AFTA Coronagraph Technology Recommendation Process

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BOARD ON PHYSICS AND ASTRONOMY
Irvine CA

November 19, 2013


Exoplanet
Missions
JWST
AFTA
TESS
Kepler
New Worlds
Telescope
Spitzer
Hubble
Ground-based
Observatories
Astronomy and Astrophysics
in the New Millennium
2001
Decadal
Survey
New Worlds,
New Horizons
2010
Decadal
Survey

AFTA Coronagraph Recommendation

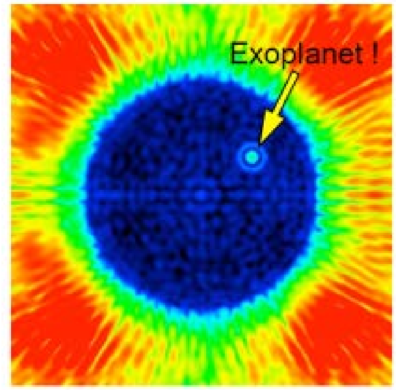
Why: In response to NASA Administrator's guidance, and Astrophysics Director's Implementation plan, AFTA must produce a compelling and viable mission concept including coronagraph *within guideline budget and schedule* for potential new mission start in FY17

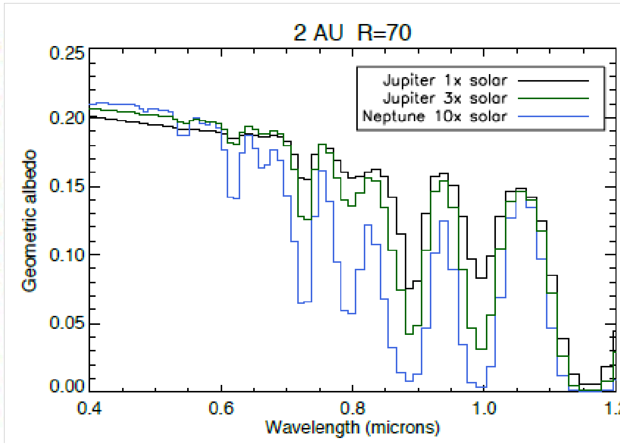
What:

- Choose primary and backup coronagraph technology to focus design and technology investments

AFTA = Astrophysics-Focused Telescope Asset

AFTA Coronagraph Instrument





Coronagraph Instrument → Exo-planet Direct imaging

Exo-planet Spectroscopy

Bandpass	430 – 980nm	Measured sequentially in five ~10% bands
Inner working angle	100 – 250 mas	3λ/D, driven by challenging pupil
Outer working angle	0.75 – 1.8 arcsec	By 48X48 DM
Detection Limit	Contrast = 10^{-9}	Cold Jupiters, not exo-earths. Deeper contrast looks unlikely due to pupil shape and extreme stability requirements
Spectral Resolution	70	With IFS, R~70 across 600 – 980 nm
IFS Spatial Sampling	17mas	This is Nyquist for λ~430nm

AFTA Coronagraph Instrument will:

- Characterize the spectra of over a dozen radial velocity planets.
- Discover and characterize up to a dozen more ice and gas giants.
- Provide crucial information on the physics of planetary atmospheres and clues to planet formation.
- Respond to decadal survey to mature coronagraph technologies, leading to first images of a nearby Earth.

Recent History

- **January 6 2013:** ExoPAG#7 endorses coronagraph for AFTA
- **May 30:** NASA Administrator gives permission for AFTA pre-formulation activities including a coronagraph
- **June 20:** AFTA Coronagraph Working Group (ACWG) Charter signed by NASA Headquarters, identifying Members.
- **July 23-25:** AFTA Coronagraph Workshop (ACW)#1 held at Princeton University
- **September 9,10:** AFTA Science Definition Team (SDT) meeting
- **September 25-27:** ACW#2 held at JPL
  - Preliminary science requirements and evaluation criteria established
- **October 21-22: ACW2.5 Telecon**
- **November 20-22: ACW3 at JPL**

Approach to Recommendation

- **Objective:** Recommend a primary and backup coronagraph architecture to focus design and technology development leading to potential new mission start in F17
- Recommendation by ExEPO and ASO based on inputs from
  - **SDT:** Sets the science requirements
  - **ACWG:** Delivers technical FOMs and technology plans
    > *Aim for the positive: a consensus product*
    > SDT delivers science FOMs
  - **TAC:** Analysis of technical FOM, TRL readiness plans, and risks
- **ExEPO and ASO** recommendation to **APD Director** based on:
  - Technical and Programmatic
  - Musts (Requirements), Wants (Goals), and Risks
  - Distinguish description from evaluation
- **APD Director** will make the decision

ACWG = representatives of ExEPO, ASO, SDT, Community

TAC:
Alan Boss (Carnegie Mellon)
Joe Pitman (EXSCI)
Steve Ridgway (NOAO)
Lisa Poyneer (LLNL)
Ben Oppenheimer (AMNH)

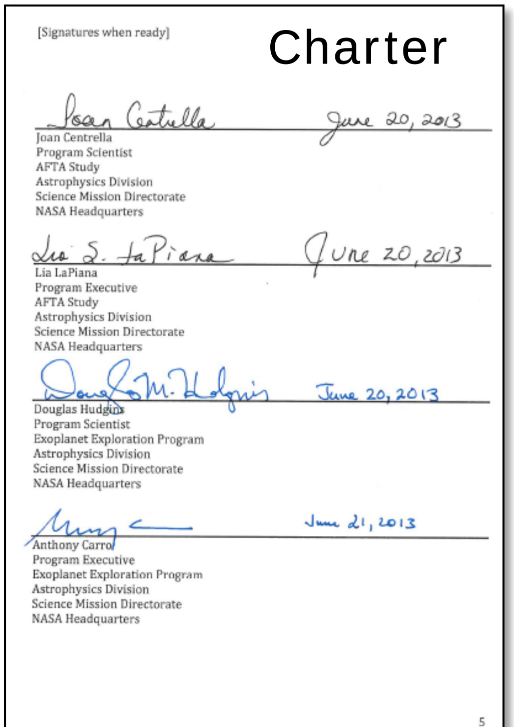
How do we define a successful outcome?

