Annals in the Search for Earth 2.0

The ISS as a Testbed for Future Large Astronomical Observatories: The OpTIIX Demonstration Program

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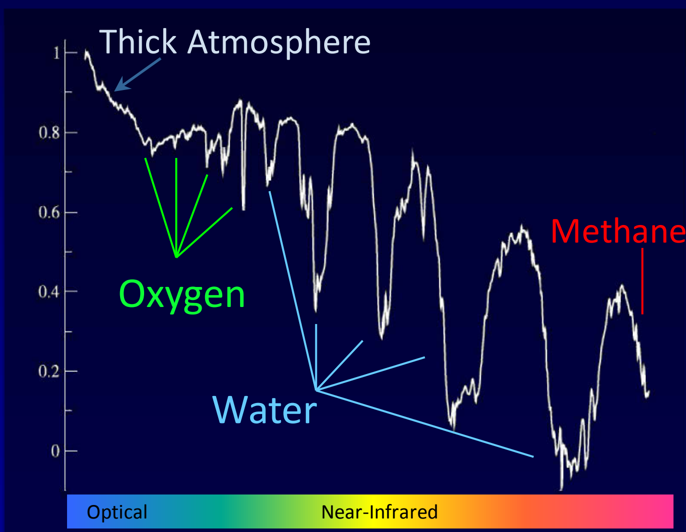
Summary
The Optical Testbed & Integration on ISS Experiment (OpTIIX)

- OpTIIX will demonstrate an affordable path that scales to very large space telescopes proposed to search for Earth-like worlds (aka, Earth 2.0)
  - Integrating the substantial technology investments made by NASA and DoD
  - Leveraging the existing ISS facilities and robotics
- This revolutionary approach brings together, for the first time, fully active telescope technologies and in-space assembly & upgrade via JSC, JPL, GSFC, and STScI
- Advances the timescale for many kinds of ambitious space science missions by at least 10 years through major reductions in cost and risk for a cost of ~$125 M.
- As an operational asset on ISS, OpTIIX will provide an observatory with immediate scientific value, and, in the longer term, a testbed for new instruments and investigations
- Currently in Phase B, with launch planned for as early as March 2015

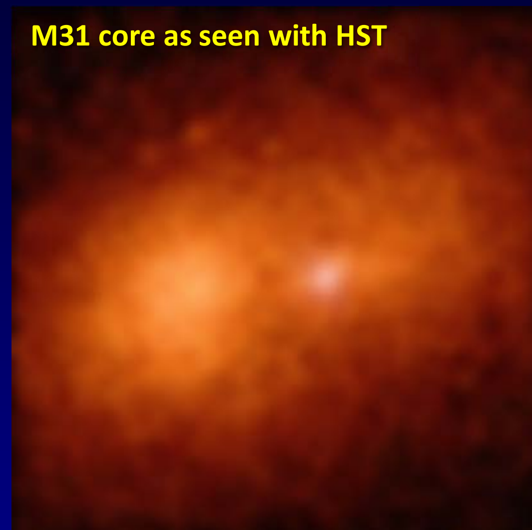
A Large Space Observatory is ***Required*** to Understand the Earliest Universe and to Detect Life on Exoplanets

How do we Search for Life in Extra-Solar Planets?



The signature of life is encoded in the spectrum of the Earth

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.

