Space mission and instrument design to image the Habitable Zone of Alpha Centauri

αCenA
Eduardo Bendek¹ (D-PI) eduardo.a.bendek@nasa.gov
, Ruslan Belikov¹ (PI), Sandrine Thomas¹, Julien Lozi², Sasha Weston and the ACESat team (Northrop Grumman Xinetics / Space systems Loral)

αCenB

¹ NASA Ames Research Center, ² Subaru Observatory
α Cen AB: a Unique Opportunity for small optical space telescopes

1,400 light years away!
Exoplanet detection techniques

42 CCD
2200x1024
>10'x10' FoV
223,000 Stars in the FoV
100,000 usable targets (m_v<14)
Precision 2.3 to 93.5 ppm
**Exoplanet next step:** Image an earth-like planet

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

- Alpha Centauri is 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 doubles the probability of finding an 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 an Earth-like planet in the HZ of the star.
Scientific requirements

**Goal:** Image 0.5 to 2.0 $R_e$ planets’ equivalent brightness, in the HZ of aCen A&B during a 2 year mission

<table>
<thead>
<tr>
<th>Contrs.</th>
<th>IWA</th>
<th>OWA</th>
</tr>
</thead>
<tbody>
<tr>
<td>aCen B</td>
<td>6x10^{-11} 0.4” 0.95”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6x10^{-11} 1.6λ/D 3.8λ/D</td>
<td></td>
</tr>
<tr>
<td>aCen A</td>
<td>2x10^{-11} 0.7” 1.63”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2x10^{-11} 2.7λ/D 6.5λ/D</td>
<td></td>
</tr>
<tr>
<td>Stability limit (aCen A)</td>
<td>2x10^{-11} 2.07”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2x10^{-11} 8.3λ/D</td>
<td></td>
</tr>
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**Sensitivity**
- SNR=5 1.6 Days
- ODI Calibration 30 Days

Credit: Billy Quarles, NASA Ames
**Scientific requirements**

**Goal:** Image 0.5 to 2.0 \( R_e \) planets’ equivalent brightness, in the HZ of aCen A&B during a 2 year mission

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<td>( 6 \times 10^{-11} )</td>
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<td>0.95”</td>
</tr>
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<td>1.6( \lambda /D )</td>
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**Sensitivity**

- **SNR=5**: 1.6 Days
- **ODI Calibration**: 30 Days

Credit: Billy Quarles, NASA Ames
ACESat will directly image and characterize the planets and circumstellar debris disks of Alpha Centauri A & B, with the specific objective of identifying potentially habitable Earth-like planets.

Mission Time Life and Orbit: SMEX-Class, 2-Years (>90% completeness), Earth trailing

Spacecraft Bus: LADEE Type, Secondary Payload to GTO

Instrument/Telescope: Unobstructed 45cm, Full Silicon Carbide

Coronagraph architecture: Baseline: PIAA Embedded on Secondary and tertiary telescope mirror. PIAACMC backup

Coronagraph performance: 1x10⁻⁸ raw, 6x10⁻¹¹ @ 0.4” (With ODI), 2x10⁻¹¹ @ 0.7”

Field of View (OWA): 2.5” x 2.5”

Imaging detector: 1k x 1k EMCCD 0.08”/px Sampling

Wavelength: 400 to 700 nm, Dichroics 5 bands @ 10% each.
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)
Optical and system design

TOP VIEW

- Science detector
- Multi-band dichroics
- Focusing Lens
- Flat Folding
- DM
- PIAA 2 & Folding OAP 1
- Primary mirror

SIDE VIEW

- Primary mirror 450 mm
- Secondary T/T Control PIAA 1 Stop
- DM
- PIAA 2

Science image output 5 frames 100x100px

Pointing knowledge to S/C 0.0005° @1Khz

Payload Computer

- LOWFS T/T
- Multi-Star WFC TRL-3
- Science Output

Controllers (Electronics Box Assembly)

- T/T Controller
- DM Controller TRL-5

PIAA Coronograph TRL-5

- Secondary (PIAA 1)
- Tertiary (PIAA 2)
- DM TRL-5

Tip/Tilt (5°) Focus (10μm) Images pupil on DM

Kilo DM 32x32 - 1μm

TRL 1 2 3 4 5 6

Small Sat 2015, August 2015
Low TRL Key technologies

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

- Model of Kilo-DM space qualified controller currently under design
Pointing and stability requirements

- Tight pointing and jitter requirements
- Internal instrument control loop

<table>
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<tr>
<th>Pointing Accuracy</th>
<th>+/-2.5”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jitter (RMS 1-σ between 0-0.1Hz)</td>
<td>0.1”</td>
</tr>
<tr>
<td>Jitter (RMS 1-σ 0.1 to 300Hz)</td>
<td>-3as²/Hz</td>
</tr>
<tr>
<td>Jitter (RMS 1-σ for &gt;300Hz)</td>
<td>0.5mas</td>
</tr>
</tbody>
</table>
S/C and launch

- LADEE type bus
- Integrated propulsion
- Secondary payload on top of a telecom GEO sat.
Earth Trailing Heliocentric Orbit

Δν = 800 m/s at GTO perigee

Orbital direction

Winter Solstice

Launch (Autumnal Equinox)

SC 1 year later on 1st Oct

SC 3 year later on 1st Oct
Mission operations

High stability pointing spacecraft
Unperturbed observation per quarter, 1.6 days/band/star

Quarterly operations:
- **DSN Downlink** and reaction wheels desaturation and quarter end.
- **90° Roll** to keep sunshield in position
- **Calibration** per quarter (Speckle MSWC, LOWFS).
Conclusion

1) We developed an instrument design to achieve the science goals

2) BUT it needs low TRL technologies.

3) Cube Sat mission submitted to test technologies

3) We are advancing key technologies and we need your help to test them.

email: eduardo.a.bendek@nasa.gov
Questions?
Multi-Spectral Imager

- **Wavelength**: 400 nm to 700 nm (Contains 40% aCen A flux)
- **Five channels** of 10% bandwidth each.
- **SW (400nm)**: Blue rayleigh scattering indicates earth-like atmosphere. (Const. coatings and QE)
- **LW (700)**: CH₄ absorption bands. Limited by QE and WFC bandwidth.

- E2v EMCCD 201-20 almost zero RON
- Short 10s exposure time to avoid cosmic rays
Instrument Building blocks

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

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

Continuous observation ODI -> $10^{-11}$