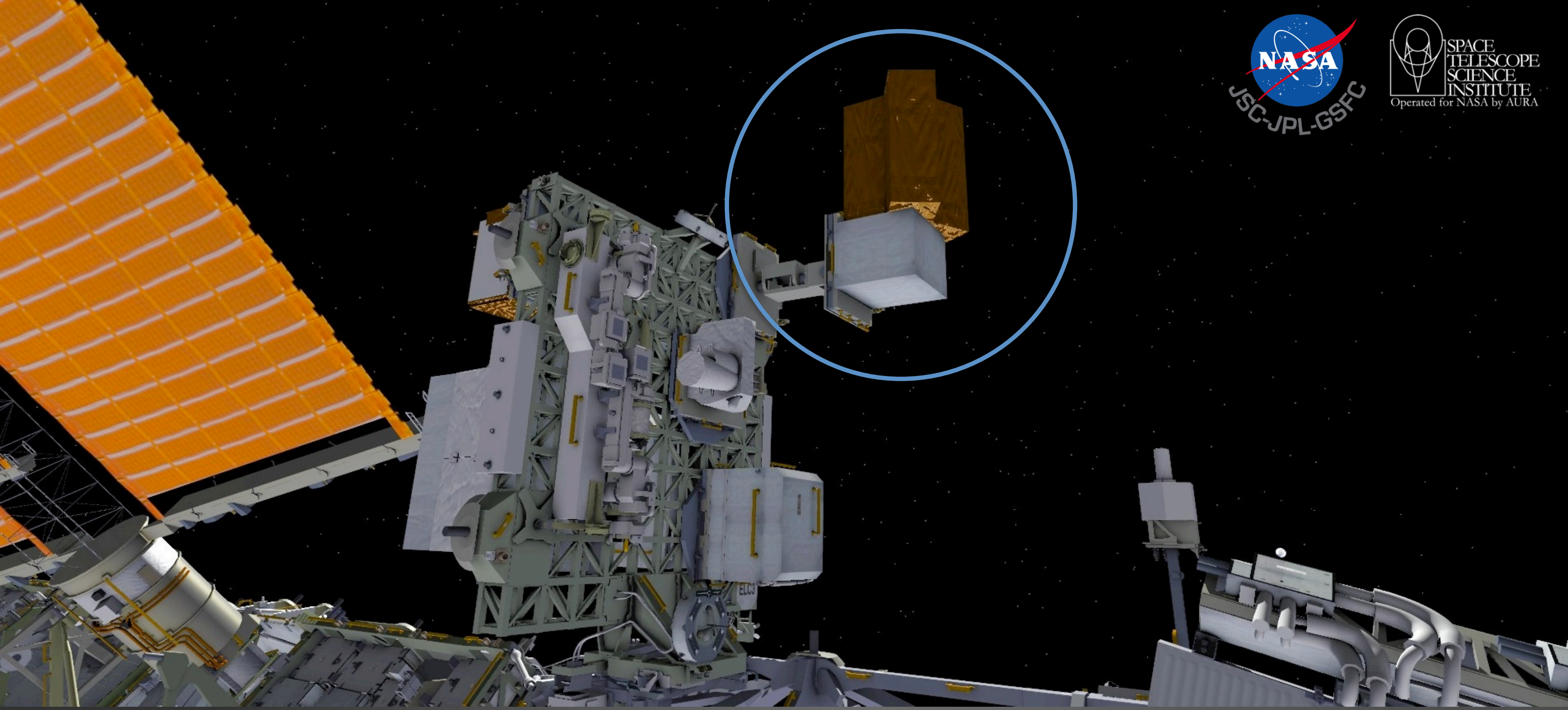
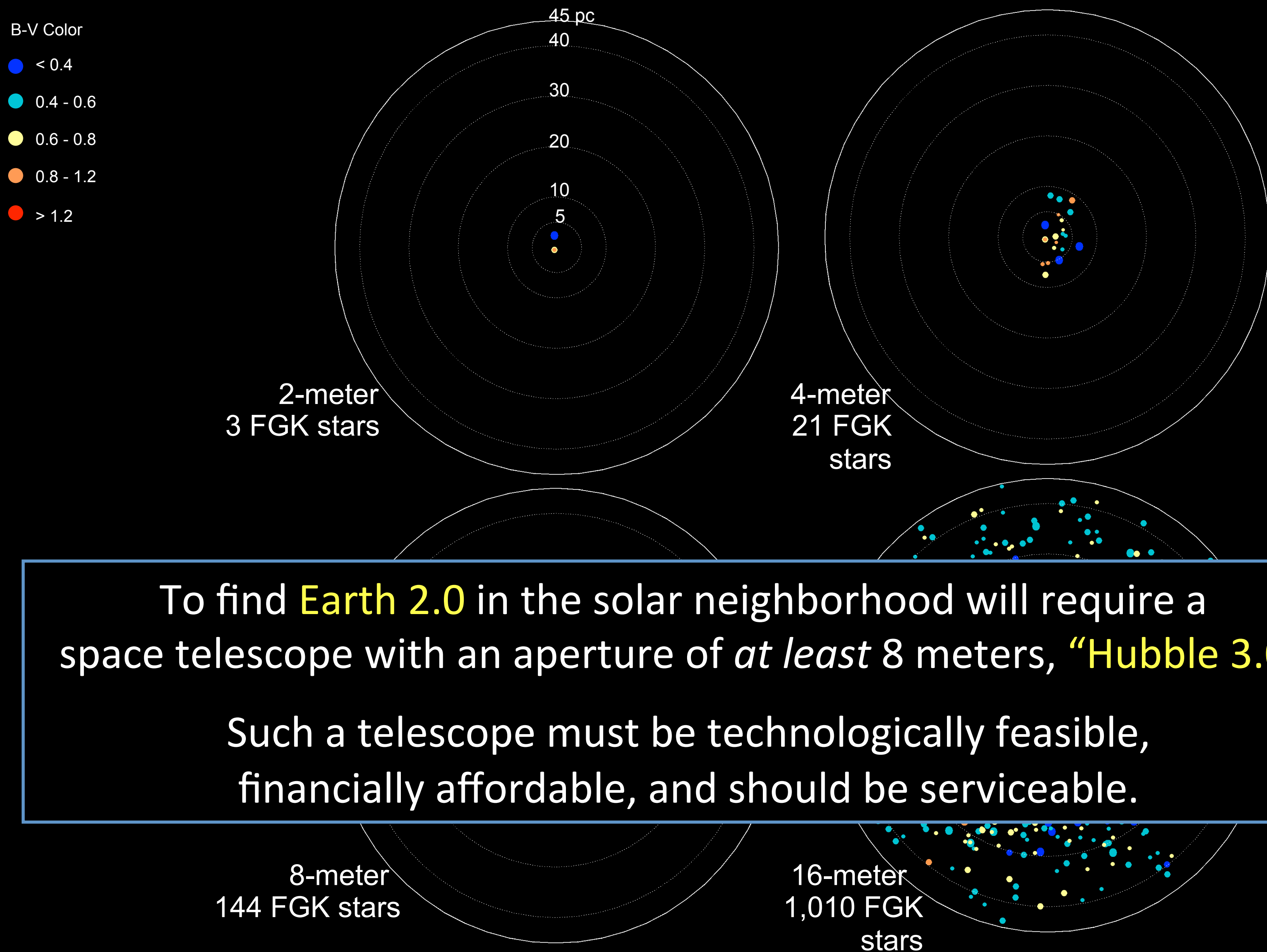


Using the International Space Station as a Telescope Technology Testbed

Marshall D. Perrin (STScI)

on behalf of many collaborators at JPL, JSC, GSFC, and STScI:
Fengchuan Liu, Renaud Goullioud, Joe Green, Mark Boyles, et al. (JPL),
Kim Ess et al. (JSC), Kenneth G. Carpenter, Harley Thronson et al. (GSFC),
Marc Postman, William Sparks, Erin Elliott et al. (STScI),

Imaging & spectroscopy of exo-Earths will need very large apertures to achieve sufficient sample size



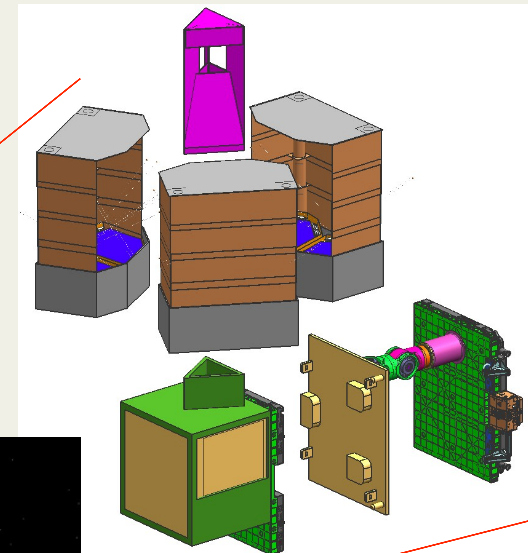
To find Earth 2.0 in the solar neighborhood will require a space telescope with an aperture of *at least* 8 meters, “Hubble 3.0”.

Such a telescope must be technologically feasible, financially affordable, and should be serviceable.

We can make such a telescope possible using the ISS as a technology development platform

Optical Testbed and Integration on ISS eXperiment (OpTIIX)

A 1.5 m modular segmented telescope 'kit' for the ISS, to demonstrate robotic assembly of precision optical systems, advance techniques for wavefront sensing & control, and provide a new platform for future technology development.



