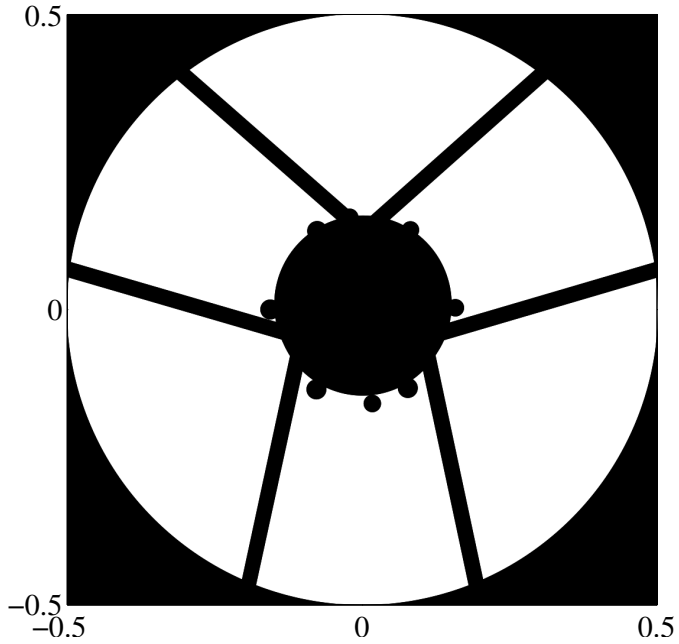
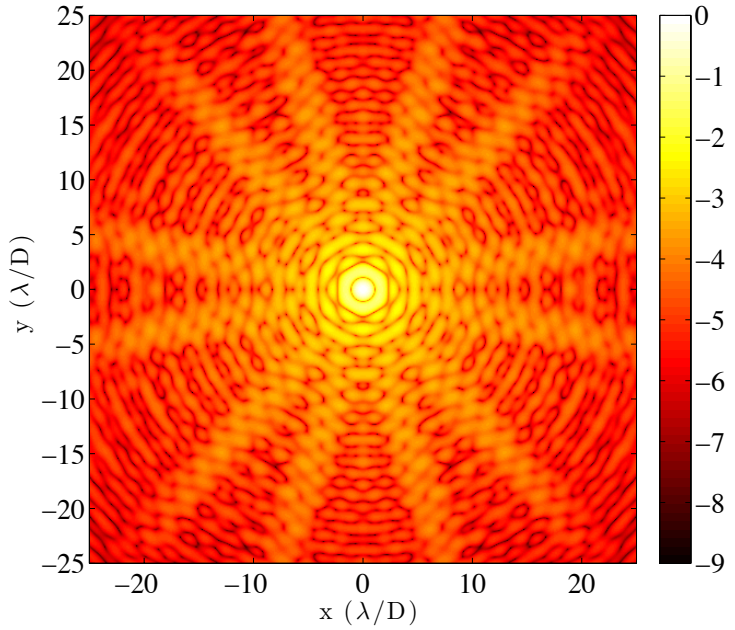
Coronagraphy with the WFIRST Aperture

N. Jeremy Kasdin

What makes it challenging?



The AFTA Pupil

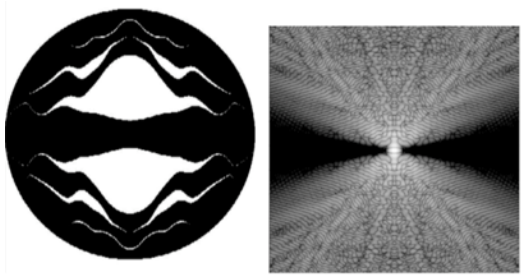


The AFTA PSF

Say anything about how this pupil makes getting small inner working angle hard?

Coronagraph selection based on maturity, robustness, flexibility

SPC



Pupil Masking (Kasdin, Princeton University)

HLC

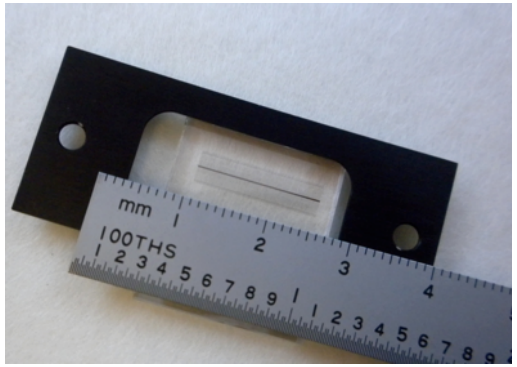
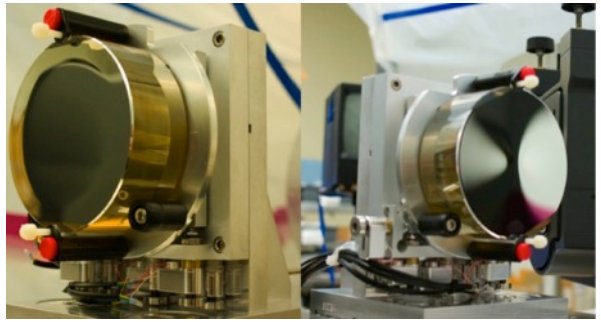


Image Plane Amplitude & Phase Mask (Trauger, JPL)

PIAACMC



Pupil Mapping
(Guyon, Univ. Arizona)

VVC

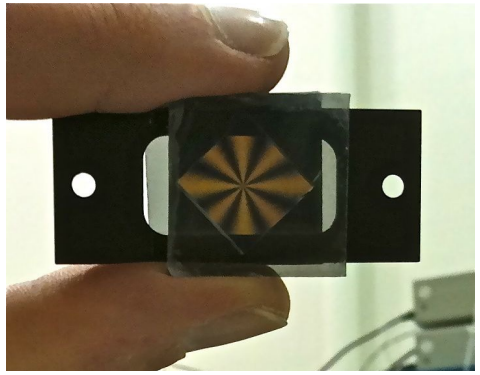
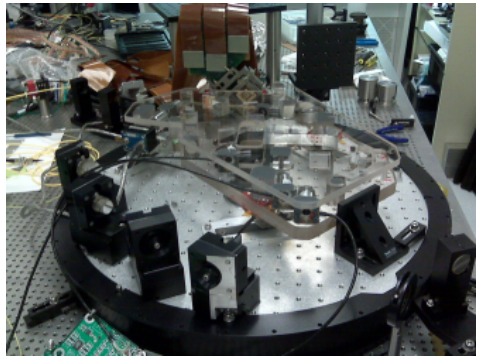


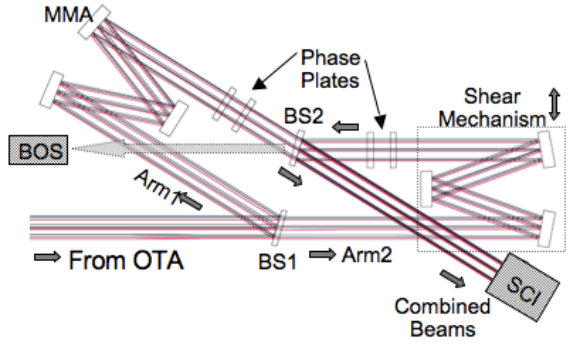
Image Plane
Phase Mask (Serabyn, JPL)

