

# WFIRST and AFTA CATE Results *Summary of 2011-2013 Studies*

The Aerospace Corporation

January 9, 2014

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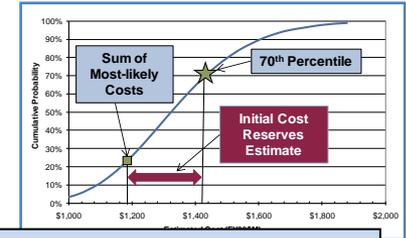
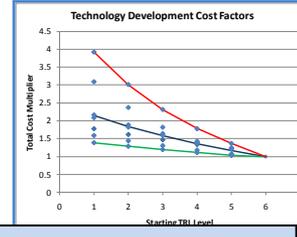
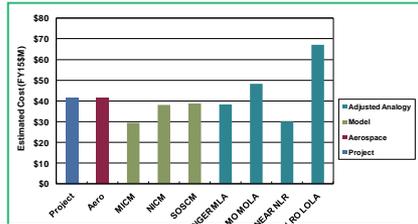
# Introduction

- **WFIRST was prioritized as a top priority Flagship mission during the NRC Astro2010 Decadal Survey**
  - *Astro2010 Decadal report released August 2010*
    - Committee used JDEM Omega as a representative concept
      - *Added/modified science goals and renamed concept to WFIRST*
    - Aerospace provided JDEM Omega CATE analysis to the Astro2010 committee
- **In the years following the Decadal, report NASA has studied the WFIRST mission**
  - *Various Science Definition Teams formed*
  - *Several point designs studied as part of the concept development process*
- **Aerospace tasked by NASA to perform CATE assessments for 3 of these point designs**
  - *These point designs represent “snapshots” in time from a continuing design process*
    - Interim Design Reference Mission (IDRM) in 2011
    - Design Reference Mission 2 (DRM2) in 2012
      - *“Probe-class” mission and results are not included in this report.*
    - Initial Astrophysics Focused Telescope Assets (AFTA) in 2013
      - *A more developed design is expected for CATE analysis in 2014*
- **This report is a summary of the results from the IDRM and AFTA CATEs**
  - *Overview followed by key charts from the 2 individual CATE reports*

# What is a CATE?: Cost and Technical Evaluation

- **CATE Process developed by NRC for recent Decadal Surveys**
  - *Previous Decadal Surveys significantly underestimated mission costs*
  - *US Congress required NRC to use an Independent CATE Contractor*
    - CATE estimates needed to reflect historical project growth
    - CATE estimates needed to reflect realistic NASA/ESA cost sharing
    - Realistic CATE estimates needed for future budget analysis & decisions
- **CATE process differs from typical ICE and process for TMC evaluation**
  - *Begins with typical Independent Cost Estimate, ICE*
  - *Adds three types of cost threats, where appropriate:*
    - Schedule, design (mass & power growth) and launch vehicle
- **CATE is used for future consideration with respect to NASA budgets**
  - *Used to evaluate science value versus budget availability*
    - Following the Decadal Survey, used to re-assess recommended concept descopes
  - *Incorporates typical growth based on the historical record and design maturity*
    - It is more conservative than an ICE of a “specific” concept presented

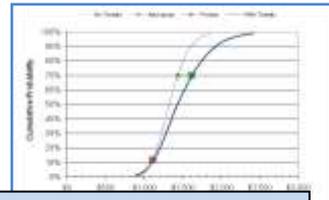
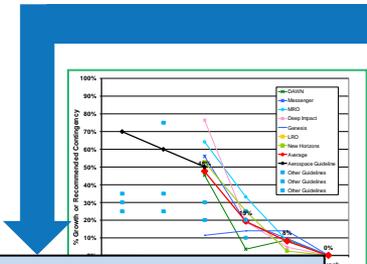
# WFIRST Cost Estimating Approach Overview



**Estimate Instruments & Spacecraft**  
Multiple analogies and models

**Estimate Other Elements**  
Based on historical data

**Estimate Cost Reserves**  
Based on probabilistic cost risk analysis



WBS Element	Project Estimate	Aerospace Estimate	Basis of Aerospace Estimate
Pre-phase A/Phase A	\$ 64	\$ 108	1.5% of Devcost per year
Mission PMSEAA	\$ 263	\$ 277	Percentage of HW based on Cassini, Galileo, MRO, MER
Instruments	\$ 639	\$ 679	MCM, MCM, SCOM and analogies to Cassini and others
Flight System	\$ 928	\$ 1,322	NAFOOM, analogy to Cassini, Galileo, New Horizons, and others
Pre-launch Ground and Science	\$ 166	\$ 240	Percentage of HW based on Cassini, MRO, MER
Phase E Costs and EPO	\$ 498	\$ 685	Based on annual rates from Cassini, Galileo, MRO
Total Reserves	\$ 758	\$ 1,293	80% from cost risk analysis
Launch Vehicle/Services	\$ 246	\$ 272	Atlas 551 cost from study guidelines + nuclear processing
<b>Total Mission Cost Without Threats</b>	<b>\$ 3,420</b>	<b>\$ 4,756</b>	
Schedule Threats	\$ 296	\$ 296	Baseline 11/21 launch; double-shift during I&T
Mass and Power Cont. Threats	\$ 537	\$ 537	Pre-Phase A contingency levels; 0% RTG
LV Threats	\$ 271	\$ 271	Difference in LV cost for Delta IV