FOM = Figure of Merit

ACWG Membership

ExoPlanet Exploration Program

- These represent Program, Study Office, SDT, and Community:


[Signatures when ready]

Charter

June 20, 2013
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NASA Headquarters

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June 21, 2013
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Astrophysics Division
Science Mission Directorate
NASA Headquarters

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Steering Group:

Gary Blackwood (NASA JPL)
Kevin Grady (NASA GSFC)
Feng Zhao (NASA JPL)
Peter Lawson (NASA JPL)
Scott Gaudi (OSU)
Neil Gehrels (NASA GSFC)
Dave Spergel (Princeton U)
Tom Greene (NASA ARC)
Chas Beichman (NExScI)
Jeff Kruk (NASA GSFC)
Karl Stapelfeldt (NASA GSFC)
Wes Traub (NASA JPL)
Bruce MacIntosh (LLNL)

Members:

Jeremy Kasdin (Princeton U)
Mark Marley (NASA ARC)
Marc Clampin (NASA GSFC)
Olivier Guyon (UofA)
Gene Serabyn (NASA JPL)
Stuart Shaklan (NASA JPL)
Remi Soummer (STScI)
John Trauger (NASA JPL)
Marshall Perrin (STScI)
Rick Lyon (NASA GSFC)
Dave Content (NASA GSFC)
Mark Melton (NASA GSFC)
Cliff Jackson (NASA GSFC)
John Ruffa (NASA GSFC)
Jennifer Dooley (NASA JPL)
Mike Shao (NASA JPL)

- Additional consultants participate at request of Steering Group

Recommendation Criteria: Defining a Successful Outcome

MUSTS (Requirements): ***Go/No_Go***

1. Science: Does the proposed architecture meet the baseline science drivers?
2. Interfaces: For the baseline science, does the architecture meet telescope and spacecraft requirements of the observatory as specified by the AFTA project (DCIL[1])
3. Technology Readiness Level (TRL) Gates: For baseline science, is there a credible plan to be at TRL5 at the start of FY17 and at TRL6 at the start of FY19 within available resources?
4. Is the option ready in time for this selection process?

WANTS (Goals): ***Relative to each other, for those that pass the Musts:***

1. Science: Relative strength of science beyond the baseline
2. Technical: Relative technical criteria
   - See details
3. Programmatic: Relative cost of plan to meet TRL Gates

RISKS and OPPORTUNITIES

- See details

[1]DCL = Dave Content Interface List

AFTA Coronagraph Science Requirements

Baseline Science (Musts: M1)	
1	**General**
a	Operate from **430 to 980 in >10% bandpasses**
b	Operate separately or simultaneously in **2 polarization channels**
2	**Characterization of previously-known Doppler planets:** Spectroscopically characterize **from 650 to 950nm** at SNR=10, **R=70** per resolution element from 600-850 at least **6** previously-known Doppler planets in 3 months of mission time
3	**Search depth for gas giant (super-neptune) planets:** Total search depth of **40** for objects from r1=4 RE to r2=13 RE and 0.1<a<5 over a survey of 200 stars observing at 550 nm with one visit per star and a total survey time of up to 2 months
4	**Search depth for ice giant (sub-neptune) planets:** Total search depth of **4** for objects of r<4RE over a survey of 200 stars observing at 550 nm with four visits per star and a total survey time of up to 2 months
6	**Exozodiacal disk detection:** Detect a disk of **10x** our solar system's zodiacal level at **SNR=5** per resolution element at **1 AU** at **450 nm** at 8 pc
Science beyond the Baseline: Wants (W1a) (Relative Weight indicated)	
1	
a	(M) Cover at least 15% bandpass
b	n/a
2	(M)
3	(M)
4	(H) Total search depth for objects of r<2RE is a important 'extra' science capability for selection, with a desirable value being >4
6	(M)
Threshold Science (Risk R4)	
5T	**Exozodiacal disk detection:** Detect a disk of **100x** our solar system's zodiacal level at SNR=5 per resolution element at **2 AU** separation around a star 8 pc away at **450 and 800 nm**
3T	**Search depth for gas giant (super-neptune) planets:** Total search depth of **10** for objects from r1=4 RE to r2=13 RE and 0.1<a<5 over a survey of 200 stars observing at 550 nm with one visit per star and a total survey time of up to 2 months

Evaluation Criteria: Mask Architecture

ExEP

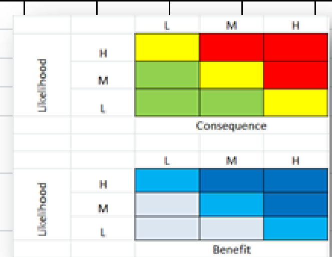
ExoPlanet Exploration Program

Decision Statement: Recommend one primary and one backup coronagraph architecture (option) to focus design and technology development

Desc					Option 1		Option 2		Option 3		Option 4		Option 5		Option 6	
		Name			Shaped Pupil		PIAACMC		Hybrid Lyot		Vector Vortex		VNC - DAVINCI		VNC - PO	
	Musts		Programmatic													
		M1	Science: Meet baseline requirements?													
		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 11/21 TAC briefing													
		M5	Architecture applicable to future earth-characterization missions													
Evaluation	Wants			Weights												
		W1	Science	40												
		a	Relative Science yield beyond the baseline													
		b														
		W2	Technical	30												
		a	Relative demands on observatory (DCIL)													
		b	Relative sensitivities of post-processing to low order aberrations													
		c	Relative TRL (level, qty) for HW, algorithms													
		d	Relative complexity of design													
		e	Relative difficulty in alignment, calibaration, ops													
		W3	Programmatic	30												
		a	Relative Cost of plans to meet TRL gates													
			Wt sum =>	100%	Score 1		Score 2		Score 3		Score 4		Score 5		Score 6	
	Risks				C	L	C	L	C	L	C	L	C	L	C	L
		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 manufacturing tolerances not meeting BL science													
		Risk 6	Risk that wrong architecture is chosen due to assumption that all jitter >2Hz is only tip/tilt													
		Risk 7	Risk that wrong architecture is chosen due to any assumption made for practicality/simplicity													
	Opportunities				B	L	B	L	B	L	B	L	B	L	B	L
		Oppty 1	Science gain for 2x smaller jitter than DCIL													

