In-Space Assembled Telescope (iSAT) Study

Activity 1b Study Members Kickoff Telecon

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Chief Technologist, NASA Exoplanet Exploration Program
NASA Jet Propulsion Laboratory, California Institute of Technology

August 30 and Sept 5, 2018
Today’s Agenda

1. **What**: Objective and Deliverables
2. **Why**: Background and Motivation
3. **Who**: Participants and Roles
4. **How**: Process
5. **When**: Next Steps
What: Objective and Deliverables
Study Objective and Deliverables

• **Study Objective:**
  
  – “*When is it worth assembling space telescopes in space rather than building them on the Earth and deploying them autonomously from single launch vehicles?*”

• **Deliverables:**

  A whitepaper by June 2019 assessing:

  1. the telescope size at which iSA is necessary (*an enabling capability*)
  2. the telescope size at which iSA is cheaper or lower risk with respect to traditional launch vehicle deployment (*an enhancing capability*)
  3. the important factors that impact the answers (e.g., existence of HEO-funded infrastructure, architecture of space telescope (segments or other), cryogenic or not, coronagraph capable (stability) or not, etc.)
  4. A list of technology gaps and technologies that may enable in-space assembly

The intention of the whitepaper is to inform NASA and the 2020 Decadal Survey of the cost and risk benefits of iSA telescopes (iSAT).
Why: Background and Motivation
A rendering of newly discovered Earth-size planets orbiting a dwarf star named Trappist-1 about 40 light-years from Earth. Some of them could have surface water.

Circling a Star
Not Far Away,
7 Shots at Life

By KENNETH CHANG

Uber’s Culture
Of Gutsiness
Under Review

By MIKE ISAAC

Migrants Hide, Fearing Capture on ‘Any Corner’

By VIVIAN YEE

IMMIGRATION A police department worries a crackdown will harm work to fight gangs. PAGE 44

MEXICO The secretary of state pays a visit at a time of rising

durars. If deportations have always been a threat on paper for the 11 million people living in the country illegally, it rarely imperiled those who did not commit serious crimes. But with the Trump ad-

TRUMP RESCINDS
OBAMA DIRECTIVE
ON BATHROOM USE

ENTERING CULTURE WARS

Question of Transgender Rights Splits DeVos and Sessions

This article is by Jeremy W. Peters, Jo Becker and Julie Hirschfeld De-

vils.

WASHINGTON — President Trump on Wednesday rescinded protections for transgender students that had allowed them to use bathrooms corresponding with their gender identity, over-

ruling his own education secretary and plac ing his administra-

tion firmly in the middle of the cul-

ture wars that many Republicans have tried to leave behind.

In a joint letter, the top civil rights officials from the Justice

Department and the Education Department rejected the Obama administra-

tion’s position that nondiscrimination laws require schools to allow transgender stu-

dents to use the bathrooms of their choice.

That directive, they said, was improperly and arbi-

trarily de-

vised, “without due regard for the primary role of the states and lo-

cal school districts in establishing
Cumulative Number of Detections

Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness
Modulation
Astrometry

Discovery Year

3778 (as of 8/27/18)
Transit Exoplanet Survey Satellite
Launched April 18, 2018

Credit: NASA
James Webb Space Telescope
Planned launch March 2021

Credit: Northrop Grumman
Wide Field InfraRed Survey Telescope (WFIRST)
Planned launch approximately mid-2020s
Gaia
Astrometric Discovery of Exoplanets (Launched December 2013)

Credit: ESA
New Ground-Based Extremely Large Telescopes
24 – 40 meters in diameter, approximately 2020s
We now know that in our Galaxy…

Planets are common (> 1 per star)

Planets with sizes 0.5-2 times Earth are the most common

Earth-size planets in the Habitable Zone are common

…we’re ready for the search for life
Potential Biosignature Gases

Spectral Lines

[Graph showing spectral lines with labels for O$_3$, O$_2$, H$_2$O, CH$_4$, CO$_2$, H$_2$O]

Robinson 2016
External Occulters (Starshades)