**Estimate Design Threat**  
Re-run estimate with Aerospace contingencies

**Estimate Schedule Threat**  
Based on ISE results and project burn rates

**Integrate Results & Level Across Concepts**  
Cross-check with CoBRA

# CATE Primarily for Prioritization within Budget Constraints

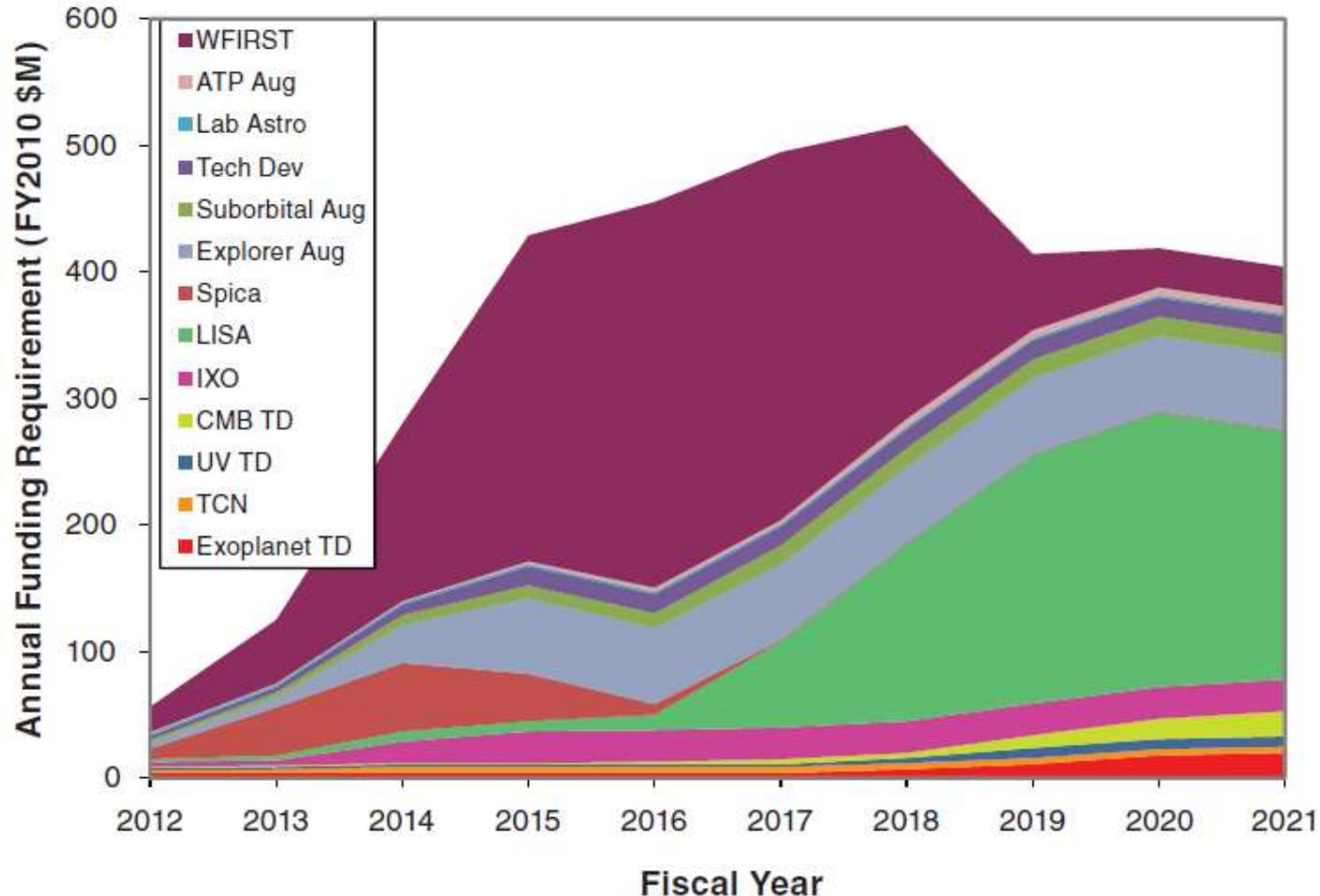


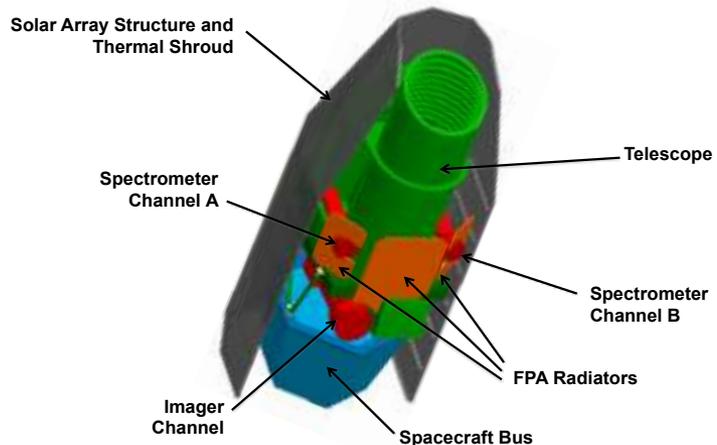
Figure from “New Worlds, New Horizons in Astronomy and Astrophysics”, Committee for a Decadal Survey of Astronomy and Astrophysics, 2010

