Jet Propulsion Laboratory
California Institute of Technology

In-Space Assembled Telescope (iSAT)

Study Members Kickoff Telecon

May 7 and 8, 2018

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CL#18-2390

Today’s Agenda

1. Background and Motivation
2. Plan Forward
3. Participants and Roles
4. Process
5. Next Steps

Background

Background

- SMD is interested in advancing exoplanet science which benefits from ever-increasing large telescopes to detect theses faint objects and characterize them through spectroscopy.
  - Large telescopes also advances many topics in general astrophysics
- But why do these telescopes have to cost so much? Is there a way to break the cost model of telescopes that appears to go as something like $\$ \propto D^{2-3}$?
- Last November, Harley Thronson (NASA GSFC) led a Workshop on in-Space Servicing & Assembly

70+ participants from government, industry, and academia

https://exoplanets.nasa.gov/exep/technology/in-space-assembly/

TIM Suggestions (1 of 2)

Commission a design study to understand how large-aperture telescopes could be assembled and serviced in space

- *Suggest joint SMD/STMD/HEOMD study with industry and academia participation*
- *Multi-disciplinary, multi-institutional*
- *Initiate the study in time for initial results to be available to Gateway and robotics designers within 2018, but certainly before end 2019.*

1. **Produce several iSA concepts and prioritize them**
2. **Select one implementation concept for a deeper engineering study**
   a) *identify capability needs, SOA, and technology gaps and produce a list of technologies that could be demonstrated to close these gaps*
   b) *assess opportunities for engineering demonstrations that may be deployed on the ISS within the next few years.*
   c) *determine balance of human and robotic support*
   d) *understand servicing options*
   e) *produce an early list of preliminary interface consideration to the DSG*
3. **Estimate the cost and understand scaling laws to compare costs/risks to an autonomously deployed telescope**

Extracted from Nov TIM Summary Report
https://exoplanets.nasa.gov/exep/technology/in-space-assembly/

#8) Why Now?

- **There are large future space observatories being studied and designed today to be serviceable but the servicing capabilities do not currently exist.**
- **There are large future space observatories being studied and designed today that are limited by current and future launch vehicle fairing sizes.**
  - *“We are now hitting a wall [towards what is possible]”*
- **Potential space telescope missions planned to be serviced and/or assembled in the 2030s need to start their technology activities in the 2020s.**
- **A valuable venue for assembly demonstrations, the ISS, may be decommissioned in the mid-2020s.**
- **There is a near-term opportunity to inform the 2020 Decadal Survey about the potential benefits of iSSA as a potential implementation approach for future large apertures and the current SOA.**
- **There is at present a window of opportunity through 2019 to recommend augmentations to the DSG team before their designs are frozen.**
  - *March-July 2018 is the optimal window*

Study Objective and Deliverables

- **Study Objective:**
  - *"When is it advantageous to assemble space telescopes in space rather than to build them on the Earth and deploy them autonomously from individual launch vehicles?"*

- **Deliverables:**

A whitepaper by May 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 the iSA of telescopes.

#3) How does iSSA reduce cost and risk, both technical and programmatic? (2 of 4)

Extracted from Nov TIM Summary Report
https://exoplanets.nasa.gov/exep/technology/in-space-assembly/

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**

#3) How does iSSA reduce cost and risk, both technical and programmatic? (3 of 4)

Extracted from Nov TIM Summary Report
https://exoplanets.nasa.gov/exep/technology/in-space-assembly/

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.**

#3) How does iSSA reduce cost and risk, both technical and programmatic? (4 of 4)

Extracted from Nov TIM Summary Report
https://exoplanets.nasa.gov/exep/technology/in-space-assembly/

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**

Plan Forward

Study Charter

- Draft Charter written and will be submitted for signature by the Sponsors.
- The iSAT Study Working Group is intended to represent expert knowledge in the area of telescope design and architecture, assembly and testing across academia, NASA, other gov't agencies, and industry.

