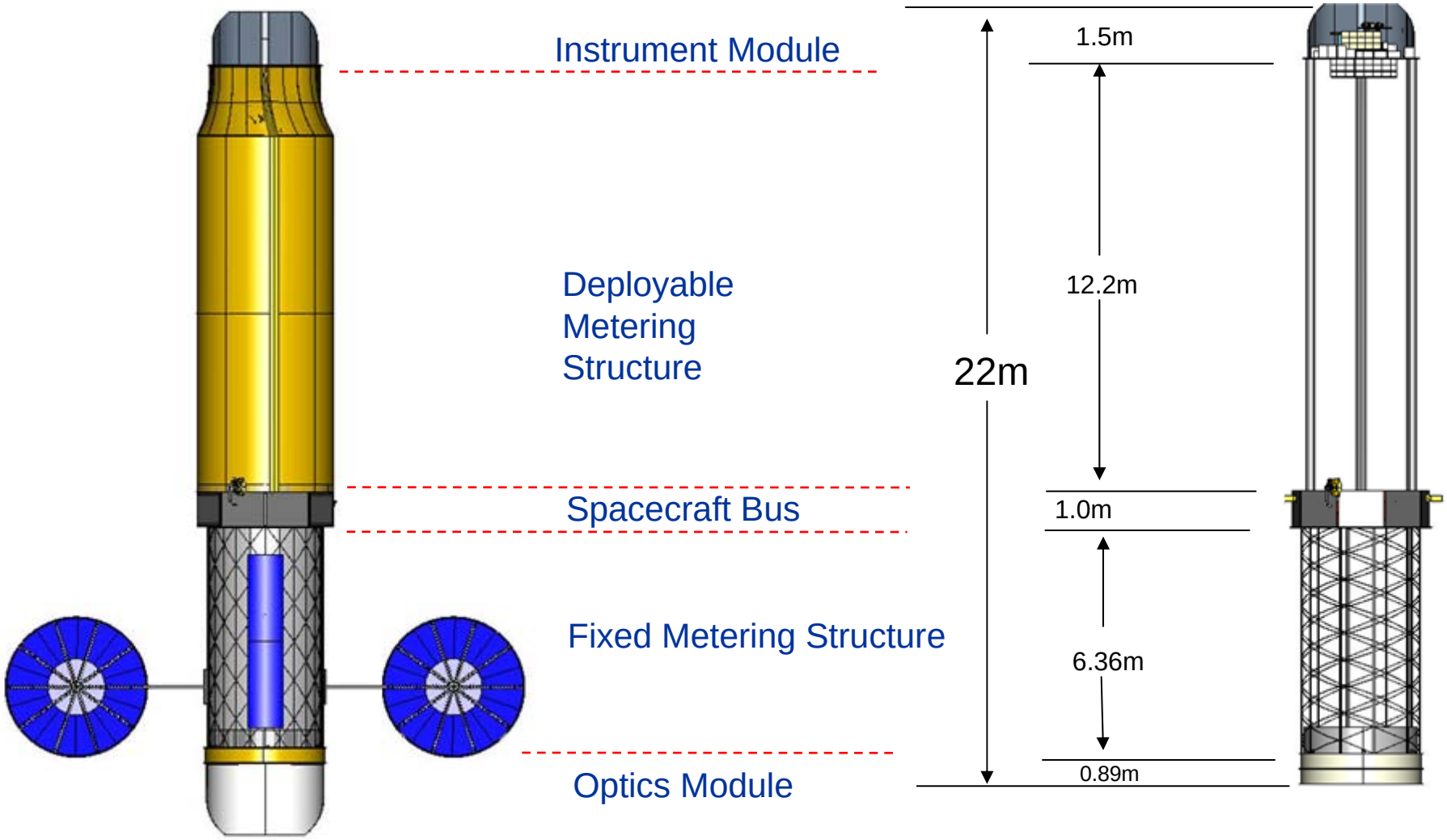


Encapsulation I/F Ring

"3302" Truss Payload Attachment Fixture

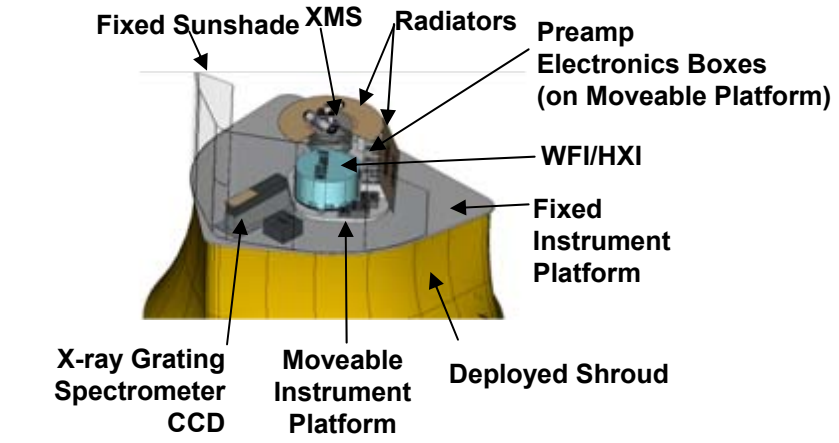
Centaur (Atlas V's 2nd Stage)

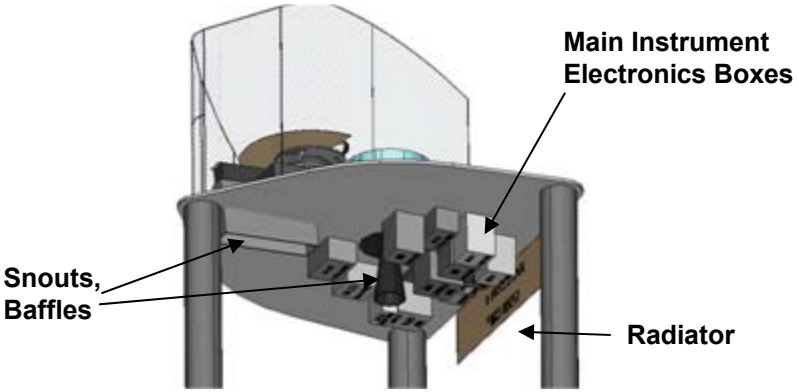
Modular Observatory Design

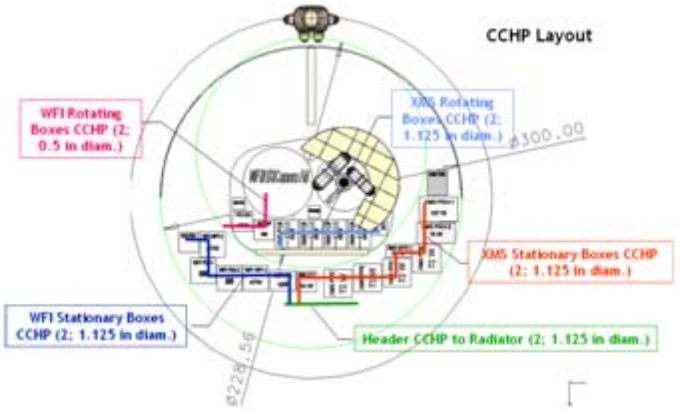


Instrument Module

- XMS and WFI/HXI with pre-amp electronics mount on Moveable Instrument Platform
  - Focus adjust mechanisms on each instrument for initial adjustment on-orbit
- XGS CCD mounts to Fixed Instrument Platform
  - Support structure provides proper interface to Rowland circle and baffle
- Main instrument electronics mount to under side of FIP and radiate in anti-sun direction
- Constant Conductance Heat Pipes (CCHP) transfer heat between electronics and radiators, both on Rotating Instrument Platform and on Fixed Instrument Platform