# General Limitations of Assessment

- Technical risk assessment
  - *Limited to top-level maturity and risk discussions*
- Cost and schedule assessment
  - *Meant for high-level budgetary estimates*
    - Often includes a profile in real year dollars
  - *It is understood that the CATE is likely to be higher than advocate estimate*
    - Decision makers consider the range in the two estimates
  - *When appropriate, reconciliation with the project occurs*
    - Typically when CATE is being presented to NASA HQ
    - Does not occur when under direct evaluation by an NRC committee
  - *Design growth threat is typically the biggest disconnect with project teams*
    - Project often defends specific concept being presented at the time
    - Advocate estimate may not adequately factor in “future” modifications and “growth”

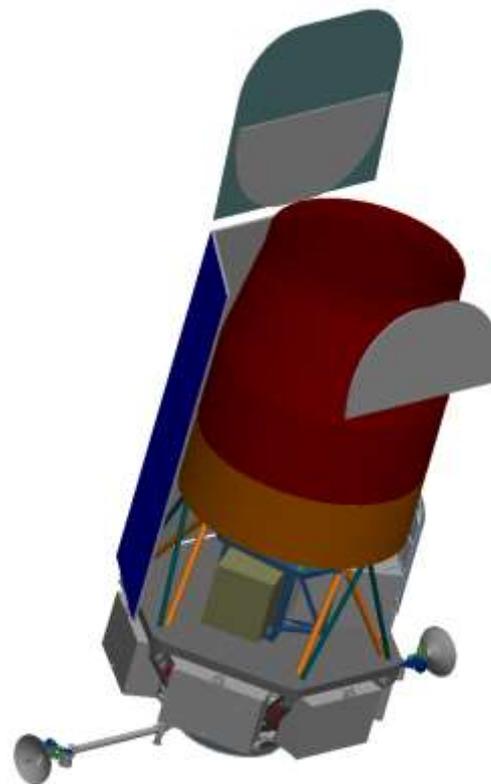
# WFIRST and AFTA Concepts

IDRM (2011)



Pictures not to same scale

AFTA (2013)



# Key Parameter Comparison

## WFIRST/AFTA

Parameter	WFIRST IDRM 2011	AFTA DRM 2013
Primary Aperture, m	1.3	2.4
Telescope Mass, kg	826	1773
Instrument Mass, kg	338	548
Payload Power, W	742	1,270
Instrument Raw Data Rate, Gbps	2.0	0.94
Number of Pixels, Mpixels	144	304
Spacecraft Dry Mass, kg	1,172	2,199
Observatory Dry Mass, kg	2,336	4,520
Propellant Mass, kg	146	3093
Observatory Wet Mass, kg	2482	7671
BOL Power*, W	2,459	2,859
Orbit	L2 Halo	GEO, 28.5 deg.
Launch Vehicle	Atlas V 511	Atlas V 541
Phase E Duration, years	5	5

\* BOL Power is power provided by the solar arrays at Beginning of Life

# WFIRST and AFTA CATE Cost Estimates

- **The WFIRST and AFTA concepts studied to date represent a broad range of capabilities and complexities**
  - *Reflected in broad range of CATE cost estimates*
  - *CATE estimates are for full mission costs including Phase E and launch vehicle*
- **All of these estimates were performed as part of NASA's concept study process**
  - *None of these are a preferred solution*
- **When the trade space narrows and the project proceeds into Phases A&B, cost estimates will be developed for a preferred concept**
  - *NASA cost commitment occurs at the end of Phase B (KDP-C)*

(FY12\$)	WFIRST IDRM CATE	AFTA* CATE
Year of Estimate	2011	2013
Phase A-E Cost, with LV	\$1.8B	\$2.1B

\*Note: AFTA design assessed in this report does not include a coronagraph

# WFIRST and AFTA Cost Estimate Details

FY12\$M

WBS Element	IDRM CATE	AFTA <sup>1</sup> CATE
Pre-Phase A/Phase A	\$ 36	\$ 30
Mission PM/SE/MA	\$ 110	\$ 116
OTA and Instruments	\$ 382	\$ 379
WFI	\$ 181	\$ 236
OTA	\$ 201	\$ 120
OTA to WFI Integration		\$ 23
Flight System (incl. Instrument Carrier)	\$ 240	\$ 321
Pre-launch Ground and Science	\$ 94	\$ 110
Phase A-D Reserves	\$ 322	\$ 236
<b>Phase A-D Subtotal</b>	<b>\$ 1,185</b>	<b>\$ 1,192</b>
Phase E Costs (w/Reserves)	\$ 243	\$ 238
<b>Total Mission Cost w/o LV</b>	<b>\$ 1,428</b>	<b>\$ 1,430</b>
Schedule Threats	\$ -	\$ 20
Design Threats	\$ 70	\$ 163
<b>Total Mission Cost w/o LV+Threats</b>	<b>\$ 1,498</b>	<b>\$ 1,613</b>
Launch Vehicle/Services <sup>2</sup>	\$ 258	\$ 299
Launch Threat (Delta IV-H) <sup>2</sup>	\$ -	\$ 186
<b>Total Mission Cost CATE Estimate</b>	<b>\$ 1,756</b>	<b>\$ 2,098</b>

\*Notes:

1) AFTA design assessed in this report does not include a coronagraph

2) Launch Vehicle/Services costs are estimates provided by NASA for these studies.