In-Space Assembled Telescope (iSAT) Study
4/23/2018, v2

DRAFT Charter

A. Background

Large aperture telescopes benefit all astrophysics as well as planetary and Earth science. They provide unprecedented spatial resolution, spectral coverage, and signal to noise advancing all of these science areas. Envisioning the need for future large segmented telescopes to one day exceed the fairing size of existing or even planned launch vehicles, NASA will need to begin considering the in-space assembly (iSA) of these future assets. In addition, robotically assembling space telescopes in space rather than deploying them from single launch vehicles offers the possibility, in some circumstances, of reduced cost and risk for even smaller telescopes. This possibility, however, has not been proven. Therefore, following discussions within NASA's Science Mission Directorate (SMD) and Astrophysics Division (APD), the SMD Chief Technologist and APD Division Director have commissions study to assess the cost and risk benefits, if any, of the iSA of space telescopes. In particular, the study must answer the question: ***"When is it advantageous to assemble space telescopes in space rather than to build them on the Earth and deploy them autonomously from individual launch vehicles?"*** This document charters the plan for the study deliverables, process, and membership. The goal for completion of the study is May 2019 culminating in a submitted whitepaper to the National Academies' 2020 Astronomy & Astrophysics Decadal Survey.

B. Deliverables

The in-Space Assembly Telescope (iSAT) Study Working Group is chartered by the NASA SMD Chief Technologist and APD Director to deliver by the goal of May 2019 a whitepaper 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)

* * *

Paul Hertz
Division Director
NASA Astrophysics Division

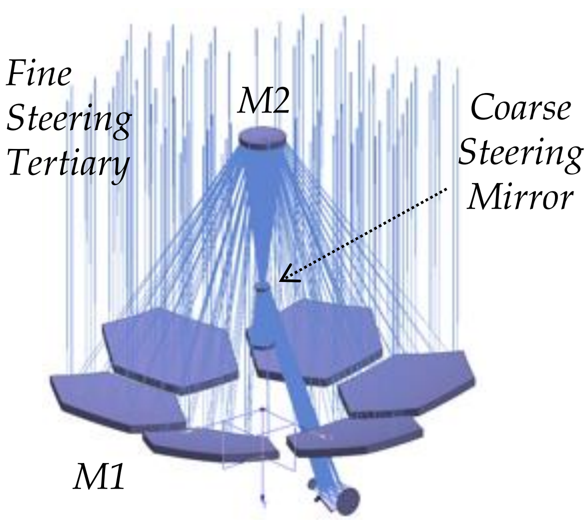
Michael Seablom
Directorate Chief Technologist
NASA Science Mission Directorate

Activity 1a

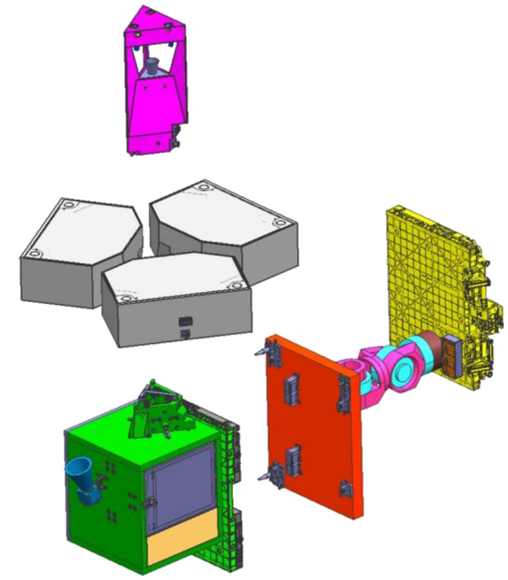
Concept Design and Architecture for the iSAT

Select a reference <u>design and architecture</u> 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):



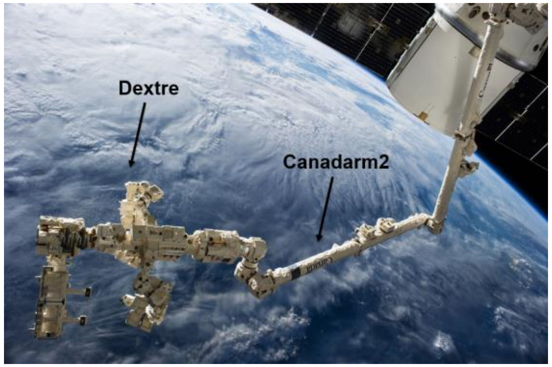
3 Mirror Anastigmat Telescope (1.45 m aperture)

