Large Mission Concept Independent Assessment Team (LCIT)

PUBLIC FINAL REPORT to Astrophysics Division Director

November 8, 2019

For Public Release

Outline

- 1. Executive Summary (slides 3-9)
- 2. Introduction and Background (slides 10-13)
- 3. LCIT Process (slides 14-16)
- 4. LCIT Assessment for each Concept (slides 17-24)
 - 4.1 HabEx
 - 4.2 LUVOIR
 - 4.3 Lynx
 - 4.4 Origins
- 5. General Observations and Recommendations (slides 25-27)
- 6. Cost Analysis (slides 28-39)
- 7. Appendices
 - 7.1 LCIT Terms of Reference (slides 41-49)
 - 7.2 Acronyms (slides 50-52)

1.0 Executive Summary

LCIT Executive Summary (1)

The LCIT recognizes the tremendous amount of work and effort that the STDTs did to develop these concepts and produce their Final Reports.

- The NASA Astrophysics Division sponsored four large-scale mission concept studies as part of NASA's preparations for the 2020 Astrophysics Decadal Survey.
- The four large mission concept studies, led by community-driven Science and Technology Definition Teams (STDTs) and supported by NASA Centers and industry partners are: Habitable Exoplanet Observatory (HabEx), Large Ultraviolet Optical Infrared Surveyor (LUVOIR), Lynx X-ray Observatory (Lynx), and Origins Space Telescope (Origins).
- As part of the process of developing and preparing the STDT Final Reports for submission to NASA and the 2020 Decadal Survey, the NASA Astrophysics Division tasked an independent assessment team called the Large Mission Concept Independent Assessment Team (LCIT) to conduct a technical, risk, and cost assessment of the four concept studies.
- Throughout the LCIT analysis process, the LCIT interacted with the four STDTs and the assigned NASA lead Centers' (GSFC, MSFC, and JPL) cost teams to identify issues and concerns, request clarification of data products provided, and specify additional products that would be needed by the LCIT in order to complete their assessment.

LCIT Executive Summary (2)

- All of these mission concepts are just that, concepts that are in Pre-Pre-Phase A and have significant work ahead for them to mature the technologies, conduct trade studies and refine their design before entering Phase A.
- The LCIT asked the Chief Technologists of the respective Astrophysics Division Program Offices to provide an independent assessment of the maturity of the technologies, reviewed their inputs, and conducted a detailed review of the technology development plans to mature these technologies to TRL 6.
- The LCIT cost analysts developed Phase B-E cost model estimates for each concept using consistent assumptions, approaches, and models for all four concepts.
- The initial LCIT reviews of the draft Final Reports (provided to the LCIT in late April and early May 2019) resulted in approximately 100 issues and concerns across the four mission concepts. These findings (along with results from STDT internal reviews) were provided to the STDTs for their use in improving, correcting, and clarifying their Final Reports before public release.

LCIT Executive Summary (3)

- The traceability from the science objectives as described in the STM are clear in all of the four Final Reports.
- Some of the missions discussed additional science objectives that may or may not be possible but are not included in the science objectives and are not supported in the Final Report.
- If the capabilities and requirements of the observatory system, instruments and operations are met, the science objectives of each concept should be achievable within a 5-year prime mission.
- Considering advanced technology development, LCIT finds that each of the four STDTs underestimate the NASA investments required to mature their enabling technologies to TRL 6. In particular, additional cost reserves for all technology development phases will be needed. Advanced Technology Development (ATD) reserve levels for pre-TRL 5 technologies should be 100% of planned baseline activity; levels for technologies starting at TRL 5, 50%.

LCIT Executive Summary (4) LCIT Advanced Technology Development Cost Assessment

- This shows for two different scenarios for each concept the impact of adding LCIT recommended cost reserves to the ATD efforts
 - It is recognized that some reserves/margins are incorporated into some of the lower-level STDT ATD activities



LCIT Executive Summary (5)

- Phase B-D cost models are based on historical data from smaller, less complex missions. Cost models do use Chandra and Spitzer data, though those missions were launched 15-20 years ago. JWST and WFIRST data will not be incorporated fully in the cost models until after launch. HST data are of limited value because of reporting and other issues. The results is large uncertainties in the estimated Phase B-D costs of all four STDT missions.
- For all four concepts, since these are large, complex missions, the use of traditional cost and schedule reserve "rules" (which are based on data bases of smaller and less complex missions) results in underestimation of the level of reserves needed.