VNC - DAVINCI



Visible Nullller - DAVINCI
(Shao, JPL)

VNC-PO



Visible Nuller – Phase Occulting
(Clampin, NASA GSFC)

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

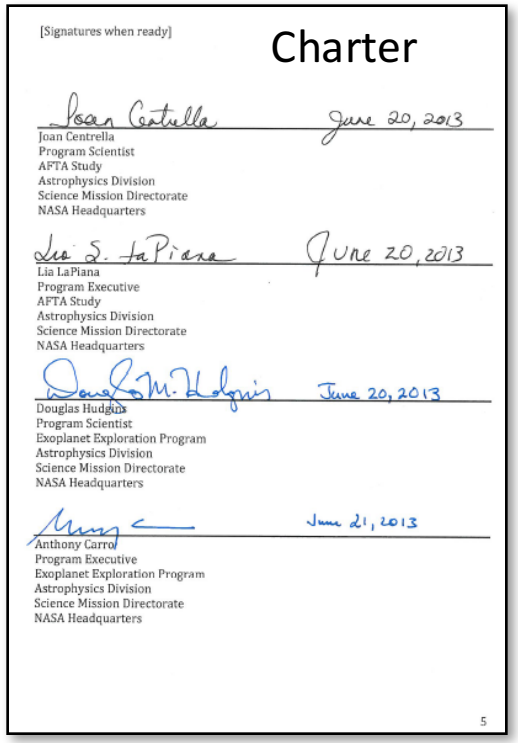
TAC:
Alan Boss (Carnegie Mellon)
Joe Pitman (EXSCI)
Steve Ridgway (NOAO)
Lisa Poyneer (LLNL)
Ben Oppenheimer (AMNH)

How do we define a successful outcome?

FOM = Figure of Merit

ACWG Membership

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



[Signatures when ready]

Charter

Joan Centrella — June 20, 2013
Joan Centrella
Program Scientist
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Science Mission Directorate
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Lia S. LaPiana — June 20, 2013
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June 21, 2013
Anthony Carro
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NASA Headquarters

