Precision astrometry mission for exoplanet detection around binary stars

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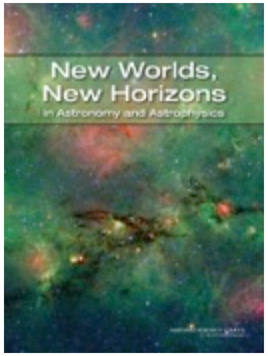
Astrometry science and Link to NASA Roadmaps

NASA Science plan 2014, *"Discover and study planets around other stars, and explore whether they could harbor life" pg. 74,*

=> Mass measurements are necessary to answer this question



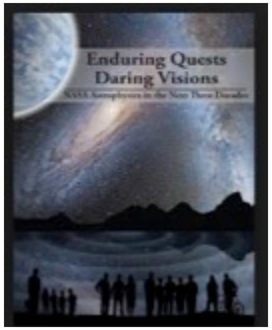
Astrophysics 2010– *New Worlds, New Horizons in Astronomy and Astrophysics*

- *"search for nearby, habitable, rocky or terrestrial planets with liquid water and oxygen… " pg. 11, 2020 Vision chapter*

  => Mass measurements are necessary

- "Stars will then be targeted that are sufficiently close to Earth that the light of the companion planets can be separated from the glare of the parent star and studied" pg. 39 paragraph 1, On the threshold chapter

  => Focus on nearby stars, which is compatible with direct imaging and astrometry



- *"the plan for the coming decade is to perform the necessary target reconnaissance surveys to inform next-generation mission designs while simultaneously completing the technology development to bring the goals within reach."* pg. 39 paragraph 2, On the threshold chapter

  => Need of measuring masses in advance of HABEX and LUVOIR and continue with the work with them

=> We need masses and direct images to get spectral information

Exoplanet Science Strategy

National Academy of Sciences

Goals in exoplanet science:

1) Understand the formation and evolution of planetary systems

=> Complete exoplanet demographics census of under sampled planets

=> Characterize atmospheres and bulk composition of planets

=> Characterize masses, radii, and atmospheres of large number of exoplanets

2) Identify potentially habitable environments and their frequencies

=> Improved multi-parameter habitability concept

=> Inferring the presence of life will require comprehensive search

⇒ *Astrometry is key to:*

- *Sample planet populations with incomplete demographics.*
  Lack of completeness is a consequence of techniques sensitivity.
- *Measure masses of known planets*

The report recommends to advance EPRV techniques and astrophysical noise calibration in order to access earth-like planets around sound-like stars. Astrometry is mentioned, but not with the same emphasis because the technology is considered immature.

Astrometry Science

Direct Imaging

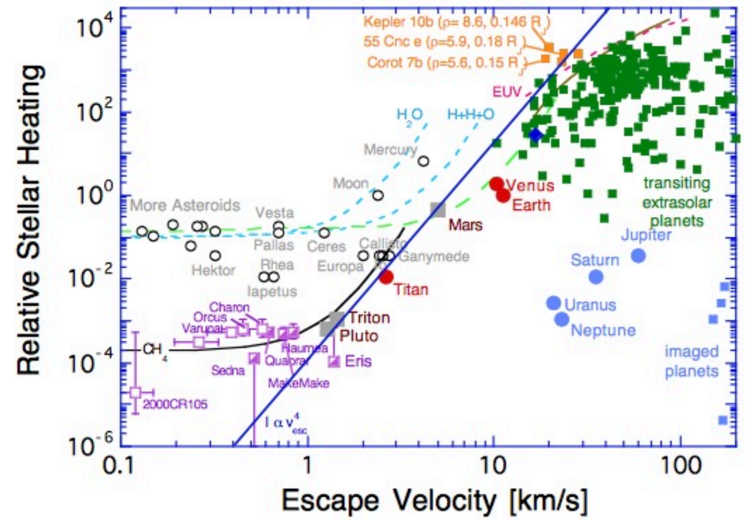
- Detection
- Atmosphere chemical composition
- Orbit, mass (hard)

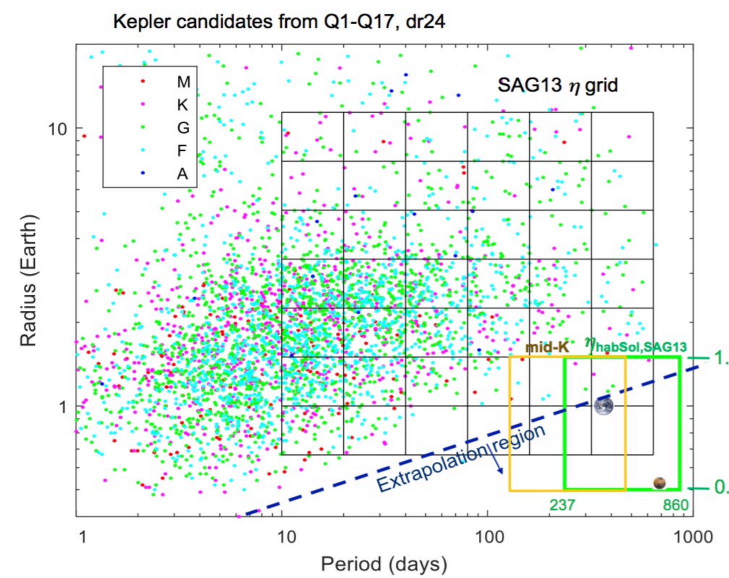
Astrometry

- Distinguish zodi / dust from planets
- Mass determination, System inclination
- Confirm RV and transit detections
- Distinguish terrestrial planets from water-rich planets and mini-Neptunes (e.g., Grasset et al. 2009)
- Assess atmospheric loss rates Cosmic Shoreline (Zahnle & Caitling 2013)

