Lynx IWG/OWG
Technology Roadmap Discussion

Angie Bukley / Linda Herrell / Justin McNeil
NASA & Civil Space Division

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Discussion Topics

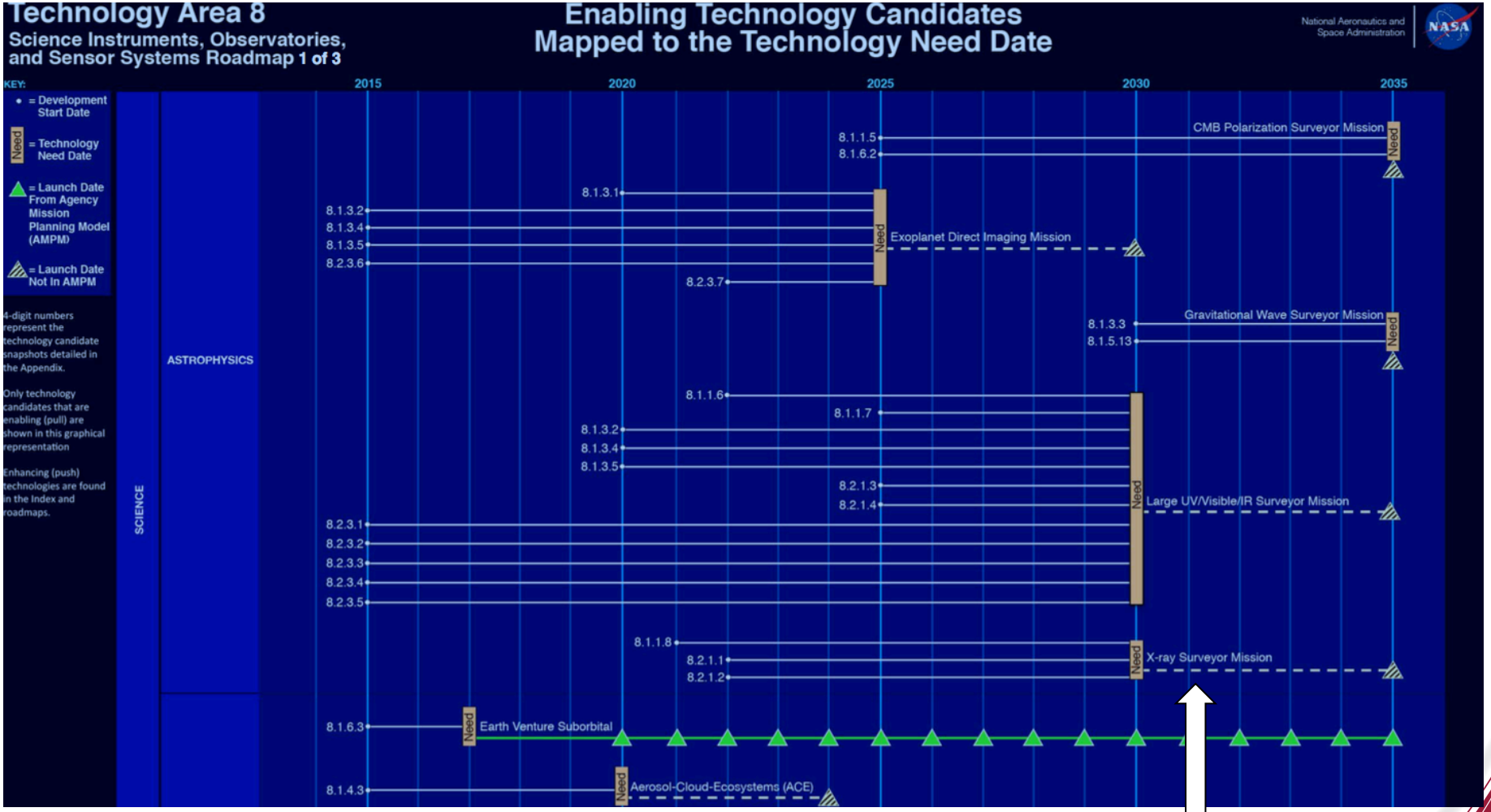
- Aerospace Team
- NASA technology roadmaps
  - *NASA Technology roadmaps last updated in 2015*
    - Technology Area 8 : science instruments, observatories, and sensor systems
  - *WFIRST*
  - *Technology Development Plan Template*
- Lynx technology status
- Key milestones for Lynx technology roadmap development

