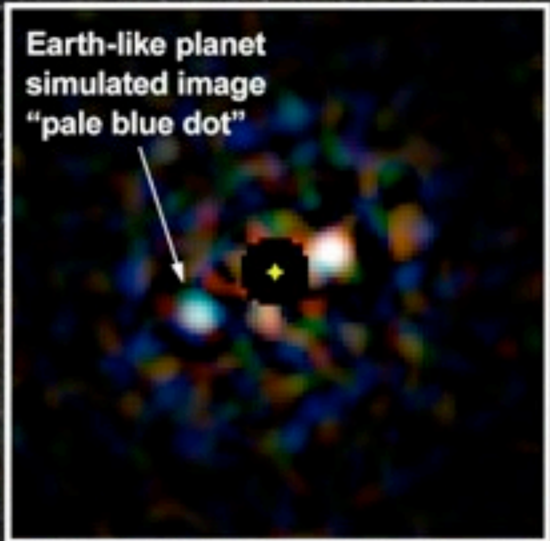

How to Directly Image a Habitable Planet Around α Centauri with a ~30-45cm Space Telescope

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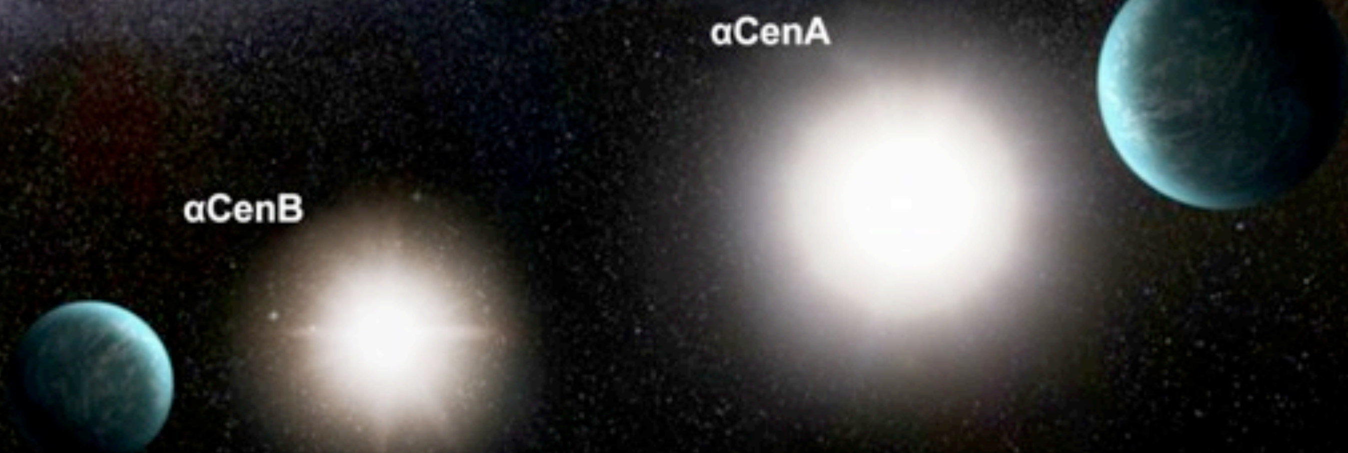
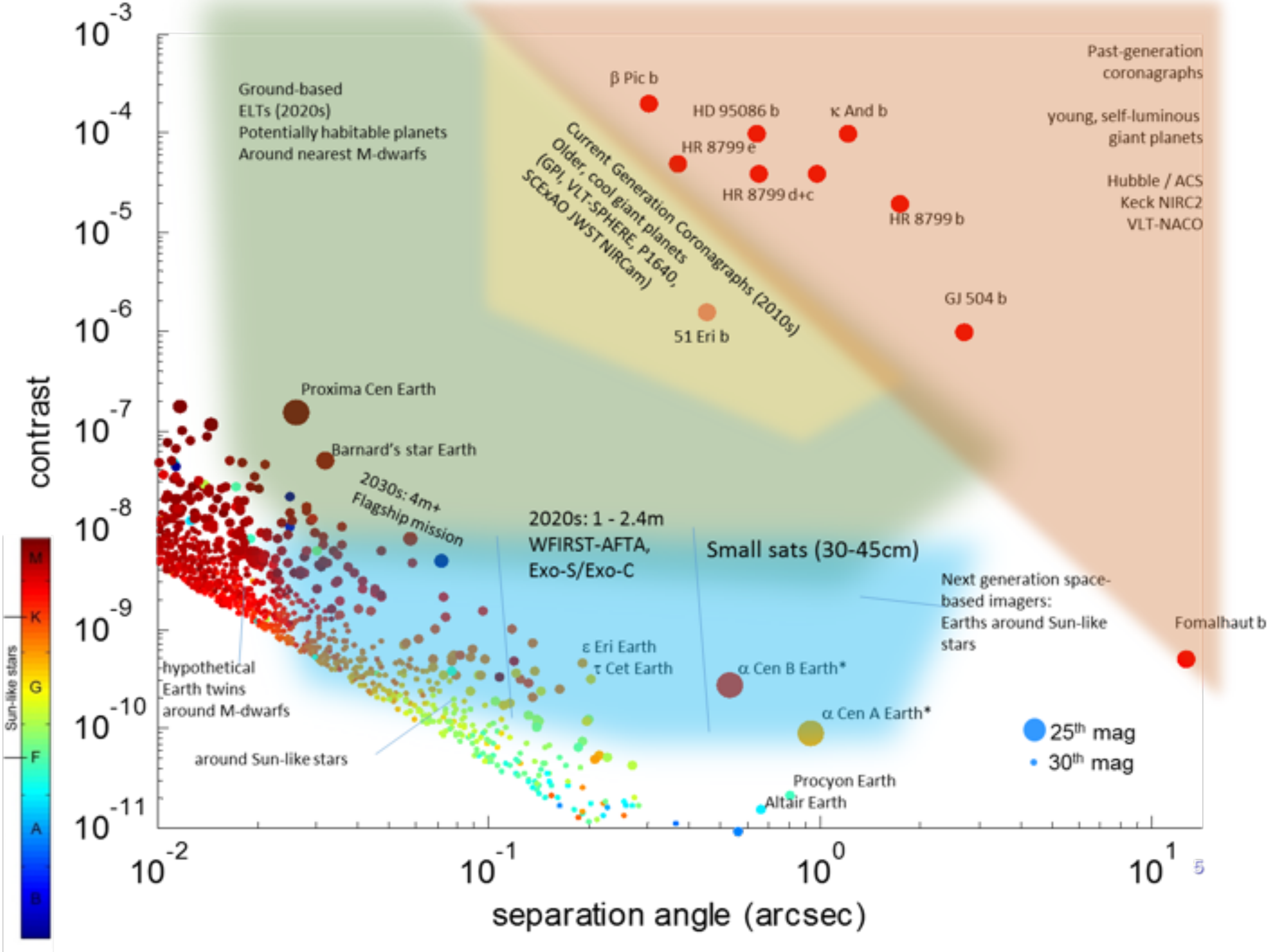