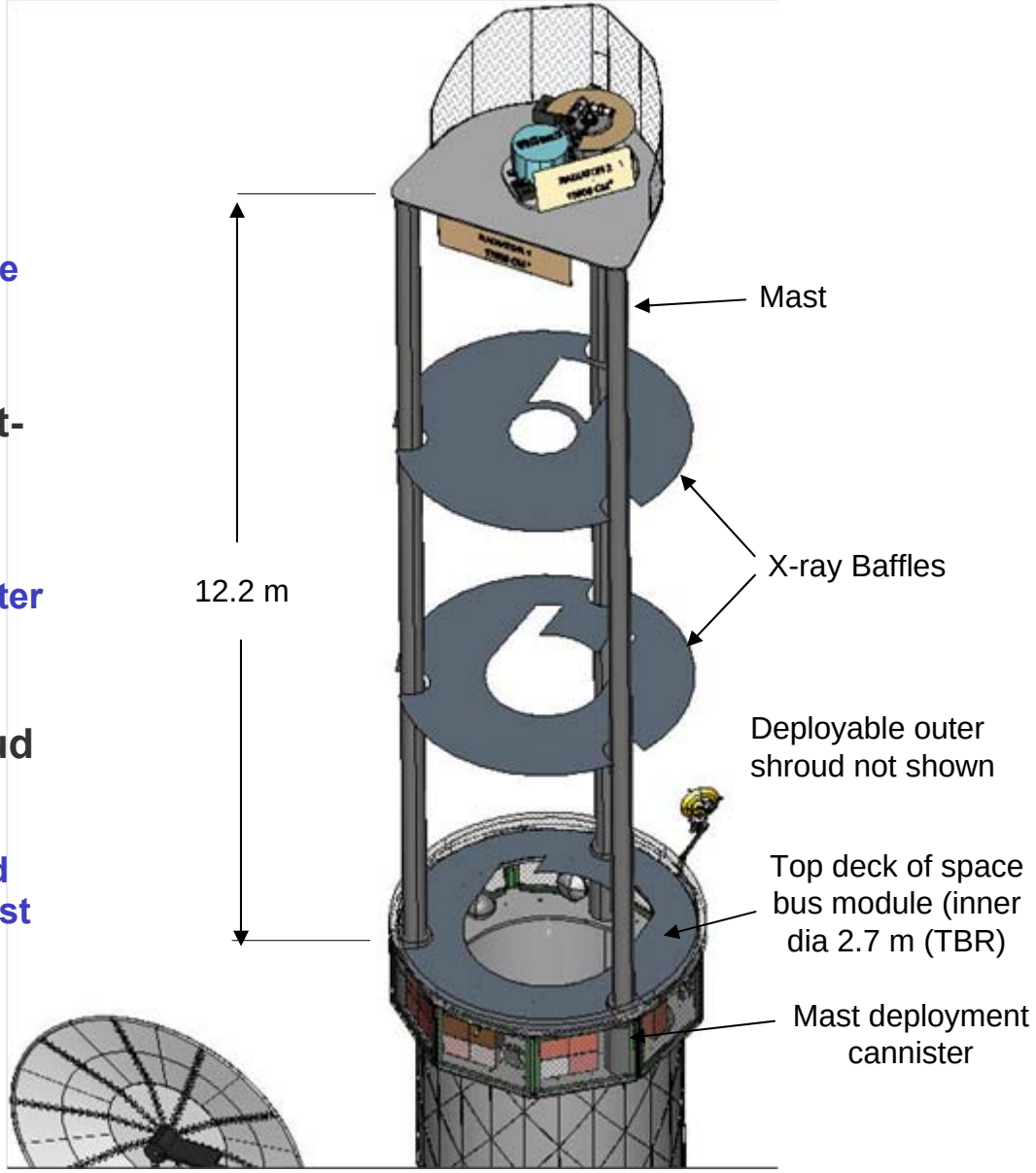




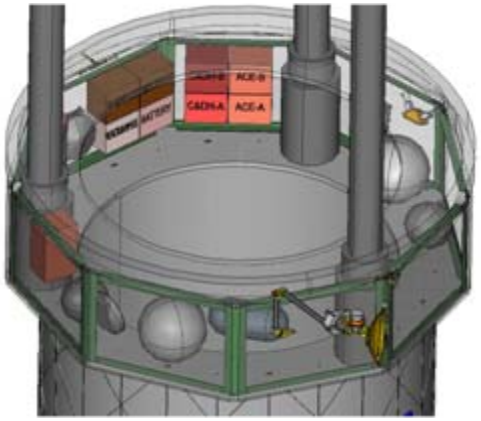


Deployable Metering Structure

- Concept studied utilizes three deployable masts for extensible structure
  - Feasibility verified with NuStar-like mast
- Deployable Telescope Shroud provides thermal protection, light-tight environment
  - Pleated shade type construction
  - Multilayer blanket with Kapton outer skin provides micro-meteroid protection
- Two X-ray baffles attach to Shroud
  - Mylar with tantalum foil
  - Harness between instruments and spacecraft bus deploys within mast system



