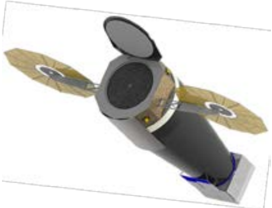
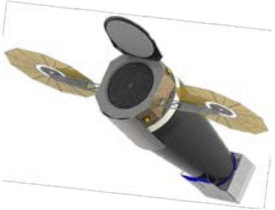


Lynx Mission Costing Methodology

Karen Gelmis / MSFC
Lynx Study Manager

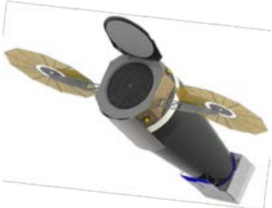
- Introduction
- Costing Inputs
- Costing Methodology Overview
- Costing Methodology Details
- Closing Comments

Introduction



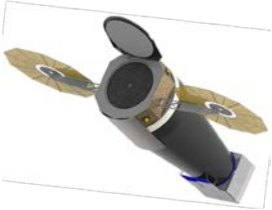
- Strong foundation for Lynx mission costing effort:
  - Clear science, mission and Observatory architecture requirements for a closed DRM design
  - Availability and leverage of deep Chandra heritage for spacecraft design, mission architecture and operations to minimize costing unknowns
  - Detailed inputs from Lynx technical and programmatic experts
  - Availability of Chandra program and contracting personnel for insights and lessons learned on programmatic, technical and costing analysis
  - Rapidly maturing Lynx technologies with clear development paths to achieve necessary TRL milestones
- Costs validated at element and mission level via analogies, in-family comparisons and multiple, independently conducted cost estimates with different approaches
- Lynx mission cost range across all methodologies is \$4.8B at 40% confidence level (CL) to \$6.2B at 70%CL in \$FY20
  - Cost confidence results highly consistent at ~40% CL, reflecting well-developed mission design with high heritage and lessons learned from past and present missions
  - Cost results diverge at 70% CL, reflecting appropriate pre-formulation-stage uncertainties
- Full details of entirety of costing efforts included in non-public Lynx Cost Book

Costing Inputs: Schedule Pre-Phase A through TRL6



- Instrument and Optics Technology Development Roadmaps lay out detailed pre-Phase A / Phase A schedules and milestones for achieving requisite TRL levels
- Requirements / assumptions:
  - Pre-Phase A funding start 10/2021
  - Architecture selection 2/2024
  - Phase A start 10/2024 / technologies at TRL5
  - Mission PDR 2/2028 / technologies at TRL6
  - All Lynx technologies remain actively funded during Pre-Phase A
    - Multiple decision points during pre-Phase A for technology down-select
    - Final down-select prior to start of Phase A based on ability to meet Lynx requirements
  - WFIRST technology development funding levels provided sanity check
- Included schedule margins for achieving TRL milestones based on risk assessments
- Iterated to arrive at schedule consistent with assumptions, technology development plans, and the overall project lifecycle schedule
- Pre-Phase A / Phase A technology development schedule provided in Figure 7.1 of Lynx Concept Study Report

Costing Inputs: Schedule Phase A - E



- Reflects inputs and development planning from Lynx technology, engineering and science operations teams

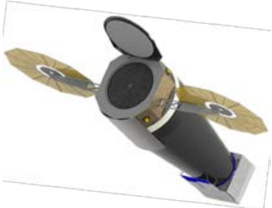
- Is consistent with technology development and current DDT&E plans for the DRM optics and instruments

- Leverages heritage and analogous AI&T, on-ground calibration, and mission and ground operations activities

- Is aligned with NASA project lifecycle milestones, and GAO best practices consistent with pre-Phase A project maturity

- Full Lynx lifecycle schedule provided in Figure 8.3 of Lynx Concept Study Report