5

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

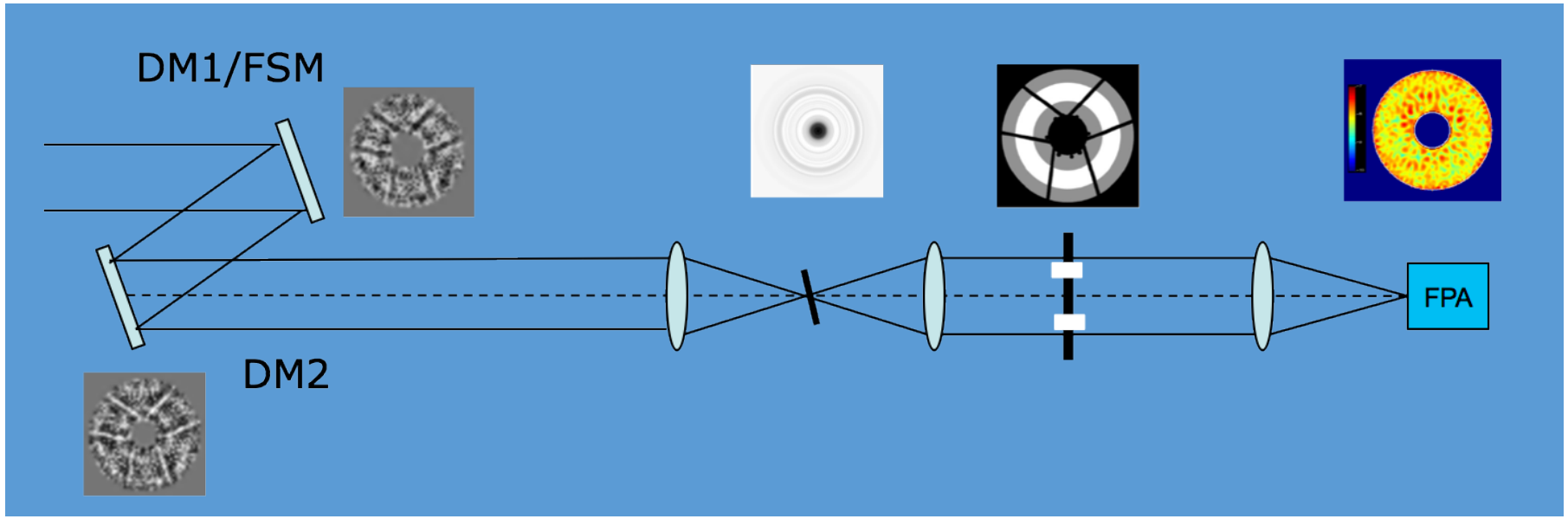
RISKS and OPPORTUNITIES

- See details

[1]DCL = Dave Content Interface List

Hybrid Lyot Coronagraph

Transmission = 48%

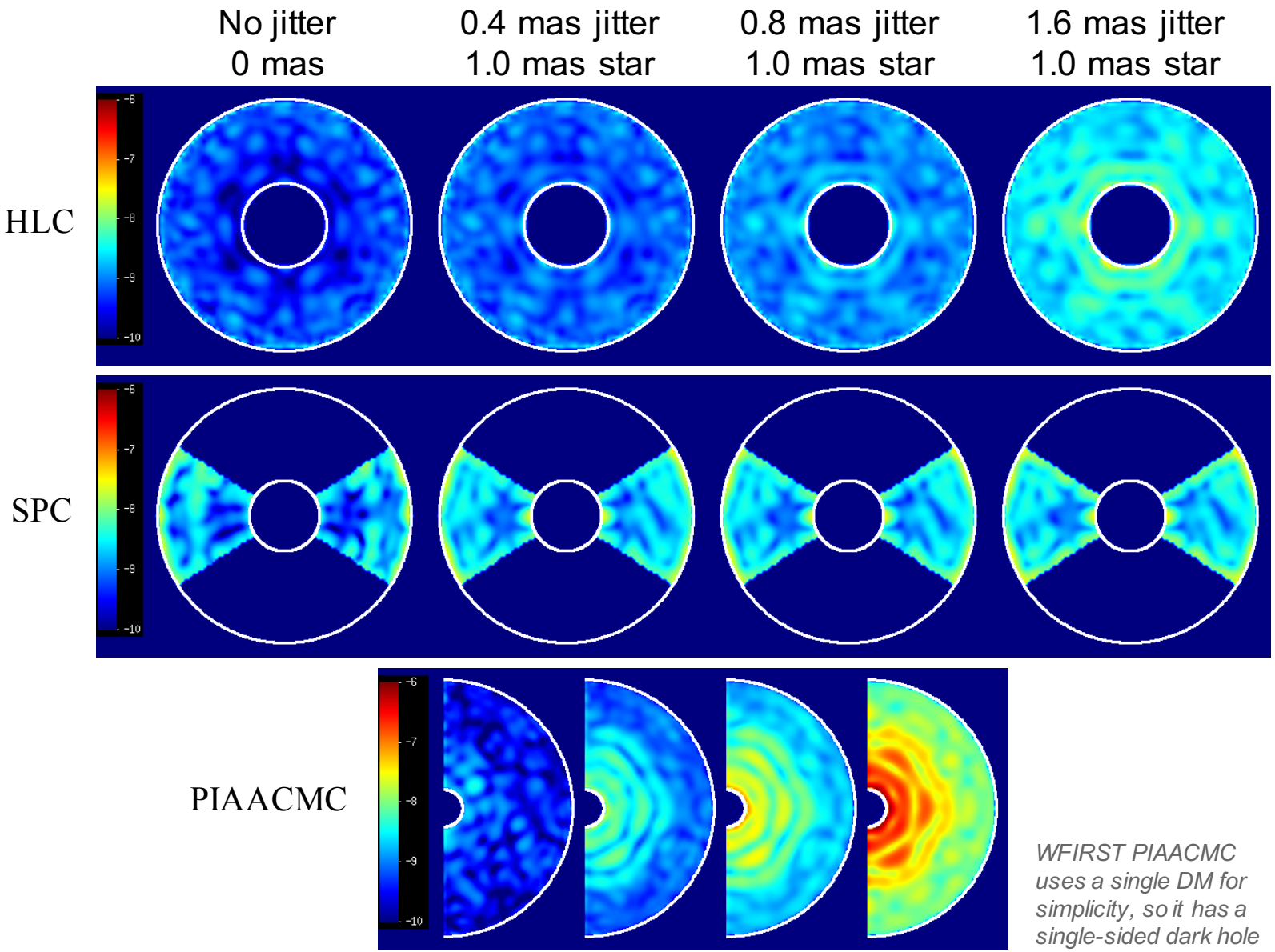


Baseline design for WFIRST/AFTA

Total PSF core throughput = 4.5%

From John Trauger, JPL

WFIRST Dark Holes with Pointing Jitter & Finite Star

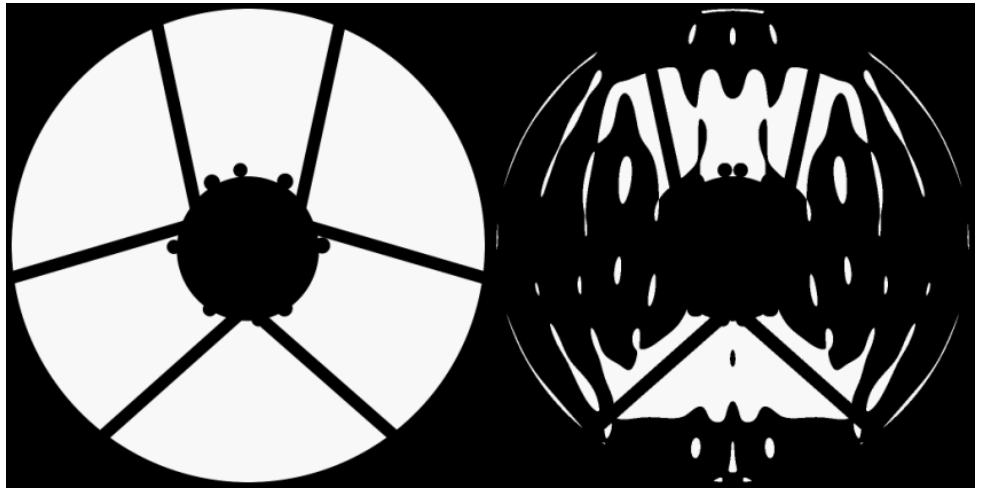


WFIRST PIAACMC uses a single DM for simplicity, so it has a single-sided dark hole