LCIT Executive Summary (6)

The LCIT defined "Cost Bins" (for Phases A-E*) as the most effective way to deal with the cost uncertainties for assessment (in FY20\$)

- Lynx and Origins are assessed to be in a \$6-8B bin
- HabEx and LUVOIR-B are assessed to be in a \$8-10B bin
- LUVOIR-A is assessed to be in a greater than \$10B bin

The LCIT was able to validate 3 of the 4 concepts cost estimates

- STDT Phase BCD costs appear reasonable for 3 of 4 concepts
- LCIT Phase BCD estimates are within 20% of the STDT value for 3 of 4 concepts
- The HabEx LCIT estimate is higher than the STDT value
- STDT Phase E costs for all concepts are reasonable, operation concepts are based on other great observatories

* Does not include ATD, pre-Phase A, ATD/pre-Phase A reserves, LV, or Contributions

2.0 Introduction and Background

LCIT FINAL Report 2.0 Introduction and Background (1)

- NASA Astrophysics Division sponsored four large-scale mission concept studies as part of NASA's submission to the 2020 Astrophysics Decadal Survey
- The four large mission concept studies, led by community-driven Science and Technology Definition Teams (STDTs) and supported by NASA Centers and industry partners are: Habitable Exoplanet Observatory (HabEx), Large Ultraviolet Optical Infrared Surveyor (LUVOIR), Lynx X-ray Observatory (Lynx), and Origins Space Telescope (Origins).
- As part of the process of developing and preparing the STDT Final Reports for submission to NASA and the 2020 Decadal Survey, the NASA Astrophysics Division tasked an independent assessment team called the Large Mission Concept Independent Assessment Team (LCIT)) to conduct a technical, risk, and cost assessment of the four concept studies.
- The LCIT was established in late 2018. The LCIT team (12 members plus an Executive Secretary) included experienced technical and cost reviewers with expertise in large space missions and in science, instrumentation, and technology.

2.0 Introduction and Background (2)

- The objectives of the LCIT in conducting this cost and technical credibility analysis were to:
 - Provide feedback to the STDTs (based on their Interim and draft Final Reports) that could be used to improve the STDT Final Reports before they are submitted to the 2020 Decadal Survey, and
 - Provide NASA Astrophysics Division Director confidence in the STDT Final Reports and the science, technical, cost and risk conclusions in the STDT Final Reports.
 - The LCIT was not to evaluate the scientific merit of the concepts but only assess if the science objectives can be accomplished by the mission concept given the observatory and instrument specifications and requirements.

2.0 Introduction and Background (3)

- The LCIT assessments were on the baseline mission concepts presented in the STDT Reports. For each of the mission concepts the baselines used were:
 - HabEx: A 4 m telescope spacecraft with four science instruments and a separate spacecraft with a 52 m starshade flying in formation
 - LUVOIR:
 - LUVOIR-A: A 15 m on-axis telescope with four science instruments
 - LUVOIR-B: A 8 m off-axis telescope with three science instruments
 - Lynx: A 3 m diameter grazing incidence mirror assembly with a 10 m focal length and three science instruments
 - Origins: A 5.9 m telescope with three science instruments

3.0 LCIT Process

3.0 LCIT Process (1)

- The LCIT used documentation and data from the following sources as the basis for its assessment:
 - STDT Interim Reports
 - STDT Draft Final Reports
 - STDT technology roadmaps and plans
 - Independent Cost Estimates (ICEs) developed by the respective lead Center cost assessment offices
 - Technology Roadmap Assessments done by the Astrophysics Program Offices
 - STDT Final Reports
- Throughout the LCIT analysis process, the LCIT interacted with the four STDTs and the assigned NASA STDT-lead Centers (GSFC, MSFC and JPL) cost teams to identify issues and concerns, request clarification of data products provided, and specify additional products needed by the LCIT in order to complete their assessment.
- The LCIT conducted a detailed review of the TRL maturation efforts.
- The LCIT cost analysts developed Phase B/C/D/E cost model estimates for each concept using consistent assumptions and approaches for all four concepts.
- The LCIT cost analysts compared the concept estimates to other Great Observatories (Chandra, Spitzer, HST, JWST and WFIRST).