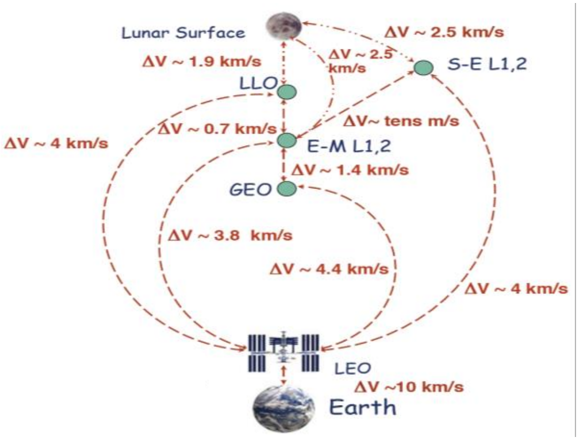


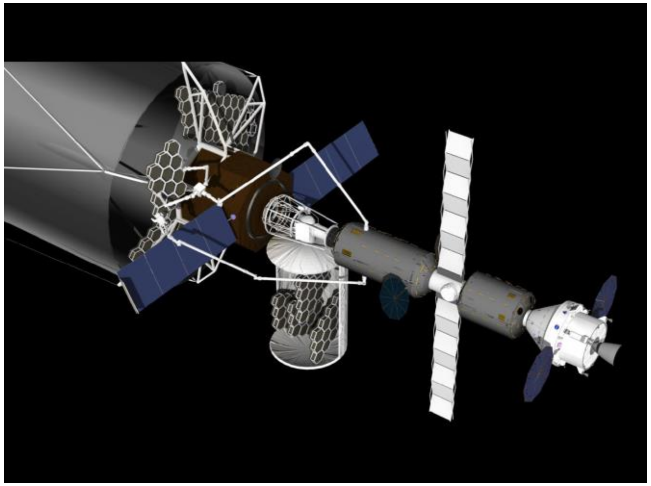
6 launch modules for assembly

Activity 1b:
Concept for Assembling and Testing the ISAT

Select a reference in-space <u>assembly and testing concept</u> for the "assemble-able" space telescope architecture, defining robotics, orbit, launch vehicle, and assembly platform.







