WFIRST Independent External Technical/Management/Cost Review (WIETR)

October 19, 2017

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Background and Introduction

The Wide-Field Infrared Survey Telescope (WFIRST) is designed to obtain observational data needed to address important questions about our Universe and about the population of extrasolar planets in our Galaxy. The principal objectives of WFIRST are to:

- investigate the accelerated expansion of the Universe by measuring its expansion history and characterizing the growth of large-scale structures;
- search, primarily with a large microlensing survey, for new populations of extrasolar planets;
- advance technological development and application of instrumentation (coronagraph) for extrasolar planet discovery and characterization of planets and debris disks through direct imaging and spectroscopy, and to support the eventual realization of a future Earth-like planet imaging mission;
- provide a portion of mission lifetime to a peer-reviewed Guest Observer and Guest Investigator program, allowing a broad range of scientific studies of astrophysical targets in the Galaxy and beyond.

NASA established the WFIRST Independent External Technical/Management/Cost Review (WIETR) near the end of WFIRST's Phase A, responding to the National Academies' recommendation in both its 2014 report, *Evaluation of the Implementation of WFIRST/AFTA in the Context of New Worlds, New Horizons in Astronomy and Astrophysics*, and in its 2016 report, *New Worlds, New Horizons: A Midterm Assessment*, that NASA charter an independent technical, management, and cost assessment of WFIRST, including a quantitative assessment of the incremental cost of the coronagraph, before the Project enters Phase B.

This report responds to the questions asked in the Terms of Reference (TOR) that established the WIETR and includes recommendations and options for NASA to consider. This report is input to NASA in support of its formulation of the WFIRST implementation plan so that the mission is both 1) well understood in terms of scope and required resources (cost, funding profile, schedule) and 2) executable. The WIETR recognizes the scientific importance and timeliness of WFIRST. The objectives of this ambitious mission are driven by the goal of answering profound questions about the Universe beyond our solar system and planet Earth. This ambition comes with challenges that must be recognized and addressed—these are the focus of this report.

Acknowledgements

The WIETR panel wishes to acknowledge the following organizations and individuals for their assistance in making the work of the WIETR possible:

- The WFIRST Project and team members and their responsiveness to the panel's questions both at a plenary meeting of the panel with the Project and during subsequent WIETR subpanel site visits focused on various aspects of WFIRST;
- Dan Woods (HQ/SMD), the Executive Secretariat for the WIETR. He and his colleagues facilitated the planning, coordination, and scheduling of panel meetings and site visits and expertly assisted all of the panel members in carrying out the charge to the WIETR from the NASA Science Mission Directorate's Associate Administrator;
- The NASA Office for Mission Assessments (SOMA)/Cornell Technical Services (CTS) for their support bringing the WIETR members under contract in record time to enable them to support the effort;
- The Aerospace Corporation WIETR Programmatic team for their competence, patience with the endless questions, hours of analysis, and quality of the data and information;
- The WIETR members for their commitment, support, intellectual contribution, and the flexibility to adapt to last-minute travel arrangements and evolving agendas.

Key WIETR Findings-1

- The WFIRST planned science surveys program and system design offer groundbreaking and unprecedented survey capabilities to the Dark Energy, Exoplanets, and Astrophysics communities.

- The WFIRST team has done a considerable amount of work for a project that has yet to enter KDP-B, particularly in areas that minimize development and cost risk; key processes for execution and control are in place, and the science and mission system concepts are mature.

- The WFIRST Project and Subsystem Management, Science, Systems Engineering, and Business Management personnel are very experienced, including in the management of large/flagship missions, and have the necessary skills to lead a mission of the level of complexity of WFIRST.

- The WFIRST Project has been methodical, thorough, and inclusive in the analysis and derivation of the science and corresponding technical and data requirements, however, additional work is needed to: 1) negotiate and codify them clearly and unambiguously, 2) include Programmatic Direction that should be codified as Level 1 requirements; and 3) develop a plan to comprehensively validate them.

- The Wide-Field Instrument (WFI) is the primary instrument of WFIRST; a tremendous science capability that will be substantially more capable than Euclid, far better than HST or JWST, and well beyond what is possible from the ground in the conduct of faint infrared surveys that remain of high science interest.

Key WIETR Findings-2

- NASA has made a series of decisions (most notably: the 2.4m telescope, addition of a Coronagraph Instrument (CGI), In-house/Out-of-house or hybrid acquisition strategy, Dual Science Centers, Robotic Servicing, Star Shade) that set boundary conditions and the stage for an approach and mission system design that is more complex than probably anticipated from the point of view of scope, complexity, and the concomitant risks of implementation.

- The CGI Team has made remarkable progress towards advancing technology. Accommodation of the CGI, however, has been one of the mission system design and programmatic drivers. Expectations regarding performance requirements, status as science versus technology secondary payload and concomitant risk classification, science community engagement, interfaces to the Exoplanet Program and its longer term plans, and risk classification, all paint an inconsistent story that is certain to present risks to the primary mission well into the verification and validation program.

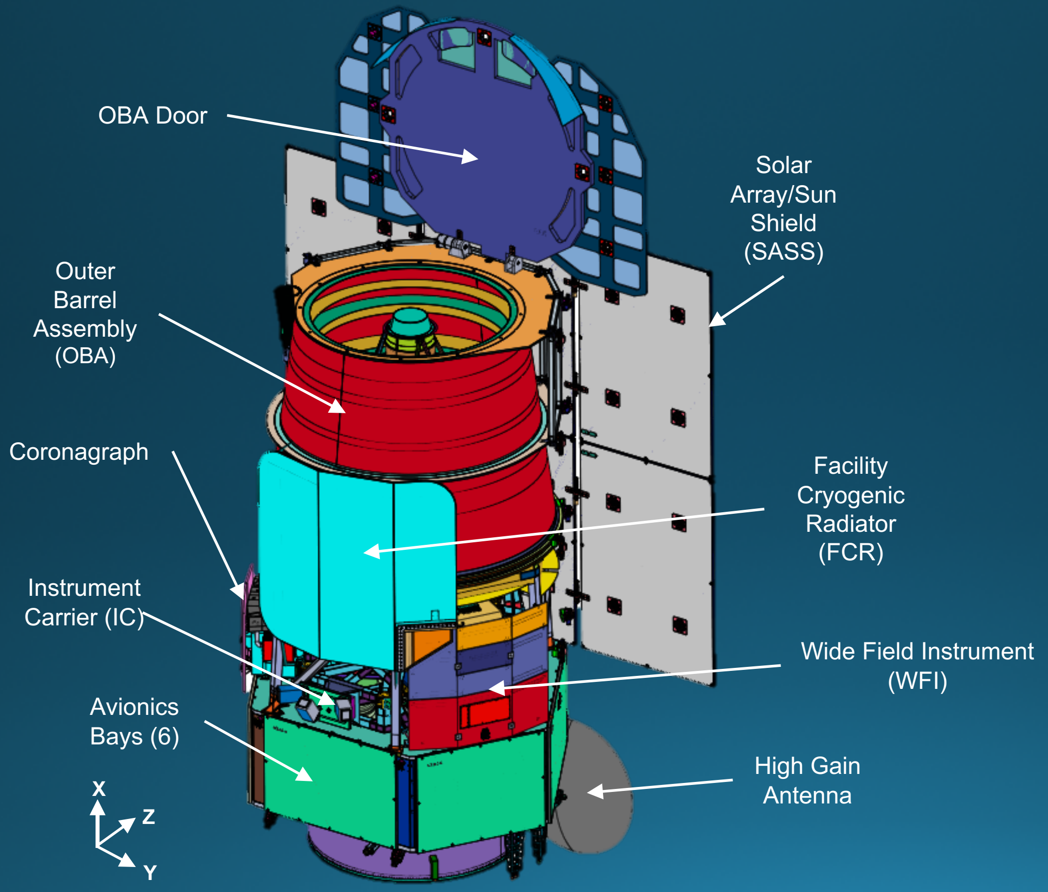
- The Class B risk classification for the WFIRST mission is not consistent with the uniform application of NASA policy for strategically important missions with comparable levels of investment and risks, most if not all of which are Class A missions.

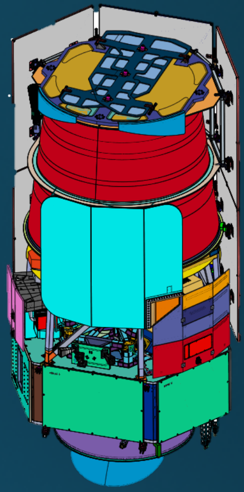
- The management agreement signed at KDP-A for the WFIRST life-cycle cost and the budget profile provided as guidance to the Project are inconsistent with the scope, requirements, and the appropriate risk classification for the mission.

- There is an urgent need (before the SRR/MDR) for NASA to conduct a top-to-bottom cost-benefit assessment to balance scope, complexity, and the available resources.

