Advanced Telescopes & Observatories Capability Roadmap Presentation to the NRC

March 15th, 2005

Agenda

Advanced Planning & Integration Office

- Introduction– Lee Feinberg
- Capability Roadmaps
  - Optics – Phil Stahl
  - Wavefront Sensing and Control and Interferometry – Jim Fienup
  - Distributed and Advanced Spacecraft – Dave Miller
  - Large Precision Structures – Ron Polidan
  - Cryogenic and Thermal Control Systems – Jim Oschman
  - Infrastructure – Gary Matthews (for Jim Burge)
- Conclusion – Howard MacEwen

Capability Roadmap Team

Advanced Planning & Integration Office

Co-Chairs

NASA: Lee Feinberg, Goddard Space Flight Center
External: Howard MacEwen, SRS Technologies

Government

Jim Breckinridge, JPL
Pete Jones, AFRL
David Tratt, JPL/ESTO
H. Philip Stahl, MSFC

Industry

Jim Crocker, LMCO
Ron Polidan, NGST
Gary Matthews, ITT
Mark Stier, Goodrich
Jim Oschmann, BATC

Academia

Jim Fienup, UofR
Dave Miller, MIT
Jim Burge, UAz
Dan Inman, Va Tech

Center Reps (Ex-officio)

John Hong, JPL
Scott Smith, MSFC
Ray Boucarut, GSFC

Coordinators

Directorate: Harley Thronson, HQ
APIO: Dan Coulter, JPL

Capability Description

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- The Advanced Telescope and Observatory Capability includes those sets of systems and associated technologies necessary to collect, concentrate and combine electromagnetic bands ranging from gamma-rays to radio waves, and including gravity-waves.
- The Committee does not consider technologies associated with the detection, conversion, or processing of observed signals into science data. These technologies are the responsibility of the Scientific Instruments and Sensors Roadmap Committee.

ATO Capability Breakdown Structure

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- 4.0 Advanced Telescopes and Observatories — Lee Feinberg, Howard MacEwen
  - 4.1 Optics — Phil Stahl
    - 4.1.1 Cryogenic Normal Incidence Optics (IR, FIR, Submm, uwave)
    - 4.1.2 Precision Normal Incidence Optics (EUV, UV, Vis, etc.)
    - 4.1.3 Grazing Incidence Optics (X-ray, etc.)
    - 4.1.4 Diffractive, Refractive or Other Optics (Gamma Ray, X-Ray, etc.)
  - 4.2 Wavefront Sensing & Control & Interferometry — Jim Fienup
    - 4.2.1 Wavefront Sensing
    - 4.2.2 Metrology
    - 4.2.3 Wavefront Control
    - 4.2.4 WFSCI Testbeds
  - 4.3 Distributed and Advanced Spacecraft Systems — Dave Miller
    - 4.3.1 Platforms
    - 4.3.2 Systems
    - 4.3.3 Subsystems
  - 4.4 Large Precision Structures — Ron Polidan
    - 4.4.1 Structure Stability & Precision
    - 4.4.2 Materials Properties
    - 4.4.3 Implementation Capability
  - 4.5 Cryogenic & Thermal Control Systems — Jim Oschmann
    - 4.5.1 Passive Cooling
    - 4.5.2 Active Cooling
    - 4.5.3 Thermal Isolation
  - 4.6 Infrastructure — Jim Burge
    - 4.6.1 Integration & Test Facilities
    - 4.6.2 In-space Observ. Support/Servicing
    - 4.6.3 Workforce

Traceability of Key ATO Drivers

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- Presidential Vision for Space Exploration "Conduct advanced telescope searches for Earth-like planets and habitable environments around other stars"
- Aldridge Report: "The Commission finds implementing the space exploration vision will be enabled by scientific knowledge, and will enable compelling scientific opportunities to study Earth and its environs, the solar system, other planetary systems and the universe"
- NASA's Direction for 2005 and Beyond (budget supplement)
- National Academy Astronomy and Astrophysics Decadal Survey
  - High Priority Major (Space) Initiatives in Priority Order:
    - James Webb Space Telescope (formerly NGST)
    - Constellation X Observatory
    - Terrestrial Planet Finder/Single Aperture Far Infrared Observatory
  - Moderate (Space) Initiatives
    - GLAST
    - LISA
    - Solar Dynamics Observatory
    - EXIST (Black Hole Finder)
  - Note: SIM was included in the 1991 Decadal Survey Moderate Initiatives and was recommended for completion.
- Reference mission list provided by Science Directorate and being reviewed by strategic roadmapping (for post-NRC update)
  - Listed as assumptions for now

Committee Assessment of ATO Roadmapped Missions to Strategic Panels

	Extrasolar Planet Science & Exploration	Universe Origins, Evolution, & Destiny	Earth System Science	Solar System Science & Exploration	Sun-Earth System Science
LUVO		X		X	
LF	X				
PI	X				
TPF-C	X				
TPF-I	X				
ConX		X			
DEM		X			
EUXO		X			
FISI	X	X			
IP		X			
LISA		X			
SAFIR	X	X			
UVOI		X			X
BHF		X			
BHI		X			
BBO		X			
EASI			X		
GEC			X		X
GSM			X		
HResCO2			X		
Leo LFSM			X		
LFFInSAR			X		
MMS					X
MTRAP					X
WS LIDAR			X		
LEO INSAR			X		
MEO INSAR			X		
GEO INSAR			X		
GEC					X
Mag Con					X
Mars EOR				X	
Telemachus					X
ASXI					X
RAM					X

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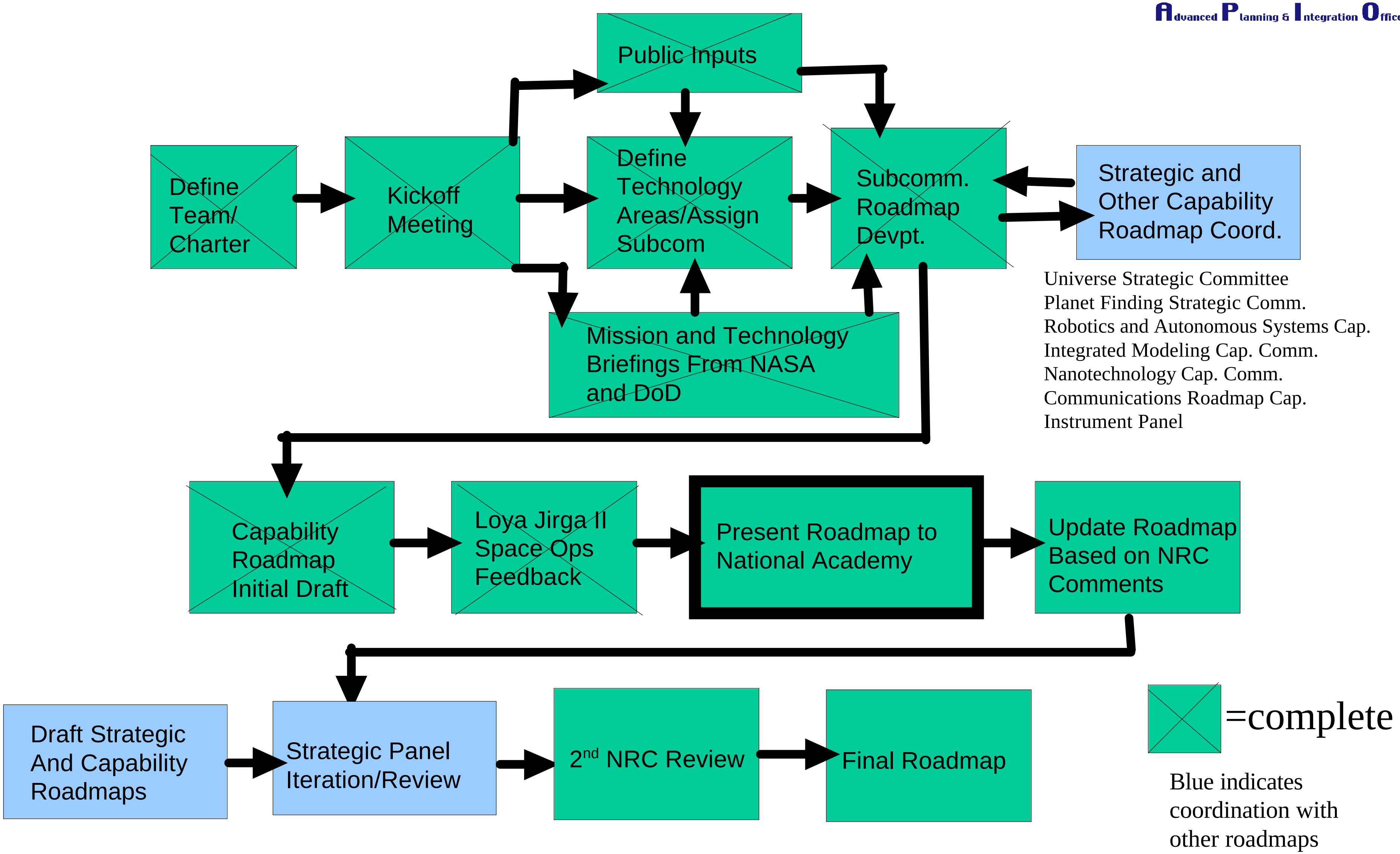
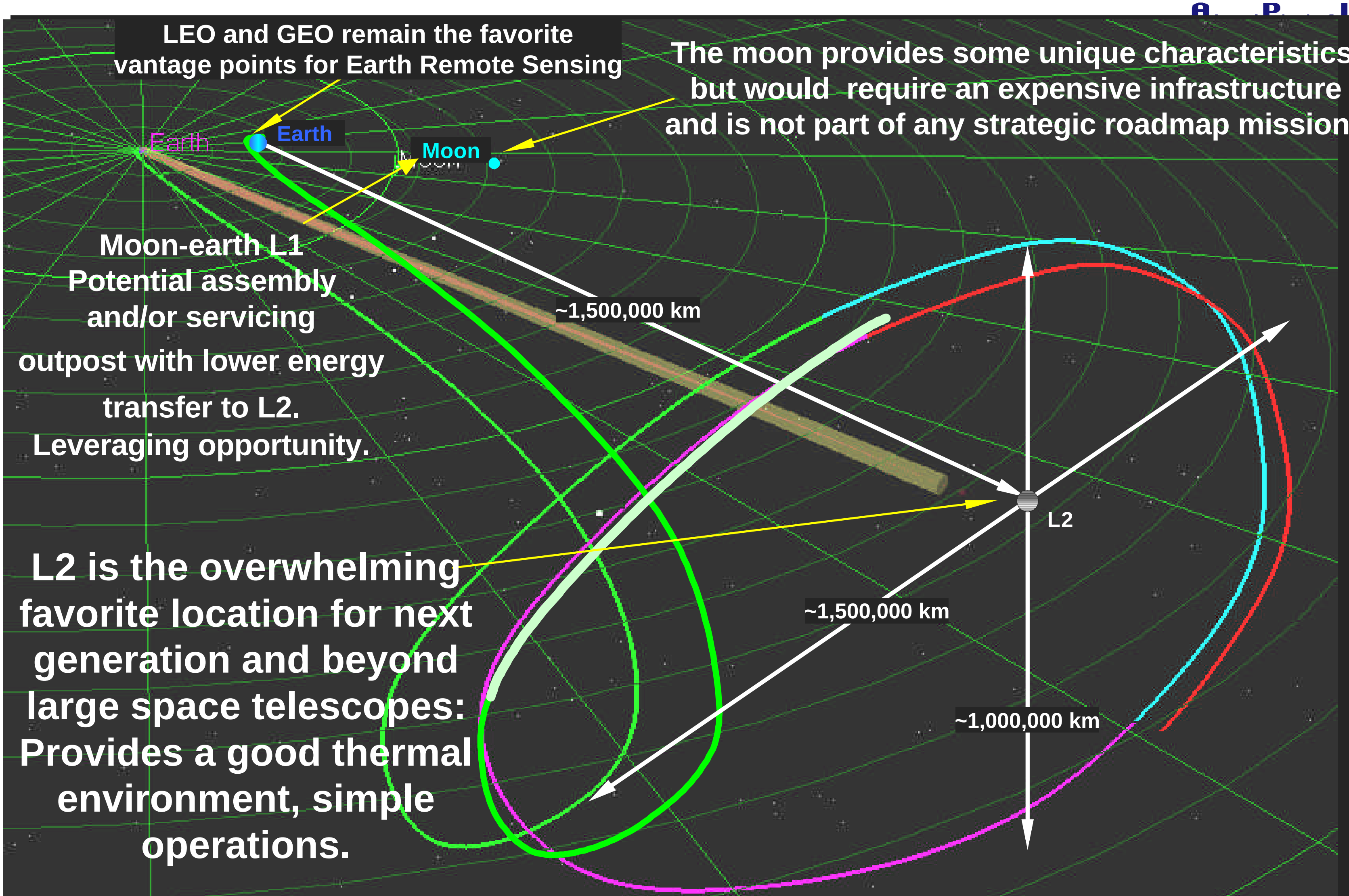
ATO Roadmap Process



Key Vantage Points for Large Observatories



Large Observatories in the Future: Not Just Bigger, But Better

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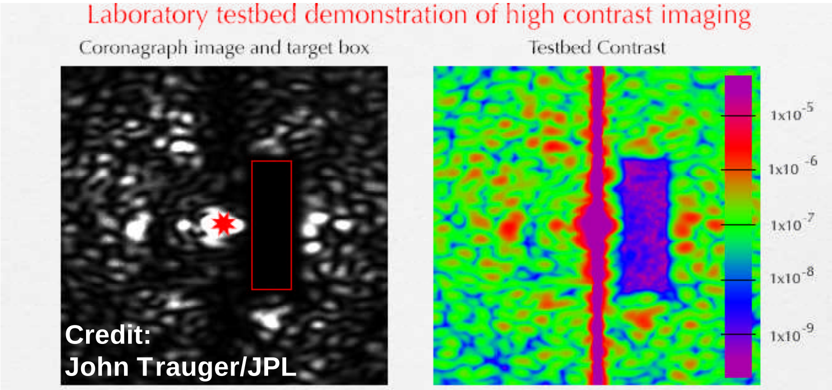
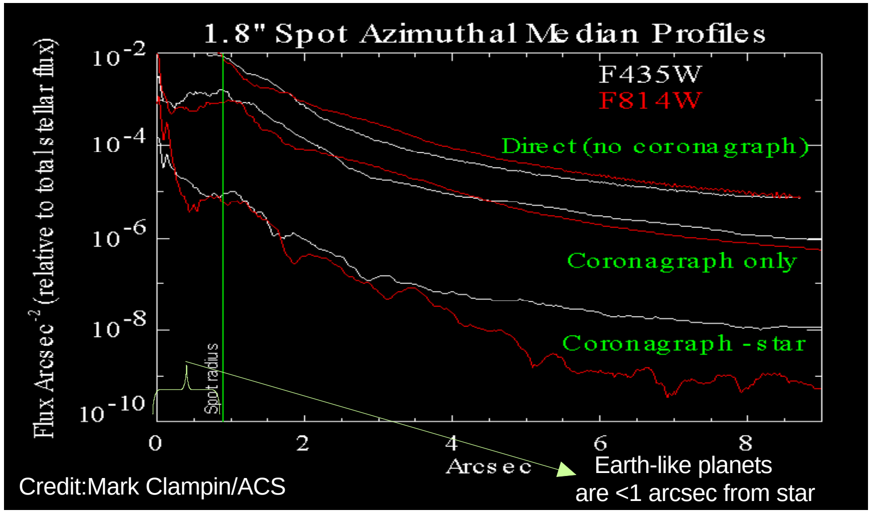
- Future Advanced Telescopes and Observatories won't just be bigger but also better. For example, if we want to study an extra-solar earth-like planet in the visible, then the amount of contrast of the system (a measure of how well an optical system can block a bright star) is critical



This laboratory coronagraph image was obtained with a linear occulting mask in December 2004. Inner boundary of the target box is 4 Airy radii to the right of the suppressed 'star' image (star position is indicated by the star-shaped fiducial). Average intensity of background speckles in the target box is fainter than the 'star' by a factor of 9×10^{-10} in 785 nm narrowband (laser) light. Contrast is stable to about 5×10^{-11} / hour with the DM actuator settings maintained open-loop at constant voltages.



- Contrast is driven by the smoothness of the mirrors, the stability of the telescope system, and the basic architecture (eg, active control), optics and algorithms used to block the bright star and image the dim planet.
- Black Hole X-ray systems and gravity wave systems also need "better" optical systems (higher precision). For FIR and Submm systems, better usually means colder.

ATO Current vs. Future Capabilities

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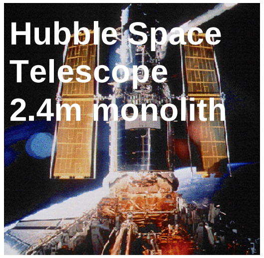
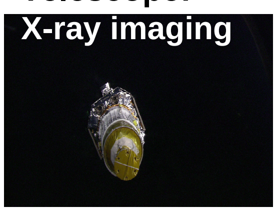
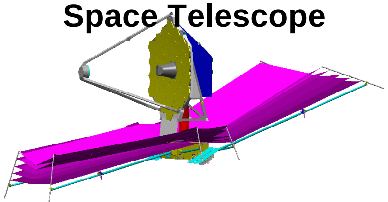


Chandra X-ray
Telescope:
X-ray imaging

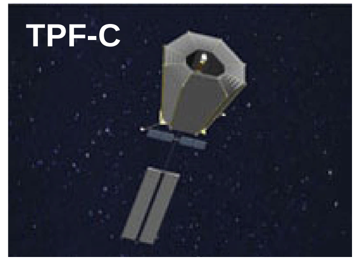


James Webb
Space Telescope

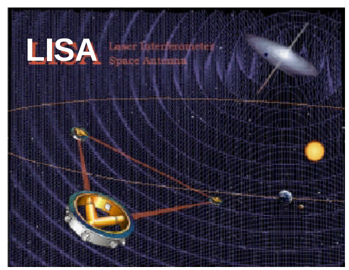


6.5m Segmented Telescope
Wavefront Sensing/Control
Sunshade Pass. Cooling
to 35K
Large Deployables

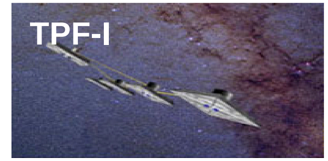
Precision Metrology
Interferometry



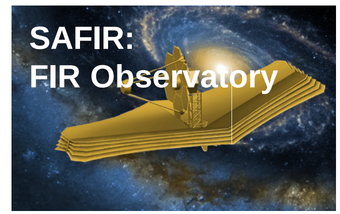
4x8 meter primary
Prec. Optics/occulters
Deformable mirrors/
Advanced Algorithms
Stable strucutres/
Active Control



Gravity Wave Detection:
3 space craft constellation.
Sub nm displacements
measured by
laser/interferometery
Mircro-thrusters



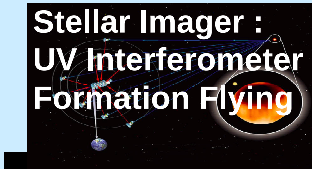
Nulling Interferometry
Formation Flying

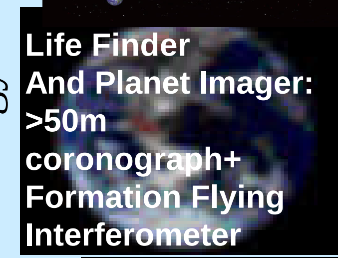


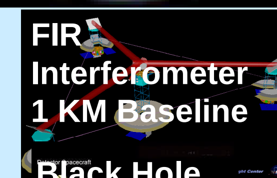
10-meter FIR Telescope
5-Kelvin Mirrors
Active/Passive Cooling

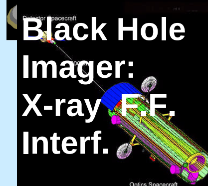
4 Co-pointed 1 meter
X-ray <15" Telescopes

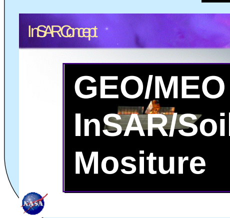
Sample Long Term Missions
That Drive Technology

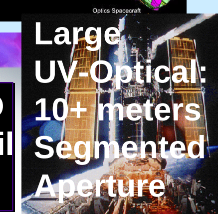












Current | In Development | 2005-2015 | 2015-2025 | 20+ Years

Note: Architectures and technologies shown are current configurations and will likely evolve.