Activities 2a and 2b

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

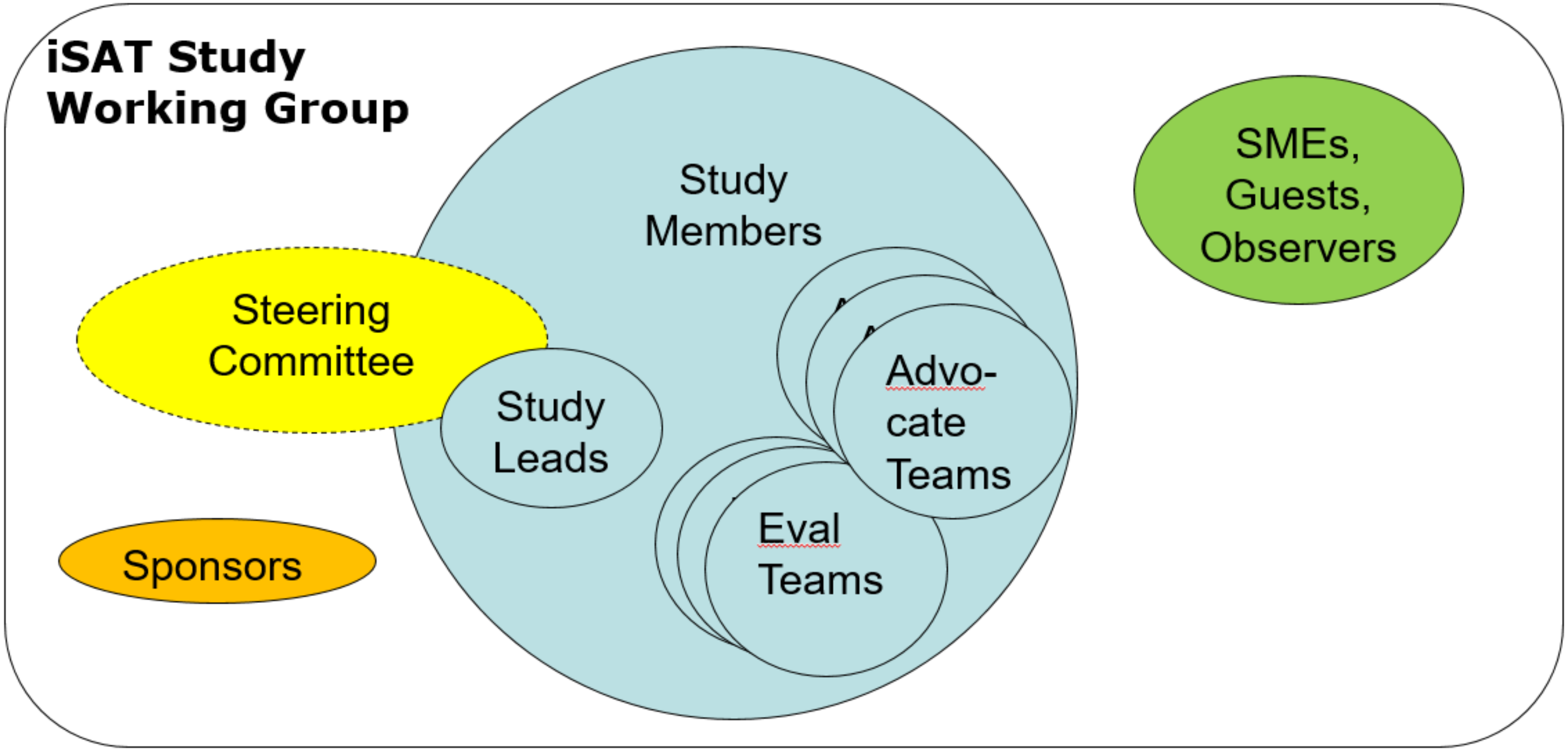
Write and deliver the Final Whitepaper

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

Participants and Roles

(US Persons Only)

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

1.	Dave Redding	NASA JPL	Study Member (mirror segments, WFSC)
2.	Joe Pitman	consultant	Study Member (opto-mech structures)
3.	Scott Knight	Ball Aero	Study Member (optical design)
4.	Bill Doggett	NASA LaRC	Study Member (telescope structures)
5.	Matthew Greenhouse	NASA GSFC	Study Member (astrophysicist)
6.	Joanne Hill-Kittle	NASA GSFC	
7.	Ron Polidan	consultant	Study Member (telescopes)
8.	John Grunsfeld	NASA (ret)	
9.	Keith Belvin	NASA STMD	
10.	Brad Peterson	STScI/OSU	Study Member (astrophysicist)
11.	Florence Tan	NASA SMD	
12.	Ray Bell	Lockheed	Study Member (telescope systems)
13.	Nasser Barghouty	NASA APD	
14.	Eric Smith	NASA JWST/APD	
15.	Keith Warfield	NASA ExEP	Study Member (systems)

Study Leads

Nick Siegler (co-)	NASA ExEP/JPL	
Harley Thronson (co-)	NASA PCOS/COR Programs/GSFC	
Rudra Mukherjee (co-)	NASA JPL	Study Member (robotics)

Study Members

Invited (C=confirmed; I=invited):

