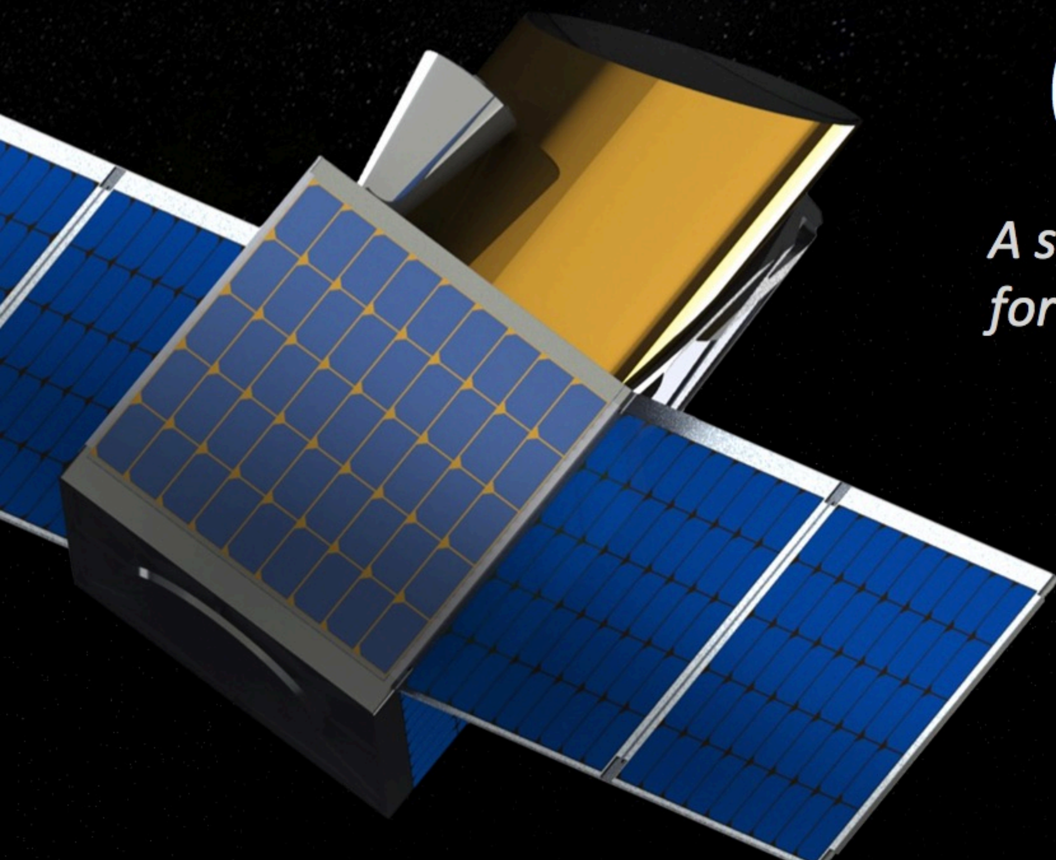

Centaur

A scientific and technology pathfinder for direct imaging exoplanet missions

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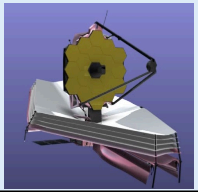
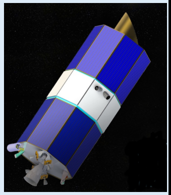
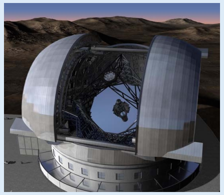
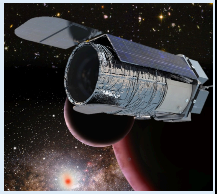
1 NASA Ames Research Center, 2 Subaru Observatory

Exoplanet next step: Image an earth-like planet

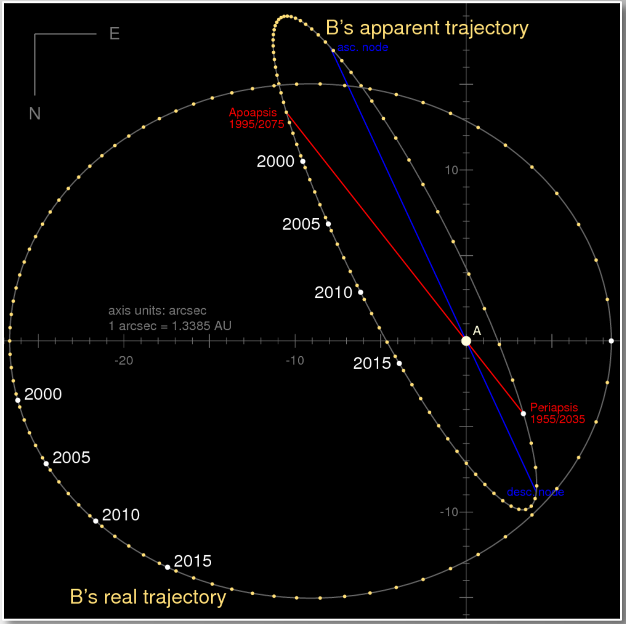
***Centaur** enables critical technology for most direct exoplanet imaging*

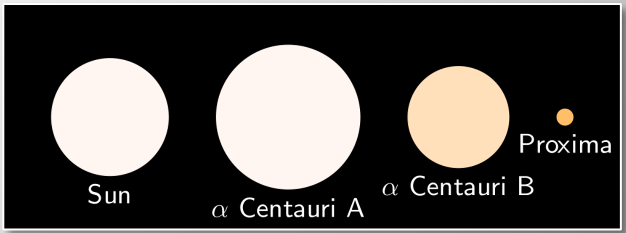
Mission name	**JWST** NASA 	**Centaur** Bendek et al. 	**ACESat** Belikov et al. 	**Ground ELTs** TMT/GMT/ESO 	**WFIRST-AFTA** NASA 	**Exo-C / Exo-S** (Stapelfeldt/Seager) 
Wavelength/Aperture	IR/6.5m	Vis 0.15m	Vis 0.45m	IR ~ 40m	NIR 2.4m	Vis 1.1m/1.5m
Launch / first light date	2018	2018	2020	2022+	2024	2024
Cost	~$8.800M	$10M	$175M	$1,000M+	~$2,000M	~$1,000
Status	under construction	this proposal	SMEX, submitted	under construction	proposed (Astro 2010 top priority)	study
Detection type	transit and Direct imaging	direct imaging	direct imaging	direct imaging	direct imaging	direct imaging
Planets around Alpha Centauri?	no	Possible	yes	no	possible	possible
Exo-zodi around nearby stars?	Only IR	Possible (>10 Zodi)	Yes	M-dwarf only	Yes	Yes
Require unproven imaging technology?		yes	Yes	Yes	Yes	Yes
Technology demonstration mission?	no	yes	Partially	no	no	No

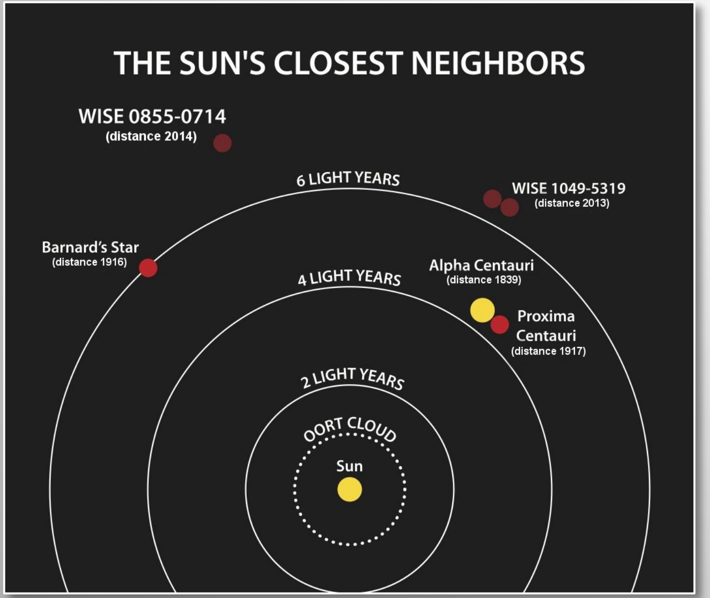
αCen AB: a Unique Opportunity for small optical space telescopes

Why Alpha Centauri?

