In-Space Assembled Telescope (iSAT)
Study Members Telecon 4

August 2, 2018

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Today’s Agenda

1. Summary of the June Cambridge Workshop
2. Where are We Now?
3. What’s New?
4. Next Steps
5. Advance Selection Criteria
Summary of the June Cambridge Workshop
The first face-to-face meeting for the iSA Telescope Study was held on June 5-7, 2018 at Caltech, hosted by the NASA Exoplanet Exploration Office.

Invited participants only:

- 46 from government, industry, and academia spanning the fields of astrophysics, engineering, and robotics.
- 29 NASA, 12 industry, 4 academia, and 1 government agency
Caltech Workshop (June 5-7)

• The goals of the Workshop were to:
  1) Create concepts (Options) for modularized telescope designs
  2) Advance the Selection Criteria
  3) Build a community of experts to advance in-space assembly

• Initial conditions for the reference telescope included:
  – A 20-m, filled-aperture, off-axis, non-cryogenic telescope operating in the UV/V/NIR, located at Sun-Earth L2.
  – The instrument suite would include a coronagraph
  – Astronaut- and robotic-enabled assembly/servicing is available
  – 5-m class LV fairing

• Participants broken into two breakout teams charged with:
  – Modularizing the Primary Mirror and Backplane
  – Modularizing the Rest of the Telescope
  – Assembly, Integration, and Testing (on the ground and in space)
Far-UV Imaging / Spectroscopy

- Minimizing the number of reflections drives the telescope design
- Need the telescope to deliver the appropriate resolution and performance so that relay and coma-free optics are not needed
Breakout Session 1:
Modularizing the Primary Mirror and Backplane

1. What is the composition of the primary mirror? What is the depth of the backplane, how is it powered, what are the reflectors and what is the pneumatic scheme, is metrology integrated or separate from the PM, are there actuators and if so, what are their roles, how is the PM phase matched, among others?
2. What are the modules that make up the assembled PM? Considerations include interfaces, power, communications, harnesses, structural connectors as well as internal composition i.e. what is contained within individual modules – please be specific.
3. What is the parking configuration within a single or multiple launch vehicle fairings?)
4. What are the SWAP (size, weight, actuation, power) requirements of each module?
5. What is the thermal architecture and how is it implemented (or accommodated) within the integration scheme?
6. What is serviceable in the PM?
7. What are the assumptions regarding modularization?
8. What is the role, if any, of post assembly adjustments?
9. Are there survivability considerations during assembly for the PM under construction and for the individual modules? And how are these different from operational conditions? How are they addressed?
Generating Modularization Design Options

• **Trade space for modularization is very open**
  – Number of modules
  – Segment size, segment carriers, sun shade
  – Backplane architecture
  – Power, latching, harnessing
  – Instrument carriers, thermal

• **Do some telescope designs benefit from iSA more than others?**
  – Let’s find out
  – Option generation starts at the Workshop but can continue after
  – Recommendation for Workshop Breakout sessions for Reference Telescopes:
    1) (a) 20 m off-axis and (b) 20 m off-axis with opportunities to move to a different configuration if benefits noted
    2) Max 5-m class fairings
Candidate Reference Telescope Design
Off-Axis 20-Meter Optical Layout

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Assumption</th>
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<tbody>
<tr>
<td>Entrance pupil diameter</td>
<td>20 meter</td>
</tr>
<tr>
<td>Field of View</td>
<td>3x3 arc-minute</td>
</tr>
<tr>
<td>Final F/#</td>
<td>F/30</td>
</tr>
<tr>
<td>Image size</td>
<td>530 x 530 mm (implied by EPD, F/#, and FOV)</td>
</tr>
<tr>
<td>Primary mirror ROC and F number</td>
<td>80 meter ; F/2.0</td>
</tr>
<tr>
<td>Primary-secondary spacing</td>
<td>36.5 meter</td>
</tr>
<tr>
<td>AOI, maximum on each mirror</td>
<td>16.0° primary; 17.5° secondary; 5.6° tertiary; 8.4° fold.</td>
</tr>
<tr>
<td>RMS WFE (nanometer)</td>
<td>18.6 maximum, 10.4 average</td>
</tr>
</tbody>
</table>
Modularized Telescope Sub-Elements
(all were discussed during the Workshop)

Telescope architecture and modularization are notional.
Workshop Conclusions

• The 20 m off-axis f/2 filled telescope would serve as a good reference for the Study

• **No** major show stoppers were found; no real energy for an alternative.

• The consensus was that assembling the reference telescope in space was feasible with current and anticipated technology and processes.