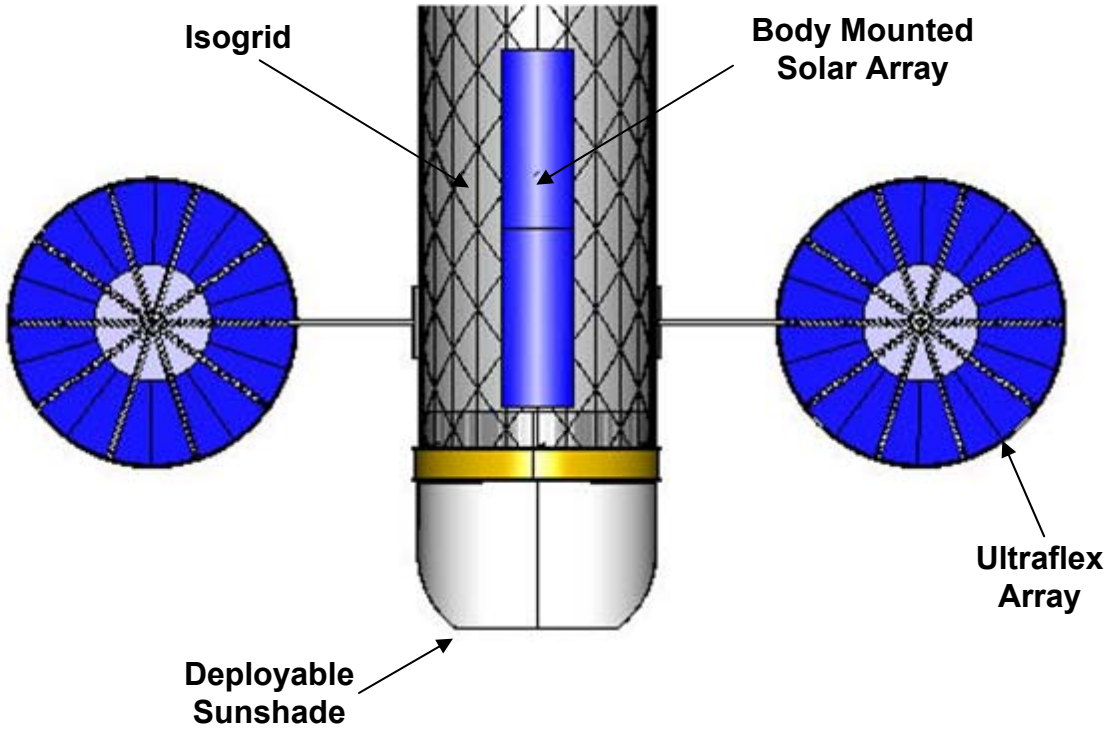
Spacecraft Bus

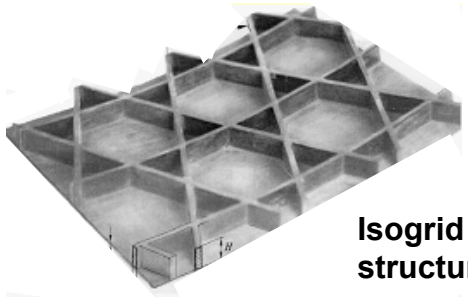


- **Mechanical**
  - Advanced lightweight composites
  - Modular design supports parallel I&T
  - Deployable Metering Structure, LV Separation System, S/As, HGA, Fore Sunshield, Moveable Instrument Platform, Focus Mechanisms, FMA Outer and Inner Covers
- **Propulsion**
  - NTO/Hz Bi-prop pressure regulated system, sized for 10 years
  - 5 tanks, 12 ea. 5 N thrusters
  - Thrusters in pure couples w/ < 0.5 mm/s per day residual delta-v from momentum unloads
- **Attitude Control**
  - 4 reaction wheels in biased pyramid, 4 star tracker heads (2 w/Alignment Monitor Periscope), IRU, sun sensors
  - 3 arcsec (3σ) overall star tracker accuracy
  - Alignment Monitor
- **Thermal**
  - Traditional thermal control (heat-pipes, louvered radiators, blankets, heaters, thermostats)
  - Thermally and electrically independent FMA thermal control system
- **Electrical Power**
  - Ultra-flex deployable and body mounted arrays
  - 18 m^2 total area: 5000 W(BOL); 28VDC, LiIon battery
  - Unlimited safe mode duration even after LV separation
- **Command and Data Handling**
  - Highly redundant web architecture
  - 300 Gbit storage supports required 60 hour nominal plus 12 hour peak data rate w/ ~2 for 3 redundancy
- **RF Communications**
  - Ka-Band for science DSN 34 meter from gimballed 0.7 m HGA at 26 Mbps
  - 30 Gbit/day (@ low science data rate): one 30 minute contact /day, Twice a month: 3 hour contact for 240 Gbits peak rate science data
  - S-Band TT&C via omni to DSN 34m and TDRSS
  - Ranging for orbit determination during downlink