Costing Inputs: Schedule Phase A - E

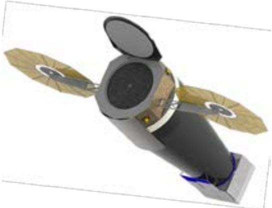


- Compared phase durations with WFIRST and Chandra as sanity check
- Included total schedule margin of 19 months consistent with MSFC practices, project complexities and risks
- Critical path runs through LXM DDT&E, through ISIM I&T, and through XRT, Observatory and launch vehicle I&T activities
- Further optimization possible based on mirror manufacturing studies, AI&T sequencing and on-ground calibration scope
- LCIT Comment: "…schedule well done"

While notional, project lifecycle schedule provides a credible path to launch in the mid-2030's

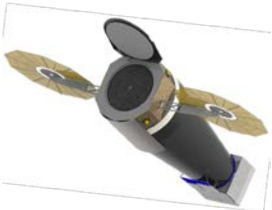
Project Milestone	~Milestone Date
Tech. Dev. / Start of Pre-Phase A	10/2021
Architecture Decision	2/2024
KDP-A / Start of Phase A	10/2024
SRR / MDR	2/2026
KDP-B / Start of Phase B	10/2026
PDR	2/2028
KDP-C / Start of Phase C	4/2028
CDR	11/2029
Start of Flight Unit On-ground Calibration	12/2031
Start of ISIM I&T	6/2032
Start of LMA I&T	8/2032
Start of XRT I&T	4/2033
SIR	6/2035
KDP-D / Start of Phase D	7/2035
ORR	3/2036
LRD	10/2036
KDP-E / Start of Phase E	11/2036
End of Primary Mission	11/2041

Costing Inputs: WBS, MEL and Power Schedule



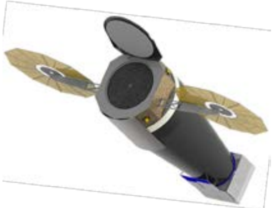
- Work Breakdown Structure (WBS)
  - Provides project organizational structure consistent with NASA guidance
  - Similar to Chandra for organizational and analogous cost comparisons
  - Defined to Level 3 for all elements, and Level 6 for XRT and SCE consistent with Observatory design details
  - Summary WBS provided in Table 8.4 of Lynx Concept Study Report (full WBS provided in Appendix E)
- Master Equipment List (MEL)
  - Provides predicted mass for XRT and SCE systems, using sub-system and component-level basic mass
  - Predicted mass based on industry-standard MGA for Pre-Phase A maturity and TRL considerations
  - Full MEL provided in Appendix D of Lynx Concept Study Report
- Power Schedule
  - Provides SCE, optics and instrument design power levels with margin for all operational phases
  - Power system components designed and costed per power schedule
  - Power schedule provided in Table 6.16 of Lynx Concept Study Report
- LCIT Comment: "…WBS complete & MEL and PEL reflect a lot of work traceable to design"

Costing Methodology Overview



- Pre-Phase A cost estimates provided by technologists in the Technology Development Roadmaps
- Phase A – E
  - Enabled by relatively straightforward and detailed Lynx Observatory design, detailed technology maturation plans, and use of rich Chandra heritage and lessons learned
  - Lynx lifecycle cost estimated and validated using multiple methods:
    - Parametric Cost Estimate:
      - Primary project estimate (point estimate + confidence level (CL) analysis)
      - Includes multiple parametric models for all cost elements
      - Consistent with pre-Phase A project maturity, GAO Best Practices and *NASA Cost Estimating Handbook*
    - Validation Methods:
      - Comparison to escalated (FY20) Chandra actuals (point estimate)
      - Grassroots estimate (point estimate)
      - Non-advocate Independent Cost Estimate (ICE) (point estimate + CL analysis)
      - Independent Cost and Technical Evaluation (CATE) (point estimate + CL analysis)
  - Validation estimates yielded results in reasonable agreement with parametric

Parametric Estimate

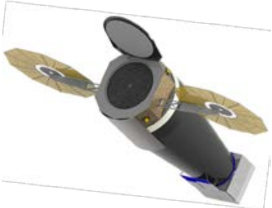


- Parametric model is primary cost estimate for Lynx
  - Consistent with pre-formulation stage design
  - True bottoms-up with vendor quotes not feasible
- Utilized multiple industry-standard models in parametric cost analysis
- Used subject matter expert inputs at the component level for all elements
- Incorporates high Chandra architecture heritage, high-TRL spacecraft components, and detailed designs for the DRM technologies

