Alternatives to the WFIRST Coronagraph Instrument for Advancing Coronagraph Technologies:

Preliminary Assessment v2

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Pre-Decisional Information -- For Planning and Discussion Purposes Only

The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech

The Problem Statement

Problem Statement:

Evaluate alternatives to the CGI for maturing coronagraph technologies in the event the WFIRST CGI is not flown.

Key assumptions:

- Technology development for the coronagraph is targeted towards large UV/O/IR direct imaging missions.
- Options are fully funded and commence in 2019.

Executive Summary

In the event the Coronagraph Instrument (CGI) is not flown on the WFIRST mission, a preliminary assessment for alternatives to mature coronagraph technologies in behalf of future large direct imaging missions was conducted. A list of brainstormed options was created along with a set of key criteria and risks for identifying compelling options.

Preliminary key findings:

1. No superior alternatives to CGI were identified, however, four options merit further consideration.

2. The options that mitigated the most risk for future large direct imaging missions were also the most expensive - smaller space missions.

3. One of the small space options, a 0.5 m-class free flyer space tech demo, had an estimated cost similar to CGI but mitigated more future residual technical risk. It could also be made “starshade ready”.

4. Ground-only demonstrations were the lowest cost options mitigating many of the residual risks for future large missions but, in important ways, less than what CGI would do.

Assessment Process

To identify alternative options to CGI for maturing coronagraph technology, a list of options was brainstormed. A set of key criteria and risks was selected to organize the pros and cons of the options. An unweighted Pugh Concept Decision Matrix was used as a preliminary approach to the assessment. This approach is useful when alternatives to a baseline approach are sought. It is, however, not a trade study and is not meant to choose but rather identify strong options for consideration.

- Pugh Matrix

Example – Concept Selection from Among Three Alternatives:

Criteria	Baseline	Alternative 1	Alternative 2	Alternative 3	Weight
Safe	0	-	-	0	1
Durable	0	+	0	-	1
Weight	0	-	-	+	1
Easy to Assemble	0	+	0	-	1
Reliable	0	-	-	-	1
Cost	0	+	0	+	1
Net Score		0	-3	-1	
Rank		1	3	2	
Continue?		Yes	No	No	

The Criteria should be carefully selected as they may be correlated and bias the assessment outcome. Weighting may be applied; robustness of the results to changes in the scores should also be considered.

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The Options

Option #:	0	1a	1b	2	3	4	5	6
Option Title:	CGI as Tech Demo (current plan)	Groundbased Technology Maturation (CGI Threshold)	Groundbased Technology Maturation (Future Mission Threshold)	Small Free Flyer (Flight Tech Demo)	Exo-C' (Flight Science Mission)	Tech Demo on ISS	Tech Demo on a Robotic Assembly Mission at the Gateway	Balloon Tech Demo
Option Description:	Reference - Class C tech demo - 2.4 m obscured monolith - starshade ready	- conduct testing completely within HCIT to TRL 6 of a WFIRST CGI mission - add telescope simulator - include disturbance source	- conduct testing completely within HCIT to TRL 6 of a future large directimaging mission - add telescope simulator - include disturbance source	- Upgraded versions of EXCEED (70 cm telescope) or ACEsat (now Project Blue, ~40 cm) like mission put in thermally stable orbit. - Class C	- 1.4 m, off-axis flight mission - changes from Exo-C: orbit changed from Earth-trailing to SEL2, made starshade ready (analagous to CGI)	- externally-mounted 0.5 m-class instrument - coronagraph built with jitter control or isolation to combat Station dynamics - 2002 Jovian Planet Finder (MidEx proposal)	OpTIIX-like (robotically-assembled telescope) with coronagraph - attached to the platform (not-free flier) - assume free HEO platform exists - 1.5 m off-axis, segmented telescope - A variant option could be assembled in GEO by the DARPA-RSGS station	- 0.5-1 m telescope - similar to PICTURE-C upgraded to 2 DMs, LOWFSC, EMCCD, vibration isolation, pointing
Option Raw Contrast:	10-100x worse than future missions	10-100x worse than future missions	1x future mission	10x worse than future missions	10x worse than future missions	> 100x worse than future missions	10-100x worse than future mission needs	100-1000x worse than future mission needs
Option Orbit:	Sun-Earth L2	None	None	Earth-trailing	Sun-Earth L2	LEO	cislunar	Sub-orbital

The Key Criteria
(the ones that get scored)