Coronagraph simulations use validated wave-optics code

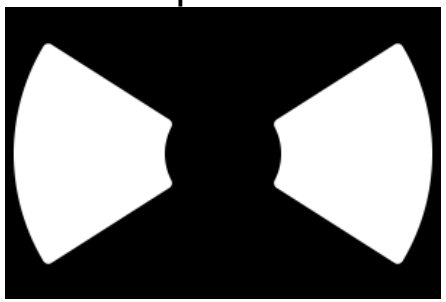
AFTA Pupil

Shaped Pupil



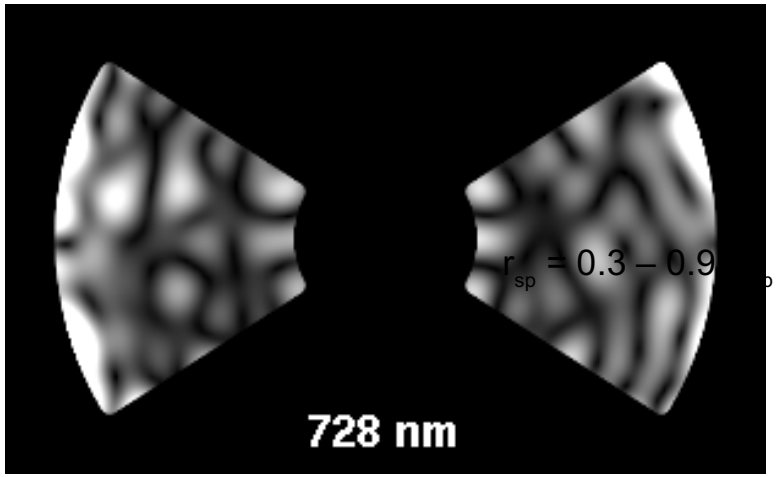
27% mask transmission

Focal plane mask

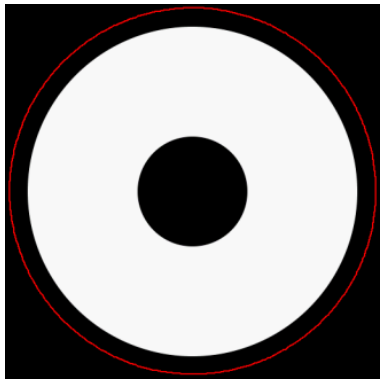


r = 2.5 – 9 λ_c/D

65° opening angle

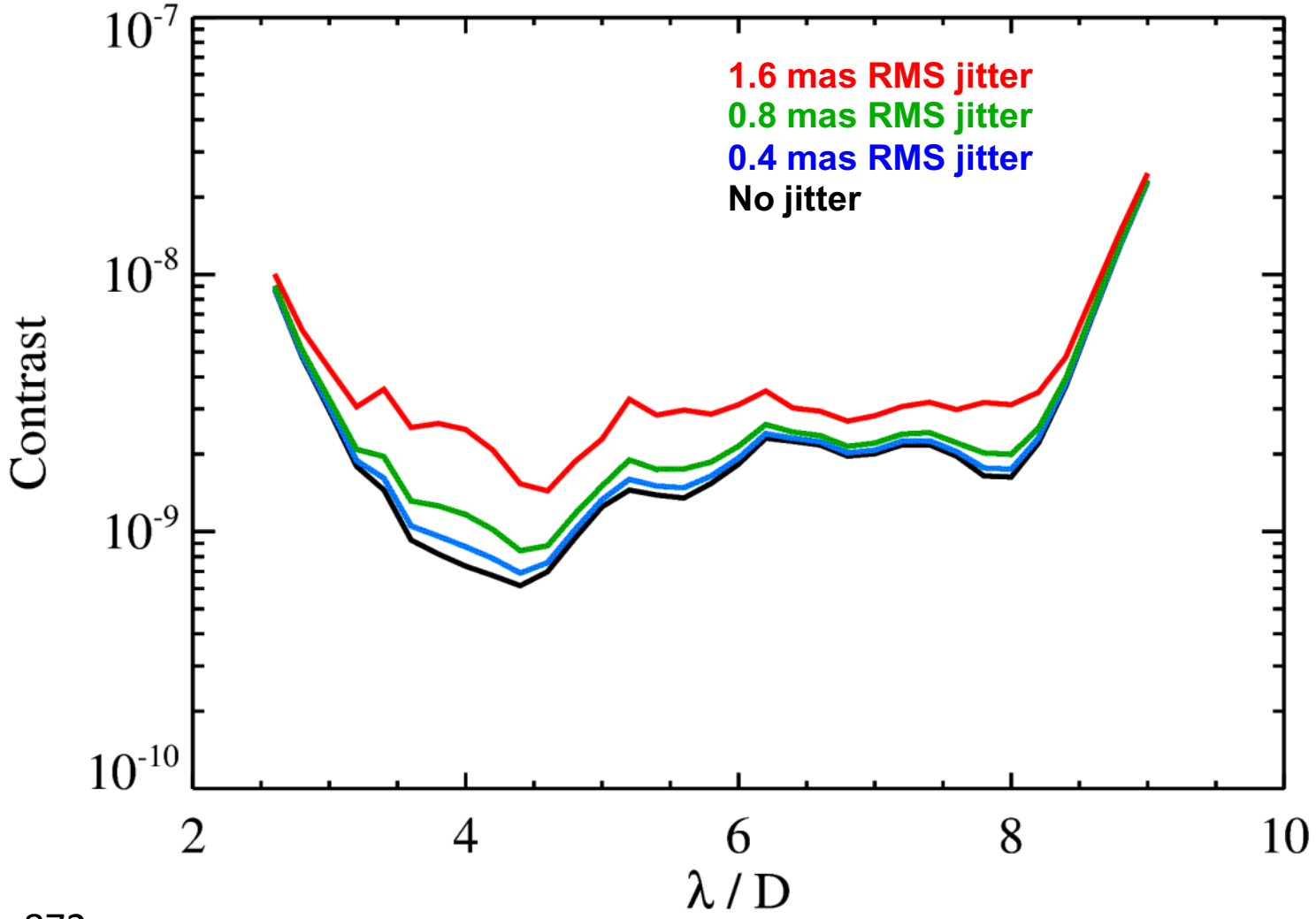


Lyot stop



Total PSF core throughput = 3.7%

Simulations show e.g. robust performance against jitter



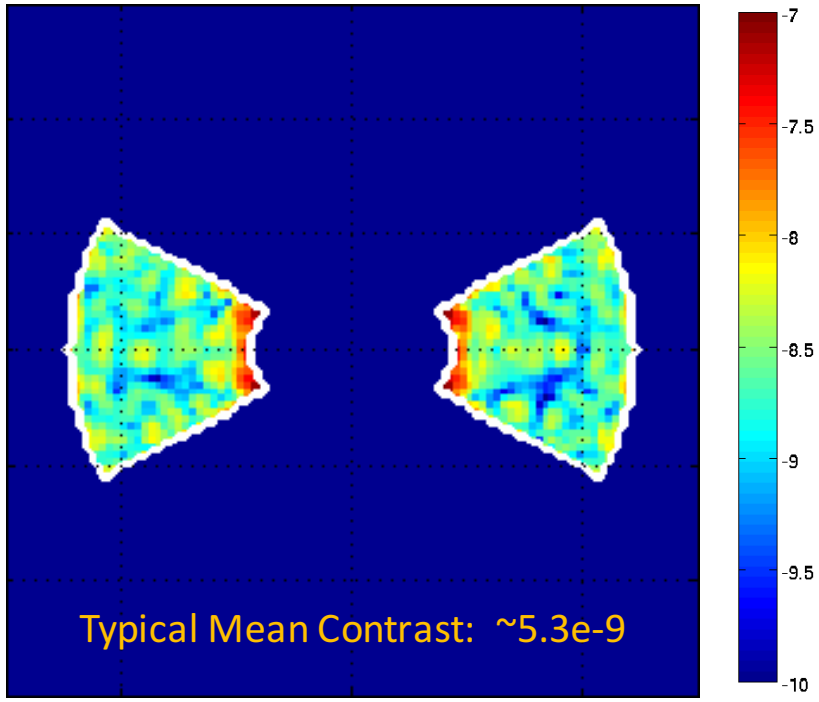
728 – 872 nm

Jitter levels shown here are after coronagraph fast tip/tilt

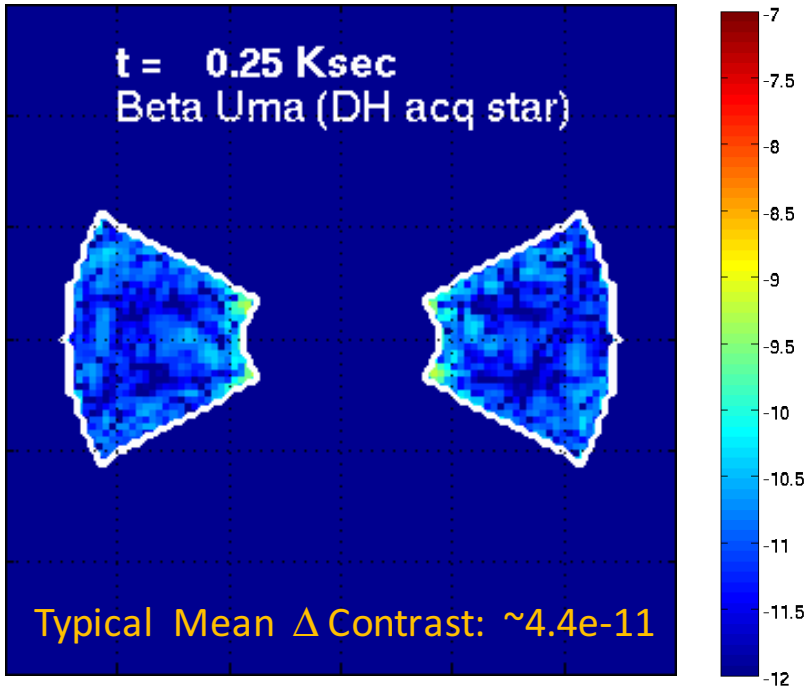
Simulations show stable high contrast with AFTA in thermal scenarios

- Proper EFC correction for telescope nominal wavefront (initial DM setting)
  - Gen 1 SPC design , 10% bandwidth, l = 550 nm, 3.9 ~12.3 l /D WA, 56 deg opening angle
  - Realistic AFTA surface aberration (amplitude +phase), and
  - Piston/tip/tilt/focus correction computed only once initially
  - The system configuration is held constant throughout the observations

