



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

Presentation to the
Committee on Astronomy & Astrophysics
October 25, 2017



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.

The WIETR report has been delivered to the NASA Associate Administrator for Science Mission Directorate, Thomas Zurbuchen, in support of NASA's 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.



WIETR 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?

This presentation focuses on the WIETR answers to TOR Question B, the answers to which encompass key aspects and findings of the other TOR questions.



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

- The WIETR panel addressed the TOR over a period of two (2) months, beginning July 18, 2017
- 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.

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



Key WIETR Findings-1

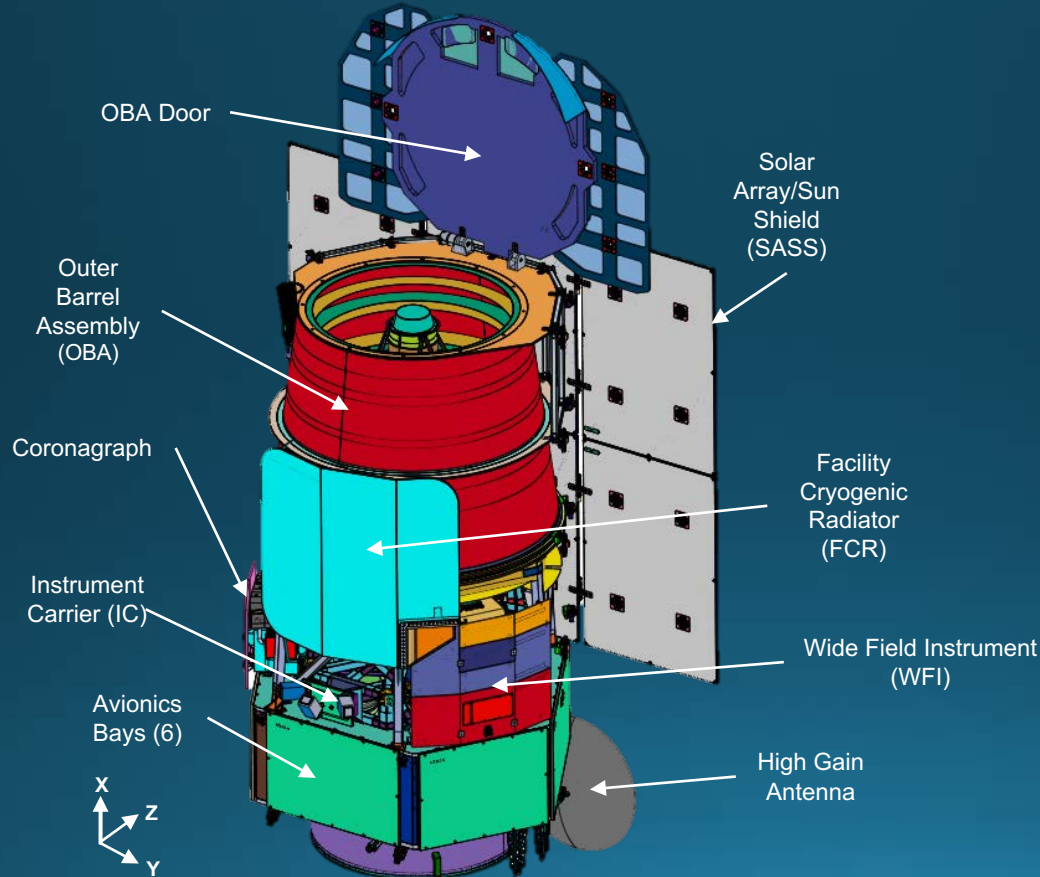
- The WFIRST planned science surveys program and system design offer groundbreaking and unprecedented survey capabilities to the Dark Energy, Exoplanets, and Astrophysics communities.
- The WFIRST team has done a considerable amount of work for a project that has yet to enter KDP-B, particularly in areas 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.



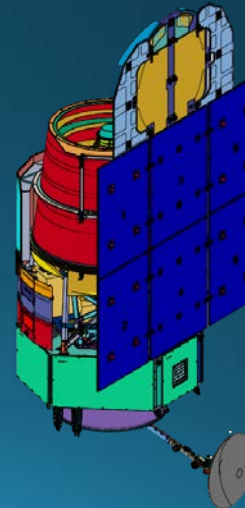
Key WIETR Findings-2

- 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 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.

