Status and path forward for the large ultraviolet/optical/infrared surveyor (LUVOIR) mission concept study

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ABSTRACT

In preparation of the 2020 Astrophysics Decadal Survey, National Aeronautics and Space Administration (NASA) has commenced a process for the astronomical community to study several large mission concepts leveraging the lessons learned from past Decadal Surveys. This will enable the Decadal Survey committee to make more informed recommendations to NASA on its astrophysics science and mission priorities with respect to cost and risk. Four astrophysics large mission concepts were identified. Each of them had a Science and Technology Definition Teem (STDT) chartered to produce scientifically compelling, feasible, and executable design reference mission (DRM) concepts to present to the 2020 Decadal Survey. In addition, The Aerospace Corporation will perform an independent cost and technical evaluation (CATE) of each of these mission concept studies in advance of the 2020 Decadal Survey, by interacting with the STDTs to provide detailed technical details on certain areas for which "deep dives" are appropriate. This paper presents the status and path forward for one of the four large mission concepts, namely, the Large UltraViolet, Optical, InfraRed surveyor (LUVOIR).

Keywords: 2020 Astrophysics Decadal Survey, LUVOIR, study process, Science and Technology Definition Teams (STDTs), Study Office: science analyses, engineering, technology, deliverables and schedule

1. INTRODUCTION

In January 2015 at the 225th American Astronomical Society (AAS) meeting, NASA charged the astronomical community via the three Astrophysics Programs Analysis Groups (PAGs); Cosmic Origins (COPAG), Exoplanet Explorations (ExoPAG), and Physics of the Cosmos (PhysPAG), to consider a list of four candidate large mission concepts: a Far-IR Surveyor (FIRS), a Habitable Exoplanet Imager (HabEx), a Large UltraViolet, Optical, InfraRed surveyor (LUVOIR), and an X-ray Surveyor[1,2]. The community was given ten months to deliberate and decide on whether these were the right mission concepts to study with full authority to make recommendations to NASA to change, add, or subtract mission concepts to the list. These recommendations were due in October 2015. After multiple open community PAG meetings and deliberations between January and October 2015 and other means of input from the community, the three PAGs endorsed all four mission concepts that were on the original list from NASA[3,4,5].

2. SCIENCE AND TECHNOLOGY DEFINITION TEAMS (STDTs): ESTABLISHING LEADERSHIP

NASA enabled these four large mission concept studies to be led by the United States (U.S.) astronomical community. Therefore, as done for prior mission concepts, Science and Technology Definition Teams (STDTs) lead each of these four mission concept studies[6,7]. In January 2016, during the 227th AAS meeting, NASA released a call to the U.S. astronomical community for self-nominations to each of the four STDTs[8]. The LUVOIR Surveyor received 136 self-nominations by the deadline February 1, 2016, and by mid-March 2016, 24 LUVOIR STDT voting members were officially selected[9].

International space agencies were also invited to participate in these four large mission concept studies by nominating

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representatives as non-voting STDT observers. Eight (8) international space agencies (so far) have appointed representatives to the LUVOIR Surveyor Study as of June 2016[9]. Table 1 shows the LUVOIR STDT voting members, the U.S. and international ex-officio non-voting members, and the Study Office.

