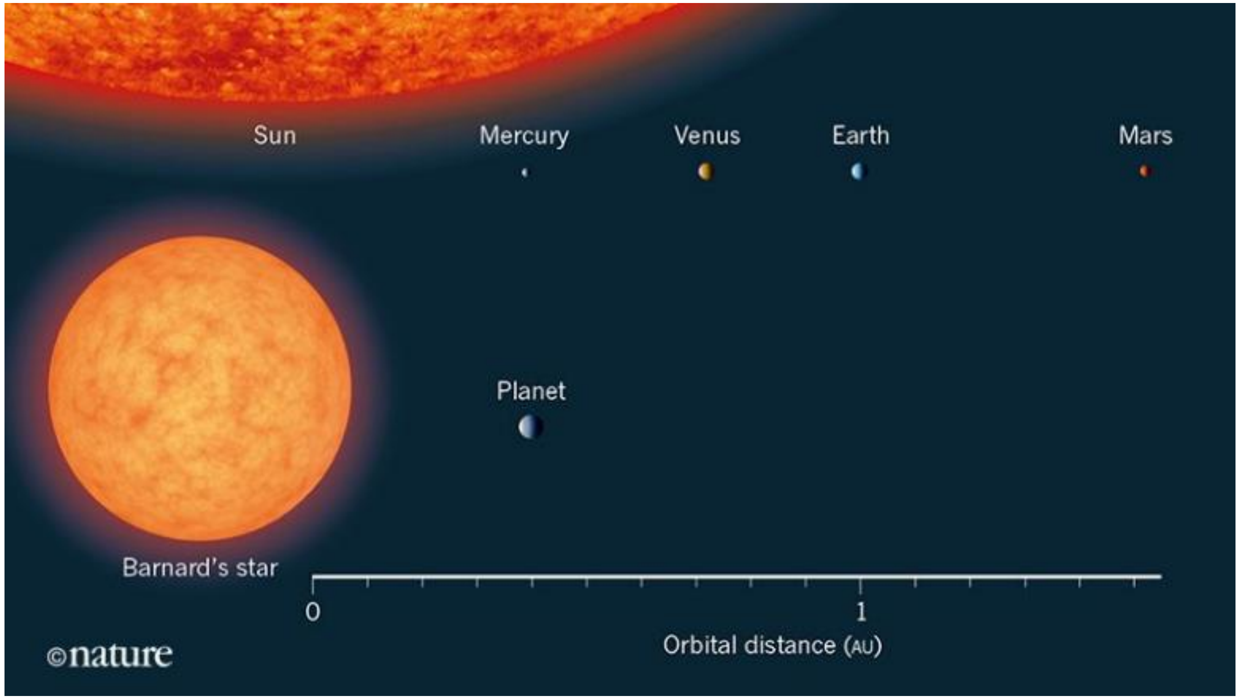
Possible Future Mission Design

THE BREAKTHROUGH
FOUNDATION

PETE KLUPAR - BREAKTHROUGH PRIZE FOUNDATION - KLUPAR@BREAKTHROUGHPRIZE.ORG

Barnard b

BREAKTHROUGH INITIATIVES



A planet around Barnard's star. Ribas *et al.* a low-mass planet orbits a Barnard's star. The discovered planet is on a relatively wide orbit. The sizes of all the objects are approximately to scale. Barnard's star is only 1.8 parsecs (less than 6 light years) away from the Sun. In their analysis, the authors had to be particularly careful in accounting for stellar activity. the next generation of ground-based instrumentation, also coming into operation in the 2020s The potential planet is likely very cold, with an estimated surface temperature of about minus 275 degrees Fahrenheit (minus 170 degrees Celsius), study team members said.

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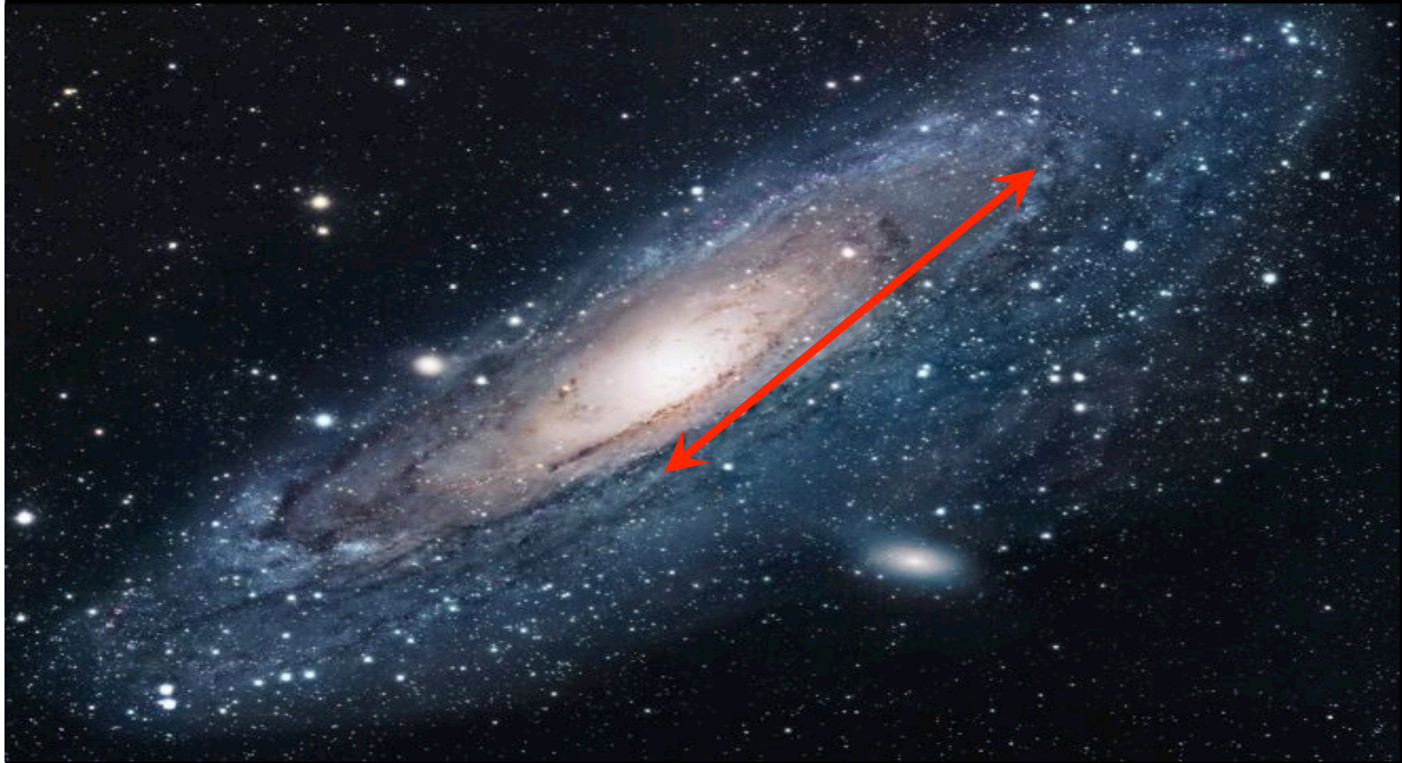
Fermi: "Where is everyone?"



Within a few thousand light years there are 10's of millions of stars

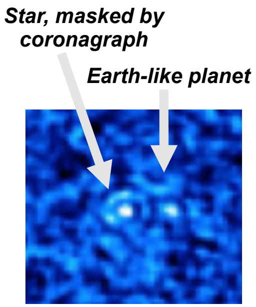
In cosmic terms, the Sun is neither particularly old, nor young…. So, If civilization, once it formed survived in the MW, why isn't there evidence of it?