Top Level Assumptions for ATO

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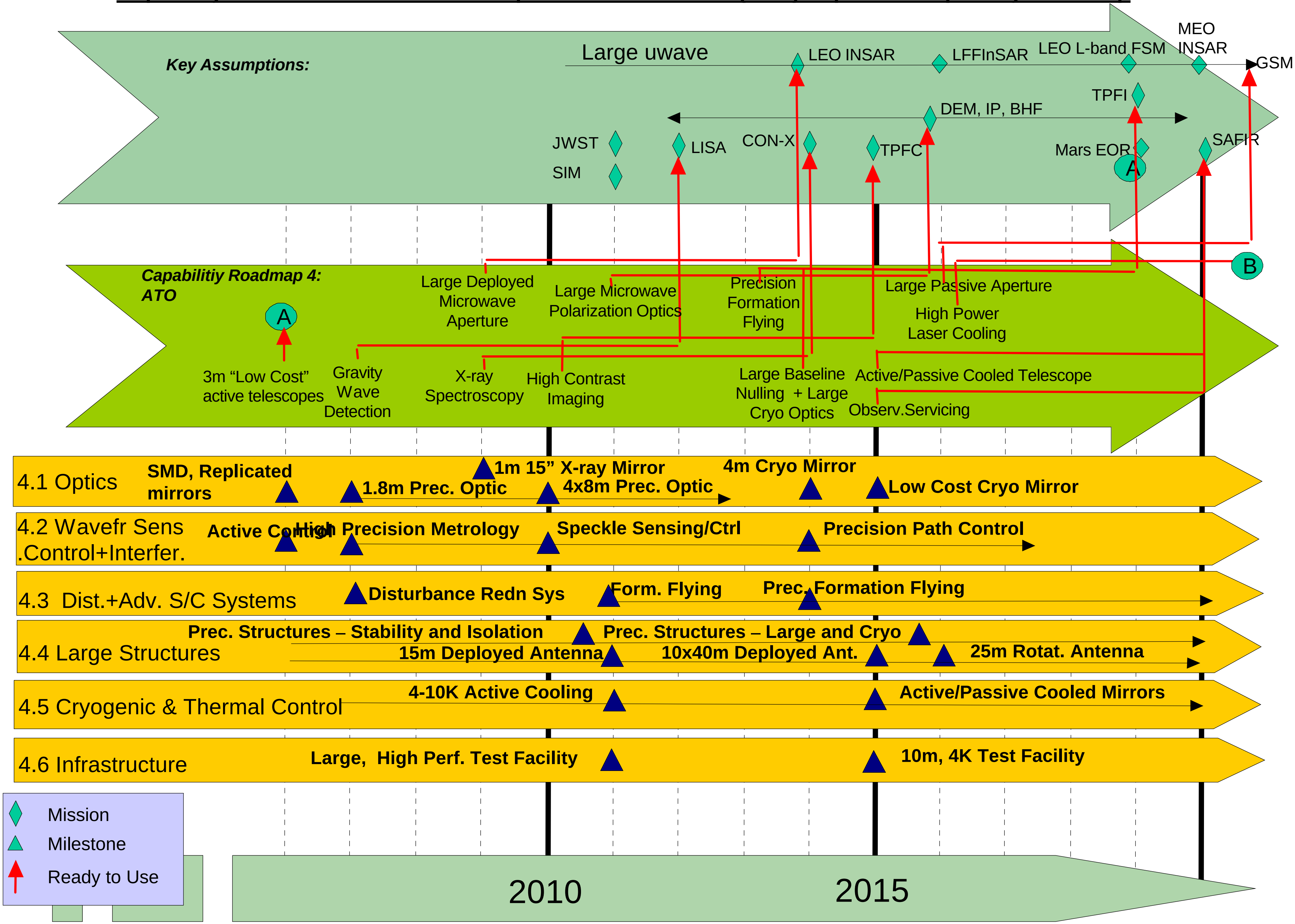
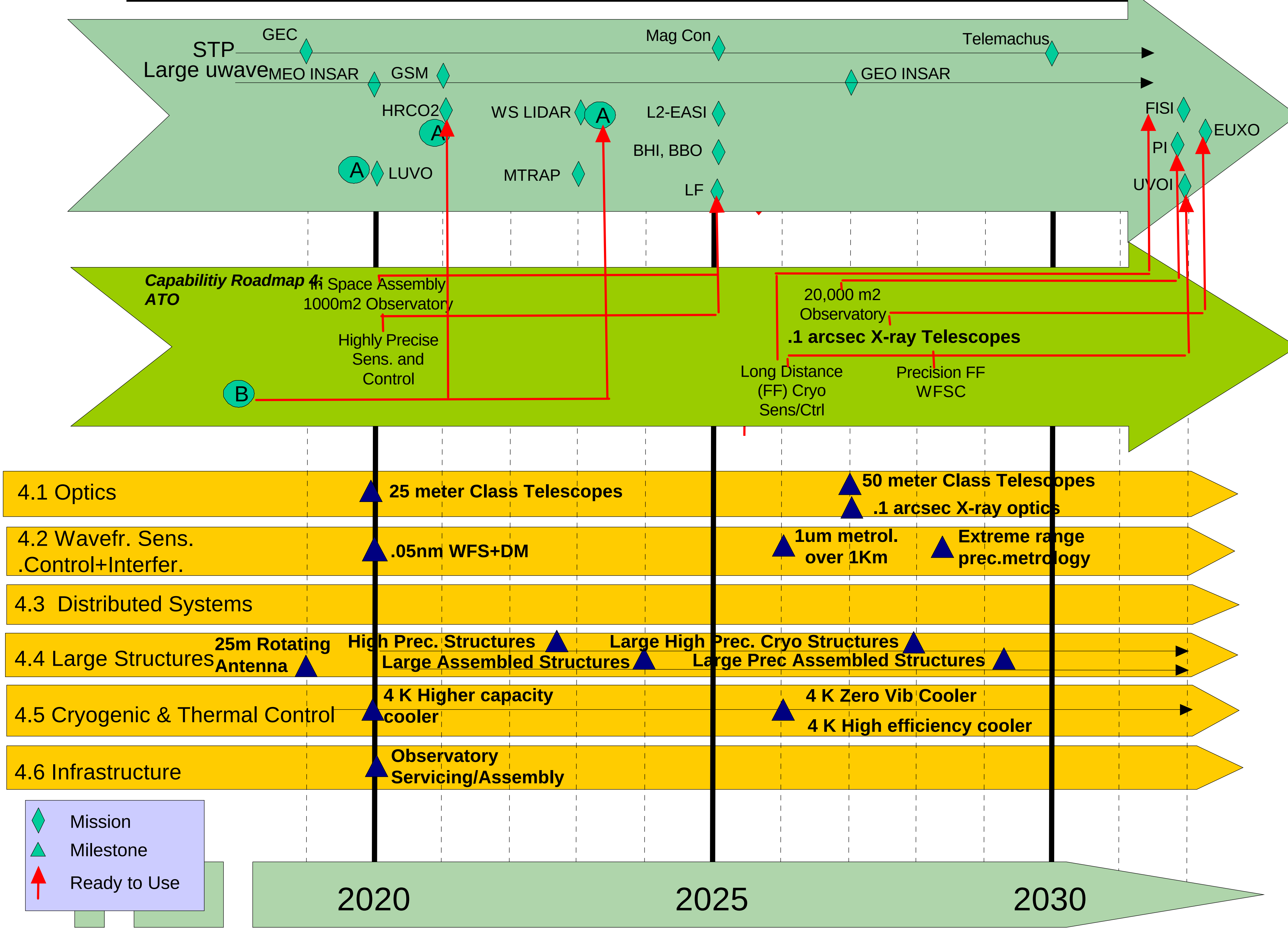
- Instrument panel covers cooling of instruments and sensors, including:
  - Black hole finder heat pipe cooling to radiators
  - Inflation Probe active cooling
    - Telescope passive cooling to 60 K
  - Optical bench cooling
  - CON-X detector cooler needs
- Instrument roadmap panel covers instrument optics
- Instrument roadmap panel covers lasers (including those used for LISA)
- Instrument panel covers microwave electronics and antennas/waveguides (ATO covers large deployed pieces)
- Modeling roadmap panel covers modeling and integrated modeling tools (included in backup slides)
- Do not roadmap JWST and SIM except to show as references where appropriate
- Key assumption was the list of missions and launch dates provided as reference missions. A summary of those missions show up on the timeline.
  - List is a subset of the reference missions provided by NASA HQ Science Mission Directorate divisions to APIO Capability roadmap teams
  - Some minor modifications to the list of missions was made at the suggestion or Strategic Roadmap Panels but we expect a future iteration of dates and missions with the strategic panels
- Mission technology needs based on NASA heritage roadmaps, presentation and reference material from missions

Capability Team 4: Advanced Telescopes & Observatories (ATO) Top Level Capability Roadmap



Capability Team 4: Advanced Telescopes & Observatories (ATO) Top Level Capability Roadmap



Capability 4.1
Optics

Presenter:

Phil Stahl, Team Lead

4.1 Optics Capabilities

- Optics Capability is defined as a system of components such as mirror substrates, coatings, actuators, and their respective manufacture & test processes necessary to enable the ability to collect and concentrate electromagnetic radiation.

- Four basic capabilities based upon wavelength region of the electromagnetic spectrum have been defined:

  - 1.1 Cryogenic Optics (for IR, Far-IR, Sub-MM, Microwave)
  - 1.2 Precision Optics (for EUV, FUV, UV, Visible)
  - 1.3 Grazing Incidence Optics (for X-Ray)
  - 1.4 Diffractive, Refractive & Novel Optics (for Gamma, X- ray or other)

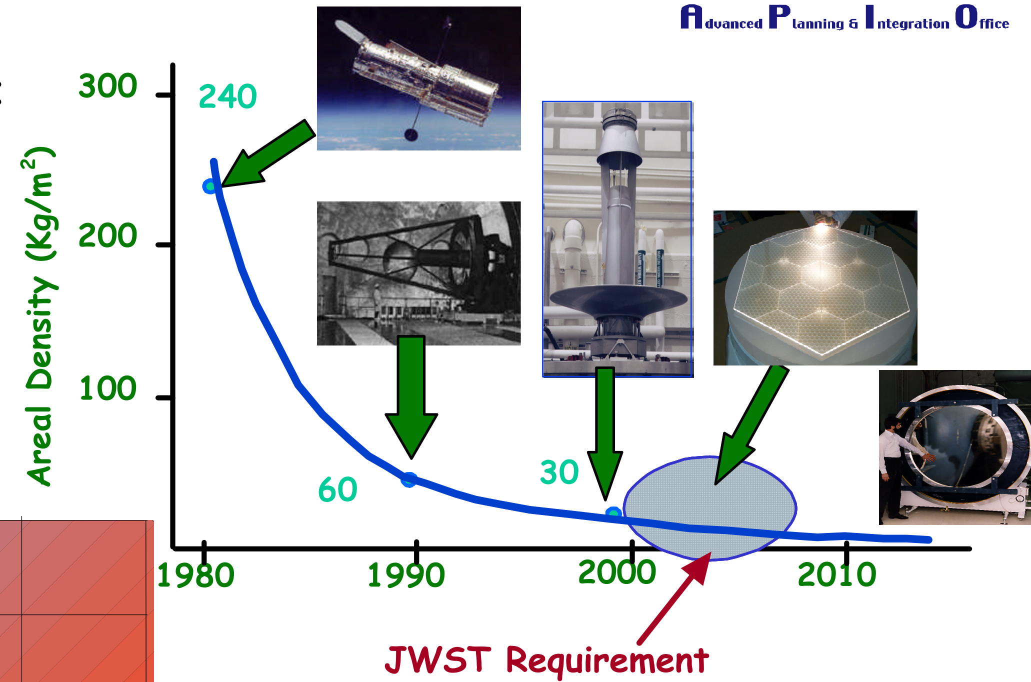
- Associated with each Capability are several Technology Figures of Merit which are closely related to system technical performance.

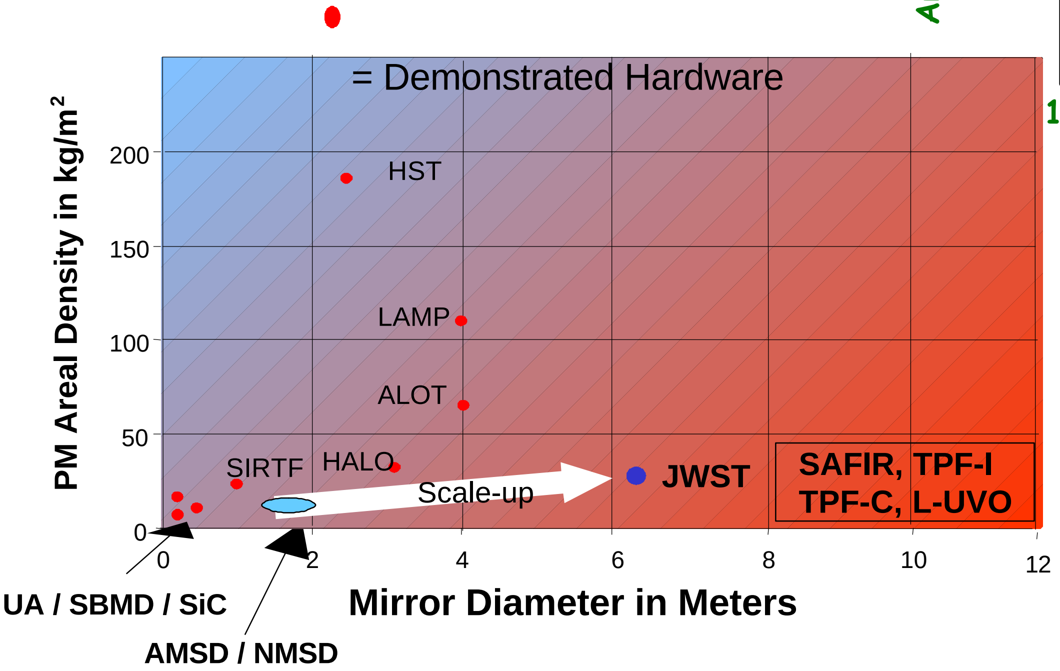
Space Telescopes need to Double in Size over Next 20 Years for NASA Science Missions

Challenges for Optical & X-Ray Telescopes:

Areal Density to enable up-mass for larger telescopes.

Cost & Schedule Reduction.





Primary Mirror	Time & Cost	
HST (2.4 m)	• 1 m^2/yr	• \$10M/m^2
Spitzer (0.9 m)	• 0.3 m^2/yr	• \$10M/m^2
AMSD (1.2 m)	• 0.7 m^2/yr	• \$4M/m^2
JWST (6 m)	> 6 m^2/yr	< \$3M/m^2

Note: Areal Cost in FY00 \$

4.1.1 Cryogenic Optics

Description of Capability needed:

Large-Aperture Modest-Quality Mirrors that enable IR/FIR/SMM/MW science missions operating at temperatures from 4 to 40K.

Low Operating Cost Mirrors that enable mission affordability, i.e. lower areal cost, shorter fabrication schedules and lower areal density.

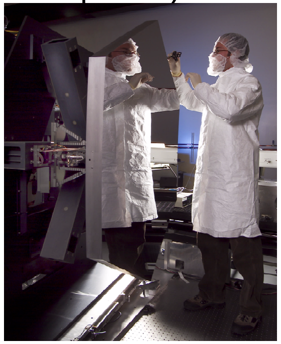
Need/Gap Assessment:

Manufacturing:
- 10X Decrease in Areal Cost
- 0 to 3X Increase in Mirror Segment Size
- 2X Decrease in Areal Density

Demonstrated Key Metrics:
- Figure Quality
- Thermal/Mechanical Stability
- Thermal Deformation

History/State-of-the-art:

- State-of-the-art/Mission History
  - Spitzer, WMAP, AMSD (flight/pathfinder)
  - JWST, Herschel, SPICA (in development)
- Leading Candidates
  - Beryllium (incumbent)
  - SiC
  - Glass – ULE, SiO2, Bk7
  - Others – Si, MgGr
- Current TRL
  - AMSD (TRL 5)
  - Various SBIR's (TRL 4)


JWST/AMSD Beryllium Mirror

Mission/Strategic Drivers:

- Potential Missions
  - SAFIR
  - Probes
  - TPF-I
  - FISI
- Key external requirement:
  - Cryo-Cooler Temp vs Aperture Dia
- Date: Continuous Cyclic Improvement

4.1.2 Precision Optics

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Description of Capability needed:

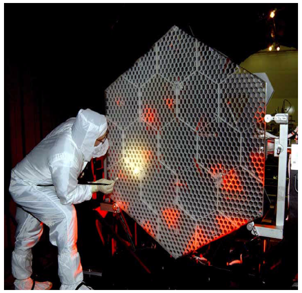
- Large-Aperture Extremely-Smooth Extremely-Stable Ambient-Temperature Mirrors that enable EUV/UV/O science missions.
- Edge Control and Phasing of Segmented Mirrors.
- Optical Test Instrumentation.
- Low Operating Cost Mirrors that enable mission affordability, i.e. lower areal cost, shorter fabrication schedules and lower areal density.
- High Reflectance Coatings from 90 to 1000 nm.
- Extremely Uniform Reflectance and Polarization Coatings from 400 to 1000 nm.

Need/Gap Assessment:

- Manufacturing:
  - Precision figure large low-stiffness mirrors
  - Polish all the way to Edges
  - Optical Testing – spatial, convex & fixture
  - 10X Decrease in Areal Cost
  - 2X Decrease in Areal Density
- Actuator Technology with 0.1 nm precision
- Coating Technology:
  - 2X Reflectivity Increase 90 to 120nm (80% Goal)
  - 10X Reflectivity Uniformity (0.1% Required)
  - 10X Polarization Uniformity
  - Dichroic, Spectral and Combiner Coatings

History/State-of-the-art:

- State-of-the-art/Mission History
  - HST, FUSE, SUMI, AMSD, TDM (flight/pathfinder)
  - KECK, ALOT (ground system)
- Leading Candidates
  - Glass (incumbent)
  - Actuated Hybrid Mirror (AHM)
  - Alternative substrate materials
- Current TRL
  - AMSD (TRL 5)
  - AHM (TRL 4)
  - Segmented Mirror Demo (TRL 5-6 FY 07)



Mission/Strategic Drivers:

- Potential Missions (Diameter)
  - TPF-C (4 x 8 meter)
  - Origin's Probes (JDEM, etc.) (2.4 meter)
  - EOR Lasercomm (3 meter)
  - MTRAP (5 meter)
  - Earth Science (2 to 5 meter)
  - UV/O Interferometer (1 meter)
  - Big Bang Observer (3 meter)
  - Life Finder (25 meter)
- Key external requirements:
  - Coatings & Aperture vs Detector Sensitivity
  - Passive Figure vs Active Control, i.e. DM
- Date: Continuous Cyclic Improvement

4.1.3 Grazing Incidence Optics

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Description of Capability needed:

Large-Aperture Precision-Quality Grazing Incidence Mirrors that enable X-Ray/FUV science missions.

Radically Low Operating Cost Mirrors that enable mission affordability:
- significantly lower areal cost,
- shorter fabrication schedules and
- radically lower areal density.