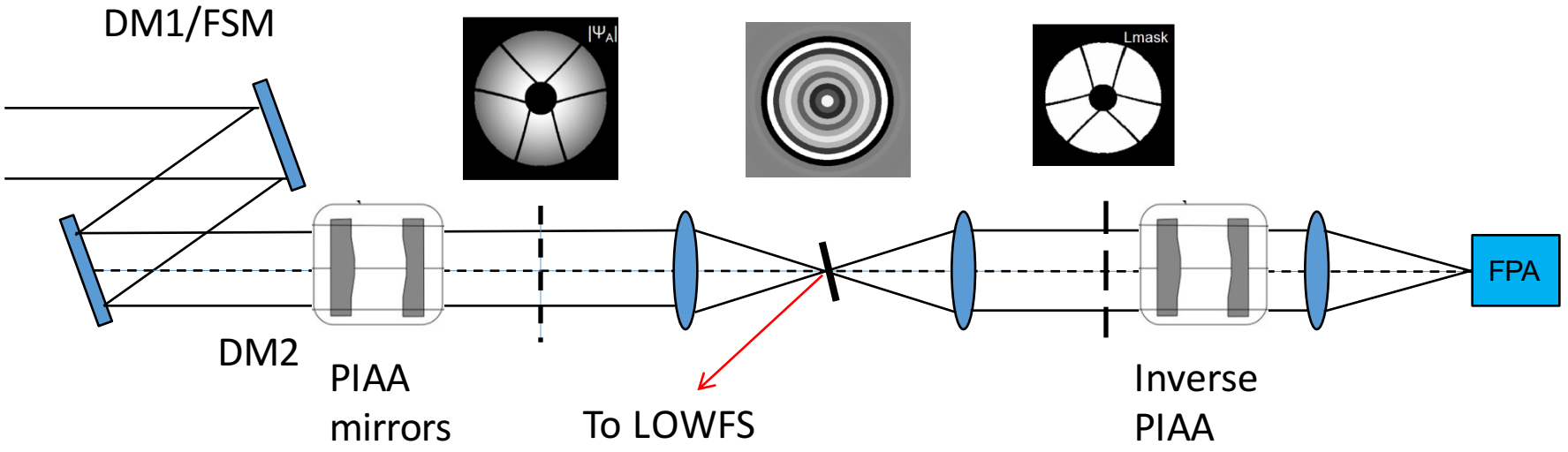
Raw speckle, S(t)



ΔSpeckle (rel. to nominal): S(t) – S(0)