Nulling Interferometry

Internal Occulters (Coronagraphs)
Challenges in the Not-So-Distant Future

- Science will require increasingly larger telescopes for which no existing or planned launch vehicles can deploy autonomously
In the Search for Life on Distant Planets
Bigger is Better

- Improved sensitivity to faint objects
- Improved angular resolution
- Improved spectral resolution
- Enables time-resolved images to characterize individual regions of an exoplanet
- Increased exoplanet yield

Illustration: ATLAST Study Team (NASA)
Challenges in the Not-So-Distant Future

- Science will require increasingly larger telescopes for which no existing or planned launch vehicles can deploy autonomously
  - SLS is not a guarantee

- Expensive telescopes and spacecrafts will continue to have relatively short lifetimes (~10–20 yr) with no chance of upgrade
  - JWST’s lifetime is expect to be 5-10 yr
  - HST is entering its 29th year of operation and still providing exceptional science
  - Ground-based telescopes can have ~ 50 yr lifetimes

- These large telescopes may occasionally need in-space repairs during their planned primary mission (as was the case with HST)
  - JWST has no opportunity to be serviced for repairs or upgrades

- Deployment designs are getting more complicated (i.e. costlier) and riskier
Telescope Size Current Limitations
Deployment Complexity, Fairing Size, and Lift Capacity

- 40 deployable structures
- 178 release mechanisms (all of which must work for the deployment to be successful)
A Possible Vision for Large Space Telescopes

1) **Assembled** in space

2) **Serviced** in space to extend their utility by:
   - replacing the instrument payloads with newer more advanced ones
   - upgrading spacecraft subsystems as they wear and age
   - refueling to extend their lifetimes,
   - repairing when needed, and
   - incrementally enlarging the apertures over time

*These potential benefits of iSSA of large future telescopes require study.*
1. We need a new approach that provides the capability to build larger telescopes for less money and with less risk.

2. We need to demonstrate that this new approach will deliver on cost and risk.

3. We need to begin developing the capabilities and technologies to enable this new approach.
Why Now?

• Inform the 2020 Decadal Survey and SMD that space servicing, upgrade, and assembly offers:
  – potential science enabling capabilities (large science telescopes, extended lifetimes)
  – cost reduction possibilities
  – risk reduction opportunities
  – synergies with other NASA directorates and within SMD, commercial, DoD

• Technology development time
  – The process of identifying, developing, and maturing the technologies to enable servicing, repair, and assembly will take time
  – We need to begin creating a technology roadmap and implementing early development efforts in the very near future, for example using ISS as a testbed prior to its termination

• Opportunity to coordinate early
  – Early involvement with industry and NASA Gateway teams offers opportunities to influence studies before designs are “frozen in”
70+ participants from government, industry, and academia

- 30 NASA Centers
- 29 Industry
- 7 NASA HQ
- 4 academia
- 4 STScI
- 1 DARPA

Planning team chair: Harley Thronson (NASA GSFC)
November 1-3, 2017
NASA GSFC
Potential cost savings offered through iSSA:

- Eliminates engineering design work and testing required to (1) creatively fit large structures into existing fairings and (2) autonomously deploy
  - JWST invested a significant effort into designing and testing the telescope’s folded wing design; even more for the observatory deployment with 40 deployable structures and 178 release mechanisms (all of which must work for the deployment to be successful)
- Reduces need for hardware redundancy
- Reduces system “ruggedization” to survive launch environment
- Reduces need for new and unique ground test facilities
  - JWST required new ground facilities to be built
- Reduces the need for a large standing army during I&T
- Leverages existing and less-costly medium-lift LVs
- New instruments can be swapped out over longer periods of time before new additional observatories are needed
Potential new challenges may also INCREASE costs:

• Would a full-scale, robotically-assembled telescope have to be demonstrated on the ground to mitigate concerns and risks? And then disassembled?

• New robotic capabilities will be required as part of iSA that would not be required in the autonomous deployment approach.

• New “standing army” post launch
  – Potential additional cost for any astronauts in the loop

• Sending multiple modules into space for assembly will require new containers and interfaces needing to undergo environmental testing.