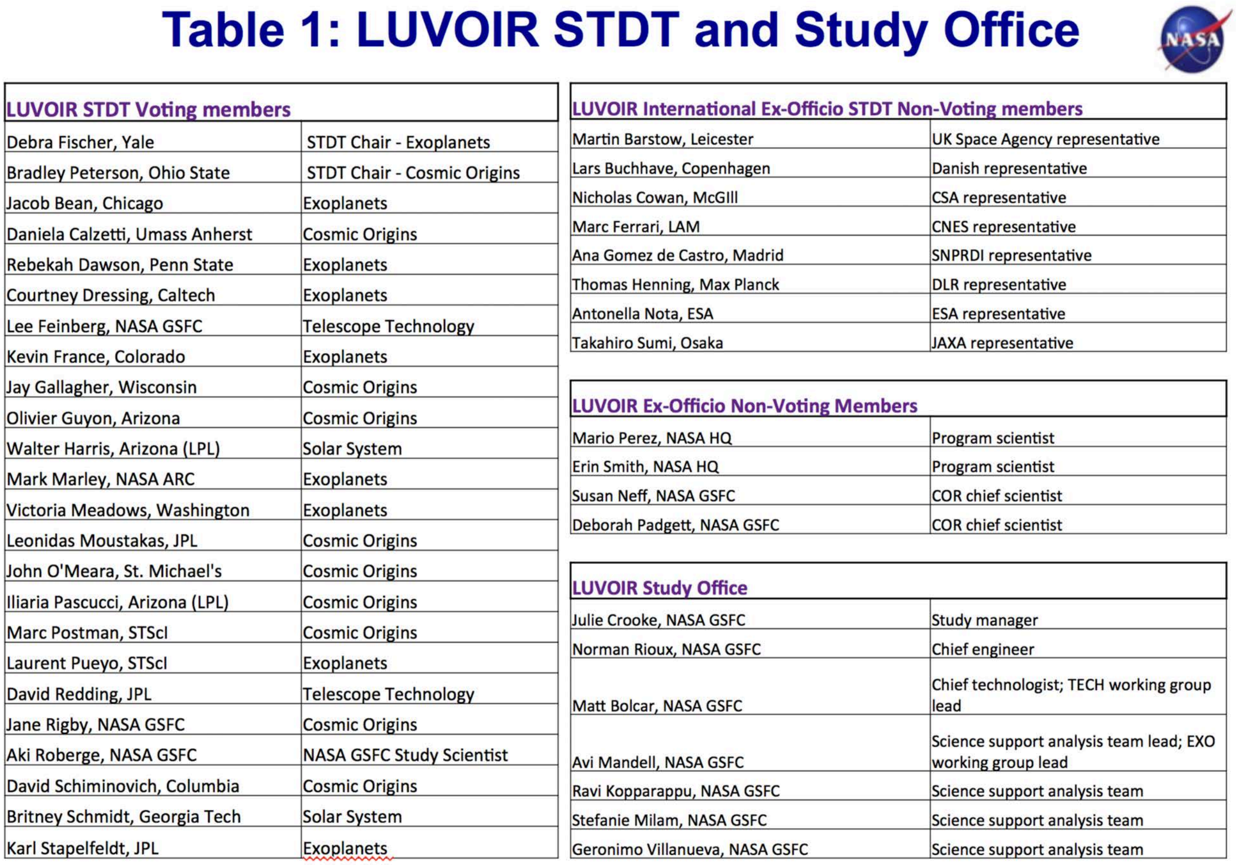


Table 1: LUVOIR STDT and Study Office

LUVOIR STDT Voting members	
Debra Fischer, Yale	STDT Chair - Exoplanets
Bradley Peterson, Ohio State	STDT Chair - Cosmic Origins
Jacob Bean, Chicago	Exoplanets
Daniela Calzetti, Umass Anherst	Cosmic Origins
Rebekah Dawson, Penn State	Exoplanets
Courtney Dressing, Caltech	Exoplanets
Lee Feinberg, NASA GSFC	Telescope Technology
Kevin France, Colorado	Exoplanets
Jay Gallagher, Wisconsin	Cosmic Origins
Olivier Guyon, Arizona	Cosmic Origins
Walter Harris, Arizona (LPL)	Solar System
Mark Marley, NASA ARC	Exoplanets
Victoria Meadows, Washington	Exoplanets
Leonidas Moustakas, JPL	Cosmic Origins
John O'Meara, St. Michael's	Cosmic Origins
Iliaria Pascucci, Arizona (LPL)	Cosmic Origins
Marc Postman, STScI	Cosmic Origins
Laurent Pueyo, STScI	Exoplanets
David Redding, JPL	Telescope Technology
Jane Rigby, NASA GSFC	Cosmic Origins
Aki Roberge, NASA GSFC	NASA GSFC Study Scientist
David Schiminovich, Columbia	Cosmic Origins
Britney Schmidt, Georgia Tech	Solar System
Karl Stapelfeldt, JPL	Exoplanets

LUVOIR International Ex-Officio STDT Non-Voting members	
Martin Barstow, Leicester	UK Space Agency representative
Lars Buchhave, Copenhagen	Danish representative
Nicholas Cowan, McGIll	CSA representative
Marc Ferrari, LAM	CNES representative
Ana Gomez de Castro, Madrid	SNPRDI representative
Thomas Henning, Max Planck	DLR representative
Antonella Nota, ESA	ESA representative
Takahiro Sumi, Osaka	JAXA representative