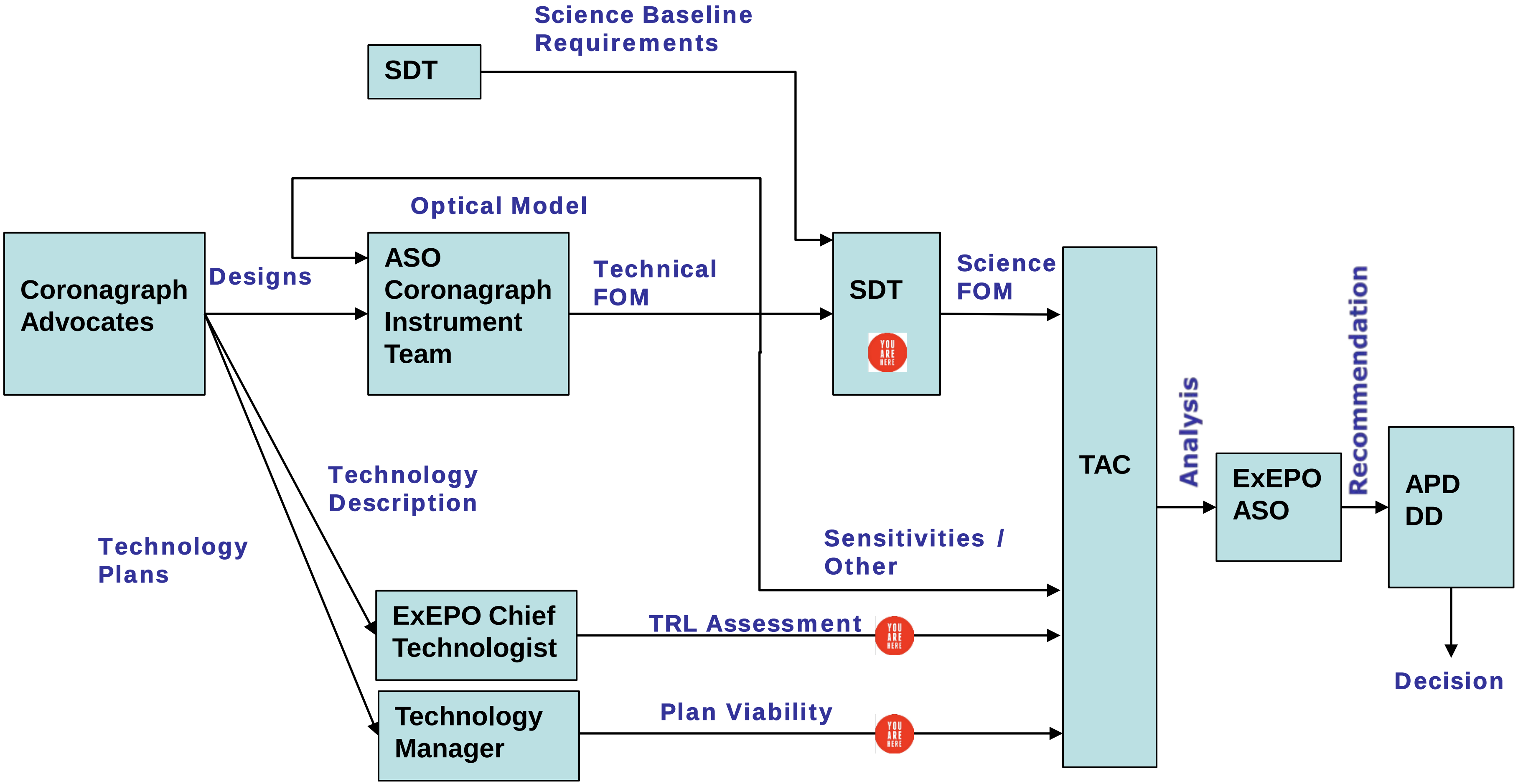
✓	yes, or expected likely
?	unknown
✗	no, or expected showstopper

