Jet Propulsion Laboratory
California Institute of Technology

In-Space Assembled Telescope (iSAT) Study

September 13, 2018

Study Members Telecon 9

Nick Siegler

Chief Technologist, NASA Exoplanet Exploration Program

Jet Propulsion Laboratory, California Institute of Technology

Rudra Mukherjee

Robotics Technologist

Jet Propulsion Laboratory, California Institute of Technology

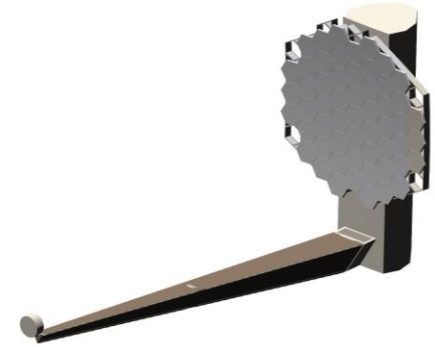
CL#18-5180

Today’s Agenda

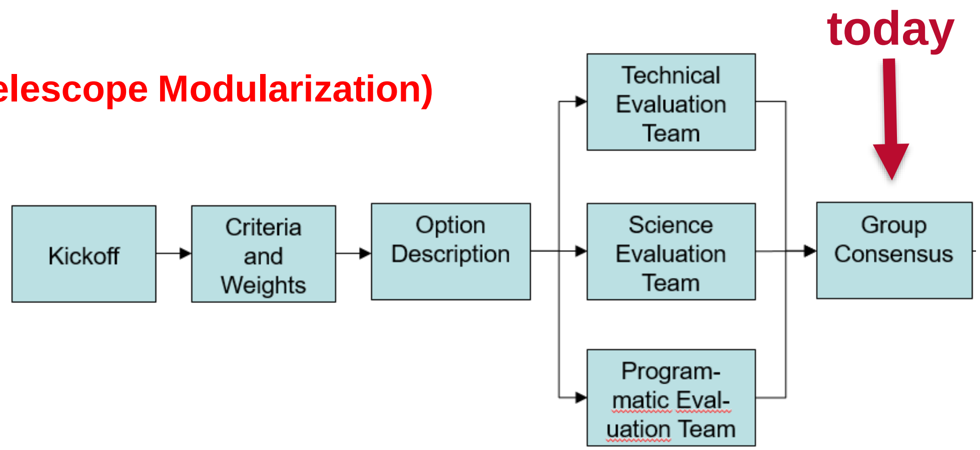
1. Upcoming schedule
2. Final recommendations for the structural trusses
3. Report out on stray light analysis
4. Recommendation for sunshade architecture
5. Final feedback/request to close out Activity 1a

Upcoming Schedule

iSAT Study Process



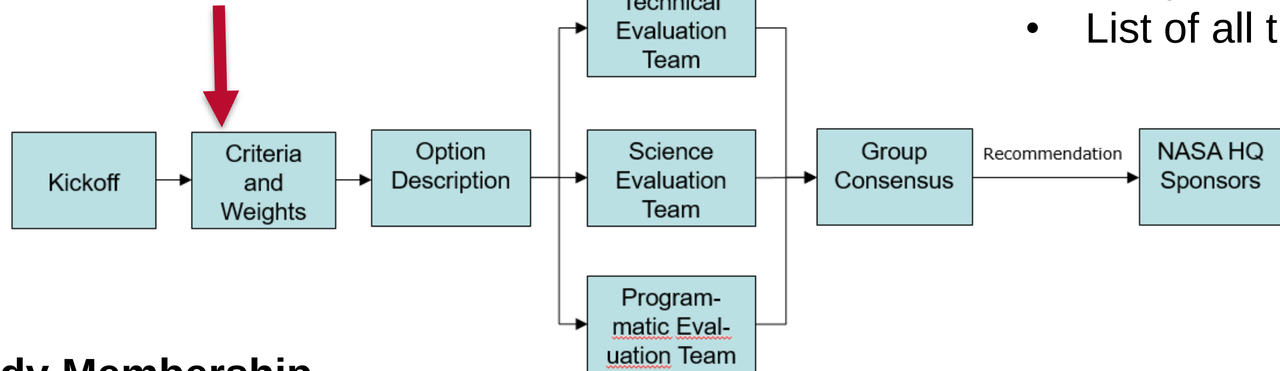
(Activity 1a – Telescope Modularization)



We're done when we concur on:

- CAD model
- Truss architecture options defined
- Scattered light analysis
- Sunshade architecture analysis
- List of all the modules

(Activity 1b – Telescope Assembly and Testing)



New Study Membership being formed more focused on robotics, orbital dynamics, assembly, and assembly platforms.

Face-to-Face at NASA LaRC Oct 2-4

Start planning Activity 2 (identifying cost and risk benefits)

Activity 1a
Analyses Report Out

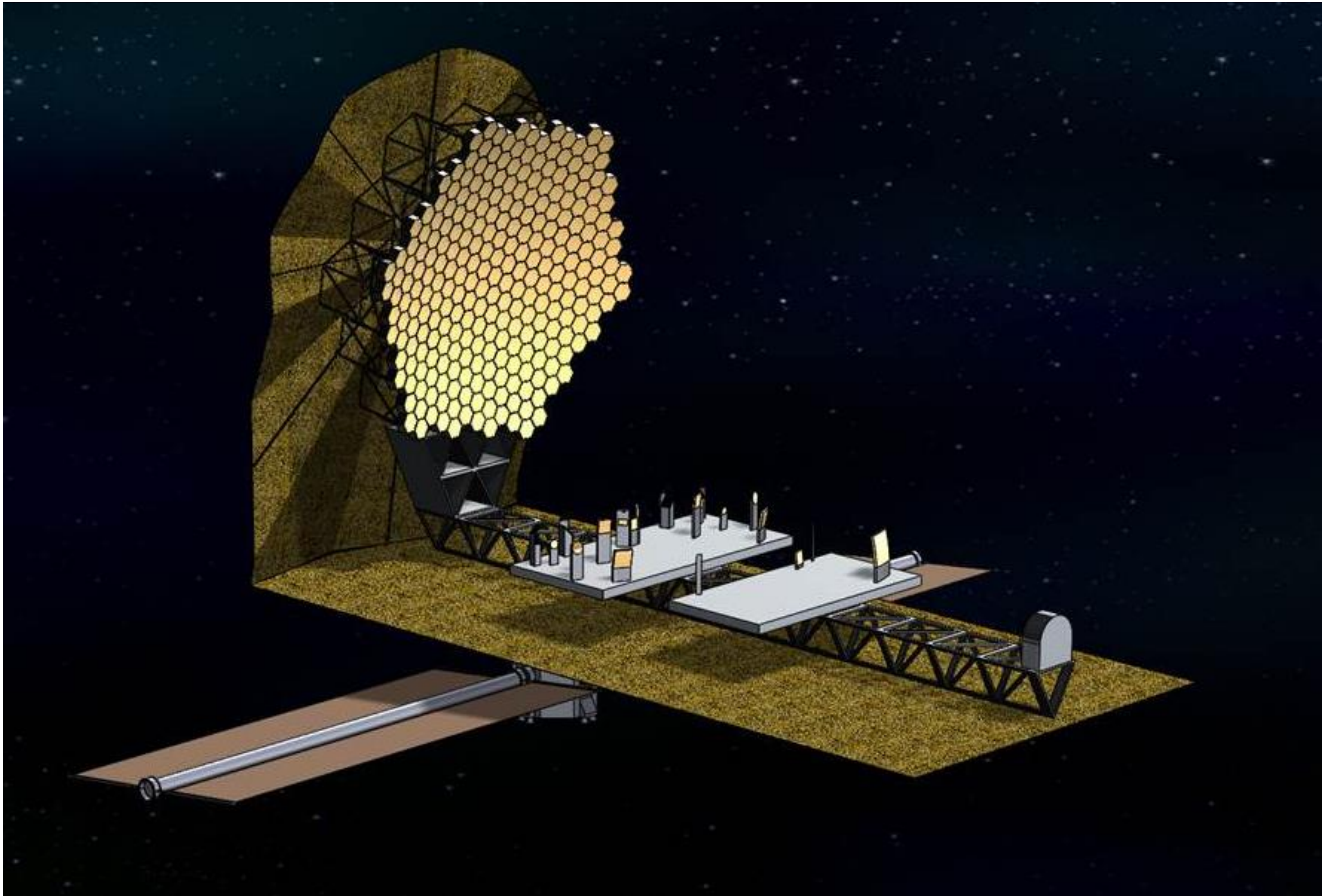
The relevant questions

- **What is the reference telescope optical design?**
- **What are the “notational” modules from which the reference telescope may be assembled?**
    - **Or alternates**
- **Are we consistent with the general approach to accommodating a CGI?**

Specific Analyses:

- **what is the ″notional″ truss design and its modules?**
- **what is the ″notional″ stray light suppression requirement?**
- **what is the “notional” light suppression architecture?**

Draft Design Concept for Modularized Telescope

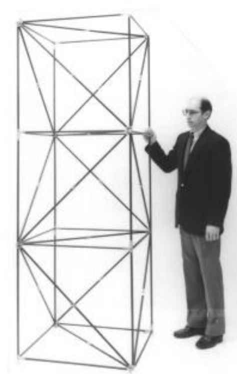


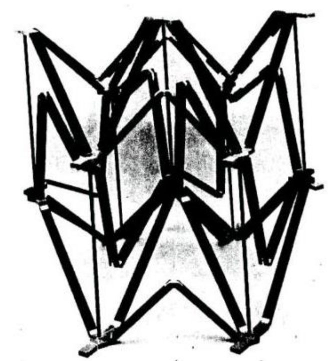
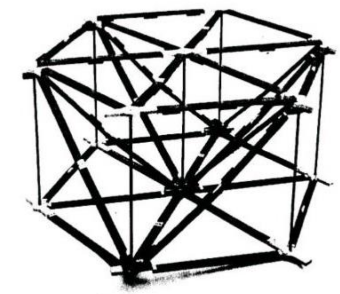
Truss Options

John Dorsey (NASA LaRC)
Rudra Mukherjee (JPL/Caltech)

Deployable Truss Modules





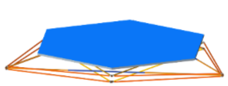
Possible to deploy large multi cell areas

Options:

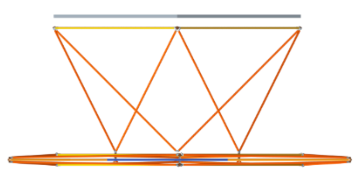
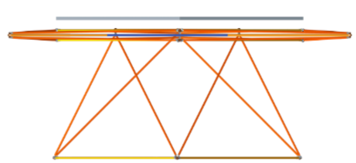
- Truss + Panels
- Truss+Panels+heat shield
- Truss then Panels then heat shield

Key Features:

- **Modules statically stable**
- **No repeated Members**
- **Load Paths ~through Center of Nodes**
- **Tunable "face" and "core" properties**
- **Supports ½ or full deployment**
- **Extremely versatile geometric design**
- **Extremely versatile structural design**