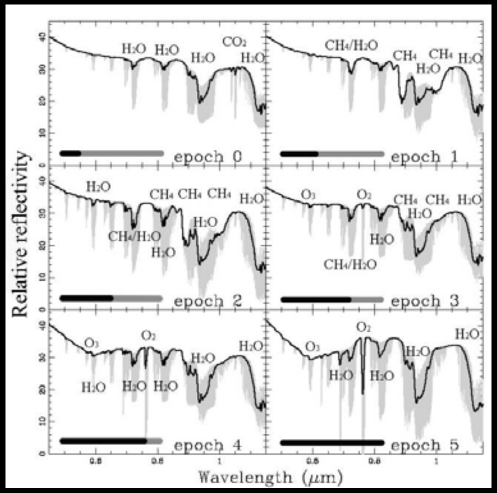
Searching for Earth 2.0

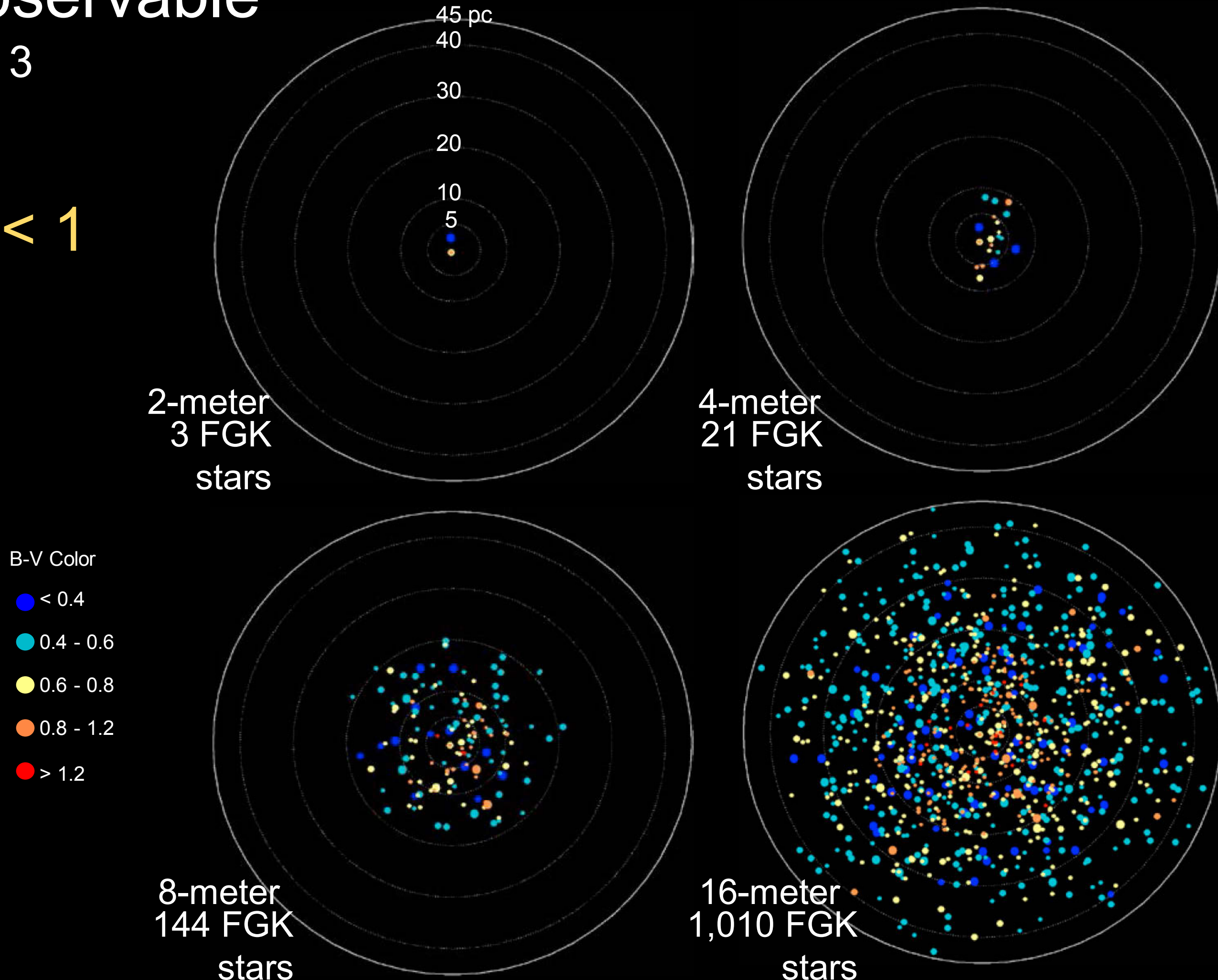
The number of observable candidates $\alpha\ D_{Tel}^{\ 3}$