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



Final Decision, Accounting for Risks and Opportunities

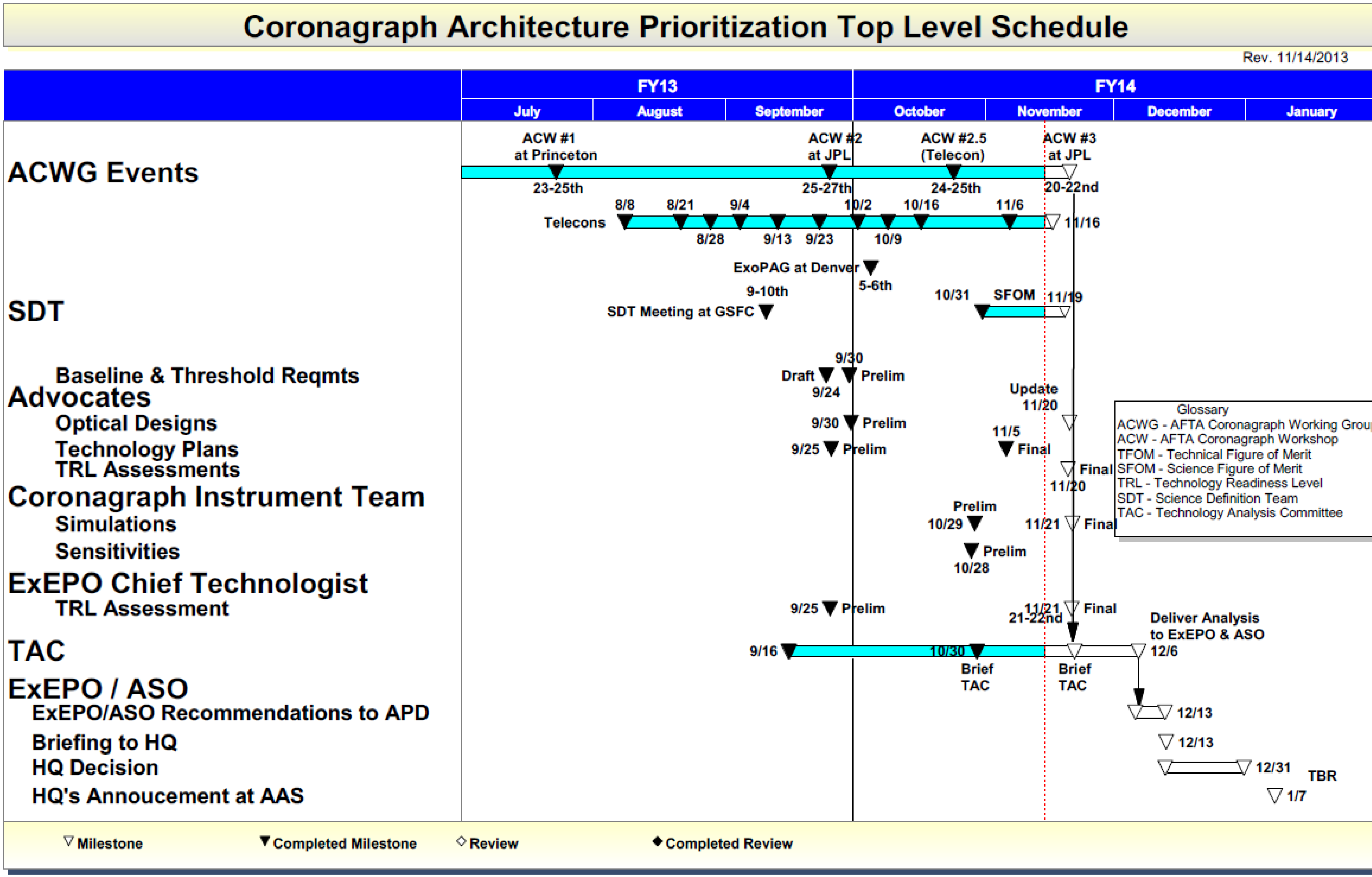
Product of ACWG: Comparative Analysis



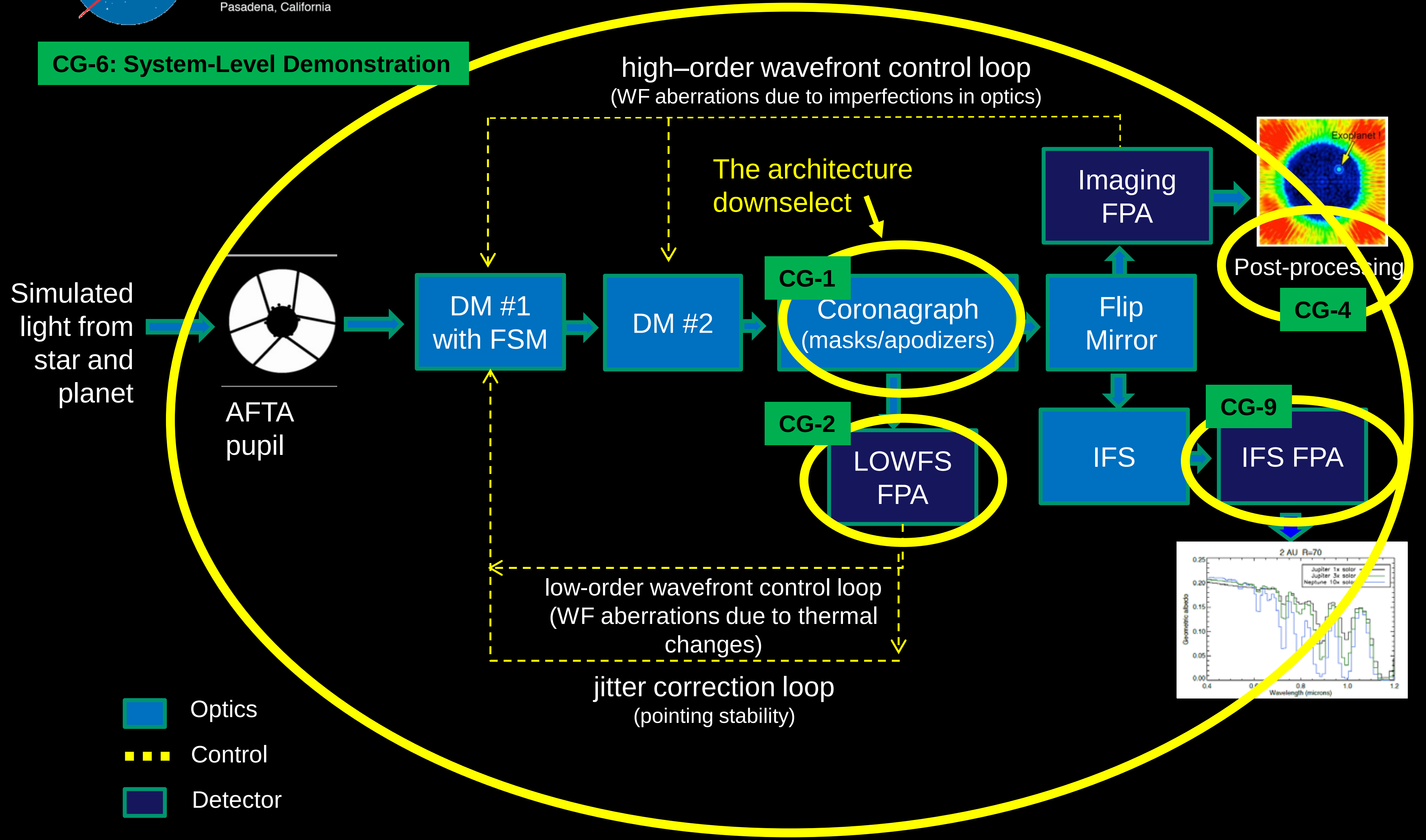
You Are Here

FOM = Figure of Merit
ASO = AFTA Study Office
ExEPO = Exoplanet Exploration Program Office

Down-select detailed schedule

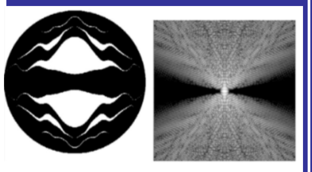


Classical Lyot Coronagraph Design

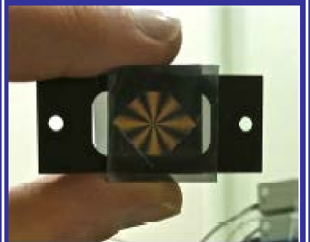


Star light suppression -- Technical Approach

Six different concepts



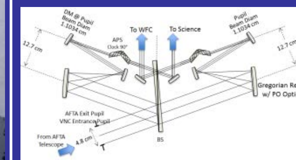
Shaped Pupil Mask Pupil Masking (Vanderbei & Kasdin, Princeton Univ.)