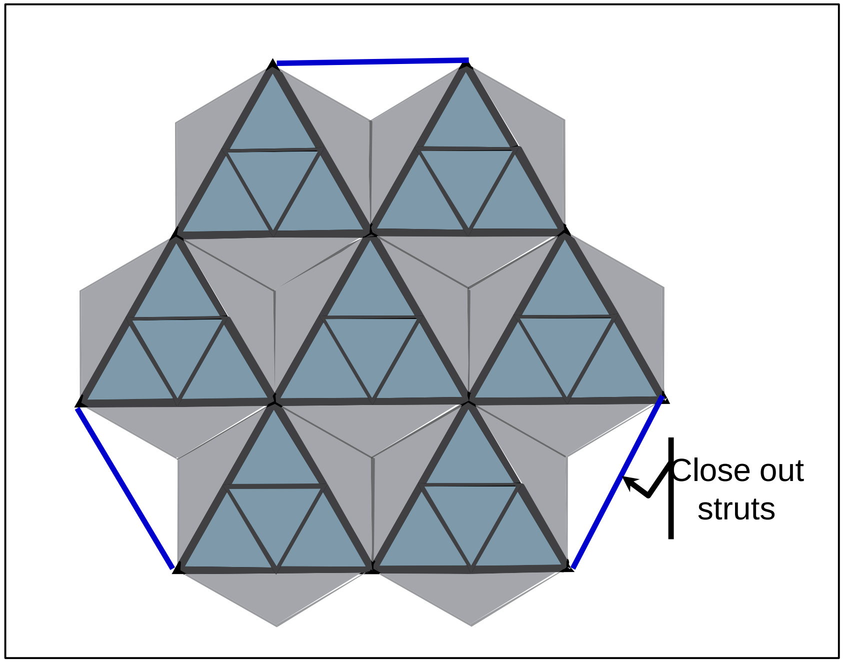
Packaged

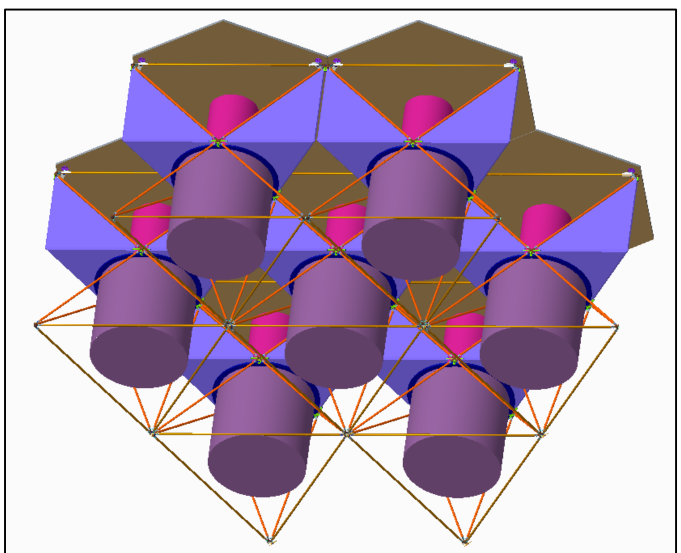



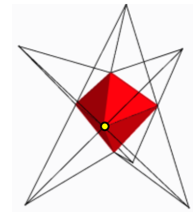
Partially Packaged

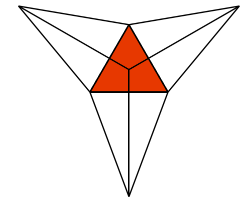
Tri Truss

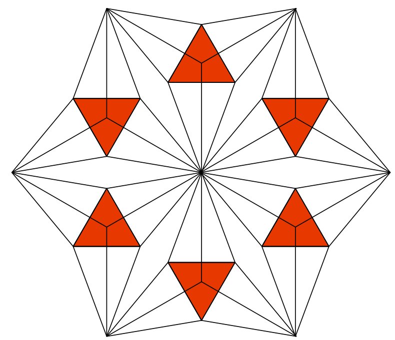
Tri Truss Packing

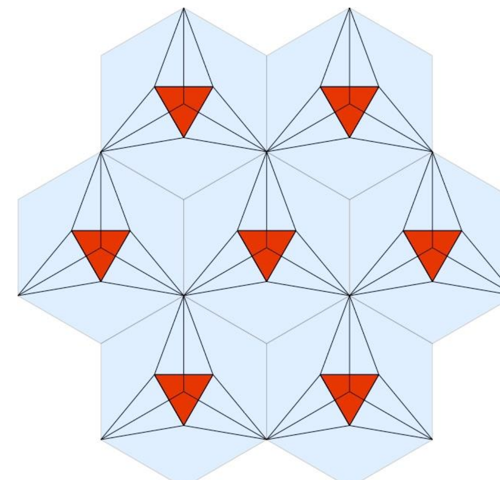


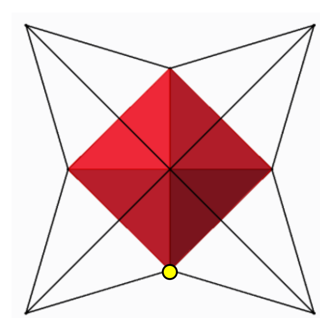


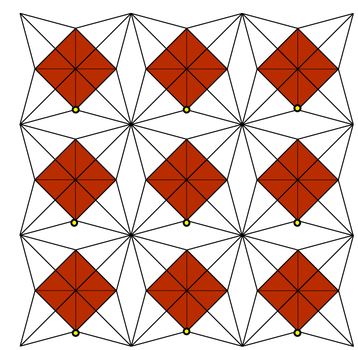




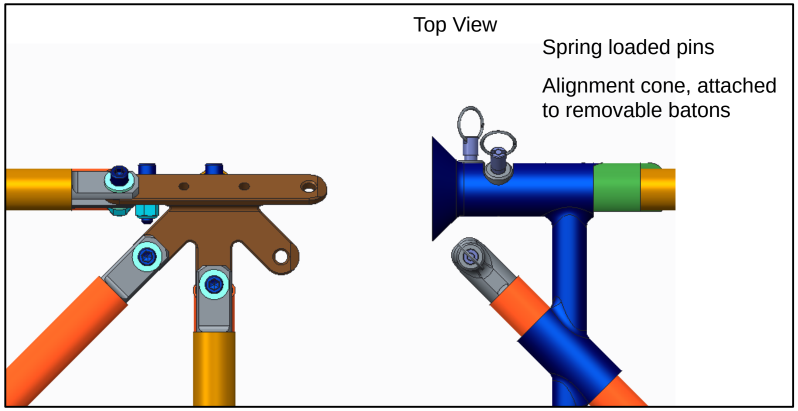


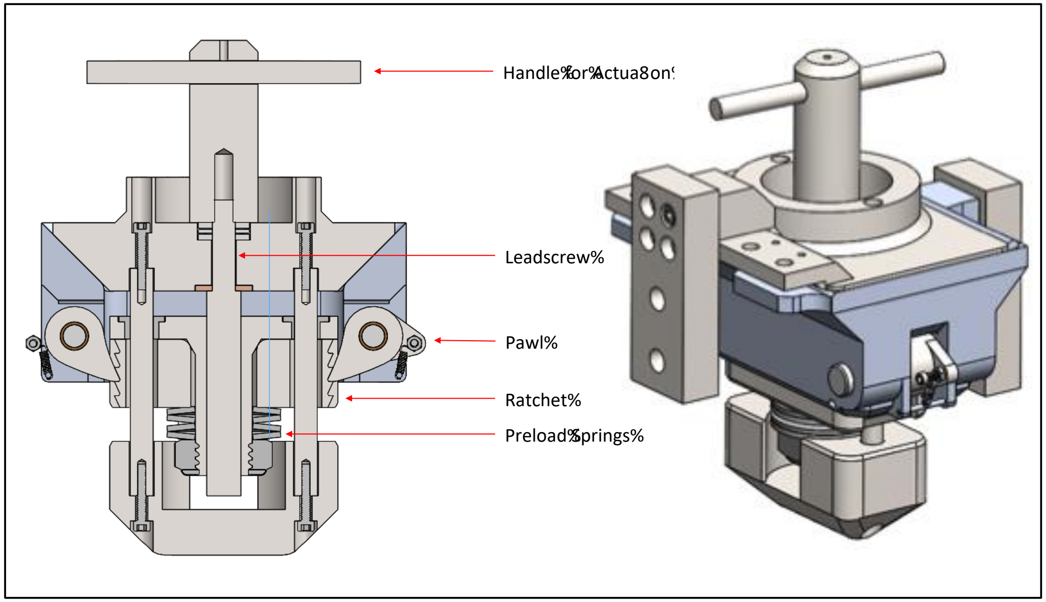






Representative Joints





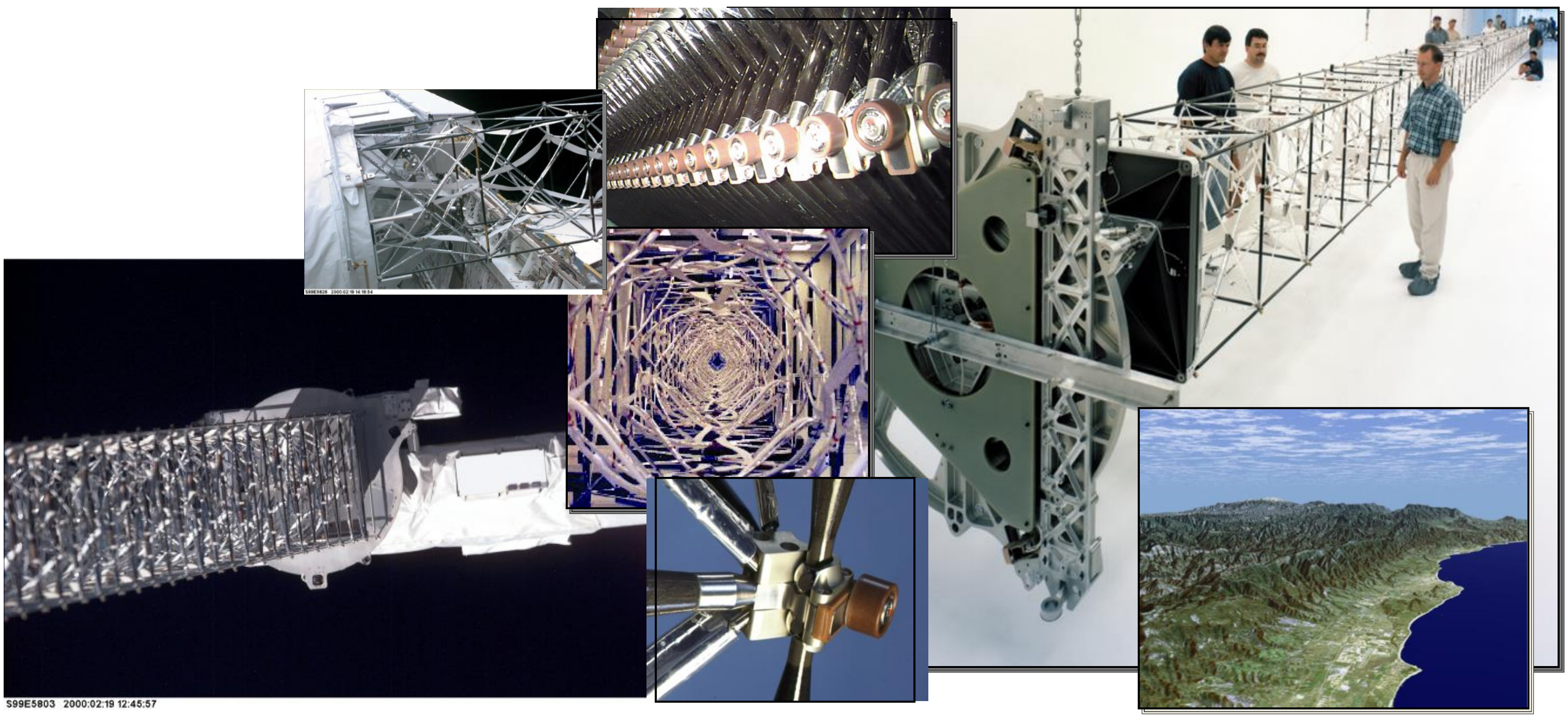
Deployable Structural System Flight Hardware Example
Shuttle Radar Topography Mission (SRTM)

ADAM 60m long Dimensionally Stable Structural System for SRTM

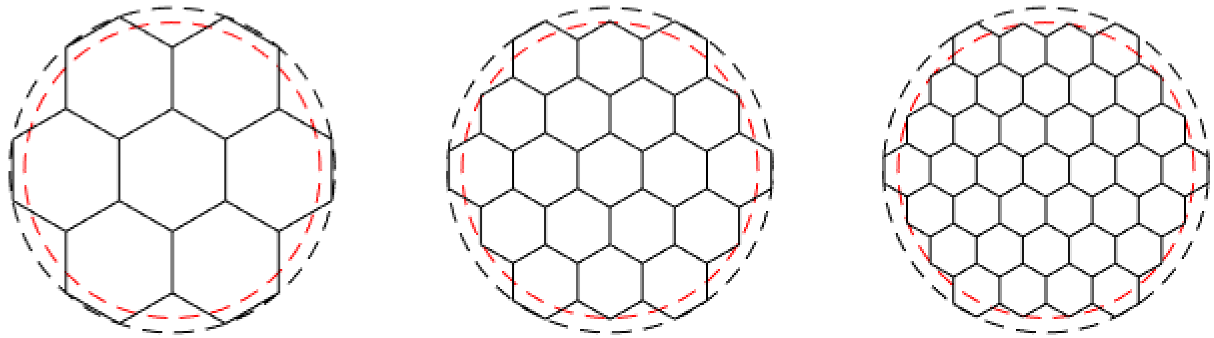
- SRTM mapped 80% of the Earth's topography in a single 11-day Shuttle Flight - Feb 2000
- Engineered/qualified for man-rated NASA missions
- Deployed/retracted 400-kg radar antenna 60-m from the Shuttle Cargo Bay
  - Including ~200-kg of electrical harnesses, coaxial & fiber optic cables along entire mast length
- Validated extreme stability and precision of ADAM technology