LUVOIR Ex-Officio Non-Voting Members	
Mario Perez, NASA HQ	Program scientist
Erin Smith, NASA HQ	Program scientist
Susan Neff, NASA GSFC	COR chief scientist
Deborah Padgett, NASA GSFC	COR chief scientist

LUVOIR Study Office	
Julie Crooke, NASA GSFC	Study manager
Norman Rioux, NASA GSFC	Chief engineer
Matt Bolcar, NASA GSFC	Chief technologist; TECH working group lead
Avi Mandell, NASA GSFC	Science support analysis team lead; EXO working group lead
Ravi Kopparappu, NASA GSFC	Science support analysis team
Stefanie Milam, NASA GSFC	Science support analysis team
Geronimo Villanueva, NASA GSFC	Science support analysis team

Figure 1: Photo of LUVOIR U.S. and international STDT members and Study Office members present at the first face-to-face meeting May 9-10, 2016 at NASA's Goddard Space Flight Center.

3. LARGE MISSION CONCEPT STUDY PROCESS:

In addition to appointing STDTs to lead each of the four mission concept studies, NASA assigned each of the four mission concept studies to a NASA field center to provide each STDT with a Study Office and engineering team to support them. The LUVOIR Surveyor Study was assigned to NASA's Goddard Space Flight Center (GSFC)[10]. NASA's GSFC values an inclusive study, and the Study Office will bring to bear the expertise of partners, including the Space Telescope Science Institute (STScI), the Jet Propulsion Laboratory (JPL), other NASA centers, academia, industry, and international space agencies.

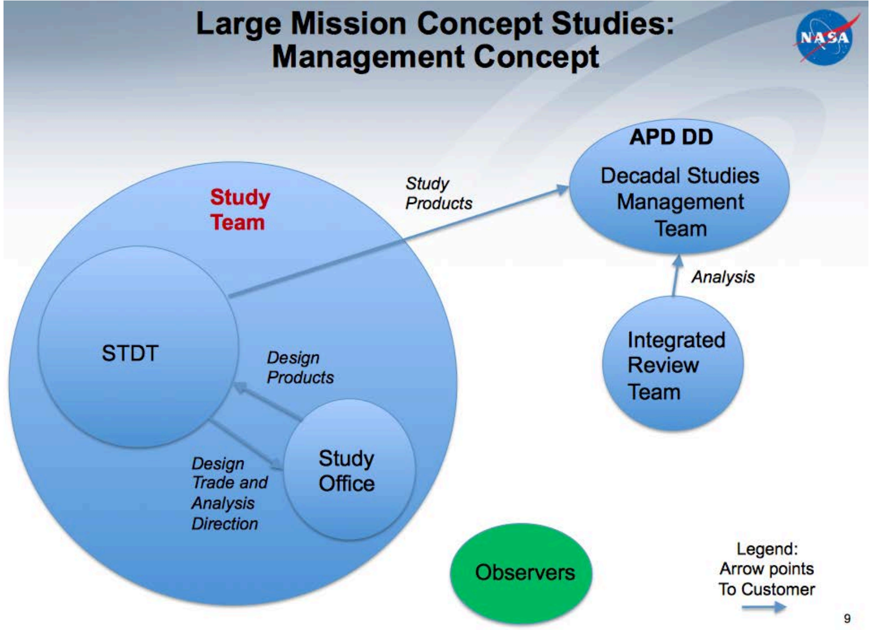
3.1 Oversight, communication, and reporting structure

NASA Headquarters (HQ) Science Mission Directorate (SMD) Astrophysics Division (APD) and the three Astrophysics Program Offices (Cosmic Origins, Exoplanetary Exploration, and Physics of the Cosmos) have established an organizational, oversight, communication and reporting structure[11] The Study teams report to the astrophysics division (APD) deputy directory (DD) as shown in Figure 2. The decadal studies management team and the integrated review team play a role to ensure all four study teams are providing the same standard product and are consistent. In addition, NASA HQ has established a milestone delivery timeline (See Figure 4)[12] to execute these studies. The goal is that all four mission concept study teams are able to develop compelling, feasible, and executable mission concepts that can be assessed on equal footing by the 2020 Astrophysics Decadal Survey. Another goal is that realistic cost and cost uncertainties for each of the four large missions are determined. To accomplish this, NASA has asked The Aerospace Corporation to be involved during the study process to work with each study team to provide technical and engineering trade guidance, risk assessments, and advice on the desired fidelity of the design reference mission submitted to the decadal. The goal of this interaction is to identify the areas of the concept design that drive the cost and technical risk, and to give the STDT the opportunity to study those areas further, explore alternate approaches associated with a lower amount of risk, or present detailed information on why those areas are not as risky as originally perceived. This should lead to cost risk assessments that are more informed and that will be based upon a level of technical understanding that is more commensurate between the design team and the independent estimate team. At the end of the process, The Aerospace Corporation will perform an independent cost estimate (ICE) and a cost and technical evaluation (CATE) assessment of each of the four mission concepts.