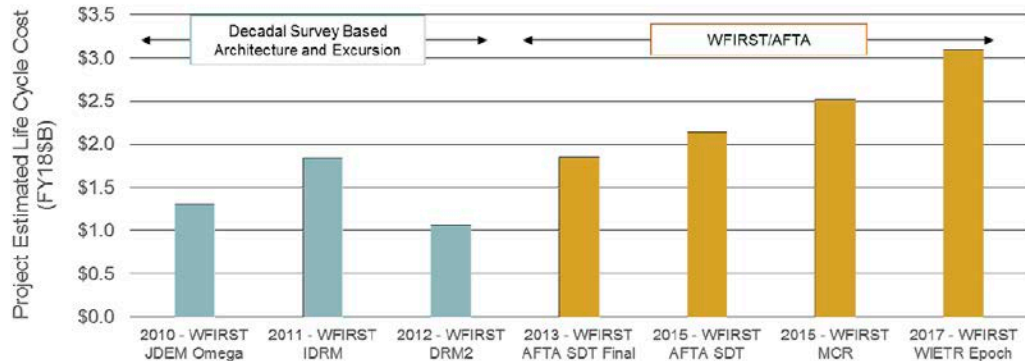
The evolution of WFIRST is provided for historical context and as an introduction to the chart that follows. WFIRST, the highest priority space mission in the 2010 NRC Decadal Survey of astronomy and astrophysics, was estimated to cost \$1.9B (FY18\$)¹ and assumed a 1.5m telescope. WFIRST adopted a 2.4m 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 IDRМ	DRМ2	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:

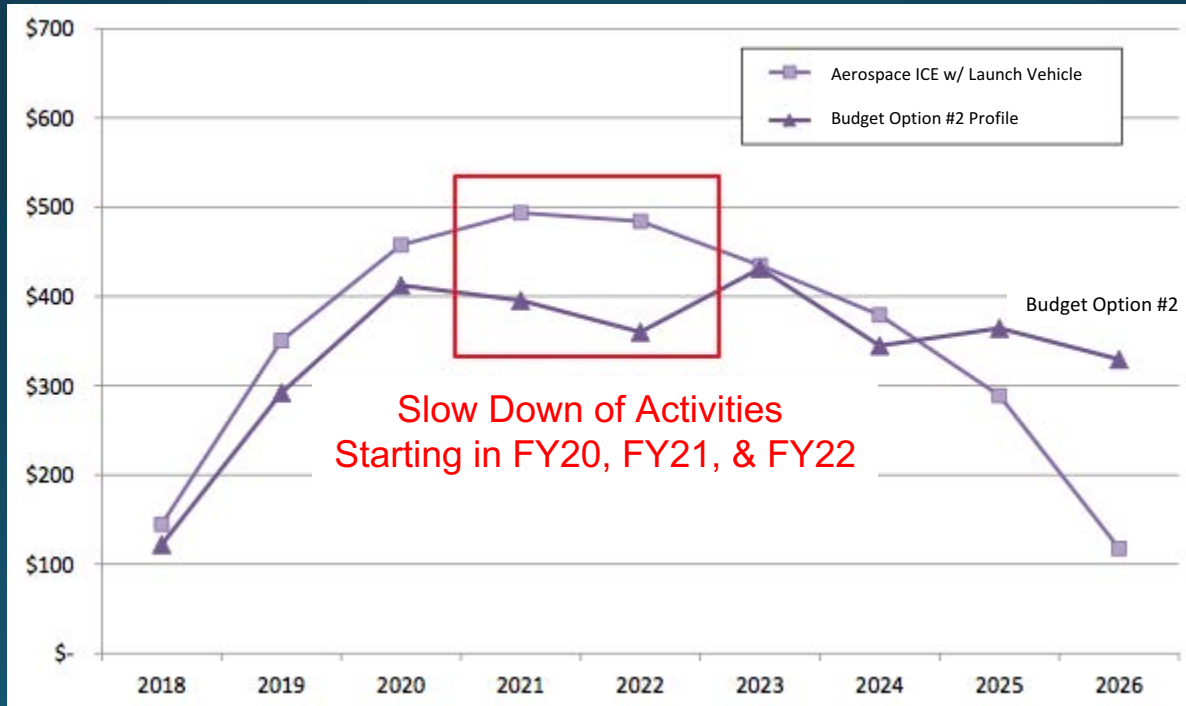
- Cost penalty result is calculated as \$230M RY\$ vs. the WIETR ICE.
- Schedule penalty result is calculated as ~9 months.

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.



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.



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.