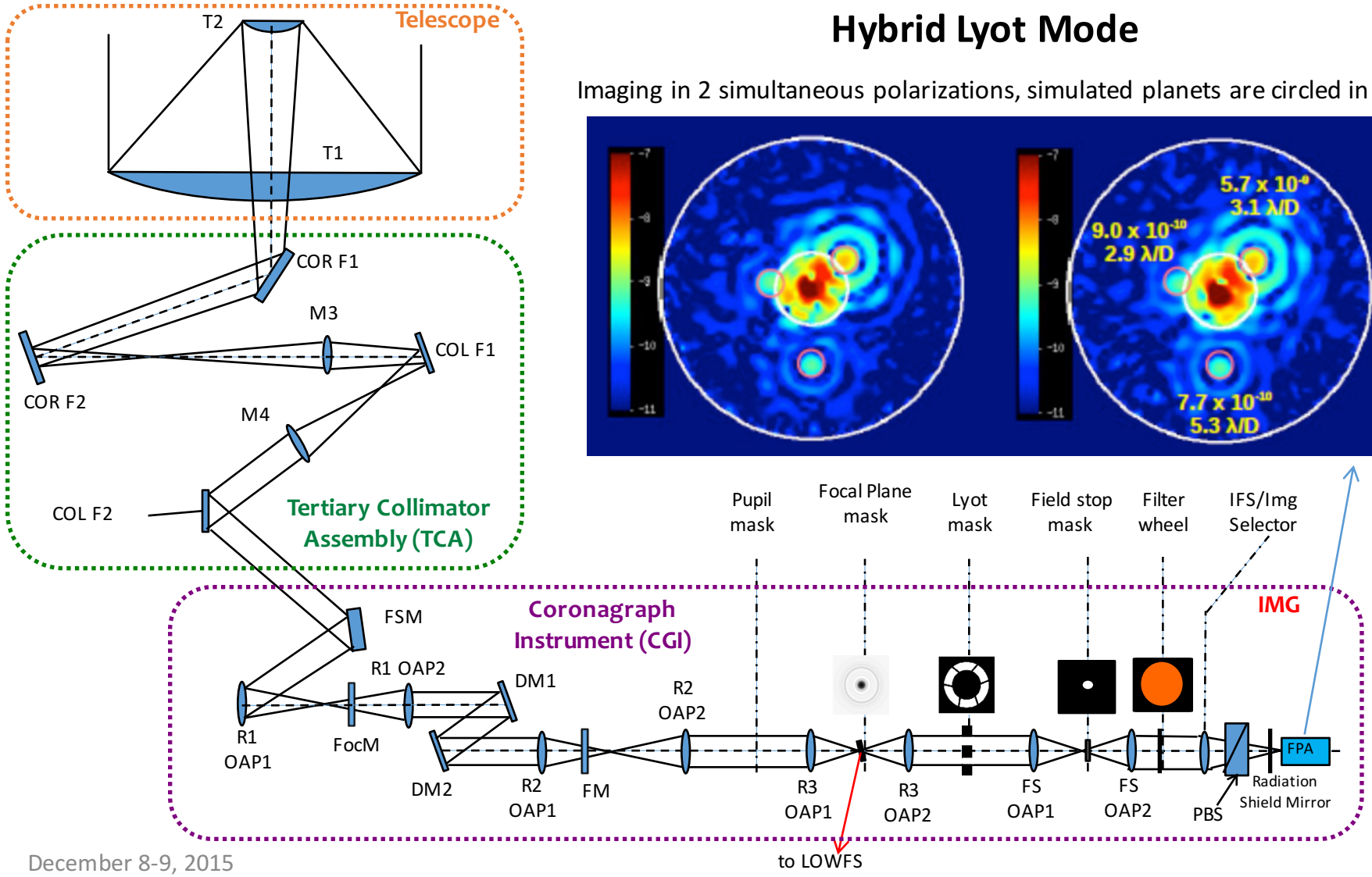
PIAA - CMC



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

CGI Operational Modes



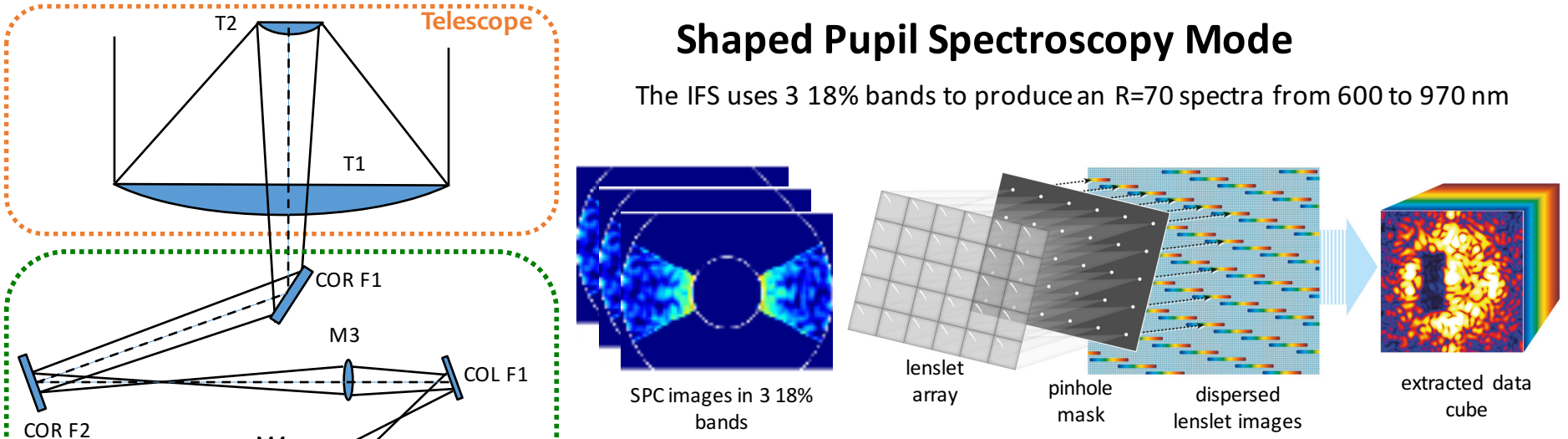
Hybrid Lyot Mode

Imaging in 2 simultaneous polarizations, simulated planets are circled in red

CGI Operational Modes

Shaped Pupil Spectroscopy Mode

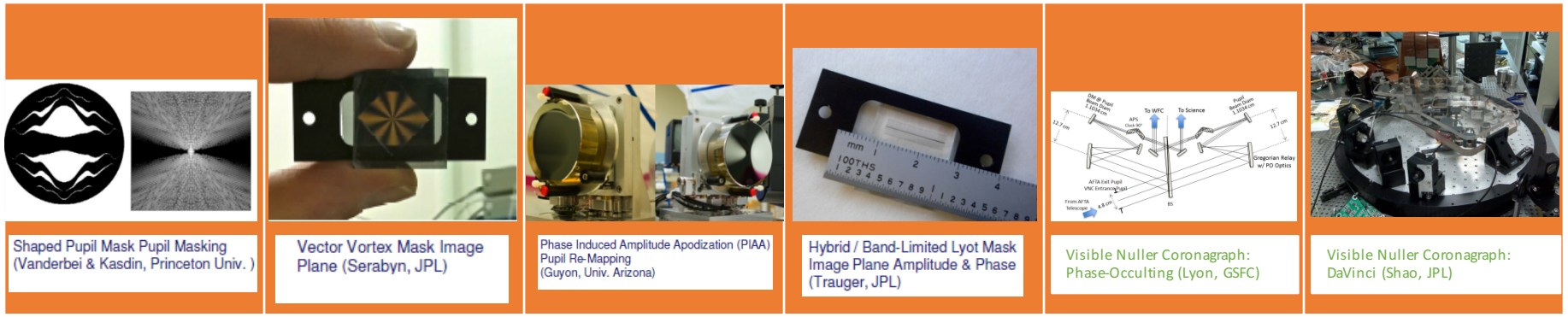
The IFS uses 3 18% bands to produce an R=70 spectra from 600 to 970 nm



Backup Slides

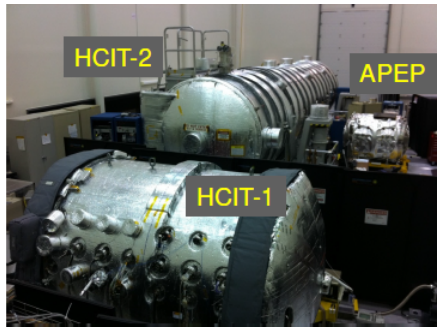
Star light suppression -- Technical Approach

Six different concepts

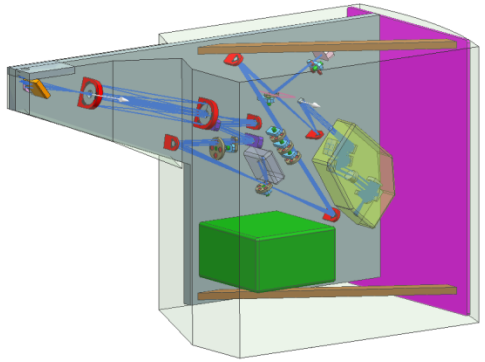


Down select 1/6/2014

Primary approach	Back-up approach

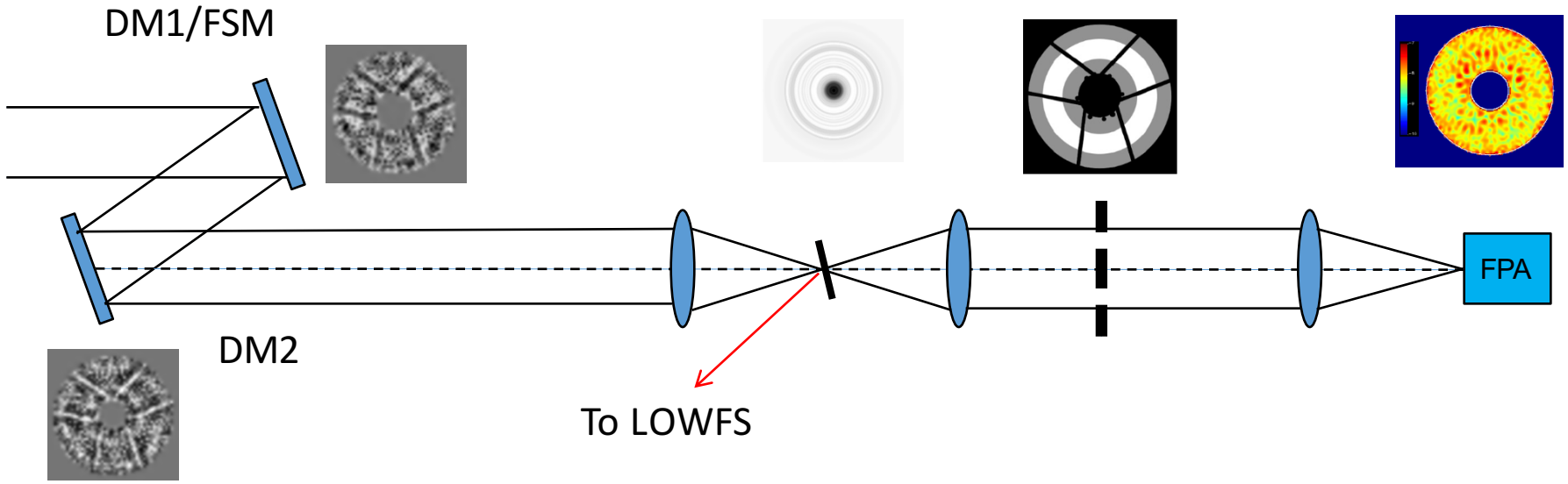


TRL-5 @ start of Phase A (10/2016)