Need/Gap Assessment:

Manufacturing:
- 100X Decrease in Areal Cost
- 100X Decrease in Areal Density
- 0 to 2X Increase in Mirror Segment Size
- Replicated Surface Figure

Mechanical:
- Mounting, Support & Alignment
- Mechanical Stability

History/State-of-the-art:

- State-of-the-art/Mission History
  - Einstein HEAO-B, EUVE, TMA, XMM, Chandra
  - SXI, Solar B
- Leading Technology Candidates
  - Glass Slumping
  - Nano-laminate
  - Replication
  - Silicon Pore Mirrors
  - Active Mirrors
  - Revolutionary
- Current TRL
  - Glass Slumping (TRL 2/3)

Mission/Strategic Drivers:

- Potential Missions (Diameter)
  - Advanced Solar X-Ray Imager (ASXI)
  - ConX
  - Reconnection and Microscale (RAM)
  - EUXO
  - Black Hole Imager
- Key external requirements are:
  - Launch Vehicle Up-Mass vs Areal Density
- Date: Continuous Cyclic Improvement

4.1.4 Diffract., Refract. & Novel Optics

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Description of Capability needed:

Diffractive/Refractive Optics for specific missions such as coded aperture & occulting imaging.

Revolutionary Optics to enable presently unachievable large-aperture science missions.

Revolutionary Optics for alternate implementations of planned future missions.

Need/Gap Assessment:

Manufacturing:

- –1000X Decrease in Areal Cost
- –1000X Decrease in Areal Density
- –100X Increase in Optic Size

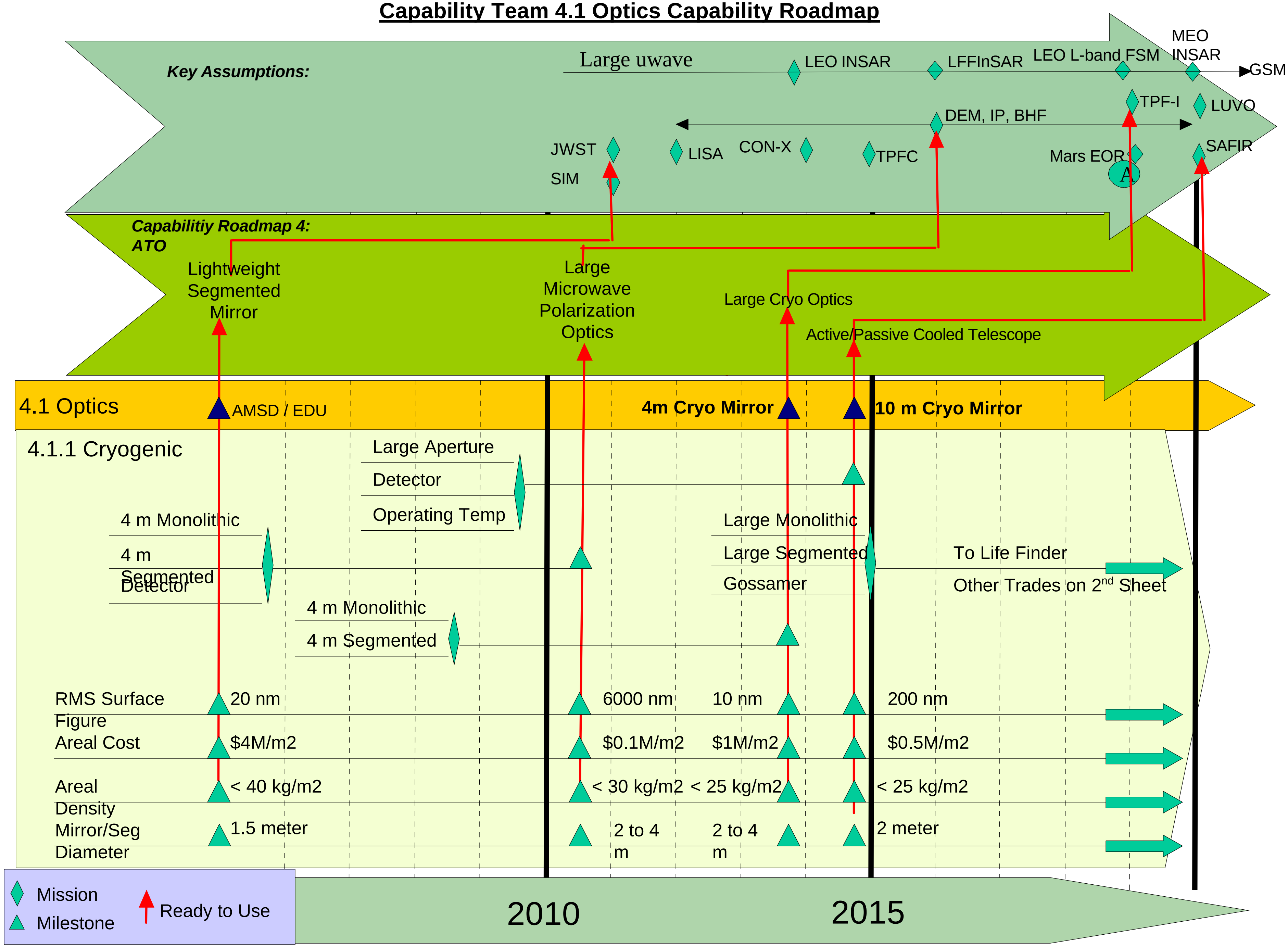
History/State-of-the-art:

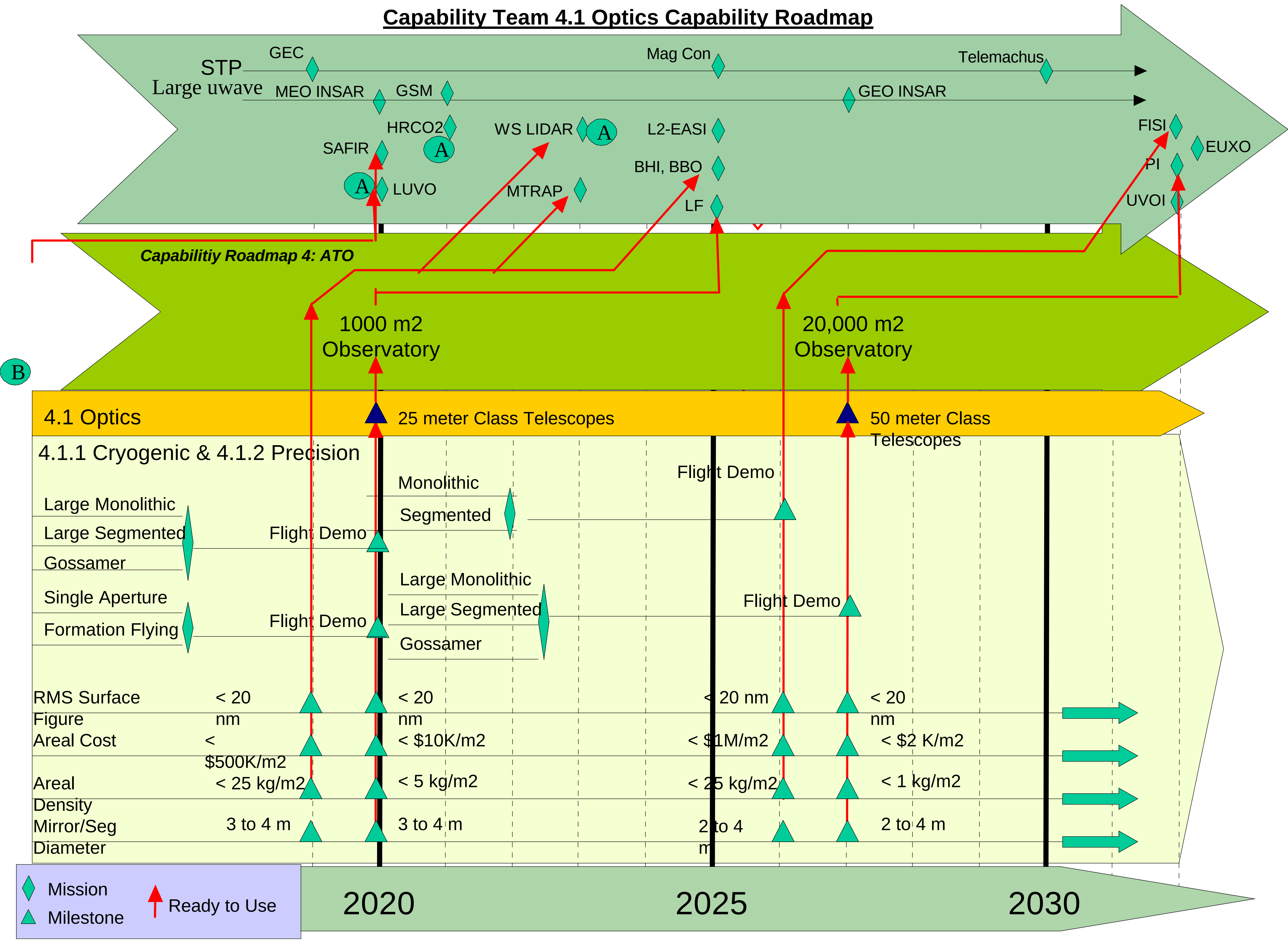
- –State-of-the-art/Mission History
  - –Compton Telescope
  - –Coronagraph
- –Leading Technology Candidates
  - –Laue Lens – Gamma Ray
  - –Fresnel Lens – Gamma Ray, X-Ray, UV/O
  - –Diffractive/Refractive X-Ray Lens
  - –Occulting Screens, Pin Hole Camera
  - –Gossamer/Membrane Mirrors
  - –Laser Trapped or Magnetic Trapped Mirrors
- –Current TRL = 1/2

Mission/Strategic Drivers:

- –Potential Missions (Diameter)
  - – Life Finder (LF)/Planet Imager (PI)
  - – Extreme Universe X-ray Observatory (EUXO)
  - – Other Future Space Science Missions

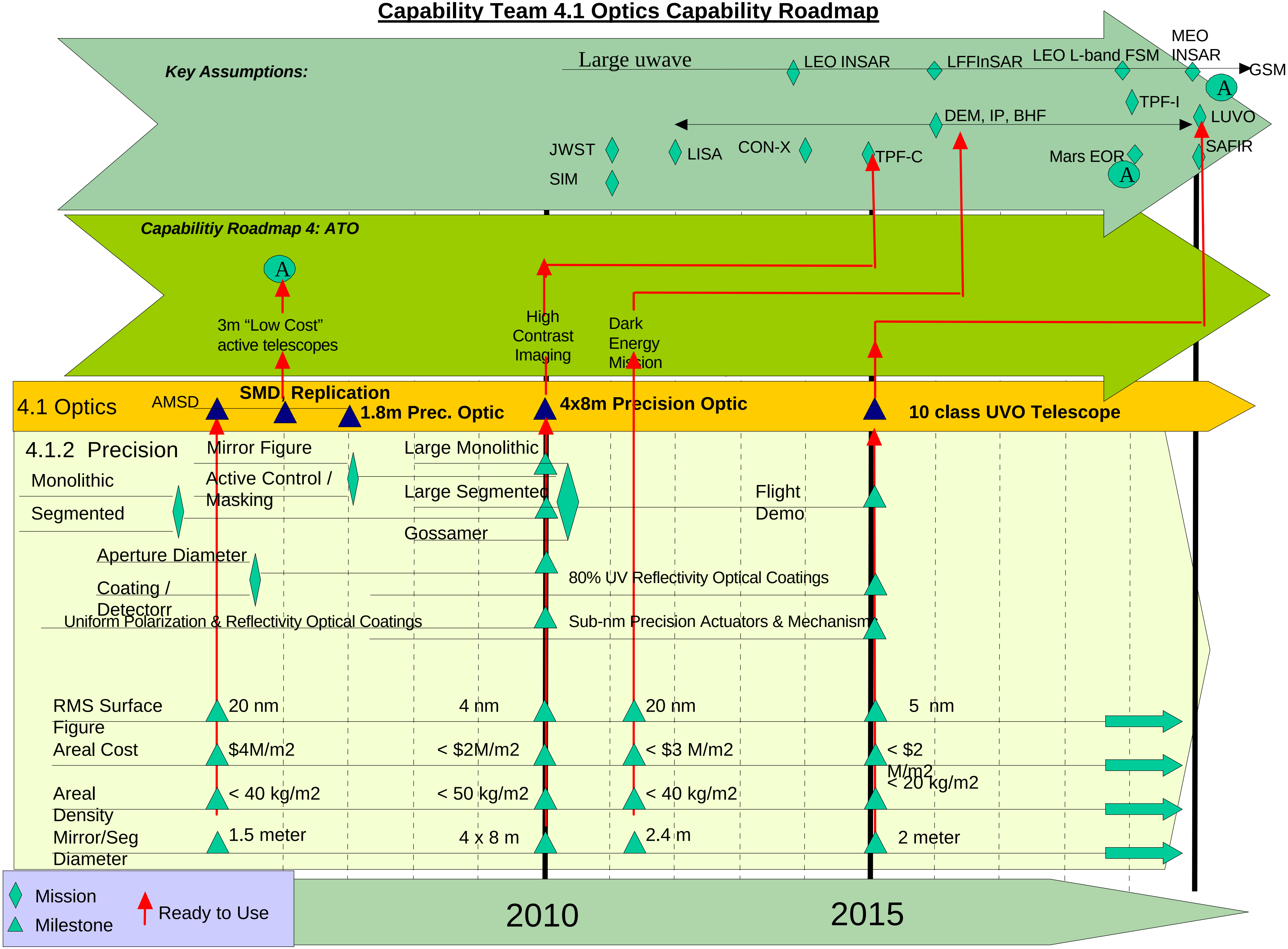
Capability Team 4.1 Optics Capability Roadmap



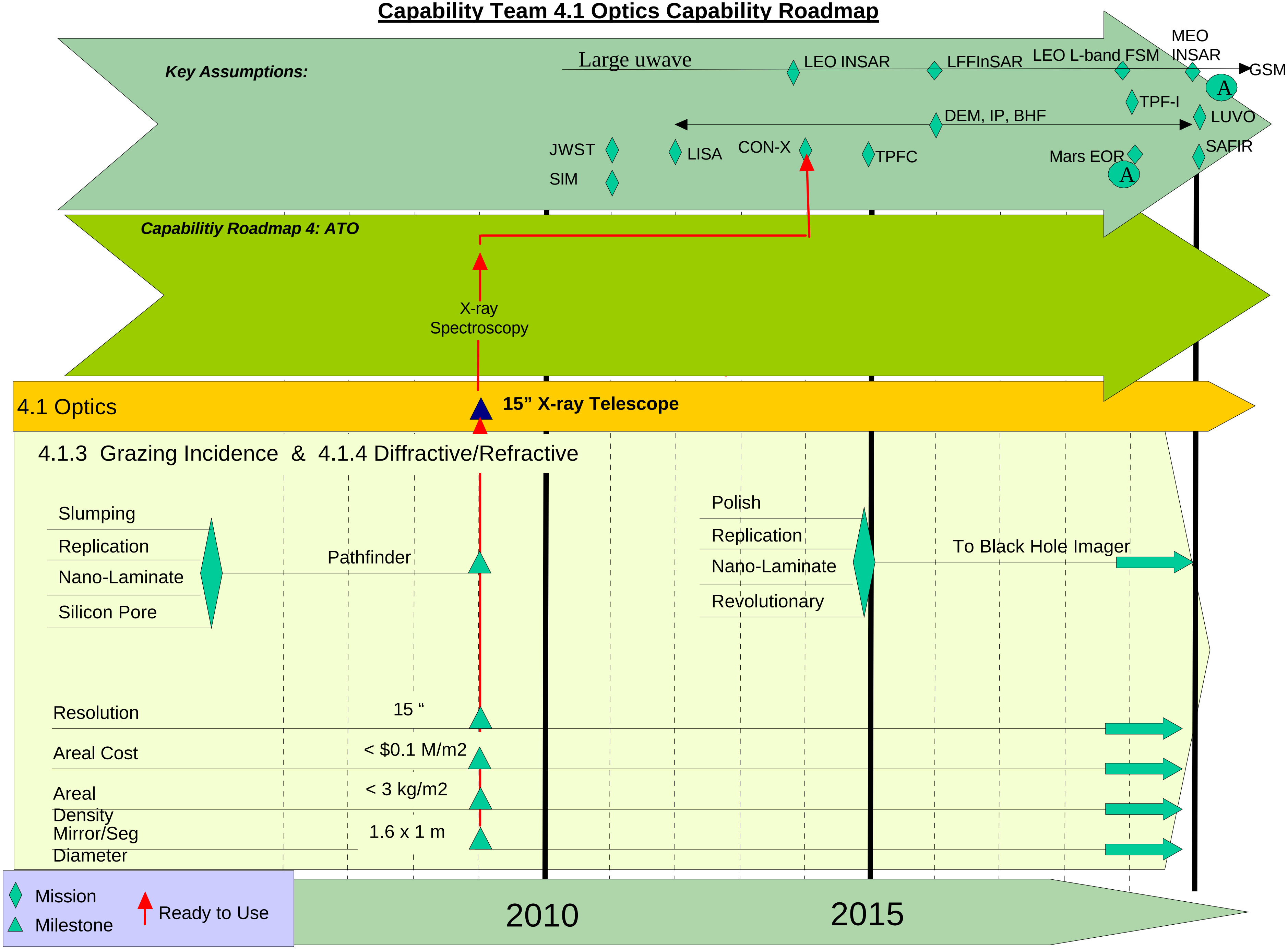


Capability Team 4.1 Optics Capability Roadmap
STP
Large uwave
GEC
Mag Con
Telemachus
MEO INSAR
GSM
GEO INSAR
HRCO2
WS LIDAR
A
L2-EASI
FISI
SAFIR
A
EUXO
BHI, BBO
PI
A
LUVO
MTRAP
LF
UVOI
Capabilitiy Roadmap 4: ATO
1000 m2 Observatory
20,000 m2 Observatory
B
4.1 Optics
25 meter Class Telescopes
50 meter Class Telescopes
4.1.1 Cryogenic & 4.1.2 Precision
Flight Demo
Monolithic
Segmented
Large Monolithic
Large Segmented
Gossamer
Flight Demo
Large Monolithic
Single Aperture
Large Segmented
Flight Demo
Formation Flying
Flight Demo
Gossamer
RMS Surface Figure
< 20 nm
< 20 nm
< 20 nm
< 20 nm
Areal Cost
< $500K/m2
< $10K/m2
< $1M/m2
< $2 K/m2
Areal Density
< 25 kg/m2
< 5 kg/m2
< 25 kg/m2
< 1 kg/m2
Mirror/Seg Diameter
3 to 4 m
3 to 4 m
2 to 4 m
2 to 4 m
Mission
Milestone
Ready to Use
2020
2025
2030

