AFTA Coronagraph Update

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Coronagraph Progress Since January SDT Presentation

- Change in telescope prescription has imposed tighter requirements on telescope/coronagraph dimensional stability.
- Previously baseline shaped-pupil coronagraph design shown to provide insufficient contrast with telescope prescription.
- New PIAA design shown to provide adequate contrast with telescope prescription. Other advantages are view of full ring around target star as well as significantly higher throughput compared to shaped pupil design. PIAA is new baseline.
- New Lyot design looks promising, but not yet analyzed with telescope prescription.
- Coronagraph thermal model was completed. Model runs are investigating thermal and dimensional stability.

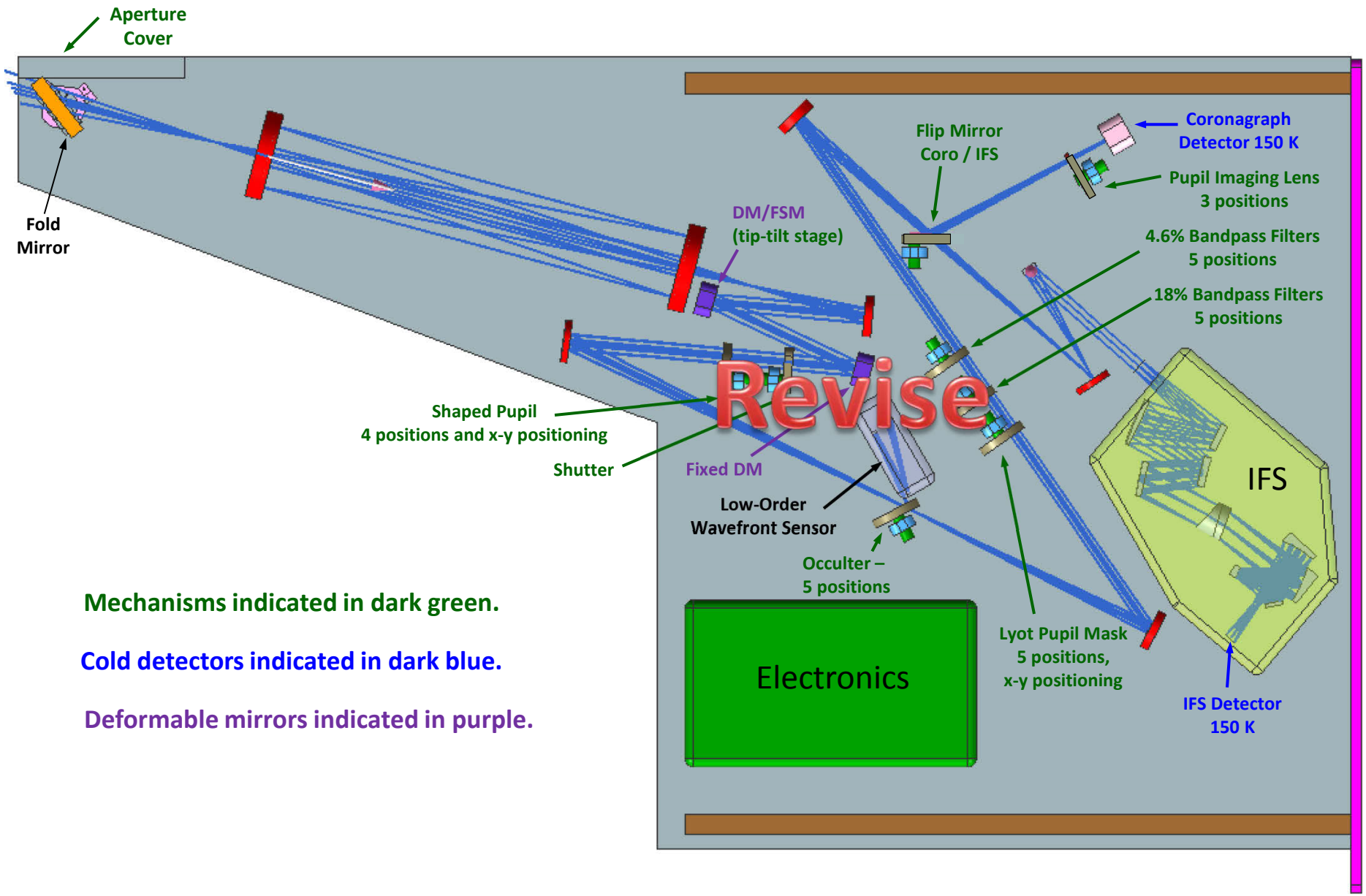
Coronagraph Performance Goals

Bandpass	400-1000 nm	Measured sequentially in five 18% bands
Inner Working Angle	100 mas	at 400 nm, 3 λ/D driven by challenging pupil
	250 mas	at 1 um
Outer Working Angle	1 arcsec	at 400 nm, limited by 64x64 DM
	2.5 arcsec	at 1 um
Detection Limit	Contrast =10^{-9}	Cold Jupiters, not exo-earths. Deeper contrast looks unlikely due to pupil shape and extrememe stability requirements.