- Alpha Centauri is a our closest star and the only one accessible where the Habitable Zone is accessible to a 30cm class telescope
- The system is binary and therefore it double the probability of finding a earth like planet reaching close to 50% chances according to latest Kepler statistics.
- An earth –size planet has been found in 2012, aCen Bb, but is too close to the star. This increases the likelihood of a earth-like planet in the HZ of the star.





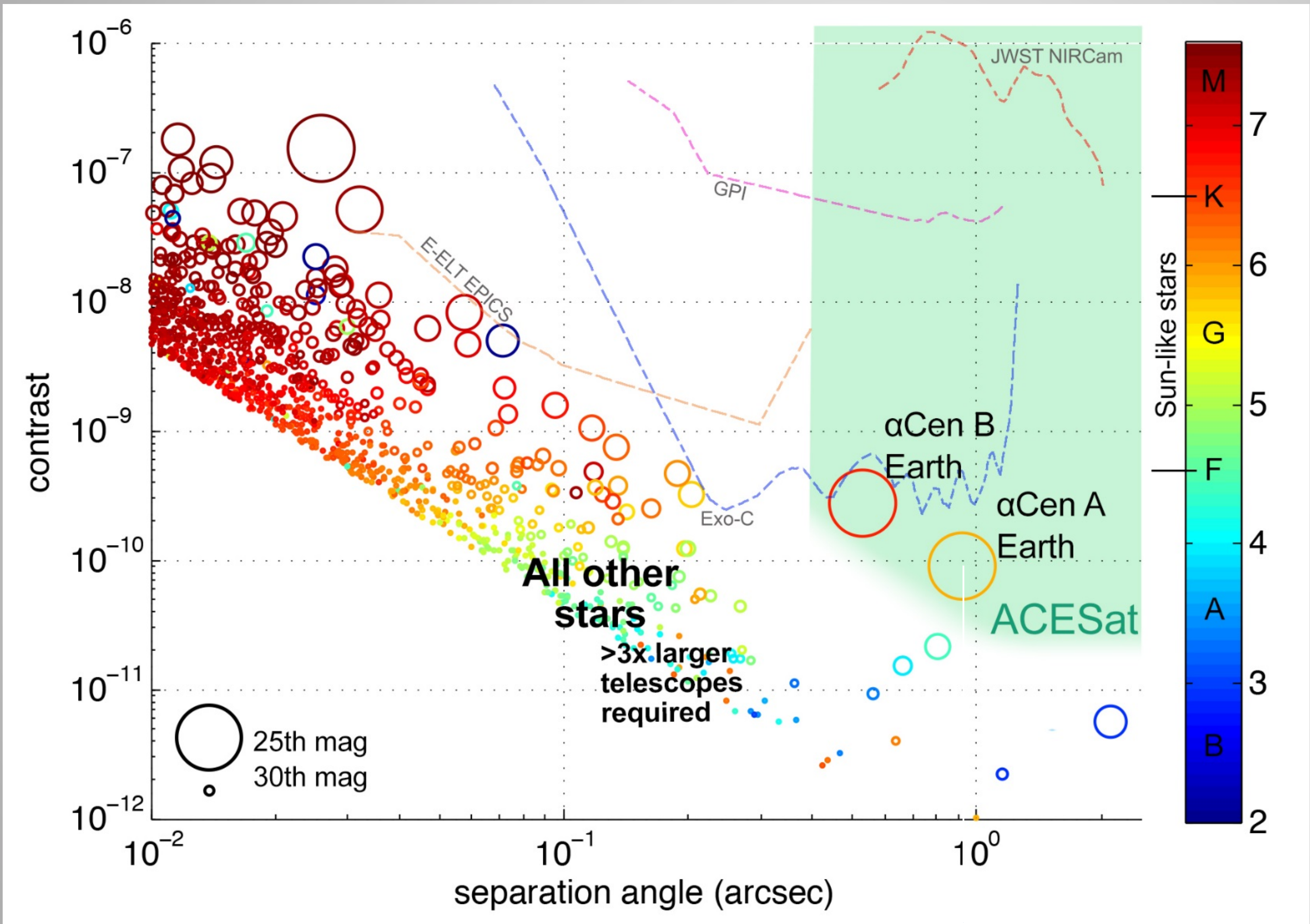


Other science cases

- ACESAT will be also able to measure the exozodiacal light at Alpha Centauri and some other nearby stars. This is critical for other NASA mission design.

αCen AB: a Unique Opportunity for small optical space telescopes

Simulation of a (hypothetical) Earth twin at quadrature around every nearby star



- Example: αCenA Earth twin with a 30cm telescope at 500nm:
  - separation: 0.92" = 2.7 λ/D
  - flux: ~1 photon per minute for ~10% end-to-end QE (roughly same as for flagship telescope looking at Earths 10pc away)
- αCen is in a class of its own: any other star requires a >3x larger (> 10x more expensive) telescope

2.7 λ/D for 30cm telescope

Centaur

Value Proposition: Enabling direct imaging of exoplanets around nearby stars leveraging ARC experience and expertise in small sats and exoplanet detection.

- Technology and scientific pathfinder for critical direct imaging technologies.
- Constrain the exozodiacal light on aCen A & B, eEri, and tCeti. retiring the “dust” risk.
- Detect visible counter part of Radial Velocity planets at eEri.
- Detection of Neptune like planets around A&B Cen.

