National Aeronautics and Space Administration

Early Stage Technology Workshop

Astrophysics and Heliophysics

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Configurable Aperture Space Telescope

NASA Ames Research Center
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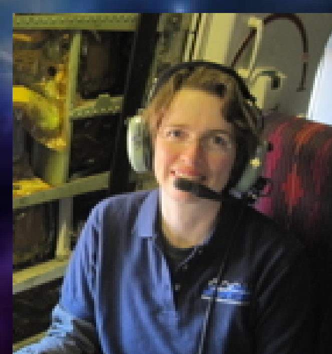
Research Astrophysicist



TECHNOLOGY DRIVES EXPLORATION

Company/Research Overview

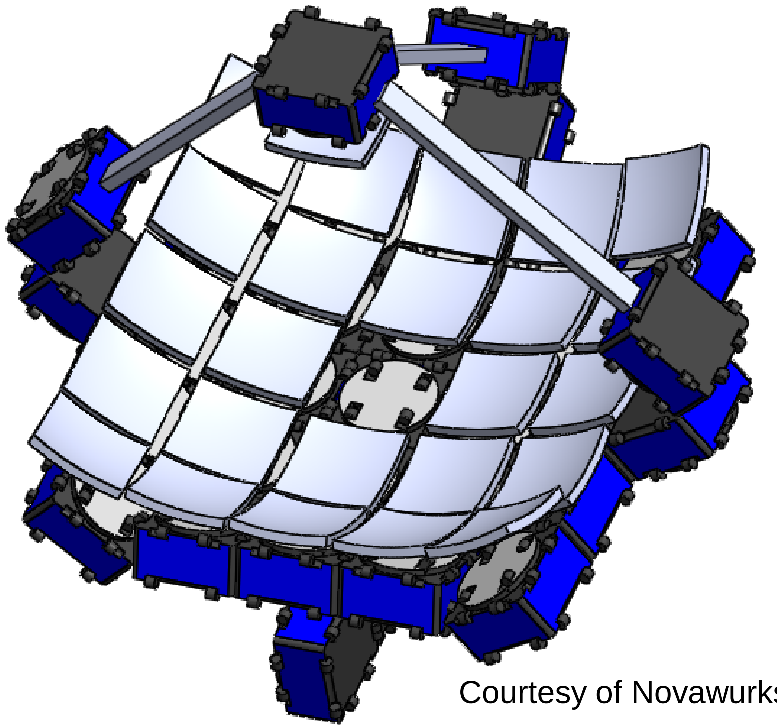
- NASA Ames Research Center, Moffett Field, CA
- Founded December 20, 1939 (NACA)
- 2500 employees
- Annual budget $857M
- Area expertise
  - Entry systems, Supercomputing, NextGen air transportation, Airborne science, Low-cost missions, Biology & astrobiology, Exoplanets, Autonomy & robotics, Lunar science, Human Factors, Wind Tunnels
- Government Lab
- Adjacent NASA Research Park (NRP)

http://www.nasa.gov/centers/ames/home/

Ames Research Center

Configurable Aperture Space Telescope (CAST)

- Dec 2014, awarded $45K Ames Center Innovation Fund to evaluate an optical and mechanical concept for a novel implementation of a **segmented telescope** based on **modular**, **interconnected small sats** (satlets).
- Current TRL is 2.
- Sept 2015 Target TRL 3.
  (1) Demonstrate 2x2 mirror system and validate our optical model and error budget
  (2) Provide strawman mechanical architecture and structural damping analyses
  (3) Derive future satlet-based observatory performance requirements



Courtesy of Novawurks

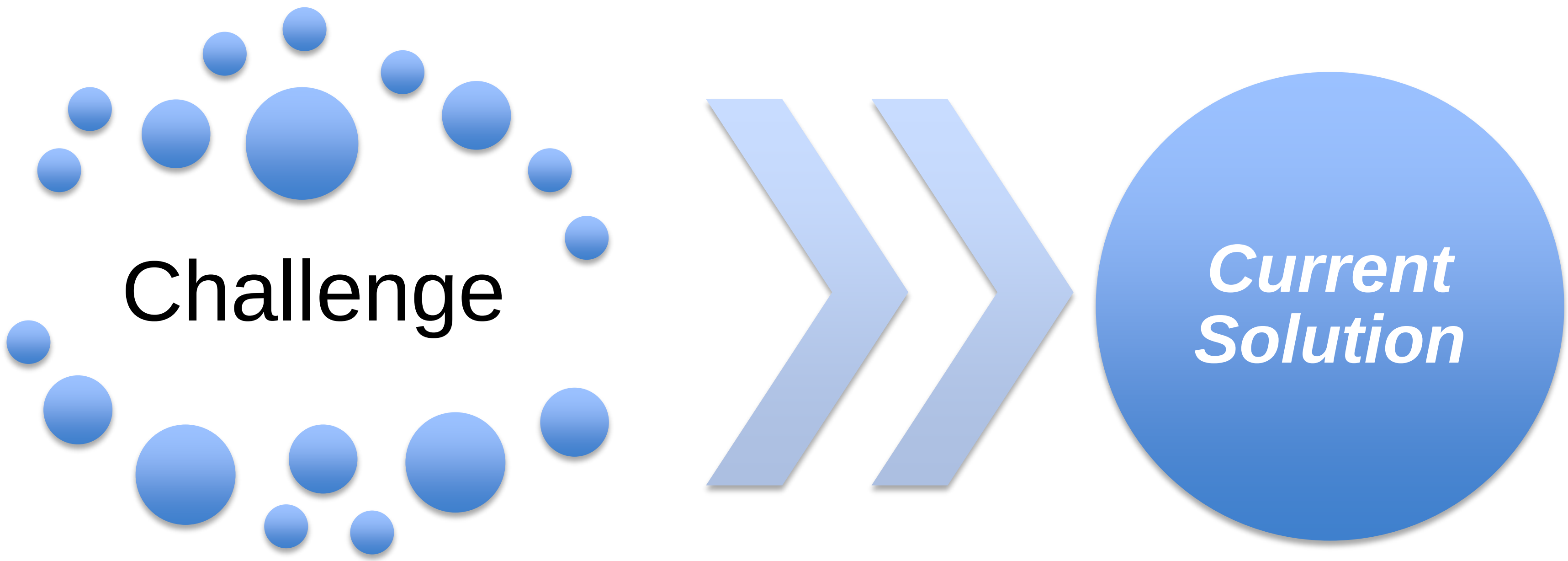
Team Members (NASA Ames)