If η_{Earth} x prob. life < 1

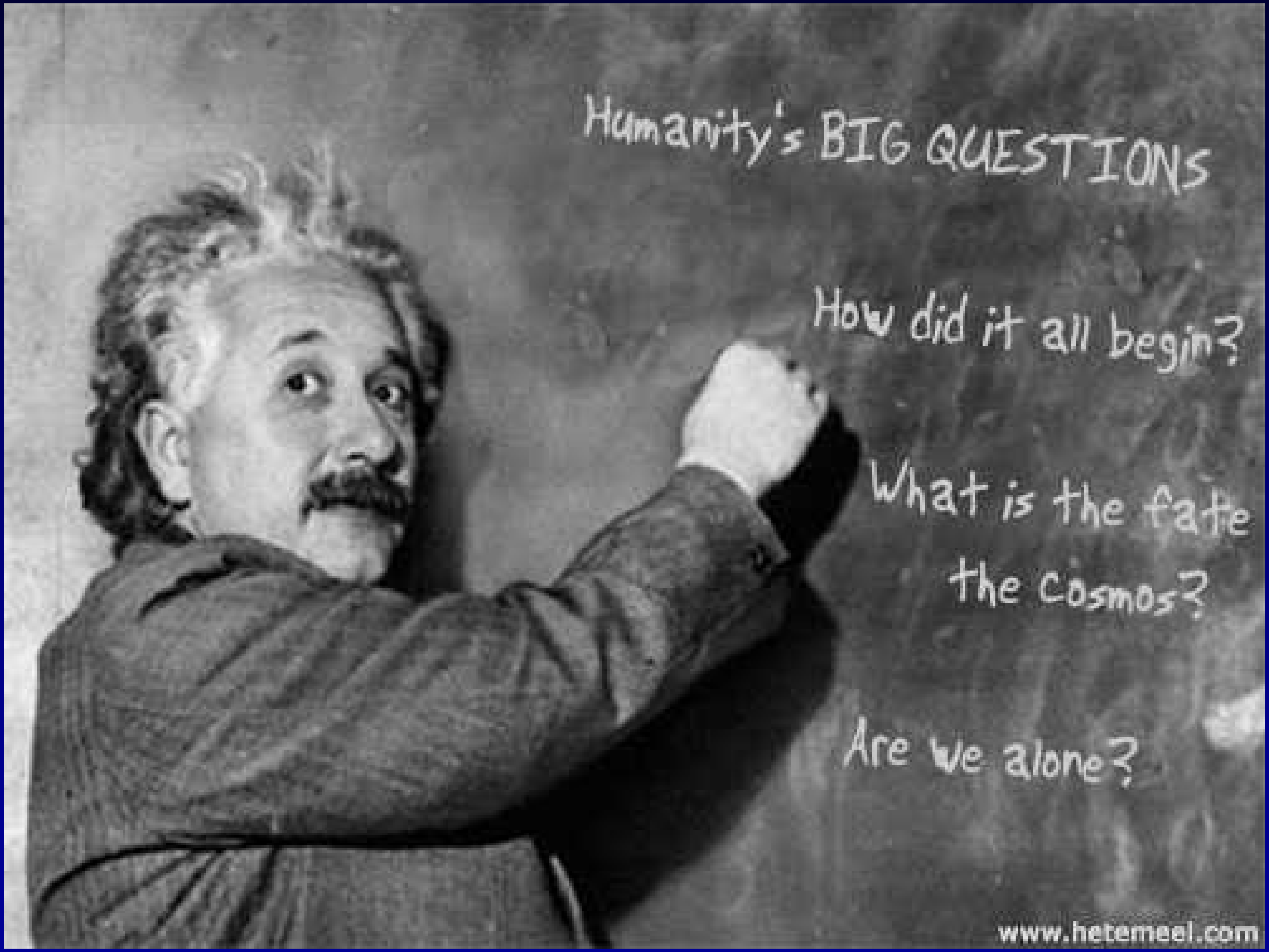
To get spectra

$D_{Tel} > 4m$





OpTIIX on ISS:
A Key Step to One of Humanity's Great Discoveries



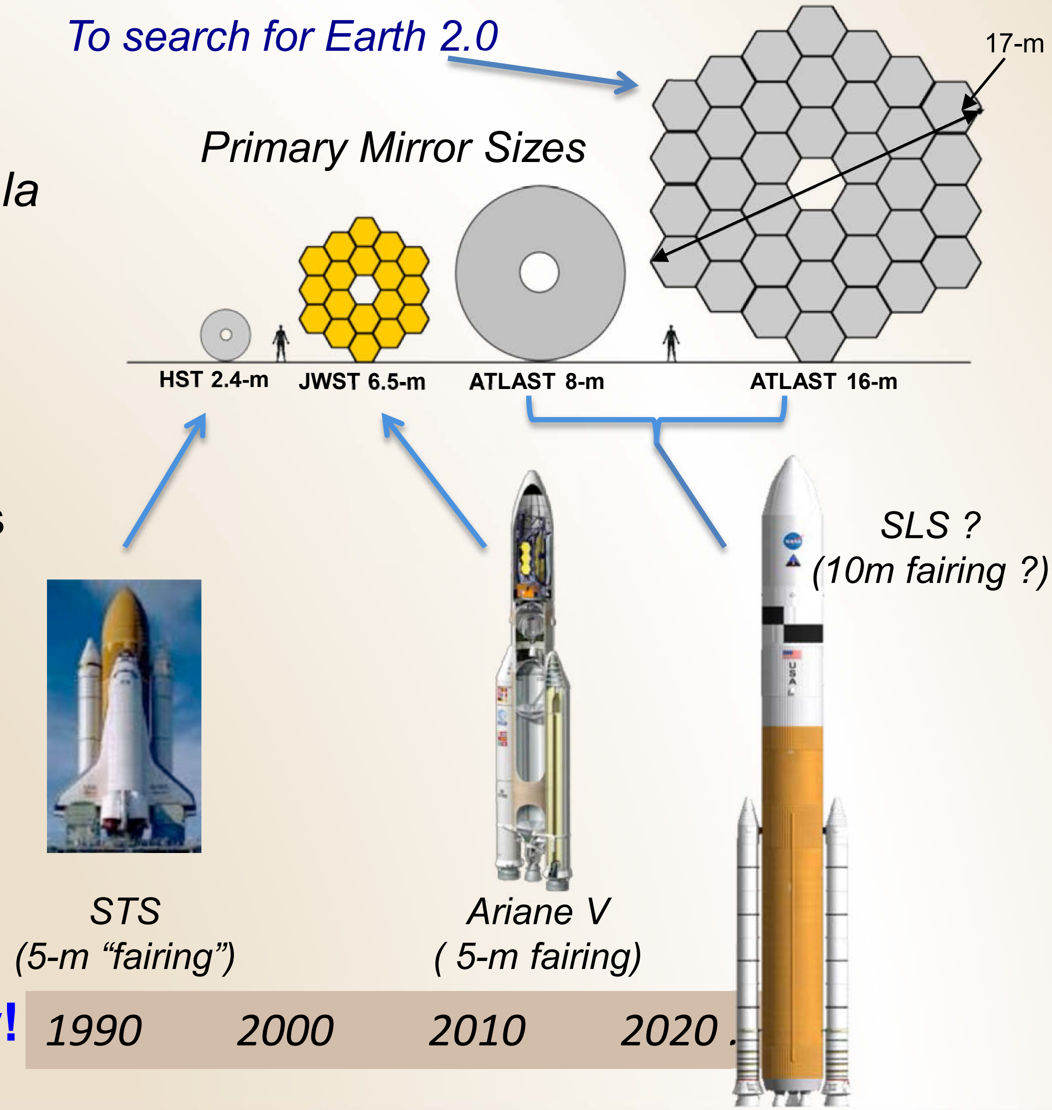
The Conventional Paradigm

Large space telescopes with conventional monolithic (*a la* HST) or pre-assembled segmented mirrors (*a la* JWST) face substantial challenges in scaling to even larger sizes, including

- Testing in 1 g
- L/V throw weight & fairing size
- Complex, precision deployments on-orbit
- Long-term performance
- Prohibitive cost

The conventional paradigm relies on future heavy L/V, large fairings and complex geometry

We believe there is a better way!



Increasing aperture <u>geometrically</u> drives cost and complexity

The New Paradigm to be Demonstrated by OpTIIX

- Build a modularized, actively controlled, segmented *scaleable* telescope by robotically assembling components in space and autonomously phasing it to diffraction-limited performance
  - 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 (~nm level)
  - Will be an on-orbit testbed for future NASA telescope and science instrument development and a centerpiece for STEM outreach.