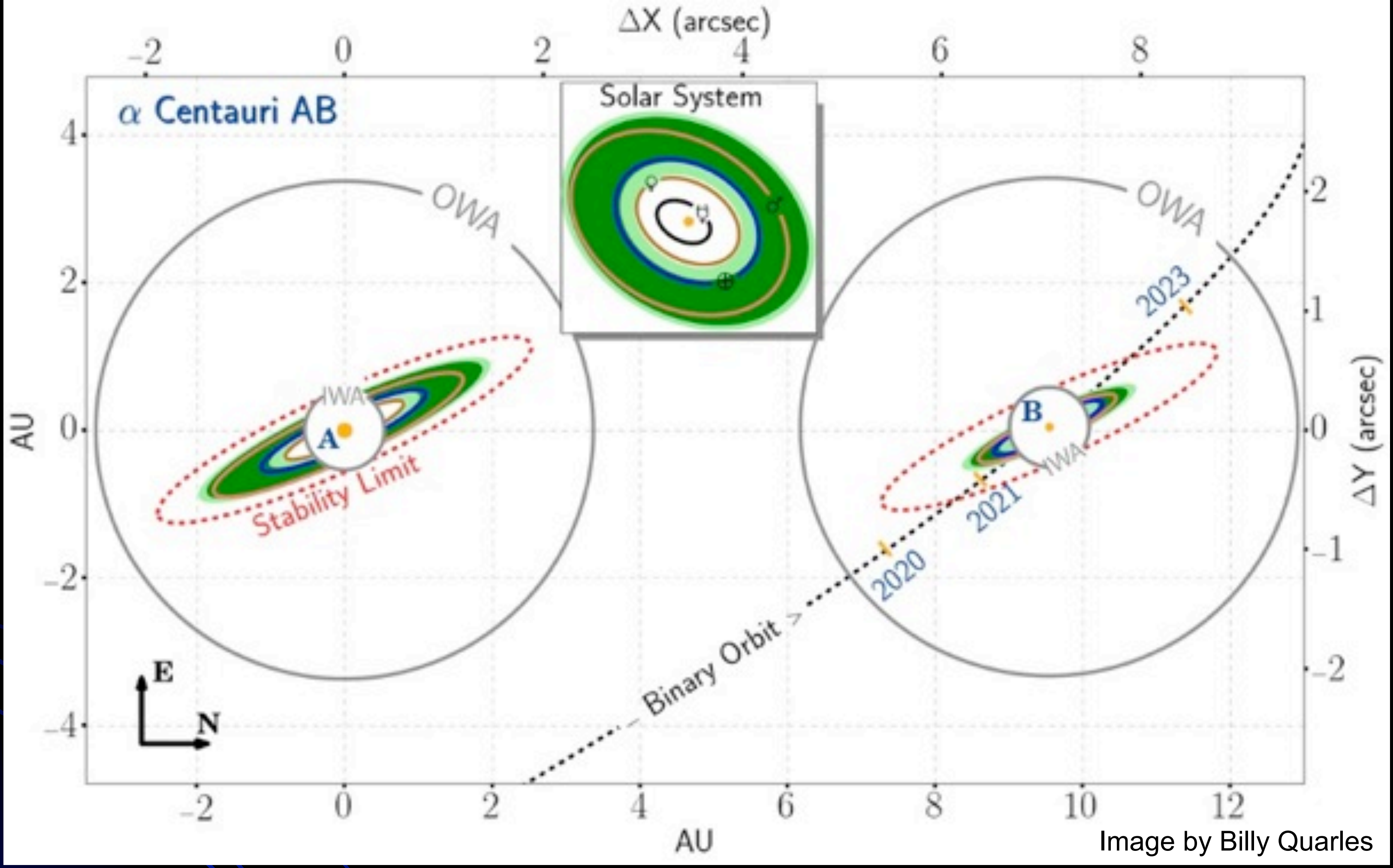
Outline

- Motivation
- Science
- Technology
- Mission concept: ACESat



contrast
separation angle (arcsec)
Sun-like stars
M
K
G
F
A
B
Ground-based
ELTs (2020s)
Potentially habitable planets
Around nearest M-dwarfs
Current Generation Coronagraphs (2010s)
Older, cool giant planets
(GPI, VLT-SPHERE, P1640,
SCExAO JWST NIRCam)
Past-generation
coronagraphs
young, self-luminous
giant planets
Hubble / ACS
Keck NIRC2
VLT-NACO
β Pic b
HD 95086 b
κ And b
HR 8799 e
HR 8799 d+c
HR 8799 b
GJ 504 b
51 Eri b
Proxima Cen Earth
Barnard's star Earth
2030s: 4m+
Flagship mission
2020s: 1 - 2.4m
WFIRST-AFTA,
Exo-S/Exo-C
Small sats (30-45cm)
Next generation space-
based imagers:
Earths around Sun-like
stars
Fomalhaut b
ε Eri Earth
τ Cet Earth
α Cen B Earth*
α Cen A Earth*