Kimberly Ennico – PI/science | Eduardo Bendek – optical engineer

Kenny Vassigh – technologist/system engineer | Zion Young – mechanical engineer

Dana Lynch – optical testing

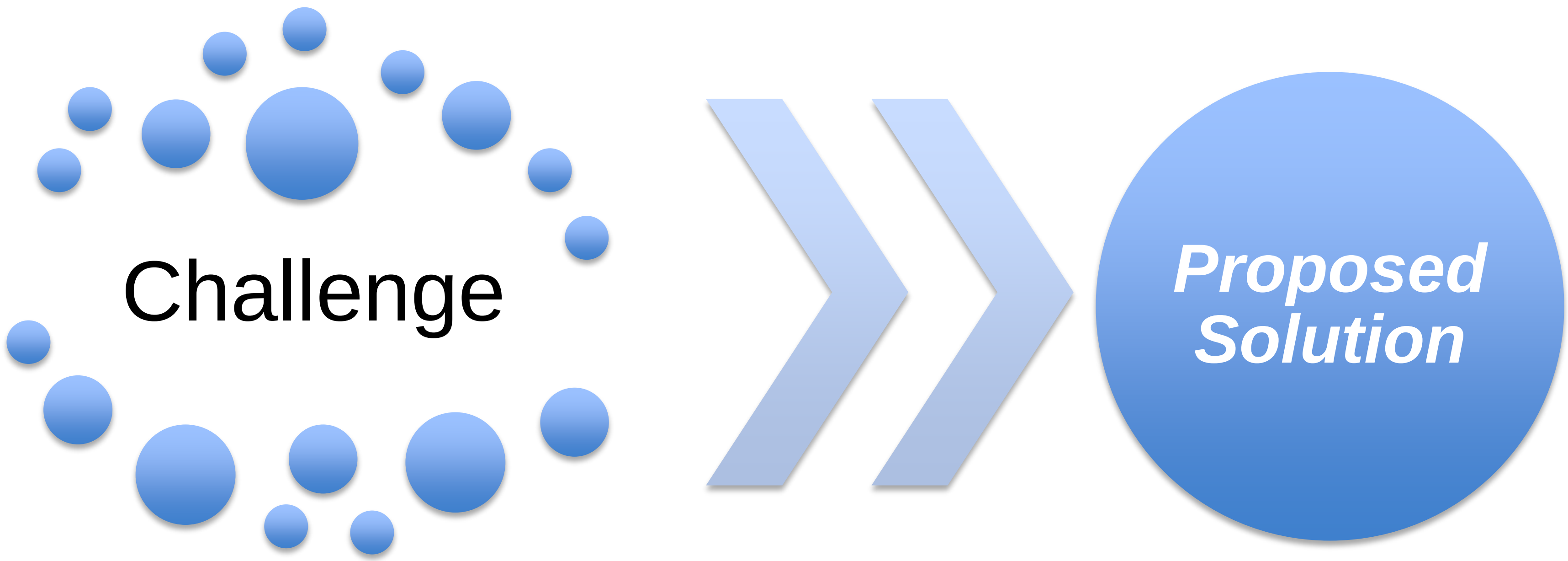
Why CAST?



- Limited number of meter class space telescopes with fixed instruments and high development cost

- Hubble (due to retire in a few years) is our visible wavelength space telescope workhorse
- JWST (fixed instrumentation) to launch 2018
- Always a new-build telescope per SMD explorer program winner

Why CAST?



- Limited number of meter class space telescopes with fixed instruments and high development cost

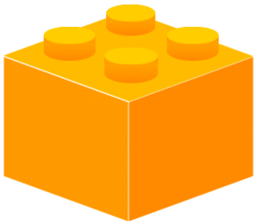
- Use small and lower-cost, ***identical*** building blocks
- Customize telescope performance for the science cases and also ***enable aperture growth (in orbit)***.

Can we MERGE a modular telescope design with a modular architecture?

Let's LEVERAGE existing segmented telescope concepts

And INFUSE emerging tech (satlet architecture)

MODULAR



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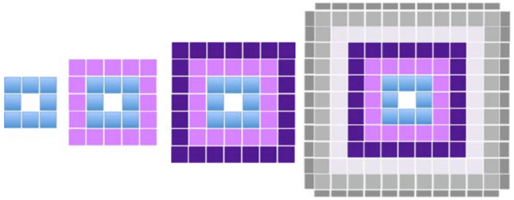
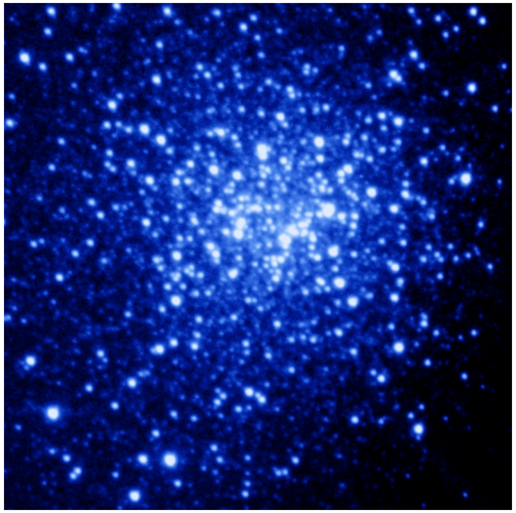
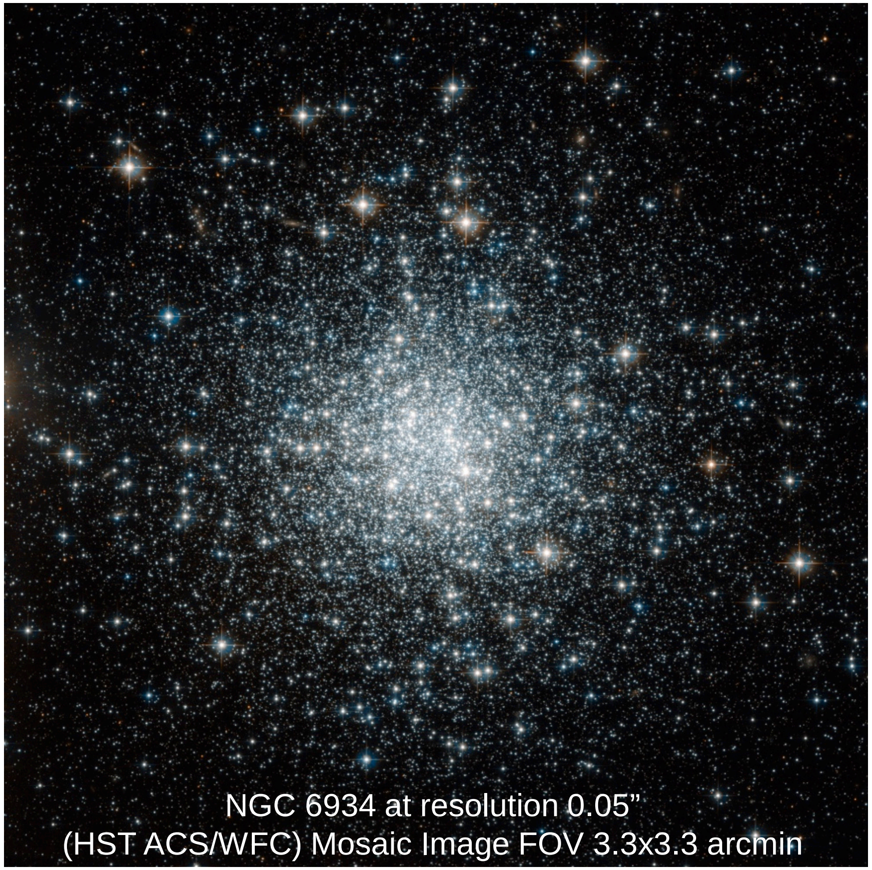


Telescopes in Space – Hubble Class

With the retirement of the Hubble Space Telescope (HST) in a few years, access to a visible-wavelength sub-arcsecond imaging platform from space will be in high demand.