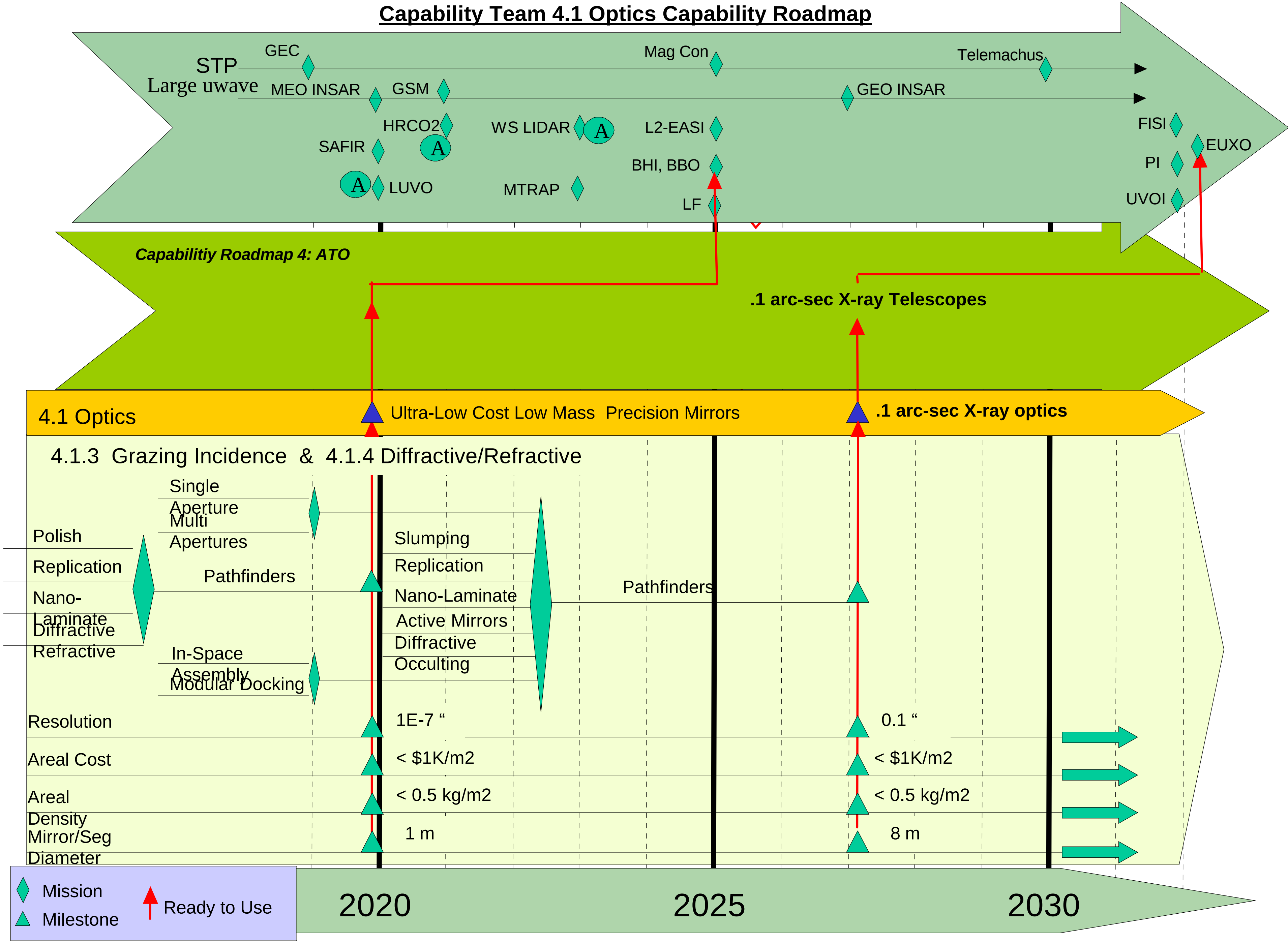
Capability Team 4.1 Optics Capability Roadmap



Capability Team 4.1 Optics Capability Roadmap



Capability Team 4.1 Optics Capability Roadmap



Capability 4.2
Wavefront Sensing & Control and Interferometry

Presenter:

James R. Fienup, Team Lead

Capability 4.2 WFSC&I

- **Description of the Capability Area**
- **Sensing the wave front from measured data, either from the object being imaged, from other nearby objects, or from beacons placed in front of the optical system. Mathematical algorithms, computer software (on-board or on the ground), and computer hardware for turning measured data into wave front information**
- **Metrology within and between telescope structures. Metrology lasers: multiple-wavelength-single-mode, long-lifetime, stable. Innovative optical test methodologies and interferometers. Edge sensors.**
- **Controlling the optics of a dynamic space structure to within a small fraction of a wave length is needed to satisfy mission objectives. Control issues include structures, active/adaptive optical surfaces, actuators, deformable mirrors, delay lines, damping, and software driving algorithms responding to an end-to-end optical system merit function such as image quality. On-board software and computing hardware to implement control algorithms at the bandwidths necessary to satisfy mission objectives**
- **Because of the relative immaturity of WFSC&I in space, testbeds are important to test the ability of hardware and software to work together under realistic conditions. Algorithms are also required for interferometry: aperture synthesis imaging, computing imagery, image restoration**

4.2.1 WFSC&I: Wavefront Sensing

Advanced Planning & Integration Office

Description of Capability needed:

- Ultra high precision WFS
- Continuous sensing of segmented mirrors, continuous mirrors, or interferometer delay line adjustments for closed loop control
- Speckle nulling

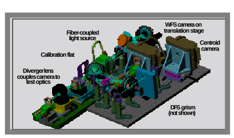
Need/Gap Assessment:

- 10^{-10} contrast for coronographic
- Innovation (e.g. speckle nulling, broadband nulling[1] multistep)
- $\lambda/20$ WFS for interferom. =8nm@ λ =155nm
- Test-beds, algorithm development[1]
- Continuous sensing for closed loop control
- Vector (polarization) optical modeling[3]
- Formation flying beacons

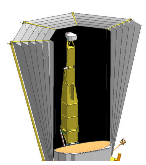
History/State-of-the-art:

- JWST testbeds: 3.5 nm WFS, 20 nm rms WFC[2] (TRL 5)
- HCIT: speckle nulling 10^{-9} contrast narrowband (TRL 3.5)
- Leading Technology Candidates: phase diversity, speckle nulling (TPF), plus others

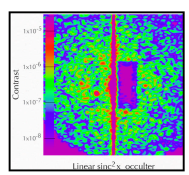
JWST



JWST Phase Retrieval Camera



TPFC



HCIT, Speckle Nulling

Mission/Strategic Drivers:

- WFSC needed for future missions to enable planet finding, stellar surface imaging
- JWST is tackling near term needs, but future missions require continuous improvements to meet future increasing precision and control for most optical/IR telescopes through planet imaging needs
- Driving missions: TPF-C, LISA, TPF-I, Large UVO, Life Finder, Planet Imager, Stellar Imager, SPIRIT, SPECS, BHI, BBO, Low Cost 3-meter telescopes for LIDAR/Lasercomm/Imaging

[1]Stapelfeldt, [2]Redding, [3]Lyon

4.2.2 WFSC&I: Metrology

Advanced Planning & Integration Office

Description of Capability needed:

Measure single aperture and distributed telescopes to enable the coherent performance necessary for high-angular resolution astronomy and exo-solar planet detection & characterization.

- Continuous metrology of segmented & continuous-surface mirrors, and interferometers.
- Interferometer delay line metrology(ambient and cryo temperatures) for closed loop control.
- Control unwanted radiation for to < 1:10E-12
- Frequency stabilized long life-time lasers
- Precision edge sensing & control for segmented mirrors

Need/Gap Assessment:

- Reject attitude control disturbances to < 80 dB, to give ~ 20 micro-arcsecond pointing
- Laser metrology gauge => repeatable measurements to 10's of picometers & absolute accuracy of microns over several 10's m.
- Accurate measurement of the structural and dynamic properties of mechanical subsystems & modeling to predict system performance: analysis, laboratory measurements, software, computational applications
- Measure & control optical wavefronts, to an accuracy < 0.001 wavelength, at spatial resolution of >~ 400 cycles/pupil, at correction frequency > 10 Hz
- Long OPD precision phase delay lines @ <70K

History/State-of-the-art:

SIM, JWST, TPF-C technology

- Measure optical surfaces to 0.005 waves rms
- 10 nm stability OPD control and picometer metrology
- Reject attitude control disturbances to < 60 dB, to give 20 milli-arcsecond pointing
- Laser metrology gauge => repeatable measurements to 10's of picometers & absolute accuracy of microns over several meters.
- Measure distances between optical fiducials on a 3-D truss to 10's of picometers
- Measure starlight angles to uas, detection position to +- 30 pm on CCD & control OPD to +- 1 nm.

Mission/Strategic Drivers:

- Direct detection and characterization of exo-solar planetary systems
- Determine the origins of the astrophysical universe
- TPF-I, TPF-C, Large UV Optical, Life Finder, LISA, BBO

Capability Need:

–Adaptive real-time wave-front correction for space telescopes
- –High precision control of wave fronts for high contrast imaging
  - –DM's
  - –Innovative field and Lyot stops
- –On-board intelligent control systems to maintain performance with on-demand communications for commissioning and system diagnosis

Note: Active primary and secondary mirrors with actuators covered under optics

Need/Gap Assessment:

- –λ/10,000 rms =50pm control & stability for coronagraphic capability
- –Higher order, longer stroke, finer precision DM's
  - -Sampling, Stability
- \- Cryogenic precision motion to Pico meter resolution
- –On board intelligent control systems
  - –Flight qualified DSPs
- –Architectures and test beds demonstrating closed loop intelligent control

History/State-of-the-art:

- –*Delay lines, actuators, mirror substrates and integrated DM systems for sub-nanometer control of alignment, phasing and figure*
- –*Many ground based systems using Adaptive Optics*
- –*Technology Candidates:*
  - – Actuated Hybrid Mirrors (JPL, LLNL, Xinetics) TRL 4-6
  - – Zonal Meniscus Mirrors (Xinetics) TRL ?
  - – Nanolaminate Mirrors (LLNL) TRL ?
  - –CAMELOT cryo actuated mirrors (Xinetics, JPL) TRL 3
  - –MEMs TRL ?

MEMs

Xinetics DMs

Mission/Strategic Drivers:

- –SIM requires Pico meter multi-baseline control
- –TPF-C #1 technology priority TRL X by 2007
- –TPF-I telescopes
- – Other large interferometers such as Planet Finder

Active system external requirement drivers:

Very difficult to scale up existing technology
- –Mass and volume limits on launch vehicles
- –Cost as system scale in size
- –Need different approach to meet tighter requirements

4.2.4 WFSC&I Algorithm Testbeds

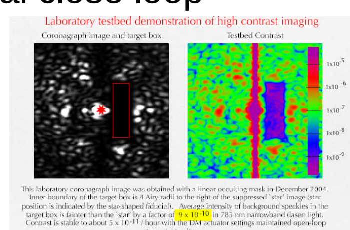
Description of Capability Needed:

- Ground WFSC+I Algorithm Testbeds capable of demonstrating new measurement approaches and their key performance criteria
- Key to understanding key system trades, technology needs, algorithm development, model correlation/validation
- Need to continue work on many existing testbeds and make testbeds that are cryo-vacuum and vibration-free for more challenging requirements

History/State-of-the-art:

- JWST: Several few segment testbeds exist, a full 18 segment testbed in development
- SIM: Metrology testbeds
- TPF High Contrast Testbed: 10-9 contrast, monochromatic
- Wide-field Imaging Interferometry Testbed – 1-D imaging
- Stellar Imaging Testbed – Initial close loop control
- MAXIM – X-ray interferometry
- Fringes

TPFC
High Contrast
Testbed Results



Need/Gap Assessment:

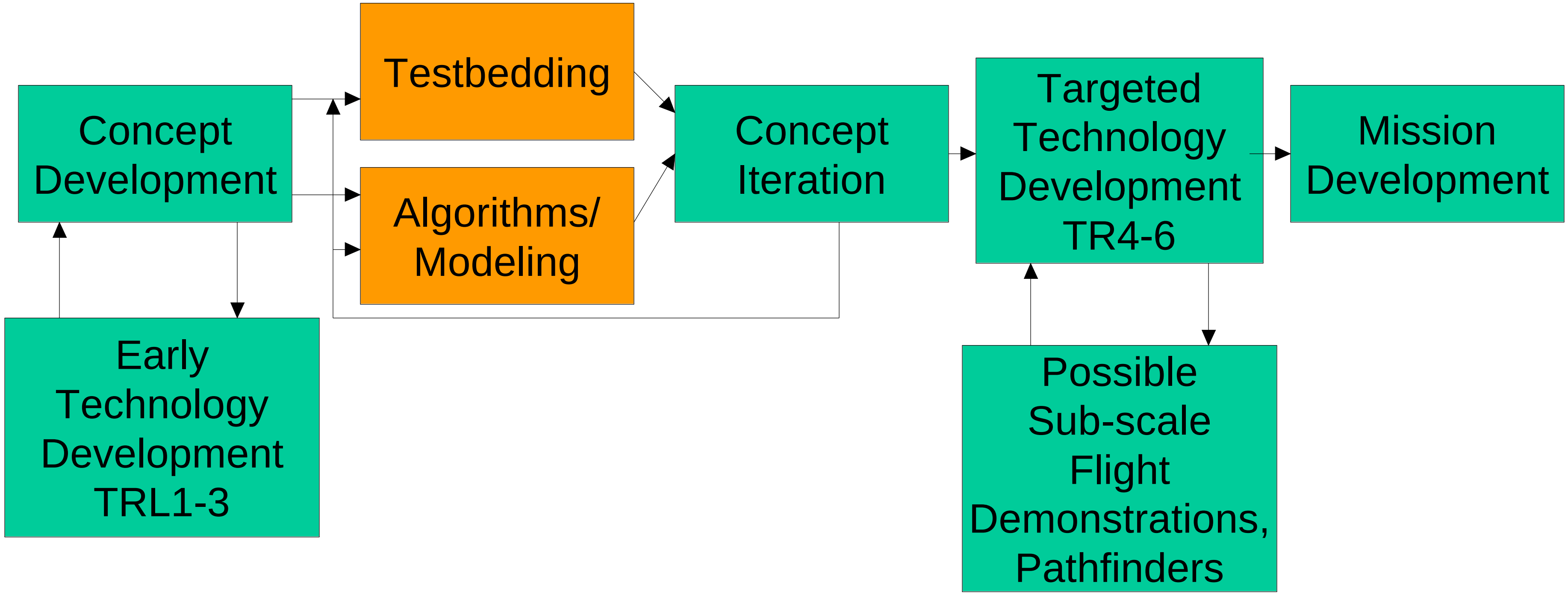
- Leading Technology Candidates: Complete existing efforts on TPFC, TPFI, SPIRIT/FISI, SI, MAXIM/BHI testbeds, LISA/BBO, L2 EASI
- Need to fund low-TRL innovative architecture/algorithm testbeds (algorithms+testbeds)
- Need to make use of Pathfinders, including flight pathfinders when necessary
- Govt needs to fund contractor involvement in early government testbeds

Mission/Strategic Drivers:

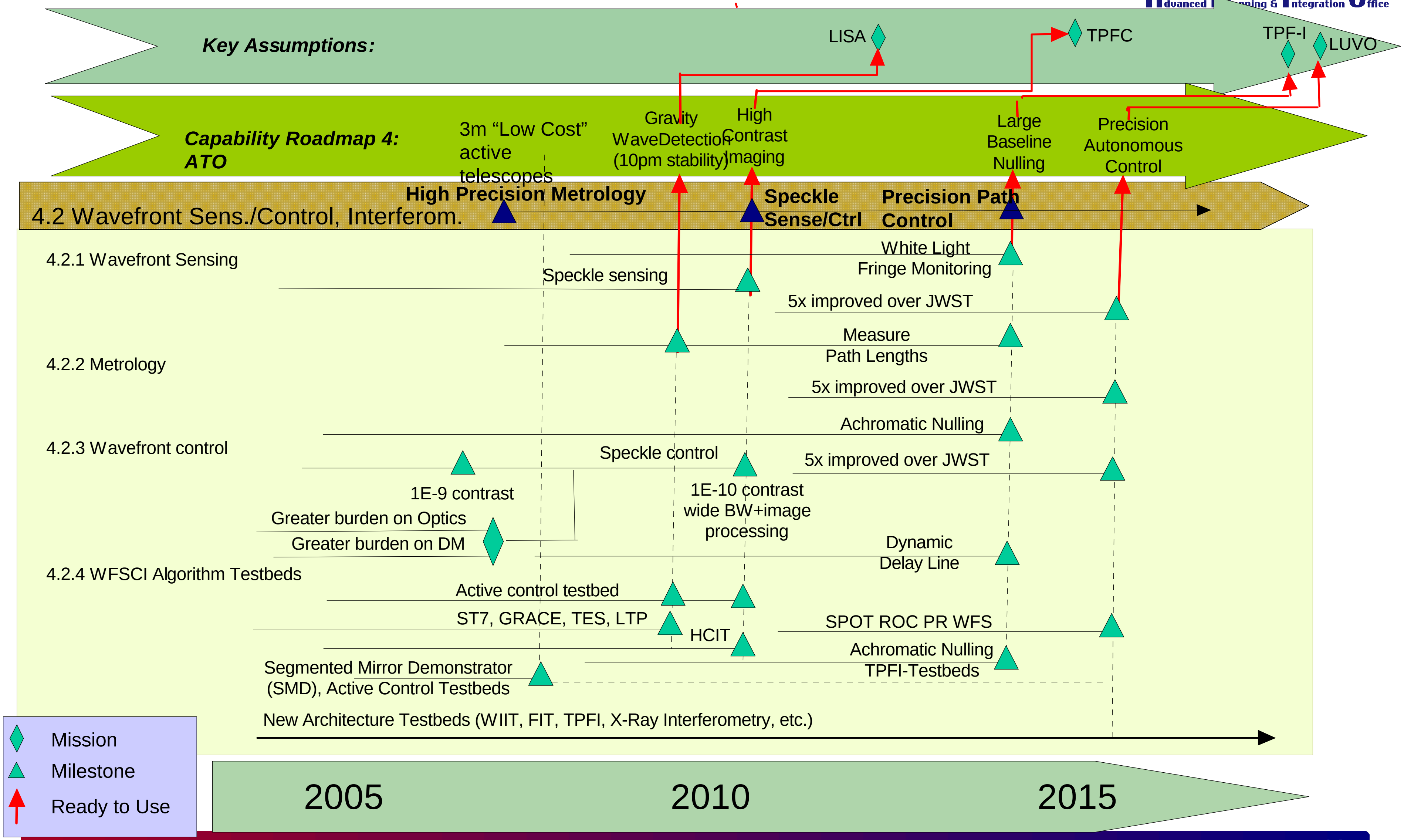
- Planet Finding: TPFC, TPFI, PI, LF
- L2 EASI – Earth Atmostpheric
- Low cost 2-3 meter LIDAR and comm telescopes
- Far-Infrared Interferometry – 2-D Spatial-Spectral wide field imaging interferometry
- Stellar Imager – Fizeau imaging interferometry
- Black Hole Imager – X-ray interferometry
- Recommend Funding Low TRL "Innovative Testbeds"