- Launch vehicle threat represents potential costs of moving up to a more expensive launch vehicle when launch mass margins are low
- Although future launch vehicle availability and pricing is uncertain, being close to the limit of medium class vehicles is a concern
- \$186M is for growth to Delta IV heavy from Atlas V541. Delta IV Heavy cost used for Launch Vehicle threat is a rough value based on estimates provided by NASA for the Astrophysics 2010 Decadal Survey.
- This threat is in addition to the Launch Vehicle/Services line item. Actual costs will be negotiated during project development phase.

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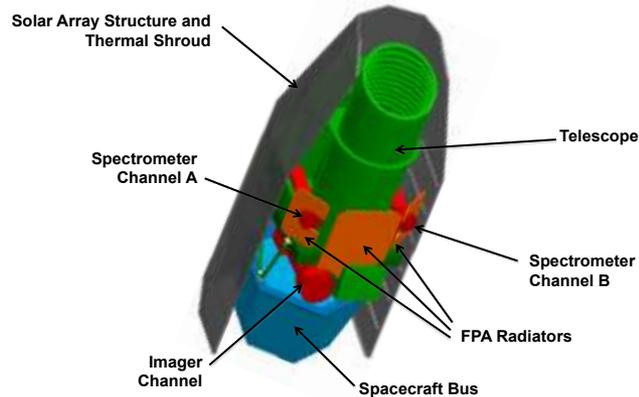


- ***2011 WFIRST IDRM***

- ***2013 AFTA***

# WFIRST IDRM – Wide-Field InfraRed Survey Telescope

## WFIRST NIR Observatory



## Scientific Objectives:

- Exoplanet Microlensing Survey
- Wide field NIR/Dark Energy Survey
  - Type 1a Supernovae
  - Baryon Acoustic Oscillations
  - Weak Lensing
  - Survey Galactic Plane
  - Guest Observer Program
- Key science themes cited:
  - Complete the statistical census of planetary systems, (Earth mass)
  - Determine the expansion rate of the universe & growth structure
  - Produce a deep map of the sky at NIR wavelengths

## Key Parameters:

- 1.3 m unobstructed primary mirror telescope
  - 243 K optics
  - FOV: 0.29 deg<sup>2</sup>
  - Angular resolution: 3-4 mas
  - Pointing repeatability: 25 mas
- Imager (0.6 – 2.0 μm)
  - 112 Mpixels (28 detectors)
- 2 Spectrometers (1.1 – 2.0 μm)
  - 32 Mpixels total (4 detectors each)
- Launch Mass: 2480 kg
- Orbit: L2 halo (5 years)

## Key Challenges:

- Large focal plane array
  - System integration
  - Detector yield & performance
  - Maintenance of calibration
- Space vehicle fine attitude control
  - 25 mas control
  - Custom fine guidance sensors
- Unobscured telescope optics
  - Operational thermal environment
  - Development issues
  - Alignment tolerances