OpTIIX Project Summary & Current Status

In FY12, a Phase A study was completed in collaboration between JPL (optics & WFSC), JSC (robotics & ISS interface), GSFC (imaging camera), and STScI (operations, data processing, outreach).

Non-Advocate Review in August: very favorable review

Technical Preliminary Design Review in September: Passed

Presented to the community at several meetings in summer 2012 (SPIE Telescopes, UV Astro HST & Beyond, ISS Utilization & Science)

In FY13, currently seeking additional funding for full implementation (~$120M total).

Also, ongoing small study to verify scalability of OpTIIX design

Seeking community engagement & support.

Could launch in 2016, assuming funding restart mid FY13.

Supported by HEOMD, SMD, and OCT.

For more information, later this week…

The Path to Affordable Future Large-Aperture UVOIR Space Telescopes

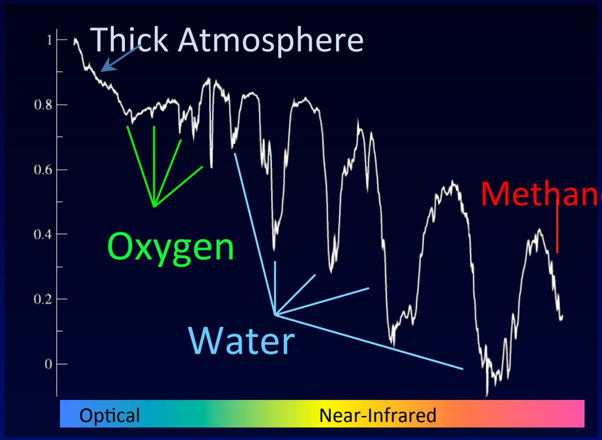
AAS Splinter Session this Thursday

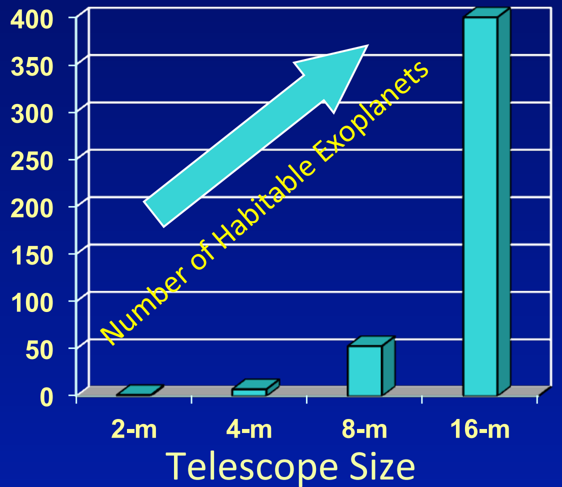
Room 202A, 9:30am – 11:30am

TIME	TITLE	PRESENTER
9:30	Welcome and Introduction	Harley Thronson (GSFC)
9:35	Affordable Large Space Telescopes: Why and Why Start Now?	Marc Postman (STScI)
10:00	Enabling Space Technologies	David Redding (JPL)
10:25	The Optical Testbed & Integration on ISS Experiment (OpTIIX) Demonstration	Renaud Goullioud (JPL)
10:50	Non-Advocate Review (NAR) Perspective on OpTIIX	Chas Beichman (Caltech)
11:00	Open Discussion with the Community	Chas Beichman (Caltech)

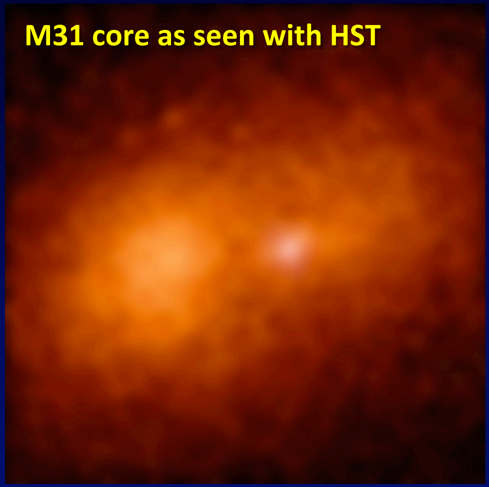
A Large Space Observatory is ***Required*** to Understand the Earliest Universe and to Detect Life on Exoplanets

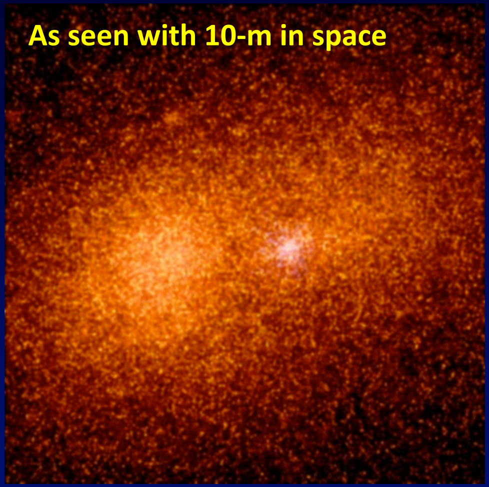
Is There Life Elsewhere in the Galaxy?





What are the Fundamental Processes that Govern Early Galaxy Formation?

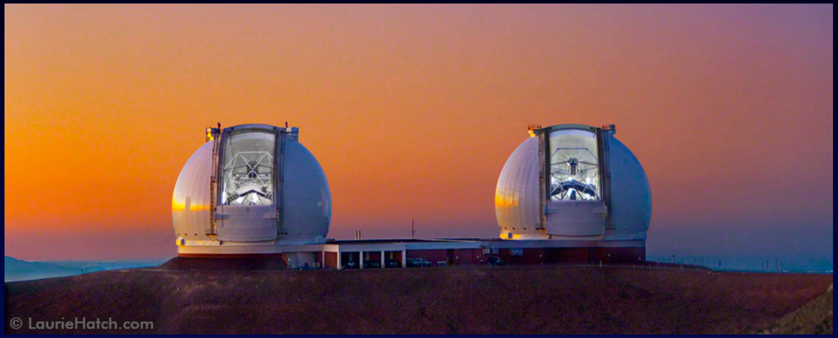




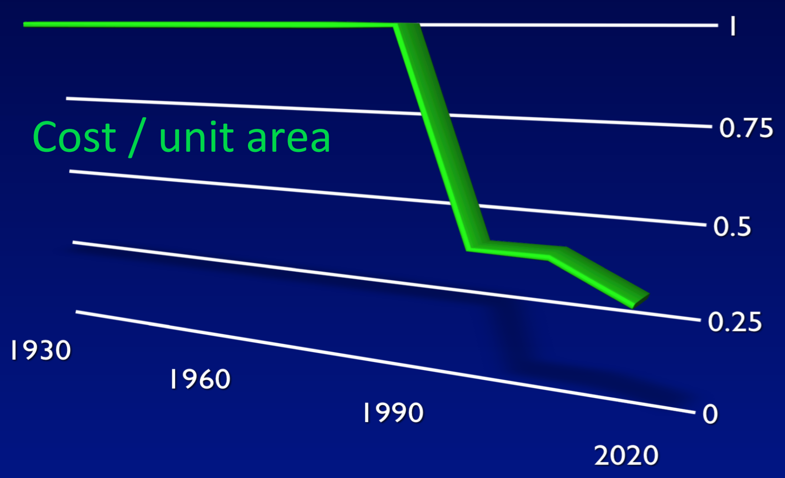
Distant Galaxy in UDF

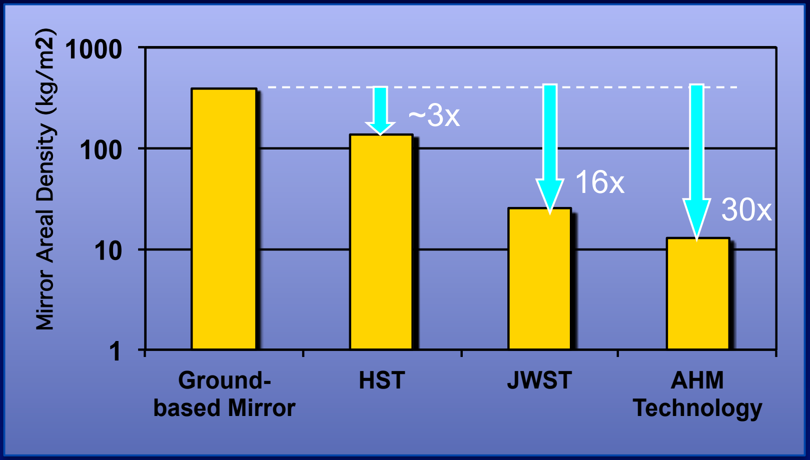
Reveal >10x more detail than HST in <5% of the time: Discover astrophysical knowledge that would otherwise be infeasible from any other facility.

Segmented, Active Telescopes enable Affordable Scalability

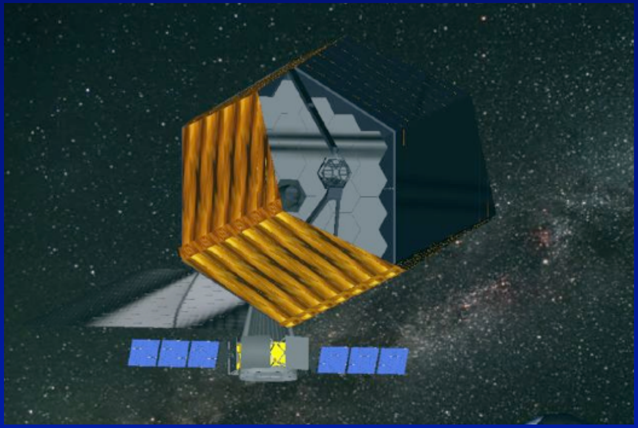


Mirror technology improvements can have a significant impact on mission costs –reducing them significantly for a given aperture size.



