In-Space Assembled Telescope (iSAT) Study

Study Members Telecon 9

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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)

Start planning Activity 2
(Identifying cost and risk benefits)

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

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

Close out struts
Representative Joints

Top View
Spring loaded pins
Alignment cone, attached to removable batons

Handle for Actuation
Leadscrew
Pawl
Ratchet
Preload Springs

11
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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Accuracy</th>
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<tbody>
<tr>
<td>Length</td>
<td>±1.3 mm (from +66C to -60C)</td>
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<tr>
<td>Tip Translation in Shear</td>
<td>±0.25 mm</td>
</tr>
<tr>
<td>Tip Twist in Torsion</td>
<td>±0.02°</td>
</tr>
<tr>
<td>Tip Rotation in Bending</td>
<td>±0.005°</td>
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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: \( E_{\text{struts}} = 40 \, \text{Msi} \)

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

Iso-frequency contours (spaced by 5 hz)

Slide Credit: Thomas Jones et.al. LaRC
20m Truss Reflector Sizing

Strut Modulus:
\[ E_{\text{struts}} = 40 \text{ Msi} \]

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

Notional 2-Ring Designs (20 & 10Hz)

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)
• 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% speculally 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 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:

| Color  | F/
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<tr>
<td>Red</td>
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<tr>
<td>Blue</td>
<td>30, 9x9 arcsec</td>
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Updated Optical Design
3x3 arcmin F/15 imager, area near FPA

High quality F/10 focus for a second field stop

Accessible Pupil stop

FPA enclosure, notional

3-mirror relay to final F/15 focus at FPA
## Updated Optical Design

<table>
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<th>Mirror</th>
<th>Channel</th>
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<tbody>
<tr>
<td></td>
<td>F/10</td>
</tr>
<tr>
<td>Primary</td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
</tr>
<tr>
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<td>1606 x 1570</td>
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<tr>
<td>Quaternary</td>
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<td>Relay mirror 1</td>
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<tr>
<td>Relay mirror 2</td>
<td>N/A</td>
</tr>
<tr>
<td>Relay mirror 3</td>
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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
- 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
- Space Sink (2.73K)
  - 13.4865 W Radiative (Rj)
- Front Face
  - 8.2325 W Radiative (Rj)
- Core Face
  - 2.39457 W Radiative (Rj)
- Back Face
  - 13.4865 W Radiative (Rj)
- Heater Plate

Real-time WFSC
- Telescope Pupil
- Apodized Pupil Mask
- Focal Plane Mask
- Lyot Pupil Mask
- Apodized Pupil Lyot Coronagraph (APLC)
- Vector Vortex Coronagraph (VVC)
- Focal Plane Array

Picometer WFS
- Change Aberration (pm)
  - 2x10^10 photons available in 95 s exposure of 10^4 magnitude star
    - Assuming B-band, 22% bandwidth, 135 m² aperture and no losses

Laser Truss Metrology

Edge Sensors

Combinations of techniques
- Sensor configuration for WFC
- Edge sensing on all segments
  - Metrology on 12 segments, WEM = 2.99
- Difference of Post-Control WF and Target WF
  - Edge piston/laser truss sensing error = 10 pm
  - In-plane motion sensing error = 100 pm
  - RMS = 0.042348 nm

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”


• 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?