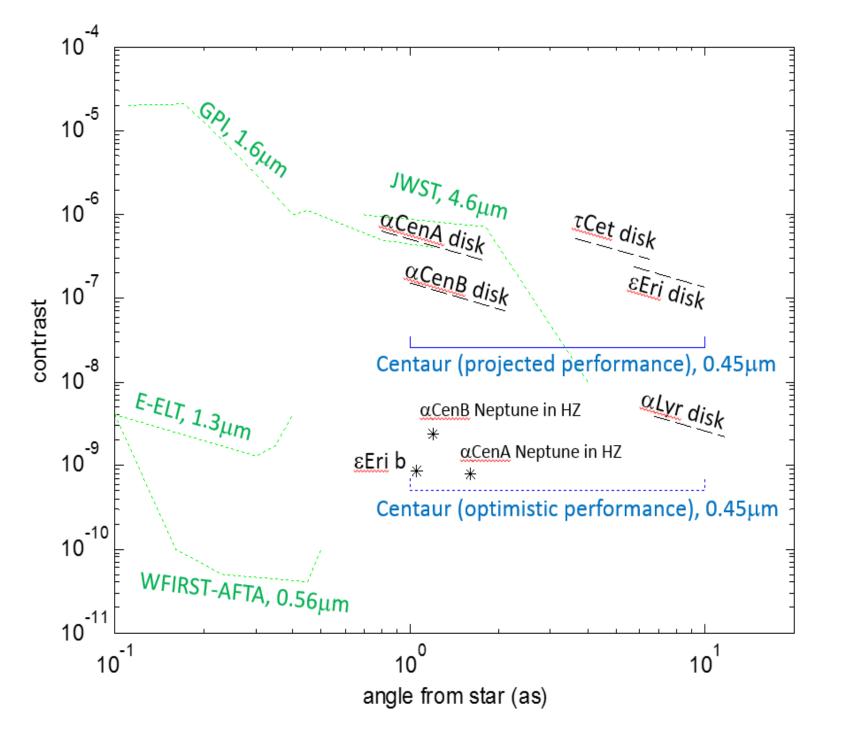


Table 1-2. Disk Science Around Nearby Stars

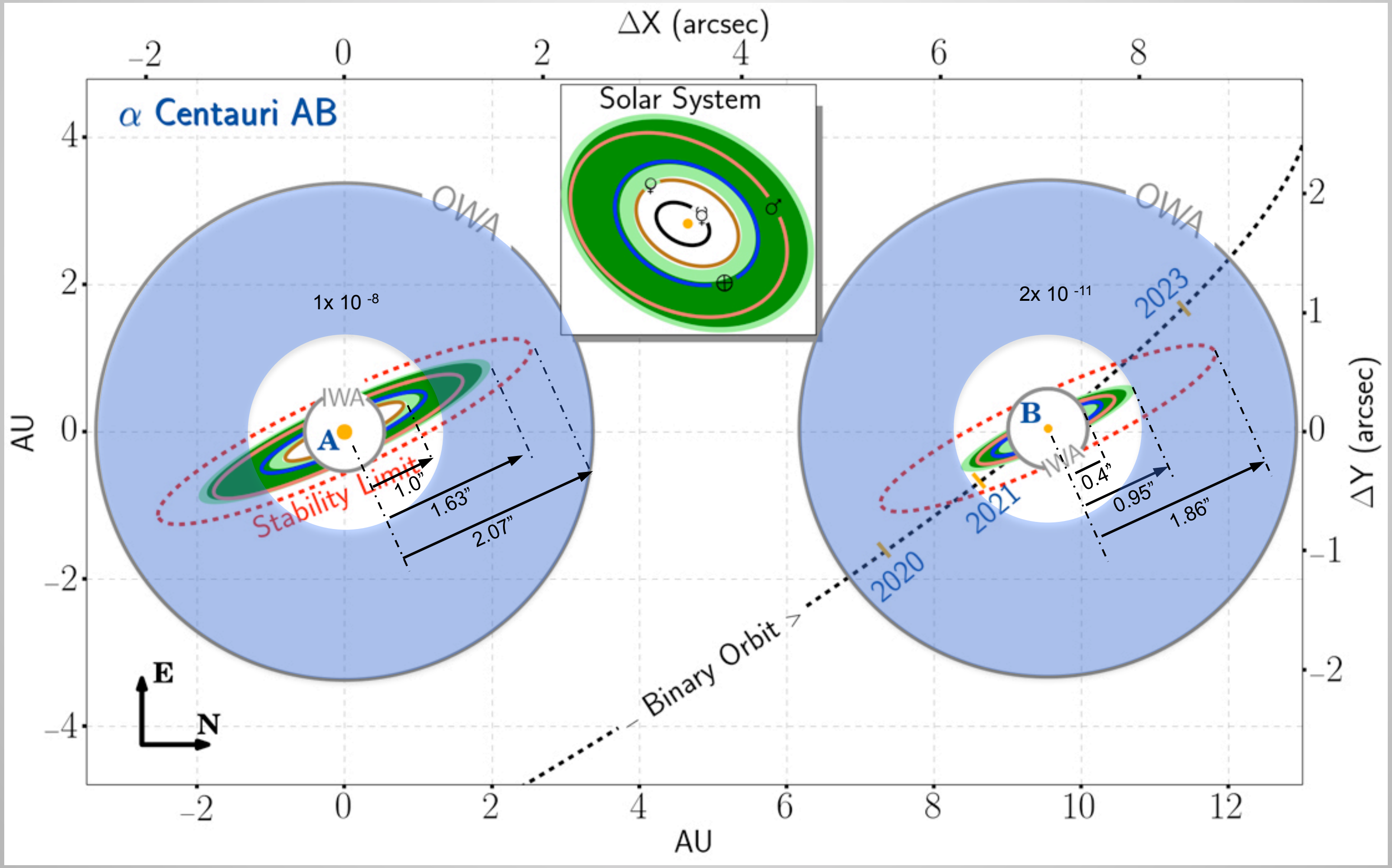
Object	D [pc]	Disk /Planet Separation		Contrast (based on 100 zodis)	Integration Times	
		[AU]	[as]	($x10^{-8}$)	Photon Noise SNR=5 [hrs]	Post-Processing Calibration [days]
α CenA	1.3	0.7-2.8	1-2.1	10	24.5	60
α CenB	1.3	0.6-2.5	0.8-1.8	30	17.2	30
ε Eri	3.2	20	6.2	15	2.1	3.53
τ Ceti	3.6	35	9.6	24	11.8	20.6

Mission overview

- 1 year, LEO SS, $10M, Launch Jan 2018
- Aperture 15cm @450nm
- 1 band 15% bandwidth
- IWA @1.6L/D =1.0”
- OWA @3.5L/D = 2.5”
- 1x10-7 raw contrast
- Distance aCen A and B by 2018 = 4.6” or 7.5L/D

aCen A&B Science

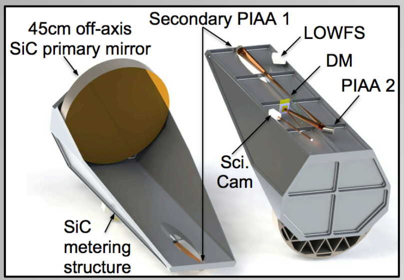
Capable of imaging most aCen A HZ and part of aCen B to constrain down to 30 Exo-Zodi or detect Neptune-like planets.