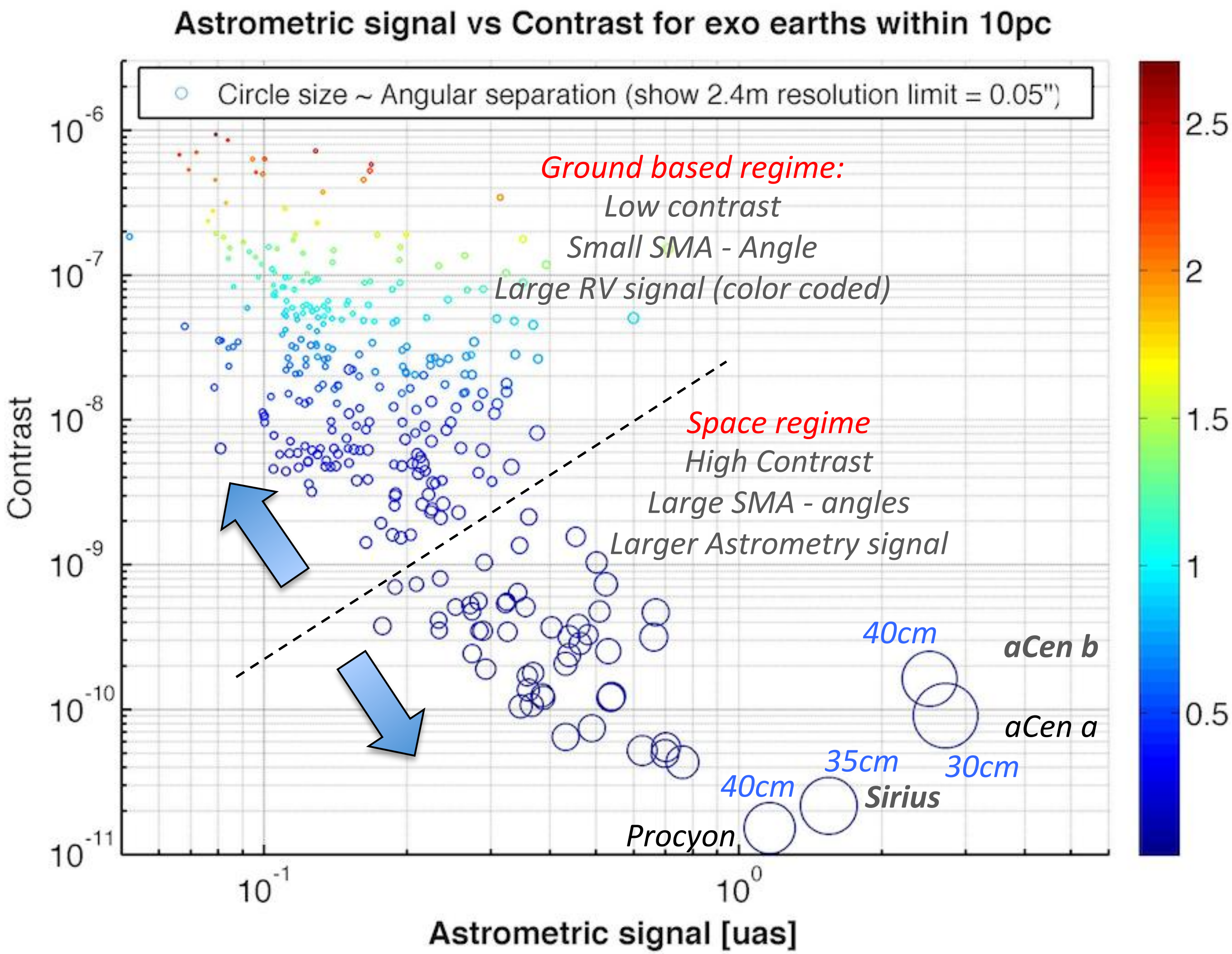
Unique advantages of Direct imaging and Astrometry

- Search and characterize long period planets (>1 year, FGK) around nearby stars (NWNH pg. 39).
- Large angular separation is good for direct imaging and astrometry
- Completeness at the extrapolation region