Fixed Metering Structure and Optics Module

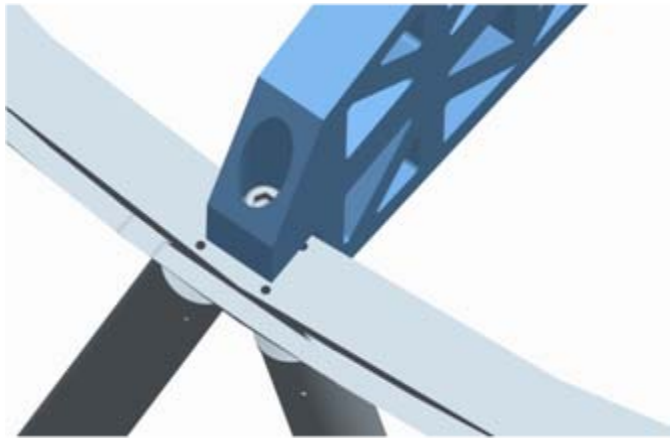
- Advanced Grid Stiffened composite (a.k.a. "isogrid") structure provides stiff lightweight primary structure
  - Same technology as Boeing 787 Dreamliner main fuselage
  - Sized for >10 Hz in launch configuration
- UltraFlex solar array positioned to minimize Center of Pressure to Center of Mass (CP-CM) offset
- FMA outer and inner covers w/ one time removal after Observatory outgassing