It's a timescale problem, 13Gyr vs. 100,000 yrs

BREAKTHROUGH
WATCH

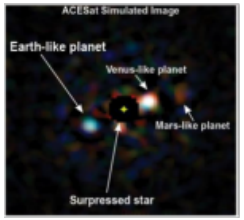
Breakthrough Watch

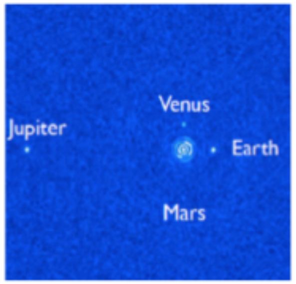
BREAKTHROUGH INITIATIVES

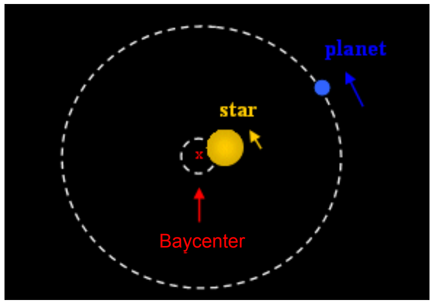


Simulated 100h exposure with 8-m telescope (Credit: Christian Marois)

Very Large Telescope (Credit: ESO)



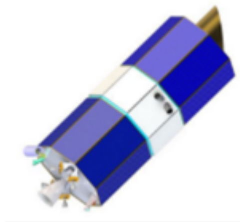




Astrometry Stars orbits around system center of mass (Barycenter)

•**Thermal imaging**: Existing 10-m class telescope have the sensitivity to catch thermal emission from an Earth-like planet orbiting Alpha Cen A or B.

•**Astrometry**: A habitable planet in orbit around Alpha Cen A or B would pull its host star by about 1 micro-arcsecond. This tiny periodic motion could be detected with a small space telescope measuring accurately the angular separation between binary systems.



•**Reflected light imaging**: A small space telescopes equipped with a high-performance coronagraph masking starlight, can catch the visible starlight reflected by a habitable planet in orbit around nearby stars.

Together, thermal imaging, and astrometry could measure the planet mass, orbit, radius, and temperature

Imaging habitable planets with large ground-based telescopes

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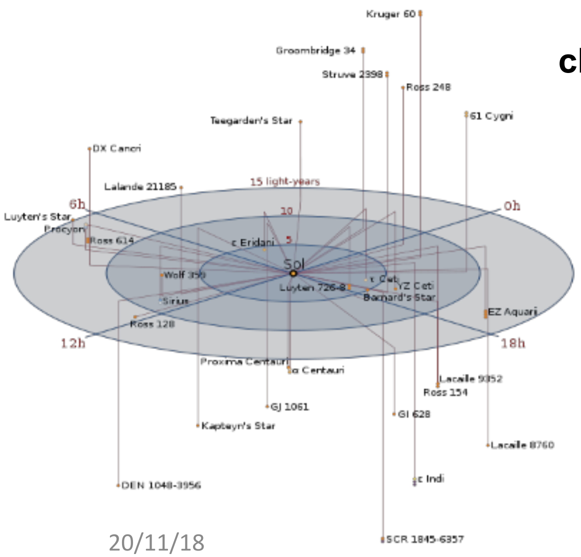
3 Extremely Large Telescopes (25 to 39m diameter) will be deployed in the mid to late 2020's

With angular resolution to image reflected light from habitable planets around nearby M-type stars (typically 1% as bright as Sun)

Kepler data suggests Habitual planet within 12 light years.



Breakthrough Watch enables imaging and characterization of multiple habitable planets

Stars within 5pc (16.3 light years):

10 "Sun-like" stars (types A,F,G,K)	*targets for habitable planet search*
46 red dwarfs	

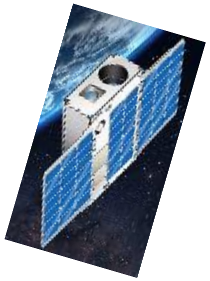
14 brown dwarfs → *Likely too faint*

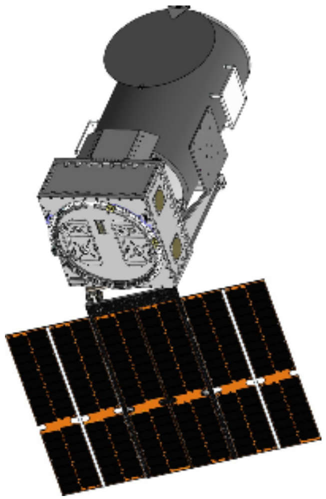
4 white dwarfs → *Challenging for life*

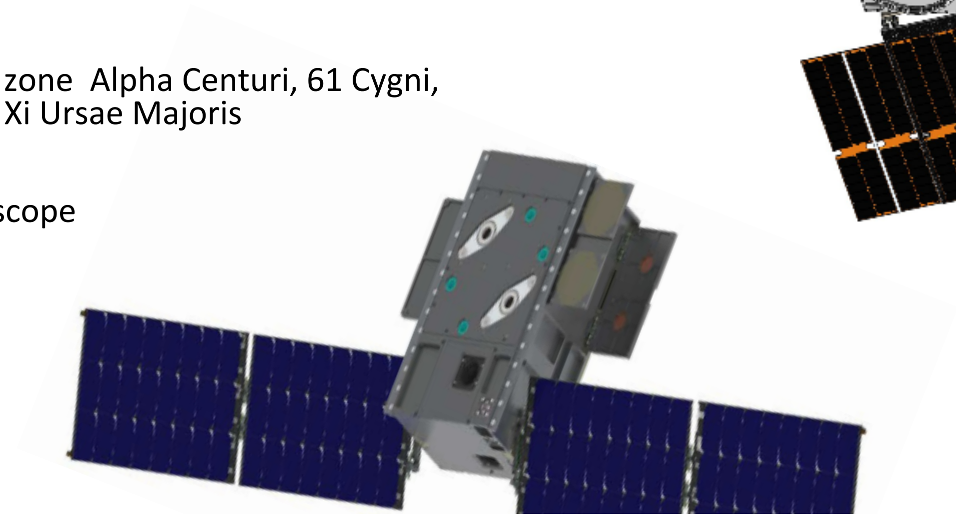
Toliman Program

BREAKTHROUGH INITIATIVES

- Toliboy
  - Technology development of Double Diffraction Telescope
  - 9 cm F20 telescope, LEO mission
  - Mission length one year
  - Launch within a year of go ahead, 2019 to 2020
  - Target size Neptune planet around Alpha Centuri and 61 Cygni
- Toliman
  - 30 to 40 cm F20 telescope, LEO or GEO mission
  - Mission length 3 years
  - Launch 2022
  - Target Earth size planets in habitable zone Alpha Centuri, 61 Cygni, 70 Ophiuchi, 36 Ophiuchi, p Eridani, Xi Ursae Majoris
- Tolicolossal
  - 100 cm class chronograph space telescope
  - Catalogue nearby planets
  - Launch 2026