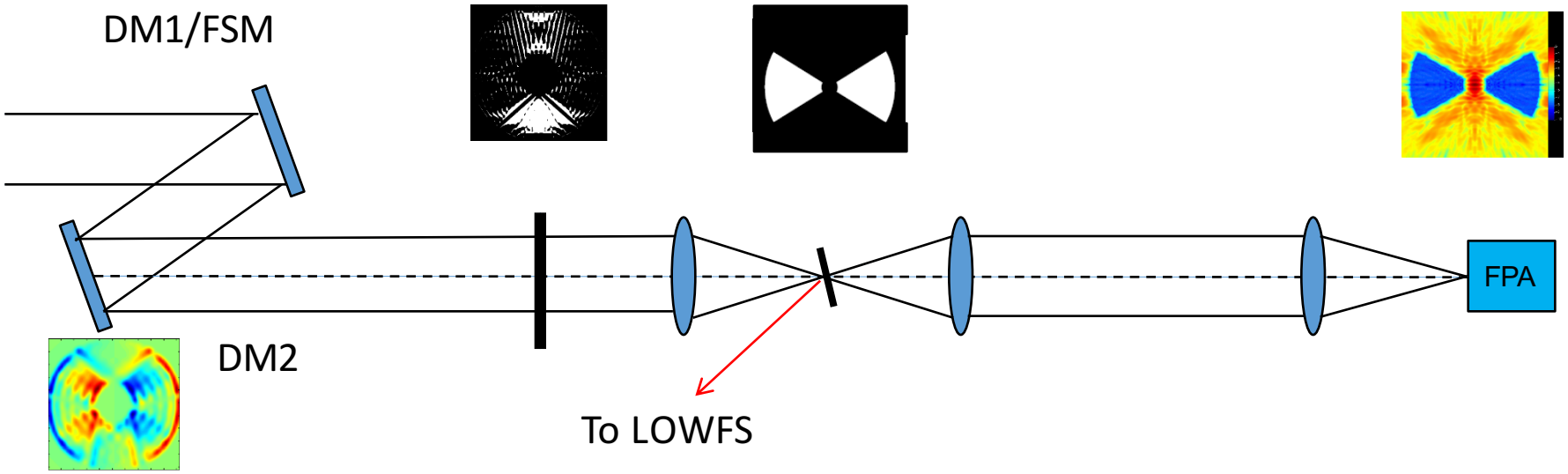
TRL-6 @ PDR (10/2018)

Hybrid Lyot



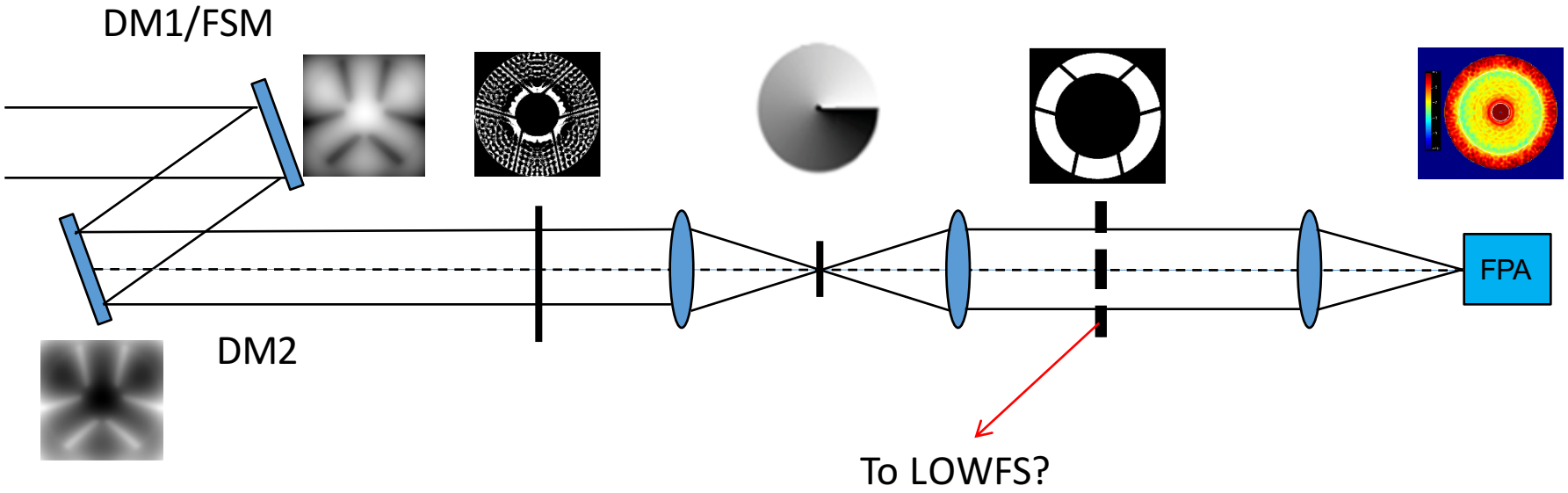
DM1, DM2	Pupil mapping	Apodizer mask	Occulting mask	Lyot stop	Inverse pupil mapping
Mild ACAD on both DMs			Complex transmission, on filter wheel	Transmission, grey, fixed	

Shaped Pupil



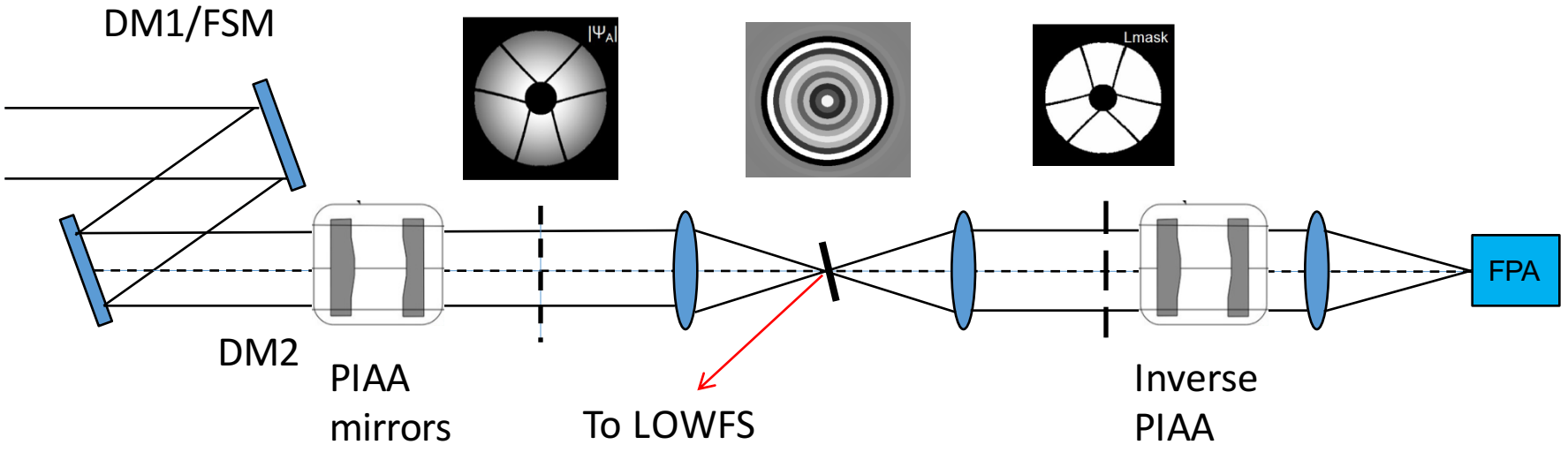
DM1, DM2	Pupil mapping	Apodizer mask	Focal plane mask	Lyot stop	Inverse pupil mapping
Mild ACAD on both DMs		Binary reflection on filter wheels	Binary transmission, on filter wheel		