4.2.4 WFSC&I Algorithm Testbeds

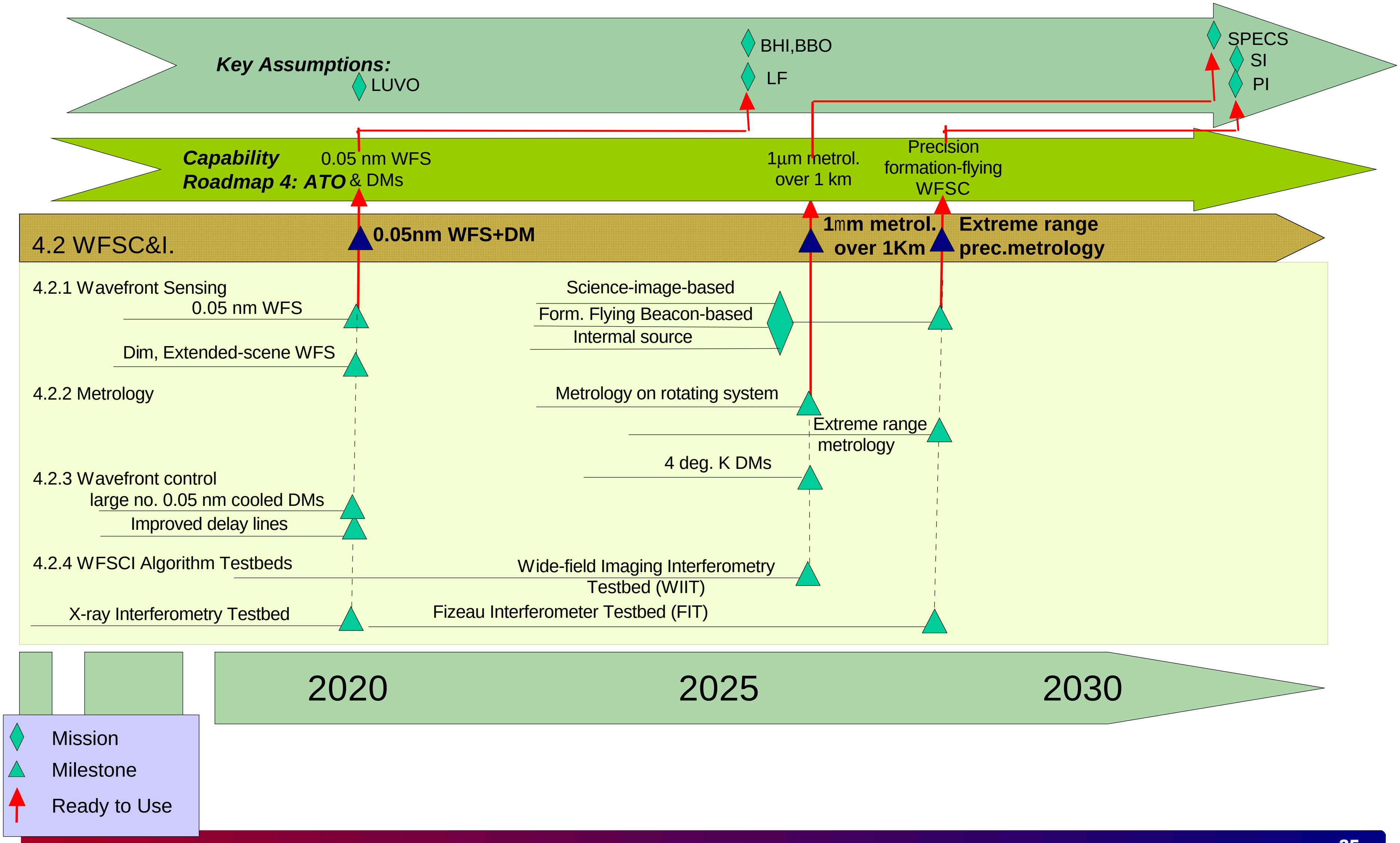
Because future observatories are often dependent on advanced algorithms, testbeds and algorithm modeling are critical during early phases to demonstrate feasibility and to perform system trades:



Capability 4.2 WFSC&I Roadmap



Capability 4.2 WFSC&I Roadmap



ATO Capability 4.3
Distributed and Advanced Spacecraft Systems
(DASS)

Presenter:

David W. Miller, Team Lead

ATO Capability 4.3 Distributed and Advanced Spacecraft Systems

Advanced Planning & Integration Office

- Distributed Spacecraft Systems correspond to any set of more than one S/C whose dynamics are coupled through sensing and control in order to enable the integration of a signal received from an observed target.
    - Inter-S/C sensing for radio & gravitational measurements.
    - Inter-S/C sensing & control for sub-millimeter through x-ray
  - Collectively, enables distributed network of individual spacecraft to act as a single functional unit that can operate more cost-effectively than a monolithic system.
  - Technical challenges include autonomy, control, path planning, contamination, metrology, propulsion, and technology maturation.
- Advanced Spacecraft Systems correspond to those architectural attributes necessary to enhance the cost-effectiveness of the distributed spacecraft system.
  - Technical challenges include S/C modularity and replication, high speed electronics and inter-S/C communications, graceful degradation and robust distributed sensing, communication and control architecture and algorithms.
- We partition DASS into Platforms, Formation Flight Systems, and Sub-systems

Requirements/Assumptions for 4.3 Distributed and Advanced Spacecraft Systems

Advanced Planning & Integration Office

- Roughly three-quarters of the proposed space science missions, not currently under development, drive DASS.
  - High production volume : UVOI, BHI, PI
  - Low production volume: LISA, Con-X, TPF-I, BBO, FISI
  - Long baseline: LISA, BHI, BBO, PI
  - Centimeter separation control: TPF-I, LF, UVOI, PI, FISI
  - Micrometer separation control: BHI, BBO
  - Earth-Sun L2 orbits: Con-X, TPF-I, LF, UVOI, PI, FISI
  - Heliocentric orbits: LISA, BBO

Space Science	SOA	LISA	CON-X	TPF-I	LF	UVOI	BHI	BBO	PI	FISI
Number of S/C	2	3	4	5	4 - 5	20-30	33	12	80 - 100	4
Geometry Maintenance	FF	FF	pointing	FF	FF	FF	FF	FF	FF	tether
Separation control	m	none	none	1 cm			5 um	1 um		
Separation knowledge	cm	<nm	coarse	1 mm			< 1 um	< 1um		
Thrust Range		1-100 uN				1 uN	uN - 0.1 N			
Min Baseline	100 m	5e6 km		75 m	100 m	100 m	1000 km	50000 km	100 km	100 m
Max Baseline	km			200 m	500 m	500 m	10000 km	~1 AU	3000 km	1000 m
Pointing Control				20 asec		10 uas	10-100 nas			
Mission Lifetime	5 yrs	10 yrs	5 yrs	5 yrs	> 5 yrs	> 10 yrs			5-20+ yrs	
Orbit	LEO	Helio	SE L2	SE L2	SE L2	SE L2		Helio	SE L2	SE L2
Launch Date		2005-2015	2015-2025	2015-2025	2025+	2025+	2025+	2025+	2025+	2025+

4.3.1 Platforms: Modularity and Replication

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Description of Capability needed:

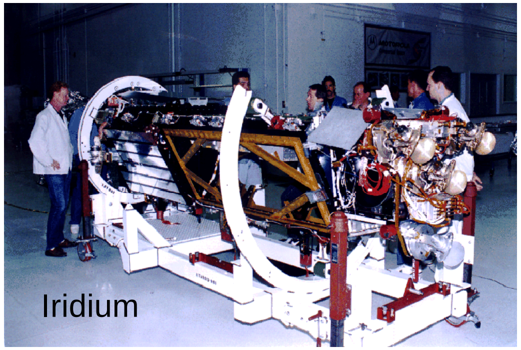
- Producing many S/C yields production savings. But, not enough S/C in most missions to justify 'assembly line'
  - Need BOTH subsystem and science payload designs that cross-cut several missions
  - Need architectures whose science productivity degrades gracefully under failures

Need/Gap Assessment:

- Need ability to extract efficiencies from small and large production volumes
  - Each poses different challenges
- Need functional redundancy where component or S/C can perform more than one role
  - Component redundancy prohibitive
  - Need associated design tools

History/State-of-the-art:

- Mission-optimized design w/customized I&T
  - Replication: GPS, Iridium (100 S/C) 25 day fab
- Several programs cancelled due to S/C costs



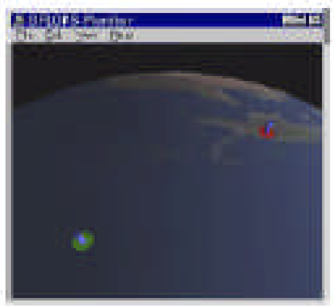
Mission/Strategic Drivers:

- Commonality across missions: *e.g., X-ray: Con-X, BHI*
- Extensibility of design: autonomy (e.g.): UVOI, BHI, PI
- Level of return on investment
  - TPF-I + LISA = 8 S/C
  - UVOI + BHI + BBO + PI = <u>157–187 S/C</u>

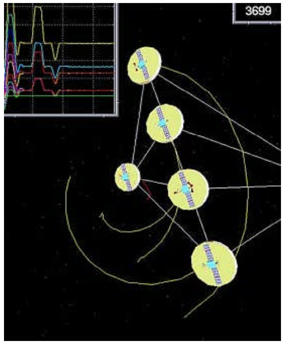
4.3.1 Platforms: Technology Maturation Programs

Description of Capability needed:

- Many programs share basic elements. Should share development costs
  - Need a reconfigurable, long duration, μ-g lab
  - Need multi-processor, regimented time mission simulation tools



MIT GFLOPS

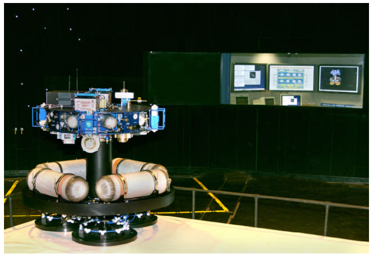


JPL HYDRA

History/State-of-the-art:

- JPL FCT, SPHERES, NRL-RSL
- HYDRA, GSFC FFTB, GFLOPS

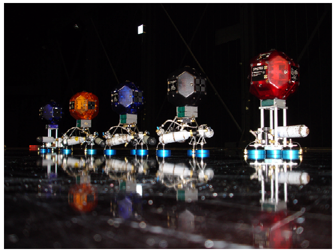
MIT's SPHERES



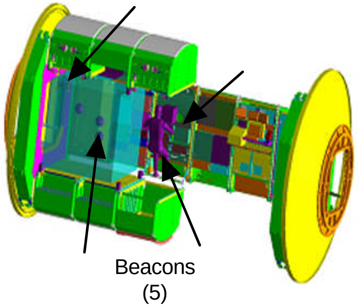
JPL Formation Control Testbed

Need/Gap Assessment:

Need more focus on
- Demonstrating robustness
- Component testing under representative conditions
- Large motion, 6 DOF, multi-S/C formation flight
- Calibration of end-to-end simulations with actual hardware test data



MSFC flat floor

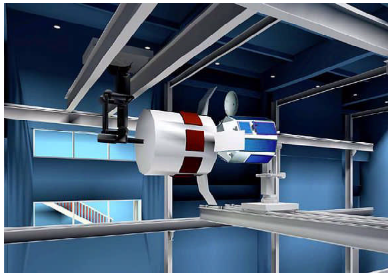


ISS Destiny Lab

Mission/Strategic Drivers:

- Multiple technologies need to reach TRL6 for mission insertion
- TPF-I, UVOI, BHI, BBO, LF, PI

GSFC Formation Flight Testbed



NRL Robotic Servicing Lab

4.3.2 Systems: Auto., Control, Contam, Ap. Synth. and supporting sub-systems

Advanced Planning & Integration Office

Description of Capability needed:

- Autonomy: effective ‘safe modes’ for close proximity, FDIR for inter-S/C faults
- Control: Robust & scalable formation control architecture (sensing, communication, control).
- Contamination mitigation, path planning for aperture synthesis, inter-S/C metrology (coarse/precision bearing & range) from deployment to instrument phasing
- Precision propulsion: m-Newton thrusters

Need/Gap Assessment:

- Robust, on-line path-planning w/constraints, learning systems, high level reasoning
- Contamination reduction: propellant-less techniques, light baffling, imping. Avoidance
- Coarse metrology (reconfiguration): asec bearing/mm position, 4p sr FOV, 100km range. Precision (instrument phasing): mas bearing/mm position, ~deg FOV, 10km range
- RF multi-path

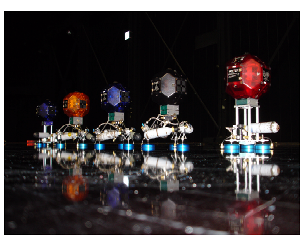
History/State-of-the-art:

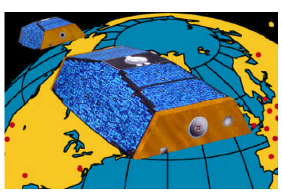
- Autonomy: Deep Space 1, UAVs.
- Earth rotation aperture synth. in RF (VLA).
  - Trade time & image quality (graph).
  - Metrology: AFF, DPCGPS ~cm range, MSTAR
  - ~km (EO-1), ~m (Shuttle), ~cm (STS & Prog)

Mission/Strategic Drivers:

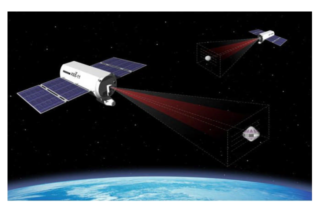
- Prox. ops, synth. Imag., many S/C
- TPF-I, LF, UVOI, BHI, PI

Five vehicle formations

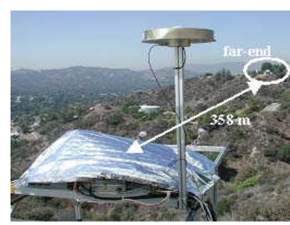




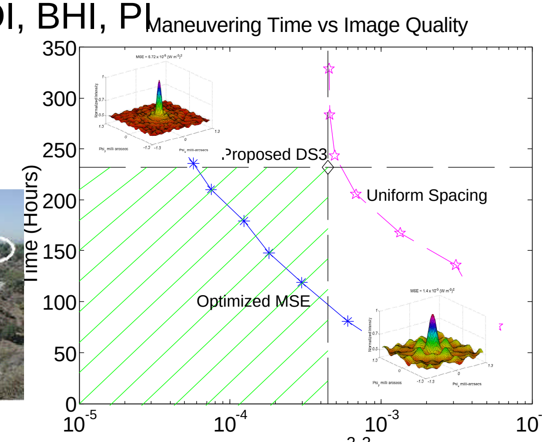
GRACE differential RF range sensor



ST6/XSS-11 range and bearing sensor



JPL AFF



4.3.3 Subsystems: Propellant-less Propulsion

Description of Capability needed:

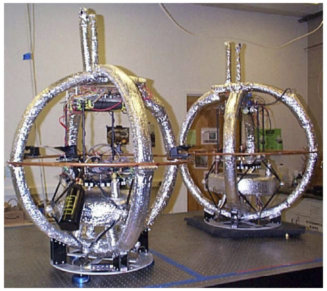
- Propellant consumption limits lifetime.
- Propellant-less formation control for high DV missions w/close proximity S/C
  - E.g. aperture synthesis, assembly & servicing, DJ2 perturbations, non-Keplerian orbits
- Options include orbital dynamics, electro-magnetics, electro-statics, and tethers

Need/Gap Assessment:

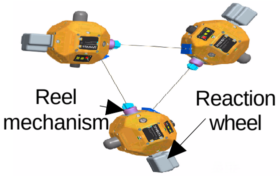
- Tethers: dynamics and controls
- EMFF and ESC need sub-system development
  - EMFF thermal management for high temperature superconductor

History/State-of-the-art:

- Tethers: 2 & 3 S/C tests (1-g flat floor)
- Electrostatic formation flight: theory
- EM formation flight: 2 S/C tests (1-g flat floor)
- Orbital dynamics: Hill's orbit ellipses



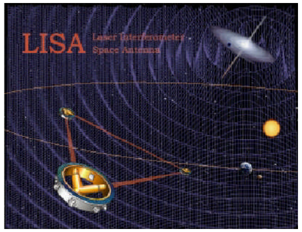
Electro-magnetics



Tethers

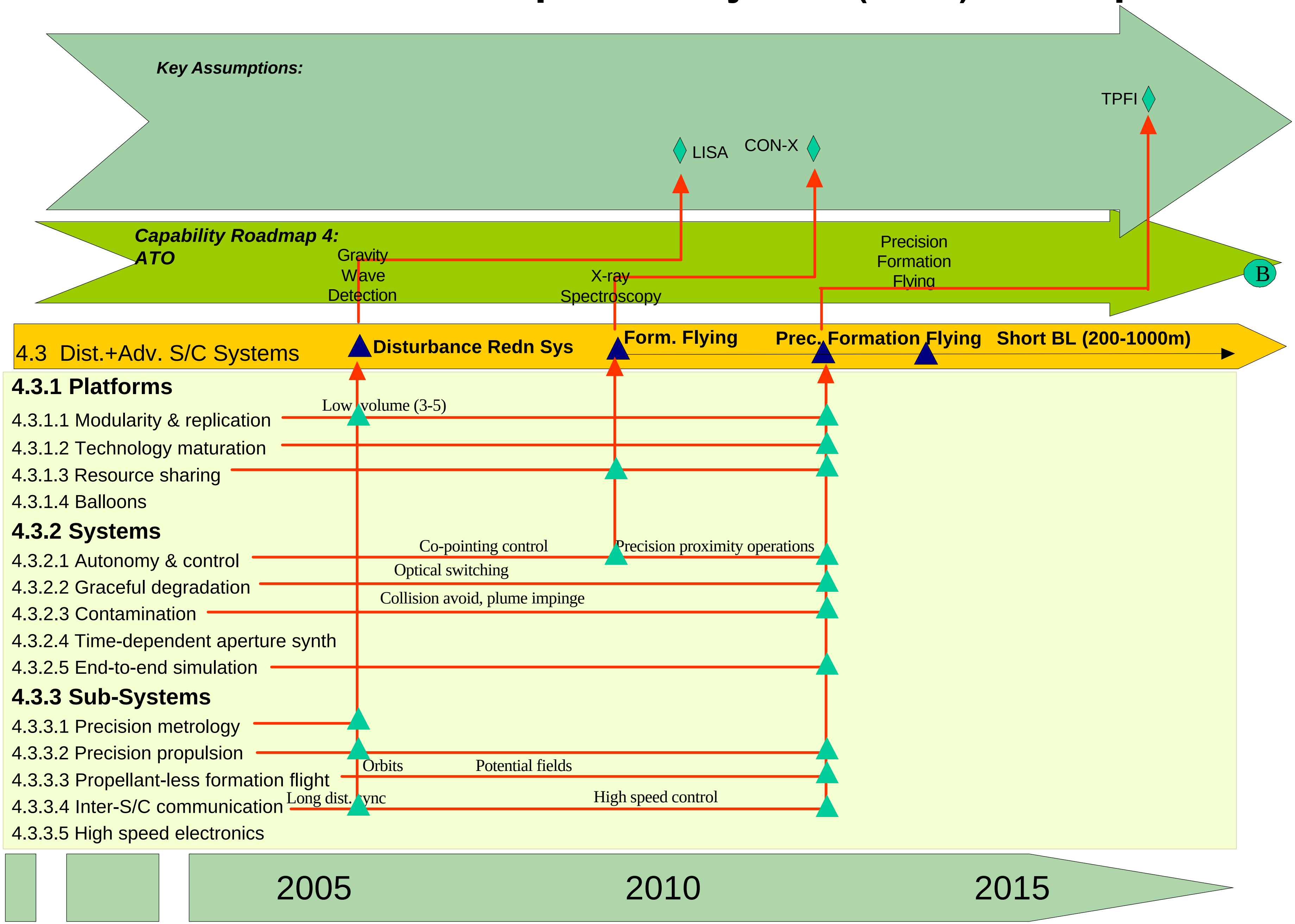
Mission/Strategic Drivers:

- LISA – orbits
- FISI – tethers
- TPF-I, UVOI – potential fields
- Propellant consumption severely limits Synthetic Imaging of UVOI & FISI