Measured Deployment Accuracy (Repeatability @ 60m)

Length	< ± 1.3 mm (from +66C to -60C)
Tip Translation in Shear	< ± 0.25 mm
Tip Twist in Torsion	< ± 0.02°
Tip Rotation in Bending	<< ± 0.005°

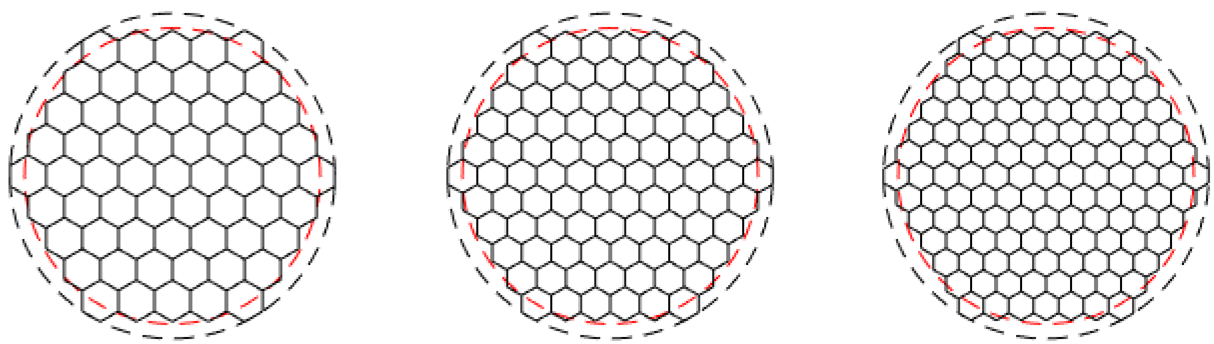


20m Truss Reflector Sizing



1 Ring 2 Rings 3 Rings

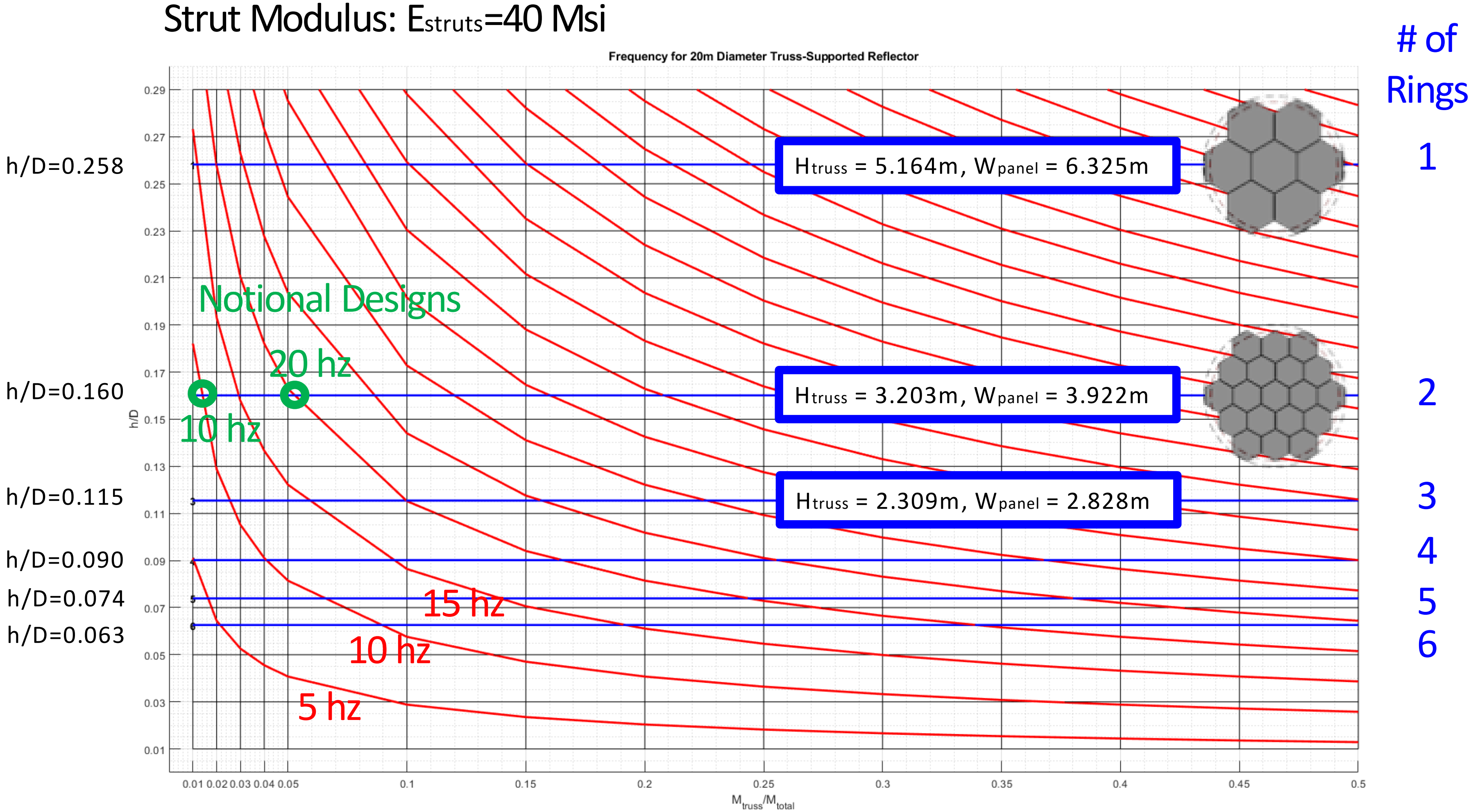
Slide Credit: Thomas Jones et.al. LaRC



4 Rings 5 Rings 6 Rings

Equilateral Tetrahedral (equal length struts) truss structure is used in these first analyses p.2-7, thus the depth of the reflector is directly related to the panel size / # of rings. (I.e. lower # or rings = bigger panels = deeper truss). The plots on p.8-10 show analyses for variable depth truss structures.

Strut Modulus: E_{struts}=40 Msi



Tetrahedral 20m truss reflector: Depth / Diameter vs. M_{truss} / M_{total} for 1st global *freq*

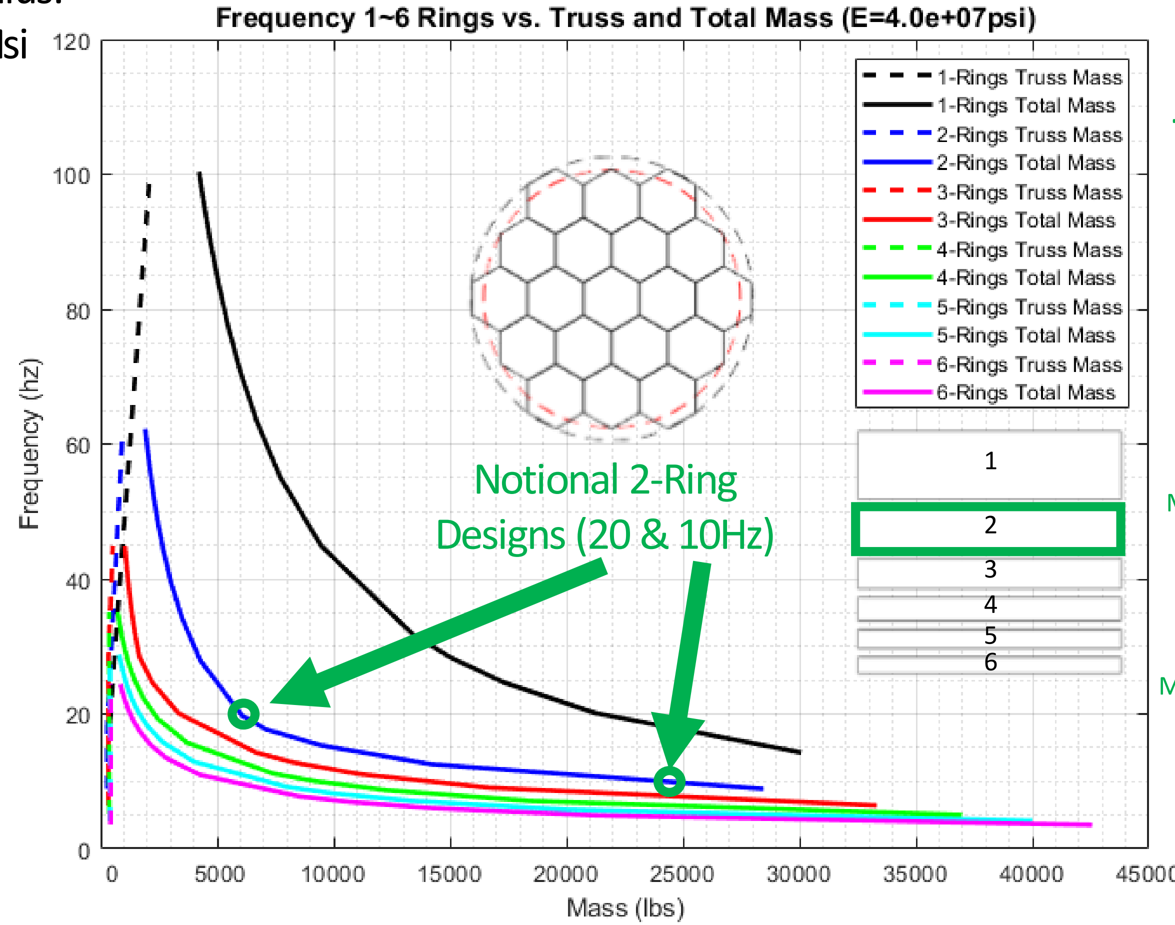
Iso-frequency contours (spaced by 5 hz)

Slide Credit: Thomas Jones et.al. LaRC

20m Truss Reflector Sizing

Strut Modulus:

E_{struts}=40 Msi



Notional Designs Tetrahedral Truss Specifications

D = 20m

W_{panel} = 3.9m

H = 3.2m

E_{strut} = 40 Msi

20Hz Truss

M_{truss} = 307 lbs

$M_{non\text{-}struct}$ = **5714 lbs**

M_{total} = 6021 lbs

10Hz Truss

M_{truss} = 285 lbs

$M_{non\text{-}struct}$ = **23835 lbs**

M_{total} = 24120 lbs

Tetrahedral equal length truss struts sized based on the greater diameter of 2 constraints: Buckling load of 1000 lbs and Local frequency = global frequency.