Name	Institution	Expertise
1. Joel Nissen (C)	NASA JPL	Metrology
2. Gary Matthews (C)	Consultant	Mirror Segments
3. Fang Shi (C)	NASA JPL	WF Sensing/Control, Coronagraphy
4. Larry Dewell (C)	Lockheed	Pointing, Stability, Control
5. Oscar Salazar (C)	NASA JPL	Pointing, Stability, Control
6. Phil Stahl (C)	NASA MSFC	Telescope Architecture
7. Jon Arenberg (C)	Northrop	Telescope Architecture
8. Doug McGuffey (C)	NASA GSFC	Systems Engineering
9. Kim Aaron (C)	NASA JPL	Systems Engineering/Structures
10. Sharon Jeffries (C)	NASA LaRC	Systems Engineering
11. Al Tadros (C)	SSL	Robotics
12. Joel Burdick (C)	Caltech	Robotics
13. Bob Hellekson (C)	Orbital-ATK	Telescope Systems
14. Gordon Roesler (C)	DARPA	Robotics
15. Michael Rodgers (C)	NASA JPL	Optical Design
16. Hsiao Smith (C)	NASA GSFC	Robotics
17. Eric Mamajek (C)	NASA ExEP	Astrophysicist
18. Shanti Rao (C)	NASA JPL	Optical Design
19. Ray Ohl (C)	NASA GSFC	Optical Alignment/Test
20. Sergio Pellegrino (C)	Caltech	Telescope Structures
21. Cal Ablanalp (I)	Harris	Telescope Design
22. Tere Smith (C)	NASA JPL	I&T
23. Paul Backes (C)	NASA JPL	Robotics
24. Jim Breckenridge (C)	Univ of Arizona	Optical Design
25. AllisonBarto (C)	Ball	Optical SE/testing
26. Jeanette Domber (C)	Ball	SE/Structures/Instruments
27. Joe Parrish (C)	DARPA	Robotic Systems
28. Acey Herrera (I)	NASA GSFC	I&T
29. Paul Dizon (I)	NASA GSFC	I&T
30. David Stubbs (C)	Lockheed	Telescope Structures/Design
31. John Dorsey (C)	LaRC	Telescope Structures
32. David Yanatis (I)	Harris	Optical Systems
33. Jeff Sokol (C)	Ball	Mechanical/I&T
34. Peter Waydo (C)	NASA JPL	I&T
35. Brendan Crill (C)	NASA ExEP	Technologist/Detectors

Expect changes to the Study Members for the Assembling and Testing concepts (Activity 1b)

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 criteria of evaluation**
3. **Will generate concepts of modularized telescope designs and architectures (a.k.a. options)**
   - …and later the assembly and testing concepts
4. **Will provide the Study with evaluation teams**
5. **Will reach consensus on the criteria assessment for each concept**
6. **Membership will change from “telescope design and architecture” focus to “robotic assembly, orbit, platform, launch vehicle, and test” focus**
7. **Bi-weekly telecons**

Subject Matter Experts, Observers, and Guests

38. Lynn Bowman (C)	NASA LaRC
39. Keith Warfield (I)	NASA ExEP
40. Rich Rynders (C)	Orbital-ATK
41. Howard MacEwen (C)	Reviresco

Subject Matter Experts, Guests, Observers are invited by the Study Leads and Steering Committee Group and participate as needed. Consultants are subject-matter experts necessary to inform the trade recommendation. Expectations on the frequency and degree of participation are lower than for the Study Members. These participants are **not required to be in consensus** with the Study Members, though are welcome to participate in the full iSAT Study Working Group deliberations. *(iSAT Study Charter)*