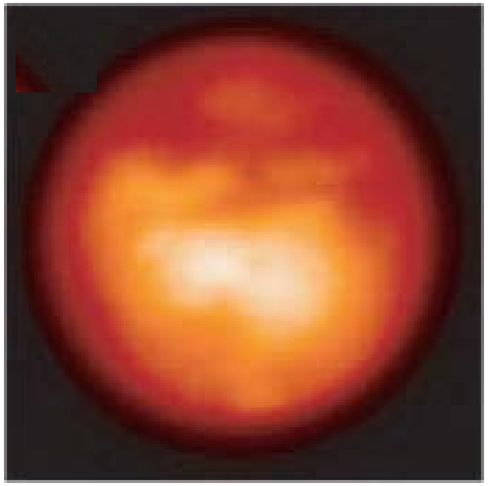


NGC 6934 at resolution 0.6”
(Gemini N/no AO)
Image FOV 105x105 arcsec

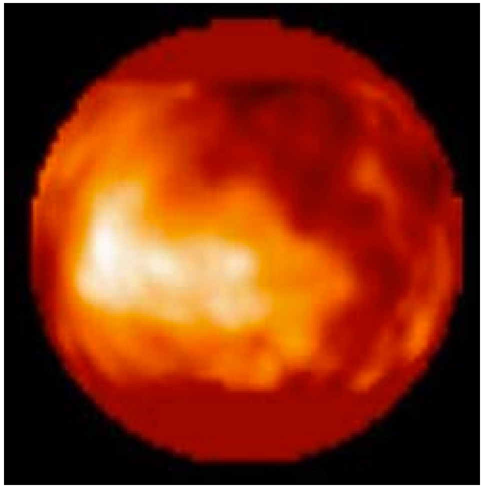


NGC 6934 at resolution 0.05”
(HST ACS/WFC) Mosaic Image FOV 3.3x3.3 arcmin

Telescopes in Space – Hubble Class



Titan at resolution 0.1”
(Keck, K’ image)

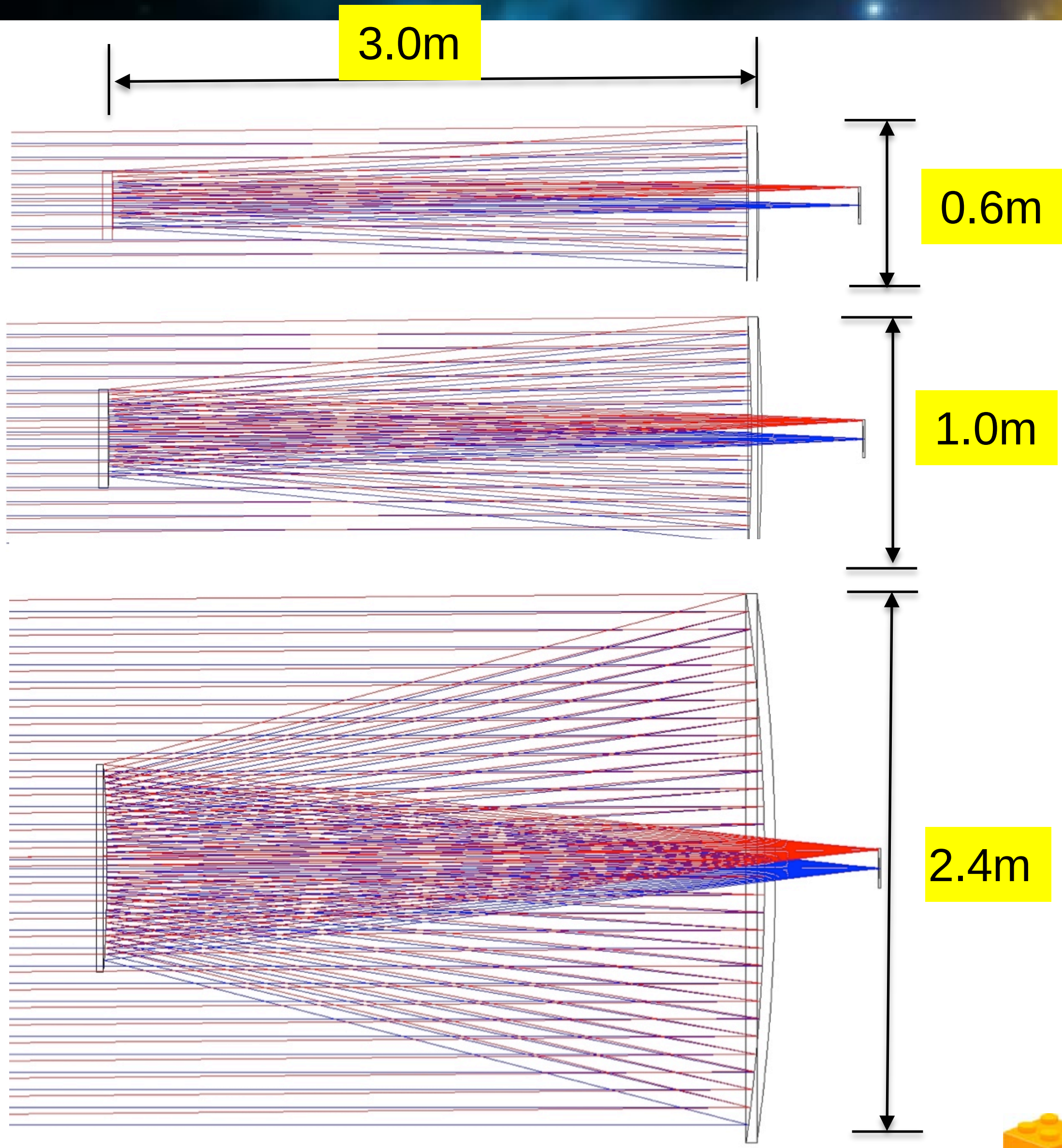


Titan at resolution 0.05”
(HST WFPC2, NIR)

Example 1.0m-2.4m diameter
CAST Science Applications

- Detect 15 m diameter 0.1 albedo Near Earth Objects at 0.10 AU from Earth
- Resolve largest asteroids & Titan
- Map star formation regions
- Measure transiting exoplanet atmospheres
- Monitor AGNs & galaxy dynamics