25th mag
30th mag
Procyon Earth
Altair Earth
hypothetical
Earth twins
around M-dwarfs
around Sun-like stars

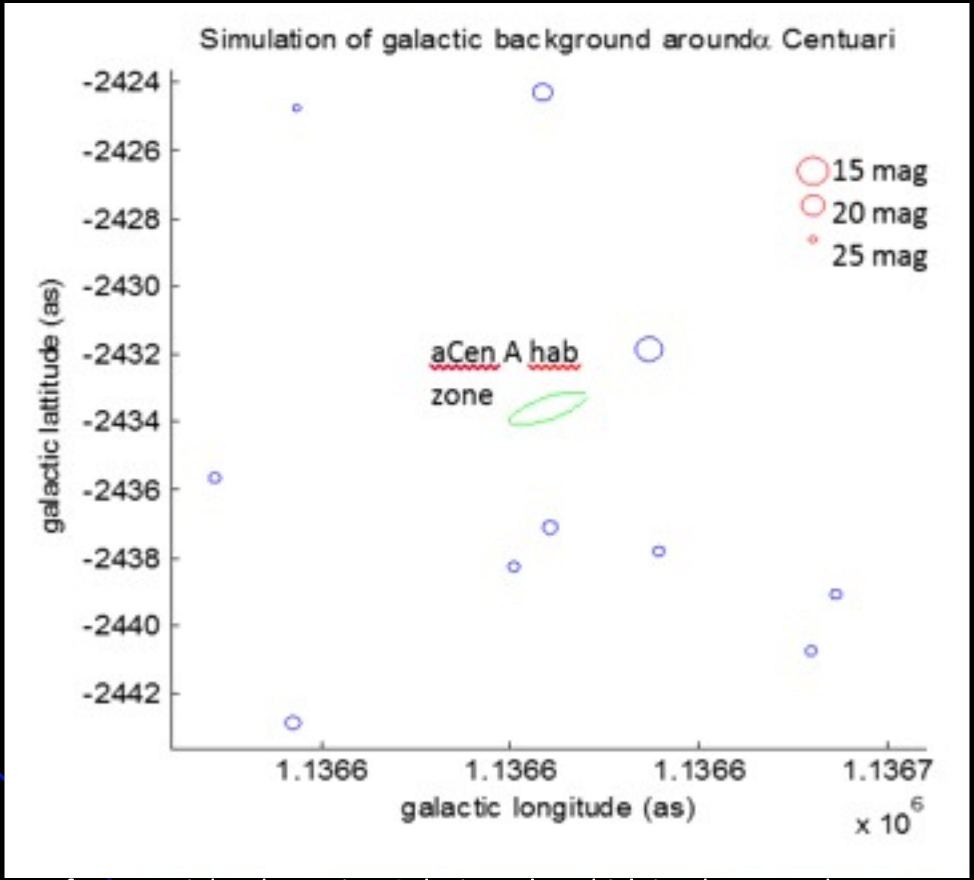
Habitable Zones of αCen AB



- Both HZs are fully accessible with a 0.4” (0.5AU) inner working angle (IWA)
- Orbits are stable out to ~ 2.5 AU (Holman & Wiegert 1999; Quarles & Lissauer 2015)
- If η_{Earth} ~22% -> ~40% for the binary system; if η_{Earth} ~50% -> ~75%

Confusion with background sources: not an issue

Simulation of background stars in the vicinity of alpha Centauri line of sight



Data from Daniel Huber using Galaxia code, which implements the Besancon model

- Probability of confusion in any one image: 0.03
- The high proper motion of aCen (4”/yr) will remove any (already unlikely) confusion with background objects