• Confidence there are cost savings and risk mitigations moving forward

• Structural stability to enable primary mirror WFE stability remains a risk if the coronagraph for exo-Earth science is adopted
Identified Workshop Analyses

Three analyses requiring advancement:

- Primary mirror truss architecture
- Stray light analysis
- Sunshade architectural concept
Where are We Now?
## Features of Kepner-Tregoe Decision Process

<table>
<thead>
<tr>
<th>Decision Statement</th>
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<tbody>
<tr>
<td><strong>Feature 1</strong></td>
<td>Option 1</td>
<td>Option 2</td>
<td>Option 3</td>
</tr>
<tr>
<td><strong>Feature 2</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Feature 3</strong></td>
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</table>

### Description

- **Musts**
  - M1
  - M2
  - M3

- **Wants**
  - W1 w1%
  - W2 w2%
  - W3 w3%

### Evaluation

- **Risks**
  - Risk 1
  - Risk 2

### Final Decision, Accounting for Risks

C = Consequence, L = Likelihood
<table>
<thead>
<tr>
<th>ID</th>
<th>OPTION DESCRIPTORS</th>
<th>COMMENTS</th>
<th>Reference Option A</th>
<th>Reference Option B</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>Architecture</td>
<td>on- or off-axis, segmented or monolith</td>
<td></td>
<td>off-axis, segmented</td>
</tr>
<tr>
<td>D2</td>
<td>Size of primary mirror segments</td>
<td>1.3-1.5 m segments are industry SOA; all have RBAs, but need for figure control actuators are TBD at this time.</td>
<td>1.3-1.5 m class</td>
<td></td>
</tr>
<tr>
<td>D3</td>
<td>Number of primary mirror segments per module</td>
<td>7 (This minimizes number of interfaces during final assembly as compared to single segment per module; good heritage in testing this size module on the ground.)</td>
<td></td>
<td>Combination of laser metrology and edge sensors</td>
</tr>
<tr>
<td>D4</td>
<td>ROC and segment-to-segment control</td>
<td>Common electronics run the segments self-contained metrology system and actuators, includes simple thermal management - cold bias with heaters and thermal insulation. Could consider wireless power/comm but could also use proven mechanical connectors (mated upon segment installation).</td>
<td></td>
<td>Common electronics run the segments self-contained metrology system and actuators.</td>
</tr>
<tr>
<td>D5</td>
<td>Electronics and thermal architecture</td>
<td>Related to module sizes. Look out for fairing sizes that do not yet exist (&gt; 5-m class); larger is in play but may score poorly in some areas and may carry schedule and cost risks.</td>
<td></td>
<td>Would fairing sizes greater than 5 m pose opportunities worth considering?</td>
</tr>
<tr>
<td>D6</td>
<td>Fairing size needed</td>
<td>nominal vertical packing (5x16.5 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D7</td>
<td>Module packing within LV fairing</td>
<td></td>
<td>Includes assembly platforms, robotics, astronauts</td>
<td></td>
</tr>
<tr>
<td>D8</td>
<td>Number of modules</td>
<td></td>
<td>Robotically-assembled, human-supervised</td>
<td></td>
</tr>
<tr>
<td>D9</td>
<td>Use of space infrastructure and resources (existing, projected, or assembled robotically or robotically with astronaut support)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D10</td>
<td>Assembled robotically or robotically with astronaut support</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D11</td>
<td>Number of new technologies</td>
<td>Best to complete during Assembly 1b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D12</td>
<td>Type of LV needed</td>
<td>Look out for unique launchers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D13</td>
<td>Number of LVs to complete system assembly</td>
<td>3 launches for the PM (mass limited?), 1 launch for instruments, 1 for trusses, 1 for bus</td>
<td>Not all modules will be required to be serviced. Certainly instrument modules. Anything with consummables including fuel batteries. Servicability should occur at simple interfaces. Modules should be refurbished/replaced at the assembly platform.</td>
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</tr>
<tr>
<td>D14</td>
<td>Serviceability</td>
<td>What modules can and can't be serviced?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D15</td>
<td>Need for new Industry facilities</td>
<td>vacuum chambers, test facilities, etc</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Musts

<table>
<thead>
<tr>
<th>Modular design option MUST...</th>
<th>COMMENTS</th>
<th>Reference Option A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1 Enable necessary adjustability and correctability of key optical components.</td>
<td></td>
<td>Will require modeling with MUFs with integrated modeling</td>
</tr>
<tr>
<td>M3 Permit module servicing (repair, replacement, refueling) of all instruments and key spacecraft elements.</td>
<td></td>
<td>Things that have high failure rate, things that can go obsolete, things that get consumed/ degrade. Not all modules will be servicable but all consummables, instruments, key spacecraft hardware, mirror segments.</td>
</tr>
<tr>
<td>M4 Not enable a failure within a module to propagate through to the system</td>
<td></td>
<td>Expected in the design; need to think through replacement instrument process</td>
</tr>
<tr>
<td>M5 Fit into the selected LV</td>
<td>Sanity check</td>
<td>Sanity check for mass, volume, separate instruments into different launches</td>
</tr>
<tr>
<td>M6 Enable the direct imaging and spectral characterization of exoplanets with a coronagraph at contrast levels of 1e-8 or less</td>
<td></td>
<td>Expected</td>
</tr>
</tbody>
</table>