CAST Optics: Scalable



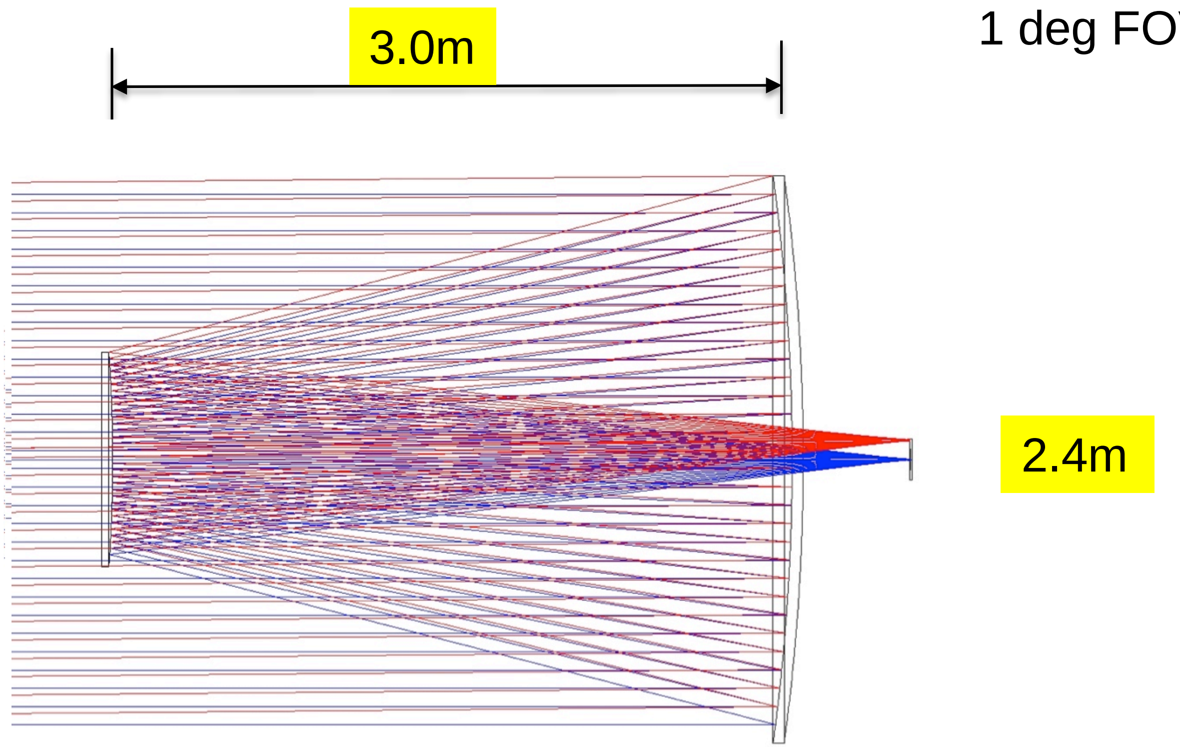
- Three different apertures for a common radius of curvature R=11.4m
- Large FoV, aperture independent
- 1° FoV to left (Red rays mark 30 arcsec; Blue rays are on-axis)

Base satlet size (20 x 20 x 10 cm)