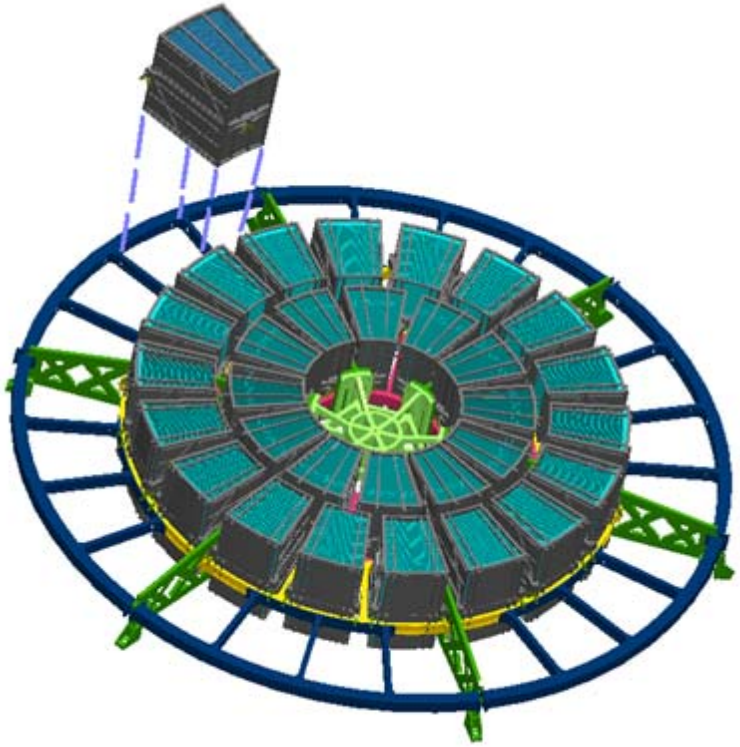


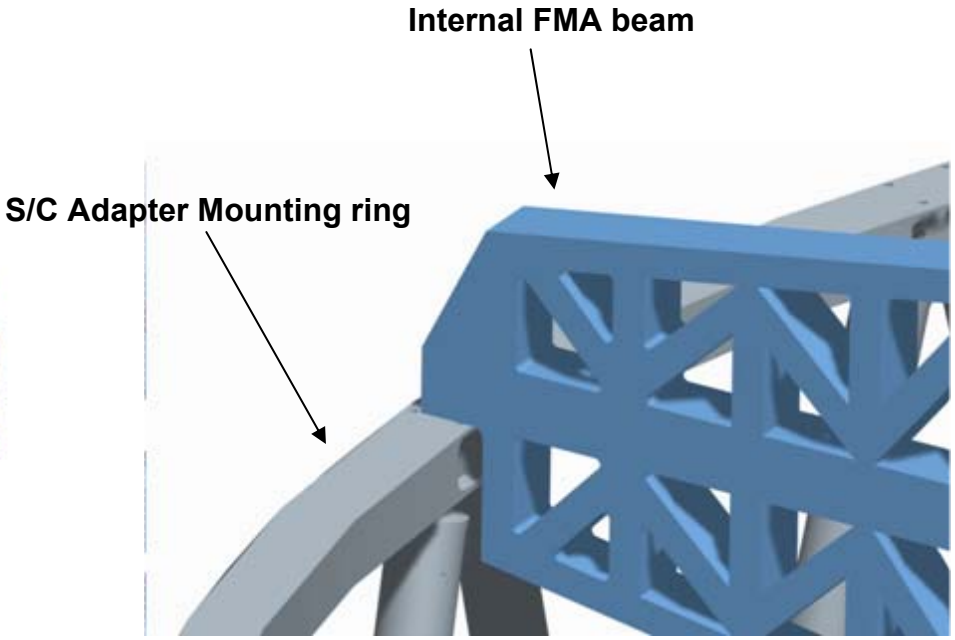


FMA to Spacecraft Interface

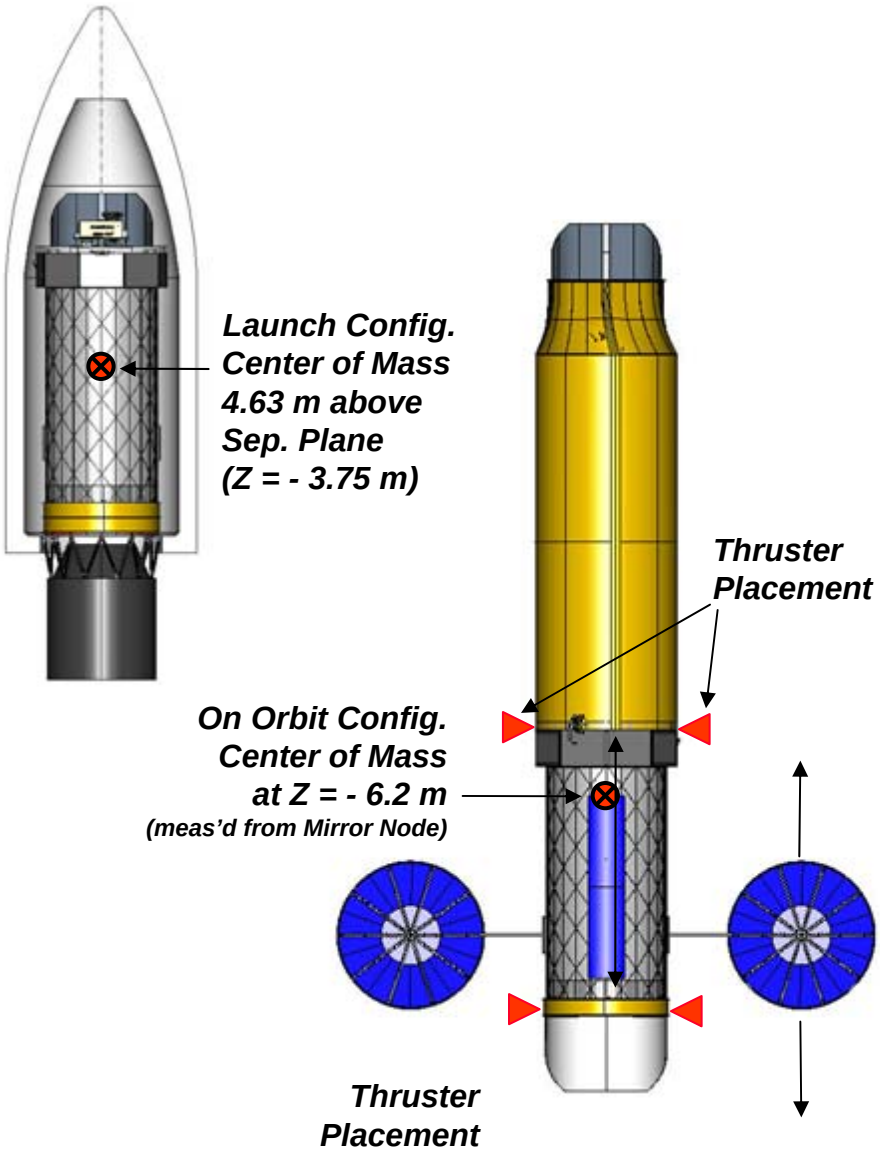
- The FMA primary structure interfaces with the spacecraft at six places with 1” shear fit bolts. The interface is integral to the FMA main beams.
- FMA is not in the load path between adapter and metering structure.