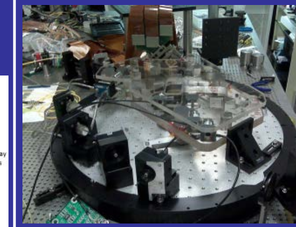
Vector Vortex Mask Image Plane (Serabyn, JPL)

Phase Induced Amplitude Apodization (PIAA) Pupil Re-Mapping (Guyon, Univ. Arizona)

Hybrid / Band-Limited Lyot Mask Image Plane Amplitude & Phase (Trauger, JPL)



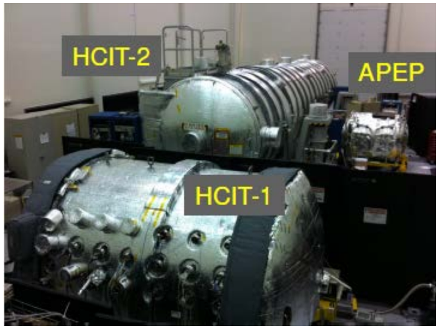
Visible Nuller Coronagraph: Phase-Occulting (Lyon, GSFC)



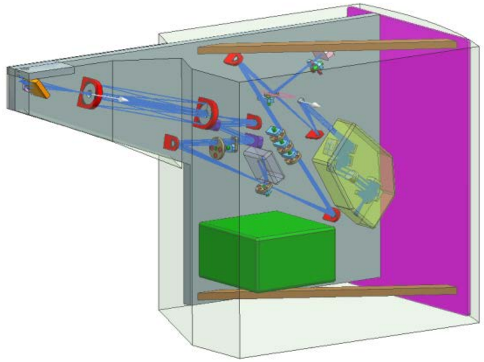
Visible Nuller Coronagraph: DaVinci (Shao, JPL)

Down select 1/6/2014

Primary approach	Back-up approach

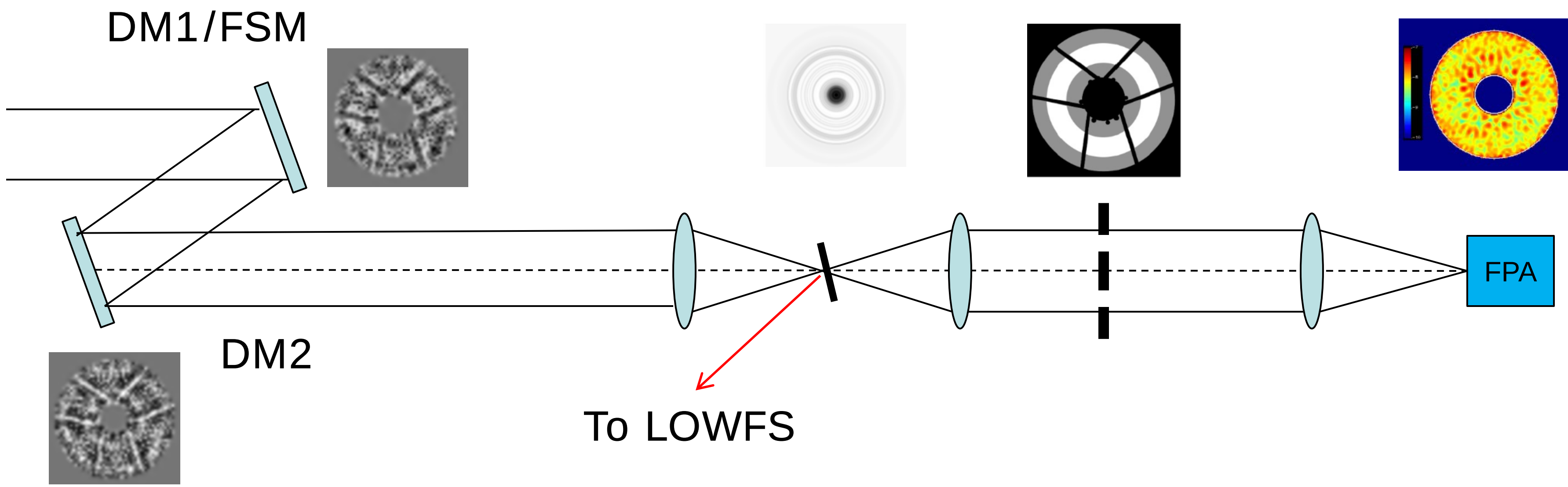


TRL-5 @ start of Phase A (10/2016)