CAST Optics: Scalable

Concentric spherical architecture: Grow Aperture like Tree Rings

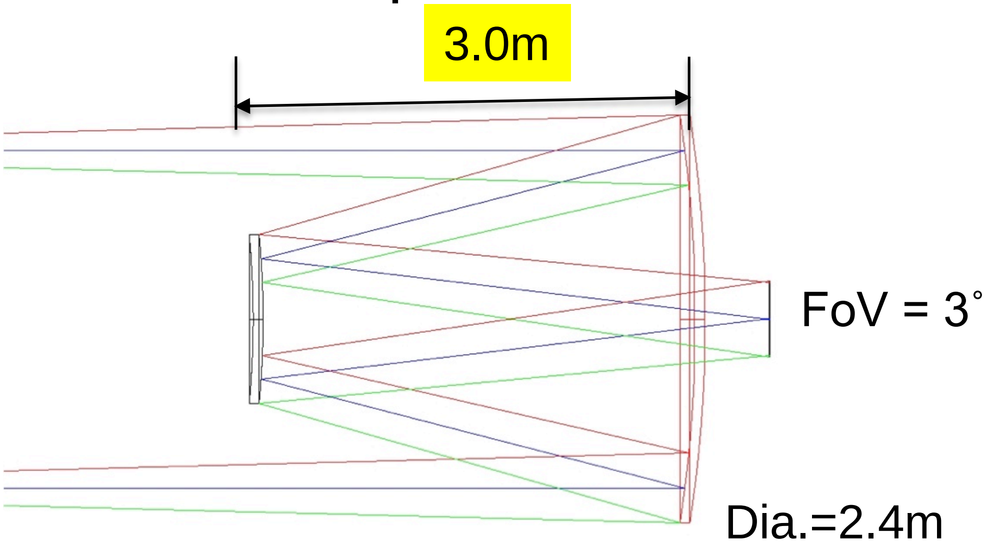
1 deg FOV Strawman

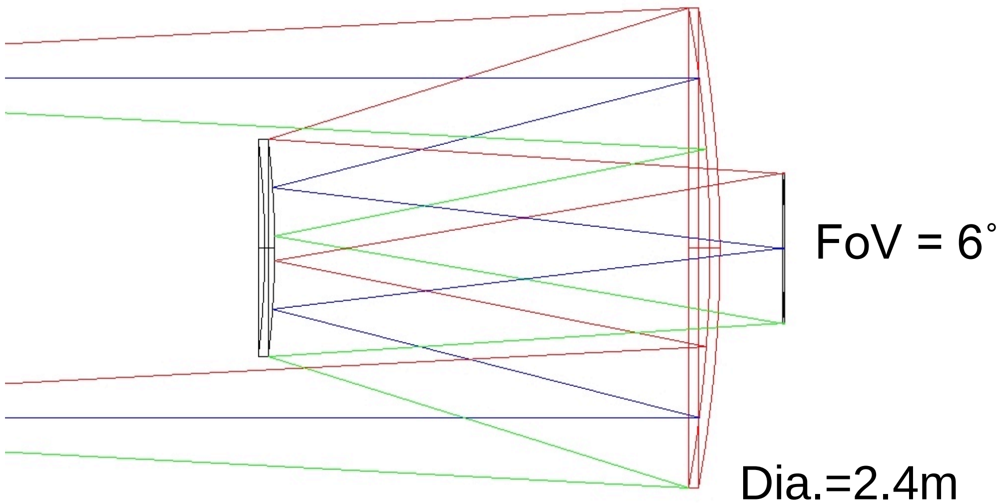


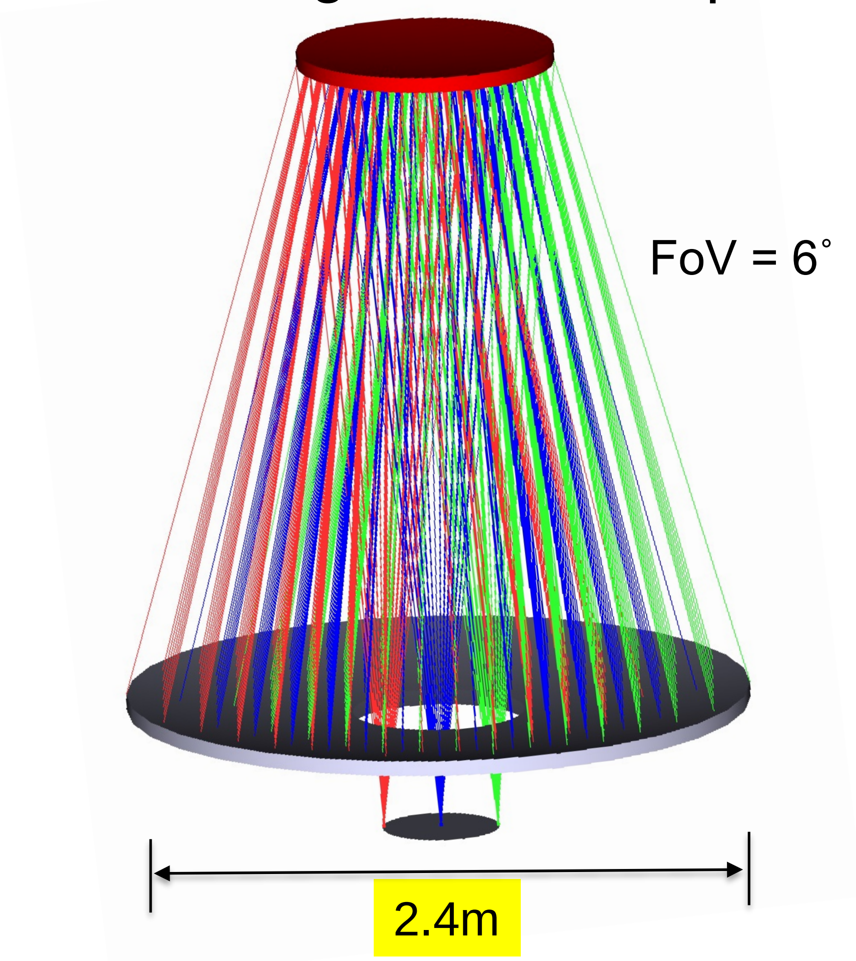
Base satlet size
(20 x 20 x 10 cm)

CAST Optics: Scalable

Concentric spherical architecture: Enables Large FoV concepts





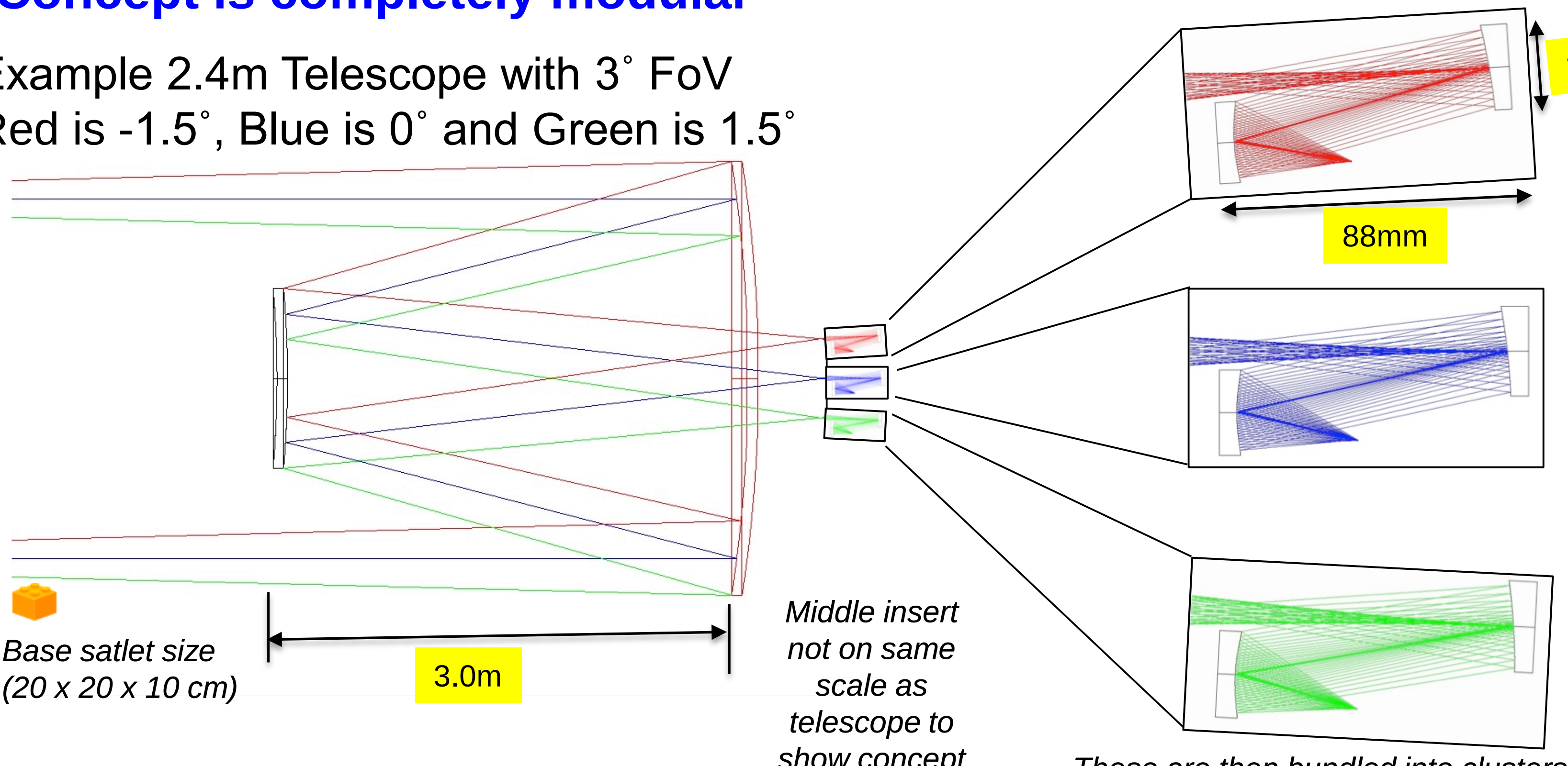


Base satlet size
(20 x 20 x 10 cm)

CAST Optics: Scalable, Modular

- Adopting approach proposed by Burge & Angel (2003)
- Correctors are arranged in groups, each correcting a FoV of ~4 arcminutes
- Correctors can be sized to fit as many as necessary to sample whole FoV
- Each corrector is placed on a concentric sphere
- Correctors are identical
- **Concept is completely modular**

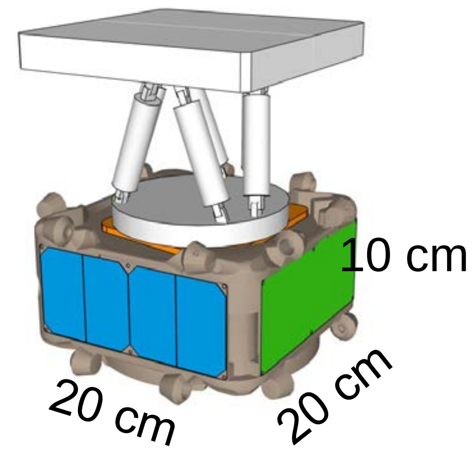
Example 2.4m Telescope with 3˚ FoV
Red is -1.5˚, Blue is 0˚ and Green is 1.5˚



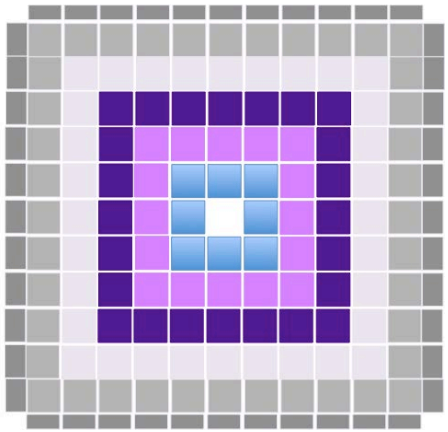
These are then bundled into clusters compatible with satlet-based backbone

CAST Mechanical: Modular

- Smartly-interconnected customizable "satlets"
- Highly-segmented architecture
  - Smaller segments be thinner (lighter), while still providing sufficient internal rigidity
- Telescope Concept
  - Dedicate one satlet per mirror segment each with its own active control support (tip/tilt/piston)
  - Secondary mirror supported/controlled by own satlet
  - Modular aspherical corrector optics and instrumentations are supported/controlled by own satlets
- Observatory Concept
  - Add appropriate satlet modules for power, data, control loop, etc.