Aerospace Team

- Angie Bukley – Study Manager
- Linda Herrell – Study Technical Lead
- Frank Wong – Aerospace Economic & Market Analysis Center Director
- Roy Nakagawa – Technical Coordination
- Justin McNeil - MSFC Science & Technology Project Coordinator

Communications should go through Bukley & Herrell

2015 NASA technology roadmap shows 2030 need date



X-ray surveyor mission

Ref: https://www.nasa.gov/sites/default/files/atoms/files/2015_nasa_technology_roadmaps_ta_8_science_instruments_final.pdf

2015 Technology Roadmap – Area 8: Instruments, Observatories & Sensor Systems

- NASA technology roadmap identifies three technology elements supporting an X-Ray Surveyor mission with need dates of 2030
  - *8.1.1 Detectors and Focal Planes*
    - Challenges include low-noise, high- speed, and low-power readout integrated circuit electronics for large FPA instruments; high quantum efficiency, low noise, high resolution, uniform and stable response, low power and cost, and high reliability large-format arrays
      - ***Technology Candidate 8.1.1.8*** *– Large-format X-ray microcalorimeter array or very-high-energy-resolution, pixelated focal plane detector*
  - *8.2.1 Observatory Mirror Systems*
    - Achieve increased sensitivity and resolution while reducing areal cost
    - Challenges include lightweight mirror systems with high degree of thermal and dynamic stability, wavefront sensing & control with diffraction limited performance
      - ***Technology Candidate 8.2.1.1*** *High energy X-ray grazing incidence precision surface lightweight mirrors*
      - ***Technology Candidate 8.2.1.2*** *– Low energy X-ray grazing incidence precision surface lightweight mirrors*

Example:
WFIRST Technology Plan / Roadmap Overview

Reference: November 2014 Presentation by Poberezhskiy, et al.

https://conference.ipac.caltech.edu/wfirs2014/talks/WFIRS2014_Poberezhskiy.pdf

Coronagraph Technology Development

- Technology Development Plan for maturing coronagraph technology to TRL 5 by 9/30/2016 was developed and approved
  - Working toward testbed demonstration of starlight suppression that meets science requirements in presence of optical wavefront disturbances expected on orbit
  - Mature key components – spectrograph detector and deformable mirror – to TRL6
  - 9 key milestones
  - Passed 2 of them, plan execution currently ahead of schedule
- Progress monitored by independent Technology Assessment Committee (TAC)
- Many institutions involved in coronagraph technology development and science