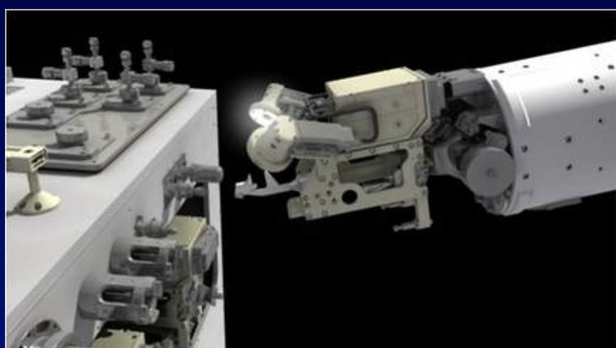


Segmented mirrors and active lightweight optics dramatically reduced costs for 8-10 m telescopes, and are crucial to enabling planned ~30 m ones.



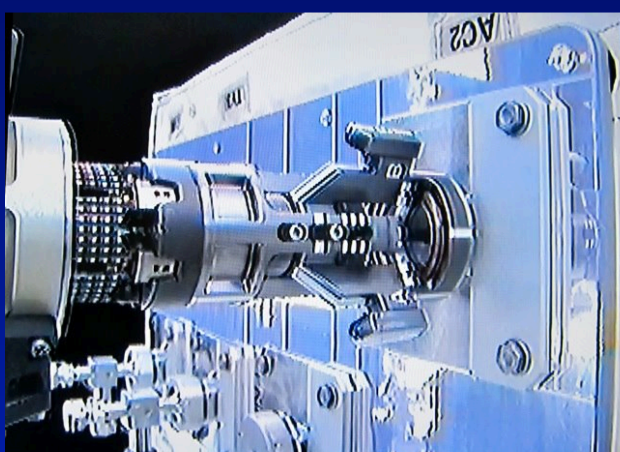
Robotic Servicing of Complex Spacecraft already in development at ISS

The ongoing Robotic Refueling Mission (RRM) demonstration program at the ISS is already maturing technologies for fully robotic servicing, repair, and refueling of space facilities.



The next step in evolving these technologies will be proving that we can

- assemble in space complex systems with tight tolerances
- service and and/or replace modular instruments



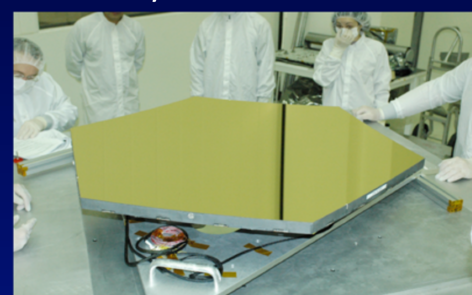
These technologies would be broadly applicable to many future missions (e.g. serviceable WFIRST or ATLAST, or even IXO or LISA eventually) – as well as being directly relevant to human exploration goals.

Key Enabling Technologies

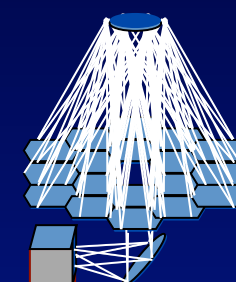
- A completed International Space Station and its supporting infrastructure (NASA and International investment)

- Nanolaminate Active Mirrors (DOD investment) and Laser Metrology (NASA & DOD)

Actuated Hybrid Mirror Technology



Compact Laser Metrology



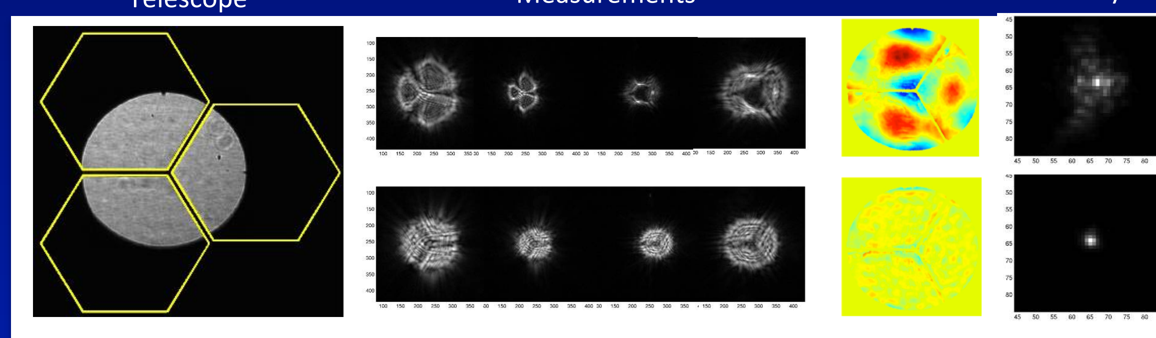
- Multi-segment telescope wave front sensing and correction capabilities (NASA and DOD investment)

JWST Wavefront Control Testbed with Segmented Telescope

Wavefront Sensing Camera Measurements

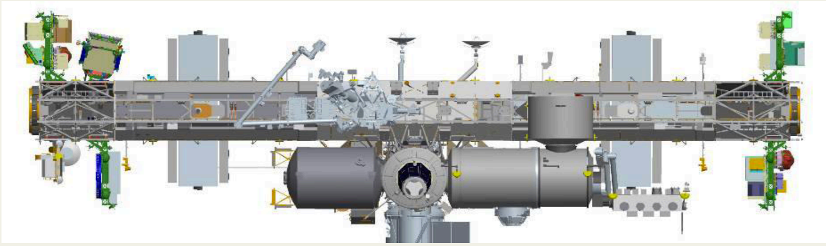
Wavefront

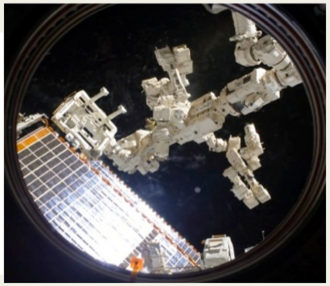
Image of Laboratory Star



Key Enabling Technologies

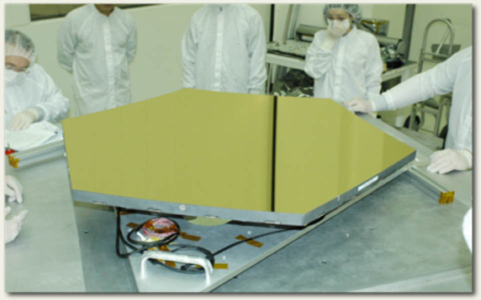
- A completed International Space Station and its supporting infrastructure (NASA and International investment)



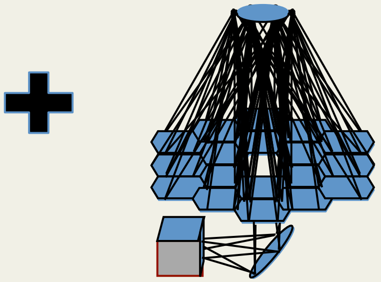


- Nanolaminate Active Mirrors (DOD investment) and Laser Metrology (NASA & DOD)

Actuated Hybrid Mirror Technology

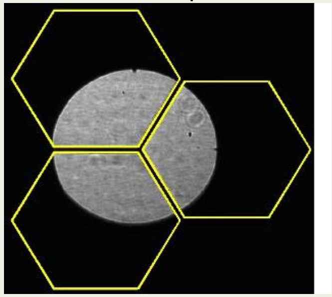


Compact Laser Metrology

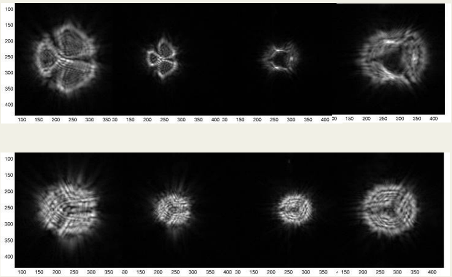


- Multi-segment telescope wave front sensing and correction capabilities (NASA and DOD investment)

JWST Wavefront Control Testbed with Segmented Telescope



Wavefront Sensing Camera Measurements



Wavefront

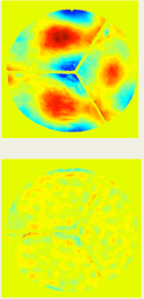
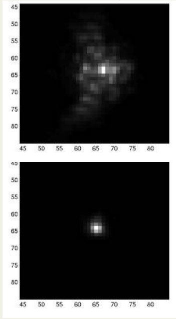