Under review
## Wants

<table>
<thead>
<tr>
<th>WANTS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technical</strong></td>
<td></td>
</tr>
<tr>
<td><strong>W1</strong> Few technologies exceeding the SOA</td>
<td>The more mature the concept the better, the fewer “Miracles” the better; the larger the number of low TR subsystems the worse, reach TRL 5 at earliest possible date</td>
</tr>
<tr>
<td><strong>W2</strong> Clear and simple architectures and interfaces.</td>
<td>This speaks to the level of complexity. Clear, simple architectures and interfaces are preferred over those that require unique tools, infrastructure, large number of non-identical modules, large number of interfaces.</td>
</tr>
<tr>
<td><strong>W3</strong> Robust architecture</td>
<td>Modularization concept is robust to localized failures, LV failure is not a mission failure,</td>
</tr>
<tr>
<td><strong>W4</strong> Enables the direct imaging and spectral characterization of exo-Earths at contrast levels of 1e-10 or better</td>
<td>Exo-Earth imaging and characterization is expected to require a greater level of stability on the observatory. WFE stability is expected to be 10s of pm over 10 min time scales</td>
</tr>
<tr>
<td><strong>W5</strong> Enables in-space access to all serviceable modules for repairing or replacing.</td>
<td>Architectural flexibility - the more access the better but perhaps not all modules need accessing; just the critical ones.</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td></td>
</tr>
<tr>
<td><strong>W7</strong> Minimize cost</td>
<td>The less expensive the better. Common elements/standardization. Size of modules consistent with industry capabilities - use of existing facilities. The greater the consistency with industry capabilities the lower expected cost.</td>
</tr>
<tr>
<td><strong>Schedule</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Programmatic</strong></td>
<td></td>
</tr>
<tr>
<td><strong>W8</strong> Flexibility to serve more science communities</td>
<td>If the modularized design reduces the size of the science community then it would be weighted less. An example is narrow FOV, another is only a narrow wavelength.</td>
</tr>
<tr>
<td><strong>W9</strong> Life span</td>
<td>Would like at least a 30 yr life time which will require servicing both the instruments and the spacecraft.</td>
</tr>
<tr>
<td><strong>W10</strong> Modularized design does not preclude an evolvable architecture.</td>
<td>Evolvability may be an important feature but not a Must.</td>
</tr>
</tbody>
</table>
When do we know we’re done with Activity 1a? (Concept Design and Architecture for the iSAT)

1. Select a reference **design and architecture** concept for a 20 m, filled aperture, non-cryogenic space telescope to be assembled and tested in space.
   - Musts and Wants completed; Risks captured
   - Is there a second concept to bring up?

2. Advance the three analyses

3. Modularization diagram
iSAT Study Process

(Activity 1a – Telescope Modularization)

(Activity 1b – Telescope Assembly and Testing)
Activity 1b:
Concept for Assembling and Testing the ISAT

Select a reference in-space assembly and testing concept for the "assemble-able" space telescope architecture, defining robotics, orbit, launch vehicle, and assembly platform.
What’s New?
What’s New?

- **Activity 2 Funding**
- **Workshop III at NASA Langley Research Center**
  - Oct 2-4
  - Focus will be on Activity 1b: Assembly, Testing, Robotics, Assembly Platforms, Launch Vehicles
  - Another Musts and Wants List and expect several concepts
Next Steps
Next Steps

• **Complete Selection Criteria**
  – Through upcoming telecons and emails
  – Weekly cadence

• **Complete Activity 1a (Telescope Modularization)**
  – Complete the three analyses
  – Canvas the Study Members for other modularization concepts for the reference telescope
  – Complete description of Concept A including module definitions and Musts/Wants/Risks

• **Start Activity 1b (Module Assembly, Testing, etc)**
  – Membership (and Steering Committee) will morph towards more assembly/robotics focused
  – Need names

• **Start planning Activity 2 (concept definition - cost and risk benefits)**
Advance Selection Criteria Concurrence

(switch to Excel)
Additional Slides
Activities 2a and 2b
(Not Yet Funded)
Detailed Engineering Design and Costed

**Activity 2a:** Advance the engineering fidelity of the concepts sufficiently so that they can be costed.

- a) Inputs from Activity 1a and 1b
- b) Select a team of NASA engineers, academia, government labs, and commercial companies to conduct the work.
- c) Needs funding

**Activity 2b:** Estimate, through an independent body, the cost of designing, architecting, assembling, and testing the reference 20 m space telescope?

- a) Input design from Activity 2a
- b) Identify risks
- c) Parameterize the cost to smaller apertures
Activity 3
Deliver Final Whitepaper

Write and deliver the Final Whitepaper

a) Submit to APD Director who submits to 2020 Decadal Survey