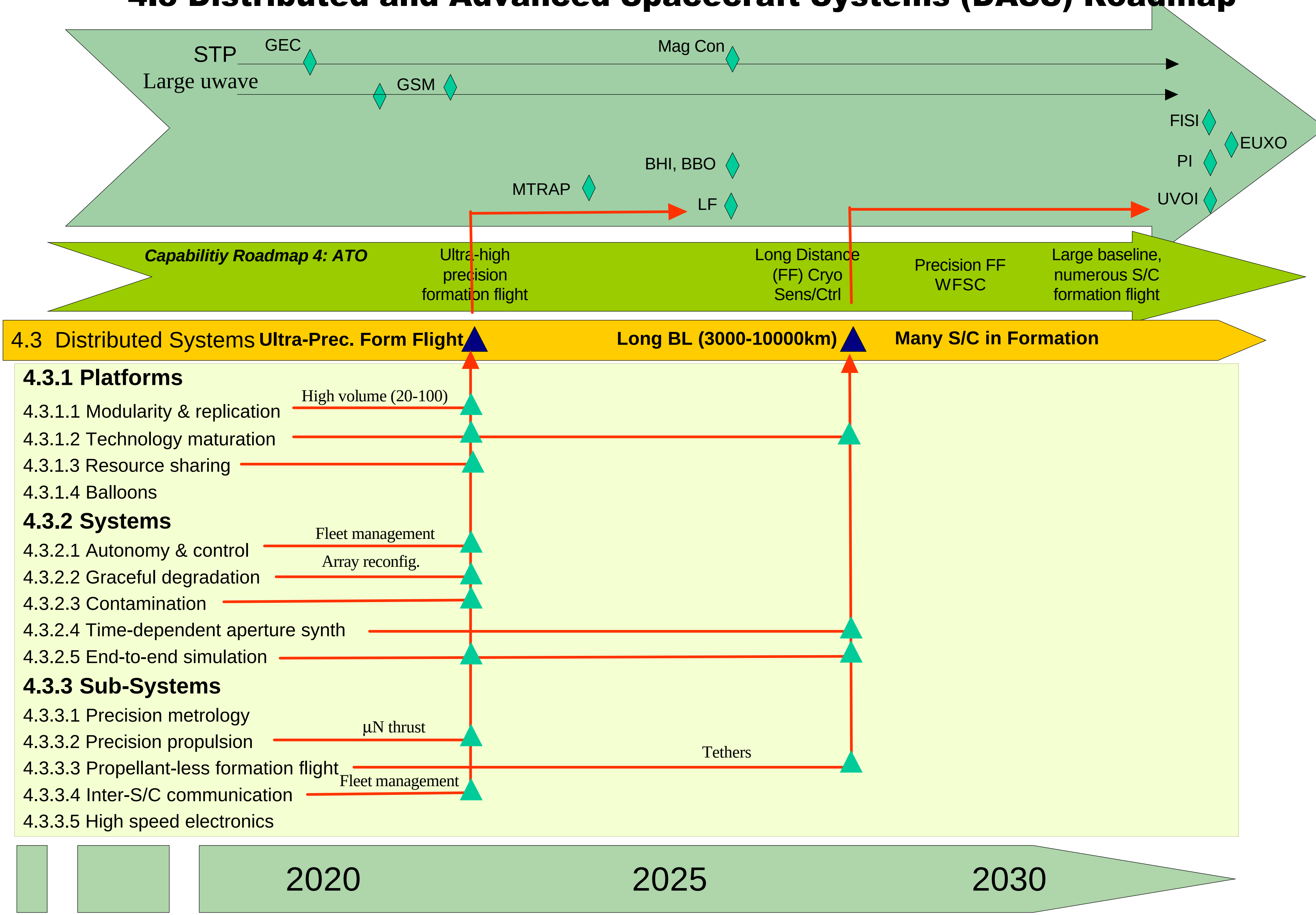


Orbital dynamics

4.3 Distributed and Advanced Spacecraft Systems (DASS) Roadmap



4.3 Distributed and Advanced Spacecraft Systems (DASS) Roadmap



4.4 Large Precision Structures for Observatories

Presenter:

R. S. Polidan / Northrop Grumman

Capability 4.4 Large Precision Structures

- Large Precision Structures for Telescopes are the structural elements that form/support the electromagnetic (g-ray through radio-wave) and gravity wave systems of telescopes and observatories. This capability includes:
  - Filled Apertures, Interferometers, and "Antennas (Radar, microwave, etc)"
  - Sunshields/Sunshades
- In order to support these large telescopes and observatories large *precision* structures are required to provide the
  - Basic optical structure elements that form the telescope
  - Sunshields that protect the telescope from solar light and heating
  - Modular elements and their connectors that allow these telescopes to fit within (small – at least relative to the telescopes) launch vehicle fairings, and be deployed or assembled in space
- Related capabilities covered in other CBS areas are:
  - Tethered systems: CBS 4.3 Distributed and Advanced Satellite Systems
  - Optical surfaces and substrates: CBS 4.1 Optics (CBS 4.4 Structures supplies the rigid body support for the optics)
  - Metrology systems: CBS 4.2 Wavefront Sensing and Control
  - Modeling and Simulation: CBS 4.6 Infrastructure

4.4.1 Stability and Precision

Description of Capability needed:

- Precision static, deployable, or assembled structures are required to enable all the large NASA observatories (> 4 m aperture).
- High stability/precision is a key enabling capability that overcomes size, packaging, and space environment issues to allow us to operate the advanced telescopes and observatories identified in NASA's strategic plan.

Need/Gap Assessment:

- Current in-space mechanical and thermal stability metrics are 2 or more orders of magnitude worse than what is needed for future observatory missions
- Technologies in both passive and active stability control are required

History/State-of-the-art:

- State-of-the-art/Mission History
  - *SIM-PlanetQuest and JWST* define the development current state of the (NASA) art for precision structures
  - There also exists programs in the classified environment
- Leading Technology Candidates
  - SIM Interferometer Beam
  - JWST Observatory structure
- Current TRL
  - SIM-PlanetQuest Interferometer Beam: TRL 6
  - Telescope structure systems: TRL 6 (JWST)

Mission/Strategic Drivers:

- Example Missions and Drivers
  - **TPF-C:** Size, Deployment, and Stability of large operational structure)
  - **Land Surface Topography Mission:** Large (3x15m evolving to 10x40m) L-band Radar antennae
  - **SAFIR:** Large deployable telescope structure and sunshade
  - **L2 EASI:** 8m interferometer boom
- Date: 2011 for TPF-C

4.4.2 Materials Technology

Advanced Planning & Integration Office

Description of Capability needed:

– Materials technology covers the physical properties of materials, outgassing & contamination control,cryogenic performance, response to space environment, coatings, charging, and smart materials.

– This is a basic enabling capability that supplies the technical/physical information that allows us to build the precision structures and operate them in the space environment.

Need/Gap Assessment:

- Need a comprehensive set of laboratory and space test data on the properties and performance of applicable structural materials in appropriate environments
- Need properties of materials at space-cryogenic temperatures
- Need to incorporate developments and information on nanomaterials into space structures development

History/State-of-the-art:

–-History
  - Materials information for in-space large precision structures is patchy and incomplete
  - New materials (e.g. nanotechnology) are just beginning to appear
  - Cryogenic performance of many materials are not well known

–State-of-the-Art: JWST example
  - Issue: Accurate data on material properties at JWST temperatures are generally not available and will require testing to generate and not the test data will not be available in time.
  - Potential Impact: The performance of the integrate observatory may not be accurately predicted and the uncertainty of the predicted performance may not be understood.

Mission/Strategic Drivers:

–Example Missions and Drivers
  - **TPF-C:** Size, Deployment, and Stability of large operational structure)
  - **Land Surface Topography Mission:** Large (3x15m evolving to 10x40m) L-band Radar antennae
  - **SAFIR:** Large deployable telescope structure and sunshade
  - **EASI:** 8m interferometer boom

–Key external requirements are:
  - Robust laboratory materials program to populate needed database

–Date: First version: 2008

4.4.3 Implementation Capability

Advanced Planning & Integration Office

Description of Capability needed:

- Implementation technology spans the range of application of the large precision structures:
  - Launch Load Reduction & Fairing Technology
  - Deployed structures
  - Assembled structures
  - Inflatable and "Growable" Structures
- Each implementation path has it own unique needs.

Mission/Strategic Drivers:

-Example Missions and Drivers

TPF-C: Size, Deployment, and Stability of large operational structure

Land Surface Topography Mission: Large (3x15m evolving to 10x40m) L-band Radar antennae

SAFIR: Large deployable telescope structure and sunshade

EASI: 8m interferometer boom

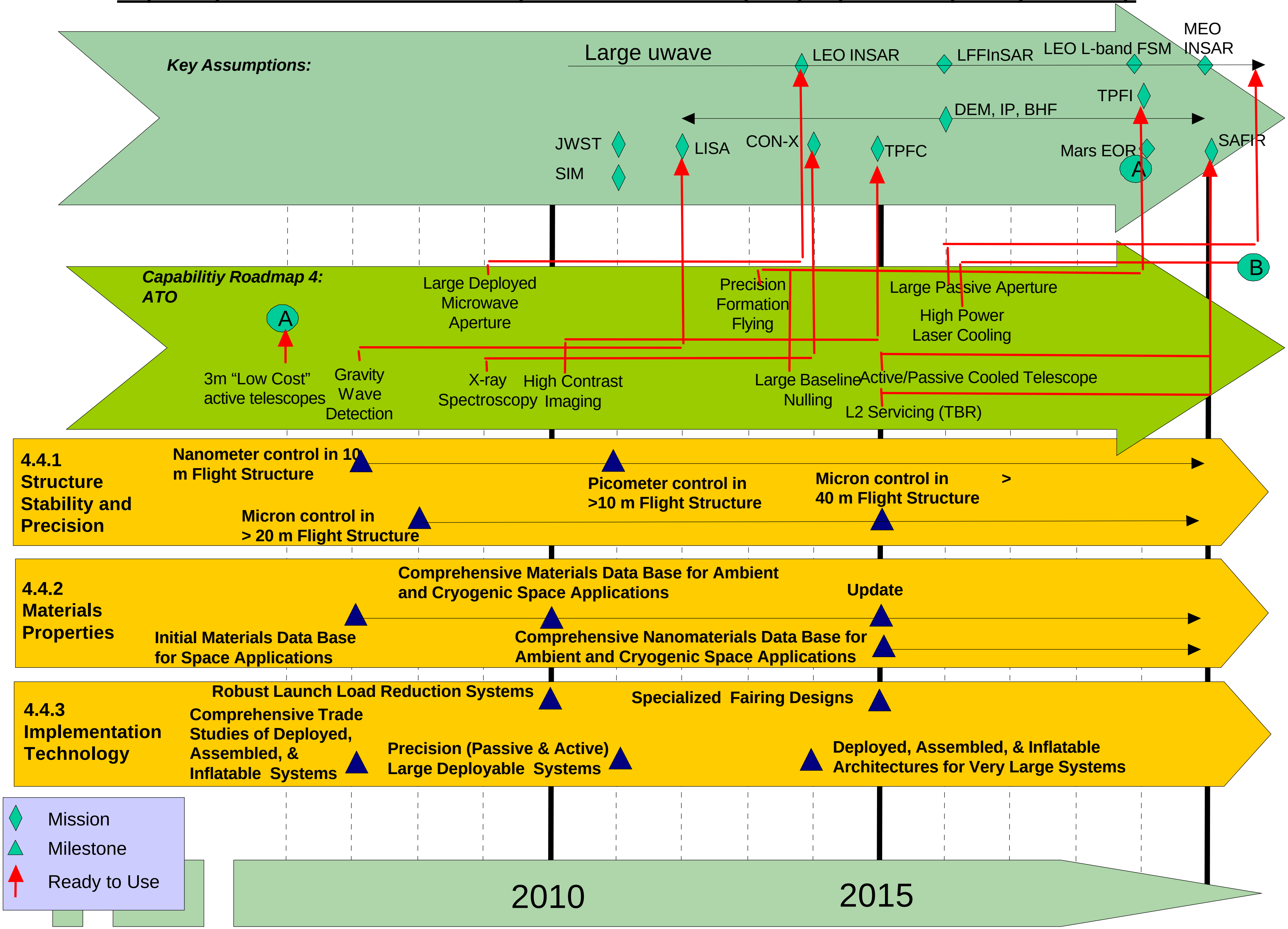
History/State-of-the-art:

- AFRL/Boeing have produced initial systems for vibrational and acoustic dampers
- Deployed structures have been flown but not close to the combined size/precision needed for observatories
- Space station is the state of the art for assembled structures but it is far from the precision structures that are needed for observatory structures
- Initial inflatable antenna structures have been flown but do not have the size and performance required for large telescopes

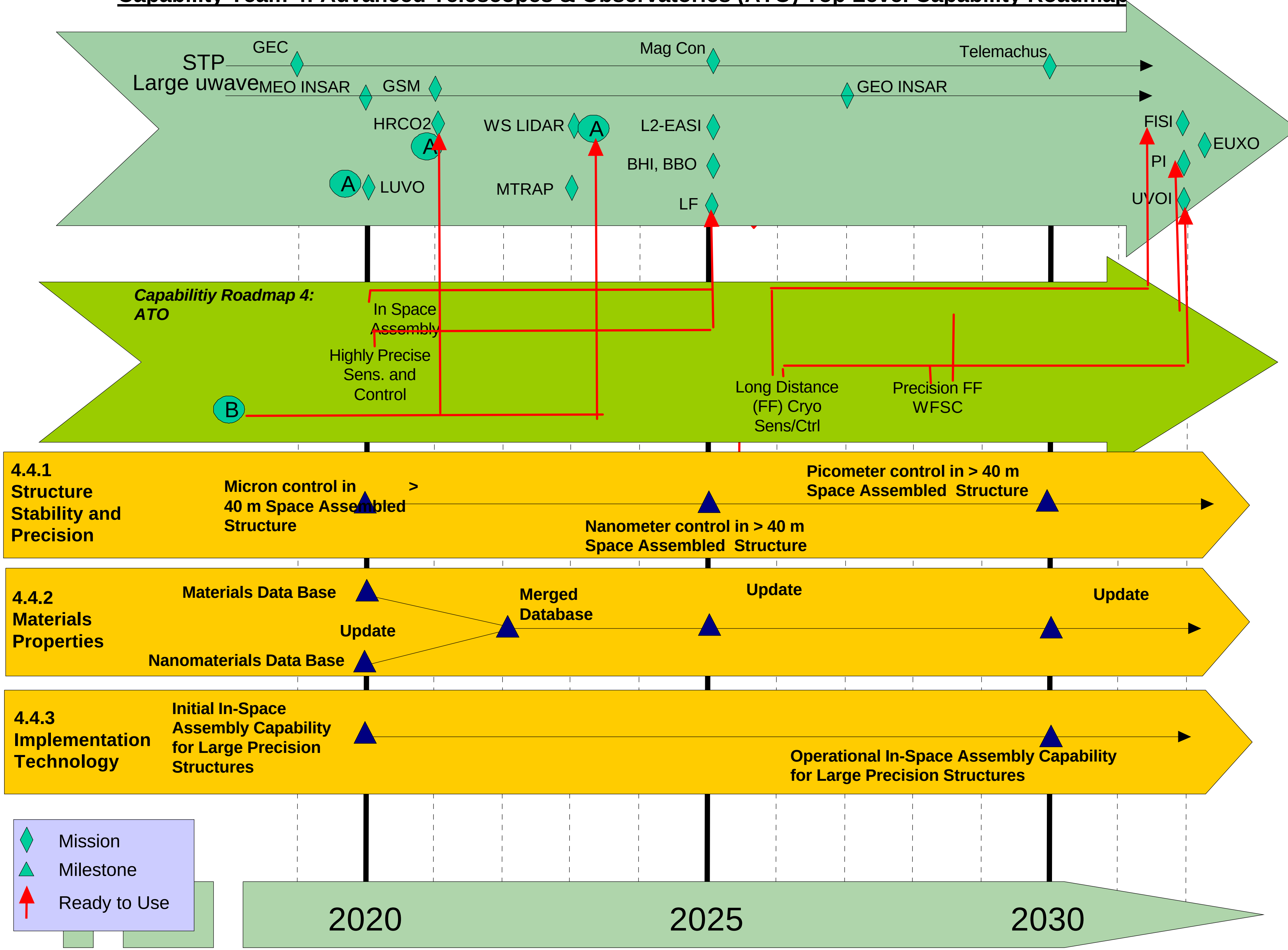
Need/Gap Assessment:

- Launch Loads and Fairings
  - Low cost production of fairings, custom fairings, load alleviation technology
- Deployable, Assembled, Inflatable Systems
  - Understanding of system trades and risks across implementation approach
  - System level assessment of size and stability (mechanical & thermal) properties from both passive and active approaches

Capability Team 4: Advanced Telescopes & Observatories (ATO) Top Level Capability Roadmap



Capability Team 4: Advanced Telescopes & Observatories (ATO) Top Level Capability Roadmap



Capability 4.5 Cryogenic and Thermal Control Systems

Presenter:
Jim Oschmann / BATC
Team Members:
Peter Jones / AFRL
Ron Polidan / NGST

Capability of Cryogenic and Thermal Control Systems

- Enabling technology for mid to far IR through mm wave telescopes
  - 4 - 50 K for large deployed optics and structures
  - 10 K - Milli-kelvin for sensors
    - Technology overlaps with sensors
      - Need system level designs
      - Includes other wavelengths
      - Tie in to sensors road mapping needed
  - Needs both active and passive improvements to realize goal
  - Isolation of warm and cold spacecraft areas needs improvement
- Large fraction of future IR missions require this thermal performance to reach their stated scientific goals

4.5.1 Passive Cooling

Capability Needed

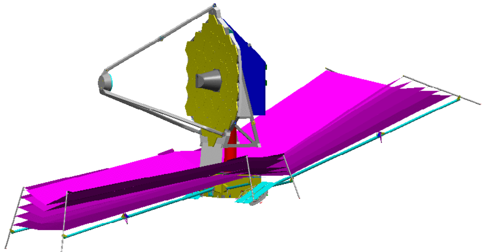
- Passively cool large and/or distributed optics (30 to 80 K, depending upon mission)
  - Reduce thermal background on sensors
  - Precool optical bench
  - Precool optics that are actively cooled to lower temperatures
- Improved sunshade, radiators, heat distribution, thermal materials, coatings, and assembly

Need/Gap Assessment

- Need temp of sunshade on cold side ~15 K
  - Eases requirement on cryocoolers
- More sunshade layers and/or new materials
  - Newer composites
  - Enhanced emittance at very low temp
- Improved MLI isolation (lower conductance)

History/State-of-the-art

- Spitzer (0.8 m) at ~35 K passively
- JWST (6.4 m) at >35 K with passive sunshade/isolation
  - In design phase



James Webb Space Telescope

Mission/Strategic Drivers

- SAFIR
- TPFI
- Any cryogenic system

Spitzer Space Telescope

4.5.2 Active Cooling

Capability Needed

Cool optics below temp limits of radiators w/o life- and mission-limiting cryogens

Pre-cooling for sensors (6 K - milli K levels)

30-100 mW cooling @ 4 K

Simultaneous 150-400 mW @ 18 K & 1-2 W @ 40 K

Low vibration, mass, & power

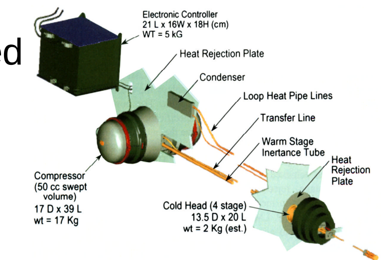
Need/Gap Assessment

Demo ACTDP electronic controls at TRL 5 by FY10

No high capacity zero vibration cooler for coronagraphs – need TRL 5 by FY10

Extend cooler operation to 5 K with 0.1 W thermal load (TRL 5 by FY14)

Space demo ~ FY08 needed



History/State-of-the-art

Multiple coolers (50 – 80 K) developed by DoD & NASA are operating in space

DoD 10 K & multistage 35 K coolers at TRL 5 in FY07

ACTDP 6 K/18 K cooler at TRL 5 in FY07

Planck sorption 18-20 K cooler launch FY07

No other flight electronics <30 K at TRL>3

Mission/Strategic Drivers

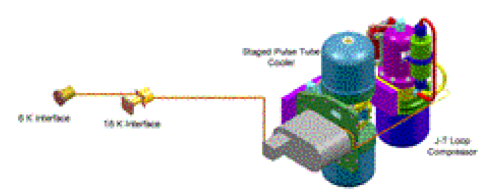
–SAFIR (8-10 m aperture at 4 K)