3.0 LCIT Process (2)

- The initial LCIT reviews of the Draft Final Reports resulted in approximately 100 issues and concerns across the four mission concepts. These findings were provided to the STDTs for their use in improving, correcting, and clarifying their Final Reports before public release.
- The STDTs received the findings and recommendations from the LCIT and their own internal Red Team reviews and made significant modifications to their Final Reports before public release.
- The STDTs also provided feedback to the LCIT for each finding as well a summary of changes to address the finding and references to where changes appear in the Final Reports.
- The LCIT reviewed the STDT Final Reports to see if LCIT findings (issues and concerns) had been adequately addressed. As a result, the final set of remaining issues and concerns was significantly reduced.

4.0 LCIT Assessment for each Concept

4.1 LCIT assessment – HabEx (1)

<u>Strength</u>

- HabEx represents a well thought out mission concept to address high priority science questions relative to exoplanets and their potential for habitability.
- The concept report also addresses other priority astrophysics science questions in the UV and NIR.
- The concept report provided very detailed descriptions of the instruments, capability, and supporting analyses are provided.
- The Science Traceability Matrix is logical and complete, and the mission system architecture is responsive to the STM and includes assessment of error budgets to support and demonstrate system level implications.
- The coronagraph instrument benefits from the WFIRST technology demonstration coronagraph.
- The study offers several credible alternatives to the baseline architecture with assessments of the science impact.

4.1 LCIT assessment – HabEx (2)

Overarching Concern

- The HABEX mission is quite ambitious in its scope
- The instruments and requirements for thermal control will be challenging
- The ATD costs provided were at a higher level with no breakout by cost type (labor, material, GSE, facility).

4.2 LCIT assessment - LUVOIR (1)

Strength

• The STDT took to heart the call for "bold and ambitious mission concepts", and did not shy away from understanding and estimating the complexities of such mission concepts.

• The creation of a Pre-Phase A Program Office chartered to lead and manage architecture trades and analyses closely coupled to multiple technology development efforts and trades are a strength

• The STDT took the approach of a modular design and scalability to maintain flexibility with launch vehicles, which also supports servicing concepts.

• Opportunities for contributions from other countries (11 claimed) can be a strength (also a risk)

4.2 LCIT assessment - LUVOIR (2)

Overarching Concern

• LUVOIR A pushes the envelope of technology and engineering beyond anything NASA science has done or will do in the near to mid term future, although that is not to say that the other STDT concepts are not leading edge and ambitious. Such an effort will challenge SMD, the implementing Center, and NASA in every technical, programmatic and contractual respect.

• The concept will have to rely upon modeling and simulations that need to be grounded in smaller scale articles and independent verifications.

• Facilities to handle the size of the elements are going to be a challenge for production, the mirrors in particular, and handling/testing.

• Contamination control are areas of concern as well.

4.3 LCIT assessment – Lynx (1)

Strength

• A mature reference mission with heritage traceable to Chandra, the on-going work on the ESA Athena mission and JAXA XRISM mission. The WBS is complete and the MEL and Power Equipment List (PEL) reflect a lot of work that is traceable to the mission design and/or other missions.

• Excellent technology maturation plan and discussion of requirements, including extensive use of references to back up the technology claims and traceability to heritage.

• The Science Traceability, Mission Traceability, architecture schematics, and the integration, calibration and test logic flows are very good and reflect understanding of the work to be done.

• Independent Cost Estimate is well done and credible. Programmatics (organizational structure, WBS, schedule, cost) are very well done with credible analogies and understanding of the task at hand.

4.3 LCIT assessment – Lynx (2)

Overarching Concern

• The scale of the Lynx mirror assembly, with its 37,492 mirror segments, is orders of magnitude more complex than previous and current X-ray mirrors. Fabrication and integration of the Lynx Mirror Assembly and contamination control requirements are going to be a challenge and big programmatic drivers for this mission.

4.4 LCIT assessment – Origins (1)

<u>Strength</u>

- The basic telescope system follows a Spitzer-like non-deployable aperture architecture and a simplified (when compared to JWST) passively cooled sunshield.
- The cryocoolers that maintain the telescope at 4.5K and detectors at subkelvin temperatures have a high degree of heritage and are ganged together to provide robustness.
- JAXA and a CNES-led European consortium are active participants in the mission concept study, with each contributing an instrument design.