CM Considerations



Three "Center of Mass" (CM) considerations:

1. **Launch Vehicle "CG height limitation"**
   - Height limit of CG in Atlas 551 using a "3302" Truss Payload Adapter: 571.5 cm above Separation Plane
2. **Propulsion thrust vector**
   - Must locate all thrusters on non-deployable parts of the Observatory (welded prop system)
   - CM must be "embraced" by thrusters "above and below"
   - Thrusters must be as far apart as possible for large "slew" moment arm
3. **Center of Mass – Center of (solar) Pressure**
   - Minimizing CM-CP offset:
     - by proper positioning the solar arrays on the Fixed Metering Structure…

   minimizes:
     - solar torque disturbance
     - propellant and frequency of momentum unloading

Low Risk Mission Approach

The Spacecraft (i.e. Observatory minus Science Payload) has numerous features to guarantee mission success:

- **Class B Mission**
  - **No performance degradation w/ single point failure**
- **Credible Deployable Mast performance**
  - **Performance analyzed with existing Nustar-like booms (20m focal length); static pointing performance meets and outperforms IXO needs**
- **Failsafe mechanisms**
  - **Slightly degraded mission possible w/ only 2 of 3 masts deployed**
  - **Failsafe Moveable Instrument Platform mechanism enables actuation even upon failure of the primary mechanism**
- **C&DH**
  - **Ultra redundant "spacecraft wide web" Spacewire architecture**
- **Robust "no-microprocessors" Sun-positive Safe-Mode**
  - **Body mounted solar arrays allow the Observatory to maintain Survival Mode indefinitely even w/o deployed solar array wings**

Mass Rackup

ITEM	CBE	Margin	Alloc.
Optics Module (OM)	2016		2621
Fixed Metering Structure (FMS)	491		638
Spacecraft Bus (SCB)	673		875
Deployable (Aft) Metering Structure (10.6m)	408		530
Instrument Module	695		903
PAF and LV Separation System	227		241
OBSERVATORY DRY LAUNCH MASS	**4509**		**5808**
Propellant Mass (10 Years)			308
OBSERVATORY WET LAUNCH MASS			**6116**
Atlas V 551 Med Fairing Contractual Throw Mass			6425
Project Reserve			309
Project Reserve %			5%

Propellant Calculations

DELTA V BUDGET FOR 5 YEARS				
	Estimate	ACS Tax	Contingency	Subtotal
Launch Window	10 m/sec	5%	0%	11 m/sec
ELV Dispersion Correction	40 m/sec	5%	0%	42 m/sec
Mid-Course Correction	10 m/sec	5%	5%	11 m/sec
Orbit Lowering Maneuver	25 m/sec	5%	0%	26 m/sec
L2 Stationkeeping for 5 years	20 m/sec	5%	5%	22 m/sec
Momentum Management for 5 years	1.8 m/sec	0%	5%	2 m/sec
De-orbit	1 m/sec	5%	5%	1 m/sec
			Total Equivalent Delta V	115 m/sec

ALLOCATION PROPELLANT BUDGET	
	Allocation
Allocation Dry Mass	5574.9 kg
Prop Mass (use equivalent Isp =275)	241.9 kg
5% Ullage and Residual	12 kg
Allocated Propellant Mass	254.0 kg

DELTA V BUDGET FOR 10 YEARS				
	Estimate	ACS Tax	Contingency	Subtotal
Launch Window	10 m/sec	5%	0%	11 m/sec
ELV Dispersion Correction	40 m/sec	5%	0%	42 m/sec
Mid-Course Correction	10 m/sec	5%	5%	11 m/sec
Orbit Lowering Maneuver	25 m/sec	5%	0%	26 m/sec
L2 Stationkeeping for 10 years	40 m/sec	5%	5%	44 m/sec
Momentum Management for 10 years	3.6 m/sec	0%	5%	4 m/sec
De-orbit	1 m/sec	5%	5%	1 m/sec
			Total Equivalent Delta V	139 m/sec