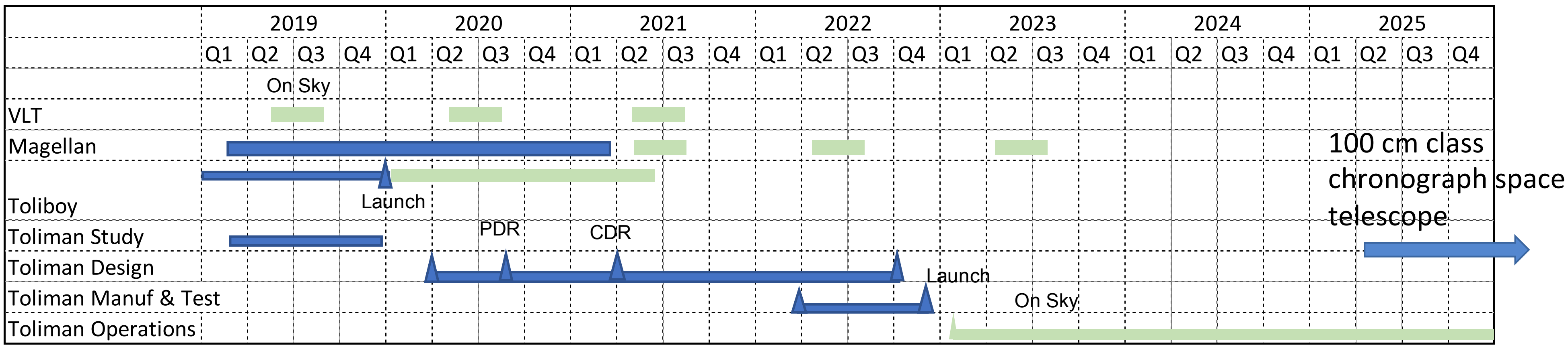




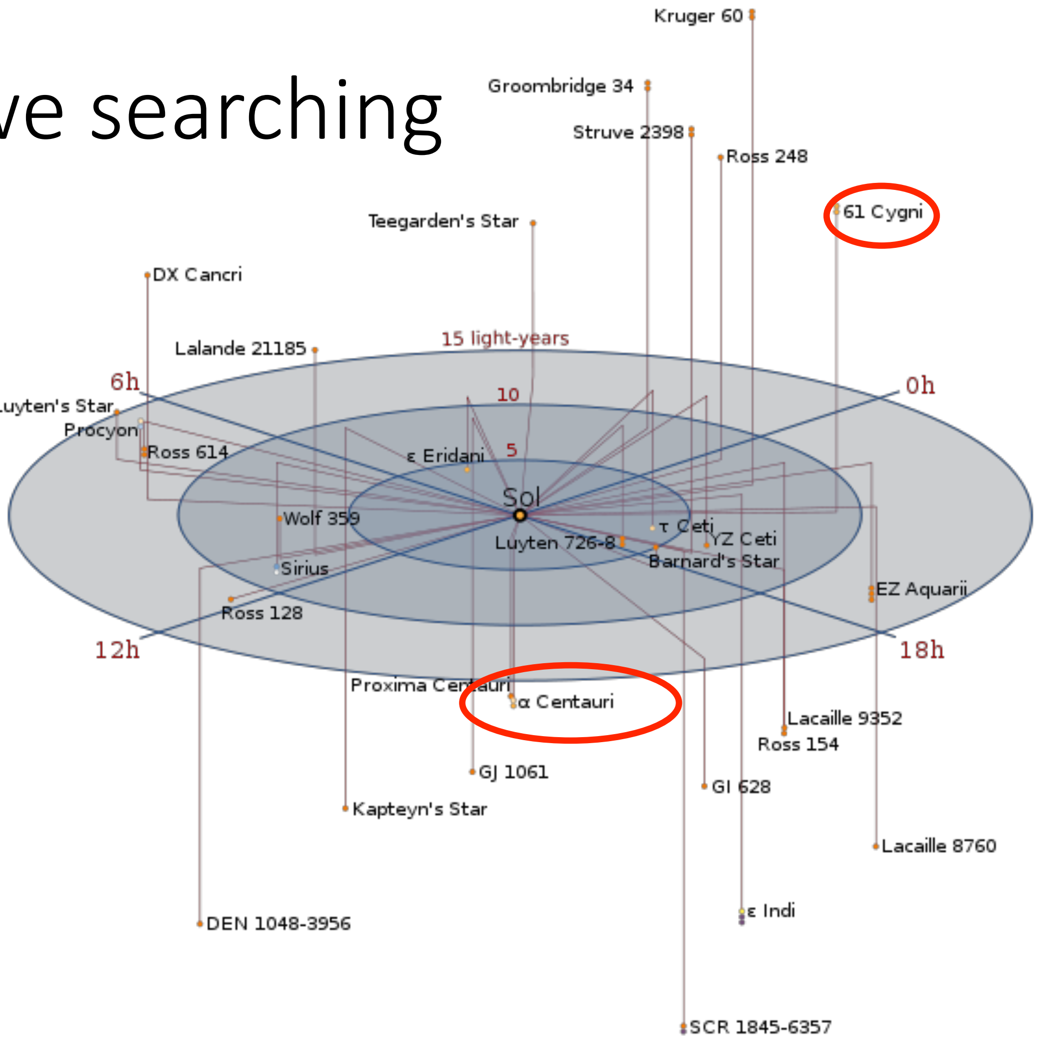


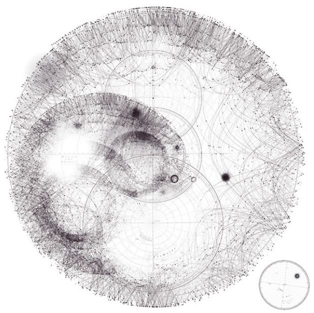
BREAKTHROUGH INITIATIVES

- Watch Long Term Goals
  - Find habitable exoplanets within 5 pc (16 light years) of earth, which will be targeted for future interstellar travel (Breakthrough Star Shot initiative).
  - Extensively characterize (orbit, mass, temperature, atmospheric composition, exolife signatures) those planets that are found within 5 pc of earth that have an opportunity for life
- Near Term Goals 2018 to 2025
  - Detect earth-like planets in the HZ around our nearest nieghbors.
  - Extensively characterize (orbit, mass, radius and surface temperature) planets found.



Where are we searching





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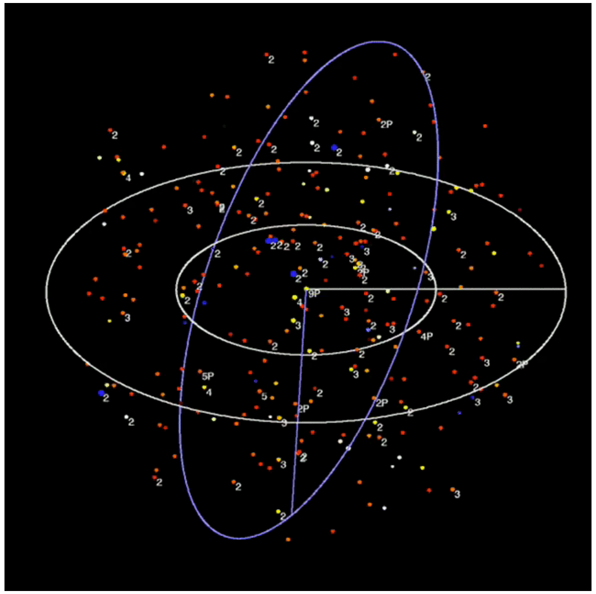
Stars within 10 pc of the Sun



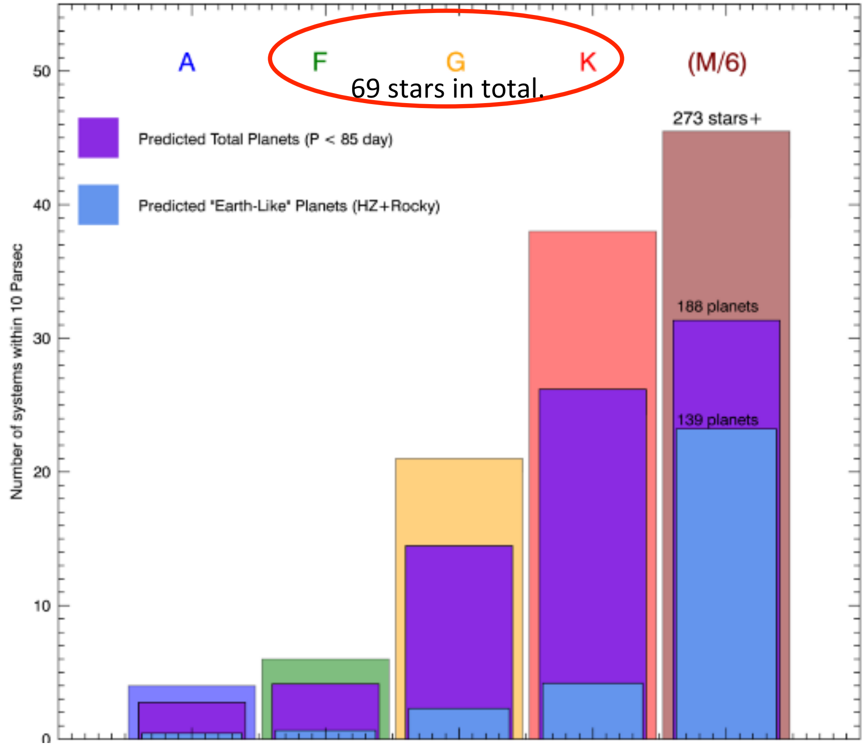


Image Credit: A. Riedel, T. Henry, and RECONS .

