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REPORT IN BRIEF

Evaluation of the Implementation of WFIRST/AFTA in the Context of New Worlds, New Horizons in Astronomy and Astrophysics

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The National Aeronautics and Space Administration (NASA) has considered several potential designs for the Wide Field Infrared Space Telescope (WFIRST), the highest priority, large-scale, space-based observatory recommended by the 2010 National Research Council decadal survey in astronomy and astrophysics, *New Worlds, New Horizons in Astronomy and Astrophysics* (NWNH). Complicating their design decision is the transfer of two 2.4-meter telescope assets from the National Reconnaissance Office to NASA in 2012. Dubbed the Astrophysics Focused Telescope Assets (AFTA), this hardware could potentially be used to implement the WFIRST mission with a larger mirror, offering the potential of substantially greater scientific return for the mission than was originally proposed in NWNH. A larger mirror would also enable the inclusion of a coronagraph, which has the potential to advance NWNH objectives for technology development toward a future Earth-like exoplanet imaging mission. However, using AFTA to implement WFIRST (WFIRST/ AFTA) comes with increased cost and technical risks—particularly if the coronagraph is also included in the mission—which is at odds with the programmatic rationale in NWNH for recommending the comparatively lower-risk baseline WFIRST mission.

In response to a NASA request, this report assesses the responsiveness of the WFIRST/AFTA mission—with and without a coronagraph—to the baseline WFIRST mission on the basis of their science objectives, technical complexity, and programmatic rationale, including projected cost. The report also assesses the responsiveness of the WFIRST/AFTA mission with the coronagraph to the objectives of the exoplanet technology development program recommended in NWNH. The study committee was not asked to recommend which version of WFIRST to use, nor to recommend whether the coronagraph should be added, only to assess WFIRST/ AFTA and its responsiveness to the recommendations of NWNH.

Introduction

New Worlds, New Horizons outlined a ten-year strategic program for conducting astronomy and astrophysics research in the years 2010-2020 for NASA, the National Science Foundation, and the Department of Energy. NWNH's highest priority recommendation to NASA for a large-scale, space-based observatory was WFIRST. As envisioned by NWNH, WFIRST is a near-infrared imaging and low-resolution spectroscopy mission designed to address some of the most fundamental questions in astrophysics.

Using three techniques—supernova distances, weak gravitational lensing, and baryon acoustic oscillations—WFIRST would probe the nature of dark energy, study the architecture of other solar systems, and advance our understanding of how galaxies, stars, and black holes evolve. Advances made in dark energy research, for example, demonstrate that research in this domain is on the threshold of new discoveries, and the report notes that the way forward is to make more accurate measurements with ever more capable telescopes and pursue several approaches in parallel.

The report notes that the scientific case for WFIRST is as compelling today as when it was considered by

NWNH. This is bolstered by the development of NWNH's highest priority large-scale ground-based telescope, the Large Synoptic Space Telescope (LSST), and the European Space Agency's Euclid mission, whose datasets will each be strongly complemented by WFIRST.

Comparison between WFIRST/IDRM and WFIRST/AFTA

After the decadal survey recommended WFIRST, NASA conducted a technical study to more fully scope out the mission. This baseline version of WFIRST is referred to as the WFIRST Interim Design Reference Mission (WFIRST/IDRM), and is the version of WFIRST that this report uses for a baseline comparison to the WFIRST/AFTA mission concept. WFIRST/AFTA would employ a larger on-axis mirror and operate at a higher temperature. The table on the facing page provides a detailed technical comparison of the two reference missions.

A significant potential difference between the two mission architectures would be the addition of a coronagraph onto WFIRST/AFTA, something that would not be possible on WFIRST/IDRM because the telescope aperture would be too small to accommodate it. WFIRST/AFTA, would also use an Integral Field Unit (IFU) in lieu of the two spectrographs recommended for WFIRST in NWNH. This report finds that using an IFU on WFIRST/AFTA simplifies the instrument complement and thermal design and reduces solar array size. The IFU will not add significant complications or cost to the mission.

The report also finds that WFIRST/AFTA exceeds the goals set out in NWNH that led to the specifications of the baseline WFIRST/IDRM mission concept. Furthermore, the report finds that the observing program envisioned for WFIRST/AFTA is consistent with the science program and responsive to all of the scientific goals described in NWNH, and that the larger aperture of WFIRST/AFTA will significantly enhance the scientific power of the mission.

WFIRST/AFTA in the Programmatic Context

The report finds that the use of the inherited AFTA hardware results in increased design complexity, low thermal and mass margins, and limited descope options that add to the mission risk and will make managing cost growth challenging compared to the baseline WFIRST/IRDM. Furthermore, if the funding for WFIRST/AFTA is not sufficient to accommodate the mission cost and provide contingency funds appropriate to the mission risk, it could be damaging to the balanced astrophysics program recommended by NWNH.

An independent team from Aerospace Corporation conducted a cost and technical evaluation (CATE) of the WFIRST/IDRM, arriving at a cost estimate of $1.8 billion (FY2012 dollars). A similar CATE of the WFIRST/AFTA mission without the coronagraph produced a cost estimate of $2.1 billion (FY2012 dollars). This process concluded that WFIRST/AFTA carries a higher implementation risk than WFIRST/IDRM. Due to the combined immaturity of WFIRST/AFTA and the coronagraph, no credible cost estimate has been performed for a WFIRST/AFTA + coronagraph mission. Furthermore, the report states that there is greater complexity in the design and uncertainty in the cost for WFIRST/AFTA than that assessed by the CATE because of the use of inherited hardware designed for another purpose. Considerable work will be required to make that hardware suitable to the WFIRST/AFTA mission. To ensure issues associated with the low thermal margins of the hardware do not lead to significant cost growth or schedule delay, the mission may have to compromise some science performance.