Spectral Resolution	70	With IFS, ~70 across the spectrum.
IFS Spatial Sampling	17 mas	This is Nyquist for λ400 nm.

Key Characteristics

Coronagraph Type	Designed to support Lyot and shaped pupil coronagraphs.
Operating Temperature	Room Temperature, due to DM wavefront specifications.
Deformable Mirrors	Two 64x64 devices, sequentially placed for broadband dark hole control. Current design is for MEMS DM with 300 um pitch.
Detectors	Direct Imaging: 1K x 1K visible detector, 12 um (TBR) pixels Low Order Wavefront Sensor: E2V 39 (TBR), 24 um pixels IFS: 2K x 2K detector, ultra-low noise. 6.5 um pixels
IFS Bandpass	5 filters: 400-480 nm, 480-577 nm, 577-693 nm, 693-832 nm, 832-1000 nm

Coronagraph Mechanical Layout (PIAA design)



Mechanisms indicated in dark green.

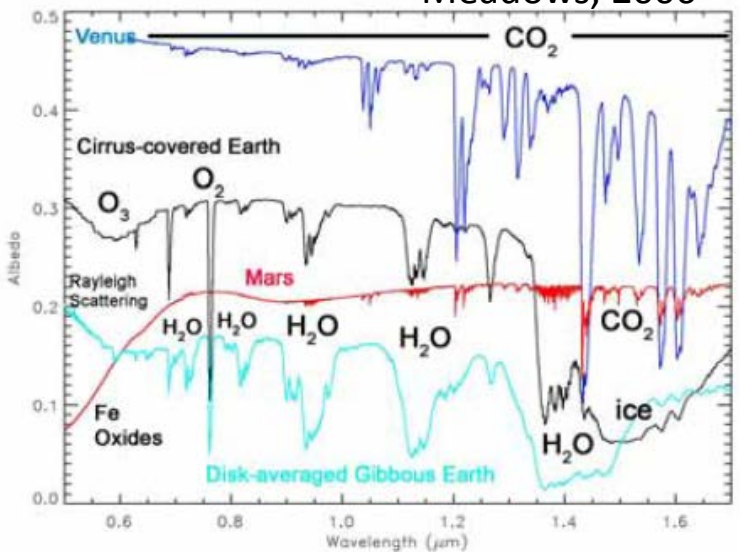
Cold detectors indicated in dark blue.

Deformable mirrors indicated in purple.

Integral Field Spectrograph

- Follows design principles of ground-based IFS instruments, e.g. CHARIS (Princeton), GPI, SPHERE. OSIRIS
- 140 x 140 lenslet array. Designed to disperse 20% band over 24 detector pixels (SR ~70).
  - Accommodates 0.4 – 1 um range using 5 bandpass filters (one at a time)
  - 17 mas ‘spaxel’ pitch.