Planet Spectra

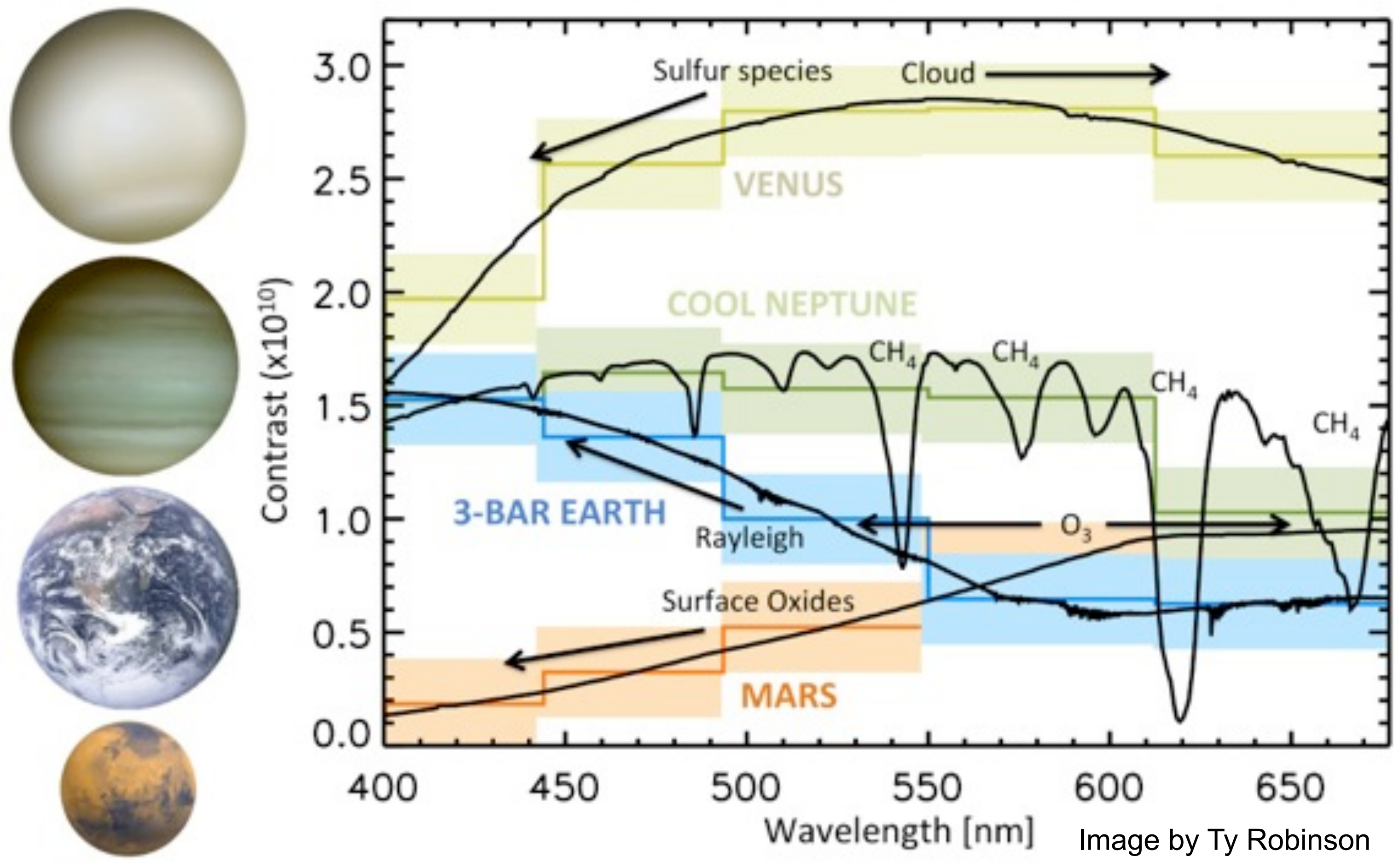
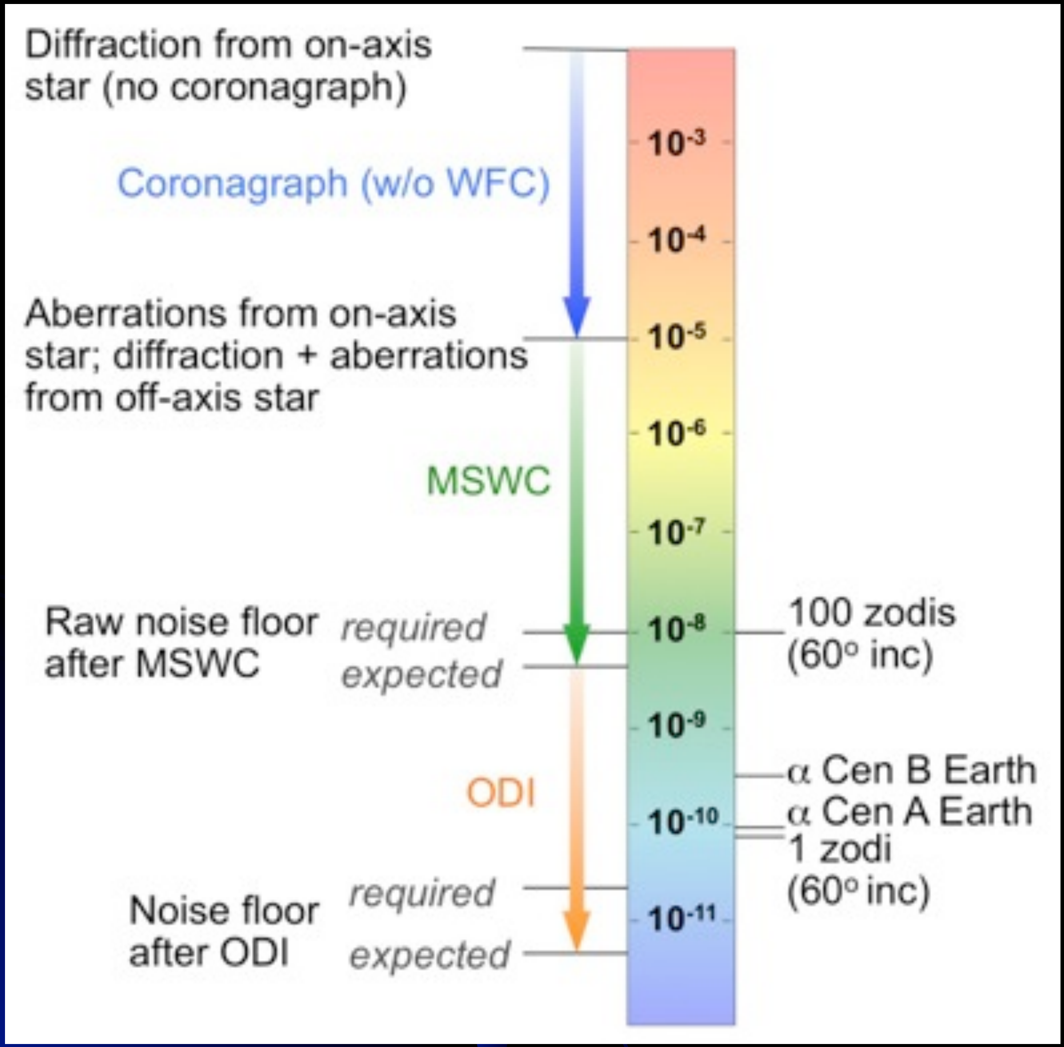