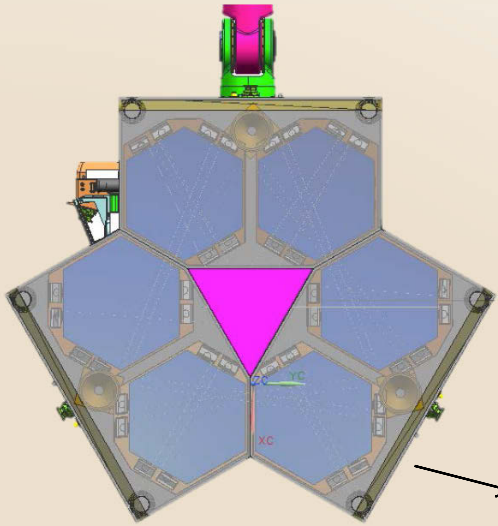
These 3 capabilities are already developed & demonstrated to TRL 4-6 through ongoing non-NASA funded technology development at JPL

- 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

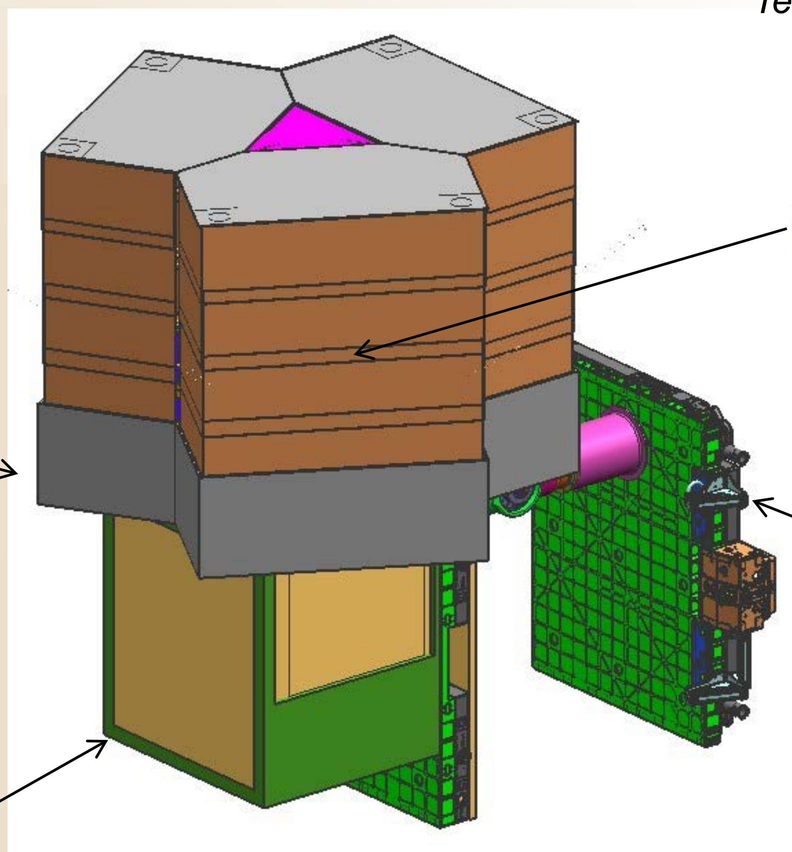
Partners: GSFC, JPL/CIT, JSC, STScI
Sponsors/Stakeholders: ISS Program, OCT, and SMD

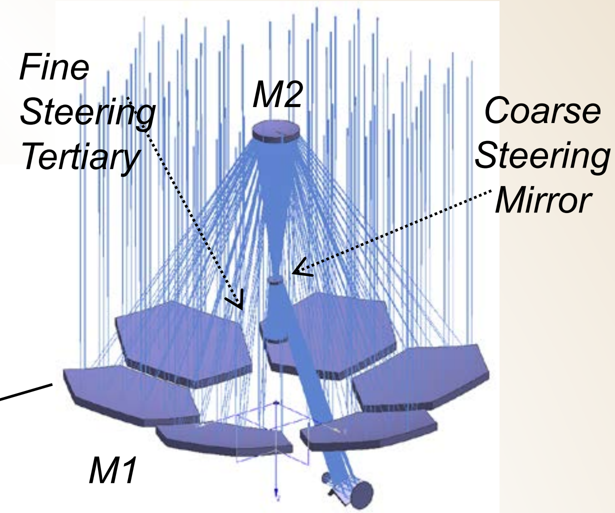
Enables new possibilities for affordable space telescopes

OpTIIX System Configuration



1.45m aperture
51cm point-to-point
segments
assembled on orbit





Three-Mirror Anastigmat Telescope

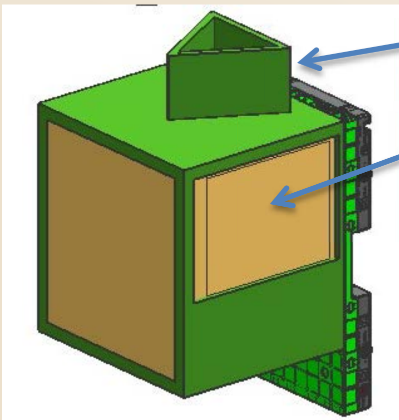
3-axis gimbal (JSC), attached to the Instrument Module on orbit; FRAM I/F on each end

Telescope Core Module
- Imaging camera (GSFC)
- Wavefront Sensing Unit
- Electronics, power, command & telemetry

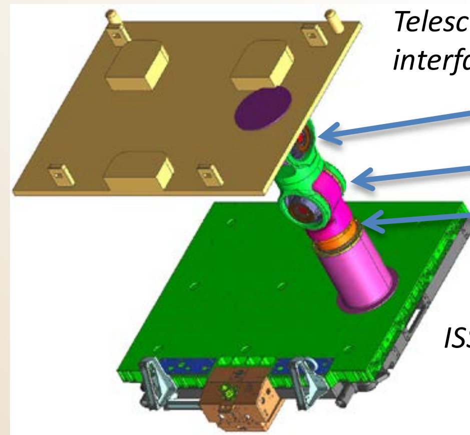
Launch Segments

- Exposed (un-pressurized) launch segments

Telescope Core Module;