• New Earth-based problems yet unknown in standardization and assembly, as well as new unknown problems created in space, will likely need to be solved.
Risk reduction opportunities arising from iSSA

• Reducing risk becomes increasingly more important as mission costs increase.

• Future larger observatories are likely to require more complex deployment schemes. iSSA can mitigate risk of failure by:
  – Modularizing the design enabling repair and replacement of faulty sections
  – Designing servicing capabilities (robotic and/or human) into the architecture
  – Minimizing single-point failures
  – Enabling end-to-end testing (often not possible on ground)

• iSA does not require next-generation launch vehicles
  – Several future mission concepts under study rely on the SLS Block II

• Launch failure need not be equivalent to mission failure
1. Commission a design study to understand how large-aperture telescopes could be assembled and serviced in space
   – Initiate the study in time for initial results to be available to Gateway and robotics designers before end 2019.

2. Initiate an iSA coordination group between the three Mission Directorates and perhaps with international space agencies as well.

3. Provide input to the 2020 Decadal Survey about iSA as a potential implementation approach for future large apertures.
In-Space Assembled Telescope Study Funded
Sponsors: Astrophysics Division and Science Mission Directorate

“When is it worth assembling space telescopes in space rather than building them on the Earth and deploying them autonomously from individual launch vehicles?”

Final deliverable:
A whitepaper to the 2020 Decadal Survey committee
How: Process
Activity 3
Deliver Final Whitepaper

Write and deliver the Final Whitepaper (around May/June)

a) Submit to APD Director who submits to 2020 Decadal Survey
Activities 2a and 2b
Detailed Engineering Design and Costed

Activity 2a: Advance the engineering fidelity of the concept(s) 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.

Activity 2b: Estimate, through an independent body, the cost of designing, architecting, assembling, and testing the reference space telescope?
   a) Input design from Activity 2a
   b) Identify risks
   c) Parameterize the cost to smaller apertures
Activity 1a
Concept Design and Architecture for the iSAT

Select a reference design and architecture concept for a 20 m, filled aperture, non-cryogenic space telescope to be assembled and tested in space.

- Paradigm shift in architecture: Modularization
- An example, from the 2012 OpTIIX study (NASA JSC/GSFC/JPL/STScI):

![Diagram of 3 Mirror Anastigmat Telescope](image)

3 Mirror Anastigmat Telescope (1.45 m aperture)

6 launch modules for assembly
Activity 1b: Concept for Assembly and Infrastructure for the iSAT

Select a reference in-space assembly and testing concept for the "assemble-able" space telescope architecture, defining robotics, assembly platform, orbit, and launch vehicle.
Activity 1a
Telescope Modularization
47 invited participants from government, industry, and academia spanning the fields of astrophysics, engineering, and robotics.
Telescope Modularization In-Process Results

Activity 1a

- A 20 m off-axis f/2 telescope would serve as a good reference for the Study
- No major show stoppers were found; no better compelling alternatives.
- The consensus was that assembling the reference telescope in space was feasible with current and anticipated technology and processes.

20 m, f/2, off-axis, segmented, filled-aperture, with coronagraph, UV/O/NIR
### Three analyses requiring additional work

- Primary mirror truss architecture
- Stray light analysis
- Sunshade architectural concept

### Telescope Modularization In-Process Results

<table>
<thead>
<tr>
<th>M1</th>
<th>Enable necessary adjustability and correctability of key optical components.</th>
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<tbody>
<tr>
<td>M2</td>
<td>Permit module servicing (repair, replacement, refueling) of all instruments and key spacecraft elements.</td>
</tr>
<tr>
<td>M3</td>
<td>Prevent failures within a module from propagating to other parts of the system</td>
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<tr>
<td>M4</td>
<td>Enable all modules to be testable and verifiable, including their interfaces.</td>
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<tr>
<td>M5</td>
<td>Fit into the selected LV</td>
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<tr>
<td>M6</td>
<td>Enable the direct imaging and spectral characterization of exoplanets with a coronagraph at contrast levels of 1e-8 or better.</td>
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</table>
Primary Mirror Rafts 24 units

Deployable Truss Modules (BSF) 24 units

BSF Sunshade 1 unit

Secondary Mirror 1 unit

Ancillary Optics Bay 1 1 unit

Ancillary Optics Bay 2 1 unit

Transition Structure 1 unit

Metering Truss (PM-SM) 1 unit

Metering Truss Sunshade 1 unit
Activity 1b
(starts now!)