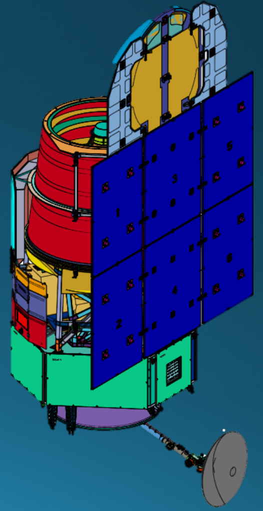
- The NASA HQ-to-Program governance structure is dysfunctional, and should be corrected for clarity in roles, accountability, and authority.

WFIRST Observatory





Stowed/Launch Configuration



Deployed Configuration

ANSWERS TO TERMS OF REFERENCE QUESTIONS

Answers to the Terms of Reference Question A

TOR Question A: "Are the technical requirements understood and reasonable?"

The WIETR viewed requirements as the product of an iterative process in which they are analyzed, understood, and evolved, to ensure that they are measurable, have a sound rationale, reflect the proper inter-relationship (vertical and horizontal), and to ensure that they are clear and unambiguous. A clear understanding of the stakeholder expectations, goals, and objectives was necessary in order for the WIETR to pass judgement on the decisions that informed the requirements being codified. The two questions below reflect recurring themes that the WIETR grappled with as the assessment proceeded and evolved:

1. Are the goals and objectives for the primary Dark Energy, Exoplanets (microlensing), and Astrophysics WFIRST mission clear, reasonable, and understood?

2. Are the goals and objectives for the addition of a secondary payload (coronagraph) that focuses on Exoplanets clear, reasonable, and understood?

The WIETR found, based on the information provided at the plenary/site visits/multiple meetings, that the answer to the first question is largely yes, and the answer to the second question is not an obvious or simple answer.

Answers to the Terms of Reference Question A

The WFIRST Project is marching along towards the end of their planned Phase A. There is a competent and motivated team in place, key processes for execution and control are in place, and the science and mission system concepts are mature. The WIETR has found, however, that there are unanswered questions that may warrant a pause before proceeding into a KDP-B. After multiple discussions that set the boundary conditions, NASA HQ made a series of decisions that set the stage for an approach and mission system concept that is more complex than probably anticipated from the point of view of scope, complexity, and the concomitant risks of implementation. These decisions are as follows:

1. 2.4m telescope <u>components</u> - *The collecting area of this fast optics telescope increases the capability of the mission significantly. It should be noted, however, that NASA did not "inherit" a plug-and-play telescope, but a telescope that has a primary mirror (which needs to be reshaped and resurfaced), secondary mirror support structure, and forward and aft metering structures, all of which require non-negligible adaptations and complex back-end tertiary optics to meet the WFI, IFC, and the CGI optical interface requirements.*

2. Addition of a Coronagraph and associated Science Investigation Teams - *Although intended as a technology demonstration, it is being treated as another science instrument and survey program. Its addition adds scope to the project implementation (e.g., mission operations design and implementation, and verification and validation).*
3. In-house/Out-of-house or hybrid acquisition strategy - *The hybrid approach for the Wide Field Instrument added complexity in technical and transactional interfaces. Coupled with the In-house approach to the spacecraft, this strategy invites temptation for continued optimization to maximize science return, as opposed to descoping science to acceptable levels of performance based on existing hardware.*

Answers to the Terms of Reference Question A

Much progress has been achieved in analyzing, understanding, and evolving the requirements to meet the primary mission objectives, including the accommodation of the secondary CGI payload. There is work still ahead to ensure clarity, and to reflect the proper vertical and horizontal inter-relationship from Level 1 to Level 2 (and below) requirements as the mission progresses through formulation; and to reflect them properly in the Project Plan and PLRA.

Accommodation of the Coronagraph, however, has been a mission system design and programmatic driver. Expectations regarding performance requirements, status as science versus technology secondary payload, science community engagement, and risk classification need clarification. Refocusing of the CGI as a technology demonstration, rather than as a secondary science payload, would allow simplification of the instrument and reduce the cost of science and mission operations ($10s of millions to $100 million). This approach would provide technology advancement for future coronagraph missions while reducing cost and risks.

The WIETR also found that the mission requirements are not consistent with the resources reflected in the Management Agreement, or with the budget profile provided as the guideline to the Project in NASA's official budget planning database. Therefore, the requirements are not reasonable.

Answers to the Terms of Reference Question A

A.a "Are the technical requirements aligned with the mission's science goals?"

The technical requirements are aligned with the primary WFIRST mission science goals and objectives, and the mission system design is well thought out to address them and to maximize science return. WFIRST is a groundbreaking and unprecedented mission in terms of its survey capabilities:

- High-resolution Mapping of the Universe
- The First Galaxies and the Early Universe
- Expansion of the Universe
- Directly Imaging Other Worlds
- Structure of Dark Matter
- Census of Exoplanets

The WFIRST Project has been methodical in the analysis and derivation of the science and corresponding technical/data requirements: from science objectives to Concept Of Operations, to spectral/temporal/spatial resolution requirements, to Level 1 requirements for the science and the mission system, and to lower-level flowdown. Additional work is needed to: 1) verify that the resulting Level 1 requirements are comprehensive and control the items Headquarters needs to control at the right level of detail; 2) include Programmatic Direction that should be codified as Level 1 requirements; and 3) develop a plan to comprehensively validate the requirements.

Answers to the Terms of Reference Question A

A.b "Are there any (obvious) science/technical requirements descopes that the Project should consider that could result in <u>acceptable</u> science return as well as lower cost, earlier launch, or reduced risk?"

The descope list at right, with associated estimated savings, represents the most significant items from a descope list presented by the project.

- Note that in some cases, the descopes are mutually exclusive, e.g., the CGI and WFI Focal Plane deletions, where only one CGI (out of 3) and one WFI Focal Plane descope (out of 2) can be taken.
- Note also, that the savings estimates for deleting the entire CGI contains all supporting/ancillary costs in the Work Breakdown Structure, whereas the other estimates include only the hardware cost.
- The IFC (~$100M) was included on the project descope list, however, the Project indicated that the descope was already included in their PPBE 19, so it is not listed in the table at right.

All of these options affect the mission system design and require resources to analyze, design, implement, document, verify and validate the changes in scope, complexity, and interfaces (science, mechanical, electrical, data, etc.).

- As a result, the actual net savings from any of these descopes may differ from the the estimates.

Item	Estimate
CGI/IFS	~$20M[1]
CGI/IFS +SPC	~$30M[1]
CGI	~$400M[2]
WFI Grism	$19M[1]
WFI Reduced Focal Plane	$62M[1]
Reduce WFI Focal Plane/Larger Plate Scale	$28M[1]
Robotic Servicing	<$10M
Star Shade	$48M[2/3]

Notes:
1) Includes the cost of hardware only
2) Includes the cost of the full mission cost including other cost elements
3) Potential Star Shade cost growth could significantly increase as Star Shade mission is defined.

Answers to the Terms of Reference Question A

The pros and cons, and level of acceptability and impact associated with these descopes also varies significantly. The WIETR did not try to define the limit of acceptability for science return to NASA/SMD.

The WIETR did not find descopes beyond what the Project was already considering.

- Taken together, all of the descopes would bring WFIRST closer to the Management Agreement if the HQ UFE is included, and the budget profile is revisited and corrected as necessary.
- The primary 2010 Decadal Survey science objectives of the WFIRST mission may be achievable with adoption of all of these descopes, albeit with degradation in performance.
  - e.g., Descoping the grism eliminates an entire Dark Energy technique for minimal cost savings.
- The approved acquisition strategy for a hybrid In-house/Out-of-house approach to the WFI instrument adds transactional and physical and electrical interfaces that add risk, noting however, that the areas of most concern have been addressed in the deliverables specified with the Request For Proposal for the WOMA.
- The In-house acquisition strategy for the spacecraft also carries risks because of the temptation for continued improvements; while recognizing that workforce capacity coverage and workforce development at GSFC is an unstated objective reinforced by the ASM decisions.

Answers to the Terms of Reference Question B

TOR Question B: "Are the scope and cost/schedule understood and aligned?"

Significant changes in the scope of WFIRST occurred that drove design evolution from the 2010 Astrophysics Decadal Survey to the concept presented to WIETR in 2017.