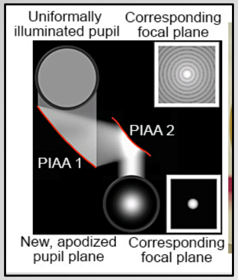


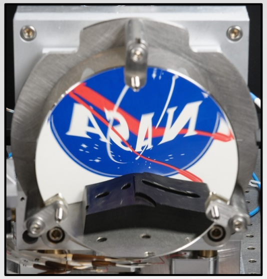
Credit: Billy Quarles, NASA Ames

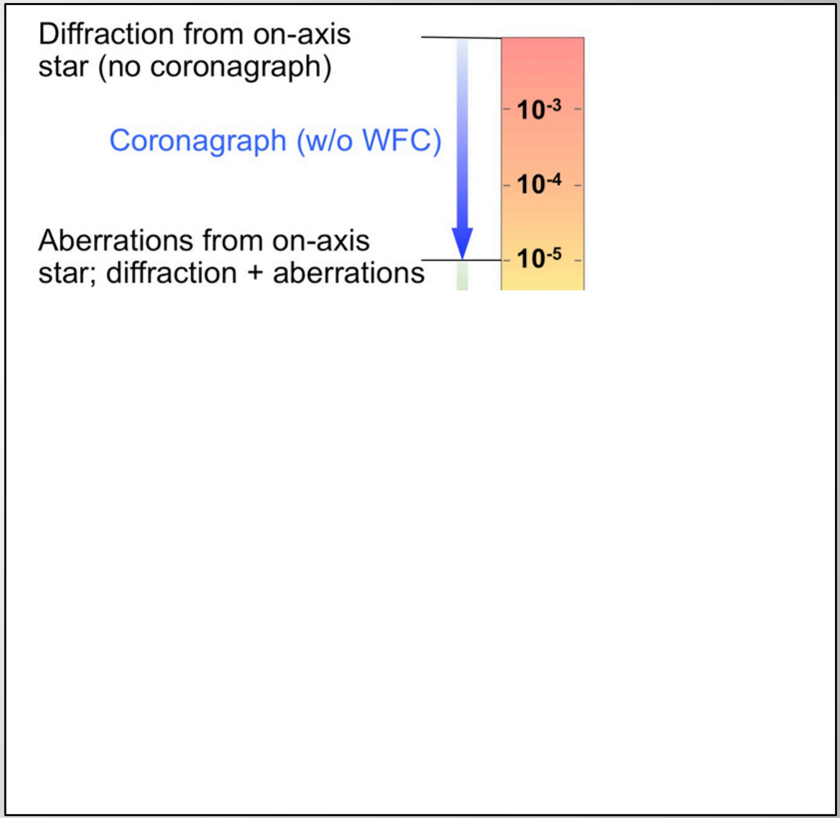
Instrument Building blocks

45 cm off-axis telescope with an **embedded** PIAA -> 10^{-5} (1.6 – 10λ/D)









Instrument Building blocks

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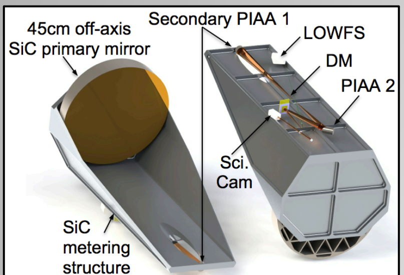
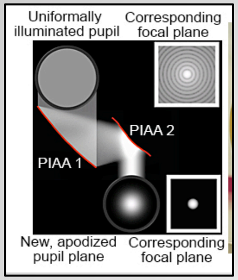
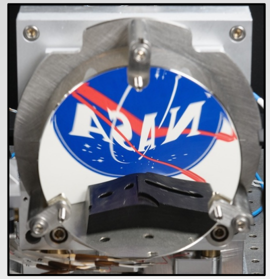
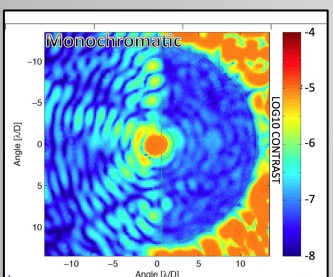
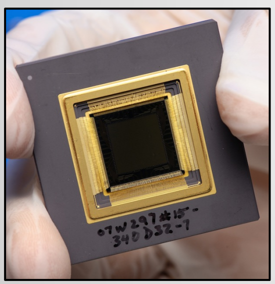