Most Likely Planet Size (Super Earth)

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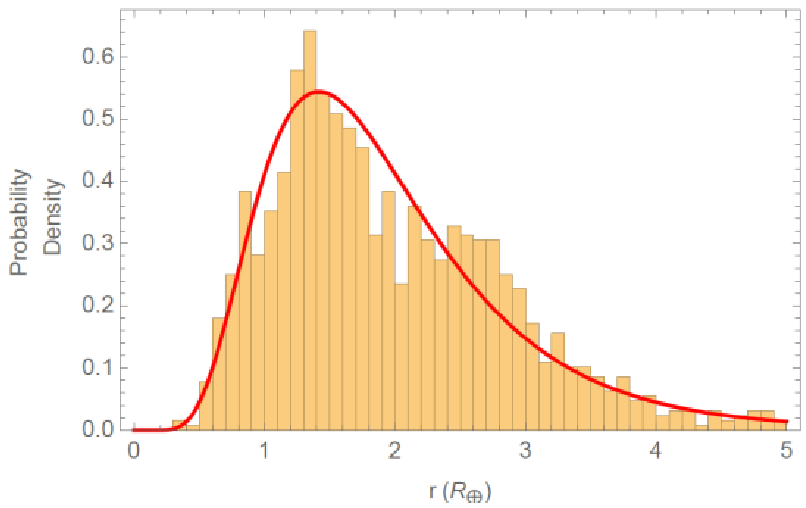


- Analyzing the overall radius distribution of 5000+ Kepler planet candidates, Log normal distribution indicative of growth process, as planets are formed by growing from small bits and pieces.
- PLANET SIZE DISTRIBUTION FROM THE KEPLER MISSION AND ITS IMPLICATIONS FOR PLANET FORMATION. Li Zeng, Stein B. Jacobsen1, Eugenia Hyung, Andrew Vanderburg, David W. Latham et al

ID Name	Proper Name	Type	D(ly)	Teff(K)	Known Planets
Sol	Sun	G2V	0.00	5778	8
Gl 551	Proxima Centauri	M5.5	4.22		
Gl 559 A	Alpha Centauri A	G2V	4.39	5770	
Gl 559 B	Alpha Centauri B	K1V	4.39	5180	
Gl 411	Lalande 21185	M2	8.31	3730	
Gl 244 A	Sirius A	A0A1Va	8.58	9530	
Gl 244 B	Sirius B	DA2	8.58		
Gl 65 A	BL Ceti	M5.5e	8.72		
Gl 65 B	UV Ceti	M5.5e	8.72		
Gl 144	Epsilon Eridani	K2V	10.49	5090	1
Gl 866 A	EZ Aquarii A	M5VJ	11.08		
Gl 866 B	EZ Aquarii B	M	11.08		
Gl 866 C	EZ Aquarii C	M	11.08		
Gl 820 A	61 Cygni A	K5V	11.35	4300	
Gl 820 B	61 Cygni B	K7V	11.39	4000	
Gl 280 A	Procyon A	F5IV-V	11.40	6630	
Gl 280 B	Procyon B	DA	11.40		
Gl 725 A		M3 11.63	11.5	3430	
Gl 725 B		M3.5 11.46	11.5	3300	

Targets ?

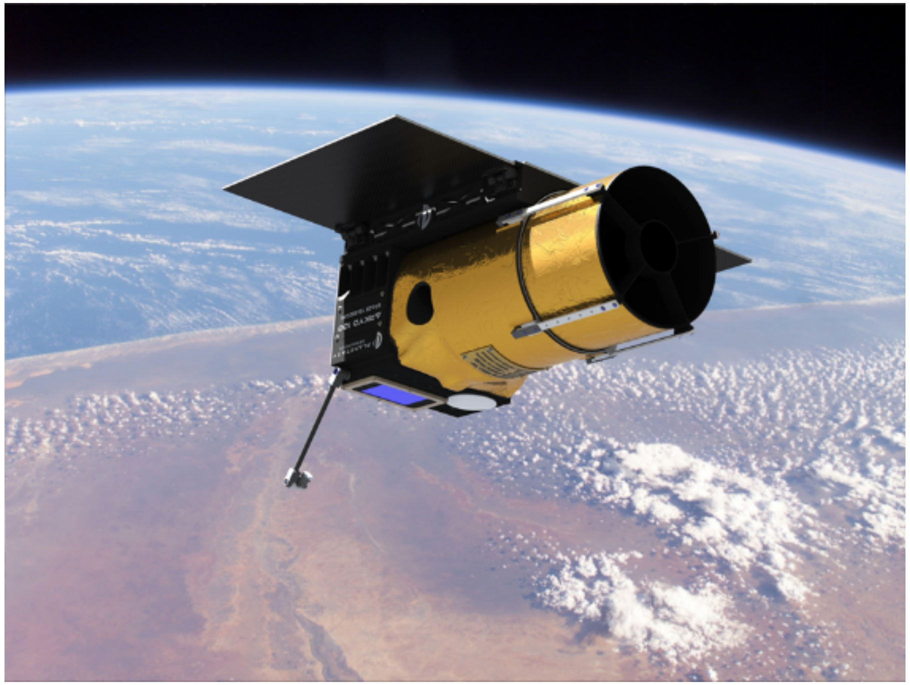
ID Name	Proper Name	Type	D(ly)	Teff(K)	Known Planets
Gl 15 A	GX Andromeda	M1	11.63	3650	
Gl 15 B	GQ Andromeda	M6Ve	11.63		
Gl 845 A	Epsilon Indi A	K4/5V	11.81	4730	
Gl 845 B	Epsilon Indi B	T1V	11.81		
Gl 845 C	Epsilon Indi C	T6V	11.81		
Gl 71	Tau Ceti	G8V	11.89	5500	
SCR 1845-6357 A		M8.5V	12.56		
SCR 1845-6357 B		T6V	12.56		
Gl 860 A		M2V	13.14		
Gl 860 B		M6V	13.14		
Gl 234 A	Ross 614 A	M4.5	13.42	3050	
Gl 234 B	Ross 614 B	M	13.42		
Gl 473 A	Wolf 424 A	M5.5eJ	14.30		
Gl 473 B	Wolf 424 B	M7	14.30		
GJ 1245 A	G 208-044 A	M5.5Ve	14.80		
GJ 1245 B	G 208-044 B	M	14.80		

Notional Space Segment Requirements

30 to 40 cm Telescope, f20

STRAW MAN

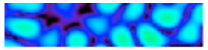
Notional. To be pulled apart.

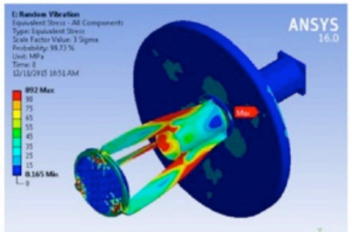


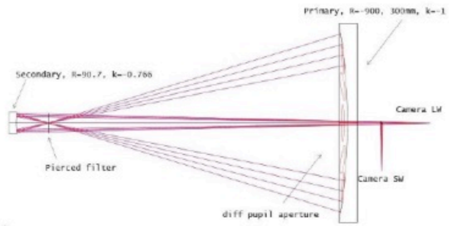
Spacecraft Mass	Up to 250 kg
Solar Arrays	200 W
Data Downlink	up to 10 GB per Day
Pointing Accuracy	±0.002° (1-sigma), 3 axes
Orbit Altitude / Orbit Lifetime	GEO / 5 Years
Temperture Stability (Interface)	+/- 0.5 Deg, -10 C, less than 5 W heat flow
Data Storage	5,000 MB
Spacecraft First Mode at least	60hz
Gross Point Control performed by spacecraft	10 arc min
Jitter less than	0.1 arc sec per sec
Sun avoidance angle	40 deg
Earth avoidance angle	20 deg

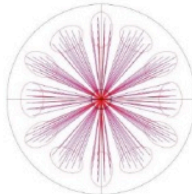
Toliman Payload

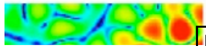
Notional. To be pulled apart.