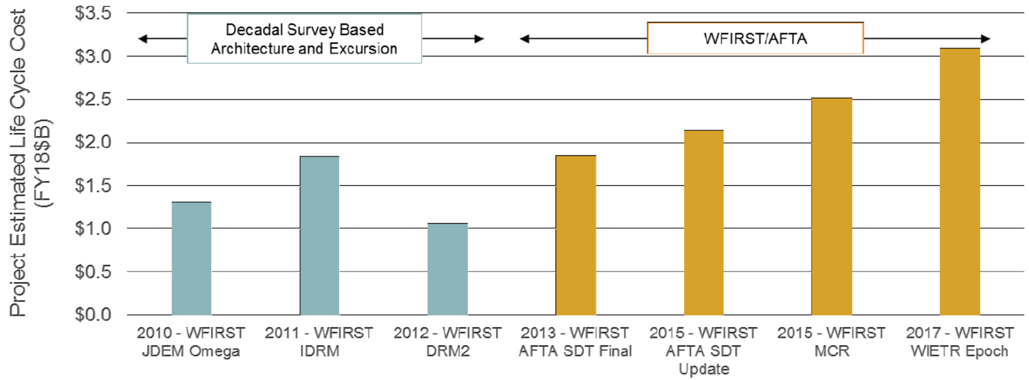
The evolution of WFIRST is provided for historical context and as an introduction to the chart that follows. WFIRST, the highest priority space mission in the 2010 NRC Decadal Survey of astronomy and astrophysics, was estimated to cost $1.9B (FY18$)[1] and assumed a 1.5m telescope. WFIRST adopted a 2.4m telescope, the product of an interagency transfer, in 2013 (AFTA SDT). As noted in the 2014 National Academies of Science report on the WFIRST mission, "*the opportunity to increase the telescope aperture and resolution by employing the 2.4-m AFTA mirror will significantly enhance the scientific power of the mission . . .*"[2]

The WFIRST mission and design concepts presented to the WIETR have evolved and matured significantly from the AFTA SDT concepts of 2013, including for example: the addition of the Coronagraph Instrument, the selection of an L2 orbit, dual data centers, OTA to instrument optical interfaces, the descope of the IFC (proposed), and Star Shade interface requirements. Also, science investigation teams joined the project. The Star Shade interface remains a risk for increase in scope going forward due to its lack of maturity.

[1] Inflated from the CATE cost of $1.6B (FY10$) referenced in "New Worlds, New Horizons in Astronomy and Astrophysics" National Academies of Science, 2010.

[2] Evaluation of the Implementation of WFIRST/AFTA in the Context of New Worlds, New Horizons in Astronomy and Astrophysics", National Academies of Science, 2014.

WFIRST Project's Design Model Costs from Decadal to Current (FY18$B)



Attribute	WFIRST Decadal	WFIRST IDRM	DRM2	AFTA SDT	SDT Update	@ MCR	2017 WFIRST WIETR Epoch
Concept Constraint	Decadal Survey Concept	Follows Decadal Survey	Minimize Cost	Incorporate AFTA Telescope	Add Coronagraph	Same Architecture	Same Architecture
Telescope dia	1.5 m	1.3 m	1.1 m	2.4 m	2.4 m	2.4 m	2.4 m
Payload Complement	NIR/Vis Imager, NIR Spec + FGS	NIR/Vis Imager, NIR Spec + FGS	NIR Imager/Spec + FGS	NIR Imager/Spec + IFC-Spec	NIR Imager/Spec, IFC-Spec, AGS + Coronagraph	NIR Imager/Spec, IFC-Spec, AGS + Coronagraph	NIR Imager/Spec, AGS + Coronagraph
Orbit	L2	L2	L2	Inclined GEO	Inclined GEO	L2	L2
Serviceable?	No	No	No	Yes	Yes	Yes	Yes
Dry Mass	2,424 kg	2,336 kg	1,868 kg	4,520 kg	4,861 kg	6,877 kg	7,324 kg
Launch Veh.	Atlas V 511	Atlas V 511	Falcon 9 v1.1	Atlas V 541	Delta IV-Heavy	Delta IV-Heavy	Falcon 9-Heavy
Lifetime	5 years	5 years	3 years	5 years	5 years	6 years	5 years

NOTES:

1. The bar chart is provided to illustrate the evolution and differences in scope and other parameters.
2. All estimates prior to WIETR are based on ideal budget profiles at a pre-Phase A level of maturity.
3. 2010 WFIRST JDEM Omega Cost Analysis and Technical Evaluation estimate was $1.9B (FY18$).
4. The 2017 – WIETR column shows the Budget Option 1, as submitted by the Project in FY17 (PPBE19), which constrains the profile in FY18 and FY19.

Answers to the Terms of Reference Question B

TOR Question B: "Are the scope and cost/schedule understood and aligned?"

The PPBE19 "In-Guide" budget and profile that was provided to the WFIRST Project are inadequate to deliver the expanded scope of the mission. The WFIRST Project proposed three (3) budget options to NASA/SMD as follows:

- Budget Option 1: Developed by the Project, tries to fit the near-term funding constraints for FY18 and FY19, and plans subsequent years consistent with mission system needs.
- Budget Option 2: Provided by NASA HQ, represents the current forecasted "In-Guide" funding available for WFIRST.
- Budget Option 3: Developed by the Project, based on a profile that minimizes time to launch if there were no funding profile constraints.

The WIETR programmatic analysis shows that the "In-Guide" budget and profile (Budget Option 2) are not aligned with the scope, complexity, and the risk classification for the WFIRST mission. Best practices show that profiles and budget underfunds of this nature during the formulation phase, where most of the consequential decisions are made, and continued underfunding into implementation, add untenable risks and management complexity. Budget Option 3, although possible, is very aggressive, particularly with long-term procurements and early developments; it is unclear as to the Project and Center's ability to execute to the Budget Option 3 plan.

The Independent Cost Estimate (ICE), derived from the Project's Budget Option 1 scope and schedule, is $3.9B RY$, which is 10% higher than Project Budget Option 1 (Project baseline, based on NASA request) of $3.6B, and includes potential risk items/reserves.

- Class A risk classification could add an additional ~$250M to ~$300M to the estimate.

Answers to the Terms of Reference Question B

The ICE indicates that the Budget Option 1 plan would need another ~$350M to achieve the 70% confidence level, and under the following assumptions: Budget Option 1 profile is fully funded, the mission is rated Class B, the IFC is not included in the WFI, and the CGI is a Class C technology demonstration. Under these assumptions:

- The ICE agrees relatively well with most cost elements
- The WFI estimate appears reasonable, and would be higher if the IFC is added back
- The CGI is reasonably funded for a Class C Tech Demo, and would be more costly if changed to a Class B instrument
- Phase F funding needs to be added to the Project ($50M - $80M)
- There is little room for the Project to cut given that their bottoms-up estimate was initially higher and reductions were taken to fit inside the Budget Option 1

The 70% ISE LRD of October 2025 shows that the schedule to meet the planned LRD of March 2026 LRD is adequate.

- The Budget Option 1 schedule is stretched, however, to accommodate early funding constraints in FY18 and FY19
- The ICE required additional funding for FY18 and FY19 and this enabled the earlier LRD. With this additional funding, the project could pull in the LRD closer to the ISE's LRD (October 2025 versus March 2026).

Answers to the Terms of Reference Question B

B.a "What is the likely range of probable cost and schedule, and what are the drivers?"

Typically the range provided at Key Decision Point "B" (KDP-B, the next major milestone) is based on:

- Low = 50% confidence level without threats = $3.56B RY$.
- High = 70% confidence level with threats = $3.93B RY$ (An additional $250M-$300M needed for Class A classification).
- The Project Budget Option 1 estimate is at the low end of the range at $3.58B RY$ ($3.14B FY18$, reflected in 2017 WFIRST WIETR Decadal to Current Project Estimate).

The 70% confidence level from the ISE is earlier than the March 2026 WFIRST Project Budget Option 1 Launch Readiness Date (LRD).

The drivers for further cost and schedule growth beyond the $3.93B would be additional capabilities changes such as: Changes in primary mission risk classification, making the CGI a Class B instrument, adding the IFC back into the Project baseline (proposed to NASA HQ as a descope in PPBE19), and risks associated with addition of Star Shade requirements.

Answers to the Terms of Reference Question B

B.b "How do non-optimal funding profiles affect the cost/schedule of the mission? "

If the Budget Option 2 profile is forced upon the Project, they will have to slow down activities starting in FY20, FY21, and FY22 with a resulting increase in development cost and schedule.

The Budget Option 1 profile is close to the nominal standard profile, but short in FY18 ($23M) and FY19 ($58M) to meet the Project's needs.

If the Budget Option 3 profile is available to the Project, the cost can be reduced and the schedule can be pulled in but there may be difficulties in ramping up to the desired level of support for FY18.

"What is the impact of staying within the funding profile guidelines and KDP-A total cost guidelines?"

If the Budget Option 2 profile is adopted, development cost and schedule will increase by another $230M above the ICE and ~9 months over the Budget Option 1 profile.

The Project's Budget Option 1 includes compromises to meet anticipated near-term funding constraints; however the Project would benefit from additional funds above the Budget Option 1 levels in FY18 and FY19, which the WIETR ICE recommends.

Answers to the Terms of Reference Question B

"What is the impact of staying within the funding profile guidelines and KDP-A total cost guidelines?" (Continued)

The Budget Option 2 profile is significantly different than the "standard" funding profile since funding constraints reduce funding starting in FY20, FY21, and FY22.

- Estimating methods assume that funds are available consistent with "standard" profile, which is not the case given WFIRST funding constraints in FY21 and FY22, so a "Funding Constraint Penalty" would need to be added.