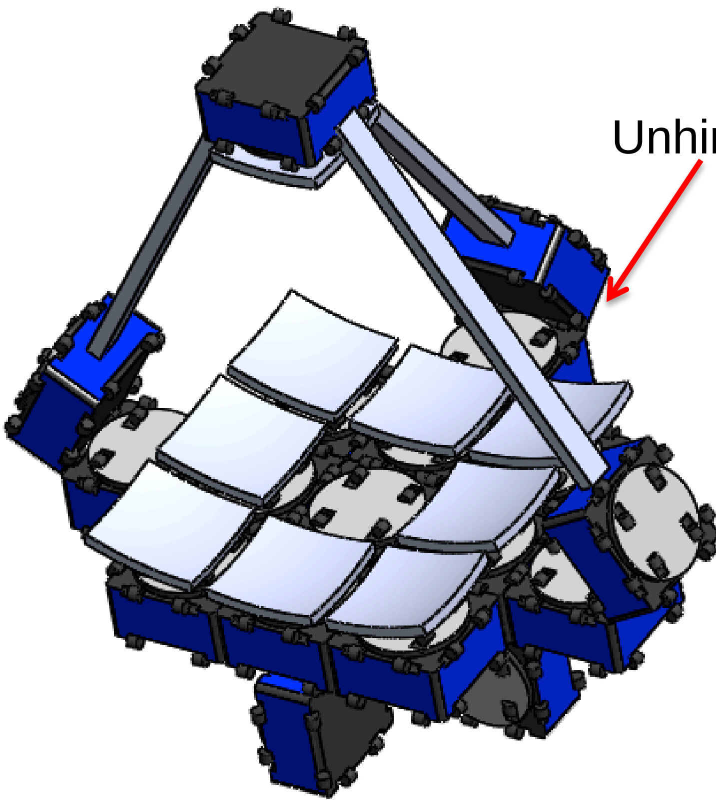


Courtesy of Novawurks

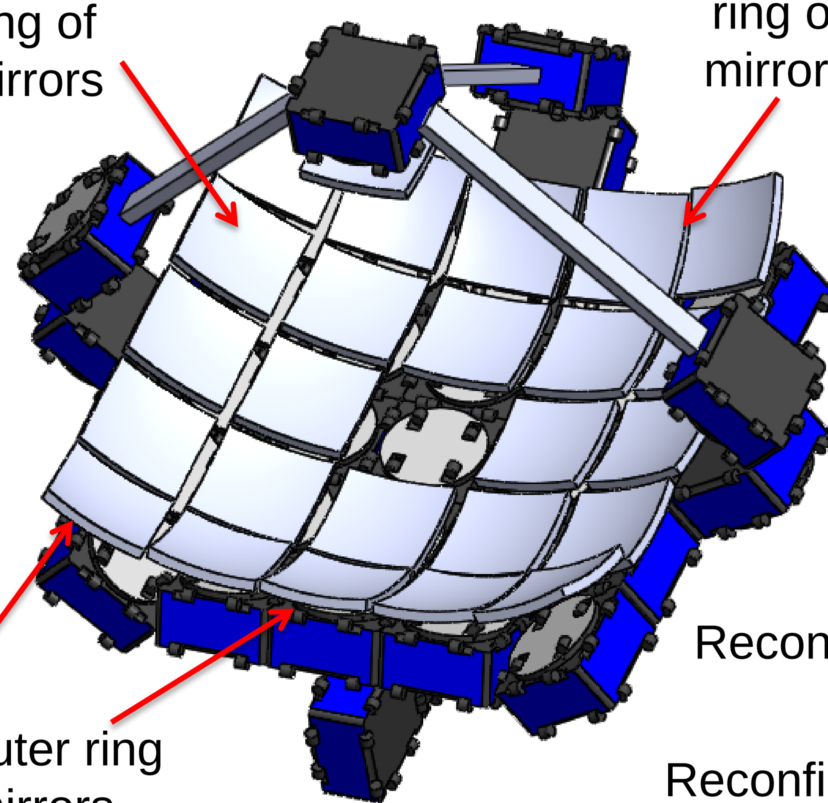


2.4m telescope
144-segmented primary

Configurable Aperture Space Telescope (CAST)