General GR&A for Lynx Parametric Estimate

Parameter	Value
Baseline Cost	$FY20 per NASA inflation tables
Phased Mission Cost	$RY per NASA inflation tables
Fee	10% applied to Spacecraft, ISIM, OBA and LMA; no fee for science instruments (assumed NASA or university-developed)
Reserves	30% on Phases B – D, excluding launch services and fee
Design Approach	Protoflight
Mission Risk Class	A
Parts Class	Unmanned space class S1 with associated redundancies (per MEL)
Flight Unit Quantity	1
Spares	10% for all subsystems
Phase A Estimate	5% of DDT&E + Flight Unit total
Public Outreach Estimate	1% of XRT (WBS 05) + SCE (WBS 06)

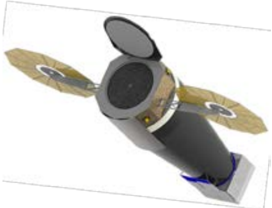
Parametric Estimate



- Other inputs and assumptions:
  - Per NASA HQ direction, Launch vehicle cost (for 2030’s heavy lift vehicle) was a pass-through
  - LXM cost was a pass through from GSFC Instrument Design Lab (IDL) cost analysis
  - Funded schedule reserves included for identified schedule risks and critical path margins
- Cost model input tailoring:
  - Necessary given scarcity of X-ray mission analogies in the historical databases from which the CERs are drawn
  - Able to realistically represent Lynx technologies given relatively high TRL and detailed, current knowledge of development approach
  - Specific parametric model inputs provided in Table 8.7 in Lynx Concept Study Report

The DRM parametric mission cost is in the range of $4.8B at a 40% CL to $6.0B at a 70% CL in FY$20

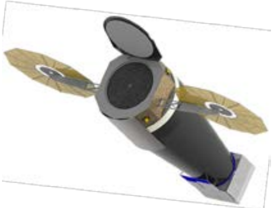
Parametric Estimate
Lynx X-ray Mirror Assembly



- LMA parametric costing given special consideration due to lack of directly applicable historical comparisons
- Complex but cost-effective assembly due to many similarly manufactured and assembled sub-components
- Modeled assuming “learning curve” to account for repeated manufacturing processes
  - “make”->”major modification”->”average modification”
- Other model specifics targeted realistic development and manufacturing
  - “Staggered development start” of meta-shells to benefit from development of first one
  - “Concurrent production” to take advantage of assumed 12 production lines
- Estimate includes cost for LMA prototype (3 meta-shells, 9 fully populated modules, mass dummies for all else), consistent with TRL maturation plans
- GSFC Silicon Meta-shell optics team provided design details to support veracity of cost modeling inputs and assumptions
- LMA manufacturing risk accounted for in 9 months of costed schedule margin

Parametric LMA estimate within 4% of GSFC Silicon Meta-shell Optics team grassroots estimate

Parametric Estimate Spacecraft



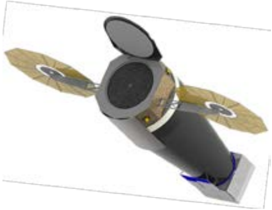
- Spacecraft parametric costing also given special consideration due to high levels of heritage in subsystem design
- “Heritage Rating” settings in parametric model reflect degree of modifications assumed for each subsystem, and play a role in the cost
- Overall Heritage Rating of 5.1 for Lynx Spacecraft system is between “major” and “minor” modification, consistent with the design

Subsystem	Subsystem Heritage Rating
Structure	5.0
Thermal Control	3.8
Electrical Power & Distribution	4.2
Attitude Determination & Control	6.2
Reaction Control	4.2
RF / Communication	6.8
Command & Data	5.8
Cost Model Flight System Heritage Rating	**5.1**

Heritage Rating Key:
>0 = All items @ TRL< 7
1 = New, but standard practice
3 = Major Modification
7 = Minor Modification
10 = Exact Repeat (copy)