Image of Laboratory Star



A New Paradigm to be demonstrated by OpTIIX

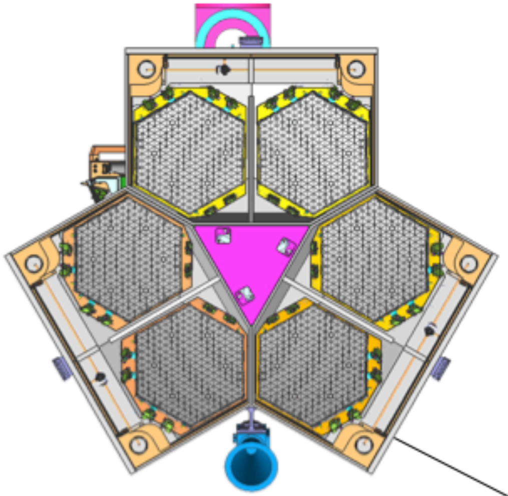
- Build a modularized, actively controlled, segmented *scaleable* telescope by robotically assembling components in space:
  - Modules launched separately to ISS and robotically assembled,
  - Uses lightweight, low-cost, deformable mirror segments,
  - Uses active wavefront sensing and control and laser metrology,
  - Assembled to mechanical tolerances (~sub-mm precision) and aligned, figured and controlled to optical tolerances (~few nm)

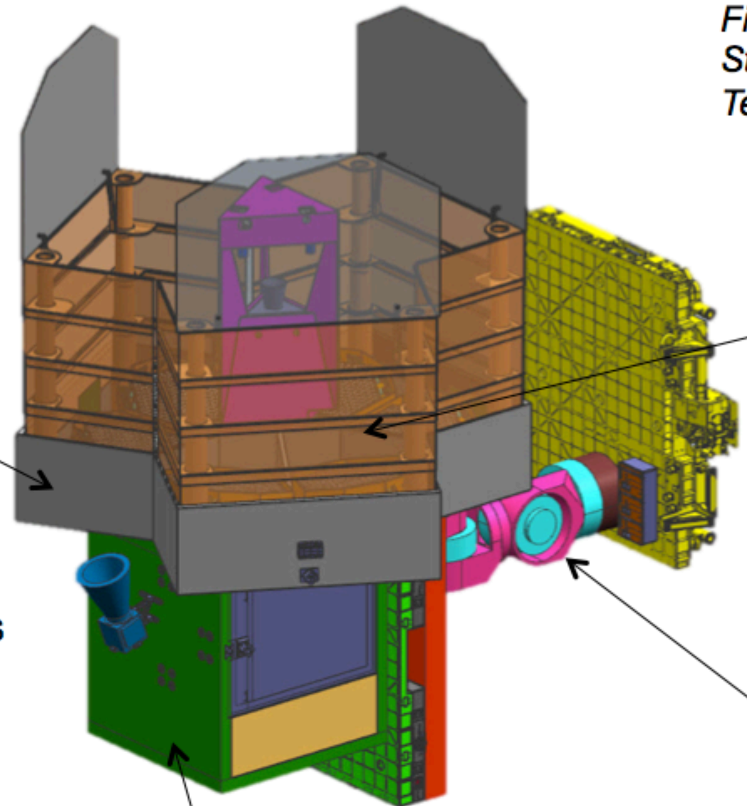
These capabilities are already developed & demonstrated to TRL 4-6 through ongoing technology development at JPL & elsewhere

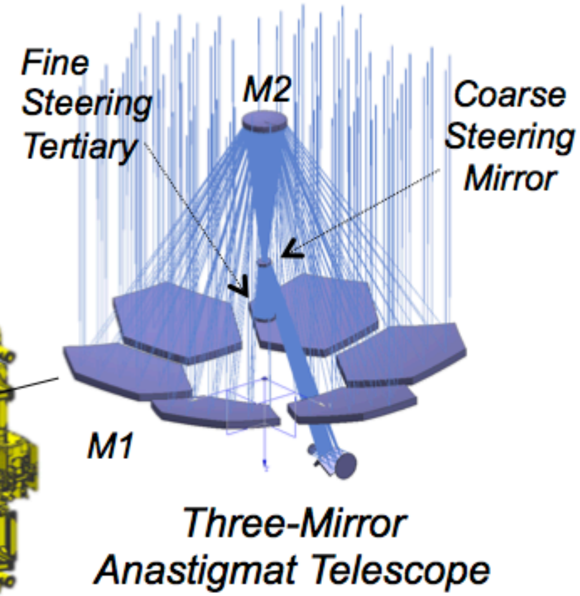
- Responsive toward Astro2010 priorities for New Worlds Tech Development and Future UV/Optical Space Capabilities.

> - Aperture size is no longer limited by manufacturing, ground testing, launch and deployment constraints.
> - Intrinsically tolerant to imperfections anywhere in the optical chain arising during manufacturing, launch, assembly or operation.
> - Eliminates need for large system-level ground I&T facilities.
> - Enables new possibilities for affordable space telescopes.

OpTIIX System Configuration







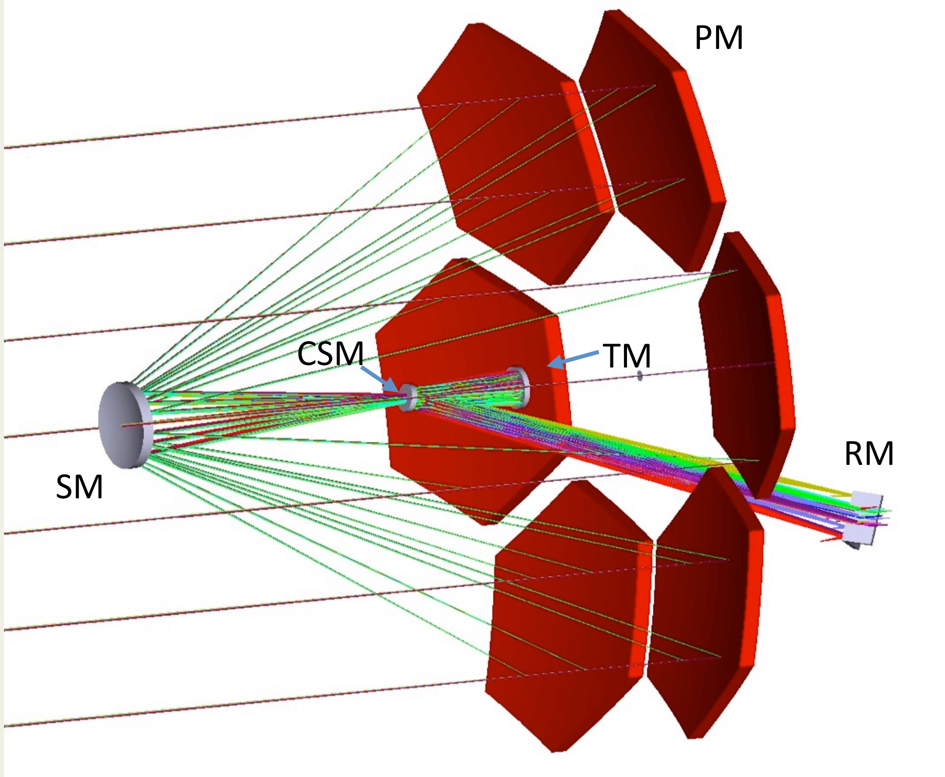
- 1.45m aperture
- 51cm point to point light-weighted segments assembled on orbit
- Replaceable segment modules
- Diffraction-limited performance
- On-demand figure and alignment control

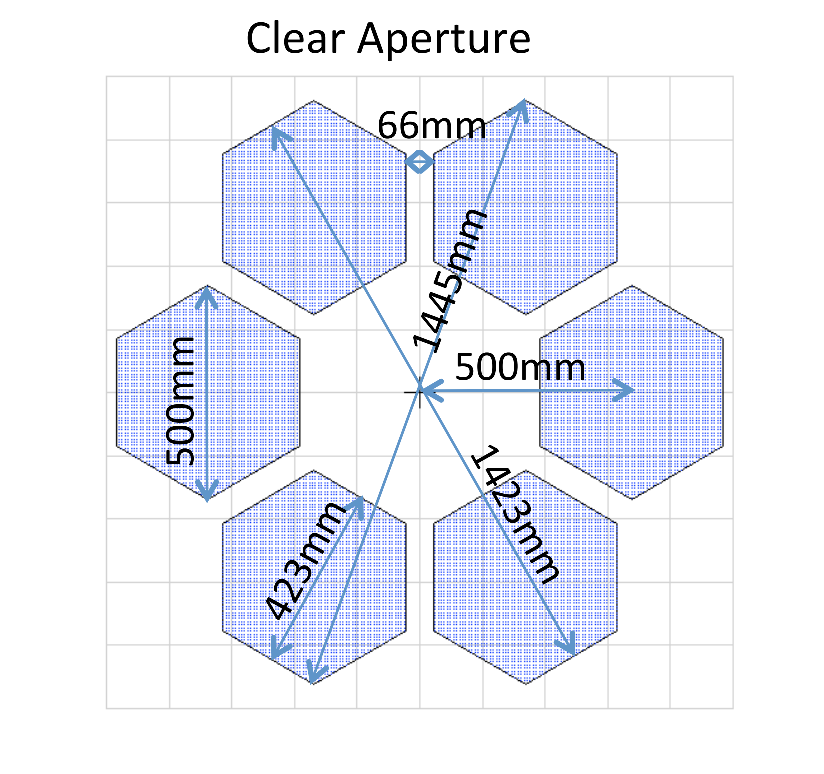
3-axis gimbal
- Attached to the Telescope on orbit
- FRAM I/F on each end

Telescope Core Module
- Imaging Camera
- Wavefront Sensing Unit
- Electronics, power, command & telemetry
- Capability to replace Imaging Camera

Telescope

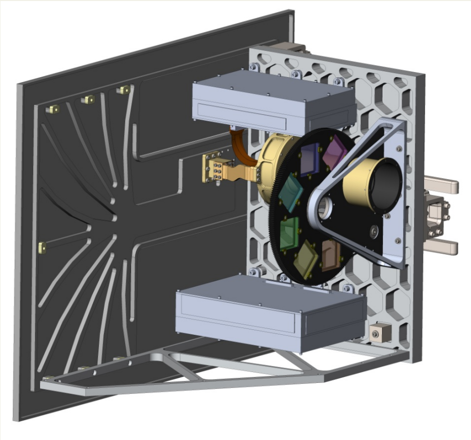
- On-axis Three-Mirror Anastigmat (TMA) configuration.
- 1.45-m aperture with 60% fill factor.
- 6 rigid-body actuated hexagonal primary mirror (50-cm) segments.
- 90 shape actuators per mirror segment.
- Warm telescope (~20 C).
- 50 nm rms wavefront error (75% strehl ratio at 650nm).