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	

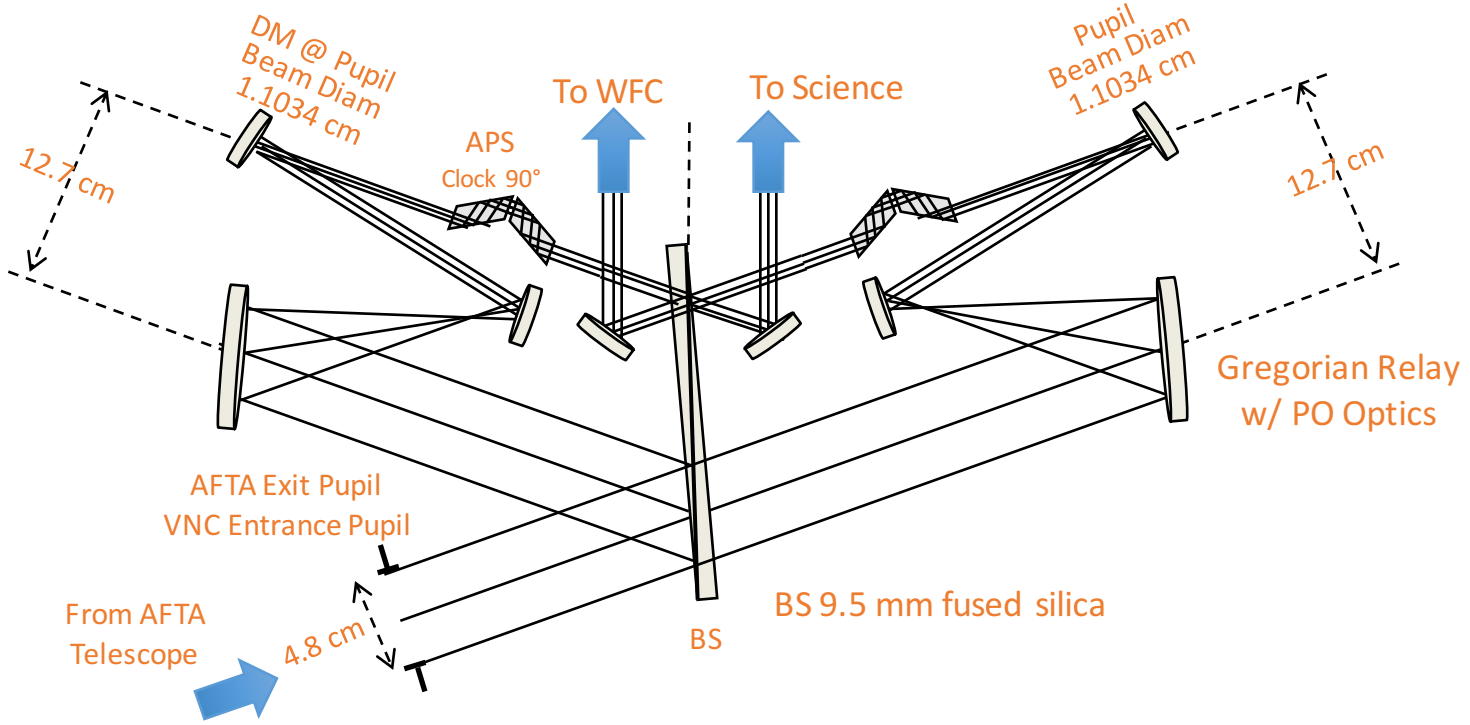
PIAA - CMC



Final design deadline extended to 11/4/2013

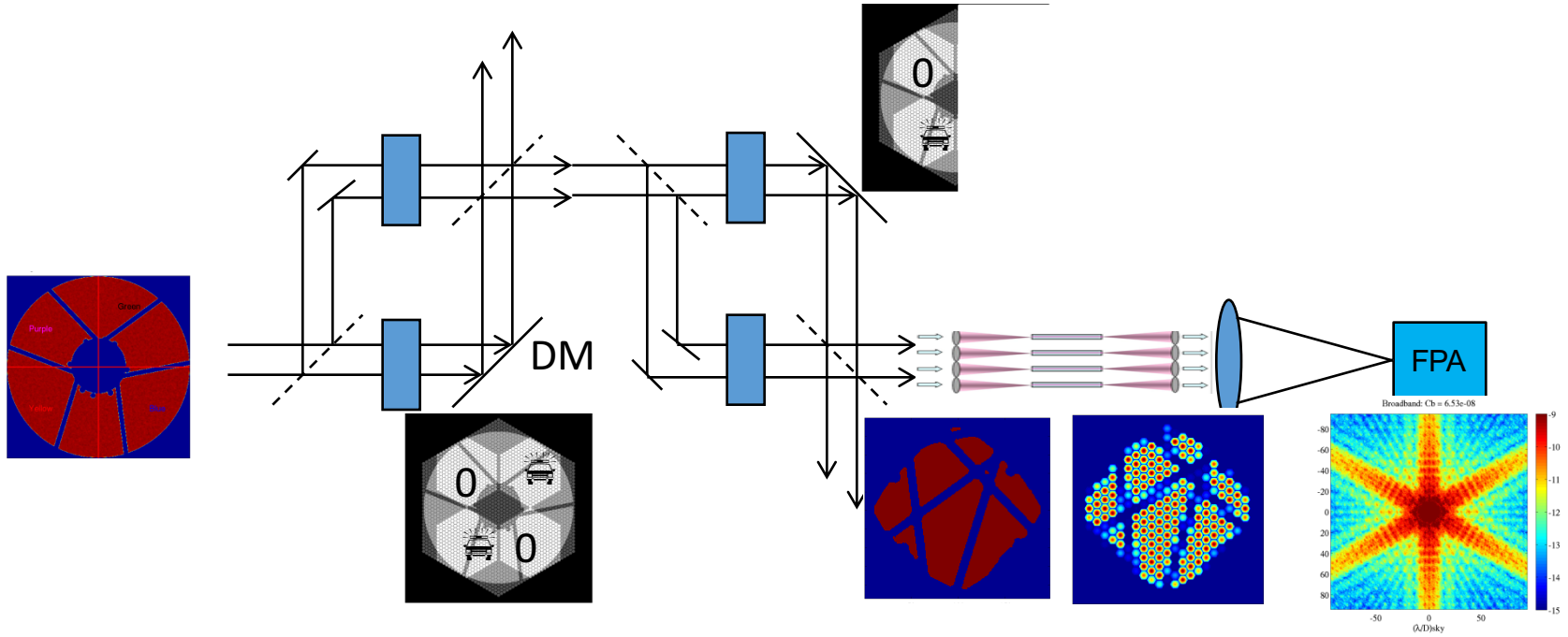
DM1, DM2	Pupil mapping	Apodizer mask	Occulting mask	Lyot stop	Inverse pupil mapping
Medium ACAD on both DMs	PIAA mirrors	Gray scale, filer wheels?	Phase transmission, on filter wheel	Transmission, binary, fixed?	Inverse PIAA mirrors

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	