No new developments for spacecraft; only modifications to existing components

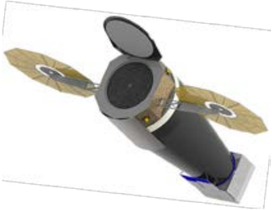
Chandra Analogy



- Mission architecture heritage and availability of actual costs make comparison of the Lynx parametric estimate to escalated ($FY20) Chandra costs possible
- A side by side comparison of requirements and costs shows that many Lynx elements are analogous or comparable to Chandra
  - Spacecraft elements and operations very similar, HDXI ~ACIS, XGS ~HETG+ACIS
  - Summary of comparisons provided in Table 8.9 of Lynx Concept Study Report
- Lynx elements less amenable to direct comparison to Chandra are the LMA and LXM
  - LMA:
    - Base material (monocrystalline Si) is inexpensive and readily available
    - Laboratory performance of machinery to shape, polish and smooth mirror segments has been demonstrated
    - Flight production is modular with assembly line cost efficiencies
  - LXM design leverages successes from Hitomi, XRISM and Athena
  - Costs for these elements are well understood

Huge gains in capability that Lynx provides do not directly translate into huge cost increases over inflated Chandra actuals

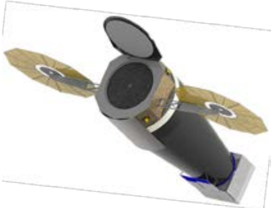
Grassroots Estimate



- Skilled and diverse team of experts developed a grassroots estimate for each WBS Level 2 code, and WBS Level 3 code in some cases
  – Team included Chandra project and prime contractor team members, and Lynx science, engineering and technology team members
- Estimates included a mix of Chandra-analogous estimates, scaled actuals for Chandra prime contractor activities, and true grassroots based on Lynx development planning
- Launch vehicle cost same as NASA HQ provided pass-through used for parametric
- Fee and 30% reserves applied as applicable
- Detailed BOE provided in Table 8.11 of Lynx concept Study Report

Lynx parametric estimate is within 4% of grassroots estimate

Additional Validation Assessments



Non-Advocate Independent Cost Estimate (ICE)

- The MSFC Engineering Cost Office performed a non-advocate ICE and uncertainty analysis on the Lynx parametric estimate
- ICE addresses uncertainty in estimating methods, input parameters, and design complexity, using Cost Office assumptions and processes
- Produced uncertainty curve for project cost
- Lynx parametric estimate (with reserves) at 38% CL on ICE uncertainty curve.
- Per MSFC Cost Office analysis, 38% CL substantially better than typical level of 15% for NASA missions at this stage

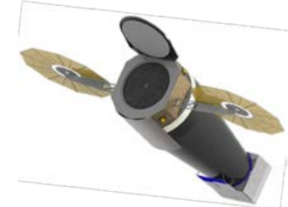
Independent risk assessment results, "…consistent with historical NASA mission cost growth behavior"