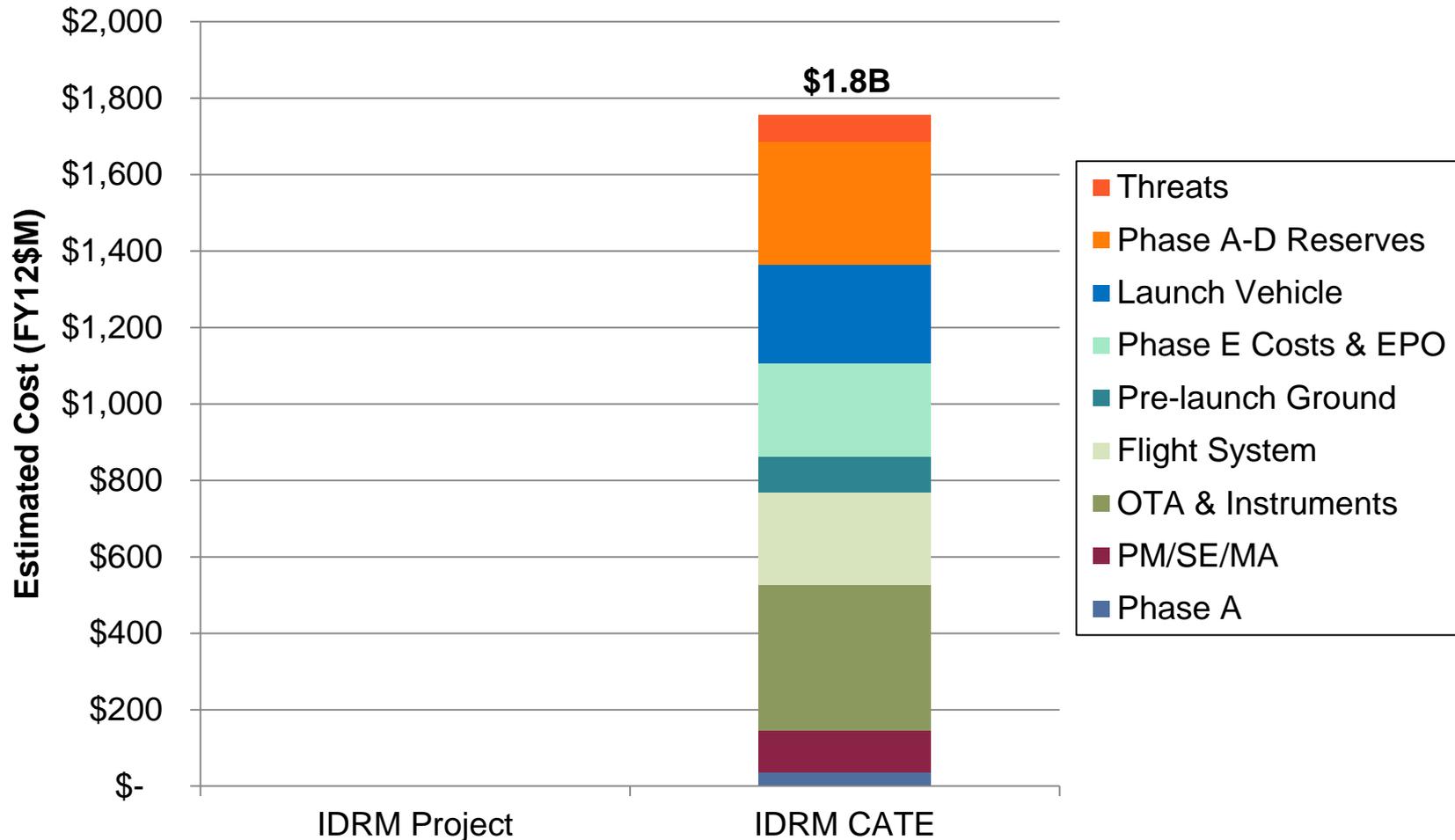
Figure reprinted courtesy of NASA

# WFIRST IDRM Technical Risk Rating, Independent of Cost

- **WFIRST IDRM Technical Risk Rating is Medium-Low** 
- *WFIRST technical risk is driven by the engineering challenge of the large focal plane array*
  - Achieving the necessary detector yield
  - Integrating the focal plane
  - Maintaining FPA calibration on-orbit
- *Secondary concerns regarding challenging space vehicle pointing requirements and development issues of unobscured telescope*
  - Pointing requirements are challenging, but not unprecedented
  - Several vendors capable of building offset optics
- *WFIRST concept is mature, but design is constantly being modified*
  - ESA and Euclid decisions still may impact design solution

# WFIRST IDRM Key Cost Element Comparison

FY12\$M



# WFIRST IDRM Cost Estimate Table

*FY12\$M*

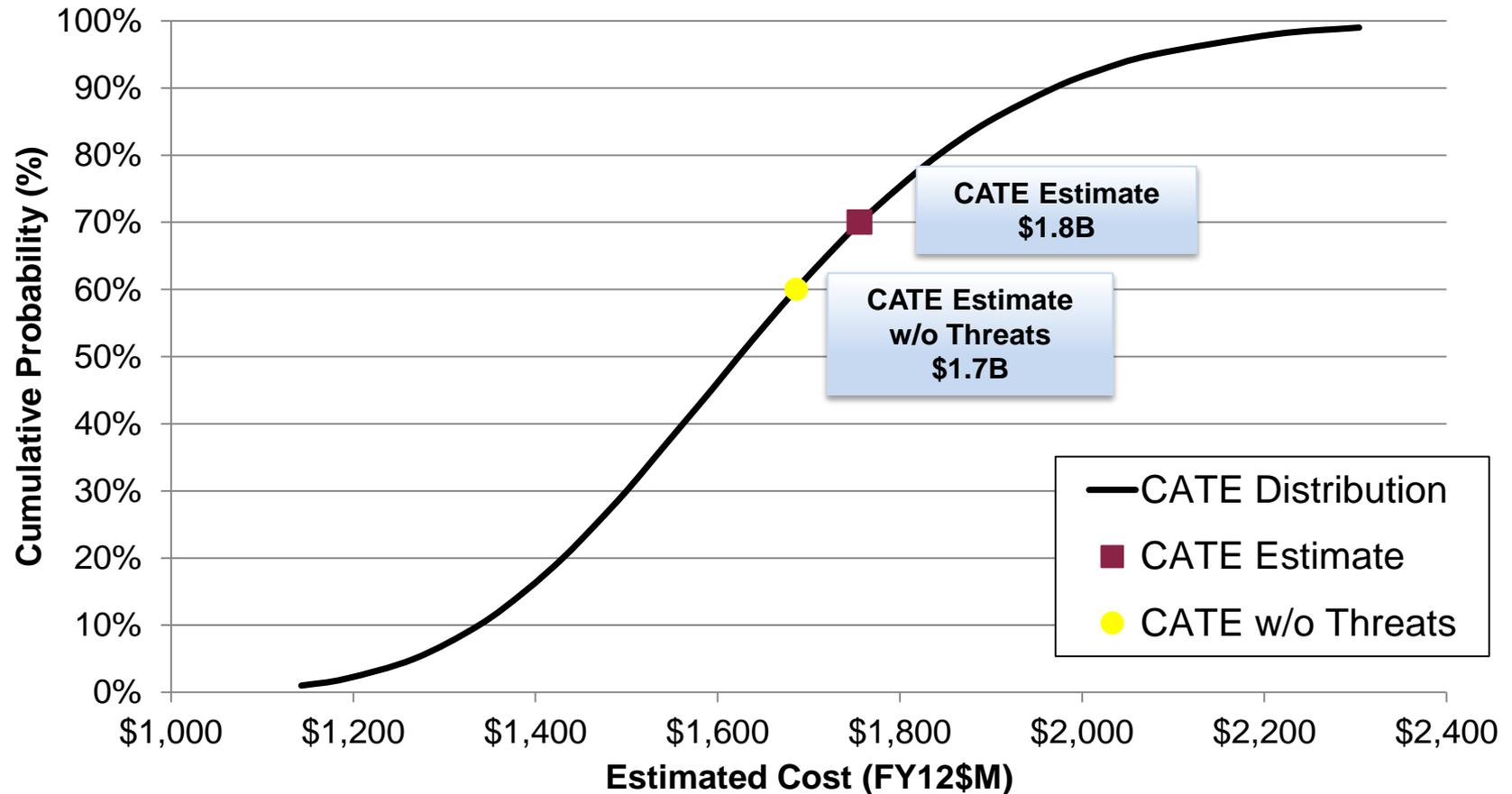
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Pre-Phase A/Phase A	\$ 36
Mission PM/SE/MA	\$ 110
OTA and Instruments	\$ 382
WFI	\$ 181
OTA	\$ 201
OTA to WFI Integration	
Flight System (incl. Instrument Carrier)	\$ 240
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Phase A-D Reserves	\$ 322
<b>Phase A-D Subtotal</b>	<b>\$ 1,185</b>
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<b>Total Mission Cost w/o LV</b>	<b>\$ 1,428</b>
Schedule Threats	\$ -
Design Threats	\$ 70
<b>Total Mission Cost w/o LV+Threats</b>	<b>\$ 1,498</b>
Launch Vehicle/Services <sup>2</sup>	\$ 258
Launch Threat	\$ -
<b>Total Mission Cost CATE Estimate</b>	<b>\$ 1,756</b>