Astrometry from space

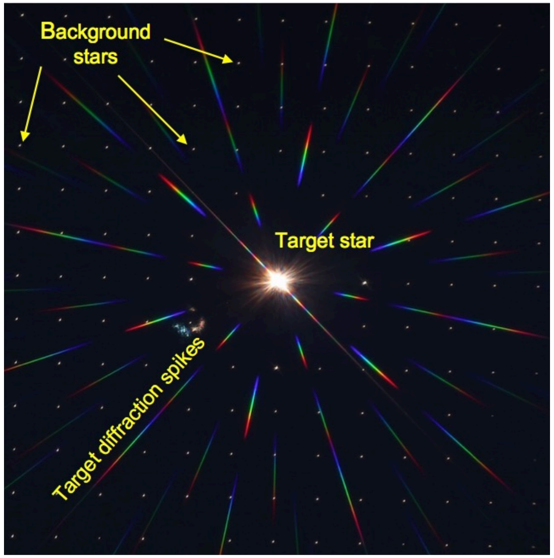


Current astrometry funded efforts at NASA

Two different technology approaches to detect planets around different targets

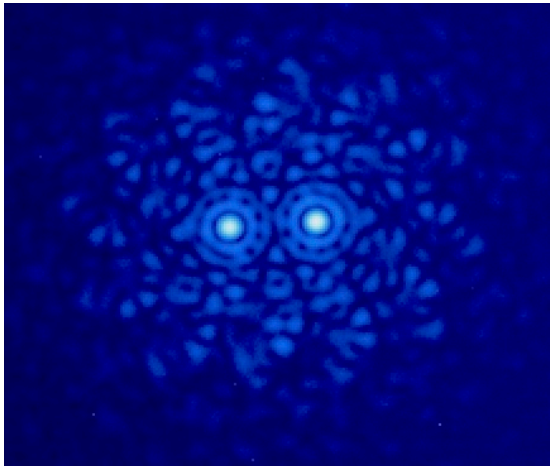
1) Single-star stellar astrometry:

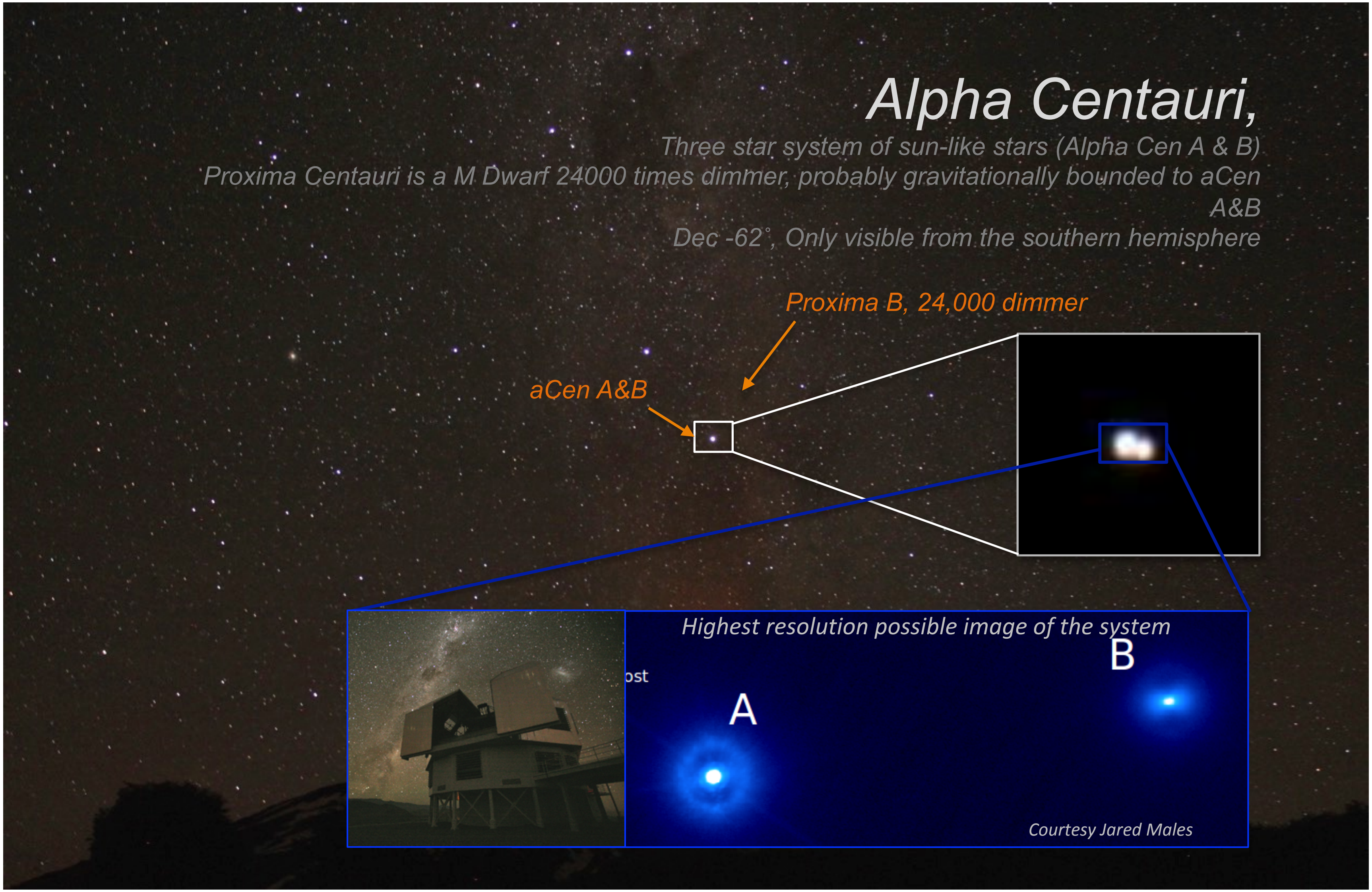
- *Measures host star orbit w/r to the background stars*
- *Key technologies: Detector, Distortion calibration, Wide FoV*
- *Funded efforts:*
  - ***TDEM 2013-2016***
    - » *Bendek et al. (TRL 3 -> 4, High fidelity lab demo)*
  - ***APRA 2017-2020***
    - » *Bendek et al. (TRL 4 -> 5 + Study for HABEX)*
  - ***MASS Small Sat concept study***
    - » *Shao et al. (35cm study in preparation for Small Sat call)*