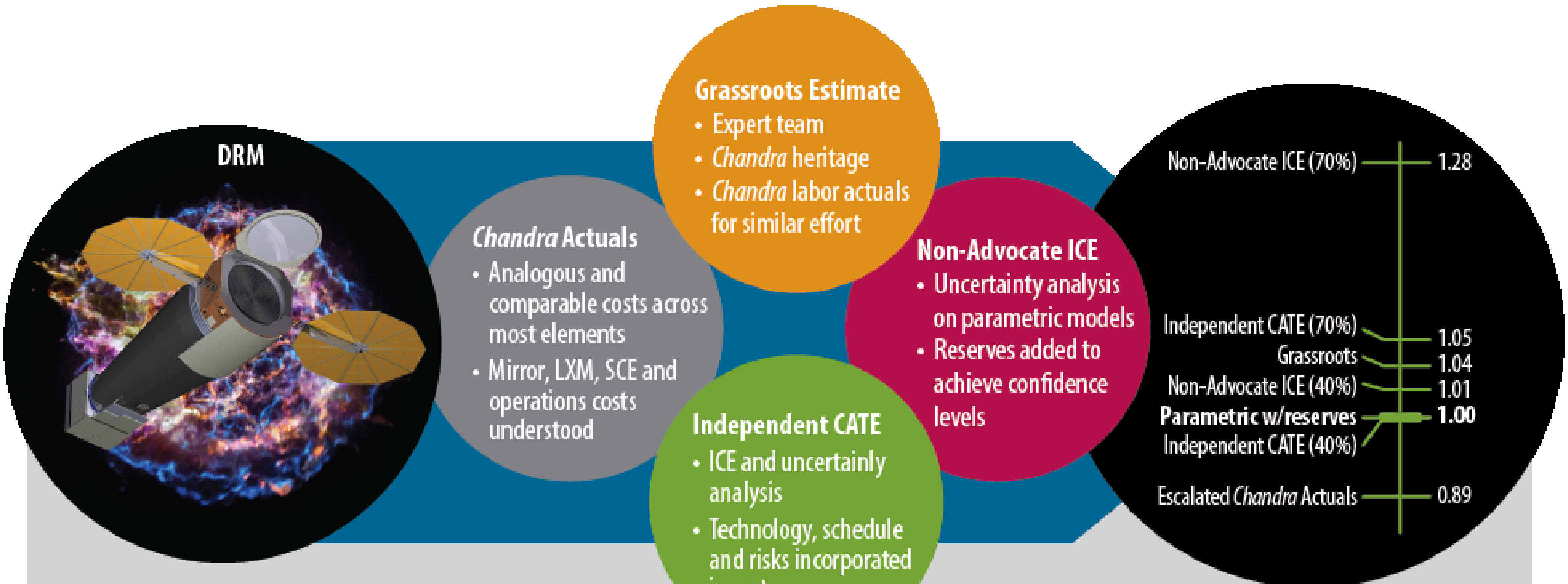
Independent Cost & Technical Evaluation (CATE)

- Lynx team procured services to perform an independent CATE for further costing validation
- Contractor developed risk-based project cost estimate and schedule forecast
  - Developed detailed, independent parametric cost estimate
  - Analyzed project schedule, Technology Development Roadmaps & DRM architecture to determine missing or underestimated development costs and schedule risks
  - Produced uncertainty curves for total project cost and schedule
- 40% CL on CATE uncertainty curve within 1% of Lynx parametric

Lynx parametric cost estimate is, "…reasonable, credible, reproducible, and consistent with the DRM parameters"

Lynx Costing Effort Summary



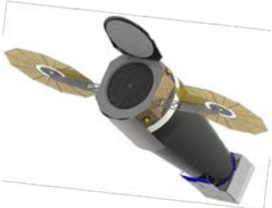


Project Parametric Cost Estimate
- Multiple parametric models for all elements
- In-family comparisons at sub-system level
- SME inputs for all elements
- Transparent and clearly defined BOE and assumptions

Multiple, Independently-conducted Cost Assessments and Estimates with Different Approaches

Credibly-costed Mission
- Cost validation analysis results range from -11% to +28% of parametric estimate
- Parametric estimate consistent with 40% confidence level on CATE and Non-Advocate cost curves

LCIT Comment: "…cost estimate very well done and credible…with understanding of task at hand"



Lynx Mission Costing Closing Comments

- Lynx mission benefits greatly from Chandra heritage and lessons learned, straightforward Observatory design, rapidly maturing technologies with clear maturation paths, and a relatively low risk posture
- All DRM technologies are actively funded, and will continue development per detailed roadmap plans, with risk and progress-based decision points up through the final architecture selection
- Lifecycle schedule is consistent with DRM technology development plans, includes analogous and heritage mission lessons learned, and includes conservative margins consistent with development risks
- Mission parametric costing effort takes advantage of multiple models and analogous elements for comparison, and detailed design knowledge to tailor inputs as necessary for credible results
- Costing effort goes beyond parametric analysis to include multiple, separately-conducted cost validation exercises providing additional peer reviews, sensitivity analyses and independent crosschecks
  - Close clustering of the costing results around the parametric
  - Good agreement, especially for this phase of mission

Substantial effort by entire Lynx team resulted in thorough and credible costing for a pre-formulation stage mission