ALLOCATION PROPELLANT BUDGET	
	Allocation
Allocation Dry Mass	5574.9 kg
Prop Mass (use equivalent Isp =275)	293.7 kg
5% Ullage and Residual	15 kg
Allocated Propellant Mass	308.4 kg

Power Loads

(CBE + 30%)	Launch	Cruise	Science	Downlink	Slew	Safehold	Peak
Observatory	66	3496	3345	3367	3623	2495	4115
Science Payload	0	2874	2874	2874	2797	1897	2874
S/C	66	622	471	493	826	598	1241
ACS	16	65	70	70	433	57	569
C&DH	0	192.4	0	0	0	0	0
RF Comm	0	57	57	104	57	57	117
Mech	0	0	0	0	0	0	0
Propulsion	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Power	5	185	217	219	210	175	305
Harness	0	25	29	30	28	24	41
Thermal	39	91	91	65	91	279	203

CBE Numbers	Mode 1		Mode 2		Safehold	Unit Power		
	Ave	Peak	Ave	Peak		Ave	Peak	Standby
Science Payload	2152	2211	2017	1955	1459			
FMA	1394	1394	1394	1394	1394	1394	1394	1394
XMS	649	701	323	215	65	649	701	323
WFI	47	47	211	250	0	211	250	47
HXI	5	5	32	32	0	32	32	5
XGS	57	64	57	64	0	57	64	0

- *PSE BOL power delivered is the max. EOL load + 20% = 5000W (sized for 10 years L2 mission)*

Data Summary

Element		Data Rate (kbps) (Includes 30% contingency)		
		Average	Peak	Comments
FMA	Science	0.0	0.0	
	Housekeeping	1.3	1.3	
	Total FMA	**1.3**	**1.3**	
XMS	Science	52.0	2,184.0	
	Housekeeping	1.3	1.3	
	Total XMS	**53.3**	**2,185.3**	
WFI	Science	58.5	585.0	4.5 Mbps for high background;
	Housekeeping	1.3	1.3	
	Total WFI	**59.8**	**586.3**	
HXI	Science	17.0	150.0	based on BEPAC HXT
	Housekeeping	1.3	1.3	
	Total HXI	**18.3**	**151.3**	
XGS	Science	150.0	1,500.0	
	Housekeeping	1.3	1.3	
	Total XGS	**151.3**	**1,501.3**	
Total by Mode	**Mode 1**	**204.6**	**3,686.6**	
	Mode 2	**229.4**	**2,238.9**	

STORAGE MODE 1	Rate	Unit
Low Science Data Rate per sec	204.6	kbps
Low Science Data Rate - Data Volume per hour	0.7	Gbit
Low Science Data Rate - Data Volume per day	17.7	Gbit
Low Science Data Rate - Data Volume per 60 hours	44.2	Gbit
High Science Data Rate per sec	3,686.6	kbps
High Science Data Rate - Data Volume per hour	13.3	Gbit
High Science Data Rate - Data Volume per 12 hours	159.3	Gbit
Mode 1 Storage Total	**203.5**	**Gbit**

STORAGE MODE 2	Rate	Unit
Low Science Data Rate per sec	229.4	kbps
Low Science Data Rate - Data Volume per hour	825.8	Gbit
Low Science Data Rate - Data Volume per day	19.8	Gbit
Low Science Data Rate - Data Volume per 60 hours	49.6	Gbit
High Science Data Rate per sec	2,238.9	kbps
High Science Data Rate - Data Volume per hour	8.1	Gbit
High Science Data rate 12 hours	96.7	Gbit
Mode 2 Total	**146.3**	**Gbit**

Summary and Future Work

- Baseline mission concept appears viable
  - Spacecraft (i.e. Observatory minus Science Payload) appears feasible with technologies that exist today
- Work is continuing by refining the design in every discipline with recursive iteration thru all system implications until full convergence:
  - Finite Element Modeling (launch and on-orbit configurations) to validate mass estimates
  - Control System requirements definition (full science requirements flow-down) and performance analysis
  - Alignment Monitor definition and accommodation
  - Component layout, both Spacecraft and Science Payload
- Future mission configuration work is anticipated to address
  - 20 vs. 25 m focal length trades
  - Payload modifications to achieve hard X-ray response
  - Compatibility with micropore mirror
  - Compatibility with Ariane V launch vehicle