Image by Ty Robinson

- Flux sufficient for low-res spectra
- Enough to distinguish between Earth-like, Venus-like, Mars-like, and many other types of planets

Getting to high contrast on αCen:
Two new enabling technologies



- MSWC: multi-star wavefront control
  - Suppresses light from both stars
  - Thomas, Belikov, Bendek, accepted by ApJ, 2015 (http://arxiv.org/abs/1501.01583)
  - No new hardware required
- ODI: Orbital Differential Imaging
  - Continuous imaging of the system enables 20K images and large post-processing gains
  - Males, Belikov, et al., in prep
  - No new hardware required

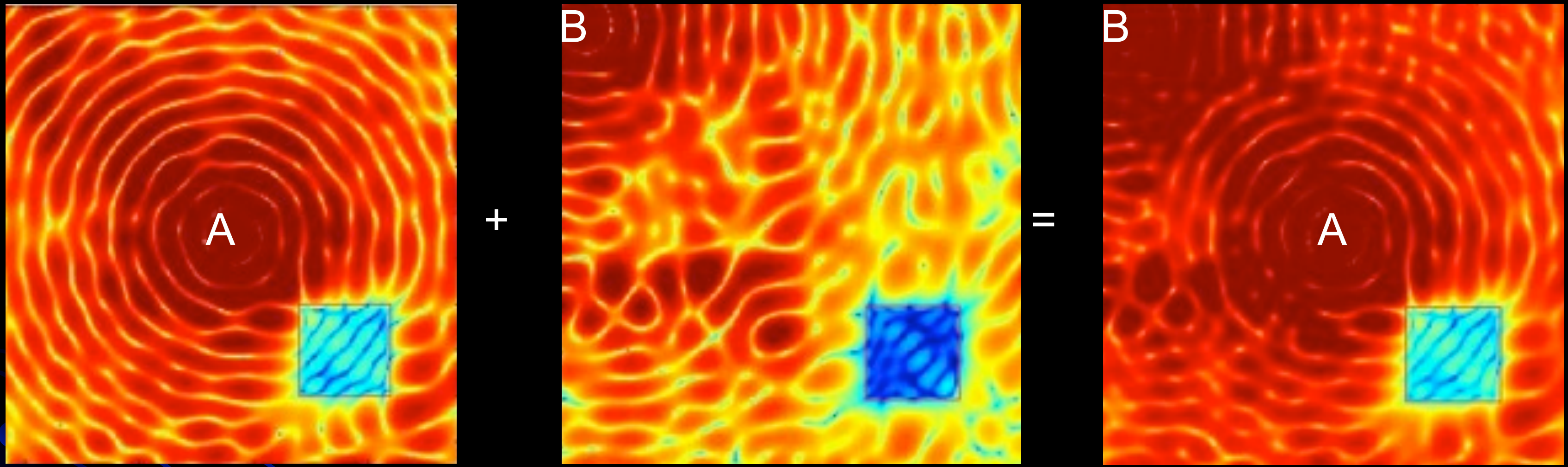
Multi-Star Wavefront Control

Thomas, Belikov, Bendek, accepted by ApJ, 2015
http://arxiv.org/abs/1501.01583

On-axis star:
Use lower order
DM modes

Off-axis star:
Use higher order
DM modes

Result:
Independent control
of both stars' speckles

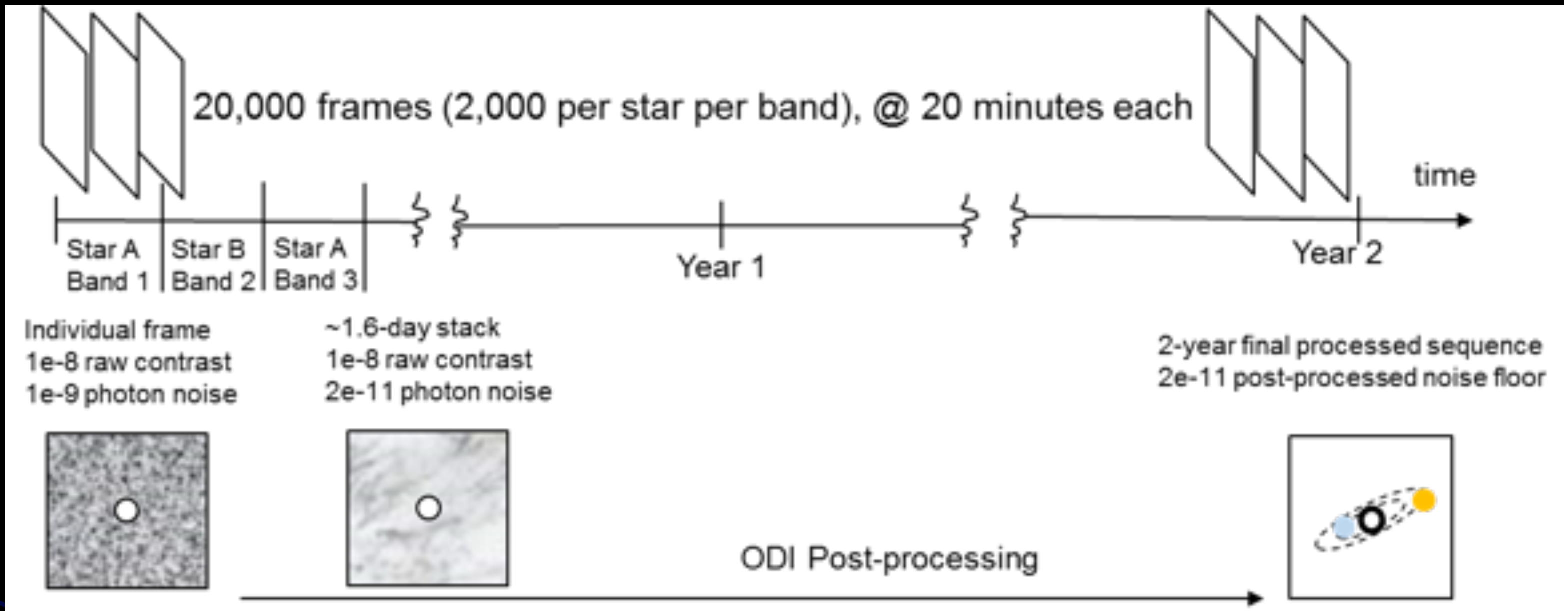


(preliminary proof of principle simulation)

- Main idea: use independent DM modes for each star (halving the dark zone)
- Preliminary simulation demonstrates independent control of two stars' speckles