Payload Volume	45 x 45 x 80 cm
Power to Payload	below 100W
Payload Mass	below 125 kg
Telescope Stiffness first mode above	40 Hz
Jitter less than	0.05 arc sec per sec
Super Fine Pointing Control	+/- 0.1 arc sec input driven by payload
Temperature stability	+/- 0.5 Deg, -10 C, less than 5 W heat flow
Exposure time	0.1 sec
Command Interface	Camera Link, LVDS
Data Interface	Camera Link or LVDS or USB3

Toliman Pointing Control Loop

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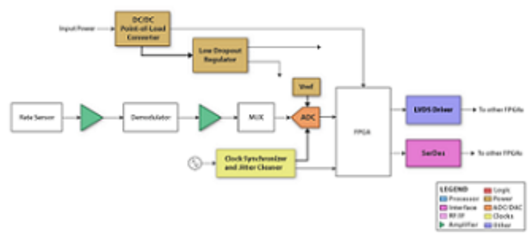
- Several spacecraft control modes
- Acquisition of the target while maintaining earth (20°) and sun(40°) exclusion zones
- Gross pointing control to keep the target within the field of view of the telescope on the order 10’ arc min
- Super fine pointing control target centered on focal plane 1 to 0.1 “
  - Fast steering mirror or piezo control
  - Spacecraft control with Payload input

Block Diagram



Wheel Jitter Performance

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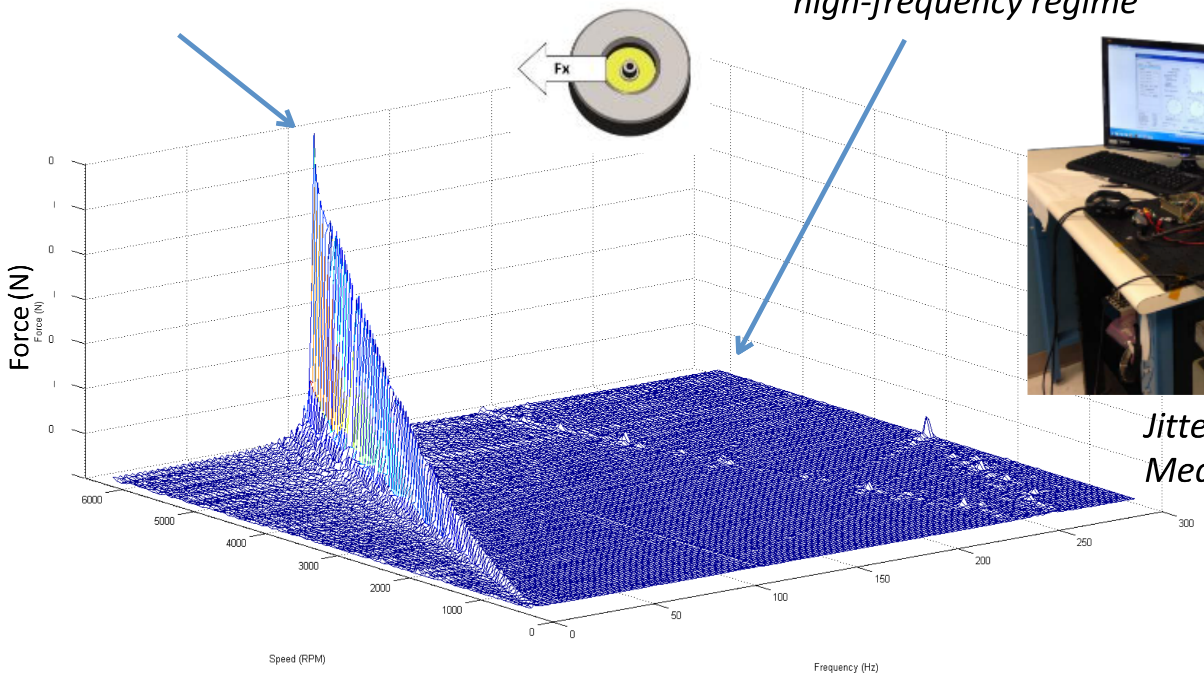
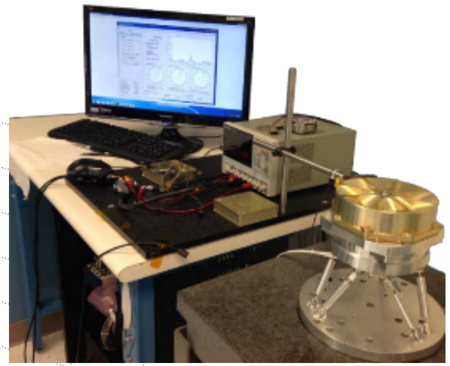
- Blue Canyon wheels have extremely low jitter
- Low wheel disturbances result in low payload line-of-sight motion
- Plot is characteristic of all BCT wheel sizes

Extremely quiet high-frequency regime



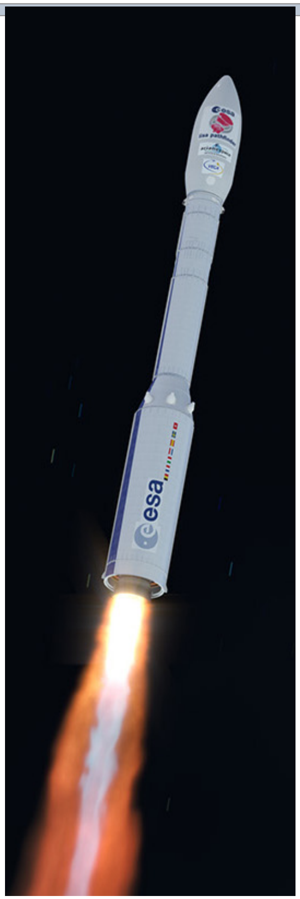


Jitter Environment Measurement System

Rideshare to LEO Sun Sync

BREAKTHROUGH INITIATIVES

- Payload and cost to 700km sun sync
  - Rocket Lab 135 kg at $ 7m
  - PSLV 1,100 kg at $ 31m
  - Vega C 1,500 kg at $ 37m
  - Falcon 9 7,400 kg at $ 60m