OpTIIX First-Generation Instruments

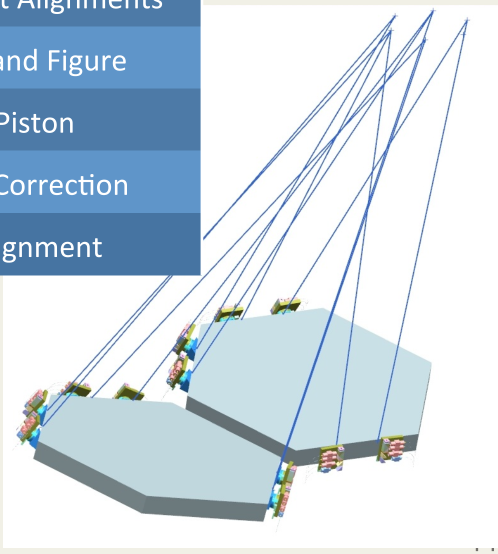
- **Imaging Camera**
  - 4k x 4k H4RG-10 HyViSi detector, provided by NRL JMAPS program
    Directly at telescope focus   66 mas/pixel, 4.5' x 4.5' FOV
  - Filter wheel with 3 narrow, 3 wide band filters and 1 dark mask.



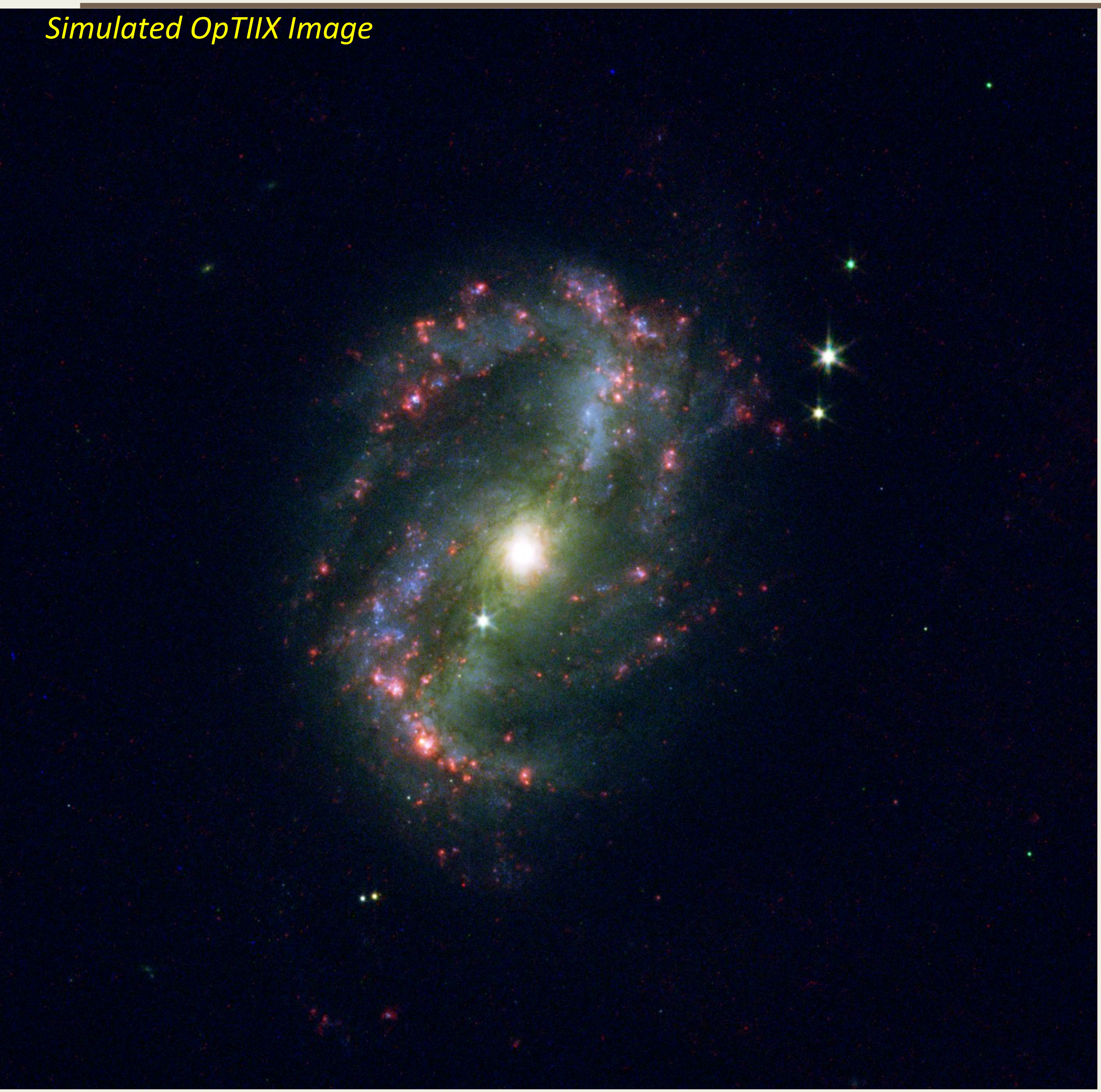
- **WFS Camera / FGS**
  - *Fine Guidance Camera (FGS)*
    - Guide Star Steerable mirror for Guide Star acquisition.
    - Small format/Fast CCD detector for 1kHz pointing error estimation.
  - *Wavefront Sensing Camera (WFS)*
    - Shack-Hartmann Sensing for initial segment alignment.
    - Dispersed Fringe Sensing for segment co-phasing.
    - Phase-Retrieval Sensing for fine wavefront adjustment.

Wavefront Sensing	Control Objective
Rigid-Body Actuator Encoders	Capture Segment Alignments
Shack-Hartmann Sensing	Segment Tilt and Figure
Dispersed Fringe Sensing	Segment Piston
Phase Retrieval	Total System Correction
Laser Metrology	Maintain Alignment

- **Laser metrology**
  - monitor motion of the primary mirror segments and secondary mirror.
  - Integrated into segment modules and secondary tower



OpTIIX Optical Performance



55 nm RMS WFE = ~75% Strehl ratio at 650 nm for the WFS camera.

~85 nm RMS WFE = ~50% Strehl ratio at 650 nm for Imaging Camera long exposures Limited by pointing jitter and non-common-path WFE.

OpTIIX Image Simulation assuming:

- **4K x 4K pixels Hawaii-4RG HyViSi imager**
- **50 kilosecond total exposure time**
- **0.066 arcsec/pixel on the sky**
- **Readout Noise: 15 e- or less**
- **Quantum Efficiency: >70% from 450 nm to 900 nm**

A fully assembled OpTIIX provides an unprecedented platform for technology development

The project Non-Advocate Review board believed that OpTIIX could serve a unique role as an ISS testbed for novel technologies relevant to future NASA missions:

"After the completion of its primary mission, it is possible that OpTIIX could become a flexible ISS testbed that NASA could use to raise from midlevels to TRL 9 a wide range of technologies (e.g., detectors, coatings, deformable mirrors, wavefront sensing technologies, instrumentation, electronics, etc.) that are not easily tested with rocket and balloon missions. This is an approach well suited to ISS"

By periodically robotically replacing the baseline Imaging Camera with subsequent instruments, OpTIIX could test and validate a wide range of technologies, including but not limited to:

- Next-generation UV, visible & infrared detectors
- Advanced mirror coatings
- Novel energy-sensitive photon counting detectors
- Improved detector control electronics
- Tunable filters
- Advanced wavefront sensing and beam shaping
- Fully automated closed-loop-on-orbit wavefront control
- Miniaturized deformable mirrors
- Coronagraph shaped pupils and apodizers

OpTIIX will advance technologies for exoplanet exploration, both during and after assembly.