- Recently awarded technology development to increase dark zone size (in broadband), and do a lab demo
- **No new hardware development is necessary (only DM control algorithm)**

Orbital Differential Imaging:

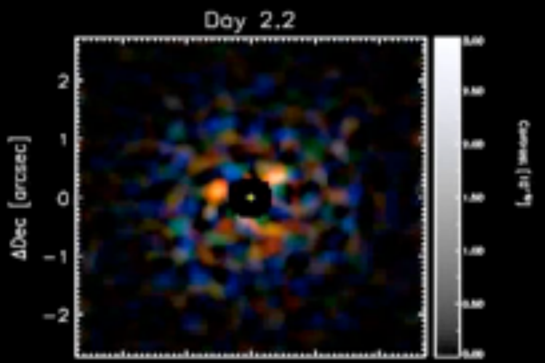
Powerful post-processing enabled by



- A very large number of images -> beats down random noise
- Capture continuous Keplerian orbit motion -> differentiates planets from systematic and residual random noise
- ODI pipeline:
  - KLIP PSF subtraction
  - Temporal filter to eliminate everything that does not appear to move on a Keplerian orbit (this includes static part of exozodi)
  - Spatial filter and other standard image processing tools
  - “Shift-and-add” along Kepler orbits to increase candidate planet signal

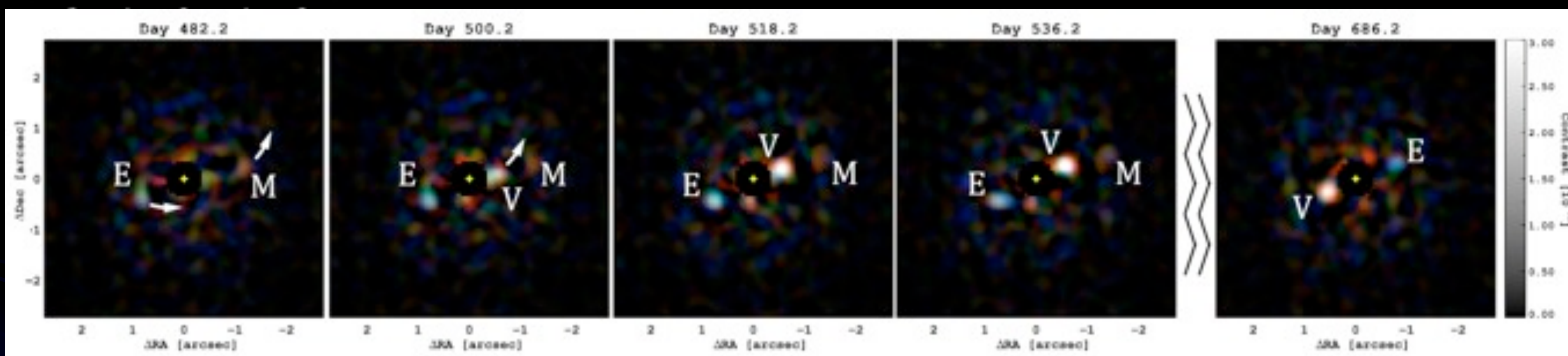
Males, Belikov, in prep.

ODI Pipeline (Simulation)

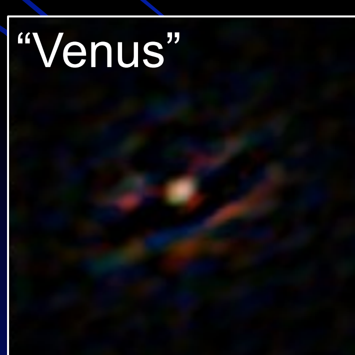


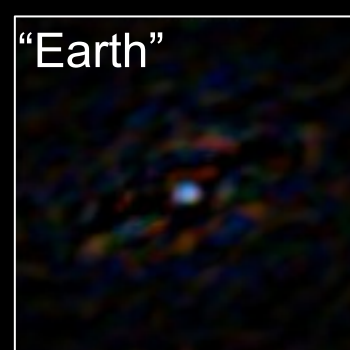
- Simulation parameters (ACESat mission)
  - D = 45cm
  - PIAA coronagraph
  - 1e-8 starting contrast (assumed after MSWC)
  - 0.5mas (1σ rms) random tip/tilt jitter
  - 5 color filters
  - 2-year mission