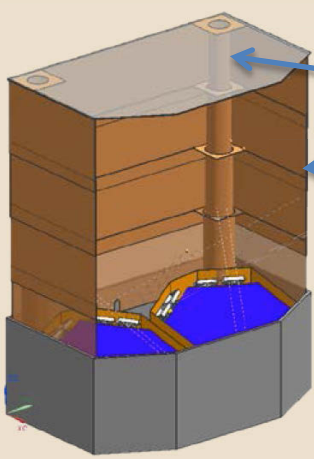


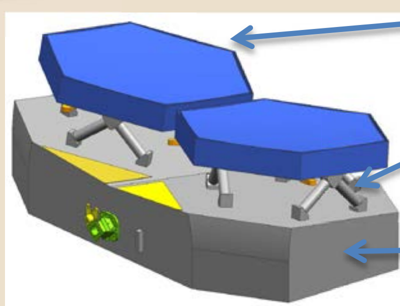
Gimbal Module (JSC)



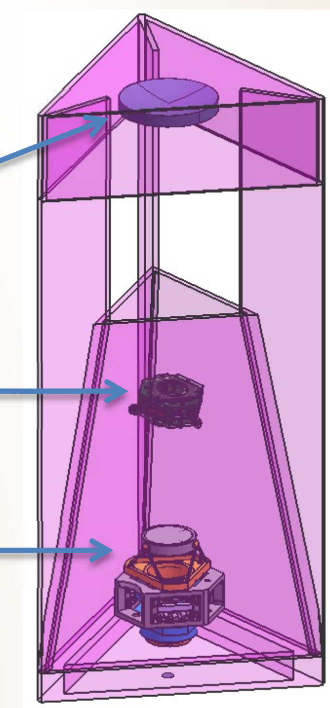
- Pressurized launch segments

Primary Segment Modules



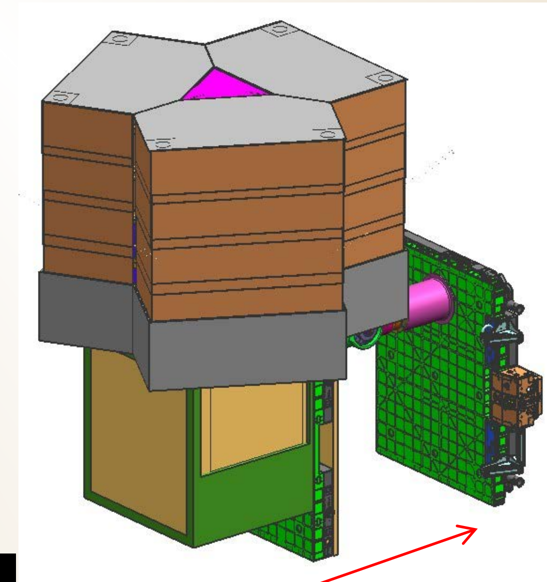


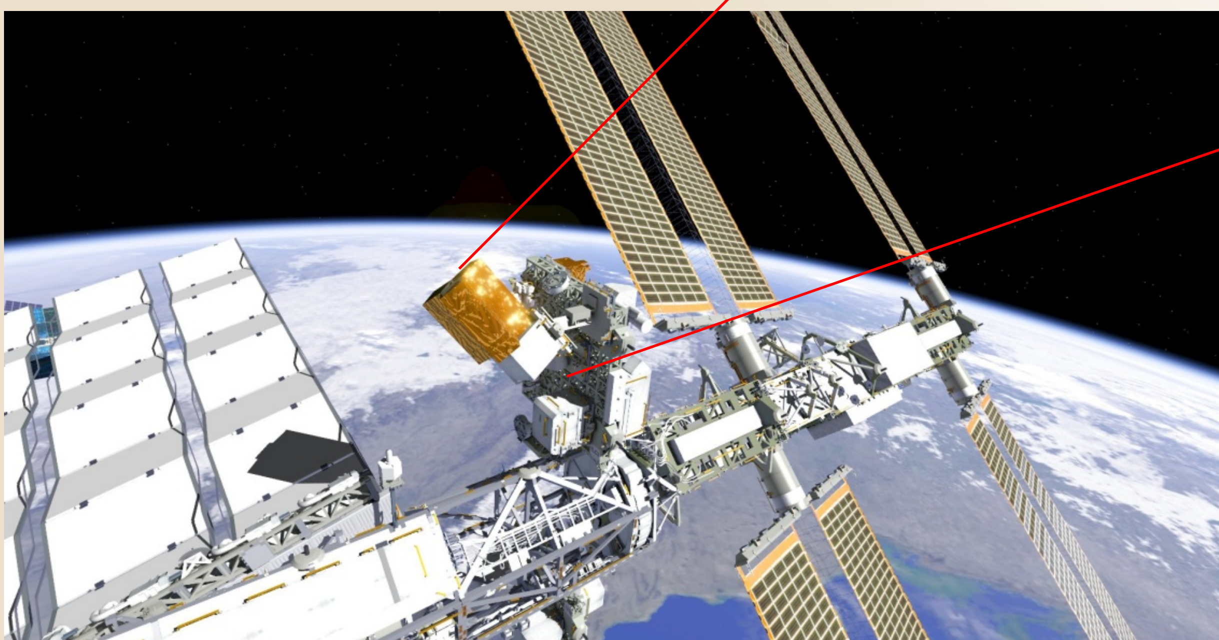
Secondary Tower Module

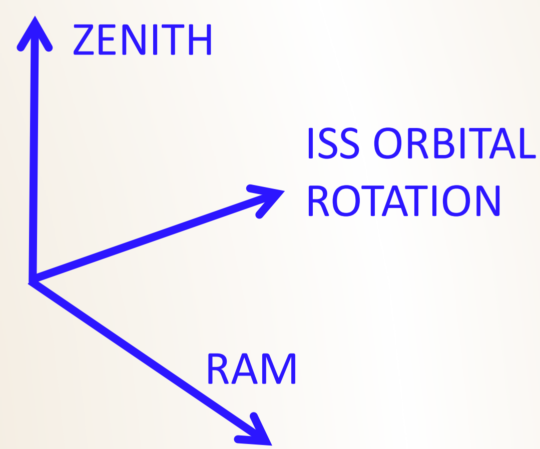


OpTIIX ISS Install Location

- Robotically assembled and mounted on Express Logistics Carrier (ELC3) Zenith-looking as a baseline with options for other locations