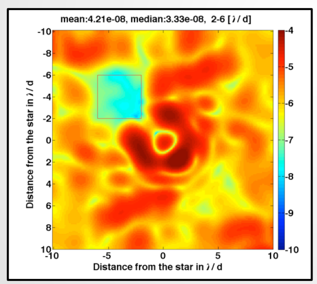


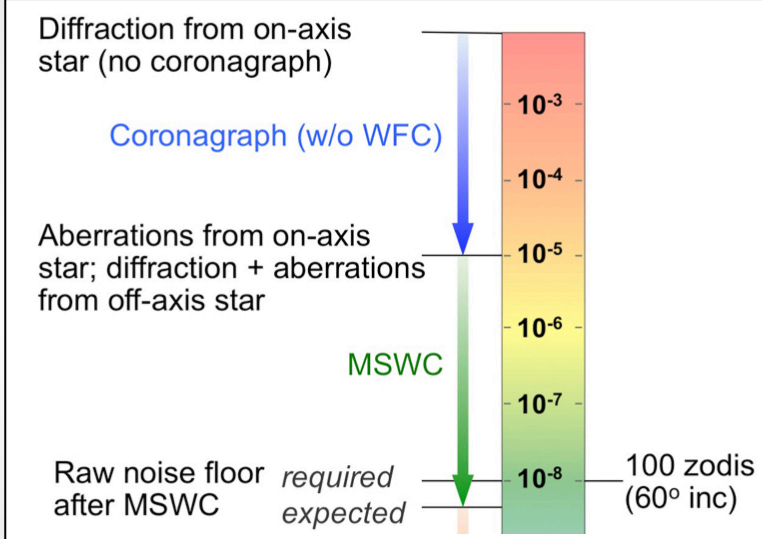


WFC (Multi-Star Wave Front Control) -> 10^{-8}



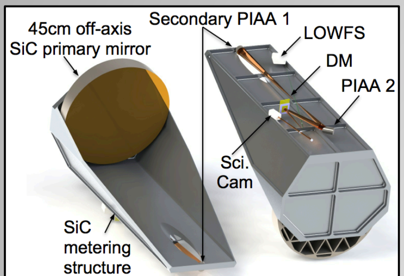


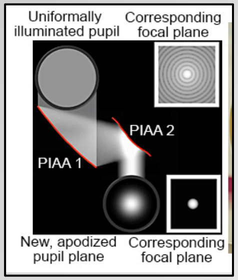


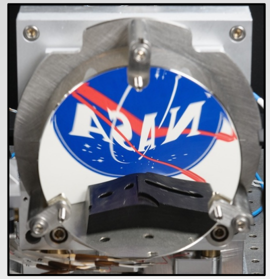


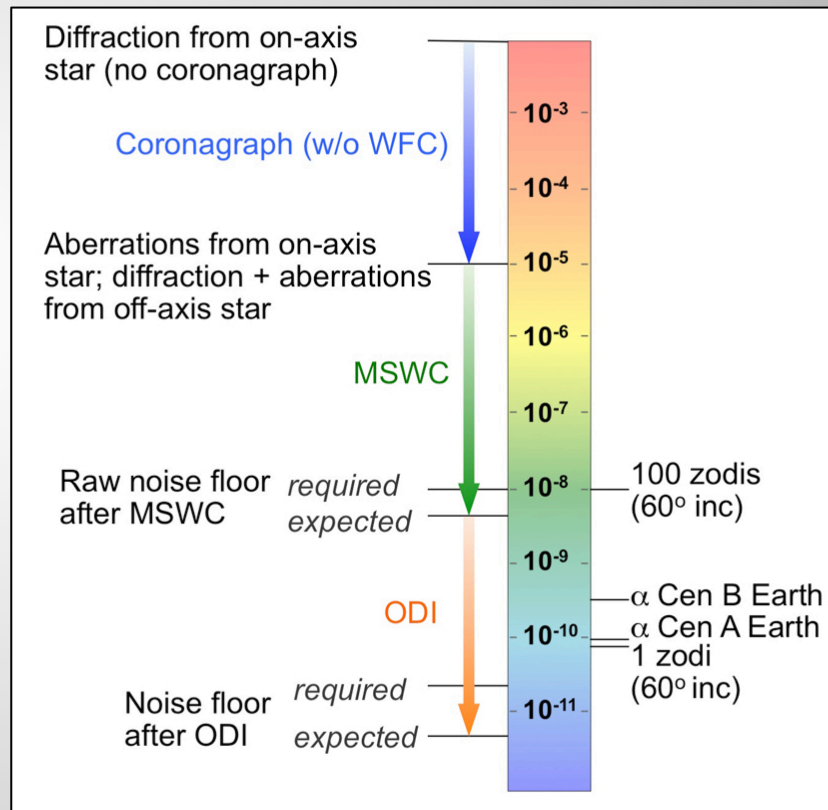
Instrument Building blocks

45 cm off-axis telescope with an **embedded** PIAA -> 10^{-5} (1.6 – 10λ/D)

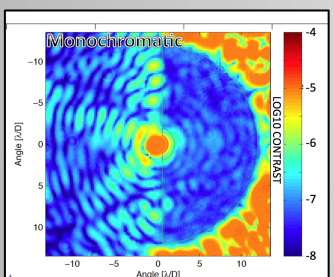


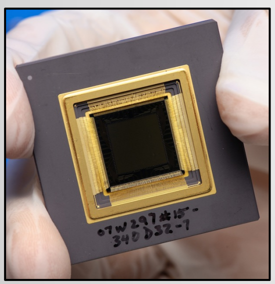


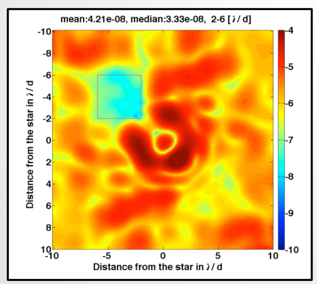




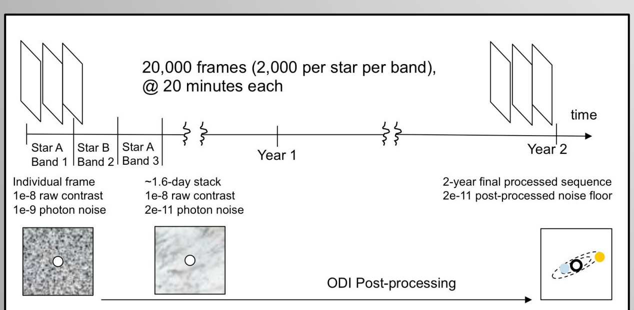
WFC (Multi-Star Wave Front Control) -> 10^{-8}