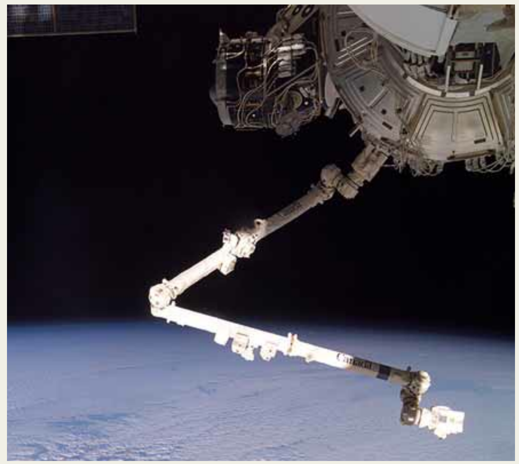
NASA JSC-JPL-GSFC

SPACE TELESCOPE SCIENCE INSTITUTE
Operated for NASA by AURA

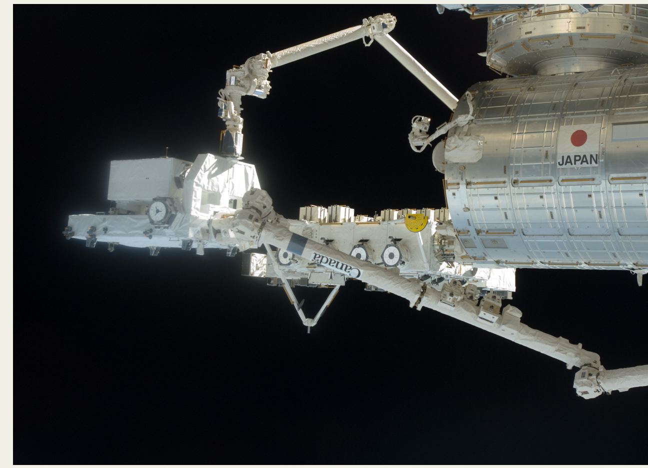
Why the ISS?

1) It’s where the robots are.

DEXTRE



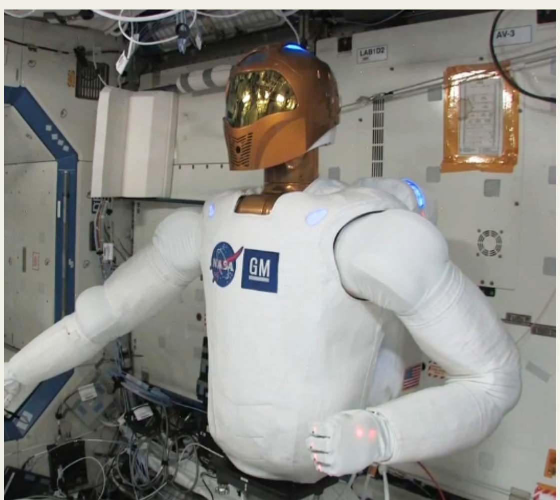
Canadarm 2 / SSRMS

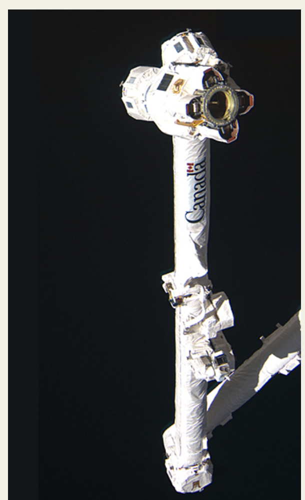


JEMRMS

Still to be launched this year: European Robotic Arm

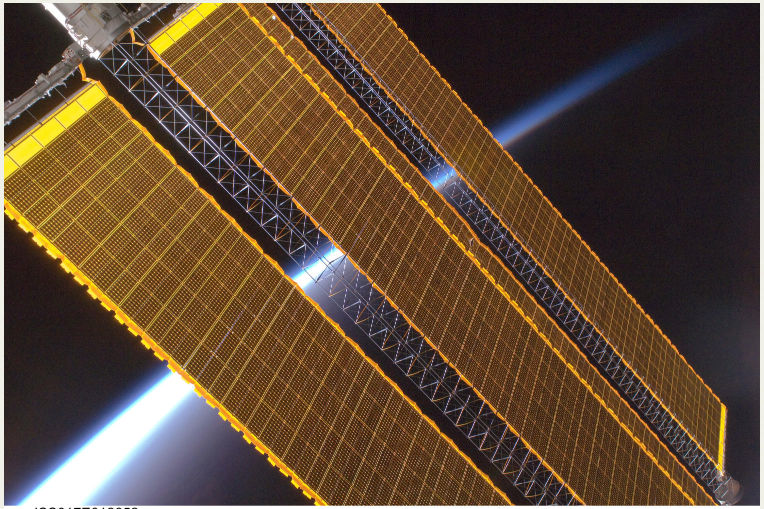
Robonaut 2



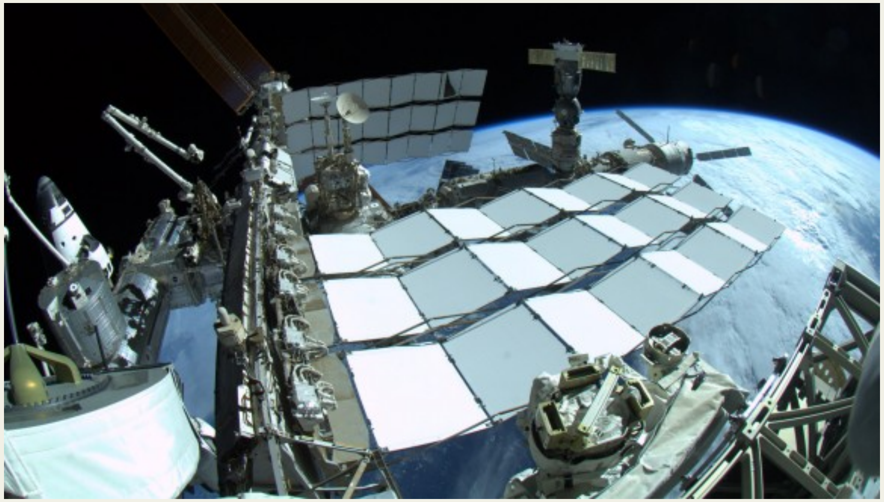


Why the ISS?

2) Extensive infrastructure and support: launch, power, telecom, attitude control…



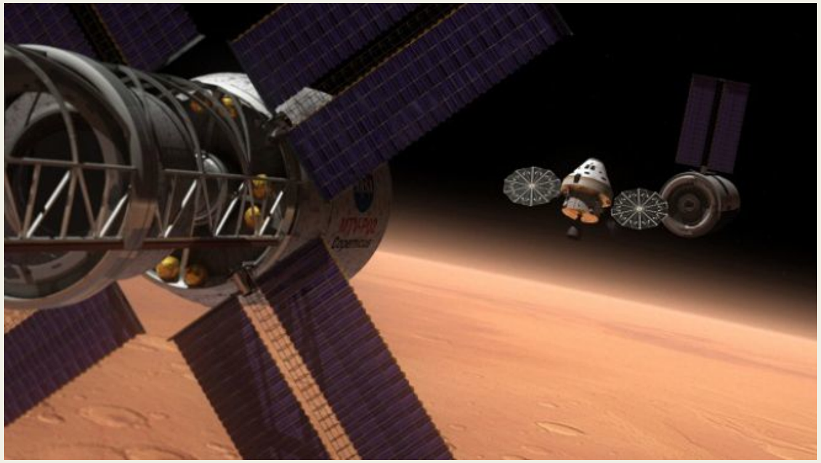
ISS017E012652



Why the ISS?

3) Synergies with human exploration build on the successes of HST, and on future human exploration goals

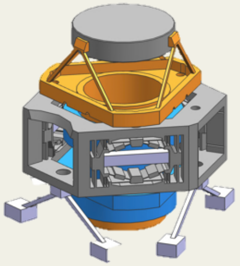


“But what about…?”

- **Vibration and pointing jitter?**

  Active & passive vibration isolation in gimbal
  500 Hz - 1kHz tip-tilt system using R<13 guide stars
  -> yields ~ 45 mas rms line of sight pointing stability



Fine steering tertiary mirror

- **Outgassing and particulate contamination?**

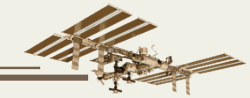
  Not a significant concern for a relatively short term technology testbed.

  Mitigate by keeping telescope aperture closed during spacecraft dockings & ISS reboosts

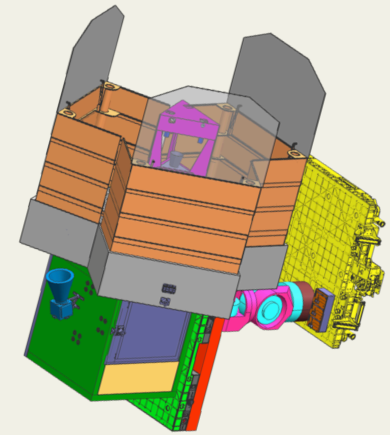
  Would be most limiting at far-UV wavelengths, but far UV is not required for OpTIIX.

While the ISS is not an ideal site for an operational flagship observatory, the benefits far outweigh the complications for an engineering testbed.

OpTIIX can establish a new path toward the characterization of terrestrial worlds.



OpTIIX will demonstrate an *affordable* approach to the launch and deployment of large space telescopes by:

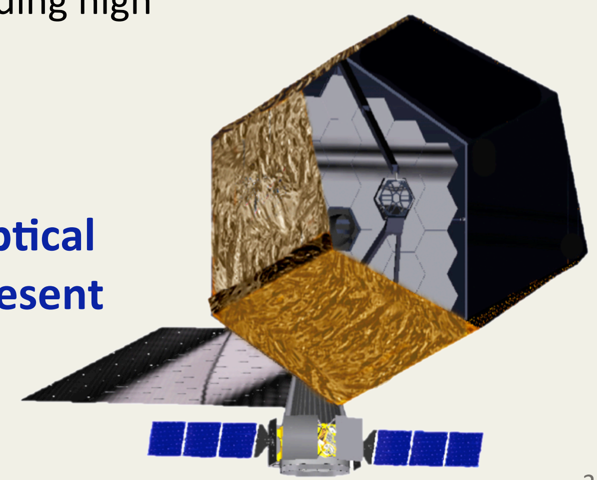


- Integrating substantial NASA & DOD technology investments,
- Leveraging existing ISS facilities and robotics,
- Bringing together, for the first time, fully active telescope technologies and in-space assembly & upgrade capabilities.