A recent study conducted by the Aerospace Corporation for the NASA HQ Cost Analysis Division derived a regression-based cost and schedule model growth due to funding reductions that predicts, based on historical data:

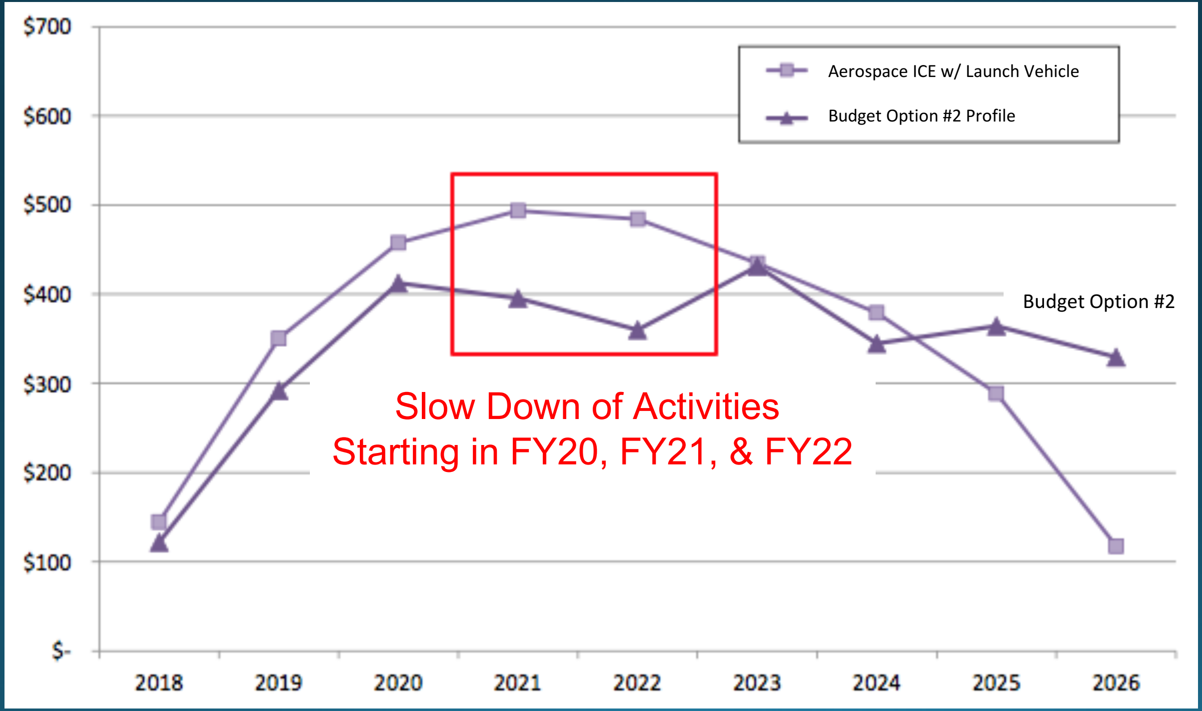
- Cost penalty result is calculated as $230M RY$ vs. the WIETR ICE.
- Schedule penalty result is calculated as ~9 months.

The Project's Budget Option 2 cost estimates of the impact of the Budget Option 2 profile (vs. Budget Option 1, the Project estimate) are consistent with the WIETR calculated penalty due to funding profile guidelines included in the PPBE19 profile.

- Additional cost and schedule is $176M RY$ and 9.3 months projected for Budget Option 2 vs. Budget Option 1.

Answers to the Terms of Reference Question B

The Budget Option 2 profile is inconsistent with mission needs and has substantial shortfalls in FY21 and FY22



Answers to the Terms of Reference Question B

B.c "Are there any (obvious) design/acquisition/technical trades that the Project should conduct that could result in lower cost, earlier launch, reduced cost of science and mission operations, or reduced technical risk?"

The WIETR did not identify anything that the Project had not already identified. The WFIRST team has done a considerable amount of work (~$300M) for a project that has yet to enter KDP-B, particularly in areas that minimize development and cost risk. There are no obvious design/acquisition/technical trades left, short of changing the approach to the mission, the mission requirements, and/or taking a more aggressive stance towards descopes captured in our answer to question A.b. All of these would result in lower cost and/or reduce technical risk.

Changing the approach could entail: accepting lower performance if and as necessary to accommodate existing and readily available hardware and software systems. Examples include: number of detector channels and/or filters, off-the-shelf spacecraft and/or components (e.g. , Ka Band, SSR), smaller telescope. All of these could result in lower cost, but technical and other risks are unknown.

Answers to the Terms of Reference Question B

Areas where the Project has conducted trades, but where the answers to possible cost, schedule, or lower technical risks are either not clear or not recommended because of the major disruptions to the present plans:

- Single vs. Dual Science Data Centers - The decision of having two Science Operations Centers added transactional interfaces and also added some complexity, however, there is little duplication with the present assignments and therefore not much to be saved in consolidating them. There is also the risk of losing expertise and investment to date, should the two centers be consolidated.

- Out-of-house Wide Field Instrument - There are experienced industry providers that could provide the complete WFI. The current hybrid approach is appropriate for both technical and cost considerations. The project is contracting out the WOMA for the WFI, which constitutes the majority of the instrument, absent the focal plane assemblies and electronics, and represents a large portion of the instrument cost. Given that GSFC is developing the detectors, it is appropriate that they also develop the associated electronics and maintain the instrument systems engineering role. As a result, there is little to be gained by changing the acquisition approach. In addition, the programmatic analysis showed that the project estimate compares favorably with the ICE.

- Out-of-house Spacecraft – Cost database and recent studies for In-house GSFC missions indicate that the cost savings for publicly available spacecraft for the required performance do not represent savings. It is possible that an "off-the-shelf" spacecraft for a non-publicly known project could meet the requirements and offer cost and schedule savings. There may be logistics and acquisition issues for these spacecraft options that impact design and performance data accessibility, and therefore impact the feasibility of such an acquisition. However, NASA should continue to explore this approach and determine its costs and feasibility in case the benefit / impact trade makes it attractive to pursue.

Answers to the Terms of Reference Question C

TOR Question C: "Are the management processes in place adequate for a project of this scope and complexity?"

The WFIRST Project produced adequate evidence and/or artifacts to allow the WIETR to ascertain that key internal processes were defined, being followed, and with ownership at the proper levels. The Risk Management process is still evolving and being codified to integrate the Encumbrances, Liens, and Threats into the process and a more distributed model for risk management. The fundamentals of risk management are being executed uniformly, but it is important to stress the need for them to be documented and communicated as soon as possible.

Some of the NASA HQ direction, processes, and policies need immediate attention to add clarity and direction in areas that drive the Program, Project organization, and the business approach and execution environment. The following findings are inter-related:

- **Business Model:** There are differing opinions as to whether the WFIRST Project should operate in a "design-to-cost" versus a "design for maximum science return" model.
    - The use of a "design-to-cost" model and tools to justify scope above the required and available resources is not consistent with a commitment to mission success.
    - Moreover, there is no doubt that the Project is operating under an "optimize for maximum science return" model and culture; a model that tends to be typical of flagship missions. However, trades and decisions indicate that the Project is being cost-conscious (e.g., primary mirror finish, temperature controls, additional metrology, jitter mitigation, V&V approach).
    - The "push" for both maximum science return and design-to-cost creates tensions and an environment where the Project's decisions and motives are second-guessed and questioned under the pressures of the budget. This is based on an assumption that "design-to-cost" model and tools will fit the mission in the box despite the fact that the totality of the present scope and complexity exceed the resources available.

Answers to the Terms of Reference Question C

- **Roles, Accountability, and Authority:** Direction is provided primarily and directly by the APD Dir/Dpty, setting the context for priorities and decisions, and where the ExEP Manager has little authority to "direct" the effort. The expectation of direction can be a source of inefficiencies and confusion:
  - The Formulation Authorization Document (FAD) stipulates that GSFC is totally responsible for the overall management and execution of the WFIRST mission within cost and schedule, and is in day-to-day contact with SMD/APD.
  - The additional interfaces delay decisions for a mission that gets a lot attention because of community interest, its importance, scope, and cost.
  - The predominant WFIRST science is Dark Energy, associated WFI surveys, and WFI microlensing survey for new populations of extrasolar planets; Dark Energy and the associated surveys are the responsibility of PCOS/COR.

- **Communications Management:** While the science cases for Dark Energy and microlensing remain strong and are well-supported within the astronomical community, there is high risk for erosion of that support as the WFIRST cost increases and its schedule slips.
  - WFIRST's position as the number one recommendation from the 2010 Decadal Survey was predicated on it being low-risk technology and having a relatively short timescale. Circumstances accompanying the WFIRST implementation have dramatically altered the mission, increasing its cost and schedule.
  - NASA HQ should be cognizant of community sensitivity regarding the perceived large and growing opportunity cost of WFIRST, relative to other compelling priorities for SMD, including other strategic missions. This is especially important as preparations are being made for the 2020 Decadal Survey.