2) Binary star astrometry:

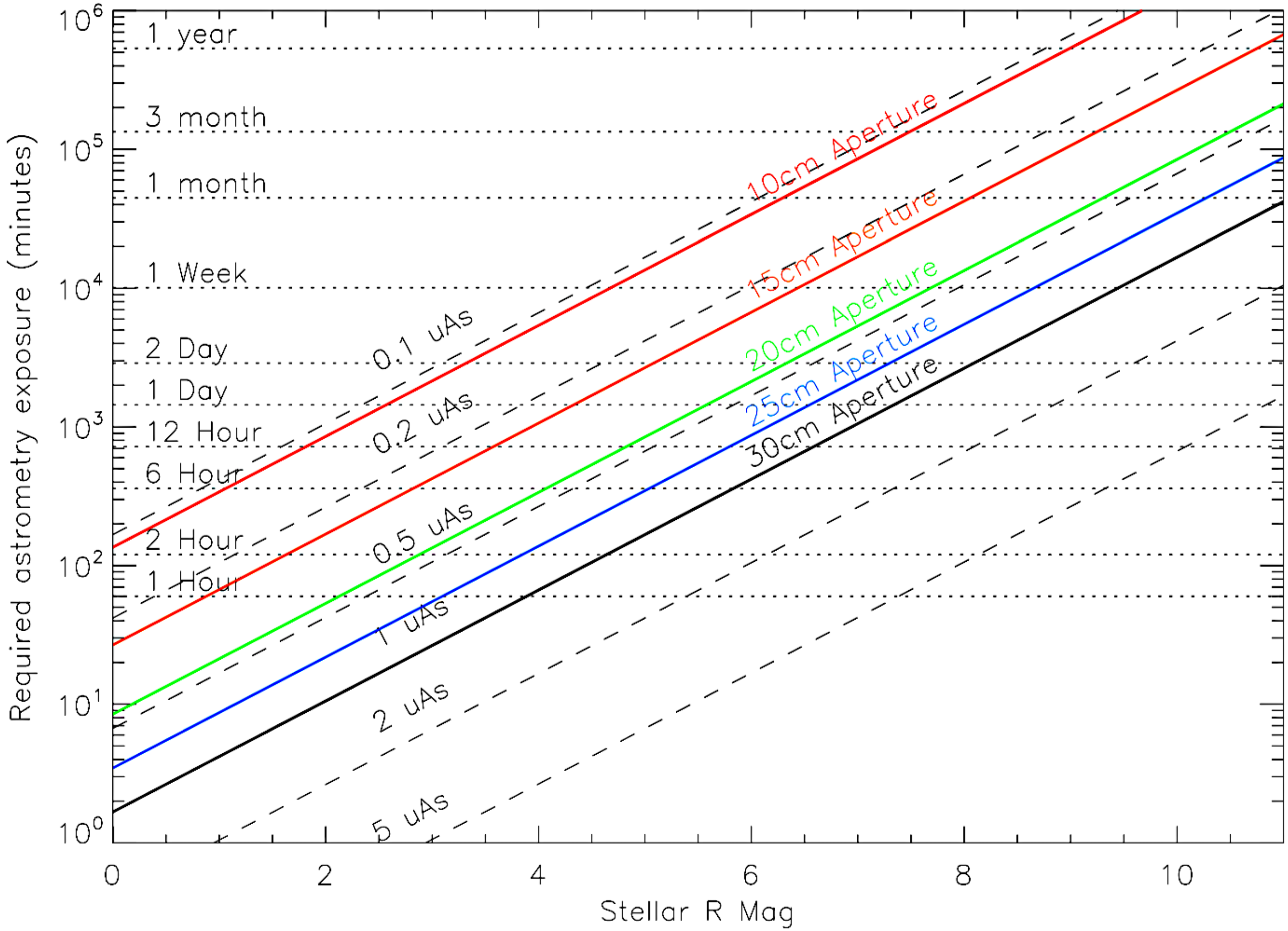
- *Measures host star orbit w/r to companion*
- *Key technologies: Detector, Distortion calibration*
- *Funded efforts:*
  - *Breakthrough award to Sydney university*
  - *Laboratory work at Ames*
  - *NASA Ames + Breakthrough agreement for TOLIBOY*