\*Notes:

- 1) CATE Phase E reserves are 10%
- 2) Launch Vehicle/Services costs are estimates provided by NASA for these studies. Actual costs will be negotiated during project development phase.

# WFIRST IDRM Cost Risk Analysis Results

FY12\$M

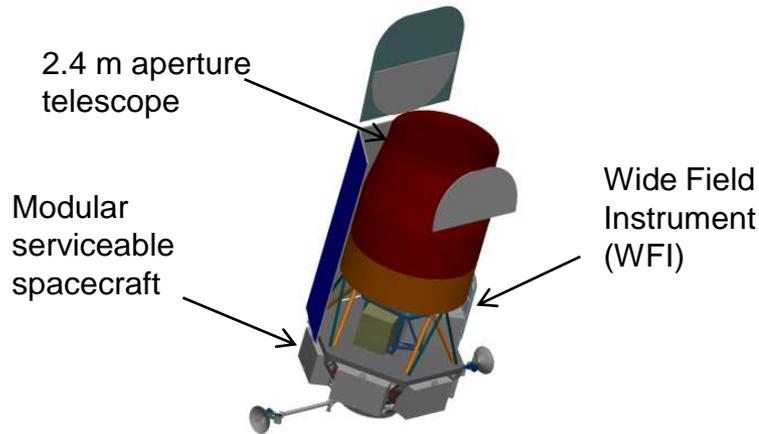


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  - ➔ – *2013 AFTA*

# AFTA – Astrophysics Focused Telescope Assets

## AFTA Design Reference Mission NIR Observatory



## Scientific Objectives:

- Exoplanet Microlensing Survey
- Dark Energy Survey
- Large Area Near Infrared Survey
- Guest Observer Program
- Key science themes cited:
  - Complete the statistical census of planetary systems
  - Determine the expansion rate of the universe & growth structure
  - Produce a deep map of the sky at NIR wavelengths

## Key Parameters:

- 2.4 m aperture telescope (provided by NRO)
  - 270 K optics
  - FOV: 0.28 deg<sup>2</sup>
  - Angular resolution: 110 mas
  - Pointing repeatability: 10 mas
- NIR Focal Plane (0.6 – 2.0 μm bandpass)
  - 18 4k x 4k H4RG HgCdTe detectors for imaging
  - Single H4RG HgCdTe detector for spectroscopy
- Fine guidance utilizes NIR Focal Plane
- Launch Mass: 7671 kg on Atlas V 541
- Orbit: Geosynchronous, inclined at 28.5 deg (5 years)

## Key Challenges:

- Large NIR focal plane array that is new to GEO space
  - Detector yield & performance for newer H4RGs
  - System integration for 3 x 6 array
  - Radiation effects on H4RG detectors at GEO
- Low launch mass margin
  - Baseline design has low launch margin on Atlas V 541
  - Additional instrumentation would increase mass further
  - Uncertainties in design modifications for robotic servicing
- End to end optics testing for integrated system
  - Challenge of mitigating 1g effects
  - Special test equipment required

Figure reprinted courtesy of NASA

# Unique aspects of AFTA

## Unique Features:

- Large aperture
- Existing telescope hardware
- Robotically serviceable
- Inclined GEO Orbit
- Accommodation for coronagraph

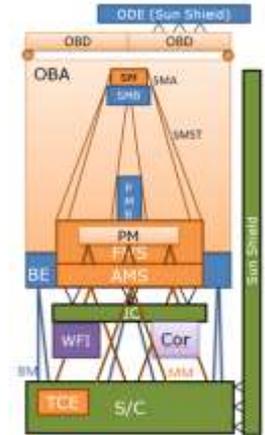
## Gifted Telescope:

Orange = ITT Existing Hardware

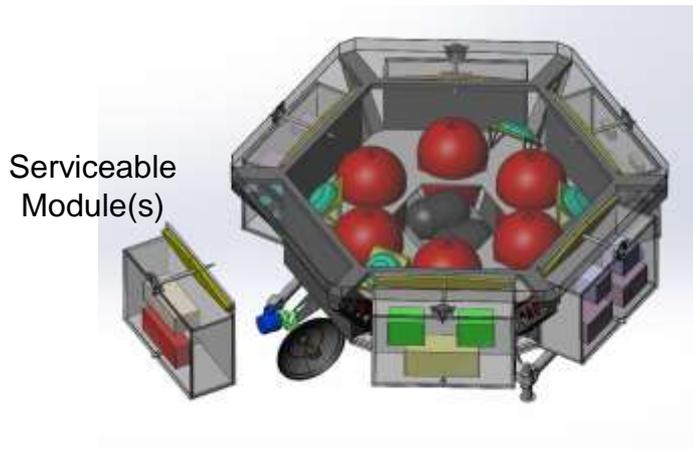
Blue = JPL New Hardware

Green = GSFC New Hardware

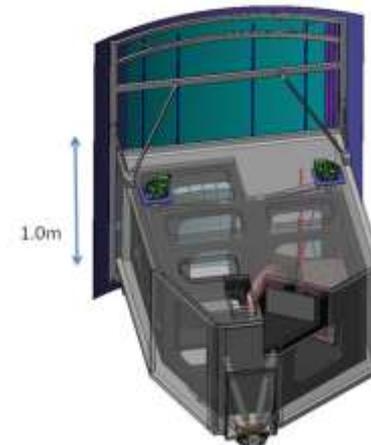
Purple = New Instruments



## Robotically Serviceable GEO Space Vehicle:



## Wide Field Instrument:



Figures reprinted courtesy of NASA

# AFTA Technical Risk Rating, Independent of Cost

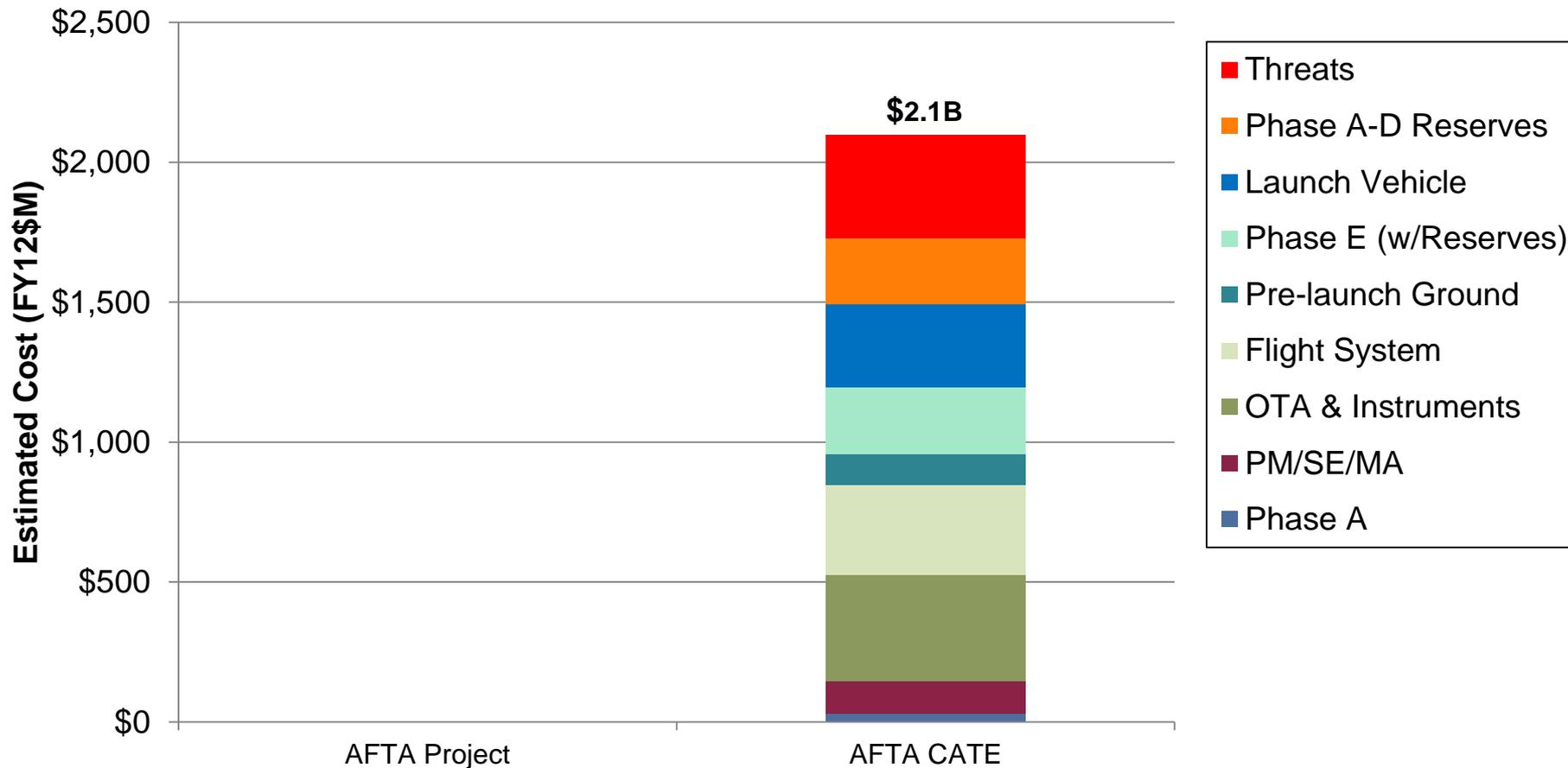
- **AFTA Technical Risk Rating is Medium**