The report recommends that NASA sponsor an external, independent technical and cost review of the WFIRST/AFTA mission and coronagraph with the objective of ensuring that the proposed mission cost and technical risk are consistent with available resources and do not significantly compromise the astrophysics balance defined in NWNH. This review should occur early enough to influence the exercising of a rescope of the mission if required.

Addition of the Coronagraph to WFIRST/AFTA: A Scientific Perspective

Because of the larger aperture of WFIRST/AFTA compared to WFIRST/IDRM, NASA asked the study committee to assess whether adding a coronagraph to WFIRST/AFTA is consistent with the scientific and programmatic rationale for WFIRST, and the goals of the exoplanet technology development program—preparing for a future exoplanet imaging mission—as recommended by NWNH. While the timeline for such a planet imaging mission is likely to shift, the report notes that the scientific priority of such a mission is unaffected.

The WFIRST/AFTA coronagraph would test and advance new technologies and exoplanet observational techniques, and the report finds that the coronagraph satisfies some aspects of the broader exoplanet technology program recommended by NWNH by developing and demonstrating advanced coronagraph starlight suppression techniques in space. The report also finds that whether the WFIRST/AFTA coronagraph satisfies the NWNH goal to establish exozodiacal light levels at a precision required to plan an Earth-like exoplanet imaging mission is uncertain due to the immaturity of the coronagraph design and uncertainty in the ultimate performance.

Telescope	**IDRM** (baseline WFIRST)	**AFTA**
Mirror diameter	1.3m, off-axis	2.4m, on-axis
Image PSF[1] **Spectral PSF**	Diffraction limited at 1 micron Diffraction limited at 3 micron	Diffraction limited at 1 micron
Instrument List	Wide field imager (includes prism) Two spectrographs (slitless prisms) Guider	Wide field imager (includes grism) Integral Field Unit (IFU) No separate guider Possible coronagraph
Imager Wavelength	0.6-2.0 micron	0.6-2.0 micron
Imager pixel scale	0.18 "/pixel	0.11 "/pixel
Imager Detectors	28 2RGS (2k x 2k)	18 H4RGs (4x x 4k)
Filters	5, including a "Wide"	6, including a "Wide"
Pixel size (physical)	18 micron	10 micron
Pixel number (imaging)	120 million	300 million
Imager FOV	0.291 sq deg	0.281 sq deg
Grism/Prism **(Imager filter wheel)**	Prism, R=75 0.6-2.0 microns	Grism, R=550-800 1.35-1.95 microns
Spectrograph Detectors	8 H2RGs (2k x 2k) (2 separate channels)	1 H2RG (2k x 2k) (IFU)
Spectrograph Resolution	Slitless, R=180-270[2] 1.1-2.0 microns	IFU R=100 0.6-2.0 microns
Spectrograph FOV	0.26 sq deg x 2	3" x 3.15" (for SN+host)
Guider	Prime: 2 pair HgCdTe Auxiliary FGS (during spect)	No separate guider
Telescope temperature	240K	TBD: 277K
Electrical power capacity	2500 W solar arrays 80 A-hr battery	TBD: 2000 W solar array; TBD: 160 A-hr battery
Orbit	L2	Geosynchronous
Mission Life	5 years	5 years (6 if coronagraph is added)

TABLE: *Basic technical comparison of WFIRST/IDRM to WFIRST/AFTA*

[1] The instruments on IDRM were designed to meet these science requirements; the imaging channel and the spectral channels have different requirements.

[2] Using quantities from the IDRM SDT report: 160-240" = R-Θ at 0.45"/pixel where spectral resolution $\lambda/\Delta\lambda$ = R= R-Θ/(2 pixel scale).

Addition of the Coronagraph to WFIRST/AFTA: A Programmatic Perspective

The coronagraph requires significant technology development, which as previously mentioned is part of NASA's rationale for its inclusion on WFIRST/AFTA. The coronagraph is in the early stages of development, many of the technologies are immature, and the design itself is uncertain with three different approaches being pursued, meaning that the cost of the coronagraph is also very uncertain.

Although the WFIRST/AFTA project team estimates that the coronagraph will cost $250 million, the cost of increased operations complexity has not been factored in, and therefore that figure is a lower limit of the cost increase to the overall mission. Ultimately, because of the immaturity of the coronagraph design and associated technologies, and limited study of accommodating the instrument on the mission, it is not possible to quantitatively assess the cost and risk impact to the WFIRST/AFTA program.

Moreover, the report notes that technology demonstration missions accept larger technical risk relative to flagship science missions. Consequently, the report finds that introducing a technology development program onto a flagship mission creates significant mission risks. Because WFIRST was chosen by NWNH in part for its low technical risk, the committee finds that the inclusion of the coronagraph compromises this programmatic rationale for pursuing WFIRST.

NWNH also made several recommendations across different mission and program sizes with a goal of programmatic balance. The implementation of WFIRST, augmentation of the Explorer (small- and medium-class) mission program, and the research and analysis (R&A) program enhancements were all ranked above the exoplanet technology development program in a constrained budget scenario. Thus, unless corresponding augmentation to these other higher-priority NASA programs accompanies funding to include the coronagraph on WFIRST, the inclusion of the coronagraph on WFIRST will not be consistent with stated priorities in NWNH.

The report recommends that NASA move aggressively to mature the coronagraph design and develop a credible cost, schedule, performance and observing program so that its impact on the WFIRST mission can be determined. Upon completion of this activity, as well as a CATE of WFIRST/AFTA with the coronagraph, an independent review focused on the coronagraph should be convened to determine whether the impact on WFIRST and on the NASA astrophysics program is acceptable or if the coronagraph should be removed from the mission.

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