Answers to the Terms of Reference Question C

Roles, Accountability, and Authority (Continued): (Summary Assessment as Illustrated in Comments)

Role	Accountability	Authority	Comment
SMD/Astrophysics Division	Program science and programmatic strategic direction, and resources	Budget, mission scope (L1 req’ts) and schedule	Direction flows straight to WFIRST; it does not flow through ExEP, except as a pass through
ExEP Program	Direction, insight, and oversight	Little to none over GSFC, budget, or resources	ExEP only has insight and oversight role
COR & PCOS Programs	None	None	WFIRST is supporting these programs yet they have no say or role
WFIRST Project	Overall management and execution of the WFIRST mission within cost and schedule	All aspects, resources, planning, and execution on day to day basis	Getting direction and guidance from many sides

Answers to the Terms of Reference Question C

- **Scope, Requirements, and Risk Management:** The expectation of a "$3.2B maximum" management agreement cap set at KDP-A is not realistic for the scope, complexity, and expectations of the WFIRST mission. Several items, already part of the mission system design at KDP-A (see list below) contribute to the scope and complexity of WFIRST.

  - The 2.4m telescope is not a plug-and-play telescope, but a primary and secondary mirror requiring non-negligible adaptations for structural support, and complex back-end tertiary optics for the WFI, IFC, and the CGI, particularly to meet the CGI optical interface requirements.
  - The addition of the Coronagraph added notable scope, complexity, technical, and programmatic risk to the mission; and even though it does not push the envelope of performance required for the Dark Energy and Astrophysics Surveys, it does drive elements of the system design. The approach of justifying it as a technology demonstration with late delivery dates or "we will fly without it" is unrealistic for the nature of the investment and the expectations that are being created, and the integrated mission design (at a minimum, a mass and thermal model of the Coronagraph would need to fly). Moreover, by the time any decision would be made to not fly the instrument due to development issues, most of the cost impact of the added optical and spacecraft system complexity and risk will almost certainly already have been realized, resulting in substantial cost and schedule growth for WFIRST.

Answers to the Terms of Reference Question C

- **Scope, Requirements, and Risk Management (Continued):**
  - The addition of requirements to support the possibility of a Star Shade-enabled Exoplanet/Coronagraph survey science also adds scope, complexity, and technical and programmatic risk. We recognize that most of the budget associated with it is outside of the WFIRST budget, but the timeliness of decisions do have bearing on processes, plans, and resource planning.
  - The robotic servicing requirement adds scope, complexity, and technical and programmatic risk; although the Project deserves credit for the reasonable approach taken to address the Congressional Bill language, there is still some risk that stakeholders may reject the approach, resulting in cost and schedule impacts.
  - Added interfaces of In-house/Out-of-house hybrid approach to the Wide Field Instrument, and new developments such as the Ka band transmitter and the Solid State Recorder, detectors and ASICs.
  - The Space Telescope Science Institute (STScI) and the Infrared Processing Analysis Center (IPAC), while both perfectly capable institutions, also added technical and transactional interfaces that add scope and complexity, although each now makes contributions consistent with their respective strengths.
  - There is uncertainty in the nature and scope of international contributions, and design or descope decisions (e.g., IFC) are being delayed as a result.

Answers to the Terms of Reference Question C

- **Requirements Management:** The WFIRST Coronagraph Instrument (CGI) is a secondary payload, characterized as a technology demonstration, being developed under a Class C risk classification for flexibility, but with requirements akin to a science payload. The description of CGI as both a technology demonstration and science instrument is a dual characterization that is misleading and and creates confusion. If CGI is indeed a technology demonstration:

    - There should be Level 1 requirements and mission success criteria consistent with a tech demo.
    - It should be integrated into the system design and project management processes on that basis.

- **Risk Classification:** The Class B risk classification for the WFIRST mission is not consistent with the uniform application of NASA policy for strategically important missions with comparable levels of investment and risks. The inconsistency is exacerbated further by the status and treatment of CGI as a science instrument versus a technology demonstration. The estimated cost of classifying WFIRST as a Class A mission is ~ $250M to $300M depending on reliability-driven design changes and other mission assurance requirements.

Answers to the Terms of Reference Question D

TOR Question D: "Are the benefits of the coronagraph to NASA objectives commensurate with the cost and cost risk of development?"

Long-term benefits of coronagraph development to NASA objectives are indisputable. Investment in WFIRST CGI technology development thus far has resulted in advances to coronagraph technologies for obscured apertures. Testbeds developed to support the CGI effort have been a major contributor to these advances, and their use will enable careful completion of both CGI technology development and subsequent testing of engineering models and flight hardware. Progress has been steady and impressive, and consistent with the National Academy of Sciences' recommendations to make substantial investments in these technologies including low-noise EMCCDs (electron-multiplying charge-coupled devices) , deformable mirrors, etc., that are critical for success.

Flight demonstration of CGI can advance technology and methods needed for future missions. Estimated remaining cost of WFIRST CGI development and flight is ~$0.4B including coronagraph science/data analysis, TCA, PM/SE and reserves; based on a Project descope estimate that was checked for credibility by WIETR, but not validated through an ICE.

Going forward, there is a risk that conflicts between Level 1 CGI science requirements (non-binding) and CGI's class C designation can be misleading for science teams and yield unrealistic expectations from the science community. The paradigm of technology demonstration instrument with non-binding science requirements causes confusion, unclear descope paths, and can result in increased cost. There is intrinsic conflict between Level 1 requirements, which are divided between non-binding Baseline Science Requirements (BSRs) and binding Technical Threshold Requirements (TTRs).

Answers to the Terms of Reference Question D

D.a "Are the science/technical requirements, resource (budget, schedule) allocation, and risk posture appropriate for a technology demonstration instrument?"

The current Technology Threshold Requirement (TTR10) for the CGI is incomplete and ill-formulated, and is not constraining enough to support PLRA Technology Demonstration Objectives 2.2.1-2.2.4. Baseline Science Requirements for CGI are not binding. There are no (binding) Threshold Science Requirements for the CGI.

The coronagraph TTRs should be revised prior to SRR; e.g., develop technology threshold requirements on raw contrast, inner working angle, bandwidth, and throughput. The Project should consider setting CGI Technology Threshold Requirements that will advance exozodiacal light knowledge needed to scope a future mission focused on exoplanet science and provide technical advances that are appropriate for a flight technology demonstration instrument. NASA HQ needs to eliminate the dichotomy between the CGI being developed as a technology demonstration and also trying to meet non-binding Baseline Science Requirements; i.e. either fully embrace it as a technology demonstration or promote CGI to a secondary science payload with lifecycle aligned to reach TRL-6 by mission PDR, including cost associated with a higher than Class C risk classification. It will also be important to manage the expectations of the exoplanet science community.

Critical testing elements have been descoped due to budget pressure; in particular there is (1) lack of mechanism life-test units, (2) lack of CCD life-testing, and (3) lack of a full set of engineering models. While compatible with a Class C tech demo, a lack of test units presents significant risks to "opportunistic science" or future "Star Shade science."

Answers to the Terms of Reference Question D

D.a "Are the science/technical requirements, resource (budget, schedule) allocation, and risk posture appropriate for a technology demonstration instrument?" (Continued)

The current budget profile is inconsistent with CGI development needs. FY18 is not funded adequately. Unless the inconsistency is resolved, it will likely drive work that should be completed in FY18 to outer years, thereby presenting a risk to the schedule of producing CGI delivery within the budget. This risk could be addressed by re-phasing funding to continue CGI development, or by providing additional STMD technology development funds to bridge the gap.

Answers to the Terms of Reference Question D

D.b "Does the technology demonstration require a space mission?"

Space flight of a coronagraph system with low-order wavefront sensing and deformable mirrors in presence of spacecraft disturbances to prove technology at a significant systems level for future space flight is a sound approach, provided the Technology Threshold Requirements (in particular TTR10) are formulated to sufficiently advance technology (see previous).

Understanding CGI performance as part of a larger flight system that includes wavefront error sensing and correction, interfaces with the telescope, observatory, and space environment, and operations and post-processing, is important before designing and implementing any future coronagraph mission.

Modelling of interactions between observatory and CGI, accounting for effects of thermal and pointing variations, polarization changes caused by the telescope primary mirror and other optics, etc., will be important for advancing understanding and for informing future mission designs.

Answers to the Terms of Reference Question D

D.c What are the cost and schedule savings (if any) of removing the coronagraph from the mission at this stage?

At this stage, the cost savings of removing the coronagraph from the WFIRST mission is on the order of ~$0.4B including removal of coronagraph science/data analysis, TCA, PM/SE and reserves; based on a Project descope estimate that was checked for credibility by WIETR, but not validated through an ICE. Given that the coronagraph is not on the critical path for the current WFIRST schedule, its removal would not likely result in any schedule savings.

- A refocusing of the CGI requirements as a tech demo combined with a concomitant redesign of the instrument could provide substantial savings.

RECOMMENDATIONS AND OPTIONS OF GREATEST CONSEQUENCE TO WFIRST

Recommendation 1 (Slide 1/3)
Match Program Resources to Mission Scope

The WIETR Independent Cost Estimate (ICE) for WFIRST is $3.9B RY$.

- Derived from the Project's Budget Option 1 scope and schedule.
- This is 10% higher than Project Budget Option 1 of $3.6B.