OpTIIX operating on ISS by mid-decade will:

- Advance the timescale for many kinds of ambitious space science missions by at least 10 years through major reductions in cost & risk,
- Set the stage for a serviceable, upgradeable NEW WFIRST, ATLAST and/or other future missions – with potential applications across astronomy, planetary science, human exploration, and national defense
- Be a centerpiece of an HEOMD/SMD/OCT collaboration providing high value, visibility and engagement with a large audience:
  - Involving both the public & the science community,
  - At a key time: 2015+, in advance of the 2020 Decadal Survey.

OpTIIX can significantly accelerate the deployment of large optical systems in space to enable many observations beyond our present abilities, in particular direct imaging of terrestrial exoplanets.



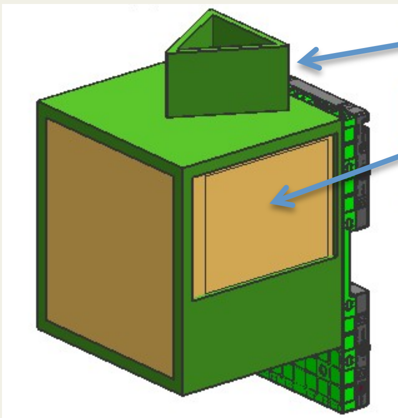
Join us later this week to continue the discussion! Thurs 9:30 rm 202A

Backup Slides

Launch Segments

- Exposed (un-pressurized) launch segments

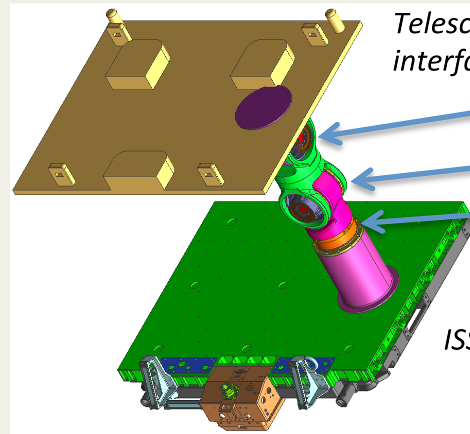
Telescope Core Module;



Snout

Imaging Camera

Gimbal Module (JSC)



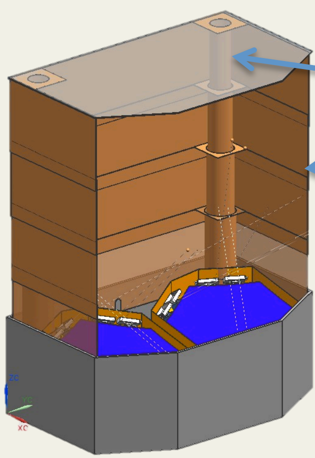
Telescope interface

ISS interface

Three degrees of freedom:
- Field Rotation (+/-20 deg)
- Elevation (+20/-45 deg)
- Azimuth (+/-90 deg)