A *taste of what is to come*...
Robot Candidates
Multi-Limbed Robot
Caltech/JPL; Lee et al. (2016)
Free-Flying Robots
NASA’s Restore-L
DARPA/SSL’s Robotic Servicing of Geosynchronous Satellites
Orbital ATK’s Mission Extension Vehicle

Credit: NASA GSFC
Robotic Arm
ISS’s DEXTER and Canadarm2
Assembly Platform Candidates
International Space Station

LEO

Image: NASA
Earth Sciences Space Station
Sun Synchronous Orbit
Lunar Orbiting Platform - Gateway

cis-Lunar orbit
Bring Your Own Assembly Platform
Free-fliers with specialized robotic arms docked to spacecraft bus

Illustration: NASA
Evolvable Space Telescope
Northrop Grumman

(Polidan et al. 2016)
Orbit Candidates
Launch Vehicle Candidates
**Who:** Participants and Stakeholders
The iSAT Study Working Group
Our Sponsors

Dr. Paul Hertz
Director
Astrophysics Division
NASA Headquarters

Mike Seablom
Chief Technologist
Science Mission Directorate
NASA Headquarters
# Steering Committee and Study Leads

## Steering Committee

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Affiliation</th>
<th>Study Role</th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Dave Redding</td>
<td>NASA JPL</td>
<td>Study Member (mirrors, WFSC)</td>
</tr>
<tr>
<td>2.</td>
<td>Joe Pitman</td>
<td>consultant</td>
<td>Study Member (opto-mech structures)</td>
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<tr>
<td>3.</td>
<td>Scott Knight</td>
<td>Ball</td>
<td>Study Member (optical design)</td>
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<tr>
<td>4.</td>
<td>Bill Doggett</td>
<td>NASA LaRC</td>
<td>Study Member (telescope structures)</td>
</tr>
<tr>
<td>5.</td>
<td>Matt Greenhouse</td>
<td>NASA GSFC</td>
<td>Study Member (astrophysicist)</td>
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<td>6.</td>
<td>Ben Reed</td>
<td>NASA GSFC</td>
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<tr>
<td>7.</td>
<td>Gordon Roesler</td>
<td>DARPA (ret)</td>
<td>Study Member (telescopes)</td>
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<tr>
<td>8.</td>
<td>John Grunsfeld</td>
<td>NASA (ret)</td>
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<td>9.</td>
<td>Keith Belvin</td>
<td>NASA STMD</td>
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<td>10.</td>
<td>Brad Peterson</td>
<td>STScI/OSU</td>
<td>Study Member (astrophysicist)</td>
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<tr>
<td>11.</td>
<td>Florence Tan</td>
<td>NASA SMD</td>
<td>Study Member (telescope systems)</td>
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<td>12.</td>
<td>Ray Bell</td>
<td>Lockheed</td>
<td>Study Member (telescope systems)</td>
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<tr>
<td>13.</td>
<td>Nasser Barghouty</td>
<td>NASA APD</td>
<td>Study Member (robotics)</td>
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<tr>
<td>14.</td>
<td>Dave Miller</td>
<td>MIT</td>
<td>Study Member (robotics)</td>
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<tr>
<td>15.</td>
<td>Keith Warfield</td>
<td>NASA ExEP</td>
<td>Study Member (SME)</td>
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## Study Leads

<table>
<thead>
<tr>
<th>Name</th>
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<tr>
<td>Nick Siegler (co-)</td>
<td>NASA ExEP/JPL</td>
<td>Study Member (robotics)</td>
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<tr>
<td>Harley Thronson (co-)</td>
<td>NASA PCOS/COR Programs/GSFC</td>
<td>Study Member (robotics)</td>
</tr>
<tr>
<td>Rudra Mukherjee (co-)</td>
<td>NASA JPL</td>
<td>Study Member (robotics)</td>
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</tbody>
</table>
## Confirmed Participants for Activity 1b