Given ICE uncertainty range, the present concept requires $3.9B to $4.2B (including Class A reclassification) or $350M to $600M more than the Project's estimate.

The WIETR Panel recommends that NASA match funding and other resources to align with the accepted mission scope.

Recommendation 1 (Slide 2/3)
Match Program Resources to Mission Scope

To better understand the options available, NASA should conduct a top-to-bottom cost-benefit assessment to determine whether to:

- 1A. Continue with the present mission requirements and scope with the proper resources (funding) and profile (schedule) required, or;

- 1B. Distribute the scope, and thus the risks over two missions (i.e. a Dark Energy/Microlensing-Exoplanets/Astrophysics mission, and a dedicated Exoplanet Imaging/Coronagraph mission), perhaps taking advantage of the system design that WFIRST has already invested in, or;

- 1C. If indeed the $3.2B "cap" is required, descoping the CGI from the WFIRST mission, together with some of the other smaller-value descopes, will approach that goal.

Recommendation 1 (Slide 3/3) Match Program Resources to Mission Scope

Pros	Cons
• Opportunity to match scope and complexity with resources (<u>total and yearly profile</u>) available early, and before consequential decisions are codified into Level 1 and lower level requirements. (All Options) • Opportunity to distribute, reduce, bound risks, and contain risks. (All Options) • Helps the "Design-to-Cost" Business Model tension issue being brought about by trying to increase scope within limited resource caps; instead, focusing on opening the trade space. (All Options)	• A major pause and extension of Phase A for the Dark Energy/Exoplanet (Microlensing) mission if Budget Option 3, and possibly Budget Option 2 depending on approach to telescope and scope. • Complete replanning required. (Options 1B and 1C) • Long lead contracts in motion may need modifications. (Options 1B and 1C) • Loss of motivation and momentum among the team. (Options 1B and 1C) • Impact to workforce capability development plans. (Primarily Option 1C) • Loses the space demonstration of needed technologies prior to a dedicated Exoplanet mission, increasing risk to that mission. (Options 1B and 1C) • Requires a new start for a dedicated Exoplanet mission not currently in the portfolio. (Option 1B) • Impacts Star Shade readiness. (Option 1C)

Recommendation 2 (Slide 1/5) Coronagraph Instrument

Key Finding: Paradigm of technology demonstration instrument with non-binding baseline science requirements causes confusion, can be misleading for science teams, yield unrealistic expectations from the science community and uncertainty in descope paths, which results in increased cost risk.

The dichotomy paints a confusing story with regard to the following expectations:

- Performance versus acceptable requirements.
- Status as science instrument versus technology payload.
- Science community engagement.
- Interfaces to the Exoplanet Program and its longer term plans unclear.
- Risk classification (Class C) of tech demo vs. science instrument (Class B) conflict.

This confusion is certain to represent risks to the primary mission well into the verification and validation program.

Recommendation 2 (Slide 2/5) Coronagraph Instrument

The WIETR panel recommends to consider the following options:

- 2A. Descope CGI from the WFIRST mission, or;
- 2B. Refocus the CGI as a technology demonstration funded independently, governed by an ICD, and with no Science Requirements (need to include some minimum science data processing), or;
    - Reassess the minimal instrument that would meet the technology demonstration goals, e.g., inclusion of only one coronagraph type, one deformable mirror (DM), one back-end instrument (e.g., remove IFS), reduce number of optical relays and mechanisms accordingly. Reduce the science planning and processing pipeline requirements to be consistent with these goals.
    - Once the technology demonstration goals are satisfied, consider offering the CGI as a Guest Observer facility.
- 2C. Promote the CGI to secondary science payload status, establish stringent, executable baseline science requirements, and allow the CGI to put additional science-driven requirements on the observatory.

Recommendation 2 (Slide 3/5)
Coronagraph Instrument

Option 2A: Descope CGI from the WFIRST mission (Same as Recommendation 1, Option 1C)

Pros	Cons
Reduce estimated cost of WFIRST by ~ $400M.	Forgo opportunity to advance coronagraph technologies and flight heritage prior to a dedicated mission.
	Forgo potential science opportunities including photometric characterization of known RV planets and exozodi emission levels.
	Disrupt momentum of experienced, world-class CGI team developing critical technologies for future missions.
	Eliminate Star Shade compatibility.

Recommendation 2 (Slide 4/5)
Coronagraph Instrument

Option 2B: Refocus the CGI as a technology demonstration, funded independently, governed by an ICD, and with no Science Requirements (including science data processing)

Pros	Cons
Reduces cost by implementing descopes and reduces science costs relative to current CGI implementation (i.e. cost, workforce, schedule) to meet Baseline Science Requirements. Avoids potential cost growth to achieve science rather than technology demonstration goals.*	Reduces science capabilities of CGI relative to current baseline. However, the current baseline science requirements are non-binding (i.e. will be waived if not achieved).
Provides tech development and space demo of starlight suppression (coronagraph and focal plane wavefront sensing), low-order wavefront sensing (LOWFS), deformable mirror (DM), and low-noise EMCCD technologies in addition to ground modeling and development of data processing techniques that will benefit future coronagraph missions currently under study.	
Elimination of confusing dual flow of Baseline Science Requirements and Technology Threshold Requirement allows focus on technology demonstration goals, reduces potential technical, management & cost risks, and will help stabilize the Observatory-to-CGI interfaces.	Potentially eliminates Star Shade compatibility (if IFS is descoped).
Retention of experienced, world-class CGI team and maintaining the momentum for the development of these critical technologies.	

*The full cost allocations and descope savings across the Project are not consistent, making an assessment of the savings from a full or partial descope of the CGI difficult.

Recommendation 2 (Slide 5/5)
Coronagraph Instrument

Option 2C: Promote the CGI to secondary science payload status, establish stringent, executable baseline science requirements, and allow the CGI to put additional science-driven requirements on the observatory

Pros	Cons
Elimination of confusing dual flow of Baseline Science Requirements and Technology Threshold Requirement allows realistic cost assessment and reduces cost risk (growth).	Would incur cost increase for the CGI and Observatory including potential upgrade of CGI to Class B development.
Executable, baseline science requirements provide clear expectations to Science teams and community. Provides best science by allowing CGI to impact Observatory requirements.	The severe contrast, bandwidth, and optical throughput limitations imposed by the heavily obscured WFIRST telescope fundamentally limits the potential science reach of the CGI relative to a dedicated probe-class coronagraph mission.
Maintains the technology development, but as a by-product of delivering the required science capability.	May reduce technology advancement since science requirements must be achievable, i.e. more risk-averse.
Maintains Star Shade compatibility.	

Recommendation 3 (Slide 1/2) Mission Reclassification

The Class B risk classification for the WFIRST mission is not consistent with the uniform application of NASA policy for strategically important missions with comparable levels of investment and risks, most if not all of which are Class A missions. NASA should require a critical reevaluation of EDUs, ETUs, spares, life test and qualification units, and V&V and support plans, ensuring they are in the baseline (not an encumbrance, lien, threat) cost of the mission from the start.

Options to NASA are:

- 3A. Designate as Class A and tailor down to reasonable application consistent with resources, or;
- 3B. Augment the Class B designation to take a more robust approach to EDUs, ETUs, spares, life and qualification test units, and for post-delivery support, bringing it closer to a Class A risk classification.

Recommendation 3 (Slide 2/2) Mission Reclassification

Pros	Cons
The risk classification will provide the policy backdrop to address the concerns behind insufficient EDUs, ETUs, spares, parts, and life test units. (All Options)	Reclassification will add additional ~$250M to ~$300M to the WIETR Independent Cost Estimate. (All Options)
Opportunity to also revisit the risk classification for the CGI secondary payload, which will address similar concerns with EDUs, ETUs, spares, parts, and life test units, and mission lifetime expectations and mismatch [e.g., CGI Electron-Multiplying Charge Coupled Device (EMCCD) detectors may be limited to < 5 years in flight.] (All Options)	

Recommendation 4 (Slide 1/2)
Roles, Accountability, Authority

- The NASA HQ to Program governance structure is dysfunctional, and should be corrected for clarity in roles accountability and authority.

  Options to NASA are:

- 4A. Remove intervening Center/Program by moving to NASA HQ, similar to the JWST program RAA structure, or;

- 4B. Grant authority for direction to ExEP if allowed under contract law, and reach agreement among all the parties as to its execution, or;

- 4C. Limit the accountability and authority to Insight and Oversight (not direction), and move to an organization independent from ExEP, PCOS, COR to provide the level of independence sought in applying the JWST lessons.