Jet Propulsion Laboratory
California Institute of Technology

NASA Goddard

PRINCETON UNIVERSITY

ARIZONA

NASA Ames Research Center

Stanford University

NExScI
NASA Exoplanet Science Institute

ipac Infrared Processing and Analysis Center

SPACE TELESCOPE SCIENCE INSTITUTE

WFIRST-AFTA Coronagraph Key Milestones

MS #	Milestone	Date
1	First-generation reflective Shaped Pupil apodizing mask has been fabricated with black silicon specular reflectivity of less than 10^{-4} and 20 µm pixel size.	7/21/14
2	Shaped Pupil Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with narrowband light at 550 nm in a static environment.	9/30/14
3	First-generation PIAACMC focal plane phase mask with at least 12 concentric rings has been fabricated and characterized; results are consistent with model predictions of 10^{-8} raw contrast with 10% broadband light centered at 550 nm.	12/15/14
4	Hybrid Lyot Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with narrowband light at 550 nm in a static environment.	2/28/15
5	Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a static environment.	9/15/15
6	Low Order Wavefront Sensing and Control subsystem provides pointing jitter sensing better than 0.4 mas and meets pointing and low order wavefront drift control requirements.	9/30/15
7	Spectrograph detector and read-out electronics are demonstrated to have dark current less than 0.001 e/pix/s and read noise less than 1 e/pix/frame.	8/25/16
8	PIAACMC coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a static environment; contrast sensitivity to pointing and focus is characterized.	9/30/16
9	Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a simulated dynamic environment.	9/30/16

Top Level Technology Development Schedule

AFTA-WFIRST Coronagraph Technology Development Top Level Schedule

Rev. 09/09/2014

FY14 | FY15 | FY16 | FY17 | FY18

N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

AFTA-WFIRST Project Milestones

AFTA Prop to NASA HQ 1/15

TRL 5 Review 10/3

Coron. Downselect 12/16

Coronagraph Tech EK Milestones

EK1: SPC Apodizer Fab & Tested 6/17

EK2: SPC Static nrwband 9/30

EK4: HLC Static nrwband 2/27

EK3: PIAA Mask Fab & Tested 12/15

EK5: OMC Static 10% 9/15

EK6: LOWFS/C Perf Meets Req 9/30

EK7: IFS Detector & Elex Meet Perf Req 8/25

EK8: PIAA Static 10% 9/30

EK9: OMC Dynamic 10% 9/30

Coronagraph Downselect

HQ Decision 1/7

SPC Testbed (HCIT-1)

SPC Static TR 4/3

2 32x32 DM's 9/15

Static Testing

10% BW, Static WF 3/4

OMC Bench Review 6/30

HLC + SPC Dynamic Testing

Reserve

Dynamic 10% BW 9/30

SPC Mask/Apodizer Fabrication

Reflective On Silicon & BT 3/31

Reflective On Silicon #2 8/20

11/12

Transmissive BT On Glass (Tentative)

Environmental Test Report Complete

HLC Testbed (HCIT-2a)

HLC Static TR 8/26

2 48x48 DMs 7/16

HLC Static Testing

2% BW Static 1/29

10% BW Static 8/12

HLC Mask/Apodizer Fabrication

Mask Fab 8/15

Environmental Test Report Complete 1/21

PIAA CMC Testbed (HCIT-2b)

Static, 10% Existing PIAA 3/18 3/31

Static, 10% AFTA PIAA 1/5 3/1

Full AFTA Config.

PIAA CMC Mask Fabrication

NB PIAA CMC Mask 7/1 2/18

1st BB PIAA CMC Mask w/Existing Mirrors

10/31

AFTA PIAA CMC Mask v.2

AFTA PIAA CMC Mask v.3

LOWFS/C

CRR 6/12

TR 3/1

#1 Closed Loop Demo

IFS (GSFC)