3.2 Study structure

Study teams consist of the STDTs and the study office (See Figure 2),[12] where the community-led STDT is the customer.

Figure 2: Study Team Governance Structure[12,14]



Large Mission Concept Studies: Management Concept

During the study process, the customer of the study team is a NASA HQ oversight and guidance committee that the four studies report to and ensure leveling. A final report to NASA HQ from each of the four study teams is due January 2019. Ultimately, the final customer is the 2020 Astrophysics Decadal Survey Committee, appointed by the U.S. National Research Council of the National Academy of Sciences, when the study teams deliver a final report in March 2019.

4.0 LUVOIR STUDY TEAM

4.1 The STDT

The STDT and its community chairs have ultimate authority over the science case, direction and deliverables for each study. The STDT will define the science goals, science and instrument priorities, and ultimately, will direct the study office in terms of what are the priority engineering and technology tasks and trades that will fold into the final product showing a feasible and executable design reference mission (DRM).

4.1.1 The Working Groups

To provide additional community input into the study process, the LUVOIR STDT has established five Working Groups (WGs):

- Cosmic Origins
- Exoplanets
- Solar System
- Simulations
- Technology

The WGs consist of members of both the STDT and the broader community. They will be forums for detailed discussion and analysis of possible science investigations and technology challenges, under the direction of the STDT. At least one member of each WG is a GSFC employee (see Section 4.2.5 below on the SSAT), to provide a connection to the Study Office and facilitate communication with the engineering team.

In particular, the Technology WG will identify the enabling technologies for a LUVOIR mission and produce a technology development plan. This includes defining the technology gaps (the difference between the existing state-of-the-art for a given technology and the desired maturity of the technology performance) for each identified technology[11]. The Technology WG will also develop roadmaps specifying a timeline and the necessary resources to mature each technology. These gaps and roadmaps will be provided to the NASA Astrophysics Program Offices (COR, ExEP, and PCOS) to help guide technology prioritization in their annual technology reports (PATRs), which in turn shape annual technology maturation proposal solicitations (the Research Opportunities in Space and Earth sciences (ROSES), Strategic Astrophysics Technology (SAT) and Astrophysics Research and Analysis (APRA) programs). Other funding opportunities for maturing LUVOIR-related technologies include NASA's Small Business Innovative Research (SBIR), Small Business Technology Transfer (STTR), and Space Technology Mission Directorate (STMD) solicitations.

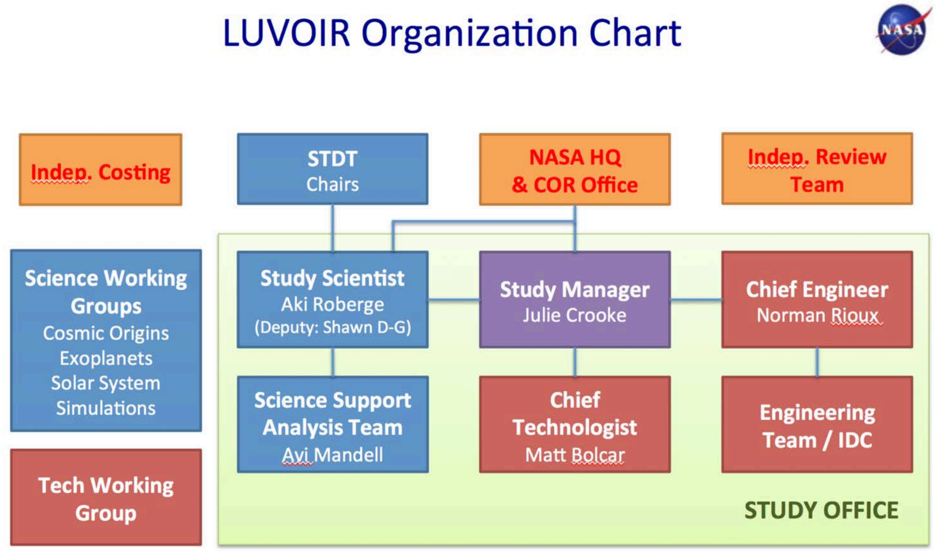
4.2 The Study Office:

The LUVOIR Study Office, at NASA's GSFC, supports the STDT and has chosen the following structure and functions to fulfill the expected requirements chartered by NASA HQ.