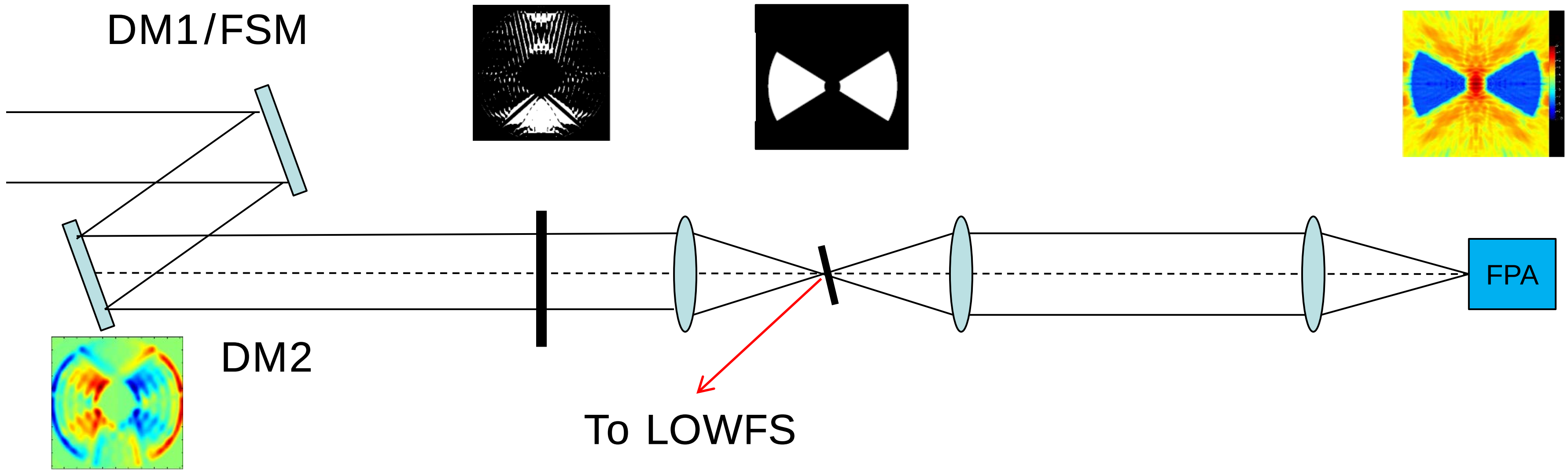
TRL-6 @ PDR (10/2018)

Hybrid Lyot



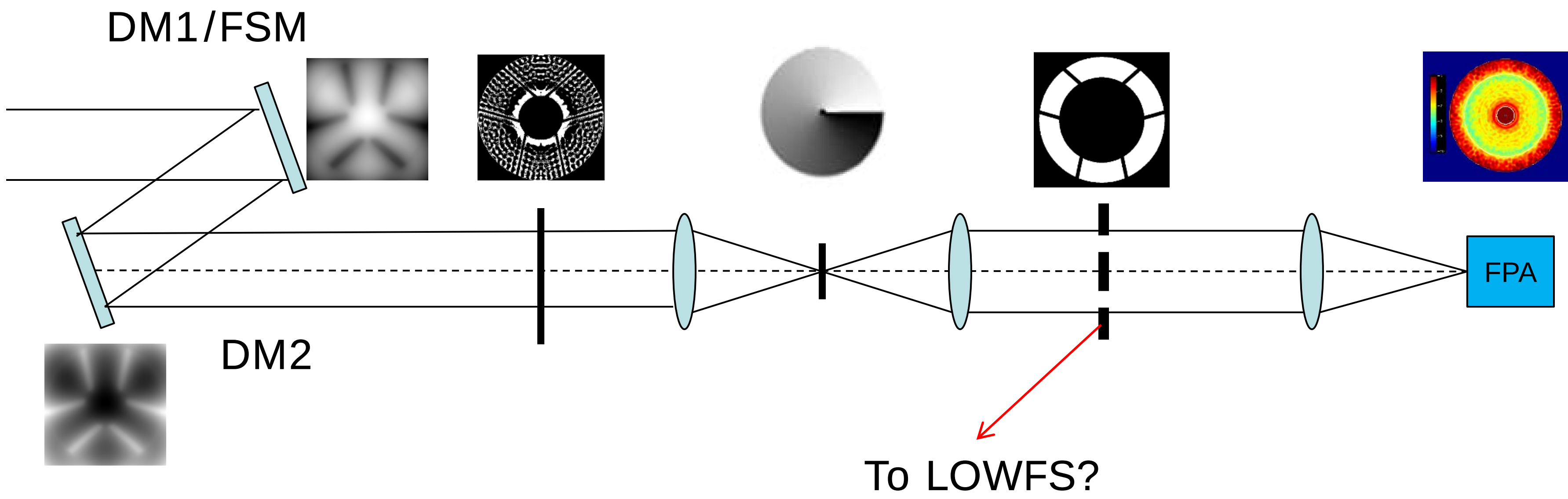
DM1, DM2	Pupil mapping	Apodizer mask	Occulting mask	Lyot stop	Inverse pupil mapping
Mild ACAD on both DMs			Complex transmission, on filter wheel	Transmission, grey, fixed	

Shaped Pupil



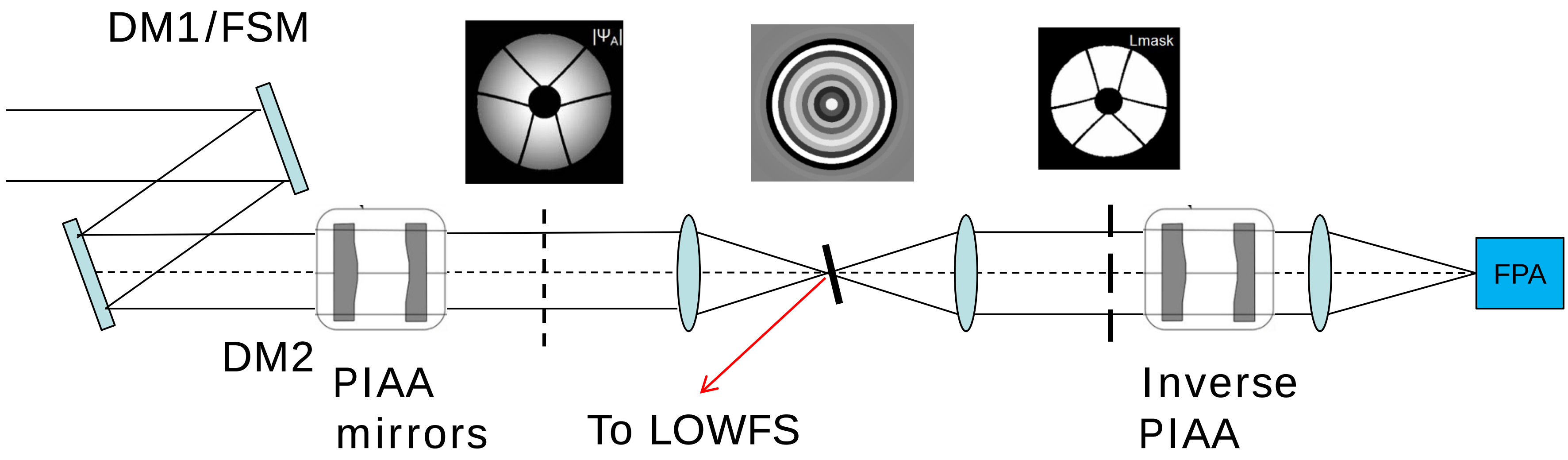
DM1, DM2	Pupil mapping	Apodizer mask	Focal plane mask	Lyot stop	Inverse pupil mapping
Mild ACAD on both DMs		Binary reflection on filter wheels	Binary transmission, on filter wheel		