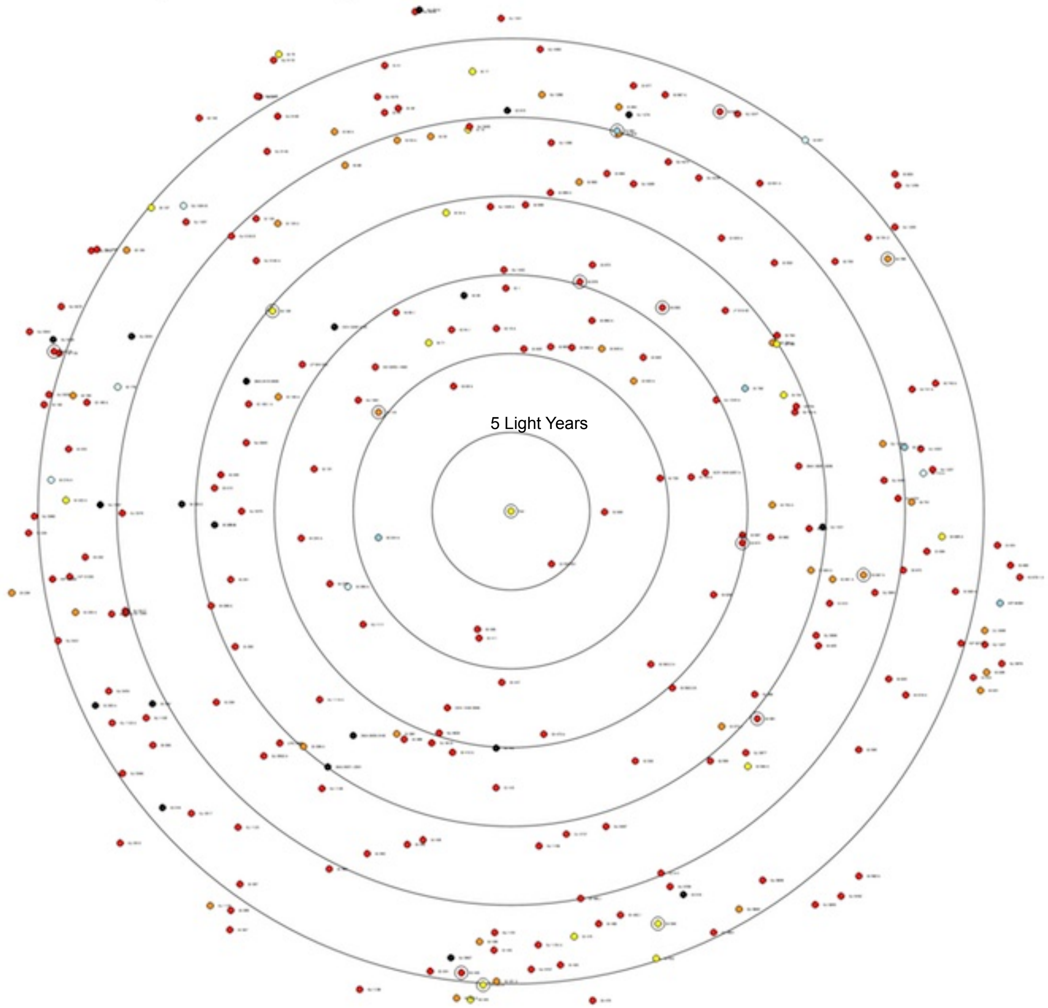


Toliman Challenges

- Temperature Stability of Focal Plane and Optical Path less than 0.5 °C
- Pointing Stability, Keeping Target Star within Field of View, 10’
- Jitter Attenuation 0.5 “ per sec
- Low Cost
- Data Processing Tools
- Launch Costs

- Major Trade
    - Do we need to go GEO

The Nearby Stellar Systems



phl.upr.edu, May 2012

BREAKTHROUGH INITIATIVES
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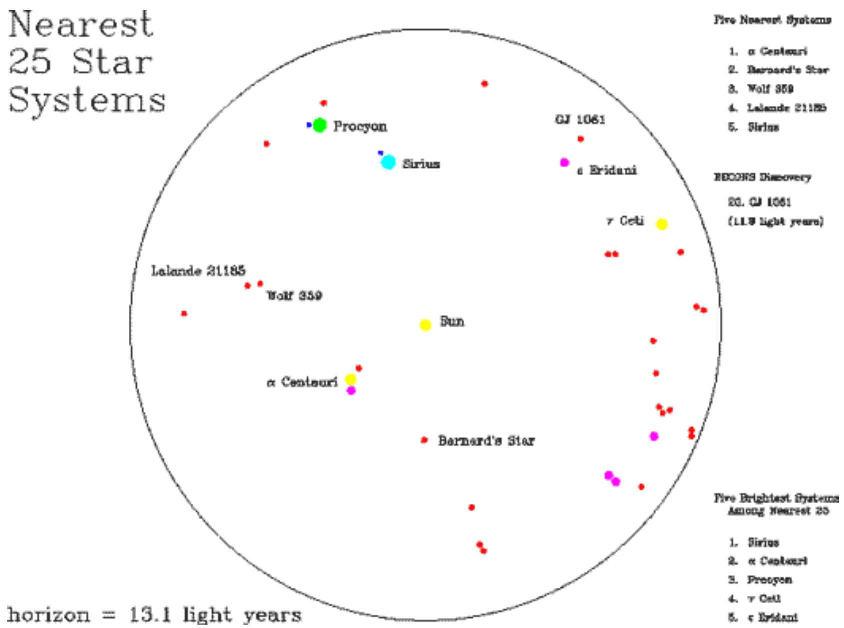
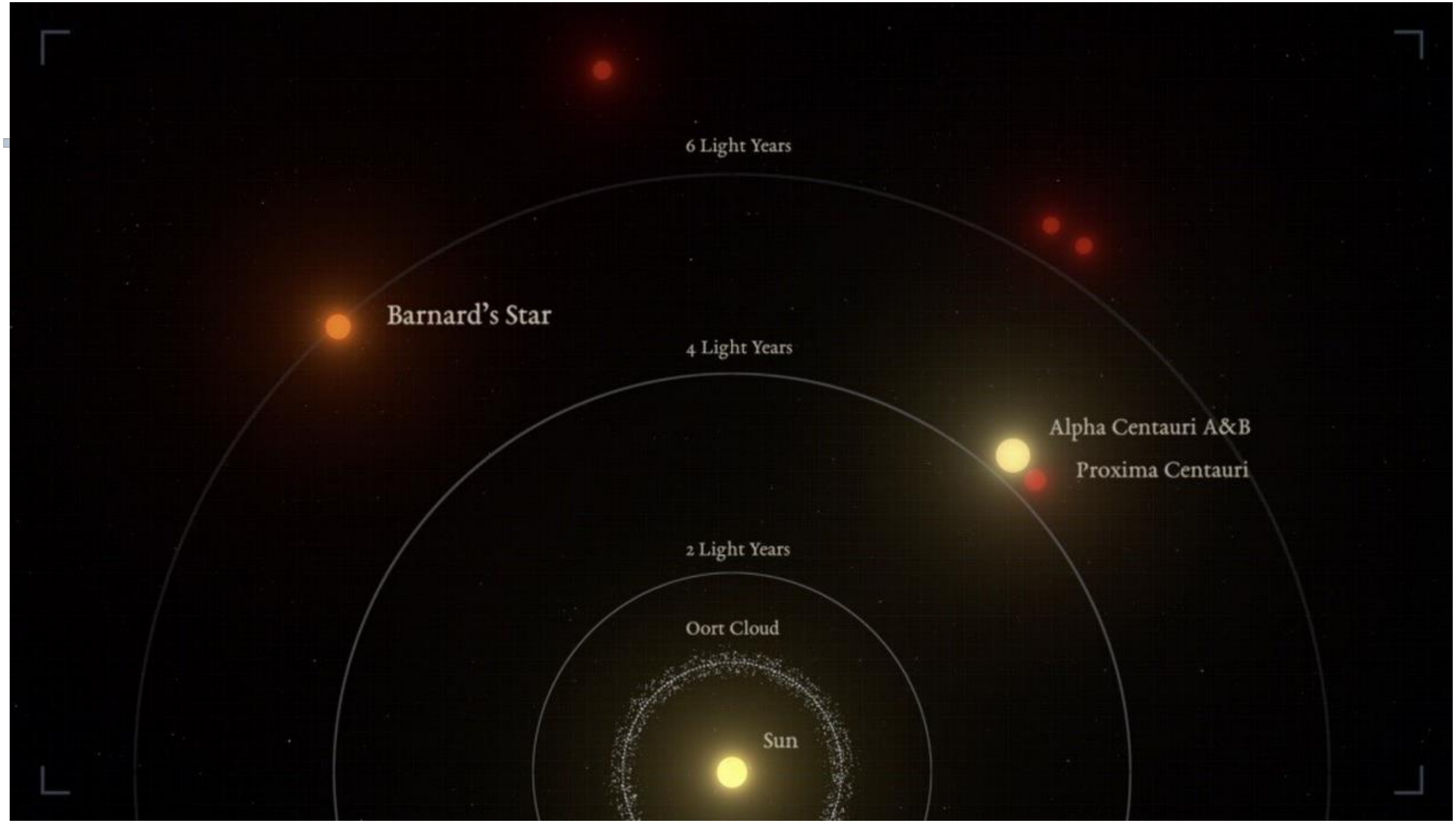
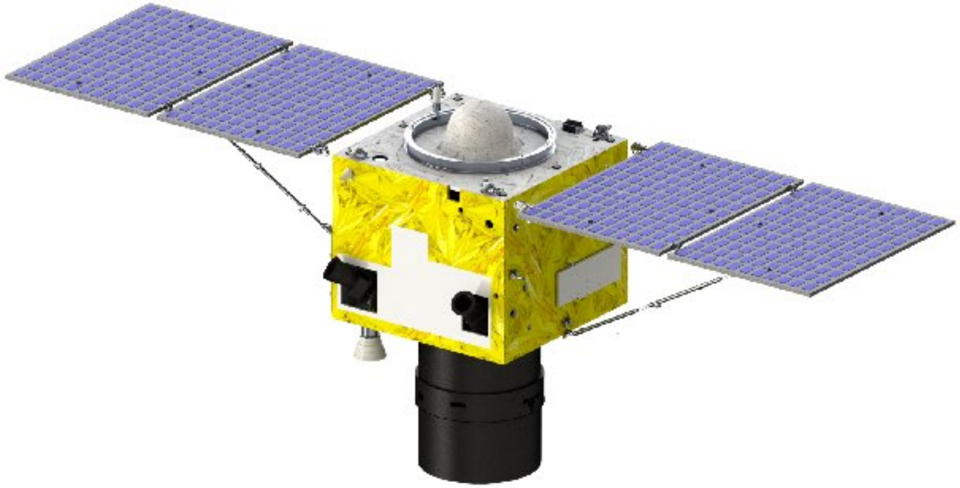
Backup