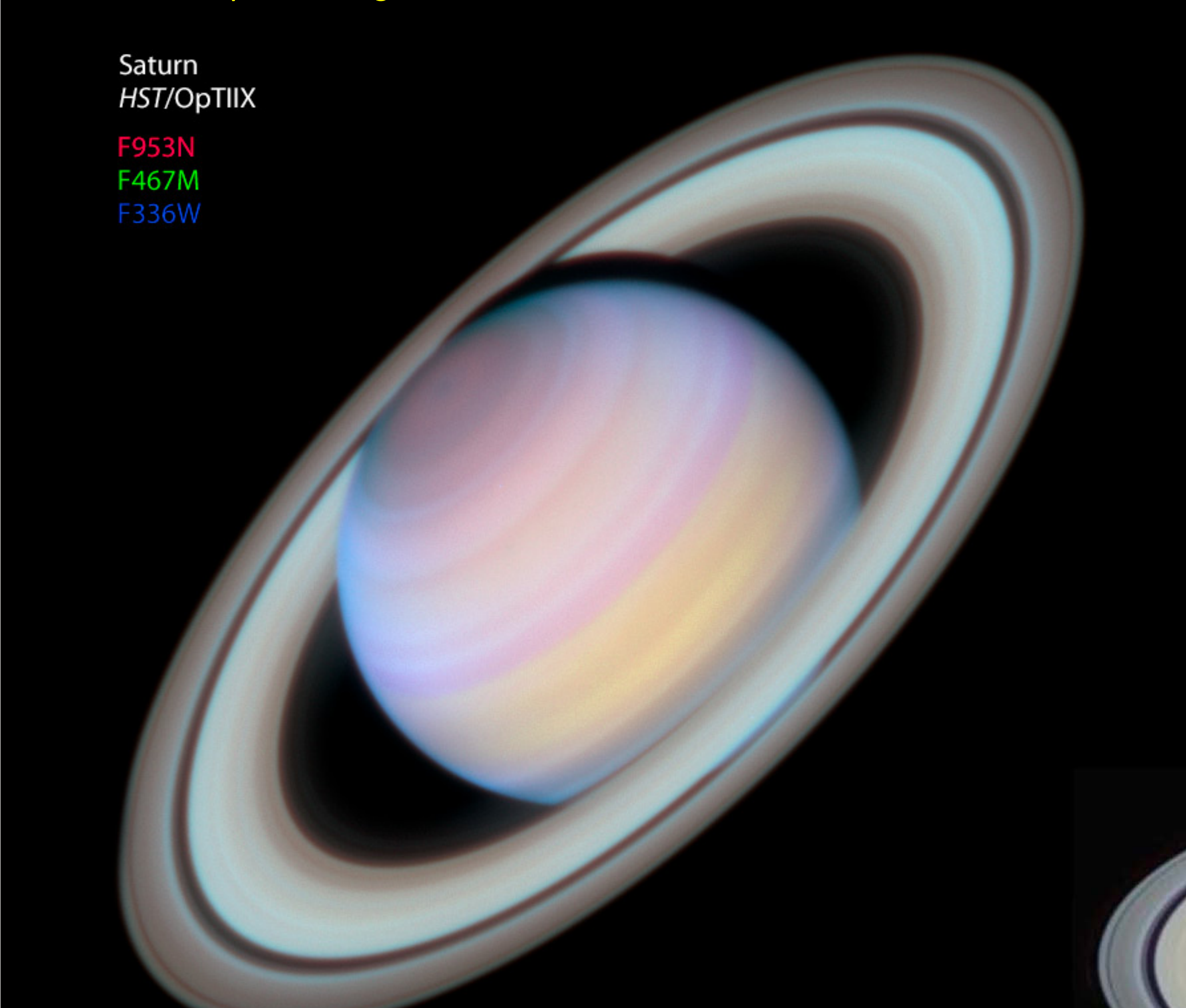






OpTIIX Imaging Performance

Simulated OpTIIX Image



SATURN: Rings close to widest open configuration (Oct 2017 is widest in its 30-year-cycle).

OpTIIX Image Simulation assuming:

- **4K x 4K pixels imager with**
- **0.05 arcsec/pixel on the sky**
- **Readout Noise: 15 e- or less**
- **Quantum Efficiency: >70% from 450 nm to 900 nm**

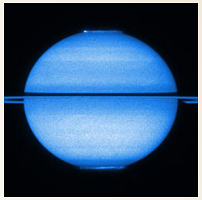
A higher performance imaging camera is being explored or could be added later.