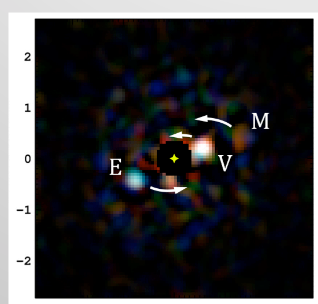




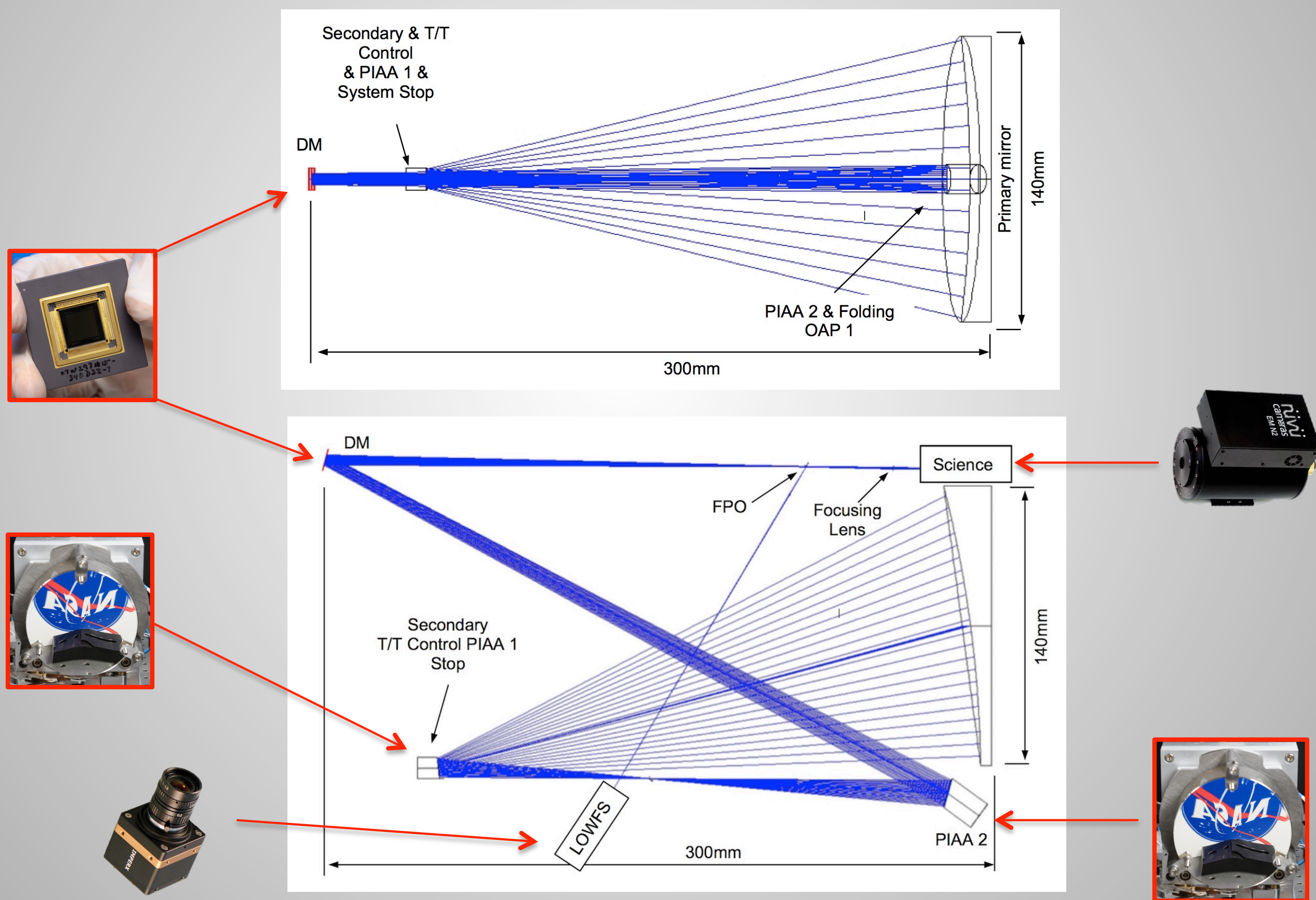


Continuous observation ODI -> 10^{-11}



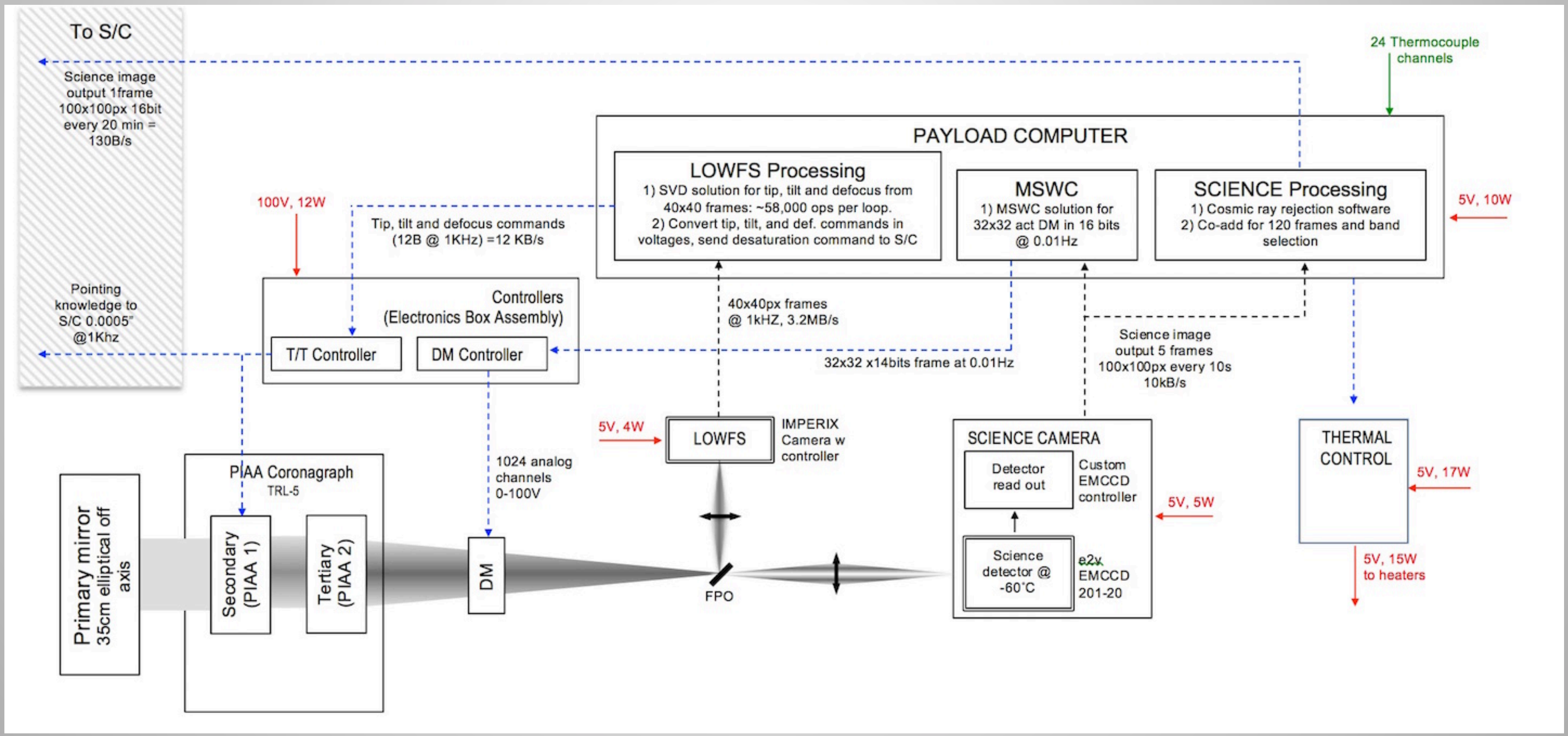


Centaur Optical Design



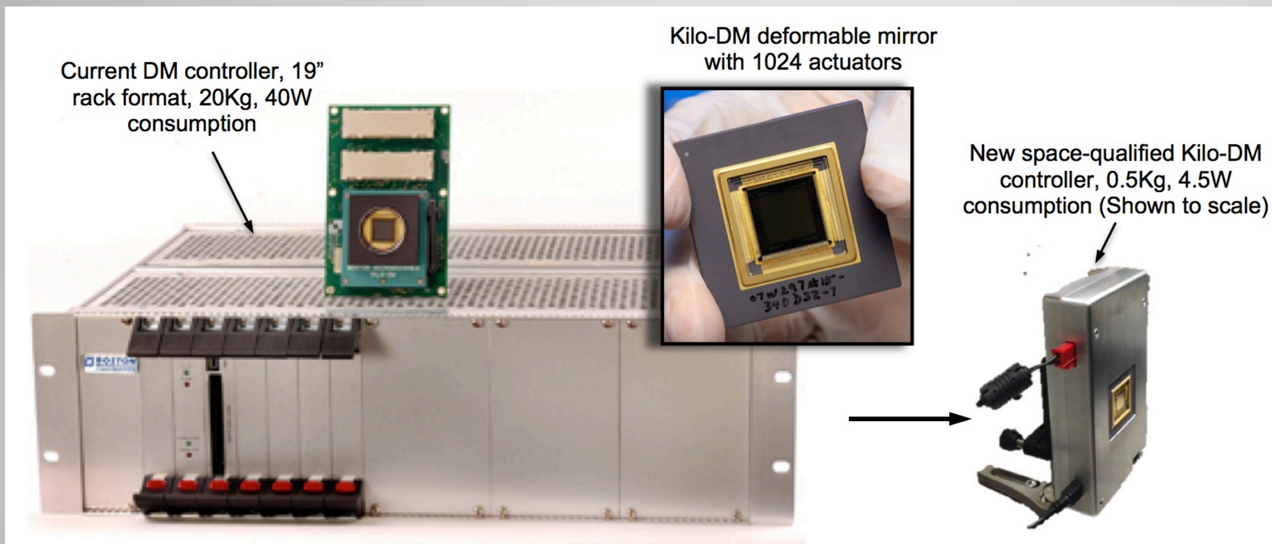
Centaur Functional diagram

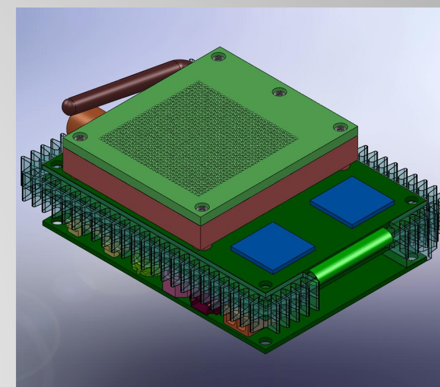
- Centaur has the stop located at the secondary mirror which is also PIAA 1 and tip-tilt mirror
- The tip-tilt mirror is controller by the knowledge provided by the LOWFS
- For fast Jitter control and small amplitude we use the DM to control