Backup


Nearest
25 Star
Systems
Procyon
Sirius
GJ 1061
ε Eridani
τ Ceti
Lalande 21185
Wolf 359
Sun
α Centauri
Barnard's Star
horizon = 13.1 light years
Five Nearest Systems
1. α Centauri
2. Barnard's Star
3. Wolf 359
4. Lalande 21185
5. Sirius
RECONS Discovery
Five Brightest Systems
Among Nearest 25
1. Sirius
2. α Centauri
3. Procyon
4. τ Ceti
5. ε Eridani


6 Light Years
Barnard's Star
4 Light Years
Alpha Centauri A&B
Proxima Centauri
2 Light Years
Oort Cloud
Sun

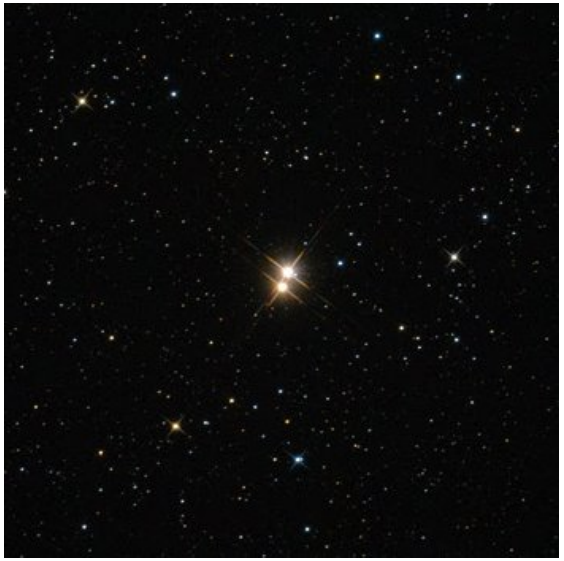
Notional. To be pulled apart.



61 Cygni

BREAKTHROUGH INITIATIVES

- 61 Cygni is a binary star system in the constellation Cygnus, consisting of a pair of K-type dwarf stars that orbit each other in a period of about 659 years. Of apparent magnitude 5.20 and 6.05, respectively, they can be seen with binoculars in city skies or with the naked eye in rural areas without light pollution.
- Distance to Earth: 11.41 light years



Epsilon Eridani b

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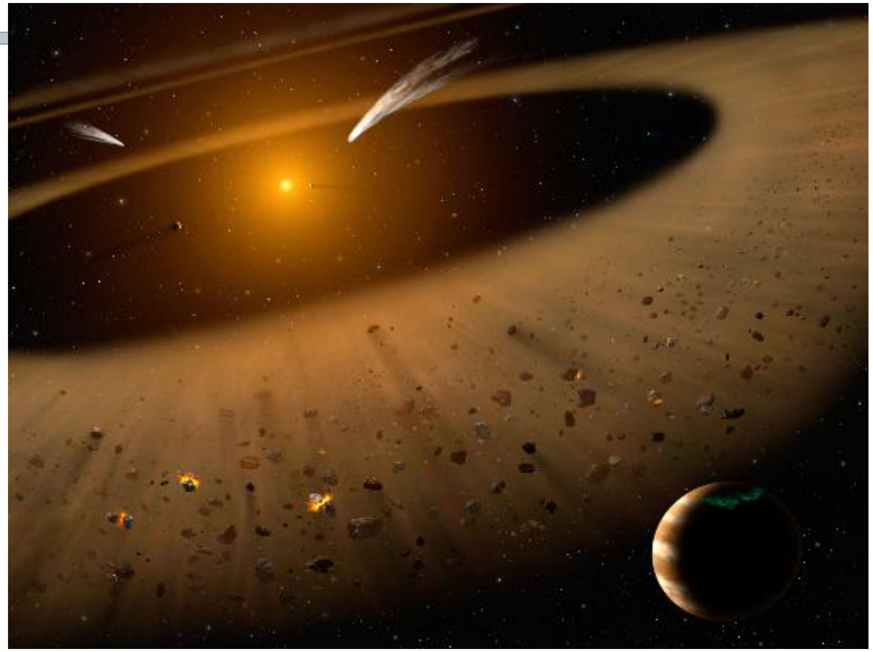
- Distance to Earth: 10.47 light years
- Apparent magnitude (B): 4.61
- Spectral type: K2V



Artist's illustration of the Epsilon Eridani system. In the right foreground, the Jupiter-mass planet Epsilon Eridani b is shown orbiting its star at the outside edge of an asteroid belt. In the background can be seen another narrow asteroid or comet belt plus an outermost belt similar in size to our Solar System's Kuiper Belt. The similarity of the structure of the Epsilon Eridani system to our Solar System is remarkable, although Epsilon Eridani is much younger than our Sun. Image credit: NASA / SOFIA / Lynette Cook.