Telescope Diameter
0.6 m

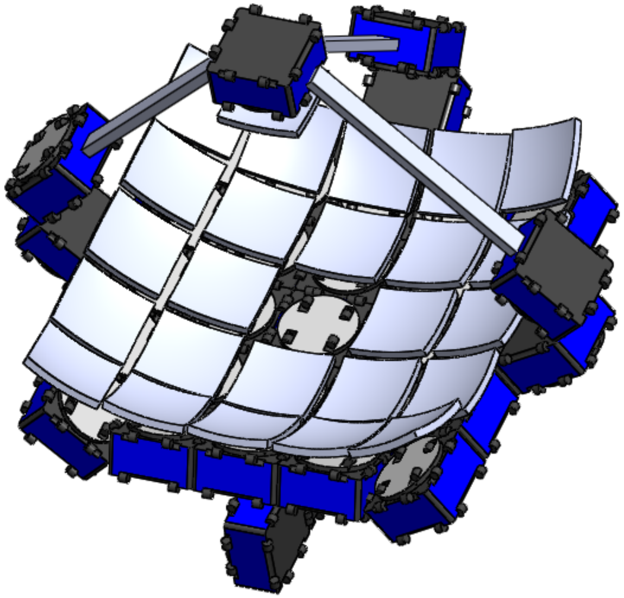


Telescope Diameter
1.0 m

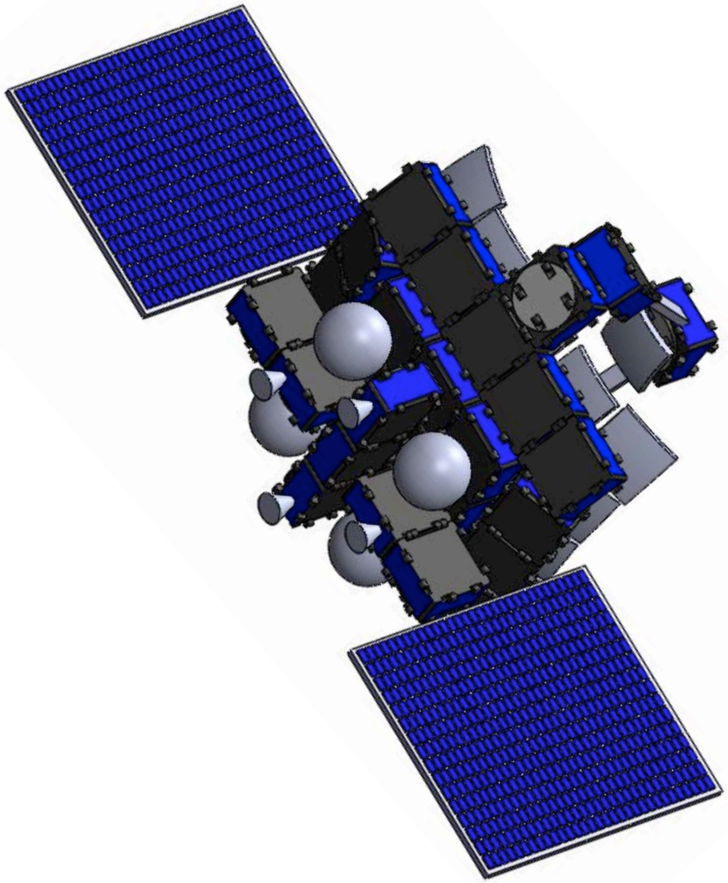
Courtesy of Novawurks

CAST Mechanical: Modular

CAST as one example for a future fully-modular space observatory



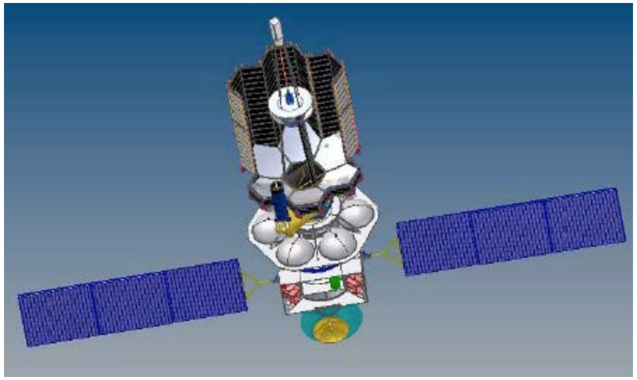
CAST Primary
1.0 m concept



Add propulsion modules, solar panels, etc. all smartly-interconnected

Courtesy of Novawurks

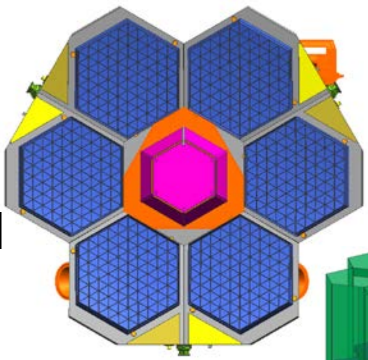
SPOT/Spherical Primary Optical Telescope

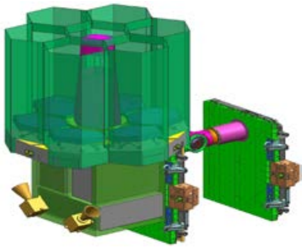


- GSFC/Internally funded since 2003
- Goal to develop a robust architecture to reduce cost of large-aperture, segmented primary mirror space telescopes.
- Achieved basic mirror performance 2010 with testbed (three segments)
- Spherical primary mirror concept restricts FOV (usages: Planetary camera, LIDAR, Laser Comm)
- **New Tech**: High-rate, center of curvature, iterative transform phase diversity phasing algorithm; low-cost mirror segment design
- **Assoc. Tech**: ALMOST (MIT/GSFC) to assess in-space robotic assembly of SPOT using ISS-Spheres.
- **Telescope Concept**: 3.5m (six 0.86m hexagonal mirrors) spherical primary testbed; a 30m concept is architected differently.

Where CAST differs: scalable on orbit, capable wide/narrow FOVs, smaller segment/primary size ratio, identical mirrors for all optics

OpTIIX/Optical Testbed and Integration on ISS eXperiment

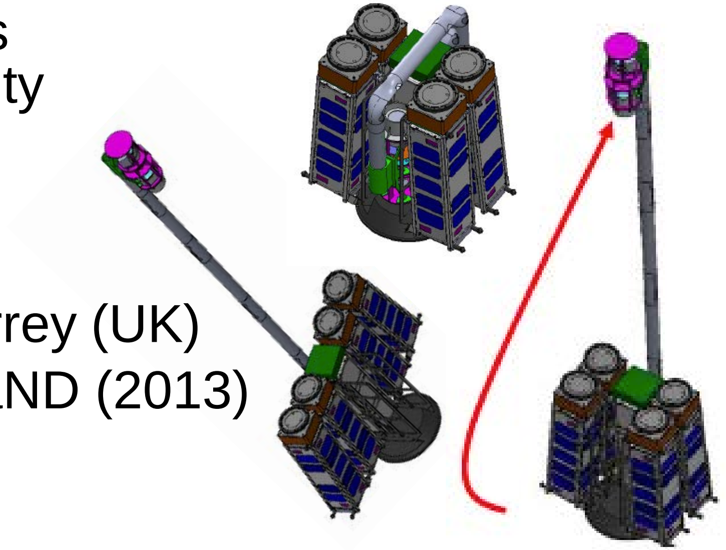




- An ISS based testbed towards a next generation, large aperture UV/Optical Space Telescope
- Collaboration between JPL, JSC, GSFC, and STScI
- Pre-Phase A concept study: July – Nov 2011
- Phase A/B: Dec 2011 – Sept 2012
- Progress and funding beyond 2012 is unknown
- **New Tech**: Use of lightweight mirrors; lower areal density, SiC based Actuated Hybrid Mirrors, on-orbit assembly in conjunction with an active optical system
- **Telescope Concept**: 1.45m aperture, 50cm segments assembled on orbit.

Where CAST differs: scalable on orbit, capable wide/narrow FOVs, smaller segment/primary size ratio, identical mirrors for all optics, spherical optics

ARREST/Autonomous Assembly of a Reconfigurable Space Telescope



- Cubesat mission to demonstrate autonomous rendezvous & docking, reconfiguration & ability to operate a multi-mirror telescope in space
- Sponsored originally by Keck Institute for Space Studies (2009)
- Collaboration between Caltech & Univ. of Surrey (UK)
- Spacecraft based on SNAP-1 (2000) & STRaND (2013)
- Lab-based Docking research 2013
- Planned Launch 2015
- **New Tech**: Autonomous deploy & re-acquire mirror-sats, docking system (electro-magnets); deformable mirror technology
- **Telescope Concept**: 0.34m aperture, 10cm segments; then expand to 0.58m aperture by moving two mirrors.