Meadows, 2006



Wavelength	Spect. Resol	Species	line depth	At this abundance level
0.58	5	O3	0.112	3 ppm
0.69	54	O2	0.088	10%
0.72	37	H20	0.13	1000 ppm
0.73	57	CH4	0.07	1000 ppm
0.76	69	O2	0.388	10%
0.79	29	CH4	0.032	1000 ppm
0.82	35	H20	0.118	1000 ppm
0.89	32	CH4	0.417	1000 ppm
0.94	17	H20	0.401	1000 ppm
1.05	40	C02	0.001	1000 ppm

Coronagraph Conceptual Operations Timeline

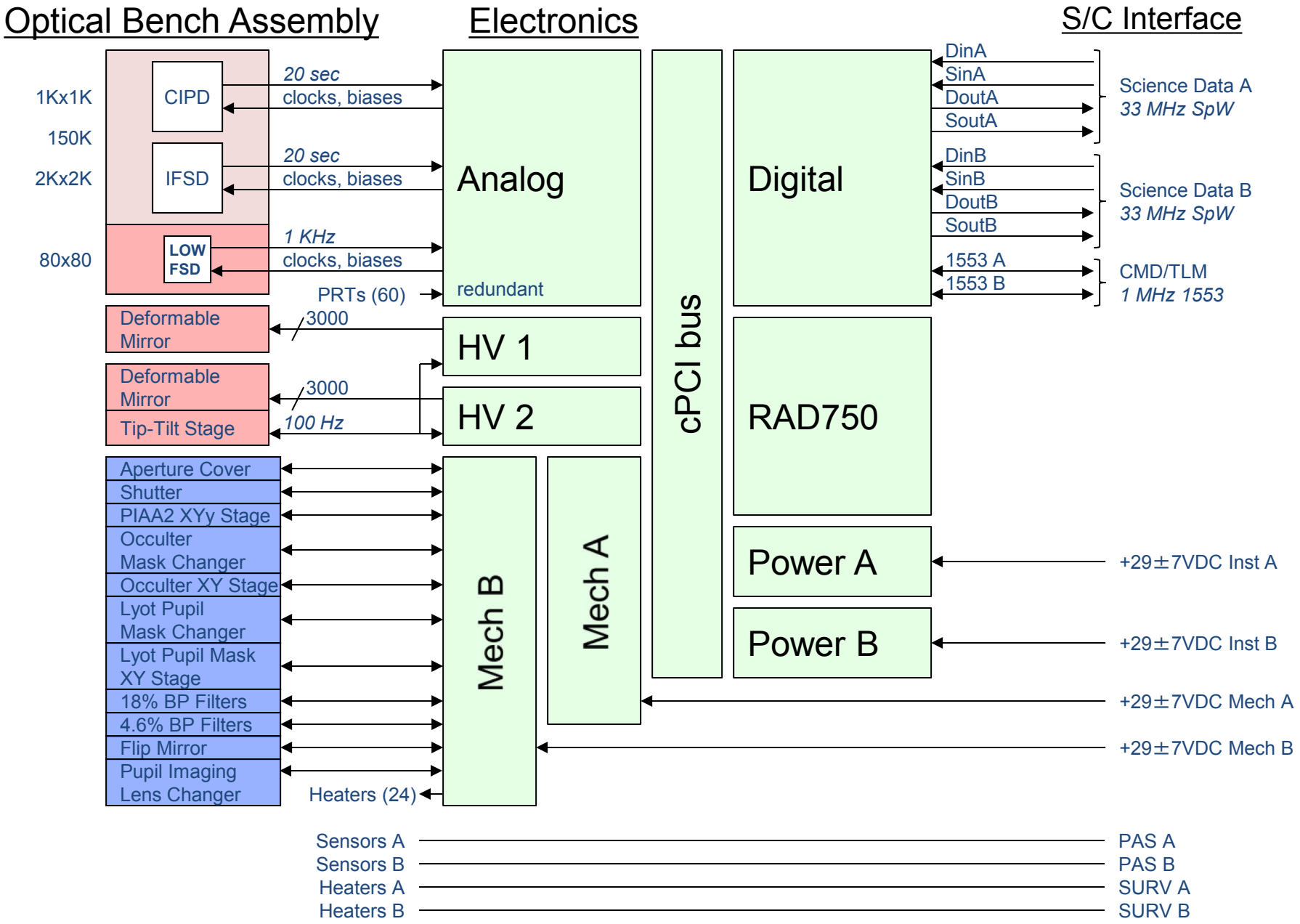
Hour	Day 1	Day 2	Day 3	Day 4
1	Point telescope Pointing control on	IFS integration in 18% band #1 (continued)	IFS integration in 18% band #3 (continued)	IFS integration in 18% band #4 (continued)
2	Telescope thermal settling time			
3				
4		18% band #2 - Set contrast to 10^{-8} with multiple sets of probes		
5		Wavefront estimation- IFS pixels summed to 4.6% bands- 4 probes		
6		IFS integration in 18% band #2		
7	Set contrast to 10^{-8} with multiple sets of probes			
8	Wavefront estimation- IFS pixels summed to 4.6% bands- 4 probes			
9	Science observation summing IFS pixels up to 18% band			
10	IFS; 18% band #1 - Set contrast to 10^{-8} with multiple sets of probes			
11	Wavefront estimation- IFS pixels summed to 4.6% bands- 4 probes			
12	IFS integration in 18% band #1			
13				
14				
15				
16			18% band #4 - Set contrast to 10^{-8} with multiple sets of probes	
17			Wavefront estimation- IFS pixels summed to 4.6% bands- 4 probes	
18			IFS integration in 18% band #4	
19				
20				
21				
22		18% band #3 - Set contrast to 10^{-8} with multiple sets of probes		
23		Wavefront estimation- IFS pixels summed to 4.6% bands- 4 probes		
24		IFS integration in 18% band #3		