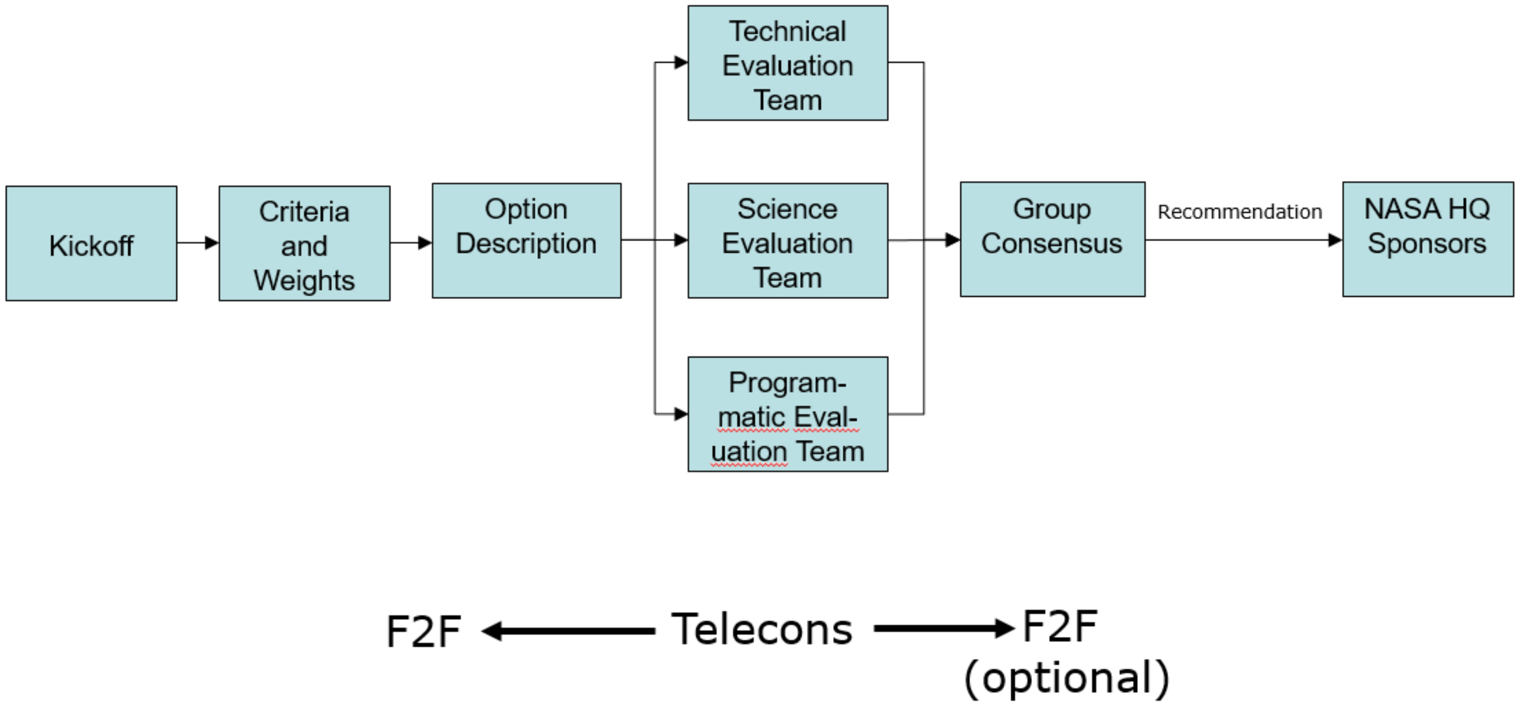
Consensus

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

Process

How will iSAT Study WG Produce a Recommendation?



- **Examples of Recommendations following this Trade Process:**
  - WFIRST Coronagraph: http://wfirst.gsfc.nasa.gov/science/AFTA_Coronagraph_Arch_Selection/Coronagraph_Downselect_Rec_Dec13_2013.pdf
  - Starshade Readiness Working Group: https://exoplanets.nasa.gov/system/internal_resources/details/original/339_SSWG_APD_briefing_final.pdf
  - Starshade Mechanical Deployment Trade Study

Features of Kepner-Tregoe Decision Process

Systematic Decision Making

Decision Statement								
Description			*Option 1*		*Option 2*		*Option 3*	
	Feature 1							
	Feature 2							
	Feature 3							
Evaluation	**Musts**							
	M1		✓		✓		✓	
	M2		✓		?		?	
	M3		✓		✓		✗	
	Wants	*Weights*						
	W1	*w1%*	*Rel score*		*Rel score*		*Rel score*	
	W2	*w2%*	*Rel score*		*Rel score*		*Rel score*	
	W3	*w3%*	*Rel score*		*Rel score*		*Rel score*	
		100% Wt sum =>	*Score 1*		*Score 2*		*Score 3*	
	Risks		C	L	C	L	C	L
	Risk 1		M	L	M	L		
	Risk 2		H	H	M	M		
Final Decision, Accounting for Risks								
C = Consequence, L = Likelihood								