Alpha Centauri,
Three star system of sun-like stars (Alpha Cen A & B)
Proxima Centauri is a M Dwarf 24000 times dimmer, probably gravitationally bounded to aCen A&B
Dec -62˚, Only visible from the southern hemisphere
Proxima B, 24,000 dimmer
aCen A&B
Highest resolution possible image of the system
A
B
Courtesy Jared Males

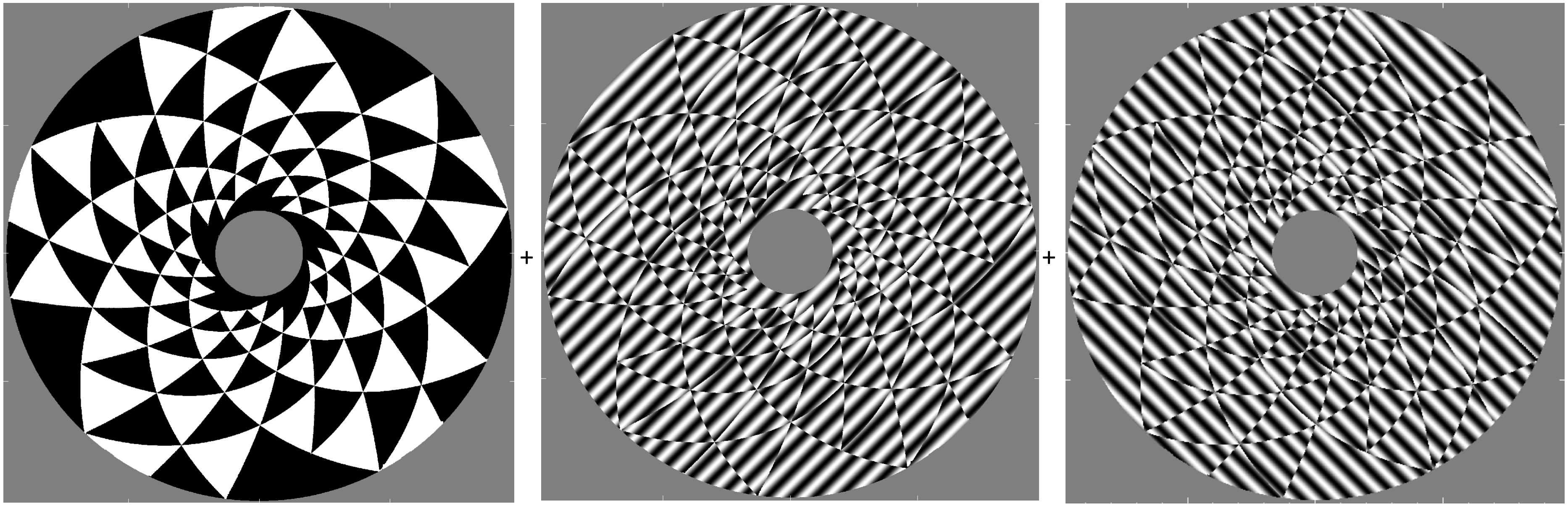
TOLIMAN Mission

Tuthill et al, Bendek et al 2018

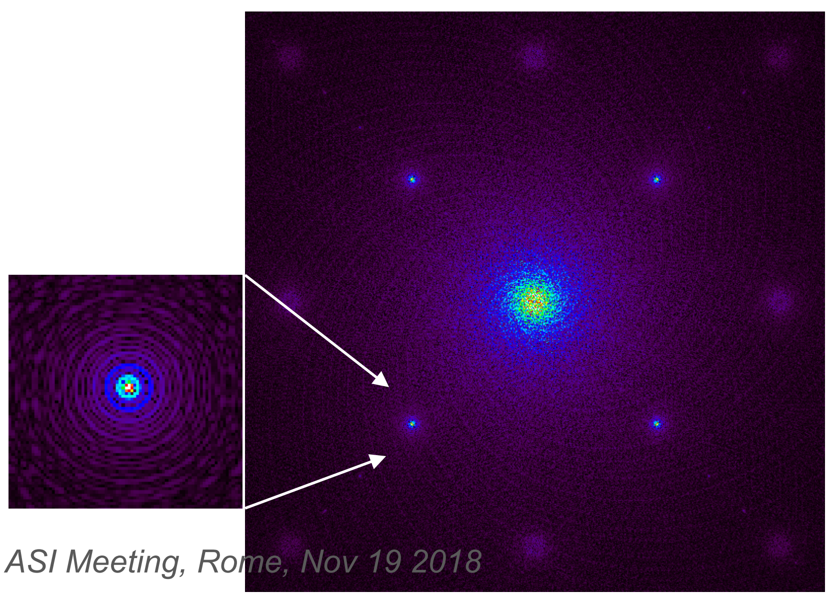


TOLIMAN Mission

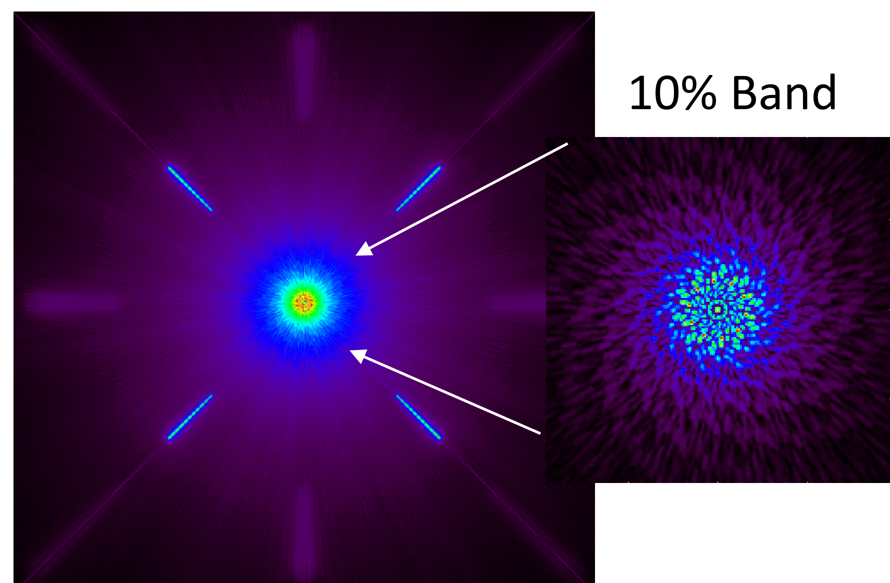
(Tuthill et al)



Monochromatic



Broadband



TOLIMAN Mission

Science Traceability Matrix

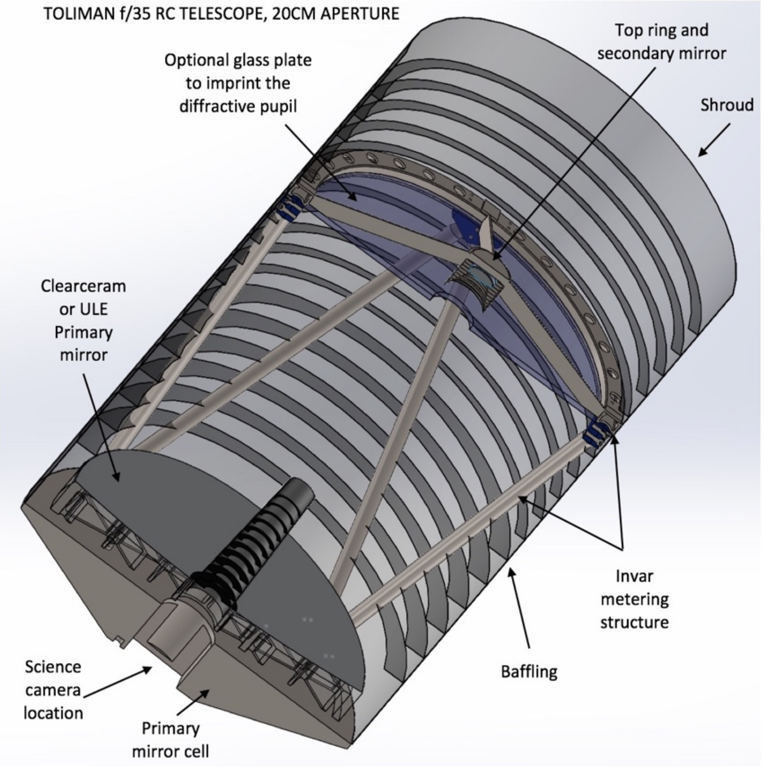
Science goals	Science Objectives	Science questions	Scientific Measurement Requirements: Physical parameters	Scientific Measurement Requirements: Observables	Instrument functional requirements	Mission functional requirements
Detect and constrain masses and orbit of planets around aCen A&B	Detect and constrain mases and orbits of planets down to sub-Earth mass, inside the HZ of aCen A&B.	1.1: Are there planets around the target stars? 1.2: What are their orbits? (SMA, Period, e) 1.3: What are their masses?	