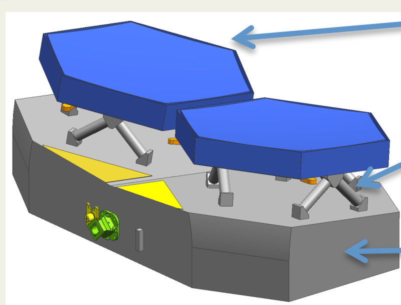
- Pressurized launch segments

Primary Segment Modules



Aperture Cover

Sunshade

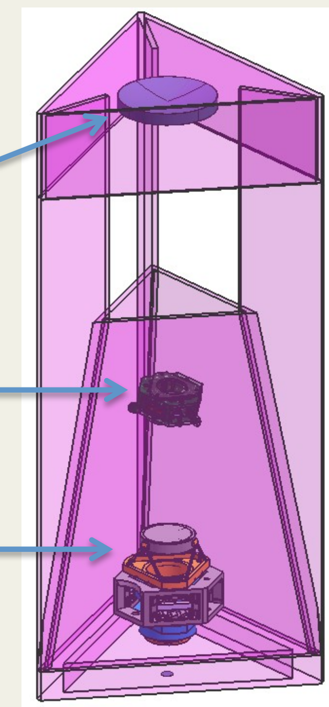


Mirror Segments

Rigid-Body Actuators

Structure, Laser & Electronics

Secondary Tower Module

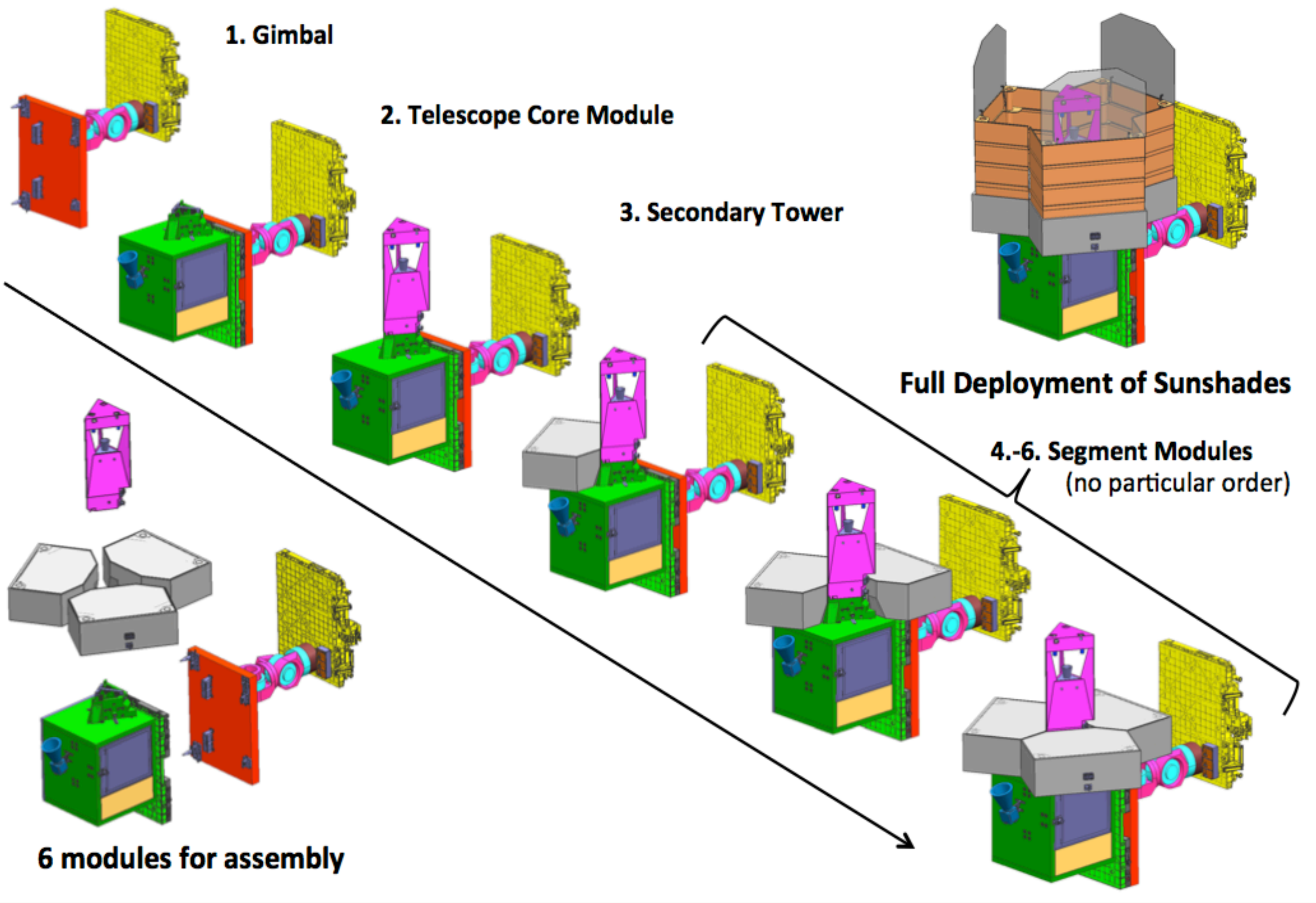


Secondary Mirror and Rigid-Body Actuators

Coarse Steering Mirror

Fine Steering Tertiary

Assembly Sequence



Imaging Camera

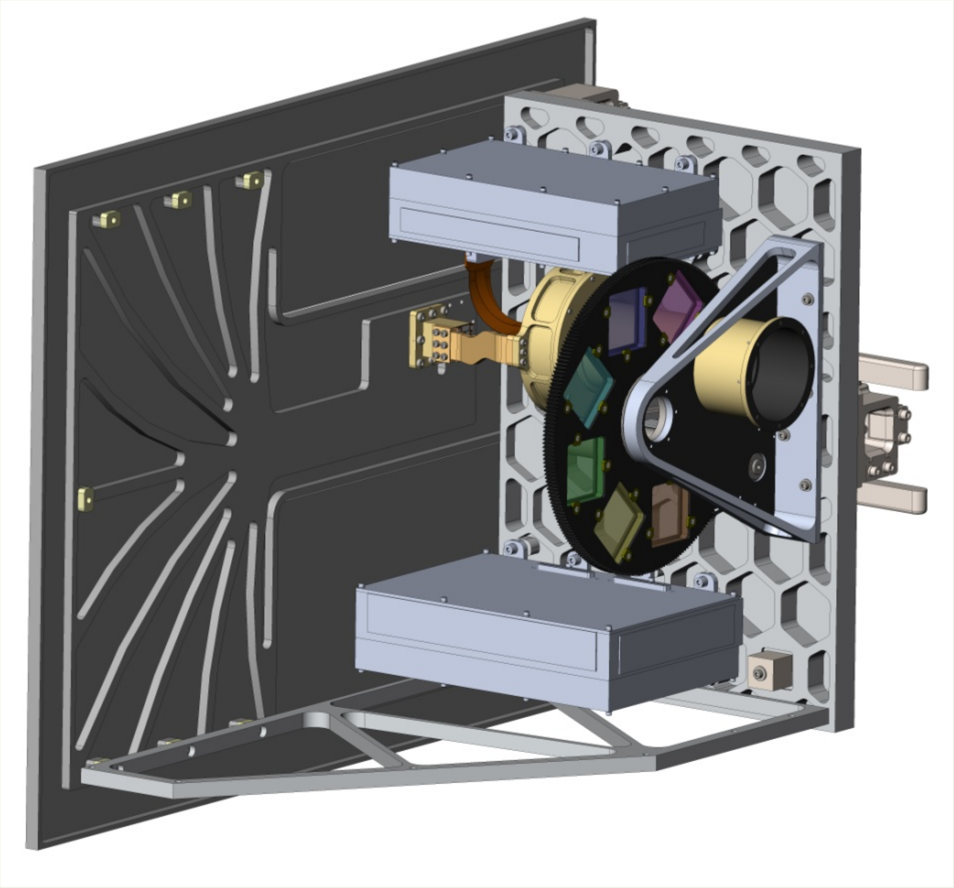
H4RG-10 HyViSI detector
- Provided by JMAPS program
- +SIDECAR ASIC

Filter wheel
- 3 broad band (Sloan *g′, r′, I′*)
- 3 narrow (Halpha, [SII], Oii)

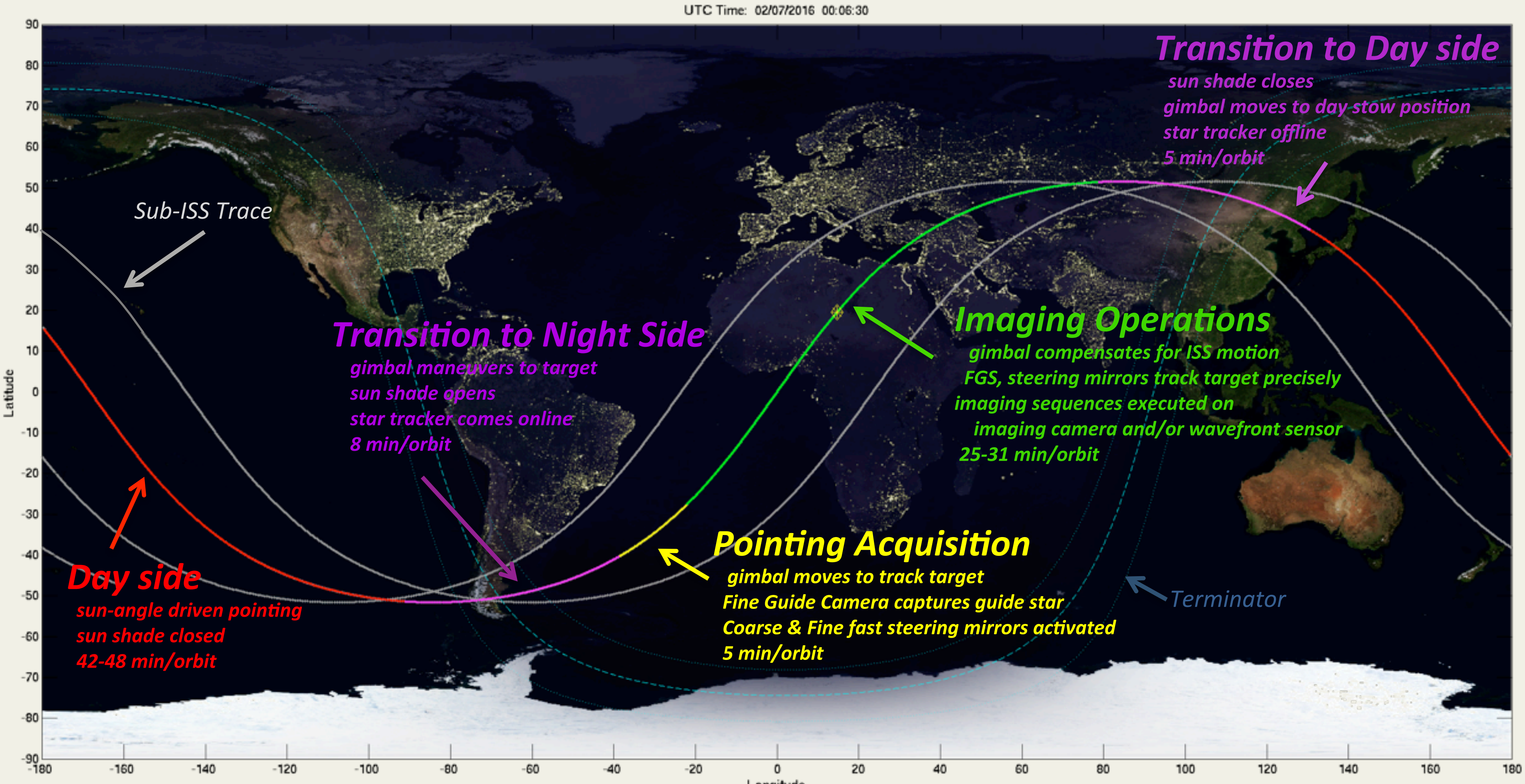
No optics other than filters

TEC cooling for detector

HST-derived mounting rails and latches, modified for robotic compatibility and blind mate



Operations Concept Overview

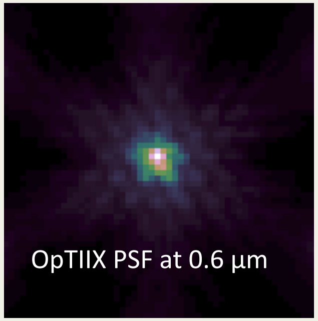


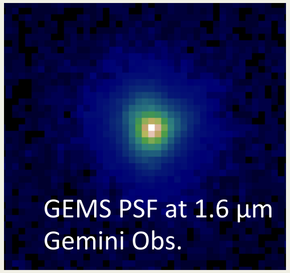
Continuous background activities:
- laser metrology and thermal control
- imaging & WFSC data downlink
- telemetry streaming

Routine periodic activities:
- daily wavefront sensing & control
- sequence & schedule uploads
- calibration observations

Even “modest” diffraction limited performance in space vastly exceeds the best Adaptive Optics in visible light

- **OpTIIX target image quality** is ~75% Strehl ratio at 650 nm for the WFS camera (= 55 nm RMS WFE).
  - For the Imaging Camera in long exposures, pointing jitter and non-common-path WFE reduce performance to ~50% Strehl ratio at 650 nm (~85 nm RMS WFE).
  - OpTIIX will achieve this performance over its entire ~4x4 arcmin Field of View





- **Today’s best wide field AO:** The brand-new Gemini GEMS 5-laser multi-conjugate AO system achieves at best 30% Strehl ratio at 1.6 µm (=290 nm RMS WFE) across a 1.5x1.5 arcmin FOV.
  At visible wavelengths this performance would give Strehl ratio essentially zero: << 0.1%.

OpTIIX will achieve 4-6x better wavefront error over 9x larger field of view, providing 0.1” resolution images at wavelengths that wide field AO simply cannot touch.

- ***Despite being so much smaller, OpTIIX will match the angular resolution achieved by the 8-m Gemini telescope and its wide-field AO system!***
- ***For the foreseeable future, no ground based instrument will approach this level of performance at optical and/or near-ultraviolet wavelengths.***

Examples of Potential Science Applications for OpTIIX (in baseline configuration)

- **High-cadence monitoring of outer solar system planetary atmospheres.**
- **Stellar population studies of nearby star-forming regions and star clusters.**
  - Both for Galactic and nearby extragalactic systems (census of Local Group)
  - Survey large areas in UVBI filters
- **Imaging of young stars and protoplanetary disks.**
  - Spatially resolved observations of edge-on disk candidates to follow-up WISE imaging.
  - Synoptic monitoring of the proplyds in Orion for variability due to accretion events and shadowing of illumination by inner-disk substructures.
  - Time-domain studies of outflows from Young Stellar Objects (YSOs). Currently only a tiny fraction of YSOs have been studied at high cadence.
- **Fast follow-up observations of transient events.**
  - Gamma Ray Bursts. Progenitors of short hard bursts unknown; there are indications of rapid early decay. If the capability to schedule OPTIIX observations within 1 or 2 orbits of notification of event is possible then OPTIIX would have deeper search capability than an 8-m telescope observing no earlier than 12 hours after the burst.
- **Nearby galaxy surveys, to assess star formation history or halo substructure.**
  - Particularly if UV filter coverage is provided, as strongly recommended by the Non-Advocate Review board.