Overarching Concern

- The primary and secondary mirrors and mirror support structures are all isotropic beryllium based on hot isotropic pressed spherical powder. The necessary specialized industrial base may not exist when the mission formulation starts.
- Early maturation of detectors and cryocooler was not sufficiently addressed.
- Contamination control is underestimated.

5.0 General Observations and Recommendations

5.0 General Observations and Recommendations (1)

- All of these mission concepts are just that, concepts that are in Pre-Pre-Phase A and have significant work ahead for them to mature the technologies, conduct trade studies and refine their design before entering Phase A.
- The traceability from the science objectives as described in the STM are clear in all of the four Final Reports.
- Some of the missions discussed additional science objectives that may or may not be possible but are not included in the science objectives and are not supported in the Final Report.
- If the capabilities and requirements of the observatory system, instruments and operations are met, the science objectives of each concept should be achievable within a 5 year prime mission.
- Each of the STDT concepts require maturation of enabling technologies in order to enable the mission concept. The STDTs plan development of these enabling technologies to TRL 6 either before start of Phase A or during Phase A. For all of the four concepts, the schedules for maturing the technologies are success oriented.

5.0 General Observations and Recommendations (2)

- For all the missions, given the challenges of advanced technology development, LCIT assesses that the levels of NASA investment claimed by the STDTs to mature their enabling technologies are underestimated.
 - It is recommended that for the technology development phases additional cost reserves are needed. The level of total ATD reserves for pre-TRL 5 technologies should be 100% of planned baseline activity; levels for technologies starting at TRL 5, 50%. This is based on the assessment that, for all the missions, the level of investment need for maturing of the enabling technologies is too low.
- Phase B-D cost models are based on historical data from smaller, less complex missions. Cost models do use Chandra and Spitzer data, though those missions were launched 15-20 years ago. JWST and WFIRST data will not be incorporated fully in the cost models until after launch. HST data are of limited value because of reporting and other issues. The results is large uncertainties in the estimated Phase B-D costs of all four STDT missions.
- For all four concepts, since these are large, complex missions, the use of traditional cost and schedule reserve "rules" (which are based on data bases that include smaller and less complex missions) results in underestimation of the level of reserves needed.

6.0 LCIT Cost Analysis

Summary of LCIT Cost Analysis Activities

- Conducted a detailed review of TRL maturation efforts
 - Included review of STDT roadmaps/plan details and the "Decadal Studies Technology Roadmap Assessment" by the NASA Astrophysics Program Office Technologists (7/30/19)
 - Feedback was provided to the STDTs
 - Details are covered in these charts
- Reviewed STDT reports and supporting data
- Developed Phase B-E cost model estimates for each concept using PRICE True Planning Space Missions (TPSM) and NASA's Space Operations Cost Model (SOCM)
 - LCIT applied consistent assumptions and approaches for all concepts
- Prepared charts to provide analogy cost comparisons to other Great Observatories (Chandra, Spitzer, HST, JWST, and WFIRST)

Cost Analysis Activity Flow



Multiple STDT updates were performed and reviewed by the LCIT between May and August 2019 (+ additional LCIT-STDT interactions)

LCIT Cost Analysis – High-Level Observations

- Technology development plans generally lack the detail needed to support sufficient independent assessment
 - The recommendation to add cost/schedule reserve was made to all teams. The LCIT feels reserves of 100% for pre-TRL5 activities and 50% for pre-TRL6 activities is appropriate
- STDT Phase BCD costs appear reasonable for 3 of 4 concepts
 - 3 of 4 Phase BCD LCIT estimates are within 20% of the STDT value
 - The HabEx LCIT estimate is higher than the STDT value
 - Cost model results support observations evident in analogy comparisons
- STDT Phase E costs are reasonable, operation concepts are based on other great observatories
- Concepts span a large range of projected Phase A-E costs
 - LCIT utilized cost bins with a \$2B range (\$6-8B bin, \$8-10B bin) and a greater than\$10B bin

LCIT Advanced Technology Development Cost Assessment

- This shows for two different scenarios for each concept the impact of adding LCIT recommended cost reserves to the ATD efforts
 - It is recognized that some reserves/margins are incorporated into some of the lower-level STDT ATD activities