Recommendation 4 (Slide 2/2)
Roles, Accountability, Authority

<table>
<tr><th>Pros</th><th>Cons</th></tr>
<tr><td>Options 4A and 4C Result in a more accurate representation of the actual direction being provided, and is commensurate with the complexity of dealing with APD’s multiple science communities, avoiding conflicts (real or perceived) between PCOS/COR/ExEP, and WFIRST.</td><td rowspan="3">No ”Cons”, but SMD and/or APD need to:
• Establish, certify, and communicate the necessary structure within SMD and APD.
• Strengthen the Insight/Oversight, and Performance Analysis capability within SMD/APD.
• Require an agreement between the parties and careful assessment of the key Insight and Oversight functions and approach to them.</td></tr>
<tr><td>Option 4B removes the burden from the ExEP of being held accountable for something they have no authority to execute.</td></tr>
<tr><td>Option 4A provides for simpler interfaces, and opportunity for higher efficiency in decision-making.</td></tr>
</table>

OTHER RECOMMENDATIONS AND OPTIONS

Other Recommendations and Options

<table>
<tr><th>Recommendation to Address Key Findings</th><th>Pros</th><th>Cons</th></tr>
<tr><td>5. Given that robotic servicing (RS) is not required to meet the L1 or threshold requirements of WFIRST, reduce the scope and complexity of robotic servicing as a requirement.</td><td>• Keeping the requirement addresses the intent of Congress, and puts WFIRST in the driver's seat for interface requirements. However, this places onto the Project the burden of rationalizing how robotic servicing is defined.
• Cost savings estimated at <$10M.</td><td>• Inclusion of RS drives or limits design solutions for placement of hardware (e.g., momentum wheels, harnesses).
• Open risk because capability of robotic servicer may not be available before end of the WFIRST formulation phase.</td></tr>
<tr><td>6. The IFC is currently written out of much of project planning, but the prospect of an IFC re-scope lingers both among the WFI team and in many other areas of the WFIRST development. It is critical to make a decision on whether to include it. WIETR is neutral on the sign of the decision regarding the IFC, but offers the pros and cons in the columns on this chart:

NOTE: The descope of the IFC would bring about savings in mass and complexity, including OTA savings on the back-end optics.</td><td>• The IFC is motivated by the supernova program, and of the three Dark Energy pillars, this is the one that is done uniquely well by WFIRST.
• At z < 1, the SITs forecasts are that WFIRST is limited by systematics. At z > 1, WFIRST cannot be beaten by ground-based supernova work.
• The IFC can help in both redshift regimes by providing spectroscopic redshifts, which improve upon photometric redshifts, and buy down systematics that limit the Dark Energy results.
• From a GO perspective, the IFC would be the most sensitive IR spectrograph available post-JWST.</td><td>• The IFC is an add-on (increase in scope) that carries a substantial cost of ~$100M, which is not included in the WIETR Independent Cost Estimate (ICE) since the IFC was already proposed as a descope.
• The WFIRST supernova program is still the best without IFC, so the IFC may not be required at Level 1.
• IFC impacts science operations.
• IFC drives calibration requirements.
• Supernova evolution could be tested from the ground with future large-aperture telescopes.</td></tr>
</table>

Other Recommendations and Options

Recommendation to Address Key Findings	Pros	Cons
7. The WFC grism is currently included in project planning, and although relatively modest in hardware cost, it carries ancillary costs in the SOCs and the SITs and consumes a significant amount of mission time, which is an opportunity cost. WIETR recommends that the Project and the SITs make a balanced assessment of the case for and relative competitiveness of a high latitude survey with WFIRST geared towards BAO. The WFIRST team should not be afraid to drop BAO as a driver of science and mission requirements if that is the best thing for the overall health of the mission.	• A slitless redshift survey would complement the weak lensing pillar of DE. • From a GO perspective, the grism offers substantial multiplex opportunity and higher sensitivity than ground-based infrared spectroscopy.	• The grism is motivated by the BAO pillar of DE, but by 2027 WFIRST is not a compelling BAO engine.

Other Recommendations and Options

Recommendation to Address Key Findings	Pros	Cons
8. The exoplanet spectroscopy is probably the least achievable part of the science case for CGI, falling short of conveying a compelling exoplanet spectra science. This brings into question the inclusion of IFS as part of CGI, except for technology development and Star Shade compatibility. Options are: 8A) Retain IFS as part of the CGI, or; 8B) Descope IFS from CGI.	• Descoping the IFS would eliminate a CGI driving requirement for high-contrast spectra. (Option 8B) • Descoping the IFS would provide a simpler CGI instrument optimized to achieve the technology demonstration goals in line with HabEx and LUVOIR technology roadmaps. (Option 8B) • Descoping the IFS reduces the CGI cost by ~$20M plus some additional ISOC costs. (Option 8B)	• Descope of IFS has a dramatic consequence on the readiness so this descope will have to be considered with the decision on Star Shade accommodation. (Option 8B) • The lifetime expectation for CGI as a Class C instrument is not consistent with a SS mission, which would come after the WFIRST baseline primary mission lifetime requirement. (Class C lifetime is typically <2 years per NPR 8705.4). (Option 8A) • SS science would ideally require higher performance than the current CGI design provides, as follows: 1) significantly more IFS bandwidth than planned for the CGI (20%); 2) Better throughput; 3) Dedicated lateral sensors (the current plan is to use the CGI LOWFS out of band). (Option 8A)

Other Recommendations and Options

Recommendation to Address Key Finding	Pros	Cons
9. The addition of requirements to support the possibility of a Star Shade (SS)-enabled Exoplanet/Coronagraph survey science also adds scope, complexity, and technical and programmatic risk. Furthermore, there are multiple incompatibilities that negatively affect the use of WFIRST for SS science. The performance of the CGI, with or without the IFS, is not well suited to SS science; neither is the performance of the heavily obscured WFIRST telescope due to its severe contrast, bandwidth, and optical throughput limitations which substantially limit potential science reach of CGI. It is recognized that the budget associated with it is outside of the WFIRST budget, but the timeliness of decisions do have bearing on processes, plans, and resource planning. Options are: 9A. Descope (SS compatibility) before SRR/MDR, or; 9B. Retain (SS compatibility) and acknowledge and assess “Cons” so they are addressed as part of an independent review for compatibility requirements.	• Descoping early will avoid risks associated with increase in scope, complexity, cost, schedule and added technical and transactional interfaces. (Option 9A) • Conduct in-depth and independent assessment of goals, objectives, and concomitant requirements for IFS and Star Shade as an end-to-end system. (Option 9B)	Option 9B • The lifetime expectation for CGI as a Class C instrument is not consistent with a SS mission. • SS science would ideally require higher performance than the current CGI design provides: 1) significantly more IFS bandwidth than planned for the CGI (20%); 2) better throughput; 3) dedicated lateral sensors (the current plan is to use the CGI LOWFS out of band) • SS science requires the WFIRST and SS vehicles to operate together as a system. There is currently no plan for an end-to-end test of the WFIRST and SS operation; this is a technical risk and significant test-as-you-fly deviation. • The cost of the V&V program has not been evaluated. • Impact on scheduling and ground support: Star Shade observations are known to be very disruptive to the overall scheduling due to the absolute time constraint of the Star Shade positioning. • Estimate of cost and impact to the CGI core mission has been pushed back to after the decadal review. • Impact on CGI software: the SS and WFIRST + CGI will work as a closed-loop system, with WFIRST and the CGI being the sensors (acquisition and lateral sensor, respectively). • CGI will not be passive during Star Shade operations. Software deltas and software interfaces for the CGI are significant and carry additional risks for the CGI. • A shutter mechanism may be required in the CGI to protect the detectors from scattered starlight from SS thruster plumes. This mechanism is not yet in the CGI design. SS scattered light is also a concern for the WFI.

Other Recommendations and Options

Recommendation to Address Key Finding	Pros	Cons
10. Expedite the Telescope/OTA effort, and take full advantage of heritage of inherited components.	• Acknowledgement that the original customer's requirements, although different from NASA's, are equally well-considered. This acknowledgement will avoid retroactively imposing NASA build standards on the existing hardware, which would result in increasing risks and cost. • Completing the Optical Telescope Assembly will save the Project significant money over the lifecycle and reduce risk of future development issues/conflicts.	• Requires re-prioritization of other efforts (e.g., spacecraft) to enable, and/or provide additional early funds.
11. Expedite decisions on international and or other collaborations and contributions.	• Finalizing decisions before the end of phase A will remove risk and distractions from an already complex effort. • Reduces interfaces and risks.	• May miss opportunities to lower cost to NASA.

Summary and Conclusion

- The NASA Science Mission Directorate Associate Administrator (SMD/AA) convened a WFIRST Independent External Technical/Management/Cost Review (WIETR) panel, to assess whether NASA's approach to Phase A has yielded a mission that is (1) well understood in terms of scope and required resources (cost, funding profile, schedule, etc.) and (2) executable.

- The answer to the Terms of Reference questions from the SMD/AA required the WIETR to assess the WFIRST project at the current stage of formulation (end of Phase A) for the following:

  - Reasonableness and understanding of the technical requirements.
  - Alignment and understanding of the scope and cost/schedule.
  - Adequacy of the management processes for a project of the WFIRST scope and complexity.
  - Whether the benefits of the coronagraph to NASA objectives were commensurate with the cost and cost risk of development.