1) Ability to detect and measure planet masses down to 0.4 and 0.7 earth masses (5-sigma) for aCen A and B respectively within the HZ of both stars. 2) Determine SMA, orbit and eccentricity down to 10% accuracy	1) Magnitude of the vector that connects aCen A and B on the sky measured at mutiple epochs with an end-of-mission accuracy of 0.34 micro-arcseconds* 2) At least 3 year data aquistion (Period of the longest period planet). 3) Minimum cadence of 1 epoch every 14.7 days (10 samples per orbit of the shortest period planet in the HZ of aCen B)	1) Measure target stars PSF position on the detector with an instrument accuracy of 0.30 micro-arcseconds per 1-day observation after plate scale and stellar spectrum sistematic calibration. 2) Minimum sampling span of 3-years. 3) Minimum cadence of 1 epoch every 14.7 days.	1) 3-year mission lifetime 2) Target revisits every 14.7 days 3) Spacecraft pointing +/-2" 4) drift / jitter < 0.1 arcsec/sec 5) Instrument operational wavelength: 590-640nm 6) Instrument operational temperature 15˚C (Ambient) 7) Instrument thermal stability +/-1˚C, Primary mirror stability +/-0.4˚C 8) Sun/Moon exclusion cone angle: 42deg. Earth exclusion cone angle: 20deg 9) Raw data rate: 9.4GB/hour 10) Downlink Data rate of 246MB per day (after on-board processing)