LCIT FINAL Report Cost Analysis Progress for LCIT TOR Tasks

Task from LCIT TOR	Approach & Current Status	Completed?
Review and assess the current TRL of enabling technologies and the plans (including cost, risk, and schedule) for maturing these technologies to TRL 6 before PDR	Plans for maturing TRL have been reviewed in detail. Shortcomings in data provided have been communicated with the STDTs and used to improve definition of ATD efforts for some of the concepts.	Yes
Develop cost assumptions to be used	BoE data expectations for technology development and Phases A-E have been defined and assessed for each concept.	Yes
Develop a process for the cost validation	Validation for Phase A-E costs includes cost models and analogy comparisons. LCIT estimates have been derived for Phases B-E.	Yes
Validate the proposed mission cost estimate and mission development schedule	Analogy comparisons, cost model results, and Basis of Estimate details have been used to assess STDT costs.	Yes
Evaluate any proposed de-scope options and their cost savings, as well as any up- scope options and their additional cost, for realism and reasonableness	Descope options are included for each concept. In all concepts, the LCIT sees opportunities to reduce cost and complexity with TBD science impact. (Best if these decisions are made before KDP-A)	Yes

LCIT Cost Products

1) Advanced Technology Development (ATD)

- "Technology Template" developed early in the LCIT process to assist collection of ATD effort technical/schedule/cost requirements
- Lower-level review of ATD activity plans and associated cost/schedule realism

2) Phase BCD and E Cost Modelling

- PRICE True Planning Space Missions estimates for Phases BCD; Approach "builds-up" estimates from the component-level MEL & schedule
- NASA Space Operations Cost Model (SOCM) estimates for Phase E
- Analogy cost comparisons include Chandra, Spitzer, HST, JWST, and WFIRST

3) LCIT Cost Assessment

- Basis of Estimate (BoE) credibility
- "Concept Cost Bin" Analysis

LCIT FINAL Report LCIT Cost Observations/Findings

1) Advanced Technology Development (ATD)

- STDTs took initiative to account for what is typically >10% of development cost
- Team results are suggestive of resource levels but lots of variance in comprehensiveness of ATD plan definition
- Teams clarified the dependence of successful implementation on ATD funding early on
- Unclear how ATD funding shortfalls and interruptions will affect implementation schedules and costs
- Need a systematic approach to assess the magnitude and risks of the efforts

2) Phases BCD and E

• Technical and operational descriptions sufficient to generate cost estimates that can be used to bin concepts in terms of required resources

3) Concept Cost Bins Ranges and Assumptions

- Assumptions:
 - ø LCIT Phase A = 5% of Phases BCD
 - ATD & Phase BCD reserves of 30% have been applied to all concepts (considered a minimum)
 - øLCIT Phase E = \$100M/yr
- Each concept has unique descope options that could reduce costs

NOTE: In all concepts, the LCIT sees opportunities to reduce cost and complexity with TBD science impact.

LCIT Final Report LCIT Cost Observations/Findings

3) LCIT Cost Bin Assessment

The LCIT defined "Cost Bins" (for Phases A-E*) as the most effective way to deal with the cost uncertainties for assessment (in FY20\$)

- Lynx and Origins are assessed to be in a \$6-8B bin
- HabEx and LUVOIR-B are assessed to be in a \$8-10B bin
- LUVOIR-A is assessed to be in a greater than \$10B bin

* Does not include ATD, pre-Phase A, ATD/pre-Phase A reserves, LV, or Contributions

LCIT FINAL Report LCIT Cost Assessment

Main Concern - Weak ATD Effort Definition

- STDT Study Effort Focus ATD vs Phase BCD Costing
 - ø All concepts provided significantly more detail for Phase BCD costing than for the supporting ATD efforts

• Why focus on ATD?

- Phase B-E estimates look 15-20 years into the future-much will change before then
- ATD execution is necessary to successful implementation and Phase B-E cost management
- Near-term ATD plans decisions determine what is possible in 2025-2035
- ø Failure to invest properly precludes some concepts
- ø "Success-oriented" schedules with minimal embedded cost/schedule margin
- The problem of estimating costs based on single designs:
 - Some teams did not focus on identifying and testing architectural cost drivers and assessing trades
 - Resulting estimates reflect cost uncertainty, not technical or operational uncertainties