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

A little consensus at a time

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

Descr	Name			Option 1 SPC	Option 2 PIAACMC	Option 3 HLC	Option 4 VVC	Option 5 VNC - DA	Option 6 VNC - PO	Notes
Musts		Programmatic								
	M1 - T	Science: Meet Threshold requirements? (1.6, x10)		Yes	Yes	Yes	No	No	U	
	M2	Interfaces: Meets the DCIL**?		Yes	Yes	Yes	Yes	Yes	U	
	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?		Yes	Yes	Yes	U	No	U	
	M4	Ready for 11/21 TAC briefing		Yes	Yes	Yes	Yes	Yes	No	
	M5	Architecture applicable to future earth-characterization missions		Yes	Yes	Yes	Yes	Yes	U	

Legend:
- ✓ yes, or expected likely
- ? unknown
- ✗ no, or expected showstopper

Wants			Weights	SPC	PIAACMC	HLC	VVC	VNC-DA	VNC - PO	Notes
	W1	Science	40							
	a	Relative Science yield (1.6, x10) beyond M1-T		Sm/Sig	Best	Sm/Sig	VL	VL		Range of opinions between "significant and small". For SPC and VNC2 the search area is ~3 times less than 360deg, and that was taken into acct in comparisons
	W2	Technical	30							
	a	Relative demands on observatory (DCIL), except for jitter and thermal stability		Best	Best	Best	Best	Small		
	b	Relative sensitivities of post-processing to low order aberrations		Best	Sig	Sig	VL	U		For n-lambda over D or different amplitudes the designs will have the same relative ranking
	c	Demonstrated Performance in 10% Light		Small	Sig	Best	Sig	VL		Demonstrated Performance (10%) and Prediction
	d	Relative complexity of design		Best	Small	Best	Small	Sig		
	e	Relative difficulty in alignment, calibration, ops		Best	Small	Best	Small	Sig/Sm		
	W3	Programmatic	30							
	a	Relative Cost of plans to meet TRL gates		Best	Small	Best	Sig	Sig		
		Wt. sum =>	100%							

Identify "Best" and others are:
- -Wash
- -Small Difference
- -Significant Difference
- -Very Large Difference

Risks	(all judged to be Hgh consequence)	SPC C	SPC L	PIAACMC C	PIAACMC L	HLC C	HLC L	VVC C	VVC L	VNC-DA C	VNC-DA L	VNC - PO C	VNC - PO L	Notes
Risk 1	Technical risk in meeting TRL5 gate		L		M		M/L		M/H		H			PIAA trend over the last three working days lower, but recommendation to keep M
Risk 2	Schedule or Cost risk in meeting TRL5 Gate		L		M		M/L		M/H		H			
Risk 3	Schedule or Cost risk in meeting TRL6 Gate		L		L		L		M		M			
Risk 4	Risk of not meeting at least threshold science		L		L		L		H		H			
Risk 5	Risk of mnfr tolerances not meeting BL science		L		L		L		M/L		H			One dissent, previous TDEM performance track record and Bala's assessment should be taken into account.
Risk 6	Risk that wrong architecture is chosen due to assumption that all jitter >2Hz is only tip/tilt		L		M/H		M		M/H		M			
Risk 7	Risk that wrong architecture is chosen due to any assumption made for practicality/simplicity	open ended question, spawned evaluations on Risk 5, Risk 6, Risk 8, and Oppty 1												
Risk 8	Risk that ACWG simulations (by JK and BM) overestimate the science yield due to model fidelity	discussed; not enough understanding at this time to make an evaluation.												Model validation is a risk that needs to be evaluated in the future

Opportunities	(judged to be High benefit)	SPC B	SPC L	PIAACMC B	PIAACMC L	HLC B	HLC L	VVC B	VVC L	VNC-DA B	VNC-DA L	VNC - PO B	VNC - PO L
Oppty 1	Possibility of Science gain for 0.2marcsec jitter, x30		L		M/H		M		L		H		

Final Decision, Accounting for Risks and Opportunities:

C = Consequence, L = Likelihood, B=Benefit

**DCIL = Dave Content Interface List

(yellow) indicates those few areas where consensus was not achieved

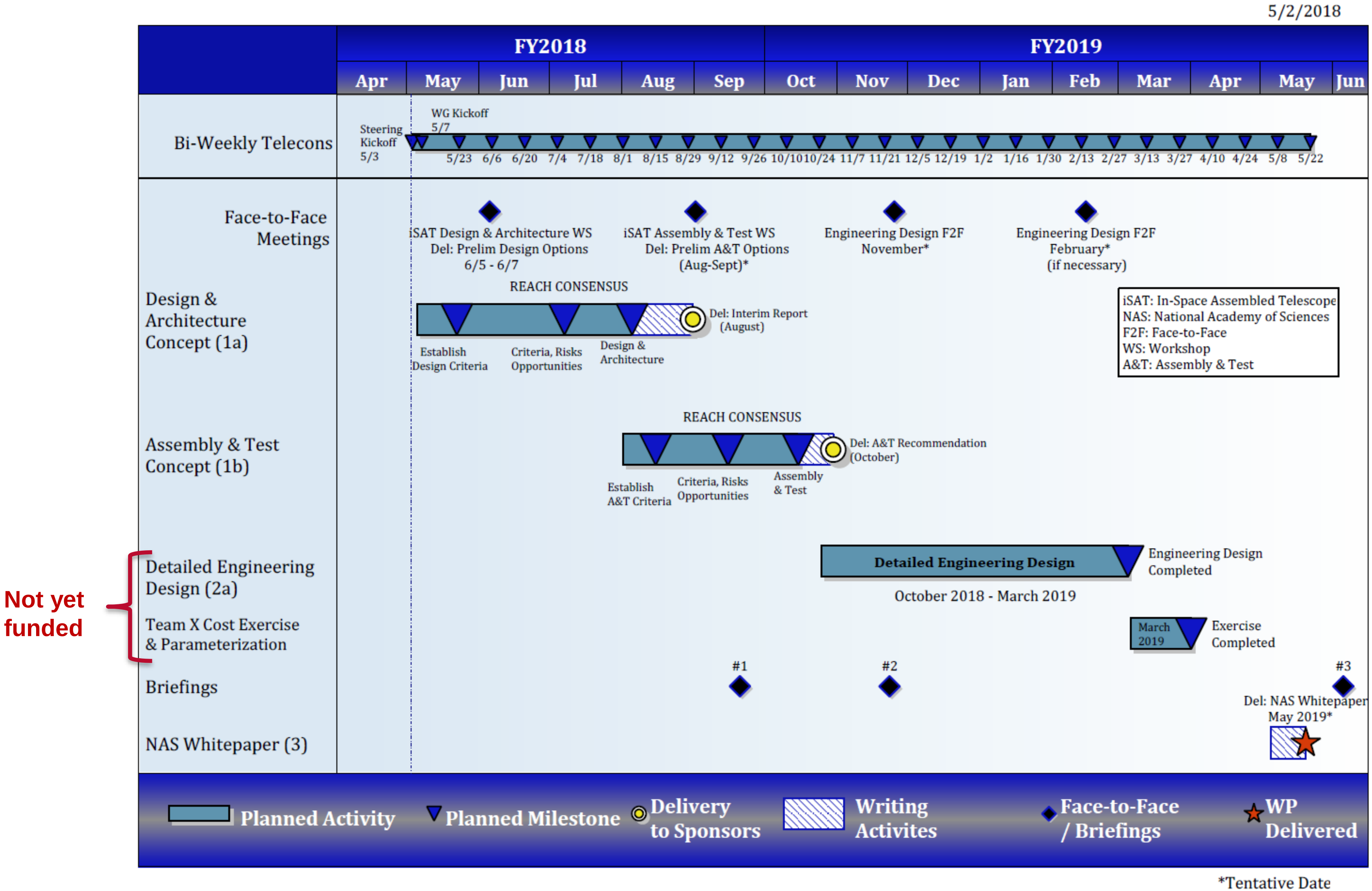
(white) consensus achieved on balance of matrix

Next Steps

Next Steps

- **Subsequent Telecons with the entire Working Group**
  - Bi-weekly cadence
  - Advance work on Selection Criteria
- **First Face-to-Face Workshop for the Working Group**
  - June 5-7 at Caltech
  - Focus is on Activity 1a: Designing and Architecting a Modularized Telescope
  - Draft Agenda completed
  - Breakout sessions

Draft Schedule (Under Review)



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