- *Yellow risk rating is driven by the combination of the two items below. Item 1 (focal plane) is similar to WFIRST DRM1-2, while item 2 (mass growth) is new*
- *AFTA technical risk includes the new Wide Field Instrument (WFI) development*
  - WFI uses large focal plane array with newer H4RG detectors though in family with WFIRST concepts
  - First time for H4RG in space and at GEO specifically
  - Can be mitigated with maturation of Engineering Unit focal plane array
- *Mass growth risks driven by new system elements and uncertainty in some mission requirements*
  - Overall CBE mass allocation is generally consistent with historical space observatories
  - Key new elements of concern for mass growth as program matures: WFI, secondary structures, and harness
  - Robotic servicing requirement adds some uncertainty to spacecraft design
  - GTO to GEO orbit transfer is a conventional feature, but consumes more launch mass capacity than previous WFIRST concepts at L2
  - Possibility of additional instruments raises concern of further mass growth, beyond Atlas V launch capability

# AFTA\* Key Cost Element Comparison

FY12\$M



\*Note: AFTA design assessed in this report does not include a coronagraph

# AFTA Cost Estimate Table

FY12\$M

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OTA	\$ 120
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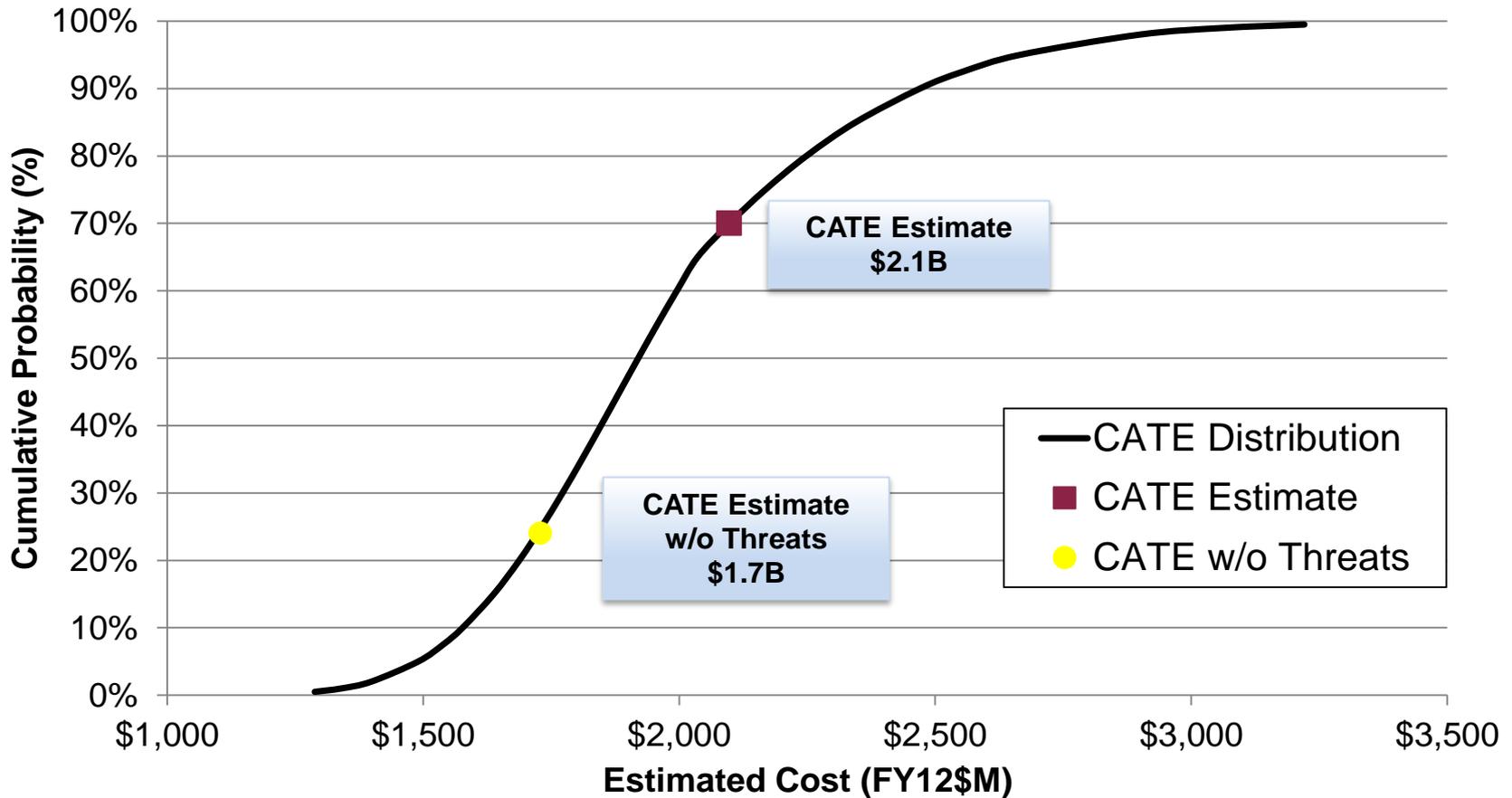
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FY12\$M



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