* See error budget in section 2.3.3 for an explanition of single observation v/s end-of-mission accuracy.

TOLIMAN Mission

Instrument Specifications

- *20cm f/35 RC telescope*
- *Narrow FoV ~ 7.5'*
- *Diffractive pupil imprinted on the primary*
- *Clearceram CCZ-HZ (CTE 5ppb) allows +/-0.4˚C thermal variations*
- *Invar metering structure*
- *Detector: E2V CIS115, 7um px*
- *Instrument mass: 9.9kg*
- *Volume: 22cm diameter x 50cm long*



Performance:

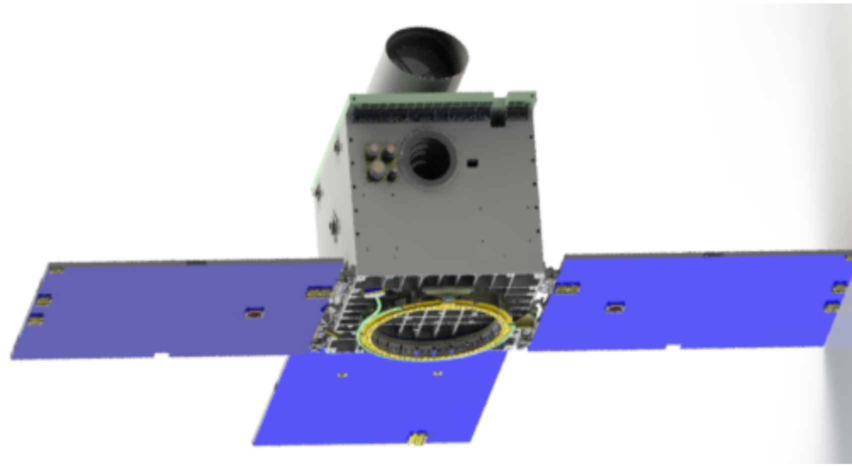
- *Exposure time per observation: 12hrs (About a day including occultations)*
- *Photon noise:* 0.15μas
- Telescope stability: 0.25μas
- Detector errors: 0.17μas

Total error budget per epoch: 0.30μas

TOLIMAN Mission

Spacecraft

- *Ball Configurable Platform*
- *Mass < 100kg, Power < 100W*
- *ESPA Compatible*
- *Instrument enhanced pointing. (Like Kepler mission)*

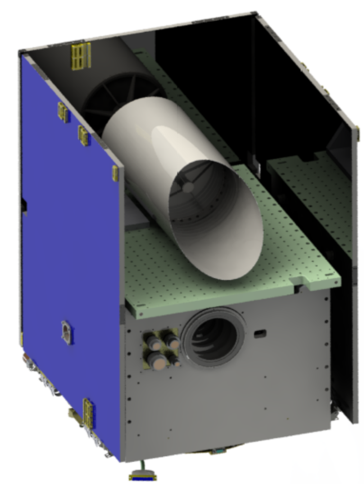


Pointing requirements

- *Pointing +/-2"*
- *Jitter <0.1"/s*

Data

- *4GB flash memory*
- *S-band transceiver*
- *Science downlink at 2Mbps*
- *Three 8-min passes a day*



TOLIMAN Mission

Orbits and CONOPS

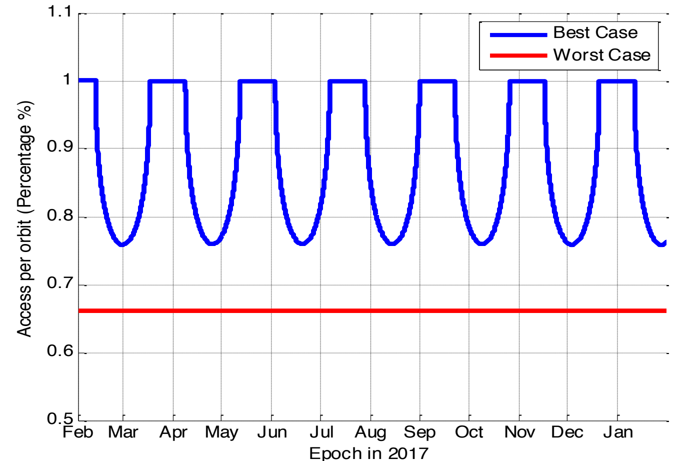
- Preliminary orbit trade performed for concept baseline definition:
- LEO Equatorial, SSO 6am-6pm, SSO Noon-Midnight, 28˚ inclination

