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

Fiona Harrison, Committee Chair, Caltech

Committee Membership

- Fiona Harrison, Caltech (Chair) *NWNH*
- Marcia Rieke, University of Arizona (Vice Chair) *NWNH*
- Roger Blandford, Stanford University *NWNH*
- Erik Burgess, Burgess Consulting, Inc.
- John Carlstrom, The University of Chicago *NWNH*
- Megan Donahue, Michigan State University *NWNH SPF*
- Timothy Heckman, Johns Hopkins University *NWNH*
- James Patrick Lloyd, Cornell University *NWNH SFP*
- Miguel Morales, University of Washington
- Edward Wright, University of California, Los Angeles
- Thomas Young, Lockheed Martin Corp. (ret.) *NWNH*

Statement of Task

The committee will consider the versions of WFIRST-2.4 (WFIRST/AFTA) with and without the coronagraph, as described in the AFTA SDT report. In its assessment, the committee will:

1. Compare the WFIRST mission described in New Worlds, New Horizons to the AFTA SDT WFIRST-2.4 design reference mission, with and without the coronagraph, on the basis of their science objectives, technical complexity, and programmatic rationale, including projected cost.

2. Based on the above comparison and taking into account any relevant scientific, technical, and programmatic changes that have occurred since the release of New Worlds, New Horizons:

   a) Assess the responsiveness of the AFTA SDT WFIRST-2.4 mission, with and without the coronagraph, to the overall strategy to pursue the science objectives of NWNH—and in particular, WFIRST; and

   b) Assess the responsiveness of the AFTA SDT WFIRST-2.4 mission with the coronagraph to the precursor science and technology objectives of the New Worlds technology development program described in NWNH.

Background on Task

- WFIRST/IDRM was considered the relevant implementation of WFIRST/NWNH (which was JDEM-Omega)
- The main committee report is the document of record
  - Not all panel recommendations were adopted by NWNH
- NASA is no longer actively studying WFIRST/IDRM
  - The committee was not asked to recommend whether to implement AFTA or IDRM
- NASA is studying the implementation of a coronagraph
  - The committee was not asked whether or not the coronagraph should be included on WFIRST

The committee focused on the scientific and programmatic (including cost and risk) consistency of WFIRST/AFTA with and without the coronagraph with NWNH recommendations

Science Comparison AFTA – WFIRST/NWNH

- WFIRST/NWNH has multiple primary science goals
  - Employ 3 different techniques to probe the nature of dark energy
  - Use microlensing to study the architecture of other solar systems
  - Perform wide-field surveys to advance our understanding of the evolution of stars, galaxies and black holes
  - Support a guest investigator program to exploit a broad range of science

Science Evaluation

- For each of the cosmological probes described in NWNH, WFIRST/AFTA exceeds the goals set out in NWNH. These are the goals that led to the specifications of the WFIRST/IDRM (with 2.0 μm cut-off)
  - WFIRST/AFTA observations will provide a very strong complement to the Euclid and LSST datasets
- No other current mission or program can address the science envisioned by the WFIRST microlensing survey
  - The WFIRST/AFTA telescope's large number of pixels and better PSF sampling will allow astrometry derived from drift scanning to break degeneracies inherent in interpreting the microlensing data
- The WFIRST/AFTA mission will enhance the power of the mission to address survey and general observer science

The observing program envisioned for WFIRST/AFTA is consistent with the science program described for WFIRST in NWNH

Science Evaluation Summary

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, primarily for cosmology and general survey science, and will also positively impact the exoplanet microlensing survey. WFIRST/AFTA's planned observing program is responsive to all the scientific goals described in NWNH.

NWNH Exoplanet Technology Development Objectives

- Program goals – prepare for Earth-like planet imager
  - Support RV surveys to understand distribution of Earth-like planets and identify promising candidates
  - Accelerate measurements of exozodiacal light
  - Compete technology development of starlight supression techniques: star shades, coronagraphs
- If sufficient progress is made on all of these engage in a technology downselect to enable an Earth-like imaging mission early in 2020

Budget constraints will slip the start of an Earth-like planet imaging mission beyond the horizon envisioned by NWNH; however, developing the technologies for such a mission and addressing the key uncertainties, such as the levels of exozodiacal light and identifying targets, remains high priority.