For Public Release

LCIT FINAL Report LCIT Cost Assessment - Other Concerns

- Insufficient Cost/Schedule Margins for ATD Efforts
 - ø "Success-oriented" pre-TRL6 schedules with minimal embedded cost/schedule margin
 - The recommendation to add cost/schedule reserve has been made to all teams; LCIT cost team feels reserves of 100% for pre-TRL5 activities and 50% for pre-TRL6 activities is the appropriate level
- Uncertainty associated with Phase E Estimates

 ø Difficult to estimate MO&DA support requirements 20yrs in the future

7.0 Appendices

7.1 LCIT Terms of Reference

LCIT Terms of Reference (1)

Terms of Reference Large Mission Concept Independent Assessment Team (LCIT)

Introduction

NASA is sponsoring four large-scale mission concept studies as part of its preparations for the 2020 Astrophysics Decadal Survey. The four large-scale mission concept studies, led by community-driven Science and Technology Definition Teams (STDTs), are:

Large-scale Mission	STDT Chairs	Study Manager
Concept Study		Study Scientist
		NASA Center
Habitable Exoplanet Imager	S. Gaudi, OSU	K. Warfield
(HabEx)	S. Seager, MIT	B. Mennesson
		JPL
Large Ultraviolet Optical	D. Fischer, Yale	J. Crooke
Infrared Surveyor (LUVOIR)	B. Peterson, STScI/OSU	A. Roberge
		GSFC
Lynx X-ray Observatory	F. Ozel, ASU	K. Gelmis
(Lynx)	A. Vikhlinin, SAO	J. Gaskin
		MSFC
Origins Space Telescope	A. Cooray, UC Irvine	R. Carter
(OST)	M. Meixner, STScI	D. Leisawitz
		GSFC

LCIT Terms of Reference (2)

The four STDTs worked closely with engineering teams at the NASA Centers assigned to each study (see Table above). Each STDT developed a publicly available Interim STDT Report. Each STDT is developing a Final STDT Report for submission to the 2020 Decadal Survey. Documents supporting the STDT process, including the Interim STDT Reports and the Management Plan for Large Mission Concept Studies, are available at https://science.nasa.gov/astrophysics/2020-decadal-survey-planning.

In advance of that submission, NASA HQ will assemble a Large Mission Concept Independent Assessment Team (LCIT) to conduct a technical, risk, and cost assessment of the four large-scale mission concept studies. The LCIT will include experienced technical and cost reviewers with expertise in large space missions and in science, instrumentation, and technology.

Charge and Review Criteria

The LCIT will conduct a "cost and technical credibility analysis" of the STDT-led large-scale mission concepts. A cost and technical credibility analysis is not a Cost and Technical Estimate (CATE); rather it is an independent assessment of the technical, cost, and schedule requirements that are described in the large mission concept draft final reports.

LCIT Terms of Reference (3)

Charge and Review Criteria (continued)

The purpose of conducting a cost and technical credibility analysis of the STDT-led large-scale mission concept studies is two-fold.

- Provide feedback to the STDTs that can be used to improve the Final STDT Reports that will be presented to the Decadal Survey.
- Provide NASA Headquarters confidence in the science, technical, cost, and risk conclusions of the Final STDT Reports that will be presented to the Decadal Survey.

Specifically, the LCIT will:

- Assess whether the proposed observatory and instrumentation can achieve the stated science goals and objectives with the proposed architecture.
- Review and assess the current TRL of enabling technologies and the plans (including cost, risk, and schedule) for maturing these technologies to TRL 6 before PDR.
- Review and assess engineering challenges beyond maturation of requirements and beyond maturation of technology
- Develop a process to assess the credibility of the cost and schedule, including assumptions to support the assessment

• Assess the credibility of the proposed mission cost and development schedule. Evaluate any proposed alternatives and their cost savings, additional cost, realism and reasonableness.

LCIT Terms of Reference (4)

Content and Format Requirements for Submission to the LCIT

To enable the independent assessment by the LCIT, each STDT will submit to NASA HQ the following material according to the schedule below.

- A draft of the Final STDT Report (hereafter called the Draft STDT Report). The Draft STDT Report will comply with the constraints set by the joint discussion in August/September 2018.
- The high-level mission design products generated by the Center design labs during the development of the mission concept, including the Master Equipment List (MEL).
- The heritage, if applicable, of each enabling technology item identified as less than TRL6, as well as any required new facilities or major test equipment needed to demonstrate TRL6 by PDR.
- The independent cost estimate (ICE) developed by the Center through its cost assessment office, as well as the supporting documentation developed during the generation of the ICE.
- The mission level risks and their recommended mitigation including risks associated with the individual instrument development schedules.