PDR 7/17

TRR 6/17

Del to JPL Testbed 9/16

IFS Characterization

IFS Characterization Complete 6/20

Post-Data Processing & Algorithm Development

Developing Algorithms 5/12

Interim Eval of Perf. 5/15

Eval against Static 10% 2/28

Eval against Dyn 10% 12/23

Final Report 3/30

IFS Detector

Preliminary Req'mts 6/30

Detector Electrical/Mech./Thermal Ready For Testing 11/30

IFS Det./Readout Elex Meets Perf. Req'mts. 8/1

DM Environmental Testing

DM Trade 2/28 5/14

DM#1 Rec'ved 1/22

TRR 2/17

Environmental Test Report Complete 4/7

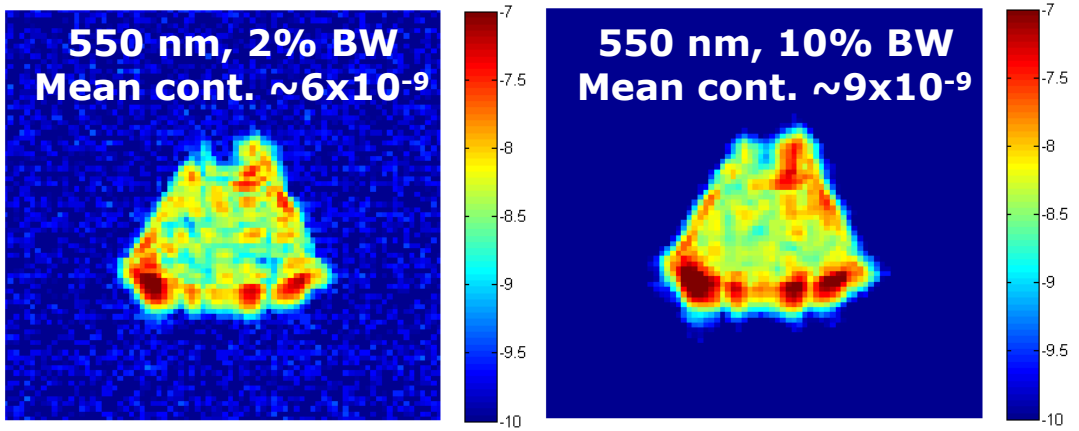
GLOSSARY:
ACWG - AFTA Coronagraph Working Group
BT - Bowtie
CRR - Concept Readiness Review
DM - Deformable Mirror
EK - External Key Milestone
HCIT - High Contrast Imaging Testbed
HLC - Hybrid Lyot Coronagraph
IFS - Integral Field Spectrograph
LOWFS/C - Low Order Wavefront Sensing and Control
OMC - Occulting Mask Coronagraph
PIAA - Phased Induced Amplitude Apodization
SPC - Shaped Pupil Coronagraph
SRR - System Requirements Review
TR - Testbed Review
TRL - Technology Readiness Level

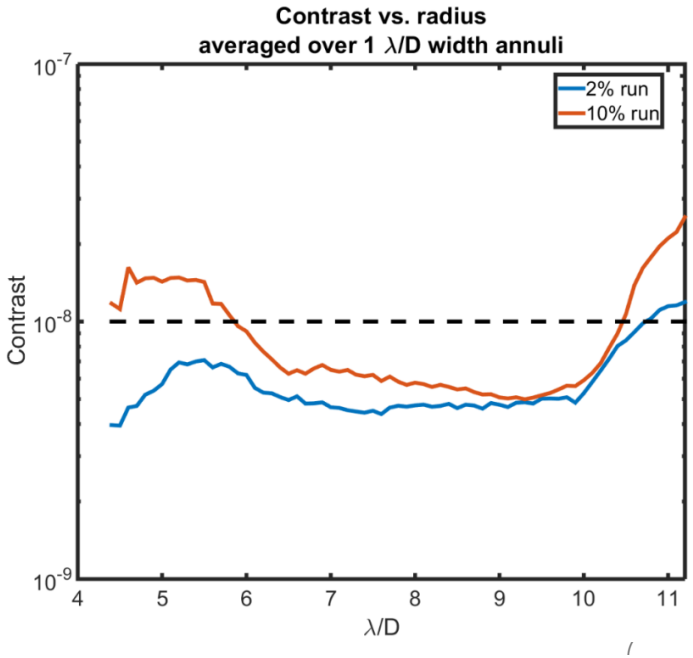
▽Milestone △HQ Milestones ◇Review Critical Path (CP) Secondary Critical Path Schedule Margin Testbed Conversion