Summary and Conclusion

- The WIETR found the following:

  - Technical requirements are understood but incompatible with the guideline resources provided to the Project and are therefore unreasonable.
  - Scope and cost are not aligned.
  - Key internal processes are adequate, but NASA governance and application of policy need improvement.
  - There are benefits to developing coronagraph technologies that are consistent with NASA's longer-term objectives for the Exoplanet Exploration Program (ExEP). Accommodation of the coronagraph, however, has been a mission system design and programmatic driver through formulation and will continue to be a driver, with concomitant risks, to the primary mission well into the WFIRST verification and validation program.

- The WIETR concludes therefore that although the scope is understood, as designed, the risks to the primary mission of WFIRST are significant and therefore the mission is not executable without adjustments and/or additional resources.

APPENDICES

Acronyms
Charter and Purpose
WIETR Panel Membership
WIETR Process

Acronyms-1

AA – Associate Administrator
AFTA—Astrophysics Focused Telescope Assets
APD – Astrophysics Division
APMC – Agency Program Management Council
ASM – Acquisition Strategy Meeting
BAO – Baryon Acoustic Oscillations
BSR – Baseline Science Requirements
CATE- Cost Analysis and Technical Evaluation
CCD – Charge-coupled Device
CGI – Coronagraph Instrument
COR – Cosmic Origins
CR – Concept Review
CTS- Cornell Technical Services
DE – Dark Energy
EDU – Engineering Development Unit
EMCCD – Electron-Multiplying Charge-Coupled Device
ETU – Engineering Test Unit
ExEP – Exoplanet Exploration Program
FAD – Formulation Authorization Document
FCR – Facility Cryogenic Radiator
FY – Fiscal Year
GEO- Geosynchronous Earth Orbit
GI – Guest Investigator
GO – Guest Observer
GSFC – Goddard Space Flight Center
HabEx – Habitable Exoplanet Imaging Mission
HST – Hubble Space Telescope
HQ – NASA Headquarters
IC – Instrument Carrier
ICD – Interface Control Document
ICE – Independent Cost Estimate
IFC – Integral Field Channel
IFS – Integral Field Spectrograph
IPAC – Infrared Processing and Analysis Center
IR – Infrared
ISE – Independent Schedule Estimate
ISOC – IPAC Science Operations Center
JWST – James Webb Telescope
KDP – Key Decision Point
L2 – Lagrange Point 2
LOWFS – Low-Order WaveFront Sensing
LRD – Launch Readiness Date
LUVOIR – Large UV Optical IR Surveyor
MCR – Mission Concept Review
MDR – Mission Definition Review
NASA – National Aeronautics & Space Administration
NPD – NASA Policy Directive
NPR – NASA Procedural Requirements
NRC – National Research Council
OBA – Outer Barrel Assembly, Optical Baffle Assembly
OTA – Optical Telescope Assembly
PCOS – Physics of the Cosmos

Acronyms-2

PDR – Preliminary Design Review
PPBE – Planning, Programming, Budget and Execution
PLRA – Program Level Requirements Appendix
PM – Program Manager
RAA – Roles, Accountability, Authority
RAA – Risk Acceptance Authority
RS – Robotic Servicing
RV – Radial Velocity
RY- Real Year
SASS – Solar Array/Sun Shield
SDT – Science Definition Team
SE – Systems Engineer
SITs – Science Investigation Teams
SMD – Science Mission Directorate
SOC – Science Operations Center
SOMA – NASA Office of Mission Assurance
SRR – System Requirements Review
SS – Star Shade
SSOC – STScI Science Operations Center
SSR – Solid State Recorder
STMD – Space Technology Mission Directorate
STScI – Space Telescope Science Institute
TCA – Transformational Communications Architecture
TOC – Table of Contents
TOR – Terms of Reference
TTR – Technical Threshold Requirement
TRL – Technology Readiness Level
UFE – Unallocated Future Expenses
V&V – Verification and Validation
WFC – Wide Field Camera
WFC – Wide Field Channel
WFI – Wide Field Instrument
WFIRST – Wide Field Infrared Survey Telescope
WIETR – WFIRST Independent External Technical/Management/Cost Review
WOMA – WFI Opto-Mechanical Assembly

Charter and Purpose

The NASA Science Mission Directorate Associate Administrator (SMD/AA) convened a WFIRST Independent External Technical/Management/Cost Review (WIETR) panel, to assess whether NASA's approach to Phase A has yielded a mission that is both:

(1) Well understood in terms of scope and required resources (cost, schedule, etc.), and;

(2) Executable.

The panel was to consist of members with considerable domain experience in program, project management, systems engineering, schedule/cost estimation, science, and instruments, relevant to the WFIRST science objectives.

The WIETR report will inform NASA deliberations and programmatic direction to the WFIRST Project as they prepare for the Systems Requirements Review (SRR) and Mission Design Review (MDR) and the subsequent NASA APMC KDP-B.

Charter and Purpose

Terms of Reference Questions

The WIETR panel was charged by NASA SMD Associate Administrator Thomas Zurbuchen to conduct an assessment of the WFIRST Project that addressed the following questions:

A. Are the technical requirements understood and reasonable?

  a. Are the technical requirements aligned with the mission's science goals?

  b. Are there any (obvious) science/technical requirements descopes that the Project should consider that could result in acceptable science return as well as lower cost, earlier launch, or reduced risk?

B. Are the scope and cost/schedule understood and aligned?

  a. What is the likely range of probable cost and schedule, and what are the drivers?

  b. How do non-optimal funding profiles affect the cost/schedule of the mission? What is the impact of staying within the funding profile guidelines and KDP-A total cost guidelines?

  c. Are there any (obvious) design/acquisition/technical trades that the Project should conduct that could result in lower cost, earlier launch, reduced cost of science and mission operations, or reduced technical risk?

C. Are the management processes in place adequate for a project of this scope and complexity?

D. Are the benefits of the coronagraph to NASA objectives commensurate with the cost and cost risk of development?

  a. Are the science/technical requirements, resource (budget, schedule) allocation, and risk posture appropriate for a technology demonstration instrument?

  b. Does the technology demonstration require a space mission?

  c. What are the cost and schedule savings (if any) of removing the coronagraph from the mission at this stage?

WIETR Panel Membership/Consultants

Member	Affiliation
Peter Michelson	Co-Chair – Stanford Univ/CTS
Orlando Figueroa	Co-Chair – NASA Retired/CTS
Dan Woods	Executive Secretariat – NASA SMD
Bob Bitten	Aerospace Corp
Roger Brissenden	Harvard-Smithsonian/CTS
David Charbonneau	Harvard-Smithsonian/CTS
Eileen Dukes	CTS
Daniel Eisenstein	Harvard-Smithsonian/CTS
Dave Kusnierkiewicz	Applied Physics Laboratory
William Green	Caltech – Retired/CTS
Lynne Hillenbrand	Caltech
Anne Kinney	W.M. Keck Observatory/CTS
James Lloyd	Cornell University/CTS
Dimitri Mawet	Caltech/CTS
Gary Rawitscher	NASA SMD
Mark Saunders	NASA – Retired/CTS
Pete Theisinger	Jet Propulsion Laboratory – Retired/CTS

Consultants	Affiliation
Bob Kellogg	Aerospace Corp
Eleanor Ketchum	National Reconnaissance Office
Tom Magner	Applied Physics Laboratory
Michael Paul	Applied Physics Laboratory
Justin Yoshida	Aerospace Corp
Joan Zimmermann	Ingenicomm, Inc.

WIETR Process-1

- The WIETR panel, comprised of science, technical, systems, program, and project management experts, was formally emplaced on July 18, 2017.

- The WIETR panel conducted their assessment over a period of two (2) months, consistent with a specific set of questions defined in the Terms of Reference signed by Dr. Thomas Zurbuchen, the NASA Associate Administrator, Science Mission Directorate in June 2017.

- Monthly meetings with Dr. Zurbuchen and regular teleconferences internal to the WIETR allowed the WIETR to organize and coordinate the effort for success.

- The WIETR approached the task by first organizing a plenary session where the full scope of WFIRST was reviewed with the WFIRST Project team during the week of August 7, 2017.

- The plenary was followed by subpanel site visits and tele-conferences conducted by seven (7) parallel WIETR subpanels where "deep dives" into areas of relevance to the TOR questions were pursued.

WIETR Process-2

THE WIETR SUBPANELS	
1	Coronagraph Instrument and Exoplanet Science
2	Wide Field Instrument and Dark Energy/Survey Science
3	Science Data Centers
4	Telescope/Optical Telescope Assembly
5	Robotic Servicing and Star Shade
6	Programmatic and Spacecraft
7	Management/Processes and Policies

WIETR Process-3

- A second plenary of the WIETR was held September 6-7, 2017 at NASA HQ, where findings from the subpanel site visits were presented and discussed, and where the WIETR began the integration of inputs for answers to the TOR questions.
- Key findings of the WIETR are summarized in the report; specific answers to the TOR questions are provided in the body of the report. The WIETR answers to the TOR questions provide NASA with context, pros, and cons for possible options of consequence; additional findings by the WIETR subpanels provide recommendations for NASA SMD and the WFIRST Project in other areas where improvements may be possible as the Project moves forward.