LCIT Terms of Reference (5)

LCIT Report and Deliverable

The LCIT deliverable to NASA HQ is a written report covering:

- Overall Summary;
- Brief description of LCIT Methodology and Process;
- Technical and Risk Assessment for each Study including Strengths and Weaknesses;
- Viability of Mission Cost and Confidence Level;
- Suggestions for improving each Study Report / Comments to the Study Teams; and
- Comments to NASA.

The LCIT final written report will be in the form of a short narrative summary and a set of PowerPoint slides with explanatory notes.

LCIT FINAL Report LCIT Terms of Reference (6)

LCIT Schedule

The LCIT will have an initial discussion with each STDT early in this process to discuss the cost data and products to be provided to the LCIT and the status and content of the draft Final Reports.

The LCIT will meet with each STDT at the beginning of the assessment phase (after delivery of the cost data, products, and the draft Final Report) to ensure that the LCIT understands the STDT's mission concept as well as to discuss with each STDT the issues and concerns regarding their mission concept.

The LCIT will meet with each STDT after the LCIT has developed its draft report to reconcile differences between the LCIT's assessment and the Draft STDT Report, and to avoid misunderstandings and preventable errors. This feedback from the LCIT's draft report provides an opportunity for the STDTs to improve their Final STDT Reports before submitting them to NASA HQ for transmission to the Decadal Survey.

LCIT Terms of Reference (7)

LCIT Schedule (continued)

Milestones	Date (as of November 2018)
LCIT formed	September 2018
LCIT kickoff meeting	October 2018
Finalize input requirements and schedule with	November 2018
STDTs	
LCIT initial discussion with each STDT	December 2018
STDTs submit required input to LCIT via	February 2019
NASA HQ	
Second meeting of LCIT with STDTs	March 2019
Third meeting of LCIT with STDTs	May 2019
LCIT submit final report to HQ	June 2019
STDTs submit final report to HQ	June 2019
HQ review and submit to 2020 Decadal	July 2019 (TBR) **

** one month earlier than Management Plan

After the reconciliation process with each of the four STDTs and after the delivery of the LCIT final written report to NASA, NASA will disband the LCIT.

LCIT Terms of Reference (8)

LCIT Membership

The LCIT will consist of 10-15 members with expertise in the science, technologies, instrumentation, management, and cost analysis relevant to the four large-scale mission concept studies. Rick Howard (Cornell Technical Services (CTS) and ex-NASA) will chair the LCIT.

NASA HQ POCs

Rita Sambruna, Decadal Studies Program Scientist LCIT Executive Secretary / Review Manager <u>Rita.m.sambruna@nasa.gov</u> 202-358-2166 office 240-381-8085 cell

Shahid Habib, Decadal Studies Program Executive Shahid.habib-1@nasa.gov 202-358-0450 office

7.2 Acronyms

LCIT Acronym List

ATD	Advanced Technology Development
BoE	Basis of Estimate
CATE	Cost And Technical Estimate
CNES	National Centre for Space Studies
CTS	Cornell Technical Services
ESA	European Space Agency
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HabEx	Habitable Exoplanet Observatory
HQ	Headquarters
HST	Hubble Space Telescope
ICE	Independent Cost Estimate
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
JWST	James Webb Space Telescope
LCIT	Large Mission Concept Independent Assessment Team
LUVOIR	Large Ultraviolet Optical Infrared Surveyor
LV	Launch Vehicle
Lynx	Lynx X-ray Observatory

LCIT Acronym List (continued)

MEL	Material Equipment List
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NIR	Near Infrared
Origins	Origins Space Telescope
PDR	Preliminary Design Review
PEL	Power Equipment List
POC	Point of Contact
SMD	Science Mission Directorate
SOCM	Space Operations Cost Model
STDT	Science and Technology Definition Team
STM	Science Traceability Matrix
TOR	Terms Of Reference
TPSM	True Planning Space Missions
TRL	Technology Readiness Level
UV	Ultraviolet
WBS	Work Breakdown Structure
WFIRST	Wide-Field Infrared Survey Telescope
XRISM	X-Ray Imaging and Spectroscopy Mission