LUVOIR's Study Office is responsible for developing an implementable DRM that meets the baseline science objectives set by the STDT. It is the desire of the LUVOIR Study Office to provide the 2020 Decadal Survey and the astrophysics community with a mission concept that includes a range of architectural/scaling options associated with different cost/schedule risks and with different levels of science capability. These options may, in turn, have different levels of starting maturity, and therefore, different degrees of feasibility depending on progress developing the necessary technologies[11]. Industry and academia will be involved as soon as possible to leverage their expertise and resources in helping mature critical technologies.

The Study Office consists of NASA GSFC civil servants including a study scientist and deputy, a study manager, an engineering team made up of pieces of multiple different discipline engineers, a lead technologist, a science support analysis team (SSAT), and an Integrated Design Center. All of these functions are described in further detail below. The Study Team welcomes participation in LUVOIR by outside entities who wish to contribute their time and effort in the working groups and/or deliverables. External participation and support is not only welcome, but encouraged and desired.

Figure 3 LUVOIR study office organization chart at NASA's GSFC.



4.2.1 Study Scientist

The Study Scientist, also a voting STDT member, represents and speaks for the STDT in the day to day engineering activities. The Study Scientist is a liaison between the STDT and the Study Office in terms of relaying NASA processes to the STDT and for relaying STDT priorities to the Study Office.

4.2.2 Study Manager

The study manager leads the study office and manages the resources and the work performed by GSFC in support of the STDT. The study manager is accountable to and will work closely with the study scientist and the STDT chairs and is also accountable to the NASA Cosmic Origins (COR) Program Office, NASA HQ and NASA GSFC management for reporting, reviews (technical, cost, and schedule) to execute the study. The study manager is also a member of the Integrated Review Team (IRT) shown in Figure 2. All four study managers are members of the IRT to provide analysis, synergy and consistency across all four studies.

4.2.3 Engineering team

The engineering team, led by the lead mission systems engineer, is composed of members of multiple different key discipline engineers as necessary on an ongoing basis. The study office team will receive science goals, prioritization, and input from the STDT. The study office and engineering team will analyze, translate and develop the science goals and prioritization into an engineering trade space. Within this engineering trade space, the study team will identify the science drivers and formulate the engineering boundary conditions to develop science payloads, schedules, cost, and risk. In addition, the engineering team will support activities that focus on the feasibility and executability of the mission-enabling capabilities. Some of these activities include performing:

- End-to-end system wavefront error (WFE) budget analyses to inform engineering and technology trades with respect to science performance capabilities and priorities. These types of analyses are critical for showing credible hardware configurations that can achieve LUVOIR science.

- Technology vs engineering trades that drive the mission architecture and must be iterated with and folded into science analyses (i.e., ultra-stable systems and dynamic and thermal stability to enable high-contrast imaging, mirror coatings that impact UV cutoff and coronagraph performance, etc.)

The study office will inform and provide status updates, progress, and present options, considerations, and decisions to the STDT.

4.2.4 Science support analysis team

The Science Support Analysis Team (SSAT) will serve in complementary to the activities of the STDT and the SWGs. The SSAT is composed of GSFC scientists who will be available to carry out detailed scientific simulations and analyses in response to requests from the STDT. Further, SSAT members will participate in the WGs, providing additional coordination with the Study Office and facilitating communication between the science and engineering portions of the Study Team.

4.2.5 Integrated design center (IDC)

NASA GSFC's integrated design center (IDC) is an environment that facilitates multi-disciplinary, concurrent, space system engineering design and analysis activities to enable rapid development of science instrumentation, mission, and mission architecture concepts. It consists of separate facilities that host the relevant discipline engineers, tools and processes to deliver the desired engineering products. It consists of three labs, namely, an optical design lab (ODL), an instrument design lab (IDL) and a mission design lab (MDL). For each lab, all required engineering disciplines work simultaneously and collaboratively with each other and with the customer team through each IDC run.