PSA: John Lien

Milestone 2: SPC Testbed Demonstration

- Obtained narrowband (2%) and early broadband (10%) starlight suppression results in the shaped pupil coronagraph testbed
  - Initially with 1 DM, stopped down to 48x48 actuators
  - Milestone 2 results submitted on 9/17/14, approved by TAC
  - Broadband result meets Milestone 5 success criterion 12 months early
- **Retired the biggest technology development risk, proving that high contrast is achievable with the obscured AFTA telescope pupil**
- Starting fabrication of Gen 2 SPC masks (with Lyot stop) designed at Princeton for improved IWA and throughput

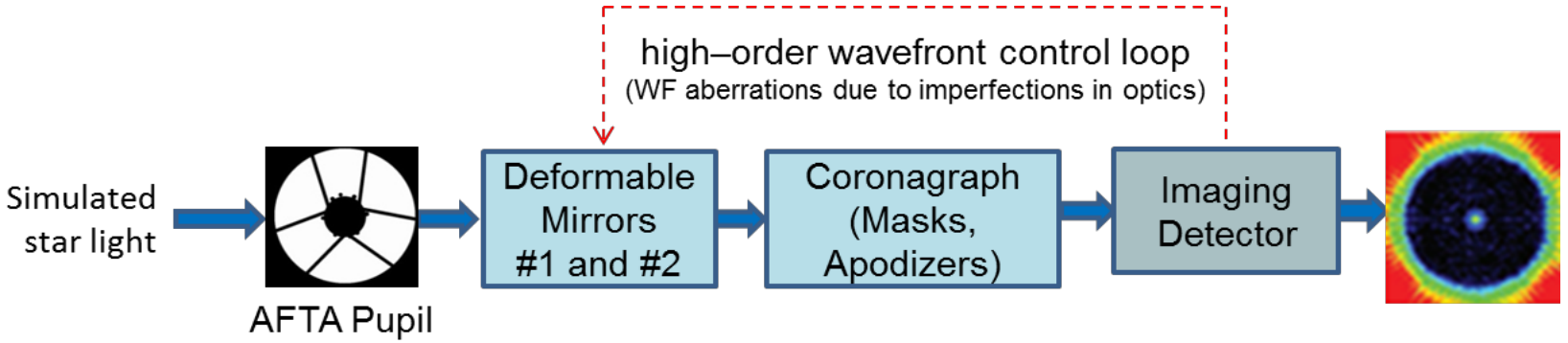




Static Broadband Demo: Milestone 5 (9/15/15)

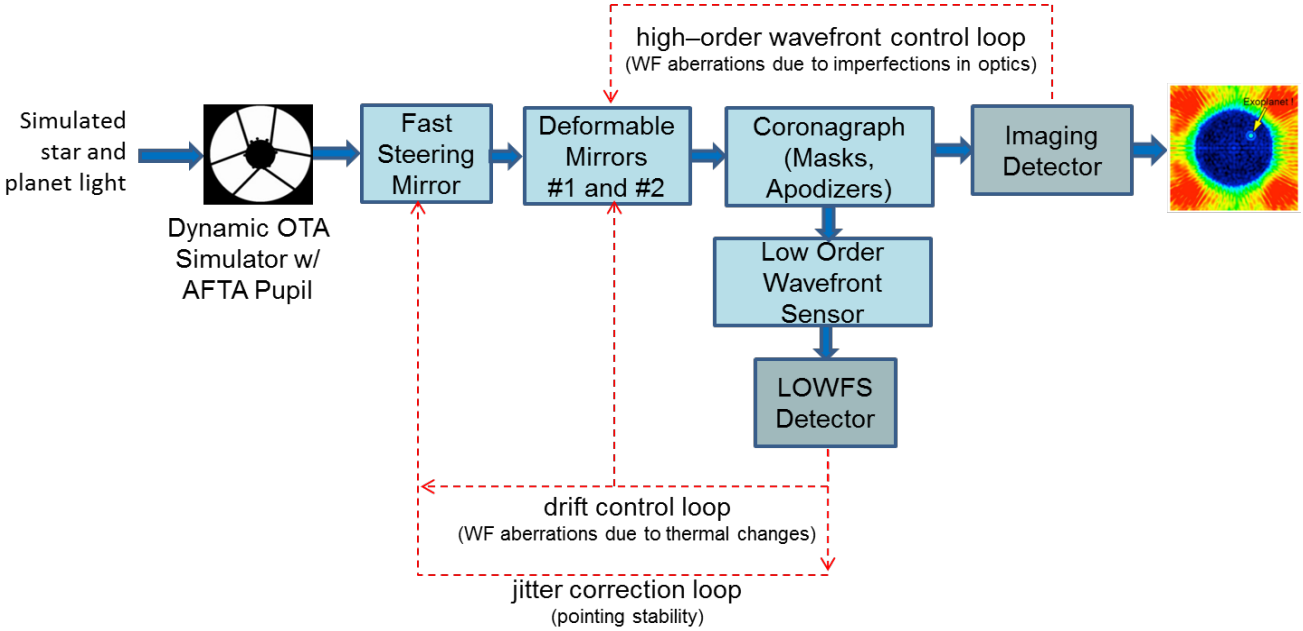
- ***Milestone 5***: Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a static environment.