	Telescope pointing and settling
	Discovery using single 18% bandpass
	Spectroscopy in 18% band #1
	Spectroscopy in 18% band #2
	Spectroscopy in 18% band #3
	Spectroscopy in 18% band #4

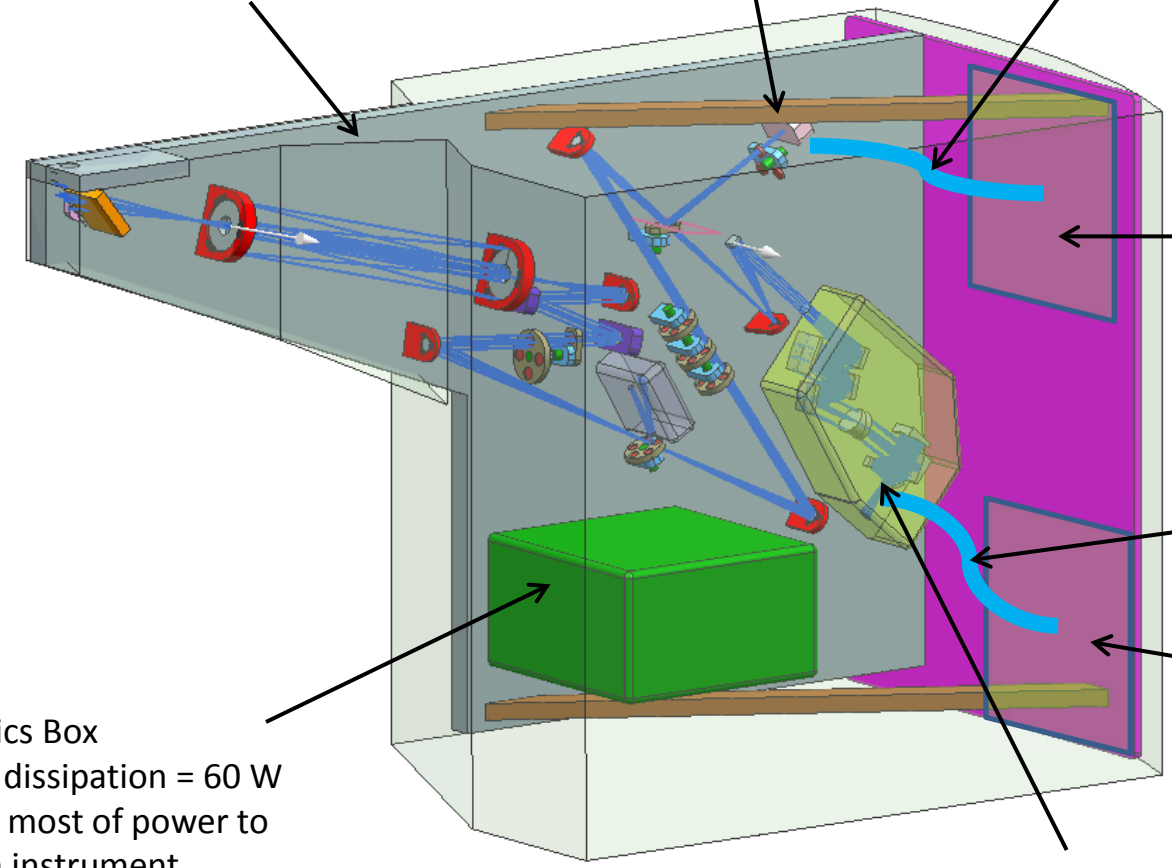
Assumptions

- 10^{-8} instrument contrast
- 4.83 mag star at 10 pc
- 10^{-9} contrast planet
- SNR=5 for planet in discovery mode
- SNR=5 for 100% spectral line depth in spectroscopy mode
- 100 sec integrations for cosmic ray rejection
- EMCCD detectors with 0.001 e-/pixel/frame read noise, 10^{-5} e-/pixel/sec dark current

Coronagraph Electronics Block Diagram



Coronagraph Preliminary Thermal Concept



Coronagraph Preliminary Resource Estimates

Mass

Item	CBE (kg)	Maturity Margin	CBE + Margin (kg)	Notes
Structure	48.00	50%	72.00	
Optical Elements	5.00	50%	7.50	
Optical Mounts	3.00	50%	4.50	
Mechanisms	12.20	50%	18.30	
Thermal Hardware	12.00	50%	18.00	
Electronics	18.00	50%	27.00	
Total	98.2		147.3	

Power

Item	CBE (W)	Maturity Margin	CBE + Margin (W)	Notes
Electronics	60	50%	90.0	
Additional Heater Control Power	20	50%	30.0	Electronics heat will help maintain instrument temperature
Total	80.0		120.0	

Data Rate

Item	CBE (Gbits/day)	Maturity Margin	CBE + Margin (W)	Notes
Data Rate	29	50%	43.5	Assumes IFS mode 2.56k x 2.16k pixels at 12 bits Downlink 100 s integrations for cosmic ray avoidance 2x compression

Coronagraph Detector Candidates

- E2v Electron Multiplying CCDs (EMCCDs)