4.2.5.1 Optical Design Lab (ODL)

The ODL product is an optical design, ray trace and spatial layout that levies engineering requirements on all other engineering discipline parameters for a given instrument or telescope in order to meet the science goals. An optical design is needed before the instrument design process. This is because the component-level, sub-system, and instrument packaging requirements flow from the optical requirements. Examples of these requirements include defining the volume, initial component and system level alignment accuracy and stability, jitter, wavefront error, and contamination requirements, to name a few. Before the ODL process can begin, initial first order input parameters derived from the science goals are required. The study office engineering team will perform the science to engineering input parameter translations that the IDL will need. Some of these input parameters include wavelength range, aperture size, field of view (FOV) and system requirements (i.e., mechanisms, interfaces to other instruments, packaging constraints, testing and calibration considerations, etc.) that will meet the science goals.

4.2.5.2 Instrument Design Lab (IDL)

The IDL product takes the optical design requirements and develops an end-to-end instrument concept that again, will meet the science goals. Each instrument definition and trade space includes thermal and mechanical modeling, performance analyses, instrument packaging, mechanism requirements and accommodations, technology and engineering trades, etc. IDL products include an instrument mechanical architecture, contamination assessments and requirements, mechanism design and performance, electrical subsystem architecture, thermal modeling, mass and power estimates, and cost modeling. A master equipment list (MEL) is also a key product of the IDL. The MEL is often used by NASA and independent cost teams (such as The Aerospace Corporation) to provide independent cost estimates.

If a large space astronomical observatory (such as LUVOIR) carries more than one instrument, an IDL may be necessary for each instrument (or at least those with the most difficult performance requirements) in order to understand the driving requirements for the telescope and the spacecraft. In addition, for LUVOIR, an IDL run is also necessary for the telescope itself as well as the accommodation, packaging and integration of all the instruments into an integrated science instrument module (ISIM). Developing an entire system package can be challenging. Ensuring the telescope output beam (whose design was driven by the science performance and instrument requirements) is distributed appropriately and meets the required beam quality for each instrument is necessary to demonstrate executability and feasibility of the science. It is necessary to execute instrument performance and engineering accommodation trades for multiple instruments to meet each instrument's performance and stability requirements as well as any other accommodating features such as serviceability (see section 4.3.2). This engineering team and SSAT will take the limited products from each IDL, conduct various performance analyses and tweak the designs as necessary to ensure each instrument meets the desired science performance.

4.2.5.3 Mission Design Lab (MDL)

Once all of the necessary telescope, instruments and instrument packaging accommodations have been designed, hereafter referred to as the payload, the MDL develops end-to-end mission concepts that meets the entire payload requirements for the spacecraft bus (mass, power, data, etc.), orbit requirements, ground system requirements, launch vehicle requirements, etc. The MDL also provides a Master Equipment List (MEL) for cost modeling for all of these mission accommodations. Products include spacecraft systems block diagrams and performance analyses, systems engineering, integration and test (I&T), mission operations, mechanical configurations and thermal analyses to name a few. Again, the study office engineering team will take the output from the MDL and perform engineering and science analyses to ensure the entire mission meets the science goals.

4.3 Possible path options

After the STDT has time to define and prioritize the LUVOIR science goals and instrument suite, the study team plans to study the accommodation of a LUVOIR mission concept in a minimum of two launch vehicle fairing sizes (internal fairing diameters accommodation). NASA’s Space Launch System (SLS) is being developed in different fairing sizes. The array of SLS launch vehicles in development are the Block 1, 5 meter fairing; the Block 2A, 8.4 meter fairing; and the Block 2B, 10 meter fairing. Each of these numbers for the different fairing sizes refers to their internal fairing diameter accommodations, in other words, the amount of diameter volume available to the payload/observatory. Each of these has different development schedules and demonstration first flight launch dates. In addition, there are multiple national and international launch vehicles with a 5 meter fairing accommodation. As of 2016, the 5 meter fairing has the least amount of operational risk in terms of future availability. Therefore, to enhance scalability and flexibility, the LUVOIR study team plans to show how LUVOIR is feasible and can be accommodated in both an SLS Block 2A or B fairing as well as a 5 meter fairing launch vehicle.