Where CAST differs: identical mirrors for all optics, spherical optics, no deformable mirrors

Next Steps for CAST (post-CIF)

Phase II - Development of a ground based 3x3 segmented telescope prototype

- Telescope optical demonstration, optical performance, model validation
- Partnership opportunities for telescope design elements and components (i.e., mirror segments, correctors, actuation mechanisms, deployment mechanisms, satlets)

Phase III: Apply lessons learned from Phase II to develop a proto-qual 3x3 segmented telescope

- Space qualified subsystems and components; Environmental testing
- Partnership opportunities for building the proto-qual telescope

Phase IV: Flight demonstration in LEO

- Government and commercial partnership opportunities to build and fund a LEO demonstration of the segmented telescope

Current Development Status of Technology

CAST tech development relevant to two NASA Technical Areas:

TA12: Light-weight structures and materials, modular structures, deployable interfaces

TA08: Mirror systems, structures, distributed apertures and optical components

What will it cost to advance this technology?

- Phase II: TRL 3 to TRL 4 $500K

Why should NASA, Industry, and other government agencies invest in this technology?

- Potential to provide low cost observatories to Government and Commercial
- Could open a new era in modular, flexible, and more frequent launch and deployment of meter class space telescopes
- Allow on orbit maintenance, aperture and instrument reconfiguration and/or re-deployment

Target Technology Market Applications

- Access to visible and/or UV wavelength space telescope with 1-meter or larger aperture for **NASA SMD Astrophysics and Planetary Science** community after retirement of HST.
- Development and deployment of small to medium size optical aperture observation systems relevant to **DARPA and DOD** missions.
- Deployment of optical aperture observation systems for Earth Science and Imaging, relevant to **NASA SMD Earth Science and NOAA** missions.
- Commercial interest in use of low cost Earth observation and data collection space assets is on the rise
  - **Google/Skybox**
  - **Planet Labs**
  - **SpaceX**
  - **Future emerging space companies**

Contacts

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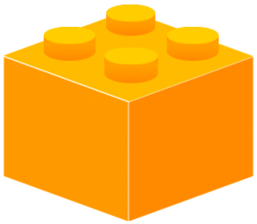
CAST

MERGEs a modular telescope design with a modular architecture

LEVERAGEs existing segmented telescope concepts

And INFUSEs emerging tech (satlet architecture)

MODULAR



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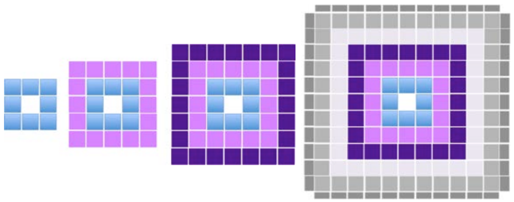
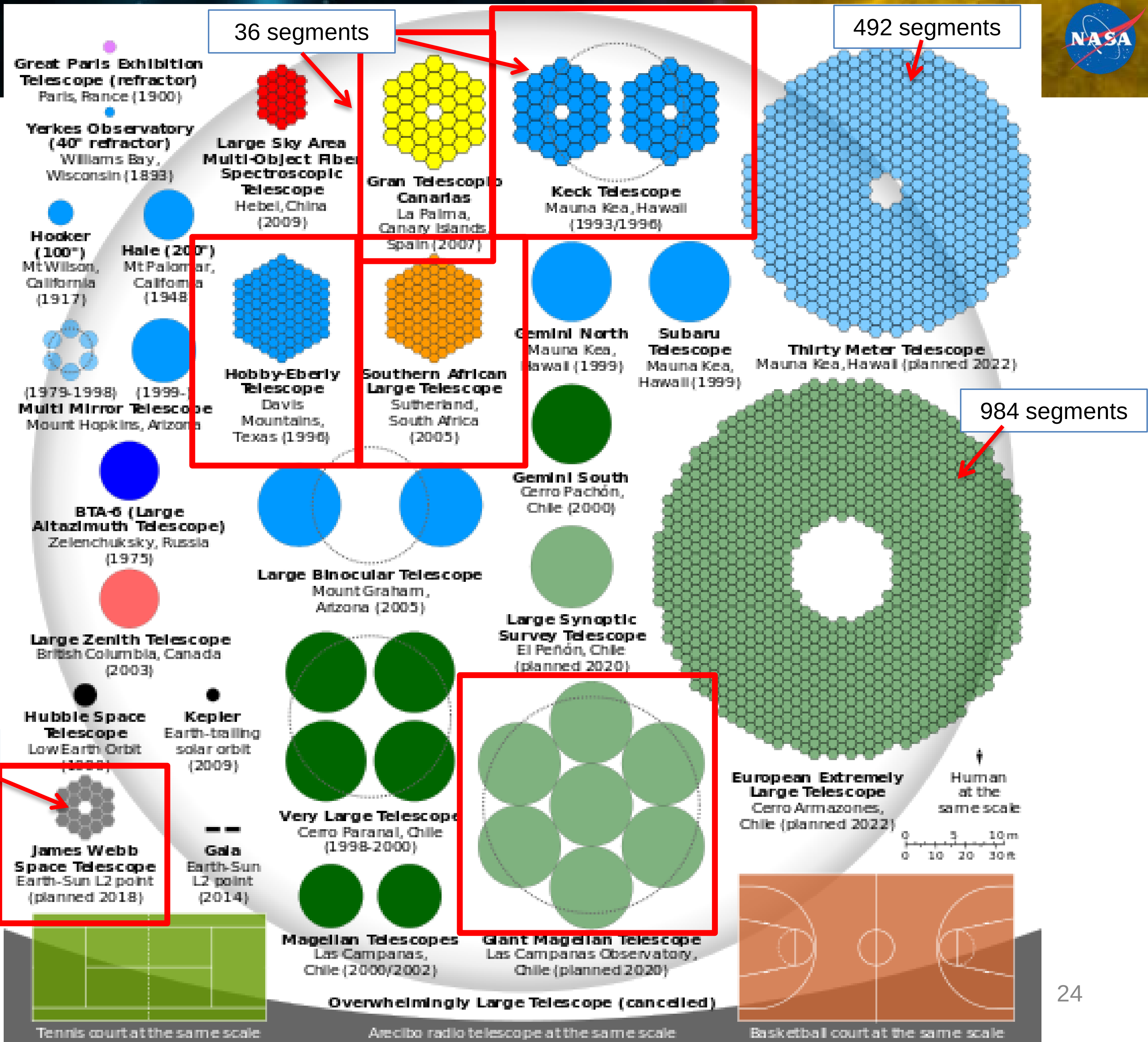


Back-up charts

Segmented Telescope are established technology



Summary of Ames Capabilities

Core technical competencies & expertise

- Low-cost space missions: From Cubesat missions to LCROSS, IRIS, LADEE
- Autonomy & Robotics: Intelligent Systems, Autonomy for Exploration, K10 Surface Telerobotics, Robonaut, SPHERES
- Exoplanets: Kepler, Coronograph tech development, TESS Science Ops
- Lunar Science: LCROSS, LADEE, Resource Prospector
- Airborne IR Astronomy: SOFIA

Manufacturing & Facility Capabilities

- Engineering Evaluation Laboratory (EEL): Provides engineering test and evaluation capabilities at proto-type, proto-flight, qualification and certification levels.
- Flight Processing Center (FPC): Facilities, equipment, supplies to carry out assembly, integration, and test of flight projects.
- Multi-Mission Operations Center (MMOC): Enables low cost mission operations
- Space Shop: Tools, machine shop, 3D print and prototyping capabilities