(* means invited but no response)

### Telescope Systems
- Lynn Allen (Harris)
- Dave Redding (JPL)
- Scott Knight (Ball)
- Allison Barto (Ball)
- Keith Havey (Harris)
- Doug McGuffy (GSFC)
- Ron Polidan (consultant)
- Bob Hellekson (Orbital)
- Ray Bell (LMC)
- Kimberly Mehalick (GSFC)

### Structures
- Kim Aaron (JPL)
- John Dorsey (LaRC)
- Bill Dogget (LaRC)
- Joe Pitman (consultant)
- Keith Belvin (LaRC)

### Autonomous Systems
- Julia Badger (JSC) *
- Ron Diftler (JSC) *
- Eric Komendera (VA Tech)

### Structures
- Kim Aaron (JPL)
- John Dorsey (LaRC)
- Bill Dogget (LaRC)
- Joe Pitman (consultant)
- Keith Belvin (LaRC)

### Orbital Mechanics/Environments
- David Folta (GSFC)
- Ryan Whitley (JSC) *

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- David Folta (GSFC)
- Ryan Whitley (JSC) *

### Launch Systems/Al&T
- Diana Calero (KSC)
- Roger Lepsch (LaRC)

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- Diana Calero (KSC)
- Roger Lepsch (LaRC)

### Robotics and Robotic Servicing and Assembly
- Jason Herman (Honeybee)
- Afif Qureshi (SSL) *
- John Lymer (SSL)
- Paul Backes (JPL)
- Glen Henshaw (NRL)
- Rudra Mukherjee (JPL)
- Gordon Roesler (ex-DARPA)
- Joe Parrish (DARPA) *
- David Akin (Univ of Maryland) *
- Michael Fuller (Orbital)
- Adam Yingling (NRL)
- Bo Naasz (GSFC)
- Kimberly Mehalick (GSFC)
- Dave Miller (MIT)

### Architectural Systems
- David Kang (NG)
- Paul Lightsey (Ball)
- Bo Naasz (GSFC)

### Architectural Systems
- David Kang (NG)
- Paul Lightsey (Ball)
- Bo Naasz (GSFC)

### Controls
- Larry Dewell (LMC)
- Oscar Salazar (JPL) *

### Controls
- Larry Dewell (LMC)
- Oscar Salazar (JPL) *

### Gateway
- Sharon Jeffries (LaRC)

### Gateway
- Sharon Jeffries (LaRC)

### Sunshade
- Jon Arenberg (NG)

### Sunshade
- Jon Arenberg (NG)

### Rendezvous & Proximity Operations
- Bo Naasz (GSFC)
- Scott Cryan (JSC) *

### Rendezvous & Proximity Operations
- Bo Naasz (GSFC)
- Scott Cryan (JSC) *

### Manufacturing
- Kevin DiMarzio (MIS)
- Bobby Briggs (LMC)
- Rob Hoyt (Tethers)

### Thermal
- Carlton Peters (GSFC)

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### SMEs/Observers
- Keith Warfield (JPL)
- Lynn Bowman (LaRC)
- Erica Rodgers (STMD)
- John Grunsfeld (NASA retired)
- Phil Williams (LaRC)
- Alison Nordt (LMC)
- Howard MacEwen (consultant)

### SMEs/Observers
- Keith Warfield (JPL)
- Lynn Bowman (LaRC)
- Erica Rodgers (STMD)
- John Grunsfeld (NASA retired)
- Phil Williams (LaRC)
- Alison Nordt (LMC)
- Howard MacEwen (consultant)

### Scientist
- Brad Peterson (OSU)
- Eric Mamajek (NASA ExEP)
- Matt Greenhouse (GSFC)
Role of the Study Members

1. The heart of the Study – the folks whose recommendations will lead to a new paradigm (or not)…

2. Will generate selection criteria

3. Will generate concepts of assembly and infrastructure (a.k.a. options)

4. Will provide the Study with evaluation teams

5. Will reach consensus on the criteria assessment for each concept

6. Weekly telecons / one face-to-face meeting
Consensus
Drawn from NASA Policy

• Consensus decisions
  – May produce more durable decisions than those by votes or decree.
  – However, convergence time can be a factor.