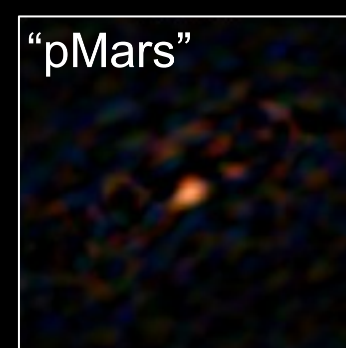
After filtering:



After shift-and-add







Note: “pMars” is larger but farther away than Solar Mars

ACESat:Alpha Centauri Exoplanet Satellite

Mission Time Life and Orbit	SMEX-Class, launch 2020, 2-Years, Earth trailing
Instrument/ Telescope	Unobstructed 45cm, Full Silicon Carbide
Coronagraph architecture	Baseline: PIAA Embedded on Secondary and tertiary telescope mirror.
Coronagraph performance	1×10^{-8} raw 6×10^{-11} @ 0.4” (with ODI) 2×10^{-11} @ 0.7” (with ODI)
Wavelength	400 to 700 nm, 5 bands @ 10% each.

proposed to SMEX, 2014

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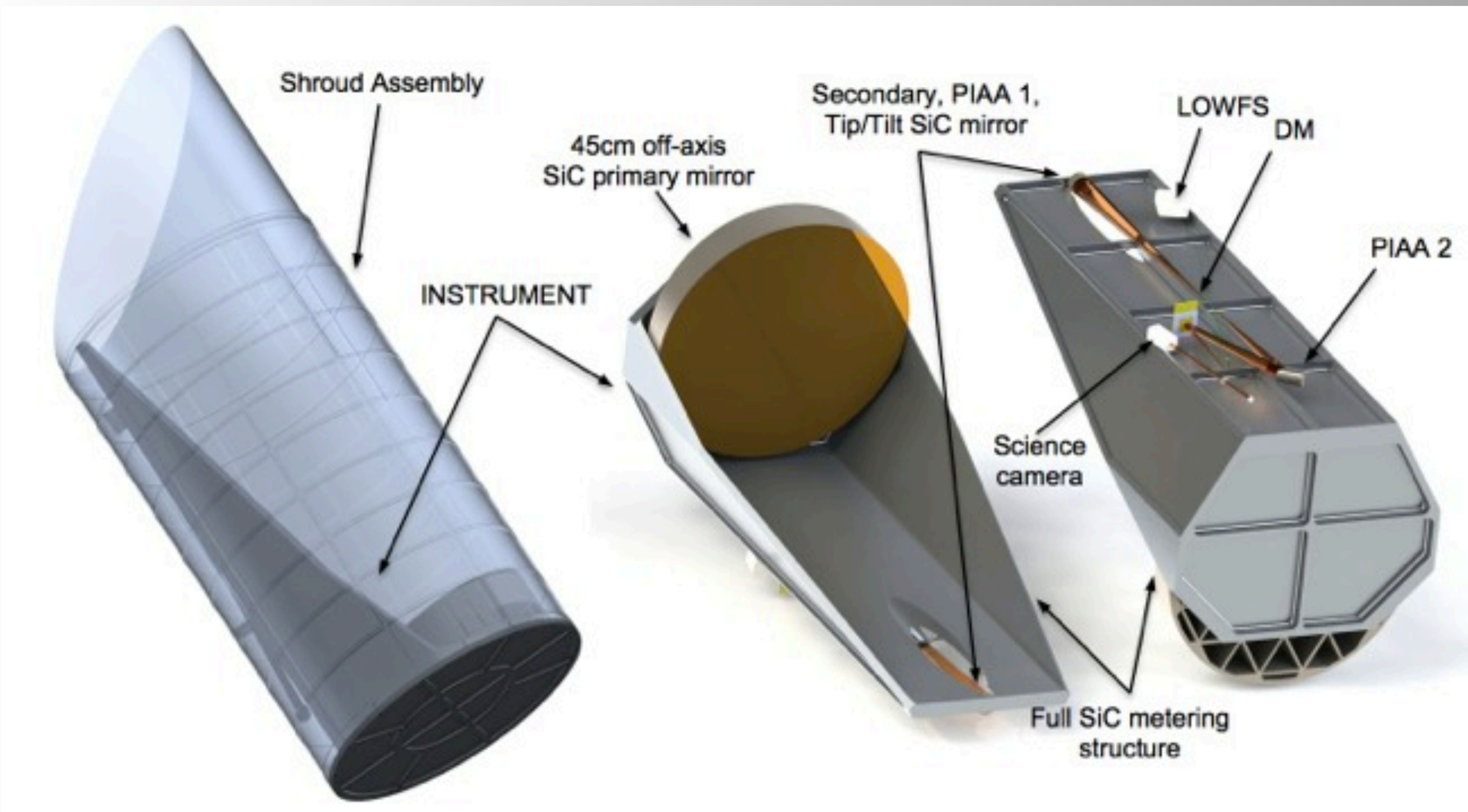
Traub, W.
Turnbull, M.
Chakrabarti, S.

Guyon, O.
Kasdin, J.
Lozi, J.
McElwain, M.
Pluzhnik, E.
Thomas, S.
Vanderbei, B.
et al.