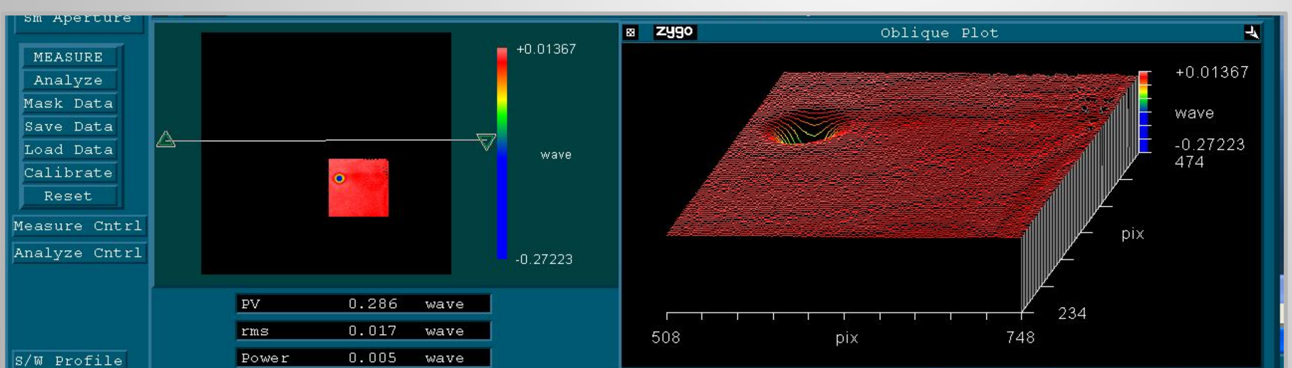
DM Controller

- New compact Kilo-DM (1024 actuators) controller being developed for this mission



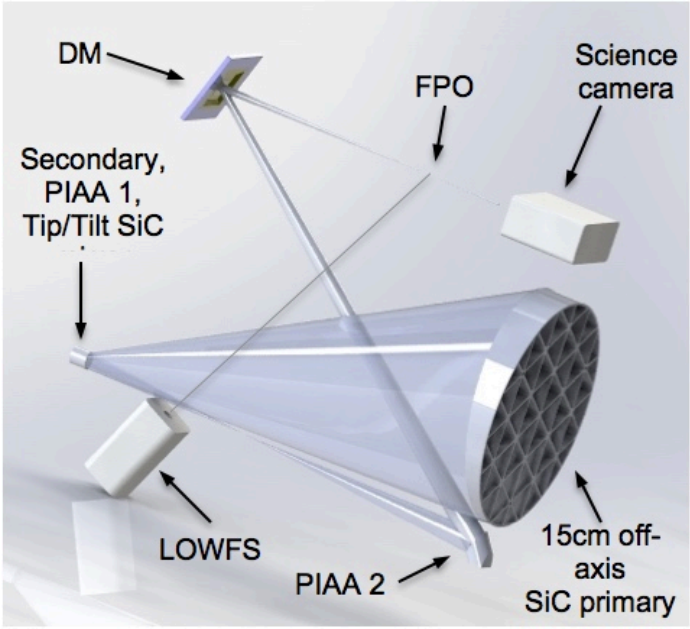


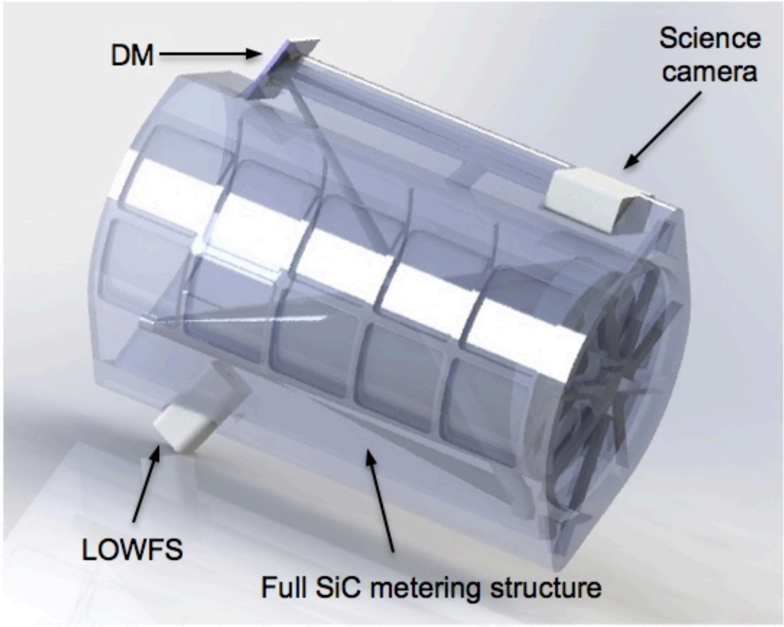
- Model of Kilo-DM space qualified controller currently under design



Telescope Hardware

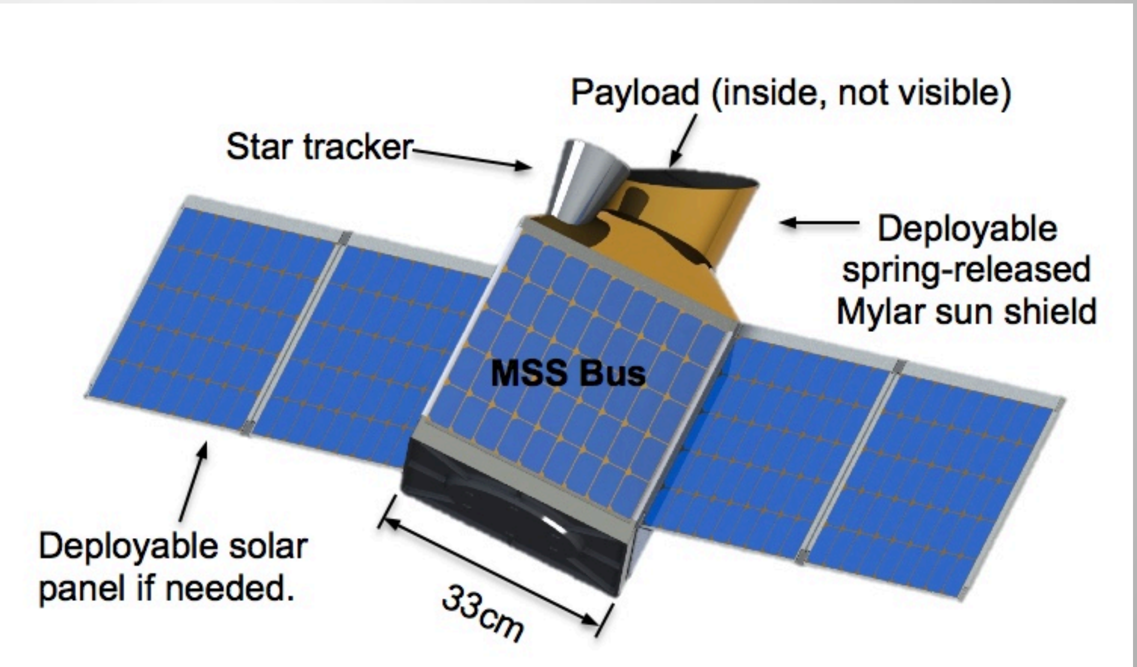
- Full SiC 15cm, Off-axis telescope, L/25 max end-to-end WFE (Total 15Kg mass)
- Active thermal control to maintain 10˚C operation with 0.3˚C PV stability
- 1.5mas RMS stability LOWFS (Demonstrated for CAT III EXCEDE Lockheed Martin)