• We adopt a Constrained Consensus method defined as:
  *Strive for consensus in the reasonable time available, else, the leaders make a decision. Dissent (if any) is captured and the groups moves on with full support of the decision.*

• Follow 7120.5E, Ch 3.4, “Process for Handling Dissenting Opinion”
  – Three options:
    (1) Agree,
    (2) Disagree but fully support the decision,
    (3) Disagree and raise a dissenting opinion
  – Treat (1) and (2) as consensus for iSAT Study Working Group
  – Dissents (3) if any will be documented and delivered to the Study Leads and to the Sponsors
How will iSAT Study Members Produce a Recommendation?

[Diagram showing the process]

Kickoff → Criteria and Weights → Option Description → Technical Evaluation Team → Science Evaluation Team → Group Consensus → Recommendation → NASA HQ Sponsors

F2F ← Telecons → F2F (optional)
Features of Kepner-Tregoe Decision Process
Systematic Decision Making

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<td>Final Decision, Accounting for Risks</td>
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<td>C = Consequence, L = Likelihood</td>
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Process Overview

- Agree on **Evaluation Criteria** and **Weights**
- Document **Options** and **Description**
- Evaluate Options vs Criteria
- Reach **Consensus** on Evaluation
- Document **Risks, Opportunities**
- Recommendation accounting for Risks, Opportunities

Credit: Gary Blackwood (NASA JPL)
Example of a Completed Trade Matrix

### Decision Statement:
Recommend one Primary and one Backup coronagraph architecture (option) to focus design and technology development.

### M o s t s  (Programmatic)
- **M1-T**: Science: Meet Threshold requirements? (1.6 x 10)
- **M2**: Interfaces: Meets the DCIL**?
- **M3**: TRL Gates: For baseline science is there a credible plan to meet TRL5 at start of FY17 and TRL6 at start of FY19 within available resources?
- **M4**: Ready for 13/21 TAC briefing
- **M5**: Architecture applicable to future earth-characterization missions

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<td>HLC</td>
<td>VVC</td>
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### W a n t s

#### Evaluation

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#### Risks

- **Risk 1**: Technical risk in meeting TRL5 gate
- **Risk 2**: Schedule or Cost risk in meeting TRL5 Gate
- **Risk 3**: Schedule or Cost risk in meeting TRL6 Gate
- **Risk 4**: Risk of not meeting at least threshold science
- **Risk 5**: Risk of mfr tolerances not meeting 8L science
- **Risk 6**: Risk that wrong architecture is chosen due to assumption that all jitter 2xH is only tip/tur
- **Risk 7**: Risk that wrong architecture is chosen due to any assumption made for practicality/simplicity
- **Risk 8**: Risk that ACWG simulations (by JK and BM) overestimate the science yield due to model fidelity

### Opportunities

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<th>SPC</th>
<th>PAACBMC</th>
<th>HLC</th>
<th>VVC</th>
<th>VNC-DA</th>
<th>VNC-PO</th>
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<tr>
<td><strong>Oppty 1</strong>: Possibility of Science gain for 0.2ms/sec jitter, x30</td>
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When: Next Steps
Next Steps

• **Subsequent Telecons with the entire Working Group**
  – Weekly cadence
  – Advance work on Selection Criteria

• **Second Face-to-Face Workshop for the Study Members**
  – Oct 2-4 at NASA LaRC (Hampton, VA)
  – Focus is on Activity 1b: Assembly and Infrastructure
  – Draft Agenda completed
  – Breakout sessions focused on concept options
Top-Level Schedule

<table>
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<tr>
<th>Activity</th>
<th>FY2018</th>
<th>FY2019</th>
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<td>Weekly Telecons</td>
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<td>ISAT Design &amp; Architecture F2F</td>
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<td>Design &amp; Architecture Concept (1a)</td>
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<td>Decadal Survey WP (3)</td>
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**Planned Activity**

**Planned Milestone**

**Deliver Interim Report**

**Face-to-Face/Briefing**

**DS WP Delivered**

*tentative date*