Slide Credit: Thomas Jones et.al. LaRC

Summary

Truss trade space was explored, prior truss assembly work was discussed and following observations can be made:

- **Deployable Truss Module designs and prototypes exist that map well to our concept (Back plane Truss)**

- **Large deployable truss designs and prototypes exist that also map to our concept (Metering Truss)**

- **Initial sizing analyses show feasibility of these deployable modules to meet notional structural stiffness within fairing imposed sizing constraints**

Recommendation

- **In the notional concept, use the Tri-truss as a representative deployable truss module for the backplane truss**

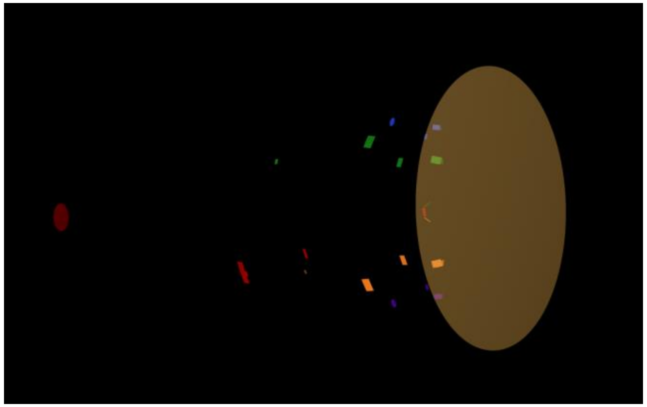
- **And use large deployable booms for the metering truss**

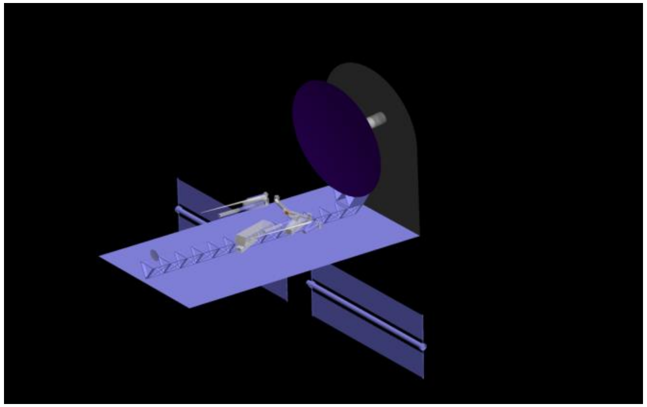
- **These provide sufficient diversity for activity 1b to understand any relative merit of one over the other from a robotic/assembly POV**

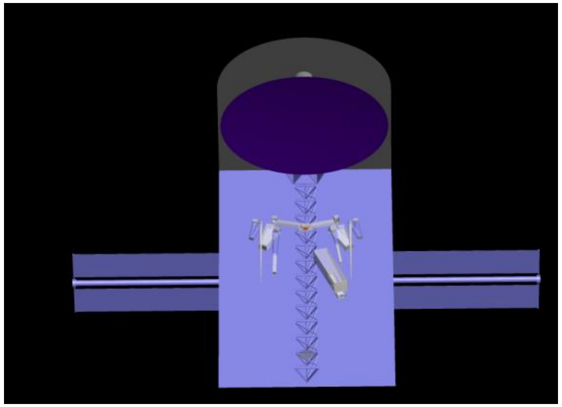
Stray Light Analyses and Notional Sunshade Architecture

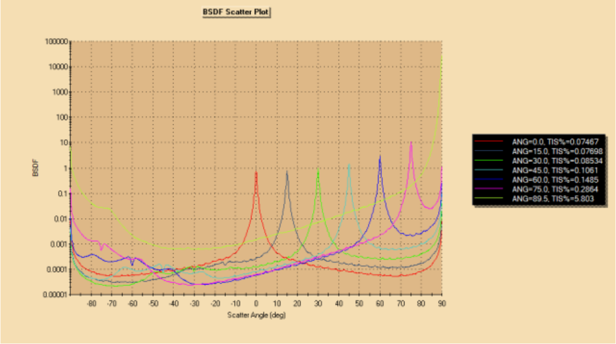
Scott Rohrbach (NASA GSFC)
Michael Rodgers (Synopsis)
Rudra Mukherjee (JPL/Caltech)

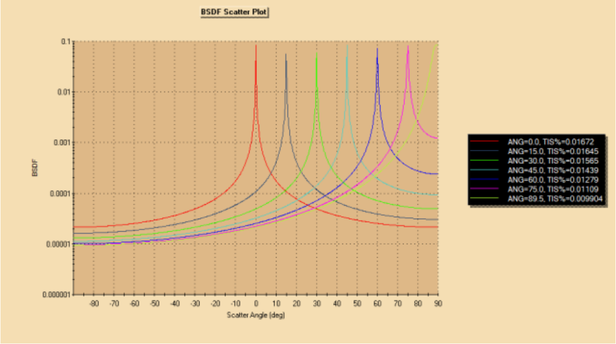
Stray Light Analyses – Model and Procedure





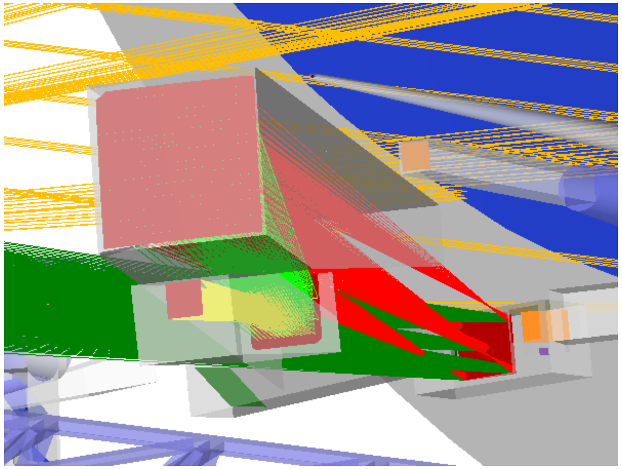


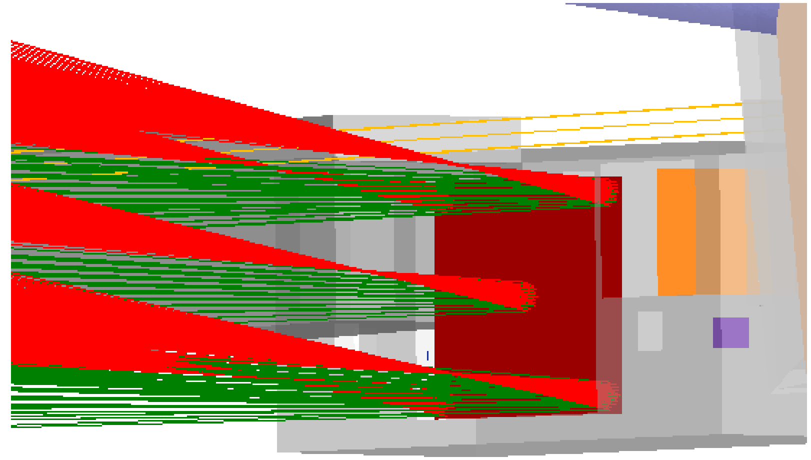




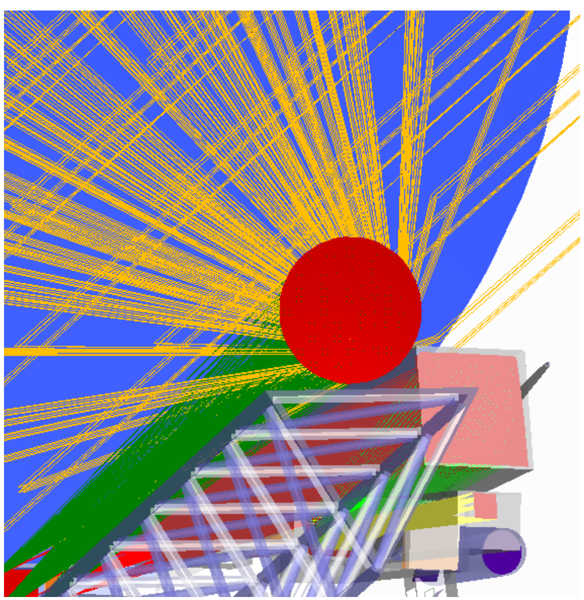
- **FRED Model created from the STEP files for the telescope CAD model**
- **CL330 Mie particulate contamination and 2.4 nm Harvey-Shack surface roughness models were chosen as reasonably representative of the expected specifications for such an observatory.**
- **The exterior of the blanketing is assumed to be Black Kapton, a BRDF model for which is available from JWST work. Similarly, the side of the sun-shield facing the optical elements is assumed to be Black Kapton.**
- **Both sides of the solar panel assemblies are assumed to be 100% specularly reflective.**

Forward Ray Trace Analyses



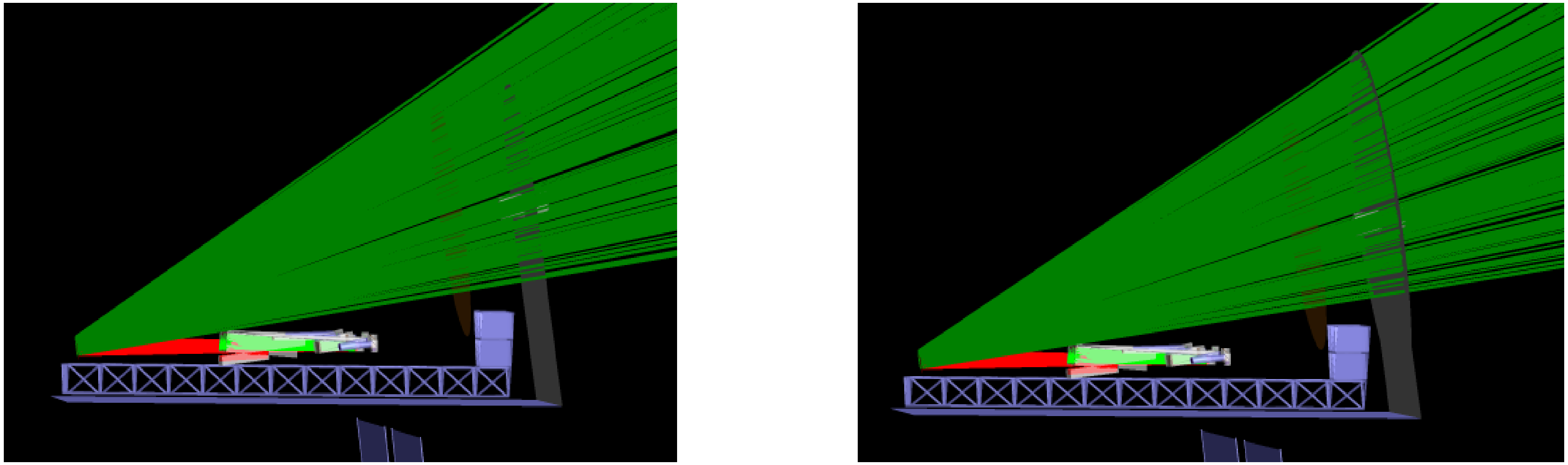


The coincidence of rays incident on Surface 5 and the intermediate focus shortly thereafter. (right) Arrow highlighting the ray bundle at the bottom of the PM perimeter going toward the SM.

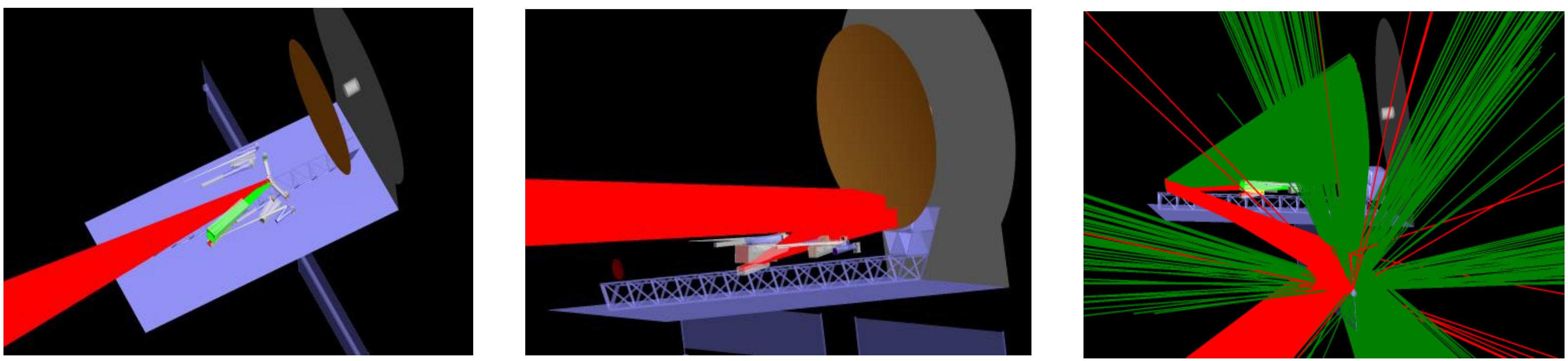


Forward ray trace of the wide field instrument. The detector plane position and highlighted ray bundle leave no margin for any kind of hardware around the instrument optics.