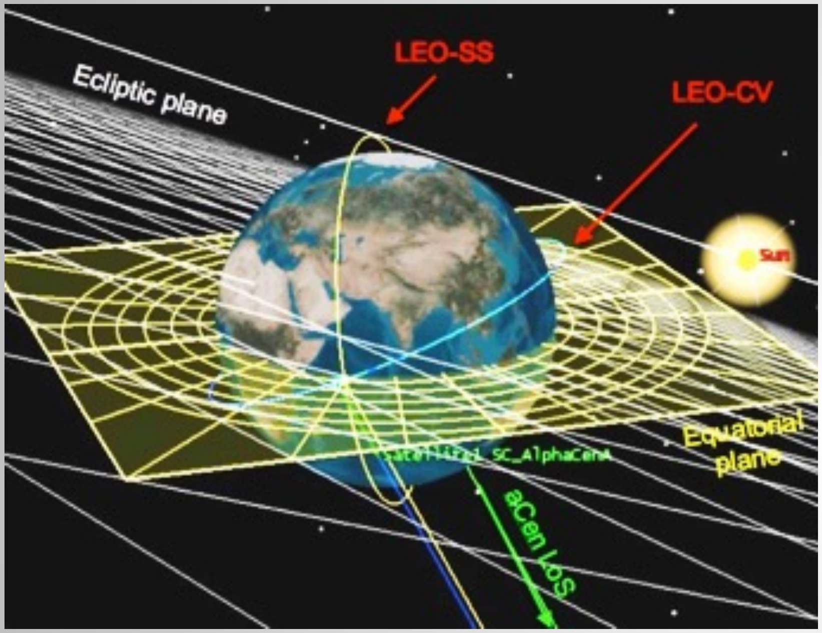


Spacecraft

- Low Cost off-the-shelf Millennium Space System 27U bus (30x30x30cm)
- We will buy one unit “as is” and will improve stability.
- Low data rates requirements allow to use normal ground stations
- 800km orbit avoid decay problems and increases target access.



Mission operations



Low Earth Orbit concept

Resilient to orbit inclination

Baseline of 800km Sun Synch.

- 23˚ inclination would allow ~25day of uninterrupted view of aCen every 3 months.
- Sun Synch provides thermal stability.
- Launch on Falcon 9, utlizing TriSept utilizing FANTM-RiDE

Table 2.2-1. Alpha Centauri (left) and Epsilon Eridani (right) Trade Inclination Vs. RAAN (Alt 800 km)

Alpha Centauri	Best Case	Worse Case		Epsilon Eridani	Best Case	Worse Case
Inclination (deg)	90	0		Inclination (deg)	10	90
RAAN (deg)	120-160, 300-340	0-360		RAAN (deg)	0-360	0-360
Total Access (days)	365	240		Total Access (days)	329	240
Max Cont. Access (days)	365	0.05		Max Continuous Access (days)	22	0.05
Min Cont. Access (days)	8760	1.1		Min Continuous Access (days)	1.3	1.1
Mean Access Per Orbit (%)	100	65		Mean Access Per Orbit (%)	91	65

Conclusion

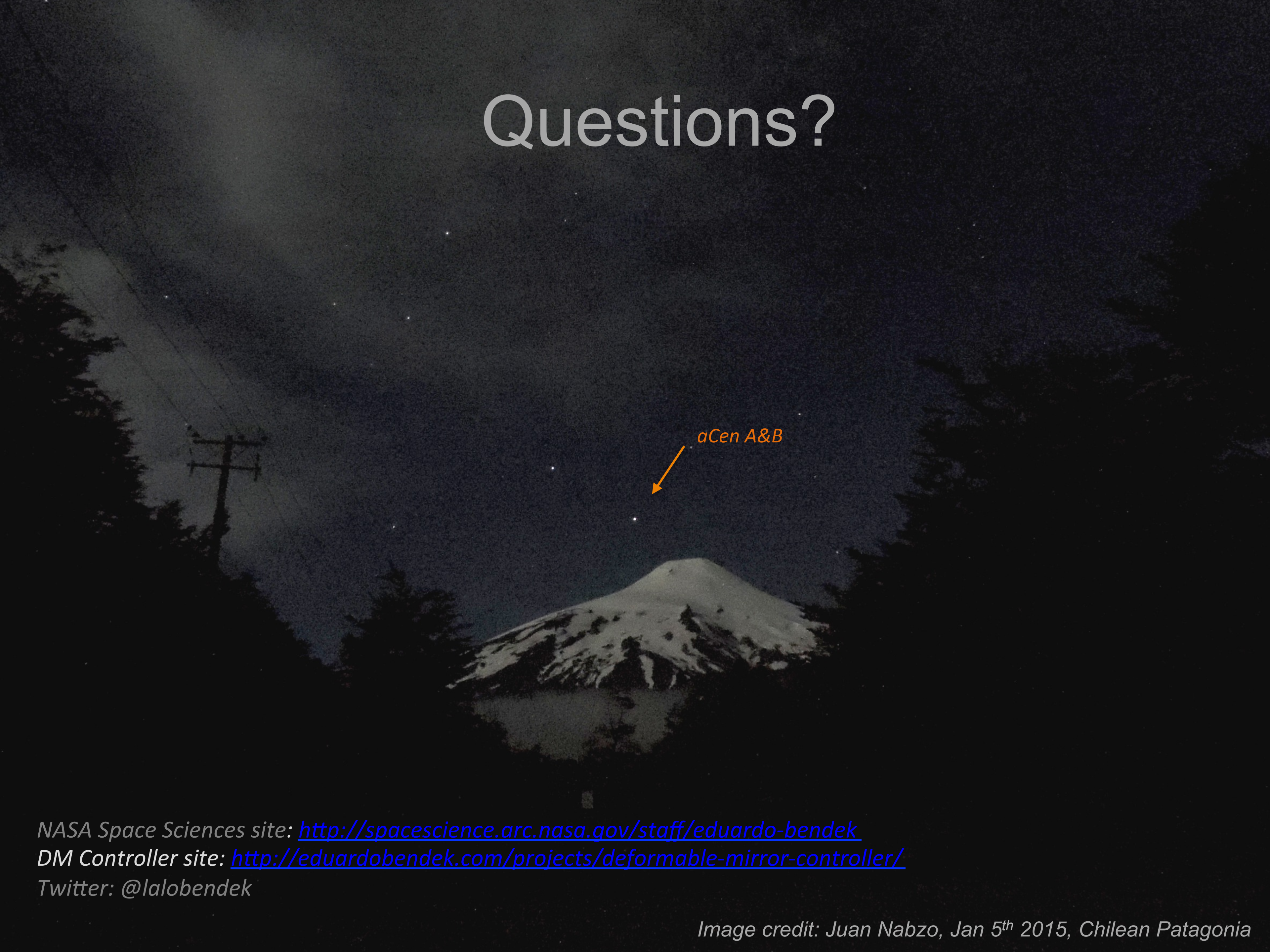
1) We developed an instrument design than can measure ExoZodi around nearby stars.

2) We developed a mission concept in low earth orbit utilizing a 27U off-the-shelf microsat

3) We are advancing key technologies (PIAA, DM, WFC, Post-processing) for ACESat and other direct imaging missions (AFTA-C, EXO-C, EXCEDE)

4) Mission is expandable to *Centaur "plus"*, **Capable of imaging earth like planet**s with a 25 cm telescope that **will fit on the same bus**

Questions?



NASA Space Sciences site: http://spacescience.arc.nasa.gov/staff/eduardo-bendek
DM Controller site: http://eduardobendek.com/projects/deformable-mirror-controller/
Twitter: @lalobendek

Image credit: Juan Nabzo, Jan 5th 2015, Chilean Patagonia