4.4 Serviceability

A U.S. Congress law was passed in 2010 and amended in 2015 that requires NASA proposed flagship missions to enable on-orbit servicing. In other words, all future flagship missions are required to accommodate serviceability (minimum accommodation: grapples, and modularity) even if the mission will not be serviced. Whether or not a mission will be serviced can be decided many years after its launch. Therefore, the LUVOIR study plans to design the observatory to be modular for its DRM. The LUVOIR DRM will not require that servicing missions be planned to accomplish the mission success criteria. However, to fulfill the requirement of this law we will intentionally make the instrument suite and other components modular to show that servicing could be accommodated while still showing that the mission is feasible and executable. Rather, designing the observatory to be modular can help lower risk during its development on the ground.

5.0 COMMUNITY INVOLVEMENT

The community is already leading the LUVOIR mission concept study via the STDT. The STDT community chairs, Debra Fischer from Yale University and Brad Peterson from the Ohio State University, are responsible for the study. They guide the discussion and voting amongst the members of the STDT, who will ultimately decide on the science and implementation path for the LUVOIR DRM submitted to the 2020 Decadal Survey Panel. In addition, given the exciting broad science a LUVOIR mission will enable, we welcome and encourage the participation by the others in the community, and not just those named herein. A LUVOIR mission warrants taking a multi-disciplinary approach and developing fruitful collaborations between the broad science community including astrophysics, planetary, heliophysics, and even earth sciences. The LUVOIR mission study will capture the richness of both general astrophysics and exoplanet exploration. The participation by multiple potential partners, including industry, other institutions, academia, international space agencies, and individuals from these organizations is welcome and needed. The LUVOIR study team (STDT and study office) should be thought of as a skeletal framework that will help coordinate and facilitate the efforts of any other community members that would like to get involved.

In order to educate and excite the broad science community about the expansive and compelling science capabilities of a LUVOIR mission, our activities will include communication of our activities at the professional and public level, to both the national and international audiences We will continue to work with professional working groups such as the Cosmic Origins Program Analysis Group (COPAG), the Exoplanet Exploration Program Analysis Group (ExoPAG), the Physics of the Cosmos Program Analysis Group (PhysPAG), the Nexus for Exoplanet Systems Science (NExSS), the NASA Astrobiology Institute (NAI), and the planetary Assessment Groups (AGs) (Outer Planets Assessment Group (OPAG), the Venus Exploration Analysis Group (VEXAG), and the Mars Exploration Program Assessment Group (MEPAG) in particular). We seek other professional groups to work with that share our interests in the common science goals. We envision our communication with each of these groups to be bi-directional, so that we can update them on the status of the LUVOIR study, solicit their feedback on our progress, and engage their community members in discussions of the science that the mission could address. This will improve the quality of the STDT's output and will help grow the broad science community needed to support this mission concept. Because of the significant overlap between the science goals for LUVOIR and HabEx, we are also engaging and coordinating with the habitable exoplanet imager (HabEx) study.

The LUVOIR study team would also like to partner with industry, academia, and other institutions and bring their expertise to bear in technology maturation efforts. As soon as practical, we plan to release space act agreements (SAAs) and cooperative agreement notices (CANs) to help formalize some of these potential partnerships.

6.0 DELIVERABLES AND TIMELINE

NASA HQ and the astrophysics program offices have established a timeline and a standard set of deliverables with associated level of details as shown in Figure 4[12]. This timeline is already underway. The final goal for each of the four studies is to develop a design reference mission at a level of detail commensurate with a tailored Decadal concept maturity level of 4 (CML4)[13]. By August 2018, each study will freeze their point design and have a CML4 audit. At this point in the process, each of the four studies will have an independent cost estimate (ICE) and cost and technical evaluation (CATE) performed by The Aerospace Corporation. This step serves as a way to have an independent external entity assess each study in terms of cost, technical maturity, and risk and will place each study in a cost bin. The final report for each study is due in January 2019 to NASA for review. Therefore, between August 2018 and January 2019, the study teams will be documenting their findings and writing their report. These reports will be submitted to the Decadal committee in March 2019. The steps between now and August 2018 consist of a CML2 audit, an interim report, and a technology gap list submitted by the studies for NASA to include in future technology solicitations.