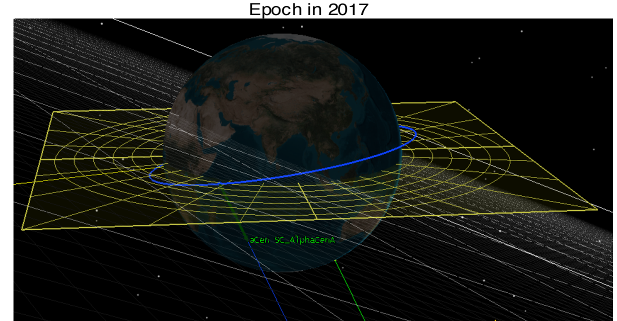
CONOPS

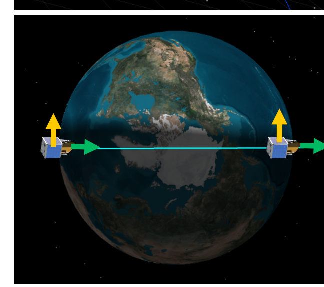
- Observations of 12hrs open shutter each (require 16 orbits ~1day)
- Each epoch is maximum 14days long
- Epoch cadence is 14.7 days
- 3-year mission has 74 epochs
- Only 60% available for science

Data rates

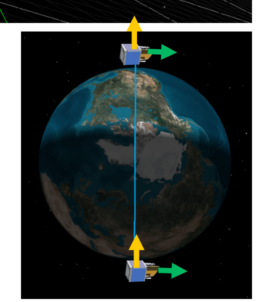
- Chip fraction to be read: 2.2%
- 10 co adds
- Compression x2
- Data < 500MB/day







SSO 6am-6pm assumed observation over 1 orbit



SSO Noon-Midnight assumed observation over 1 orbit

TOLIMAN Mission

Science Enhancement Option

Name	D (pc)	Spectrum	V Mag
aCen	1.3	G2V + K1V	0.0 / 1.3
61 Cyg	3.5	K5V + K7V	5.2 / 6.0
70 Oph	5.1	K0V + K4V	4.0 / 6.0
36 Oph	6.0	K2V + K1V	5.1 / 5.1
Xi Boo	6.7	G8V + KvV	4.7 / 6.8
P Eri	7.8	K2V + K2V	5.9 / 5.8
Xi UMa	8.2	G8.5V + G0V	4.3 / 4.8

TOLIBOY Mission

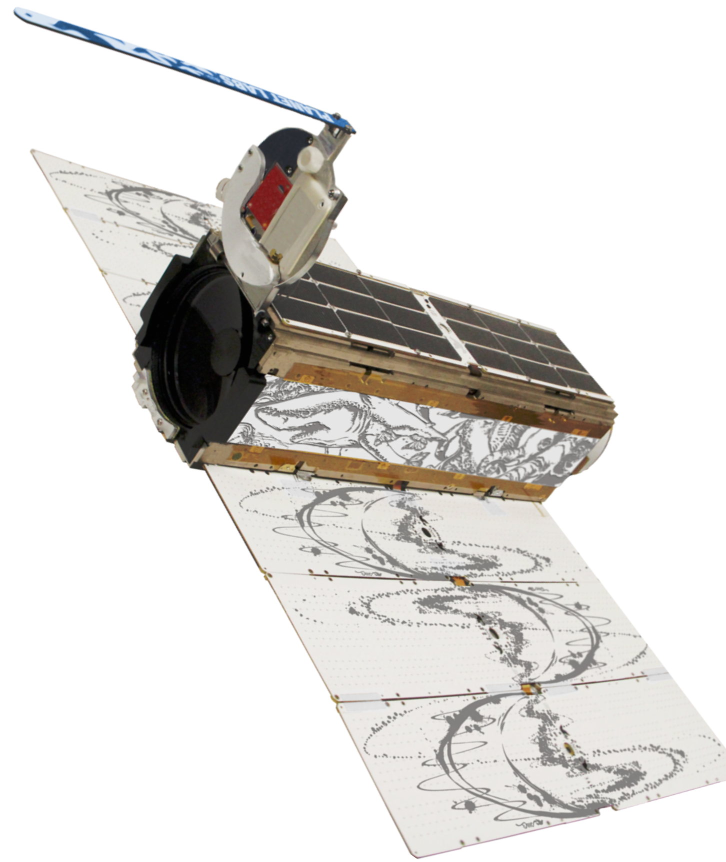
GOAL

- Technology demonstration
- Science: Super earths on aCen

Overview

- 9cm telescope
- F/15 required with 3.5um pixels
- 15' FoV
- 3 to 6U bus
- Pointing relaxed to +/- 3" and 0.25"/s jitter
- LEO orbit
- NASA Ames support

Precursor and technology demonstrator for TOLIMAN



Expected form factor similar to Planet Doves