  - Currently most viable candidate
  - Read noise is 1e-3 e-/pixel/frame in photon counting mode. Frame rate must be high enough to ensure ≤ 1 photon/pixel/frame in region of interest, and to allow for cosmic ray suppression.
  - At 170K dark current noise is 3e-6 e-/pixel/sec. 0.1 e-/pixel for 8 hours of integration.
  - Current arrays up to 1k x 1k. 4k x 4k under development.
  - Caltech plans balloon experiment in 2015 to increase TRL level.
  - Radiation exposure may increase noise – test program needed
- Geiger-Mode Avalanche Photodiodes
  - May provide read-noise-free photon counting, but required performance not yet demonstrated
  - Current arrays too small – 256x256

Technology Development Needed

- E2v EMCCDs
  - Increase in array size from 1k x 1k to ≥ 2k x 2k – under development.
  - Qualification for flight. Caltech plans balloon experiment in 2015.
- Boston Micromachines Co. MEMS Deformable Mirrors
  - Increase in number of actuators from 1k to 3k – under development through funded Phase II SBIR.
  - Qualification for flight.
- System Demonstration
  - Demonstrate a coronagraph compatible with the AFTA aperture that can achieve better than 1e-8 background and good throughput at 3 λ/D.
  - Demonstration of closed-loop low-order wavefront correction at level needed for coronography
  - Demonstrate Wavefront estimation and control using an IFS
  - Demonstrate ability to detect a planet below the speckle background