Reverse Ray Trace Analyses

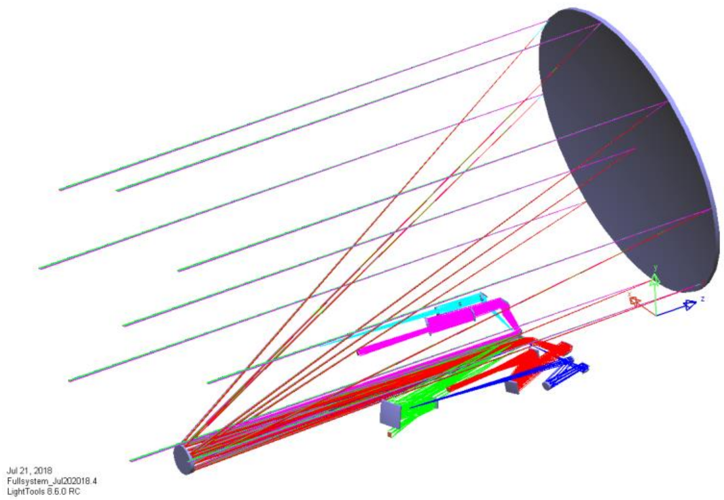


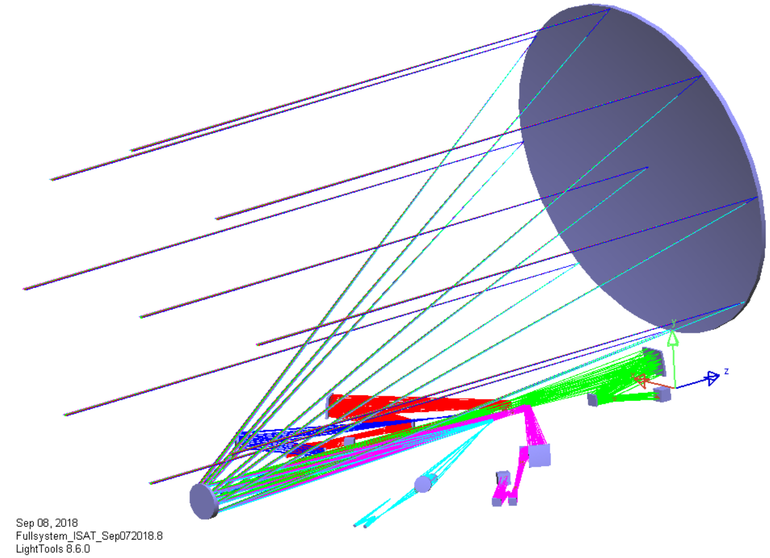
Reverse ray trace with the nominal 10.5 m radius backstop showing how specular rays can come from behind the PM into the optical path. (right) The same ray trace as the (right) image but with a 15 m radius backstop showing that it would block the specular path from behind the PM