HST WFPC2 Image

Inspire millions of students and amateur astronomers by providing access to OpTIIX for their own exploration

Examples of Potential Science Applications for OpTIIX (Phase 1)

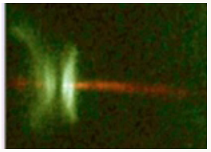
- **High cadence monitoring of outer solar system planetary atmospheres.**



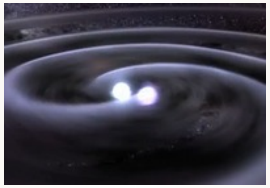
- **Stellar population studies of nearby star-forming regions.**
  - Both for Galactic and nearby extragalactic systems (census of Local Group)

- **Imaging of proto-planetary disks.**
  - Spatially resolved observations of edge-on disk candidates
  - Synoptic monitoring of the protostellar systems in Orion for variability due to evolution of surrounding structures

- **Dynamics of outflows from young stars.**
  - Time domain studies of outflows from Young Stellar Objects (YSOs). Currently only a tiny fraction of YSOs have been studied at high cadence.

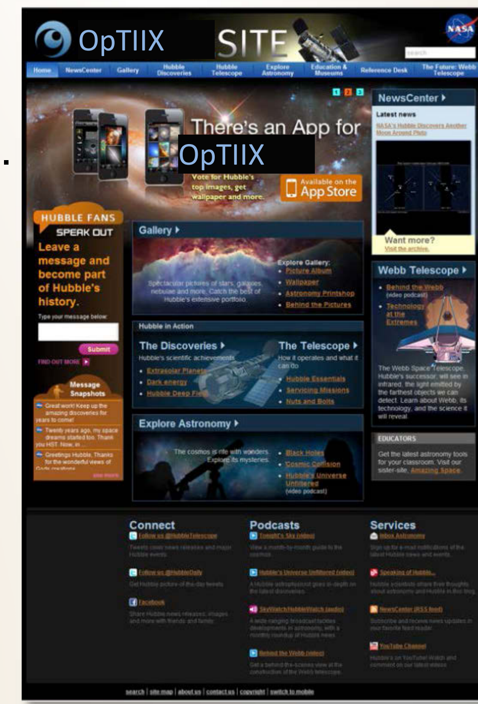


- **Fast follow-up observations of transient events.**
  - Gamma Ray Bursts. Progenitors of short hard bursts unknown. If the capability to schedule OpTIIX observations rapidly after notification of event is possible, then OpTIIX would have deeper search capability than an 8-m telescope observing no earlier than 12 hours after the burst.
  - Gravitational wave detections. LIGO and Virgo ground-based gravitational wave detectors will observe the merger of neutron star binaries with a large error box. The fast follow-up/high angular resolution of OpTIIX will allow the study and localization.



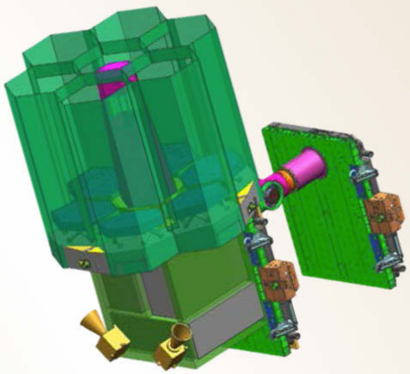
Planned OpTIIX Education and Public Outreach Program (STScI)

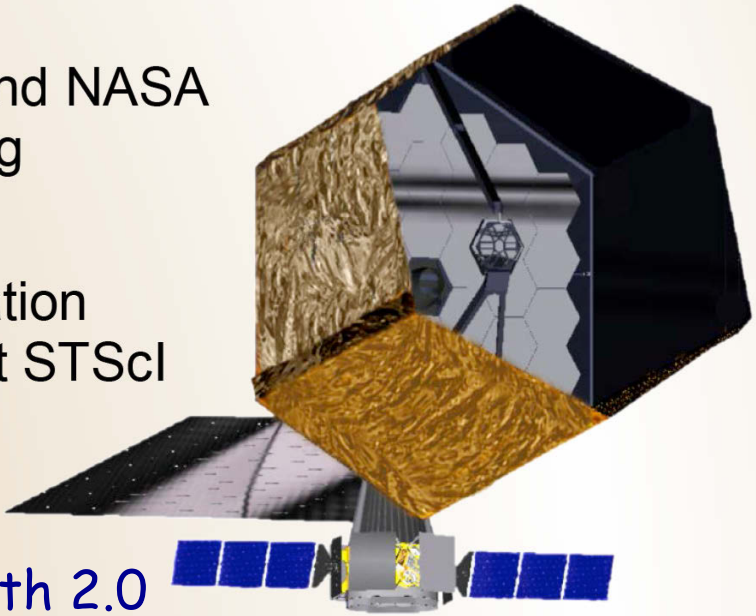
- **Allowing students to take "their own" observations from space is an extraordinarily powerful tool for increasing engagement & interest in science and engineering**.
  - As demonstrated with existing EarthKam and GRAIL MoonKam programs, or Harvard/CfA MicroObservatory's "Observing with NASA" program.
  - MoonKam has reached ~3000 schools, >100k students during a short 3 month prime mission.
  - Interdisciplinary: associated curriculum materials will include engineering & aerospace content alongside astronomy topics. Teachers can integrate ISS into the classroom.
- Web-based interface for school groups and amateurs to propose and receive observations, modeled on successful MicroObservatory website.
- Data taken on orbit, processed at STScI, and returned to school groups within a week. Potentially dozens of targets per week, target choices driven by the community.
- **Broad public engagement through website & social media.**
  - "Hubble Heritage"-style high-impact impressive color images