- ***Verification Method***: Testbed raw contrast
  - **Raw contrast must be demonstrated at working angles consistent with coronagraph science requirements**
  - Contrast will be achieved 3 times to show the process is repeatable
  - OMC demonstration means that *at least one* (goal: both) of the coronagraph technologies comprising OMC demonstrate the required level of performance.



Dynamic Broadband Demo: Milestone 9 (9/30/16)

- ***Milestone 9***: Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a simulated dynamic environment.
- Dynamic coronagraph testbed will be built and aligned by July 2015
- Interfaces with OTA simulator and contains LOWFS/C components
- Optical layout replicates flight OMC instrument
- Incorporates next generation of masks
- Designed with TRL5 model validation requirements in mind



WFIRST vs. Lynx Technology Roadmap Observations

- WFIRST technologies selected per architecture
  - *Technology plan/roadmap showed path to maturing these technologies*
- Lynx concept still evolving
- Lynx will be considering competing technologies in parallel
  - *Must develop technology maturation schedules, selection criteria, off-ramps*
- Lynx team will need to develop a clear strategy to achieve technology maturation and selection to demonstrate reduced technical and programmatic risk

Technology Development Plan Template

- Template provided to Lynx team is comprehensive – can be used to inform development of Lynx technology roadmap outline

Table of Contents

Lynx Technology Status

- Optics Team
  - *Key Technology Elements*
  - *Prior efforts?*
- Instrument Team
  - *Key Technology Elements*
  - *Prior efforts?*

Lynx Science and Technology Definition Team (STDT)

- PCOS Program Technology Capability Gap Inputs (June 2016):
  - **High-resolution lightweight X-ray optics**
  - **High-efficiency X-ray grating arrays for high-resolution spectroscopy**
  - **Fast, low-noise megapixel X-ray imaging arrays with moderate spectral resolution**
  - **Large-format, high-spectral resolution, small-pixel X-ray focal plane arrays**
- **2nd RFI: Technologies for Large-Area Sub-Arcsecond X-ray Telescopes (DUE: March 2017)**
- **1st RFI: Technologies for Large-Area Sub-Arcsecond X-ray Telescopes (DUE: April 2016)**
  - **Advanced Design Consulting**
  - **Northrop Grumman Aerospace Systems**

Key Actions/Needs for Lynx Technology Roadmap Development

- Technology outline from the Optics and Instrument teams
  - *Incorporate results of TRL assessments already executed*
- Schedule & Milestones
- Establish tailored format for Lynx roadmap
- Develop roadmap strategy
- Set up working meeting to capture technology issues & assign action items

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Assuring Mission Success

For comments/questions, please contact

Angie.Bukley@aero.org Study Manager
Linda.Herrell@aero.org Technical Lead