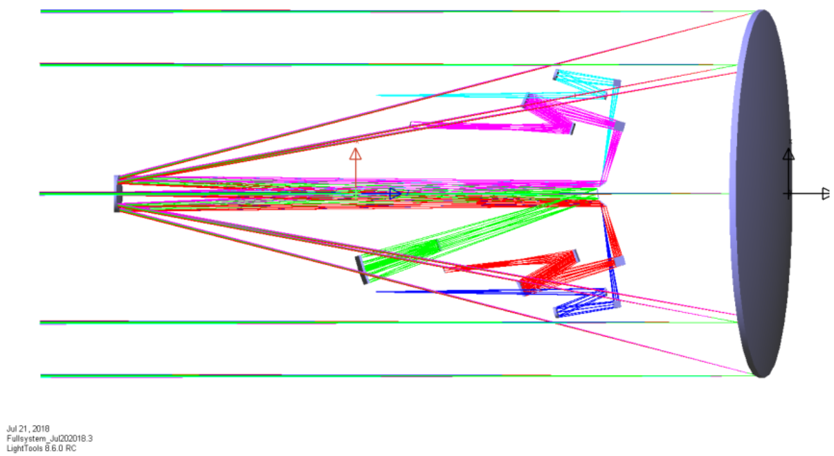


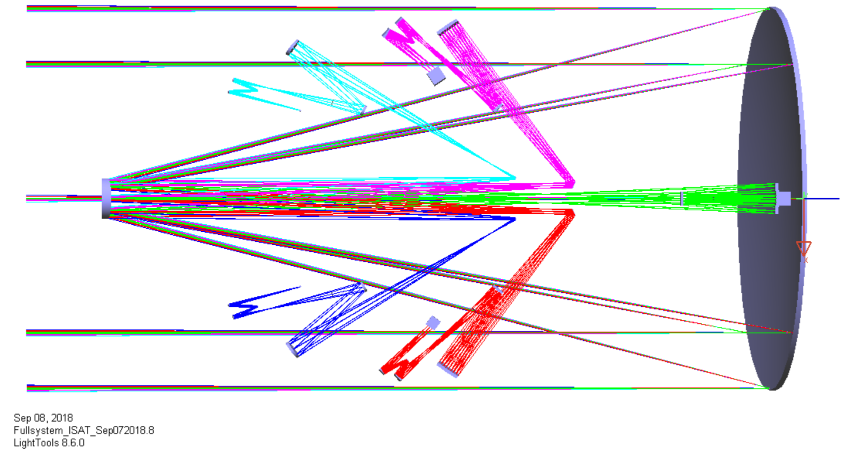
Direct Specular Paths

Updated Optical Design

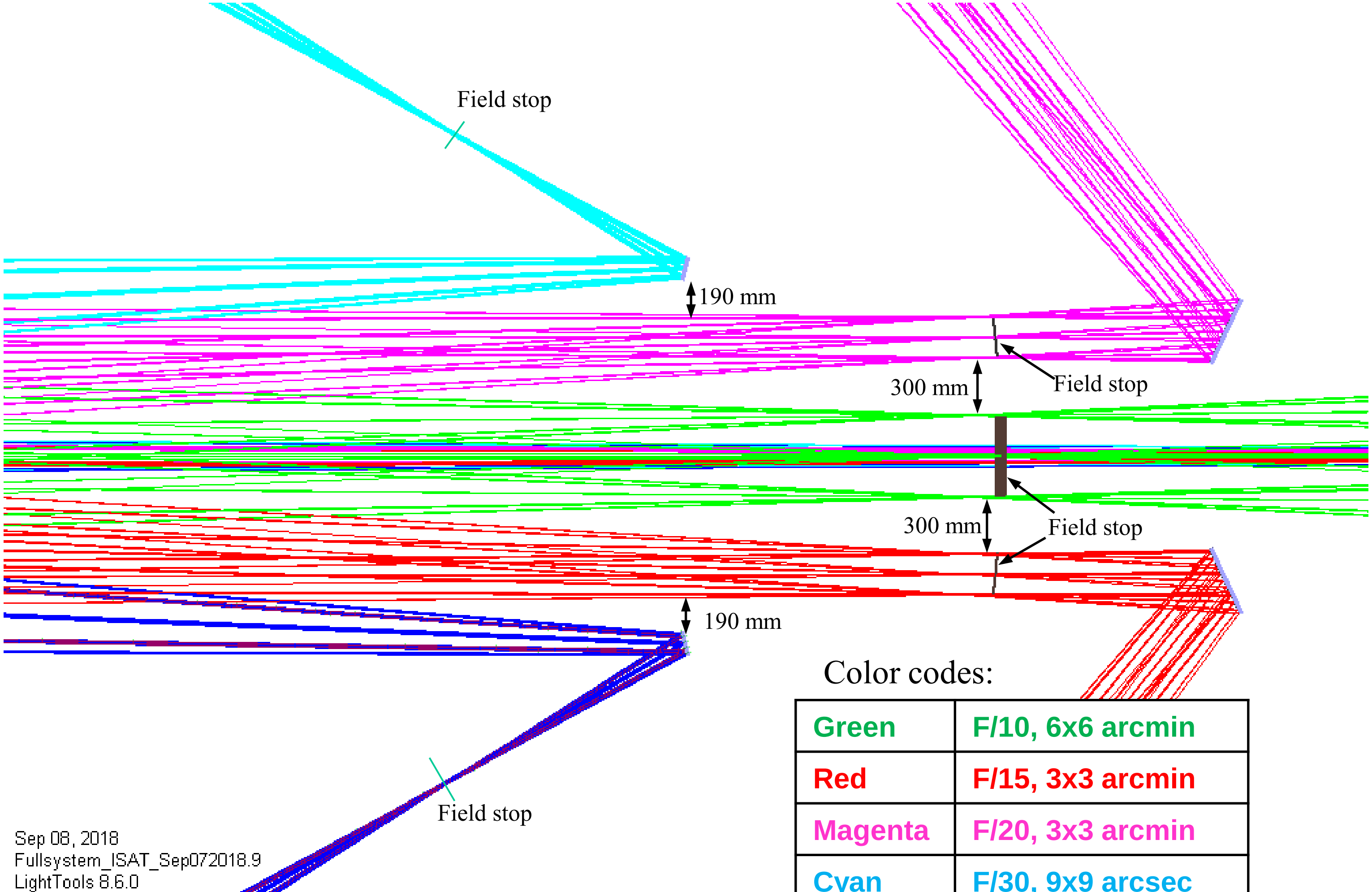








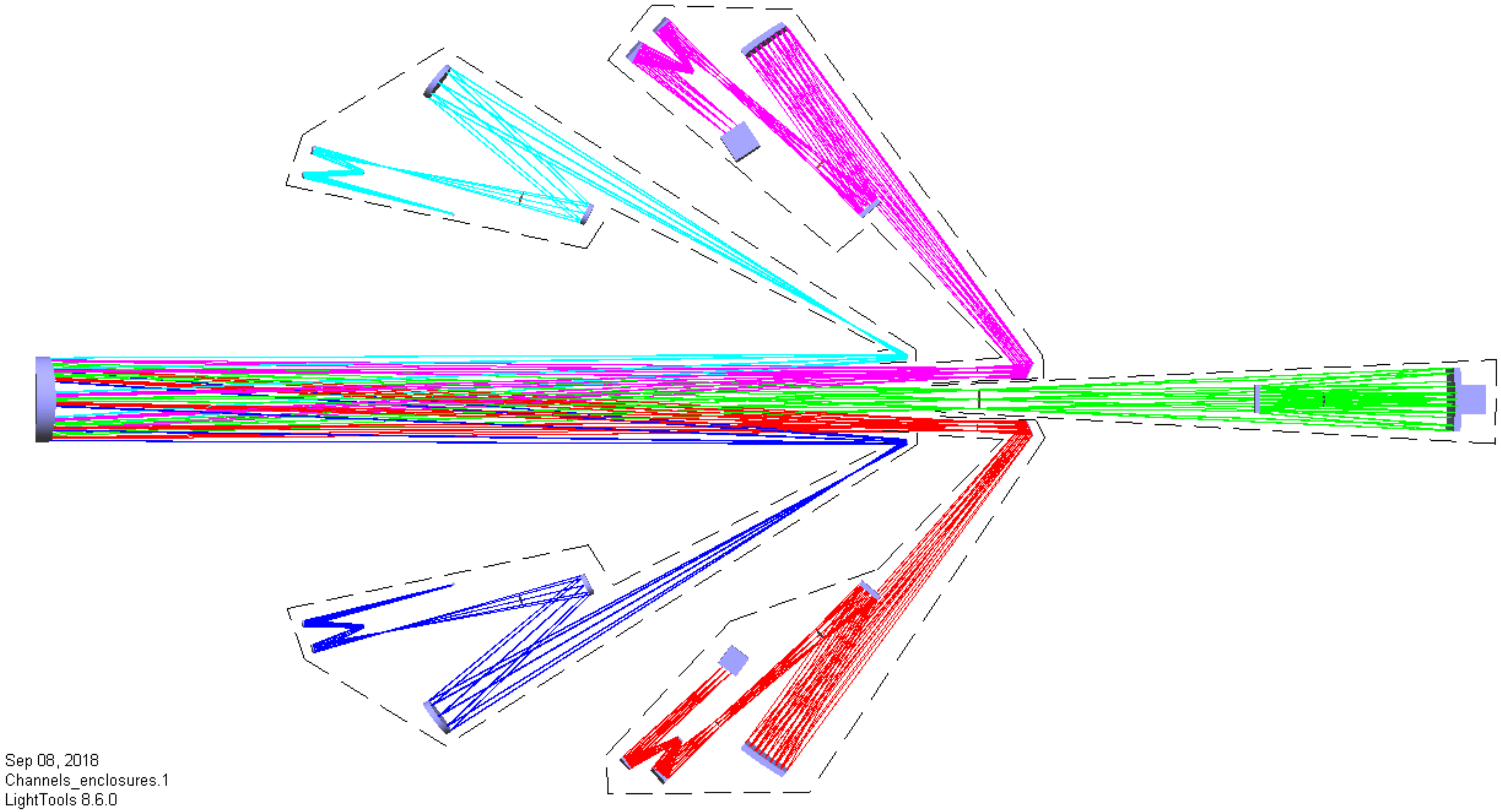
Updated Optical Design



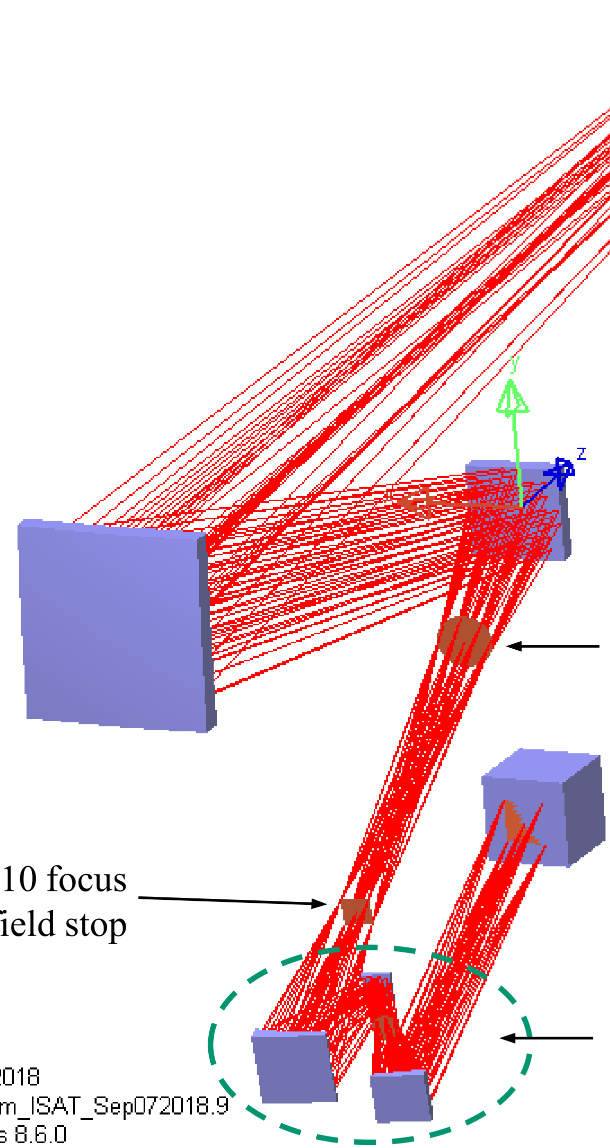
Color codes:

Green	F/10, 6x6 arcmin
Red	F/15, 3x3 arcmin
Magenta	F/20, 3x3 arcmin
Cyan	F/30, 9x9 arcsec
Blue	F/30, 9x9 arcsec

Updated Optical Design



3x3 arcmin F/15 imager, area near FPA

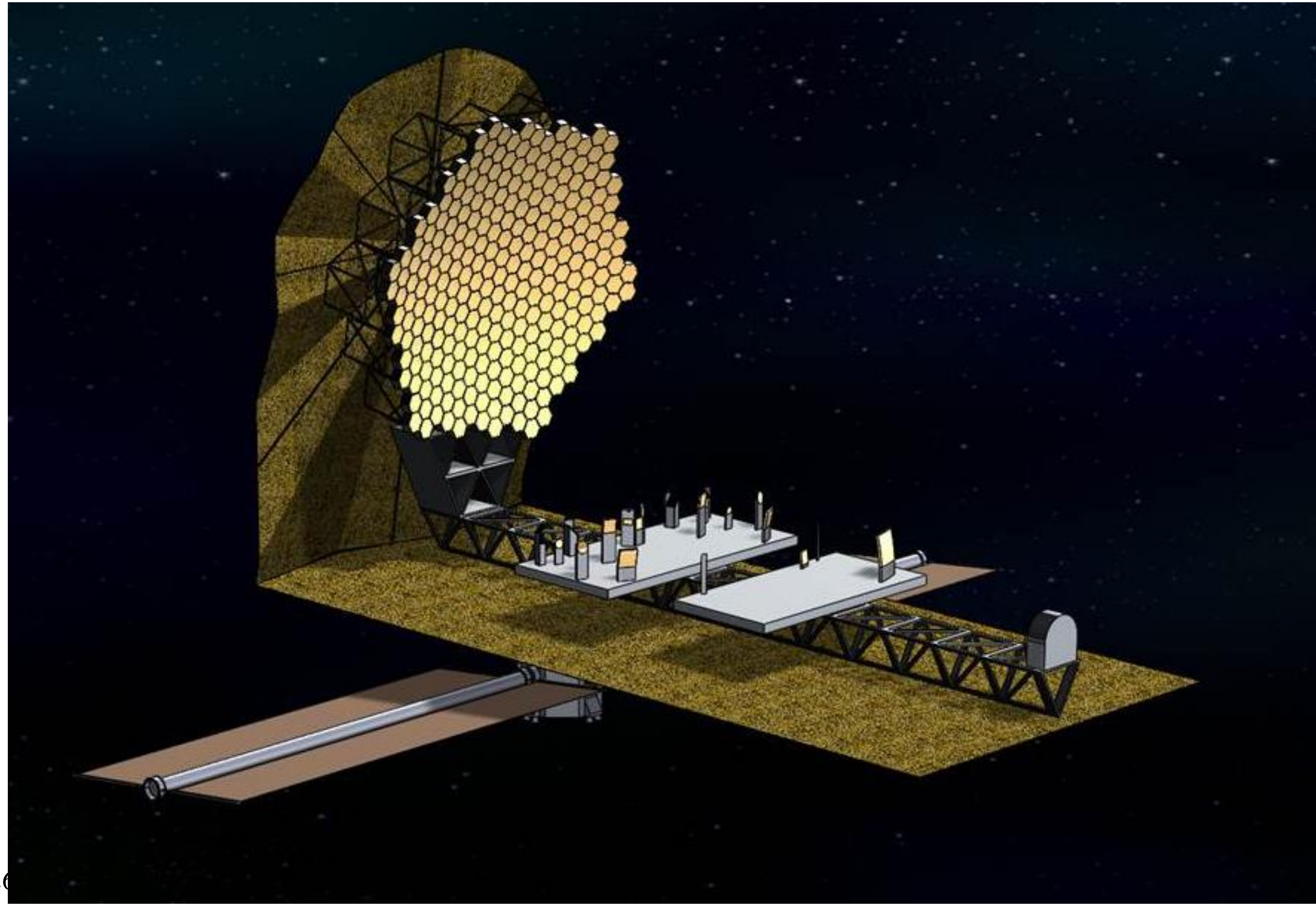


Updated Optical Design

Mirror	Channel			
	F/10	F/15	F/20	F/30
Primary	20000 diameter			
Secondary	2120 diameter			
Tertiary	1606 x 1570	1266 x 1240	1266 x 1240	970 diameter
Quaternary	710 x 700	620 x 606	620 x 606	568 diameter
Fold mirror	N/A	406 x 342	406 x 342	140 x 160
Relay mirror 1	N/A	480 x 480	472 x 474	214 diameter
Relay mirror 2	N/A	184 x 184	96 x 102	92 diameter
Relay mirror 3	N/A	332 x 352	500 x 528	170 diameter

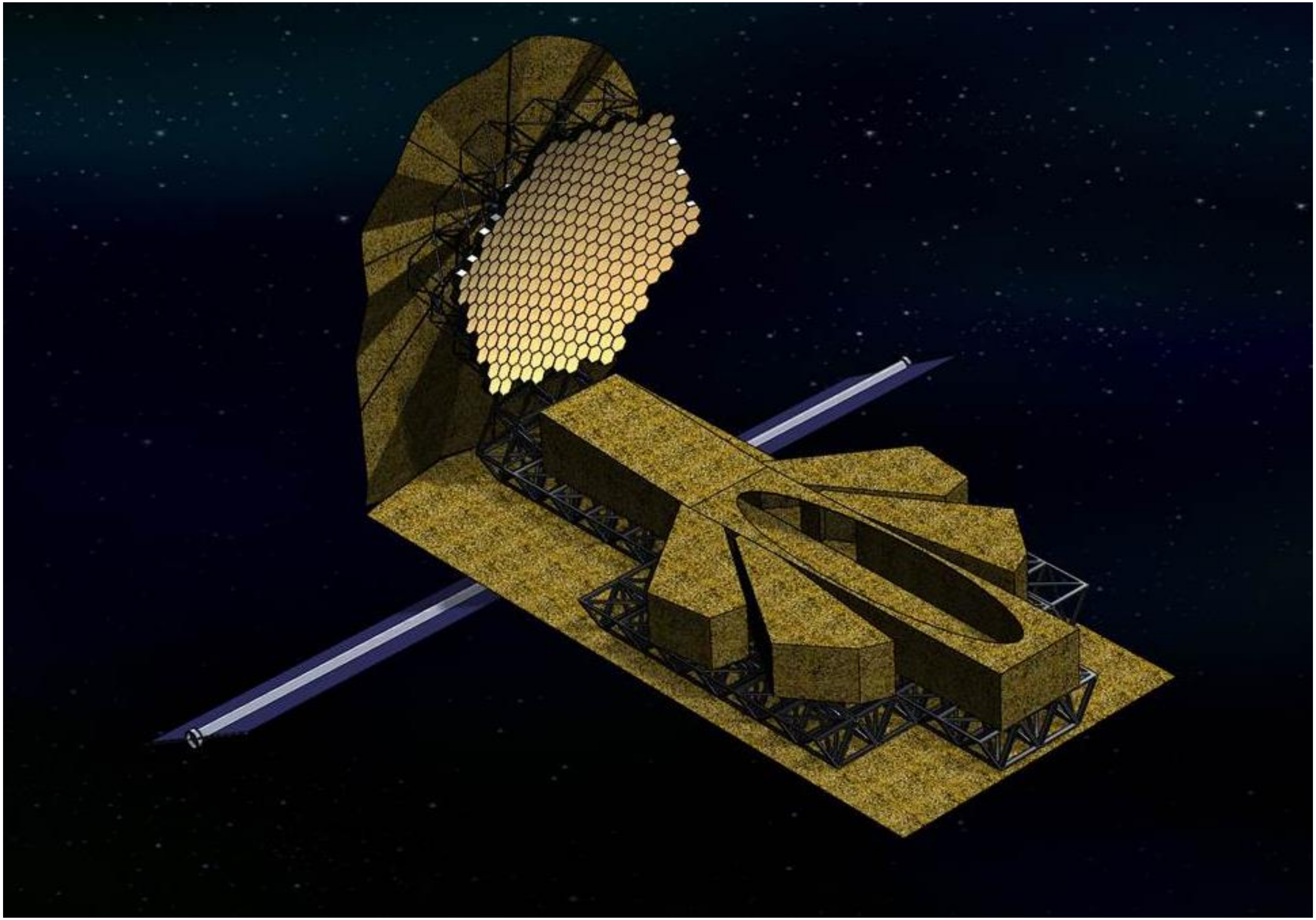
First Design Concept for Modularized Telescope