Vector Vortex



DM1, DM2	Pupil mapping	Apodizer mask	Focal plane mask	Lyot stop	Inverse pupil mapping
Strong ACAD on both DMs		Binary transmission, on filter wheel	Vortex transmission, on filter wheel	Transmission, binary, fixed	

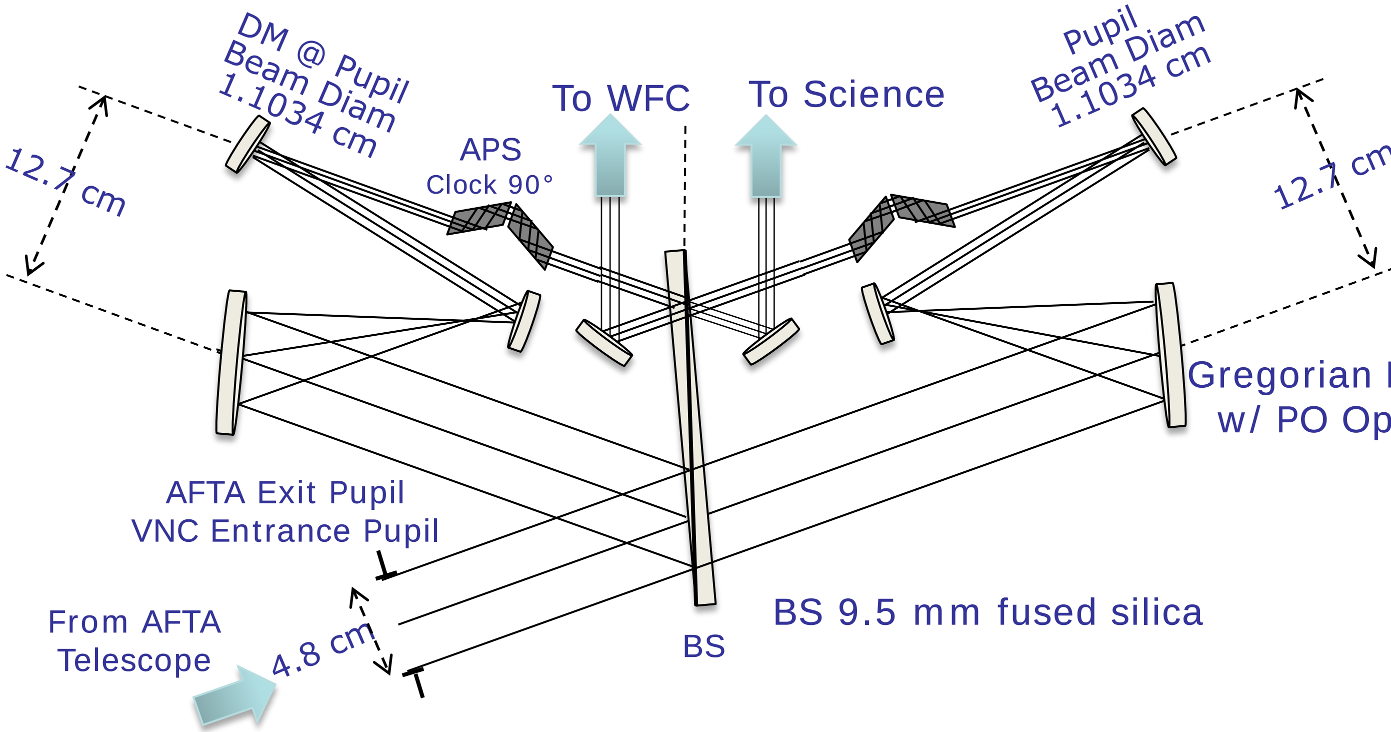
PIAA - CMC



Final design deadline extended to 11/4/2013

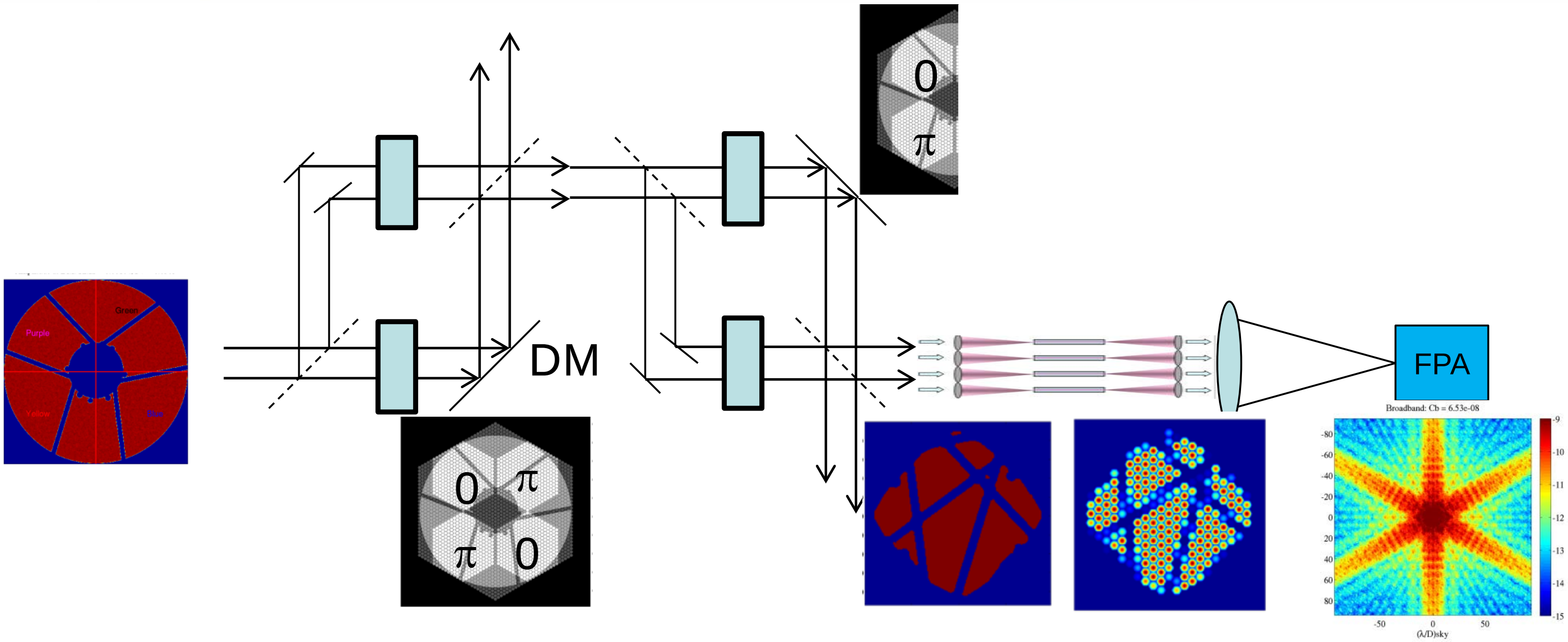
DM1, DM2	Pupil mapping	Apodizer mask	Occulting mask	Lyot stop	Inverse pupil mapping
Medium ACAD on both DMs	PIAA mirrors	Gray scale, filer wheels?	Phase transmission, on filter wheel	Transmission, binary, fixed?	Inverse PIAA mirrors