TPF-I for instruments, maybe telescopes

Several missions beyond

Probes, other large 4 K telescopes

DoD has complementary needs > 10 K



4.5.3 Thermal Isolation Capability

Capability Needed

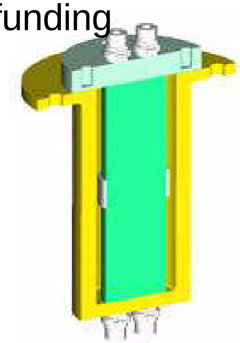
- Thermal isolation of payloads & components
- Reduce risk, cost, and mass, extend mission lifetimes, and enable new missions
- Key enabling technologies reduce thermal flow across an interface
  - Structural struts, straps, passive/active disconnects, thermal switches, and electrical thermal isolation systems

Need/Gap Assessment

- Large area 5 ± 0.1 K temp control by FY08
- System studies to better define needs
- Reversible heat switches for redundant coolers
- Reduce heat switch conductance to 0.1 W/K @ 6 K
- T-zero disconnect

History/State-of-the-art

- Spitzer heat switch allowed warm launch with stored cryogens
- Very little progress due to lack of funding
- Lack of focus and technology development
  - Some at Goddard, JPL, USAF

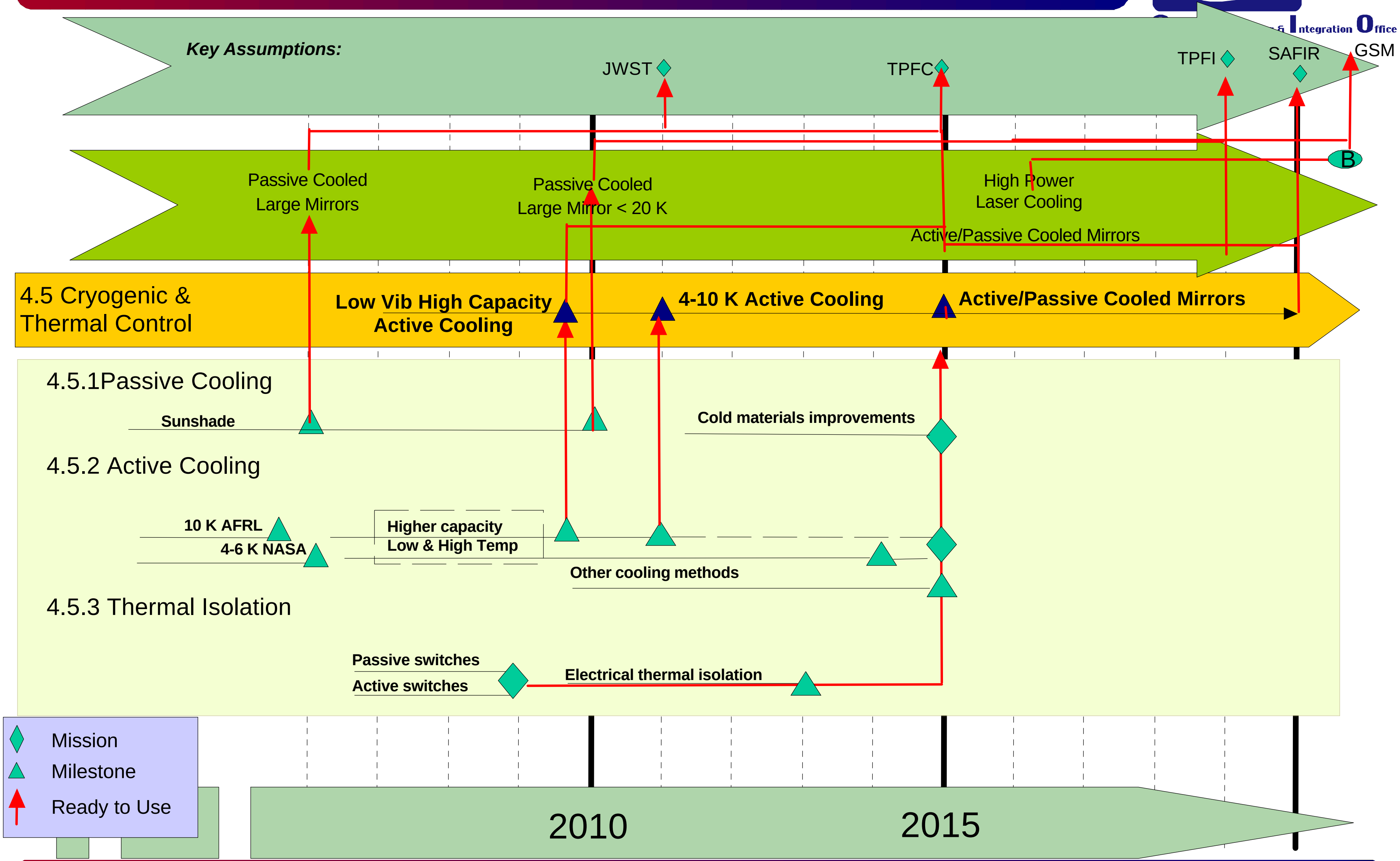


SWALES passive heat switch

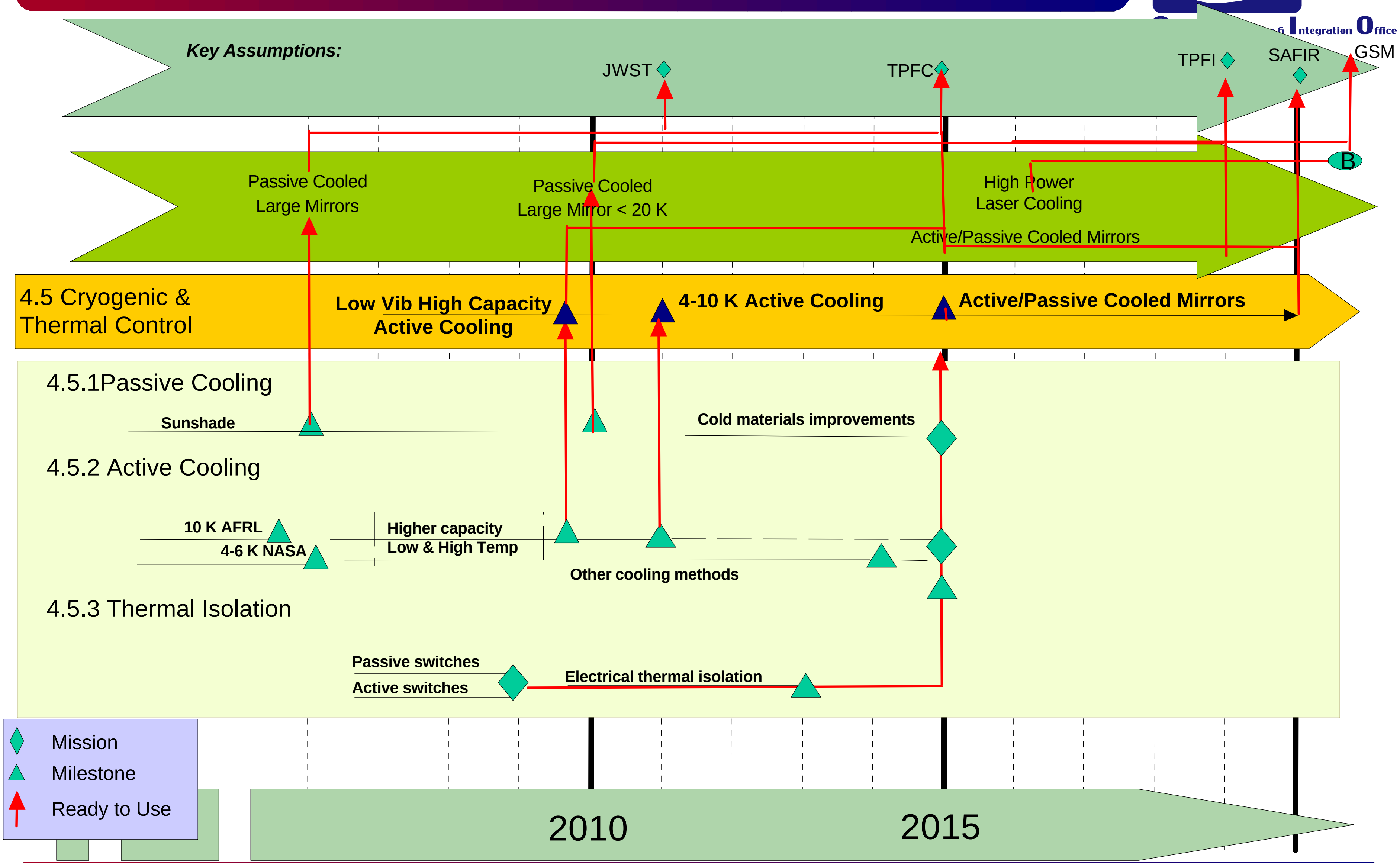
Mission/Strategic Drivers

- Most future cryogenic observatory missions
  - SAFIR
  - TPF-I
  - SPIRIT
  - SPECS

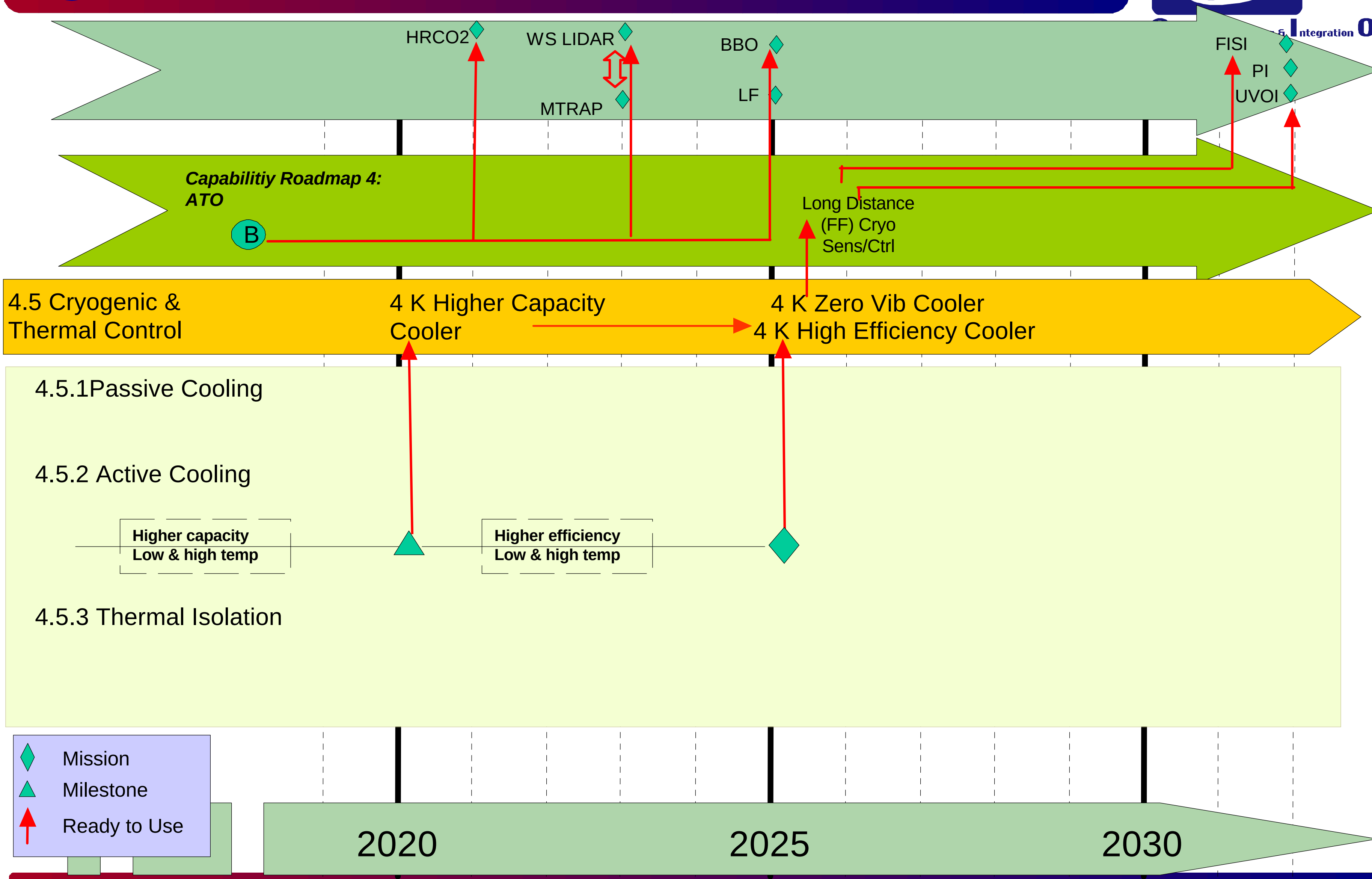
Capability for Cryogenic and Thermal Control Systems Roadmap



Capability for Cryogenic and Thermal Control Systems Roadmap



Capability for Cryogenic and Thermal Control Systems Roadmap



Advanced Telescopes & Observatories Capability Roadmap

4.6 Infrastructure

Gary Matthews, ITT

Infrastructure for ATO

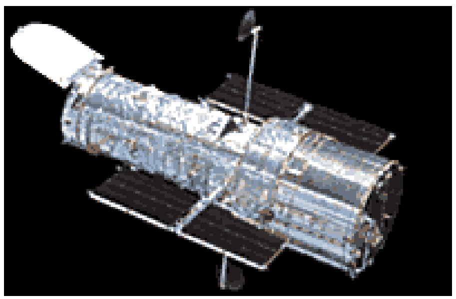
The ATO roadmap identifies technology developments necessary for future Advanced Telescopes and Observatories. This information will be used to guide long range planning that can make these programs possible. In addition to key technological advancements, we recognize the need to invest in the development and sustenance of infrastructure, which would be shared across multiple missions.

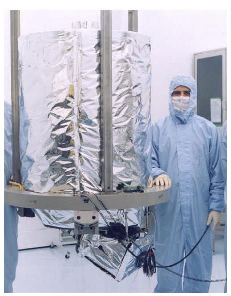
We consider infrastructure as:

- Necessary for development or operation of missions, but not explicitly part of the mission
- Requiring significant, long term effort to implement
- Ideally, infrastructure should be shared by multiple missions

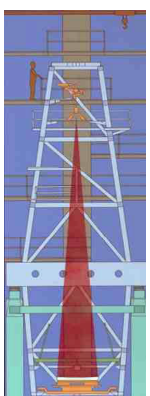
1960's – 2005 Large systems to 2.5m	2005 – 2025 Large systems to 8-10m	2025 – 2035 Large systems > 15m

Full Aperture Verification Using Standard Vacuum Chambers



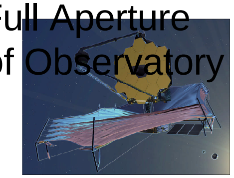


IKONOS

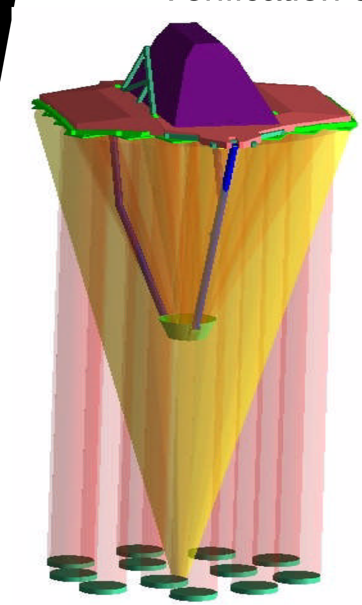


Verification Test Tower

Sampled Full Aperture Verification of Observatory



JWST



JWST Verification

Verify Subassemblies on Ground, Certify Performance After Launch(s) and Potentially On-orbit Assembly

Robust Analytical Tool Set Insures On-orbit Performance

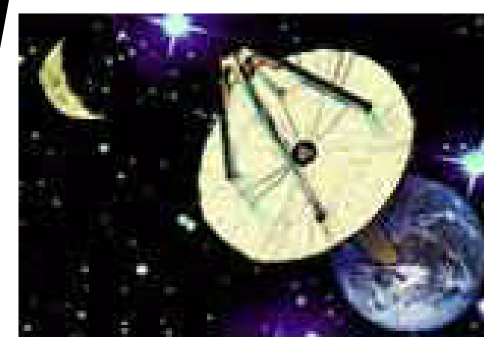
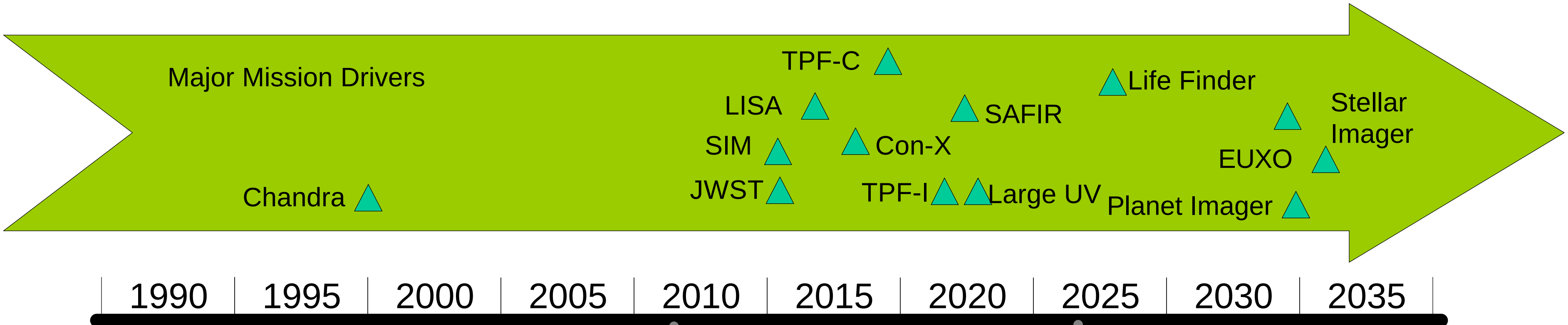


Photo: Space.com

4.6.1 Facilities (cont.) – transition of system testing full ground testing on- orbit verification

Advanced Planning & Integration Office



Full system testing and verification on the ground prior to launch:

- Vibration
- Static Loads
- Optical
- Thermal Balance
- Acoustic

Robust tool development and verification

Emphasis on system testing is reduced, Sub-scale testing

Larger, higher performance test facilities required

On-orbit system verification for giant systems

Verifications completed at subsystem level

Rely on smarter systems to accommodate system errors

4.6.1 Facilities

Advanced Planning & Integration Office

Description of Capability Needed

- Dedicated high performance optical test facility required to verify systems up to 8-10m
- Even larger facilities will be required if modeling tools are not developed
- (independent subsystem verification becomes important)

Need/Gap Assessment

- Large, dedicated facility required to test large and complex optical payloads while robust tools are being refined
  - Thermal, vacuum, dynamics, cleanliness
  - Consider location relative to Ambient I+T
  - Consider modification of existing vs. new facility
- Long term, subsystem testing and on-orbit performance flexibility will allow observatory testing to be eliminated
- Robust design/analysis/test tools needed

History/State of Art

- Full observatory verification required
- Robust tools and active on-orbit correction are not available to eliminate observatory testing
- Structure Vibration Modeling Verification (SVMV) has attacked modeling tools for prediction obviates need for full scale dynamic testing

Mission/Strategic Drivers

- Sample missions: TPFC, TPFI, SAFIR, LUVO, FISI, BHI
- Full system verification will be difficult/impossible due to gravity and thermal effects on very large systems

4.6.2 Assembly/Servicing Capability

Description of Capability needed:

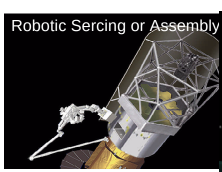
- Capability to provide on-orbit servicing, replenishment, repair/maintenance, and construction of observatory systems
- The benefit of this capability is to reduce risk, extend mission lifetimes, and enable new missions
- Key enabling technologies are architectures and components that develop standard interfaces and component/system modularity.