Before Study Members feedback

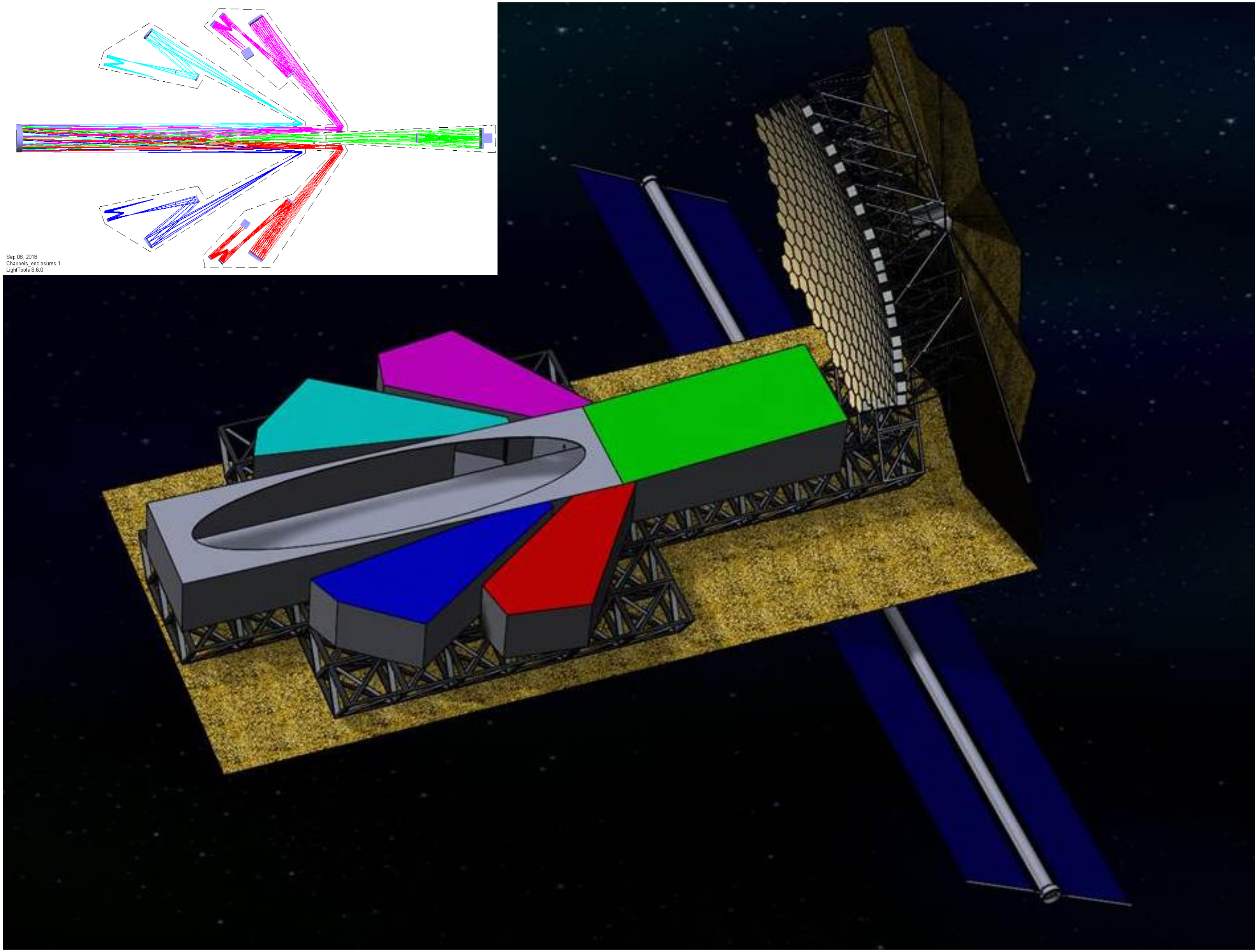


Design Concept for Modularized Telescope

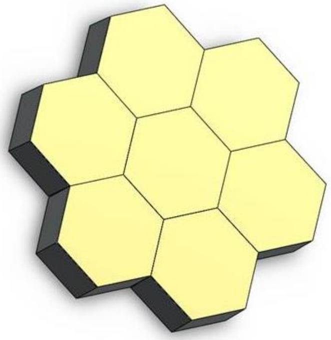
After Study Members feedback



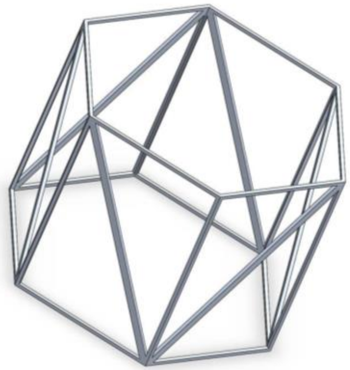
The Instrument Modules



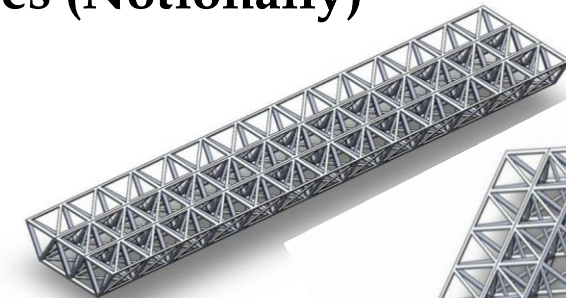
The Pieces (Notionally)



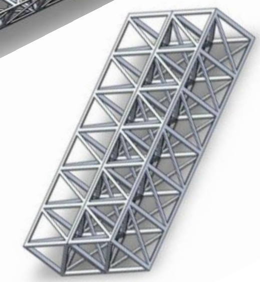
Primary Mirror Rafts
37 units



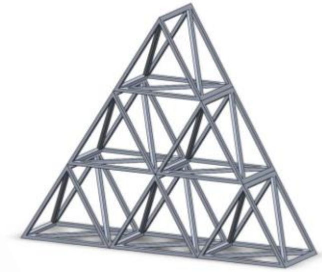
Deployable Truss Modules
24 units



Metering Truss (PM-SM)
1 unit

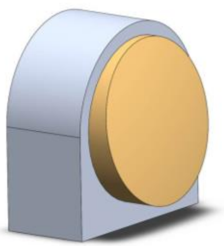


Instrument Support Truss
1 unit

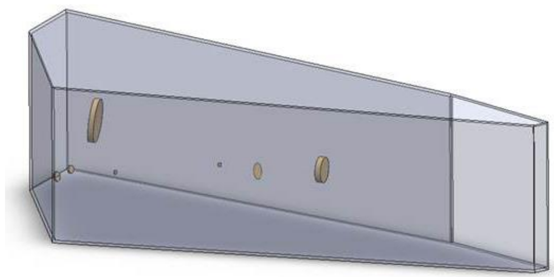


Transition Structure
1 unit

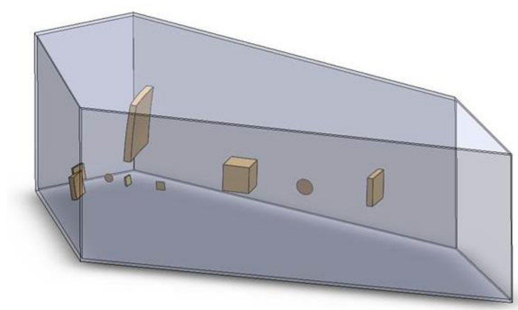
Bottom Sunshade
1 unit



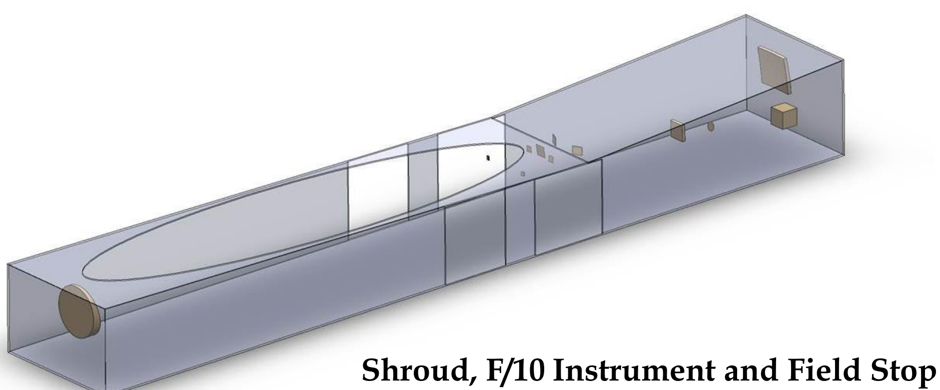
Secondary Mirror
1 unit



F/30 Instrument Module
2 units



F/15 & F/20 Instrument Module
1 unit each



Shroud, F/10 Instrument and Field Stop
1 unit each

Back Sunshade
1 unit

Summary

- **FRED based stray light analyses was conducted using the initial optical and CAD designs**
- **Recommendations were made to improve the optical and CAD concept**
- **Based on feedback, the optical design was updated to provide more spacing**
- **The CAD design was updated to provide the requisite level of stray light blockage**
- **The modularity of the observatory was updated**
- **Triggered a discussion on solar panel location**
- **Two options were identified and one was found to be the most straightforward: extend the sun shade dimensions to cover the solar panel view from the PM/SM**
    - **CAD to be updated shortly**

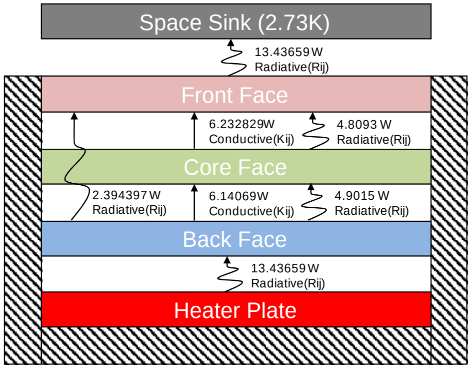
Recommendation

- **The modularity of the telescope seems adequate at this point without delving into further level of granularity**
- **The stray light analyses has been most instrumental in the update of the design and the feedback has been adequately absorbed in the updated concept**

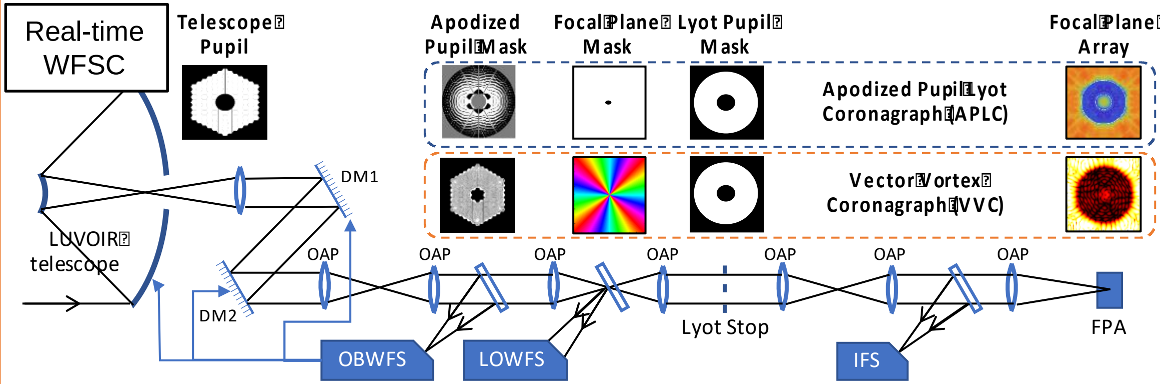
Coronagraph Accommodation

Active Control Methods for Ultra-Stability

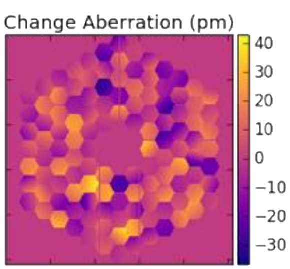
Active Thermal Control

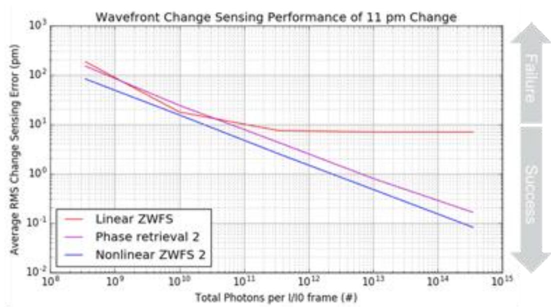


Real-time WFSC



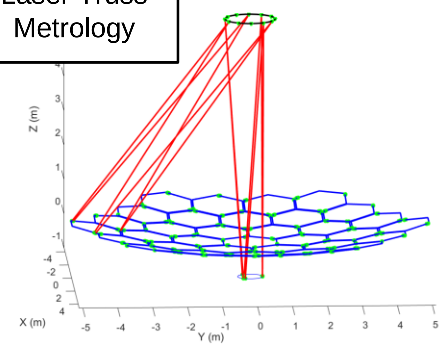
Picometer WFS

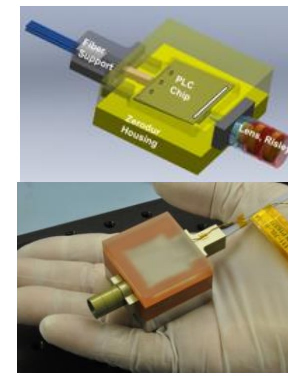




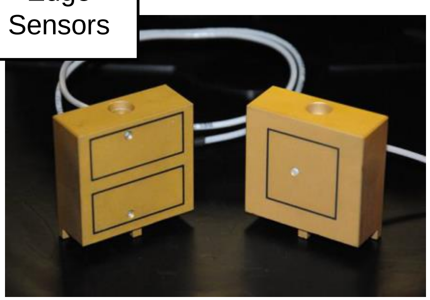
- 2×10^{10} photons available in 95 s exposure of 10^{th} magnitude star
  - Assuming B-band, 22% bandwidth, 135 m^2 aperture and *no losses*