AFTA: Phase-Occulted VNC Nulling Schematic

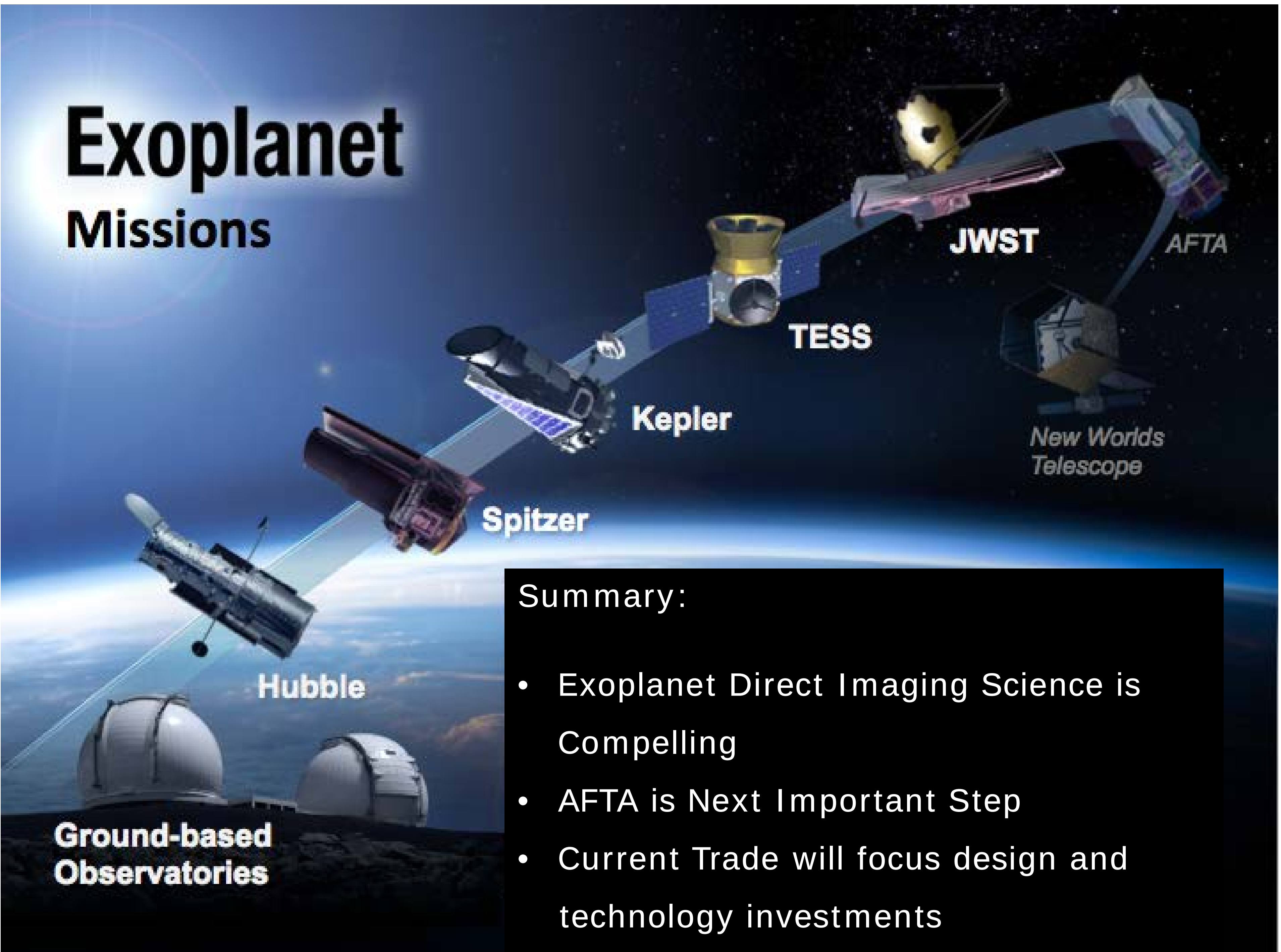


Interferometer	WFC
1 stage nulling interferometer	Two DMs for both phase and amp
Full aperture (radial shear)	Lyot stop?
Achromatic phase shifters*	
Delay line to adjust OPD	

VNC-DaVinci



Interferometer	WFC
2 stage nulling interferometers	One DM (4 quadrants) for both phase and amplitude control
Diluted aperture (4X)	Lyot stop mask (binary, transmission, fixed)
Achromatic phase shifters	Fiber bundle spatial filters
Delay line to adjust OPD	



Summary:

- Exoplanet Direct Imaging Science is Compelling
- AFTA is Next Important Step
- Current Trade will focus design and technology investments

Acknowledgements

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.