Coronagraph Addition – NWNH Technology Development Objectives

- Key Findings
  - The WFIRST/AFTA coronagraph satisfies some aspects of the broader exoplanet technology program recommended by NWNH by developing and demonstrating advanced coronagraph starlight suppression techniques in space
  - 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

Implementation Comparison

Telescope	IDRM	AFTA
Mirror diameter	1.3m, off-axis	2.4m, on-axis
Image PSF[2] **Spectral PSF**	Diffraction limited at 1 micron Diffraction limited at 3 micron	Diffraction limited at 1 micron
Instrument List	Wide field imager (includes prisn Two spectrographs (slitless prism 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[3] 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)

Implementation Comparison

- Addition of an IFU for Supernova followup
  - IFU was not included on WFIRST/NWNH or WFIRST/IDRM
  - IFU was not considered by this committee as a significant cost/risk driver
- Orbit/servicing requirement
  - Servicing requirement imposes mass risk
- Larger aperture/inherited hardware
- Addition of coronagraph

WFIRST/NWNH Programmatic Context

- NWNH placed strong emphasis on a balanced program of activities with significant increased investment in the Explorer and research and analysis (R&A) programs
- If the funding wedge provided for WFIRST/AFTA is not sufficient to accommodate the mission cost and provide contingency appropriate to the mission risk, it could be very damaging to the program recommended by NWNH

If implementing WFIRST/AFTA compromises the program balance then it is inconsistent with the rationale that led to the high priority ranking

Cost and Risk Assessment

- Aerospace cost assessment – 2.1B$ (FY12)
- Aerospace risk assessment
  - Medium-low for IDRM (&JDEM-Omega) -> medium for AFTA
  - Primary risks
    - Large focal plane (IDRM & AFTA)
      - Fewer chips total but H4RG chips new technology with unproven yield and radiation tolerance
    - Fine attitude control (IDRM & AFTA)
    - Risk of mass growth/low mass margin (AFTA only)
    - Challenging in end-to-end testing of large optical system (AFTA only)

Adopting the AFTA

- Committee finds risks associated with inherited hardware
  - Elimination of primary descope option
    - This mission is very early in the design phase – the primary mechanism to deal with mass/ technical growth – decrease in aperture – is gone. Lessons can be learned from JWST.
  - Launch loads
  - A non-negligible possibility that inherited hardware must be redesigned to accommodate eventual launch vehicle
  - Operating temperature and thermal design
    - The optic is designed for room temperature operation, not typical for an IR mission
    - Thermal margins are low. While red-end performance is better than IDRM, margins are low, and technical options are eliminated

The use of inherited hardware designed for another purpose results in design complexity, low thermal and mass margins, and limited descope options that add to the mission risk. These factors will make managing cost growth challenging.

AFTA Cost and Risk Assessment

- The mission may have to compromise some science performance to ensure issues associated with the low thermal margins do not lead to significant cost growth and schedule delay

The risk of cost growth is significantly higher for WFIRST/AFTA without the coronagraph than for WFIRST/IDRM.

Addition of Coronagraph

- The coronagraph design is immature, it involves immature technologies, and there has been limited study of accommodating the instrument on the mission. It is therefore not possible to quantitatively assess the cost and risk impact to the WIFRST/AFTA program
- No firm cost estimates provided for instrument, integration and additional operations (~0.3 B$ estimated by project)
  - Committee had no basis for firm cost assessment
- Technology demonstration missions
  - accept greater technical risk
  - Have more uncertain schedules due to low TRL hardware

Introducing a technology development program onto a flagship mission creates significant mission risks resulting from the schedule uncertainties inherent in advancing low TRL hardware to flight readiness.

Coronagraph Consistency with NWNH

WFIRST's moderate cost, low technical risk, and mature design were important to its ranking as the top priority for a large space mission in NWNH. The inclusion of the coronagraph compromises this rationale

Without corresponding augmentation to other NASA programs accompanying funding to include the coronagraph on WFIRST, the inclusion of the coronagraph is not consistent with stated priorities in NWNH. In a time of reduced budgets, the first priority in NWNH is "to develop, launch, and operate WFIRST, and to implement the Explorer program and core research program recommended augmentations." Implementing the coronagraph address some aspects of the exoplanet technology development, and that exoplanet technology development program was considered a lower priority by NWNH.

Mission Operations Complexity

- WFIRST/NWNH envisioned simple shift and stare operations
- Additional operating modes being considered
  - ToO transient followup
  - Astrometry drift scans
  - Coronagraph observations

The increase in operational complexity over the nominal NWNH/WFIRST concept required to accommodate expanded guest investigator observing modes and the coronagraph observations is an additional risk for mission cost-growth

Recommendations

- The committee recognizes scientific importance and public appeal of future Earth-like planet imager, but WFIRST primary science goals are higher priority.

Recommendation: NASA should 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, and a cost and technical evaluation 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.

Recommendation

NASA should sponsor an external technical and cost review of the WFIRST/AFTA mission that NASA plans to propose as a new start. This review should be independent of NASA's internal process. The objective of the review should be to ensure that the proposed mission cost and technical risk are consistent with available resources and do not significantly compromise the astrophysics balance defined in the 2010 National Research Council report *New Worlds, New Horizons in Astronomy and Astrophysics*. This review should occur early enough to influence the exercising of a rescoping of the mission if required