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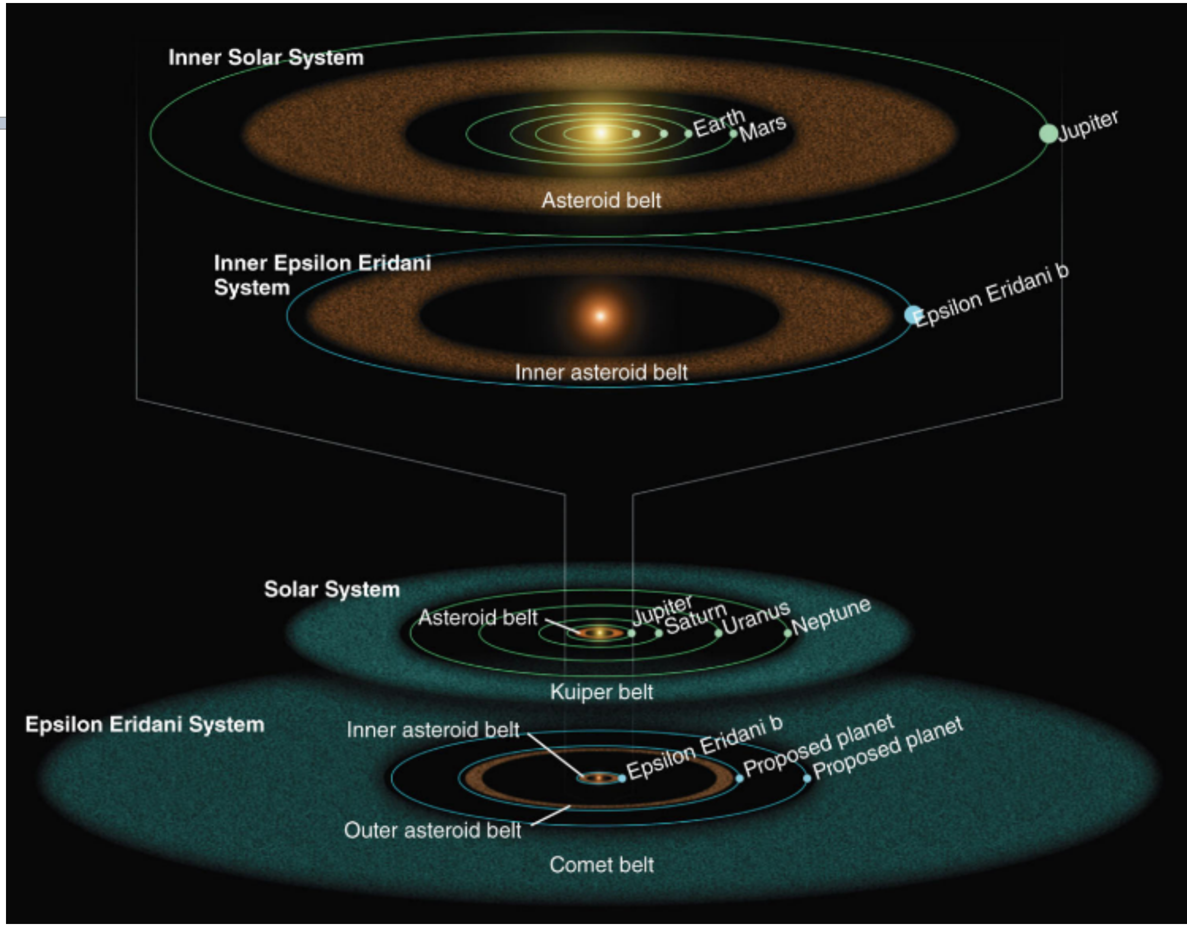
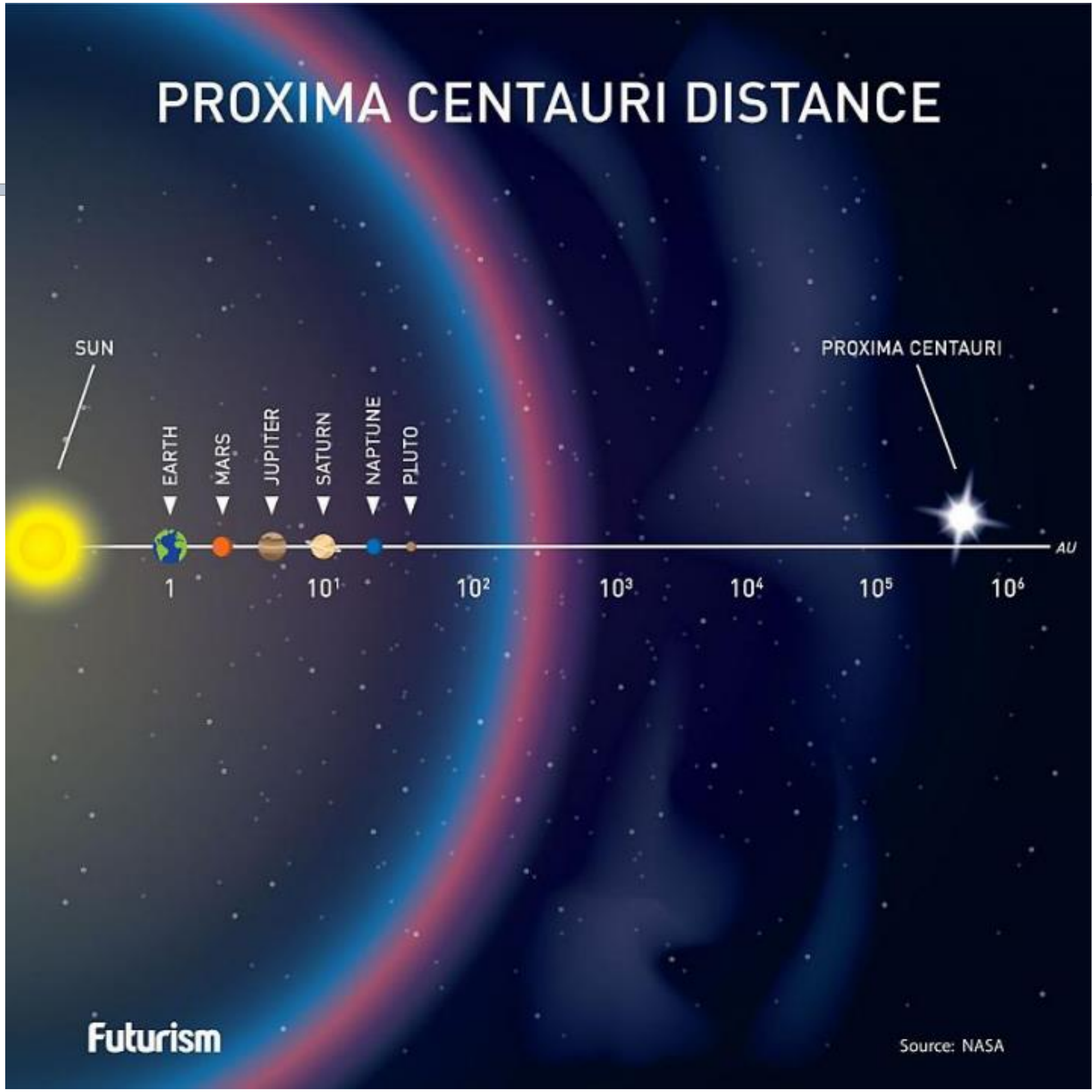
INITIATIVES



Based on Spitzer observations of the inner and outer parts of the Epsilon Eridani
Image credit: NASA / JPL / Caltech / R. Hurt, SSC


PROXIMA CENTAURI DISTANCE
SUN
EARTH
MARS
JUPITER
SATURN
NAPTUNE
PLUTO
PROXIMA CENTAURI
AU
1
10¹
10²
10³
10⁴
10⁵
10⁶
Futurism
Source: NASA

10um Ground Based Imaging

Phase 1 (Alpha Cen, VLT/Gemini) effort will enable Phase 2 (ELTs) imaging and characterization of habitable planets around a dozen nearby stars

Thermal IR imaging/spectroscopy detects habitable exoplanets, measures radius and temperature + some chemical species (CO2, H2O, O3)
Overlap with space missions targets (reflected visible light) → Direct measurement of greenhouse effect and detailed characterization of atmospheres.

ESO VLT observation campaign

Gemini South observation campaign

Detector development

E-ELT: METIS instrument upgrade for exoplanet imaging (first generation instrument)

TMT: Considering MIR instrument
visitor instrument possible

GMT: Considering MIR instrument (TIGER)
visitor instrument possible

Tab. 2 Apparent magnitude and required time for detection at 10-13 microns of various types of exo-Earth at **1.325pc** (Alpha Centauri system)

	Radius (Earth)	Temp. (K)	App. Mag. 10 microns	Time on 8m 3.0 sig. det.(h)	Time on 30m 5 sig. det.(h)	Charact ?
Earth	1	288	15.2	188	0.75	Y (30m)
Super-Earth (Kepler 22b)	2	288	13.7	19	0.05	Y
Warm Earth (Dune planet)	1	320	14.8	93	0.4	Y

Tab. 3 Apparent magnitude and required time at 10-13 microns of exo-Earth planets at **5pc**

	Radius (Earth)	Temperature (K)	App. Mag. 10 microns	Time on 30m 5 sig. det. (h)	Charact ?
Earth	1	288	18.1	157	~Y
Super-Earth (Kepler 22b)	2	288	16.6	10	Y
Warm Earth (Dune planet)	1	320	17.7	75	Y