Figure 4 shows the study's major tentative milestone deliverables and their due dates to NASA HQ[12, 14].

Study Deliverables

All products delivered to APD Deputy Division Director

M1	Comments on Study Requirements and Deliverables – Accept the study requirements/deliverables and submit plan--- or – Provide rationale for modifying requirements/deliverables	April 29 2016[1]
O1	*Optional: Deliver Initial Technology Gap Assessment* *– To impact PCOS/COR/ExEP technology cycle*	June 30 2016
M2	Detailed Study Plan – Document starting point CML – Deliver detailed study plan for achieving Decadal CML – Deliver resource required to meet the deliverables for the study duration – Deliver schedule to deliver milestones	August 26 2016
M3	Complete Concept Maturity Level 2 Audit – Identify, quantify and prioritize technology gaps for 2017 technology cycle	February 2017[2]
O2	*Optional: Update Technology Gap Assessments*	June 2017
M4	Interim Report – Substantiate achieving Concept Maturity Level 3 – Deliver initial technology roadmaps; estimate technology development cost/schedule	Early Dec 2017[2]
M5	Update Gap Assessments – In support of 2018 technology cycle	June 2018
M6	Complete Decadal Concept Maturity Level 4 Audit & Freeze Design – Support independent cost estimation/validation process	August 2018
M7	Final Report – Finalize technology roadmaps, tech plan and cost estimates for technology maturity	January 2019
M8	Submit to Decadal	March 2019

[1] APD will provide final study requirements by May 2016 (see "Near Term Activities")
[2] Timed to influence following NASA budget cycle

Figure 4 shows the list of current tentative milestone deliverables and their due dates. They are explained in further detail below.

- The milestone 1 (M1) deliverable was submitted April 29, 2016, and consisted of study team comments and feedback on the proposed NASA HQ management plan.

- The optional milestone 1 (O1) deliverable is due June 30, 2016. This O1 deliverable is a technology gap list from each of the four studies. This input to NASA's astrophysics program offices (COR, ExEP, and PCOS) allows the critical technologies to get prioritized funding in the following budget cycle. Allowing this input in June 2016 enables the astrophysics program offices to add the critical technologies for the four large mission concepts to future (FY17 and beyond) technology maturation solicitations.

- Milestone 2 (M2) deliverable is due August 26, 2016. It's a written plan from each study team explaining how they will execute their study on the given timeline to reach CML4 tailored for the Decadal.

- Milestone 3 (M3) is a CML2 audit in February 2017. In addition, a prioritized technology gap list will be submitted quantifying the resources and estimated time to reach the various technology readiness level (TRL) gates.

- Optional milestone 2 (O2) is due June 2017. This O2 deliverable is an updated technology gap list to influence the critical technologies starting in FY18 in case there have been any changes or re-prioritization of technologies.

- Milestone 4 (M4) is an interim report due in December 2017 substantiating how the study has reached CML3. In addition, technology roadmaps specifying more details on the development cost and schedule for each technology is expected.

- Milestone 5 (M5) deliverable is due in June 2018 providing another update to the technology gaps for each study.

- Milestone 6 (M6) deliverable is due in August 2018. This is the audit for CML4 and the point where each study freezes their design reference mission (DRM) concept that will be submitted to NASA and the Decadal.

- Milestone 7 (M7) deliverable is due in January 2019. This is the final report due from each concept study to NASA. This report should provide a detailed description of their design reference mission in science (compelling) and describe in appropriate detail the technology and engineering concepts to show feasibility and executability.

- Milestone 8 (M8) deliverable is due in March 2019. This is the final report to the Decadal Committee.

7.0 SUMMARY

In the post-HST, post-JWST, and WFIRST era, LUVOIR is poised to deliver transformative science, as HST has done, across all astrophysics themes including Cosmic Origins (COR), Exoplanet Exploration (ExEP), and Physics of the Cosmos (PCOS), as well as Solar System objects and planetary sciences. There are even opportunities to include the heliophysics and Earth science communities through cross-disciplinary science. Given this wealth of possibilities, the STDT will prioritize a wide range of science objectives of varying degrees of difficulty, taking into account new scientific knowledge and engineering analyses and information.

In brief, the LUVOIR study team plans to study and develop a DRM concept at the prescribed CML4 maturity while also showing scalability, flexibility, serviceability in terms of aperture size and accommodations in multiple fairing sizes.

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