Key Criteria	Comments	Weight
Residual Risk for Future Mission	The less residual risk between the implementation of the option and the requirements of the future direct imaging mission the better. Examples are exercising the critical hardware in the operational env't, performance nears requirements of future missions.	1
Schedule	Date at which TRL 6 is reached; faster the better. Assume 2019 start.	1
Cost	Less expensive the better. $M FY18	1

Most important for future large direct imaging missions

Risk		
Risk of Not Meeting Performance Goals at TRL 7	Risk of implementation	1

Risk that the Option will not succeed

Results

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	Key Criteria								
1	Residual Risk for Future Mission	Contrast performance requirement is 10-100x less than the future mission requirement. All key components of the coronagraph are demonstrated. Performance models are validated in operating environment. Disturbances from spacecraft and environment to the coronagraph are included in the model validation.	The testbed demo can already be tuned to the requirements of WFIRST CGI (big pro) except it will not have its performance models validated with information from the S/C (con) nor actually have the system performance (with spacecraft) validated in the operating environment (big con). It's the unknown/unknown in the interaction between the coronagraph and the S/C that is one of the biggest concerns and risks.	Performance better than CGI. The testbed demo can already be tuned to the requirements of a future mission (big pro), however, it will not have its performance models validated with information from the S/C (con) nor actually have the system performance (with spacecraft) validated in the operating environment (big con). It's the unknown/unknown in the interaction between the coronagraph and the S/C that is one of the biggest concerns and risks.	Performance requirements near those of a future flagship mission. Likely better than CGI with optimized telescope/spacecraft for coronagraphy. System would be much stiffer than large flagship telescope, but otherwise similar to risk reductions achieved with CGI. All key coronagraph components exercised in operational environment. Coronagraph performance models are validated with inputs from spacecraft and telescope.	Performance requirements near those of a future flagship mission. Coronagraph can drive telescope hence optimized system and better contrast performance. All key coronagraph components exercised in operational environment. Coronagraph performance models are validated with inputs from spacecraft and telescope.	ISS env't likely to prevent contrast requirements of future missions from being met. Needs more study. Stray light, out-gassing vibration, thermal instability all likely to compromise tech demo.	More thermally stable env't, away from bright Earth reduces scatter light, vibration and pointing env't of platform likely better than ISS (not clear), less outgas	Pointing and thermal disturbances limit contrast. Significantly different spacecrafts affecting disturbances and models validation.
2	Schedule	2020	2021 (2 years to TRL 6 like CGI but add a year for env't testing)	2024 (2 years to TRL 5, 2 years to TRL 6 like CGI but add 1 year for env't testing)	2021	2022	2017 (skip TRL 6; launch TRL 5 prototype by 2022)	2023	2017 (skip TRL 6; launch first TRL 5 prototype in 2021; second demo in 2022)
3	Cost	- $400M RY total delivered instrument to GSFC plus I&T and operations - $300M FY18 (savings to NASA if descoped)	$50M[0]	$70M[1] Cost (and schedule) will increase for segmented designs.	$300-400M[2]	$1,100-1,200M[3]	$80M[4]	$200-$250[5]	$80M[6]
	Risk								
4	Risk of Not Meeting Performance Goals at TRL 7	Class C	N/A	N/A	Class C	Optimized telescope driven by coronagraph requirements, clear aperture, off-axis secondary mirror	- stray light - contamination - doesn't go through TRL 6	new telescope technologies required and may drive schedule; Gateway may not even exist in time.	- Balloon has large pointing errors, beamwalk will limit contrast. - Balloon is unstable system due to day/night temperature variations - does not advance technology to TRL 7 - Likely needs multiple flights to meet all objectives; can't rely on payload surviving re-entry to surface

Much better = +2
Slightly better = +1
Neutral = 0
Slightly worse = -1
Much worse = -2
N/A

Pros and cons for each option can be read vertically: blues are "pros" and browns are "cons".