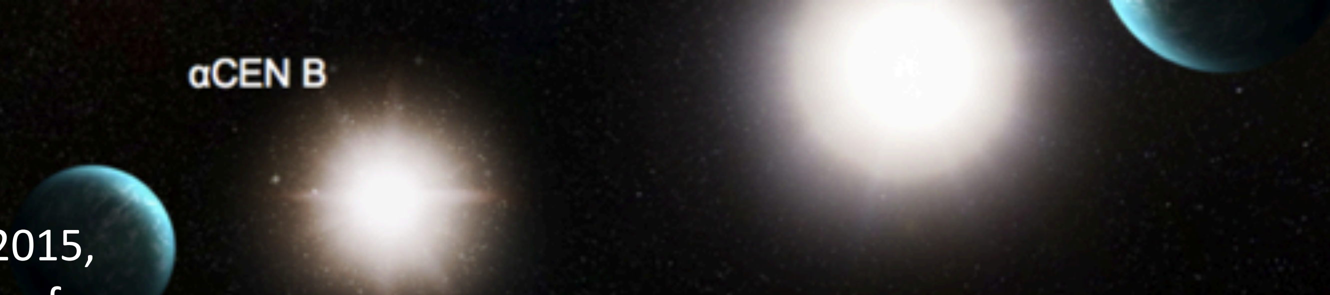
Telescope Hardware

- Full SiC 45cm, Off-axis telescope, L/25 max end-to-end WFE (Total 45Kg mass)
- Active thermal control to maintain 10˚C operation with 0.1˚C PV stability
- 0.5mas RMS stability LOWFS (Demonstrated for CAT III EXCEDE Lockheed Martin)

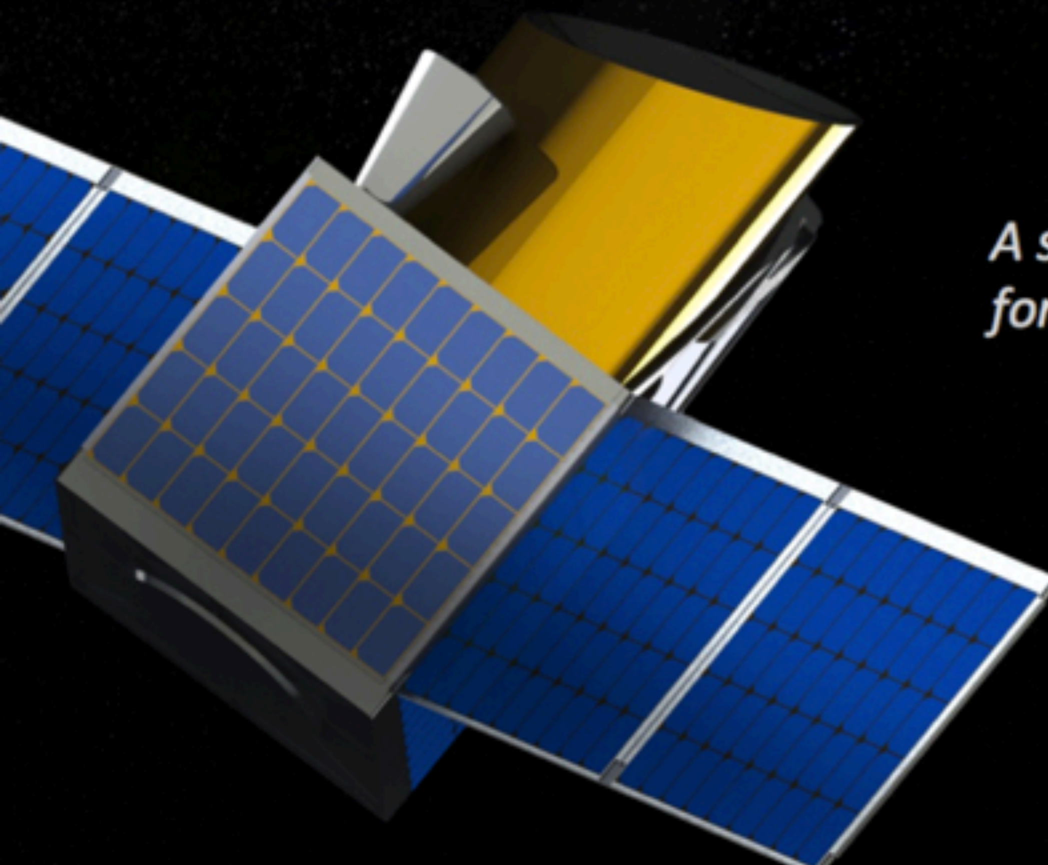


Bendek et al., 2015

Bendek et al., 2015,
Poster at this conference



A comprehensive direct imaging exoplanet technologies demonstrator in space



Centaur

A scientific and technology pathfinder for direct imaging exoplanet missions

PI: Eduardo Bendek, DPI: Ruslan Belikov

Mission Time Life and Orbit	APRA or MoO, 1-Year. Low-Earth, 800km Sun Synchronous	
Spacecraft Bus	Millennium SS Bus (30x30x30 cm)	
Telescope	Unobstructed 15cm, Full Silicon Carbide	
Coronagraph architecture	Baseline: PIAA Embedded on Secondary and tertiary telescope mirror.	
Coronagraph performance	1×10^{-7} raw	5×10^{-9} @ 1.0" (With ODI) 1×10^{-9} @ 1.2"

Conclusions

- A ~30-45cm high contrast telescope is sufficient to directly image Earth-like (and larger) planets around αCen AB
- New enabling technologies:
  - Multi-Star Wavefront Control (MSWC) to suppress second star
  - Orbital Differential Imaging (ODI) relaxes raw contrast requirements to 10^8.
- High planet frequency makes null result unlikely