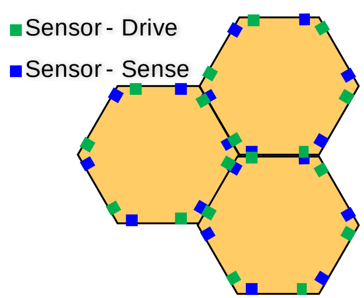
Laser Truss Metrology



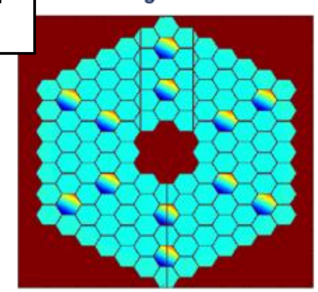


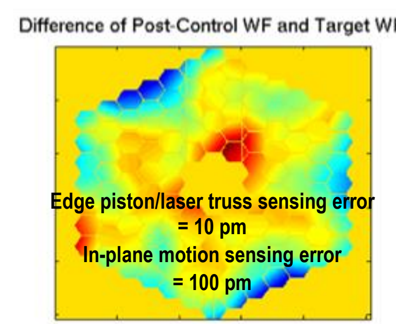
Edge Sensors





Combinations of techniques

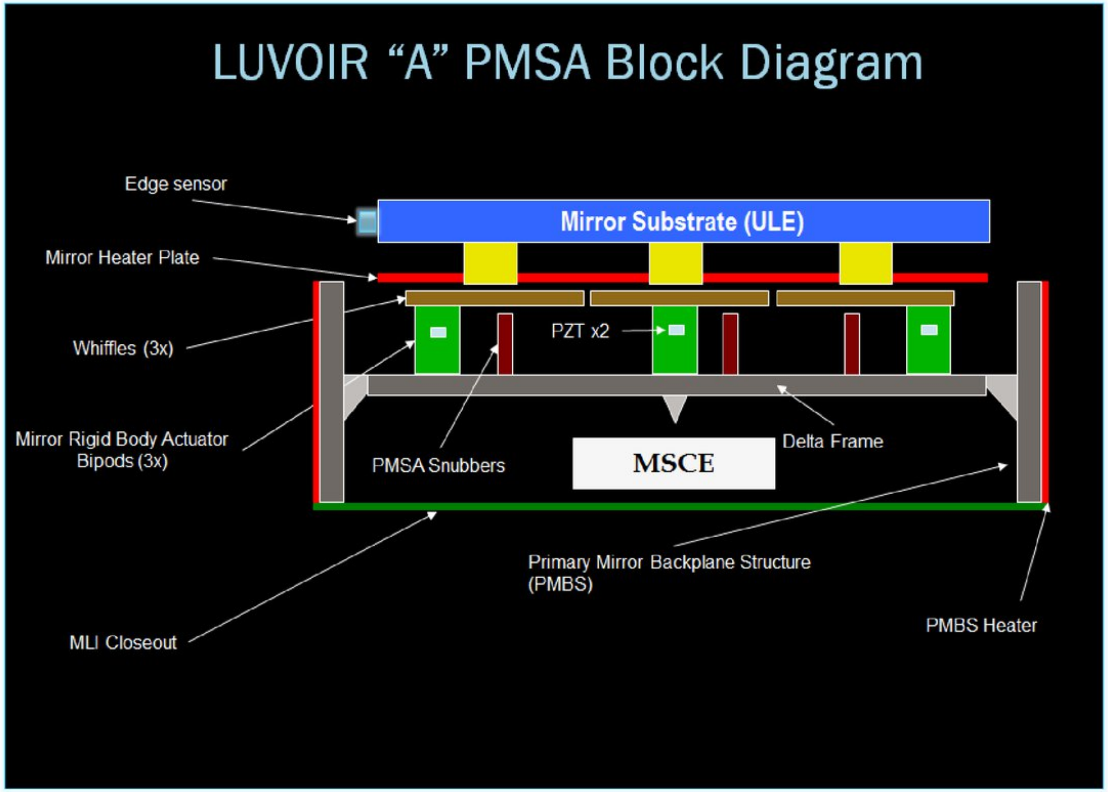


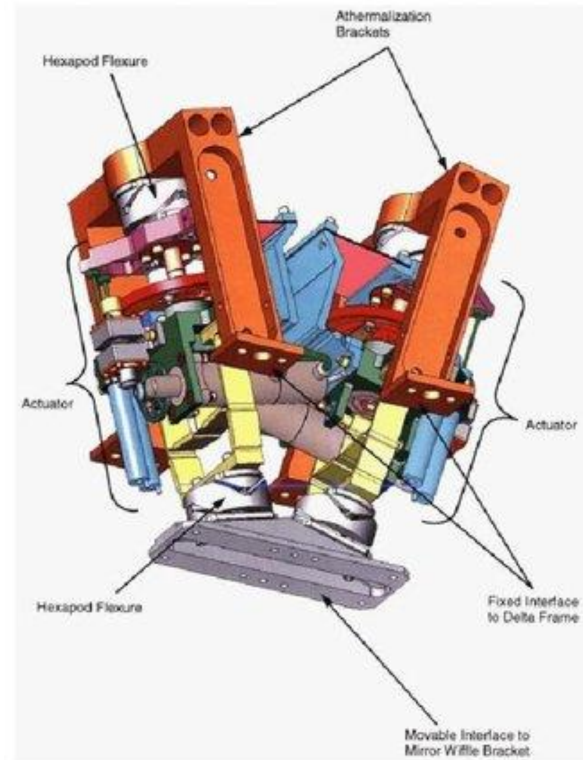


Slide Credit: Dave Redding

Imports

- "Segment piston, tip and tilt are the most sensitive terms for the primary mirror stability" – SPIE presentation of Feinberg paper

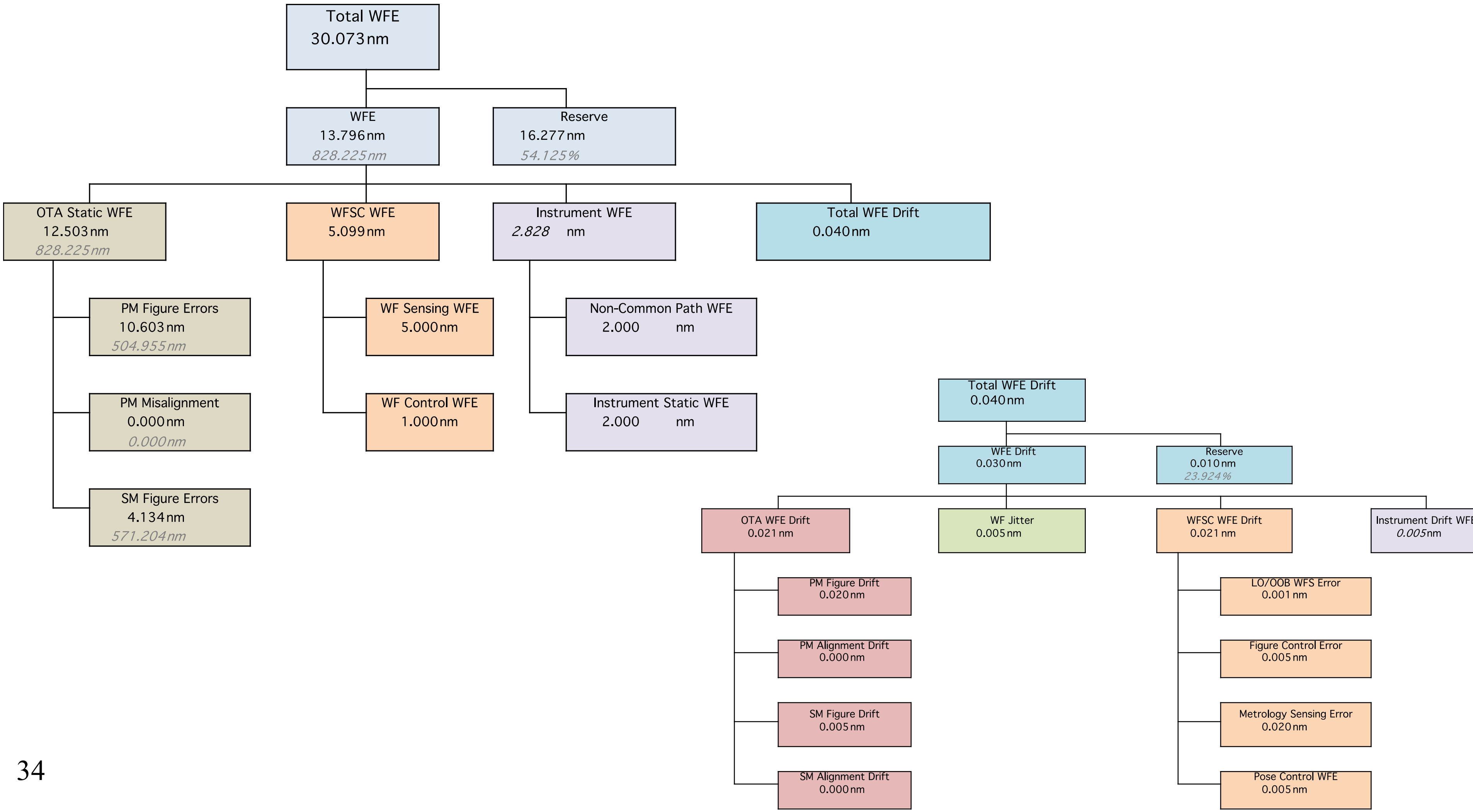




- Redding and Moore et. al. showed that a Zernike sensor can close the loop ~ 2min for 10th mag

Imports

- **CGI Accommodation is a system level problem and not just about the truss/structure**
- **Error budget developed by D. Redding for our effort is consistent with LUVOIR error budget i.e. 10nm stability for general observations and 40pm to preserve coronagraphic contrast**



Imports

- "Assume stiff mirrors (>300Hz) and picometer thermal stability achieved with 1mK heater plate (as demonstrated for ATLAST 9.2m)

- Use a Non-Contact Isolation approach (eg, Disturbance Free Payload) to sufficiently isolate the telescope for dynamics (>1hz)" i.e. CMGs are isolated
  - Micro thrusters in the future can also help in this regard

- "Use a Zernike Sensor in the coronagraph for the outer control loop for the primary mirror piston, tip, tilt updates (2 minute update for piston, tip, tilt)

- Use edge sensors and piezos to control primary mirror segment drifts (1hz to 2 minutes)
  - 450hz readout, 2 sensors per side on 3 sides similar to the TMT architecture

- Capacitive edge sensors chosen due to heritage from ground telescopes
  Laser truss also feasible which provides a common reference
  Achieve good <1pm stability between edge sensors and piezos over 2 minute intervals"

https://www.spiedigitallibrary.org/conference-proceedings-of-spie/10398/103980E/Ultra-stable-segmented-telescope-sensing-and-control-architecture/10.1117/12.2272810.full?SSO=1

- Paper lists various options being pursued to relax the pm stability requirement – not included for their architecture

Feedback

- **The basic structure is designed as a traditional structure (i.e. launch loads etc) to provide a "as good as can get" performance – not pm stability !**
  - **My understanding is that LUVOIR truss is fairly early level of fidelity at this time**

- **Coronagraph accommodation is a multi-faceted problem with significant work in progress**

- **Architecture pursued by LUVOIR is perhaps most applicable to us**
  - **We are consistent with their approach**

- **Performance of an "assembled" truss is a tall tent pole – matching a *traditional* truss performance (e.g. LUVOIR?) could be an acceptable goal/challenge**

- **Detailed error allocation, mass estimates, structural and thermal analyses, and control, actuation and sensing architectures can be pursued, if needed, for phase 2**

Recommendation

- **Our concept is architecturally consistent with the overall approach to accommodate a coronagraph subject to detailed analyses required to enable a true implementation (beyond the scope of our goals)**

- **Tent Pole: Can ISA demonstrate assembled truss work stiffness and stability comparable to a "traditional" truss work from LUVOIR or other designs?**

Jet Propulsion Laboratory
California Institute of Technology