OpTIIX is a Timely Investment

- OpTIIX operating on ISS by mid-decade will
  - Be a centerpiece of an HEOMD/SMD/OCT collaboration providing high value, visibility and engagement with a large audience (public & science community) in advance of the 2020 NRC Decadal Survey
  - Advance by at least a decade our ability to build very large telescopes to explore the universe and look for life beyond our solar system
  - Demonstrates technologies identified in ASTRO2010 NRC report
- OpTIIX is enabled by the alignment of DoD and NASA interests and their investments in key enabling technologies
- OpTIIX is an effective cross-agency collaboration among JPL, JSC, and GSFC, with partners at STScI





To search for Earth 2.0

Back Up

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Current Status

- **Pre-Phase A Concept Study: July – Nov. 2011**
- **Phase A/B: Dec. 2011 – Sept. 2012**
  - Systems Requirement Review on March 20, 2012
  - PDR in Sept. 2012
  - Planning for FY15 launch (in 3 years) and first light, assuming ideal FY12 funding.
- **Accomplishments**
  - Have developed a cost-effective implementation plan consistent with class-D, technology demonstration mission
  - Established mature telescope concept, optical description, and optical interfaces with FGC, WFS&C, Imaging Camera
  - Developed clear ISS interfaces, launch modules and configuration, robotic assembly concepts, feasibility analysis, viewing angles, and operations concept
  - Performed imaging performance & end-to-end performance simulations and analyzed gimbal, pointing and segment control performance
- **Challenges:**
  - Secure FY12 funding for long-lead procurement to protect 2015 launch readiness
  - Secure FY13-15 funding commitment
  - Balance telescope ISS operational performance vs. complexity and cost
    - Pointing stability and image quality vs. gimbal performance
    - Mirror optical stability vs. orbital thermal environment
    - Science utilization requirements vs. low cost, class D, technology demonstration

OpTIIX (Optical Testbed and Integration on ISS eXperiment)

STATUS QUO

- Launching future large space telescopes with conventional monolithic or pre-assembled segmented mirrors faces substantial scaling challenges including
  - Manufacturability and stability of precision optics and structures
  - Testing in 1-g
  - L/V throw weight & fairing size
  - Complex, precision on-orbit deployments
  - Long term performance
  - High cost

NEW INSIGHTS

- A completed International Space Station and it's supporting infrastructure
- Nanolaminate Active Mirrors and Laser Metrology
- Multi-segment telescope wave front detection and correction capability

PROBLEM / NEED BEING ADDRESSED

Lightweight, actively controlled telescope systems will be challenging to test fully in a 1-g environment; low-cost access to space, possibly including use of the ISS, will open key opportunities for maturing the TRL of the technology

PROGRAM DESCRIPTION:

- A modularized, actively controlled, robotically assembled, scalable, segmented telescope architecture demonstrated on ISS
  - 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 (~millimeter precision) and aligned, figured and controlled to optical tolerances (~nanometer precision)
  - Can serve as an on-orbit testbed for future NASA telescope and science instrument development and as a center piece for STEM outreach.

QUANTITATIVE IMPACT

- 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

PROGRAM GOAL

- OpTIIX operating on ISS by mid-decade will
  - Advance our ability to build large telescopes to explore the universe and look for life beyond our planet by at least a decade
  - Provide demonstration for the next Astrophysics Decadal Report (2018; 2019)

NASA SPACE TECHNOLOGY ROADMAPS AND PRIORITIES
Restoring NASA's Technological Edge and
Paving the Way for a New Era in Space

Reemphasized the key finding made in 2009:

A strong advanced technology development foundation is needed also to enhance technology readiness of new missions, mitigate their technological risks, improve the quality of cost estimates, and thereby contribute to better overall mission cost management…The United States is now living on the innovation funded in the past and has an obligation to replenish this foundational element. (NRC, 2009, pp. 56-57)

Committee for NASA Technology Roadmaps
Aeronautics and Space Engineering Board
Division on

And in 2012:

Currently available technology is insufficient to accomplish many intended space missions. Consider the following examples…

Future space science missions capable of addressing the highest-priority goals in astrophysics will need a new generation of lower-cost astronomical telescopes that can utilize advanced coolers and camera systems, improved focal-plane arrays, and low-cost, ultra-stable, large-aperture mirrors. (NRC, 2012, 1-1, 1-2)

EDITORIAL CORRECTION

OpTIIX is Well Aligned with the Technology Priorities and Recommendations of the NRC

- Excerpts from **"NASA SPACE TECHNOLOGY ROADMAPS AND PRIORITIES - Restoring NASA's Technological Edge and Paving the Way for a New Era in Space"- NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES (2012)** **(**Selected text is highlighted in blue by the authors of this presentation for emphasis**)**

Top Technical Challenges for Technology

C2) **New Astronomical Telescopes**: Develop a new generation of astronomical telescopes that enable discovery of habitable planets, facilitate advances in solar physics, and enable the study of faint structures around bright objects….. (Page S-6)

TABLE S.3 Final Prioritization of the Top Technologies, Categorized by Objective (16 total arcoss objectives A,B,C……… (Page S-10)

Highest Priority Technologies for Technology Objective C

Optical Systems (Instruments and Sensors) (8.1.3)
High Contrast Imaging & Spectroscopy Technologies (8.2.4)
Detectors and Focal Planes (8.1.1)
Lightweight & Multifunctional Materials & Structures (X.2)
⋮

8.1.3 Optical Systems (Appendix K-9)

Two optical systems technologies are of particular interest: active wavefront control…..Active wavefront control enables the modification of mirror figure and alignment in response to external disturbances. It allows automated on-orbit alignment of optical systems and the use of lightweight mirrors and telescopes…..Because lightweight, actively controlled telescope systems will be challenging to test fully in a one-g environment, low-cost access to space, possibly including use of the ISS, will open key opportunities for maturing the TRL of the technology….Access to the ISS may be helpful as a testbed for development of active wavefront control.