Residual Risk for Future Missions

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Option #:	0	1a	1b	2	3	4	5	6
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Residual Risk for Future Mission	Contrast performance requirement is 10-100x less than the future mission requirement. All key components of the coronagraph are demonstrated. Performance models are validated in operating environment. Disturbances from spacecraft and environment to the coronagraph are included in the model validation.	The testbed demo can already be tuned to the requirements of WFIRST CGI (big pro) except it will not have its performance models validated with information from the S/C (con) nor actually have the system performance (with spacecraft) validated in the operating environment (big con). It's the unknown/unknown in the interaction between the coronagraph and the S/C that is one of the biggest concerns and risks.	Performance better than CGI. The testbed demo can already be tuned to the requirements of a future mission (big pro), however, it will not have its performance models validated with information from the S/C (con) nor actually have the system performance (with spacecraft) validated in the operating environment (big con). It's the unknown/unknown in the interaction between the coronagraph and the S/C that is one of the biggest concerns and risks.	Performance requirements near those of a future flagship mission. Likely better than CGI with optimized telescope/spacecraft for coronagraphy. System would be much stiffer than large flagship telescope, but otherwise similar to risk reductions achieved with CGI. All key coronagraph components exercised in operational environment. Coronagraph performance models are validated with inputs from spacecraft and telescope.	Performance requirements near those of a future flagship mission. Coronagraph can drive telescope hence optimized system and better contrast performance. All key coronagraph components exercised in operational environment. Coronagraph performance models are validated with inputs from spacecraft and telescope.	ISS env't likely to prevent contrast requirements of future missions from being met. Needs more study. Stray light, out-gassing vibration, thermal instability all likely to compromise tech demo.	More thermally stable env't, away from bright Earth reduces scatter light, vibration and pointing env't of platform likely better than ISS (not clear), less outgas	Pointing and thermal disturbances limit contrast. Significantly different spacecrafts affecting disturbances and models validation.

- **Ground-only demonstrations (Options 1a and 1b) were the lowest cost options (next slide), mitigating many of the residual risks for future large missions but, in important ways, less than CGI.**
- **The options that mitigated the most risk for future large direct imaging missions were smaller space missions (Options 2 and 3).**

Much better = +2	Slightly better = +1	Neutral = 0	Slightly worse = -1	Much worse = -2	N/A

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Schedule, Cost, Risk

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Risk								
Risk of Not Meeting Performance Goals at TRL 7	Class C	N/A	N/A	Class C	Optimized telescope driven by coronagraph requirements, clear aperture, off-axis secondary mirror	- stray light - contamination - doesn't go through TRL 6	new telescope technologies required and may drive schedule; Gateway may not even exist in time.	- Balloon has large pointing errors, beamwalk will limit contrast. - Balloon is unstable system due to day/night temperature variations - does not advance technology to TRL 7 - Likely needs multiple flights to meet all objectives; can't rely on payload surviving re-entry to surface

- Smaller space missions (Options 2 and 3) that mitigated the most risk for future large missions were also the most expensive.
- Option 2, a 0.5 m-class free flyer space tech demo, had an estimated cost similar to CGI but mitigated more future residual technical risk. It could also be made “starshade ready”.
- Risk was treated as a Criterion and scored as we believe “low risk” options should be identified.

Much better = +2	Slightly better = +1	Neutral = 0	Slightly worse = -1	Much worse = -2	N/A

Numerical Results

	0	1a	1b	2	3	4	5	6
	CGI as Tech Demo (current plan)	Groundbased Technology Maturation (CGI Threshold)	Groundbased Technology Maturation (Future Mission Threshold)	Small Free Flyer (Flight Tech Demo)	Exo-C' (Flight Science Mission)	Tech Demo on ISS	Tech Demo on a Robotic Assembly Mission at the Gateway	Balloon Tech Demo
Sum of all Positives	0	2	2	1	2	2	1	2
Sum of all Negatives	0	3	3	1	3	5	5	5
Sum of all Neutrals	0	0	0	0	0	0	0	0
Total Score	0	-1	-1	0	-1	-3	-4	-3
Rank	Reference	Tied 2	Tied 2	1	Tied 2	Tied 3	4	Tied 3

- **No superior alternatives to CGI were identified.**
- **Options 2's score is commensurate with CGI's; Options 1a, 1b, and 3 all merit inclusion for further discussion.**

Additional Comments

- A conclusion from the group was ***<u>we have to do Option 1b regardless of what happens with CGI.</u>*** Option 1b is necessary for a future flagship (pending Decadal recommendation). Both HabEx and LUVOIR mission concepts require coronagraphs. We are taking a bite out of 1b already with the Decadal Survey Testbed. The specifics of Option 1b depend on the selected mission architecture, but it will have to be done to show the flagship coronagraph is at TRL 6. So with 1b it's not a question of IF, only WHEN. Hence, our options are really CGI plus 1b, free-flyer plus 1b, Exo-C' plus 1b, etc.

- We do ***<u>not</u>*** believe CGI or a flight demo of a high-contrast coronagraph (Option 2) is required before flying a future large mission, however, there is substantial risk carried forward to the future mission for reasons listed on slide 8 (row 12 of the accompanying Excel).