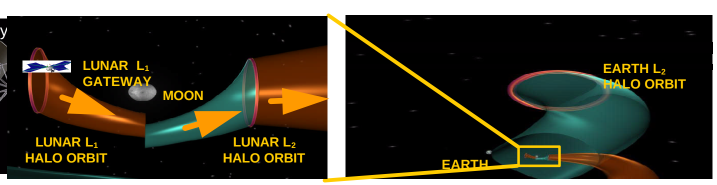
Need/Gap Assessment:

- Key gaps between state-of-art and needed performance is end-to-end mission system-level architectures that accommodate servicing and mission requirements are needed before we can assess gaps, technology needs, critical flight and ground tests required to ensure capability readiness, etc
- This capability should concentrate on large number of near term observatories going to L2 and should leverage off of Exploration infrastructure

History/State-of-the-art:

- Various missions have fluid transfer concepts and other subsystem needs, but there has been no significant system level technology effort
- Leading Technology Candidates - None
- Current TRL
  - Subsystem components: TRL 1-6 depending on subsystem
  - Architecture: TRL 1



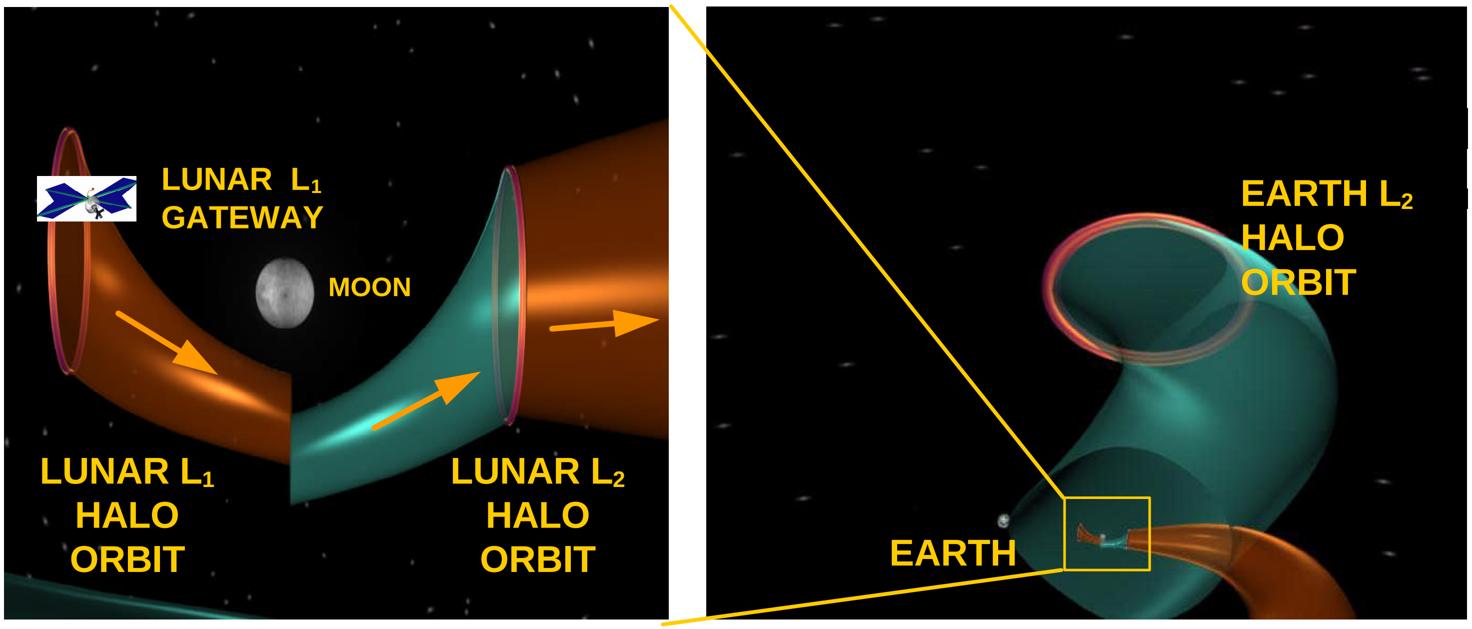


Mission/Strategic Drivers:

- Most future cryogenic observatory missions, including
  - SAFIR, TPF-I, FISI
  - Large UV-Optical: LUVO, LF
- Key external requirements are:
  - Standardized interfaces that include the human/robotic servicing requirements, safety, and priorities
  - Development of mission architectures that enable efficient and affordable servicing
- Date: SAFIR mission need date (~2016)

Potential Approach for Exploration Servicing Vehicle

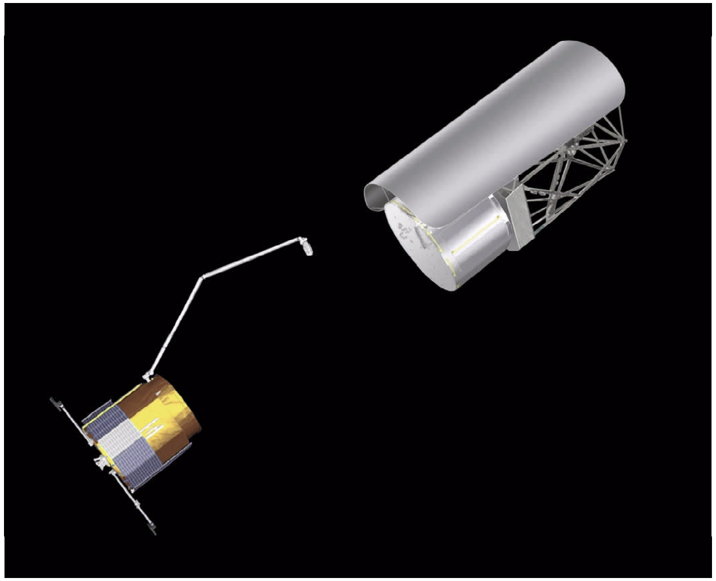
- Small Delta v (~11m/s) required to navigate between lunar gate way and L1 and L2.
- Exploration Vehicle can service and support multiple vehicles thought out earth-moon and Lagrange space.
- Argues for assessing leveraging opportunities from Exploration program

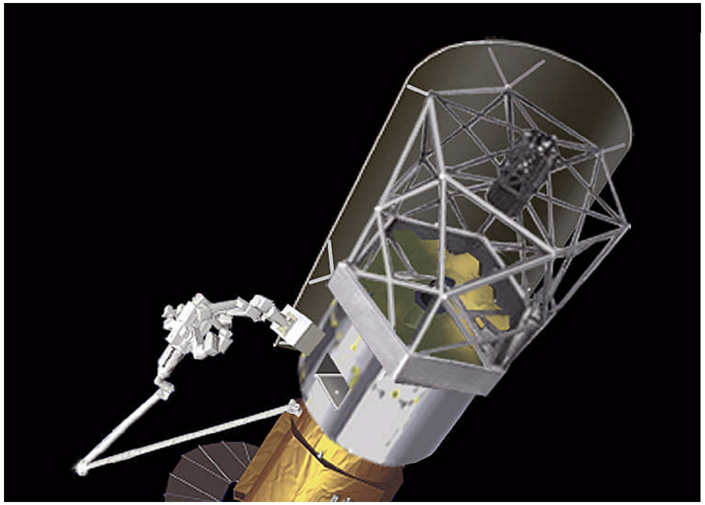


Potential Approach for Exploration Service Vehicle

Advanced Planning & Integration Office

- Use Lunar Gateway as a staging point
- Collect new instruments and repair modules at gateway for installation at Observatories located at L1 and L2
- Service and assemble through out vast volumes
- Utilize as a general purpose exploration tool





4.6.3 Workforce

Capability needed:

Specialized work force with the necessary work ethic, scientific understanding and experience to create space optics

- Optical design concepts
- New high-sensitivity, low noise detectors and electronics
- Mirrors and uniform coatings
- Metrology and large light-weight space structures for telescopes
- Thermal control
- Precision formation flying

Need/Gap Assessment:

- Need research grant program (NSF, NASA, AFOSR, ARL, etc) focused on the interdisciplinary field: Optical System Science & Engineering.
- Need technology development funds for instrument subsystem testbed demonstration as a training ground.
- Need $25M/yr. University research grant program focused on space-based remote sensing science telescopes, devices, components.
- Need funding to initiate focused programs for training technicians in optics and precision mechanics

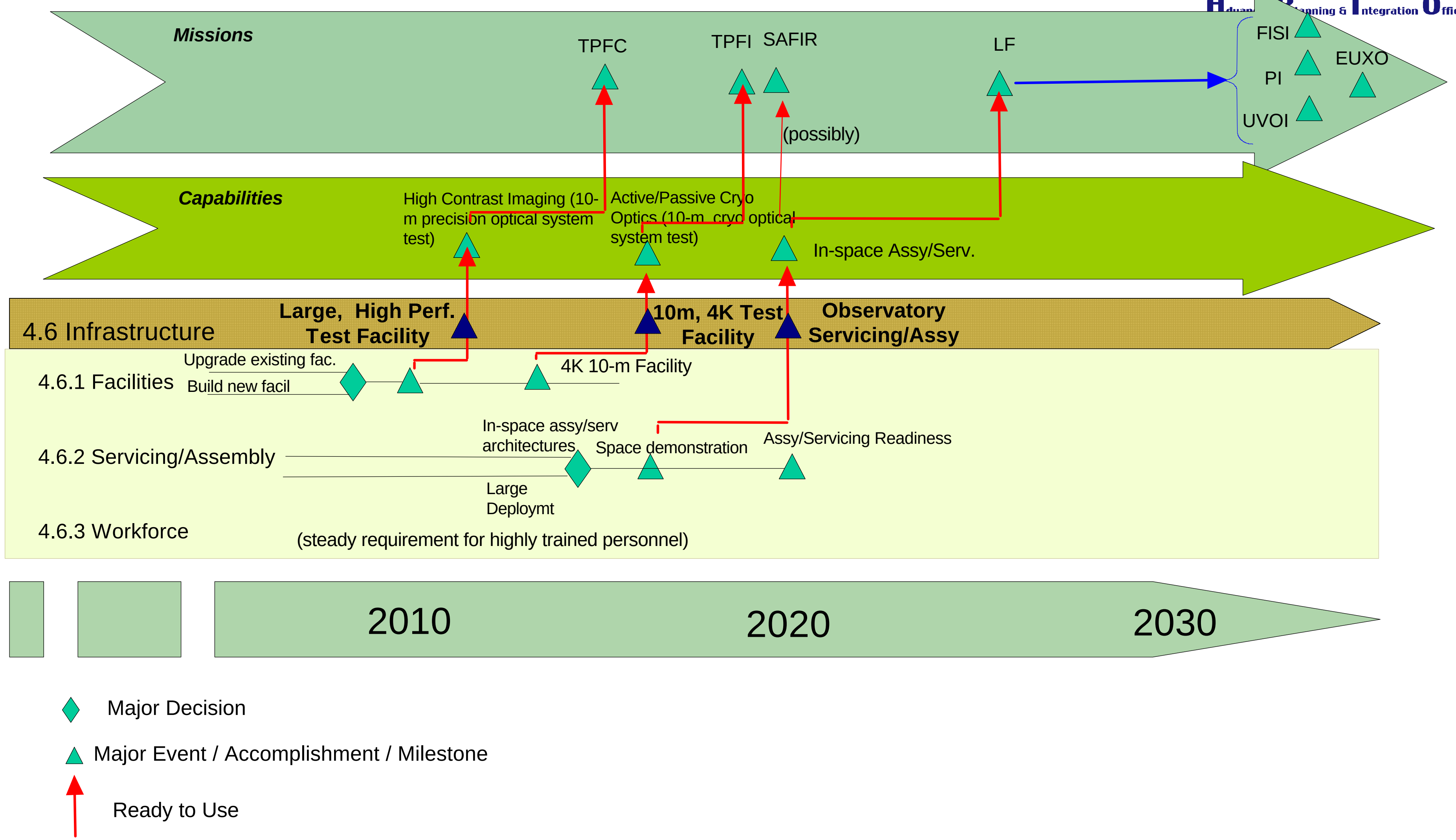
History/State-of-the-art:

- Classical telescopes were designed and built by astronomers with support from technologists and engineers
- The new complex advanced telescopes require full partnership between astronomers, technologists and engineers
- Historically Optical engineering has been divided among physics, structural, mechanical, electrical, and materials engineering. Limited educational programs in US in this area. (National capability for such PhD optical engineering graduates is <10 per year.)

Mission/Strategic Drivers:

- ATO development requires increasing skills for workers of all levels: technician, engineer, manager
- We must cross-train to retain core competency through project and employment cycles
- Coordination with Education Strategic Roadmap

4.6. Infrastructure Timeline



Concluding Charts

Howard MacEwen, SRS, External Co-chair
Lee Feinberg, NASA Chair

Partnering Possibilities

Advanced Planning & Integration Office

- Program in replicated, lightweight hybrid mirror technology aimed at UV/Visible options
  - Candidate technologies include nanolaminates, SiC, carbon composites, and MgGrEp
  - Flight demonstration/missions enabled by 3-m class UV-optical deployable telescope
    - Potential for Probe science
    - One-for-one replacement of Hubble capabilities
    - Laser communication telescope capabilities
    - Earth sensing missions
    - LIDAR (Earth, Mars, Io, Titan…..)
  - 3 X Scale-up: New approach to 9 – 10 meter class telescopes
- Launch Load Alleviation approaches
  - Synergistic with lightweight mirrors for affordability
- International partnership:
  - Formation flying via Smart 2/Darwin
- Servicing and refueling
- Material databases

External Roadmap Coordination

Advanced Planning & Integration Office

- Large Optics Working Group (LOWG)
  - LOWG an element of the Space Technology Alliance (STA)
  - Developing a “Bottoms-up” space telescope technology roadmap
  - Major LOWG players: NRO, NASA, DOD (including DARPA), DOE
  - ATO and LOWG Roadmaps provide complementary approaches to space telescope technologies: very active coordination ongoing
  - Cross-membership ATO/LOWG
    - MacEwen, ATO external co-chair, supports LOWG Chair (Howerton/NRO)
    - Multiple additional members (Stahl, Breckinridge, Smith, Jones, Tratt)
- ATO Roadmap will also coordinate with National Academy Large Optics in Space (LOIS) study
  - Co-sponsored by NASA and NRO (possible Air Force participation)
  - 12-18 month study: Begins early 2005
  - Will also be coordinated with NRC review of ATO Roadmapping

Comments/Challenges

- Optics and WFSC
  - Critical enablers for many missions, near and far term
  - Direct linkage with Science Enabled
- Distributed/Advanced Spacecraft capabilities (inc formation flying)
  - Enable a majority of longer term missions
  - Spiral technology development approach needed
- Test Facilities
  - New facilities already needed to test next generation observatories
  - Future larger space telescopes will not be ground testable
  - Requires investment in modeling and validation approaches
- Complex space telescopes may benefit from servicing and assembly/testing
  - Leveraging opportunities from Exploration need to be explored
- Current Partnering Possibilities provide opportunity for national approach to multiple missions
  - Includes potential line of low cost 3-meter class telescopes
- Strategic planning process must recognize need for continuity in key core competencies and technological capabilities
  - During the current transition to the new strategic process
  - Long term

ATO Crosswalk to Other Capability Roadmaps

	2. High-energy power propulsion	3. In-space transportation	4. Advanced telescopes and observatories	5.Communication & Navigation	6. Robotic access to planetary surfaces	7. Human planetary landing systems	8. Human health and support systems	9. Human exploration systems and mobility	10. Autonomous systems and robotics	11. Transformational spaceport/range technologie	12. Scientific instrume and sensors	13.*In situ* resource utilization	14. Advanced modeling, simulation, analysis	15. Systems engineering cost/risk analysis	16. Nanotechnology
2. High-energy power and															
3. In-space transportation															
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12. Scientific instruments and sensors															
13. *In situ* resource utilization															
14. Advanced modeling, simulation, analysis															
15. Systems engineering cost/risk analysis															

Same element

Critical Relationship (dependent, synergistic, or enabling)

Moderate Relationship (enhancing, limited impact, or limited synergy)

Summary/ Forward Work

Advanced Planning & Integration Office

- Make changes to roadmaps based on verbal feedback from NRC review
- Receive the draft Strategic Roadmaps
- Review and Assess all applicable Strategic Roadmaps and their requirements for ATO capabilities
  - Suggest possible opportunities for Strategic Roadmaps
- Make changes to ATO roadmaps to ensure consistency with Strategic Roadmaps requirements
- Continue to work with other Capability roadmaps to ensure consistency and completeness
- Develop rough order of magnitude cost estimates for the ATO Capability Roadmap
- Prepare for 2nd NRC Review which will address 4 additional questions:
  - Are there any important gaps in the capability roadmaps as related to the strategic roadmap set?
  - Do the capability roadmaps articulate a clear sense of priorities among various elements?
  - Are the capability roadmaps clearly linked to the strategic roadmaps, and do the capability roadmaps reflect the priorities set out in the strategic roadmaps?
  - Is the timing for the availability of a capability synchronized with the scheduled need in the associated strategic roadmap?

Acronyms

- ConX= Constellation X
- DEM= Dark Energy Mission
- EASI=Earth Atmospheric Space Interferometer
- EUXO= Early Universe X-ray Observer (formerly Gen X)
- FISI= Far Infrared and Sub-millimeter Interferometer (formerly SPECS)
- GEC=Geospace Electrodynamics Connections
- GSM=Global Soil Moisture
- HResCO2
- IP=Inflation Probe (formerly CMB Pol)
- ISC=In-space Construction/Servicing
- Leo LFSM=Leo Low Frequency Soil Moisture
- LF=Life Finder
- LFFInSAR=L-band Formation Flying InSAR
- LISA=Laser Interferometer ??
- MMS=Magnetospheric Multiscale
- MTRAP=Magnetospheric Transition Region Probe
- PI=Planet Imager
- SI=Stellar Imager
- SMD=Segmented Mirror Demonstrator
- UVOI=UV Optical Interferometer (formerly Stellar Imager)
- WS LIDAR=Wide Swath LIDAR

Crosswalk Tool Example -for backup

Advanced Planning & Integration Office

In-Space Transportation		Advanced Telescopes and Observatories	
Sub-Topic or Subsidiary Capability	**Capability Flow & Criticality**	**Sub-Topic or Subsidiary Capability**	**Nature of Relationship**
GN&C/AR&D	⟷ (red)	Distributed and Advanced Spacecraft Systems; Large Precision Structures	All advanced telescope and observatories will require guidance, navigation, attitude, reaction control and determination
Structures	→ (blue)	Large Precision Structures	Primary structures will interface with large precision and potentially deployable telescope structures.
Propulsion Systems (Chemical)	⟷ (red)	Distributed and Advanced Spacecraft Systems	All advanced telescope and observatories require Attitude / Reaction Control Systems, Main Propulsion System (including Propellant Pressurization System), and Orbital Maneuvering Systems. This is particularly applicable to formation flying arrays.
Non-Chemical Propulsion Systems	⟷ (red)	Wavefront Sensing & Control & Interferometry, Distributed and Advanced Spacecraft Systems; Large Precision Structures	Some Interferometers may require tethers. Some large telescopes may require solar sails for momentum dumping (eg TPF-C). Precision formation flying interferometers require precision low thrust propulsion for on-orbit maneuvers. All advanced telescopes
Thermal Systems	⟷ (red)	Cryogenic and Thermal Control Systems	Infrared telescopes require cooling to cryogenic temperatures. Almost all advanced telescopes and observatories require significant thermal management to minimize thermally induced distortions.
Avionics	→ (red)		All advanced telescope and observatories require avionics
Cryo-fluid Management	⟷ (blue)	Cryogenic and Thermal Control Systems	Infrared telescopes require cooling to cryogenic temperatures which may require transport of cryo-fluids to cool various parts of the system.
Vehicle Health Management	→ (blue)		All advanced telescope and observatories will require instrumentation/software for monitoring vehicle health and status
Robotic Craft Earth Departure Stage	→ (red)		All advanced telescope and observatories will require launch vehicles
Red - Critical			
Blue - Moderate			