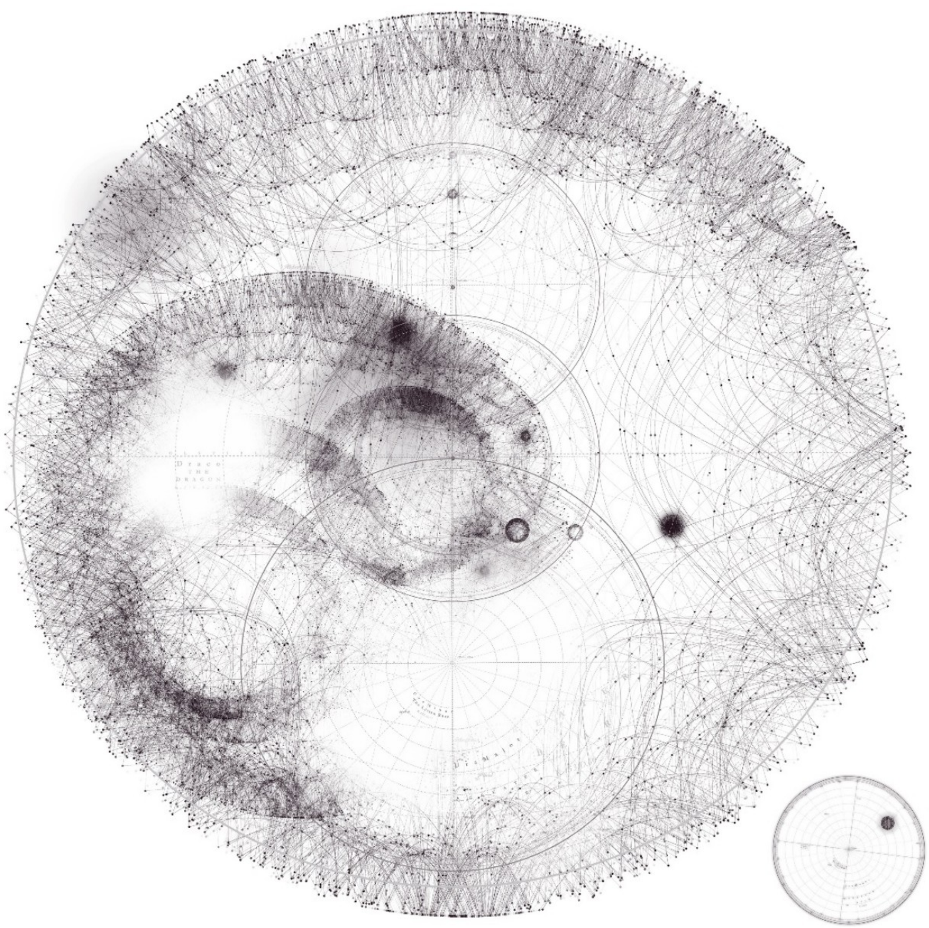
BREAKTHROUGH INITIATIVES

WATCH



Olivier Guyon
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Breakthrough Watch Advisory Committee chair

Subaru Telescope, NAOJ, NINS
University of Arizona
Japanese Astrobiology Center, NINS

BREAKTHROUGH
WATCH

Identify and charararacterize nearby habitable planets

Targets: Nearest stars < ~5pc

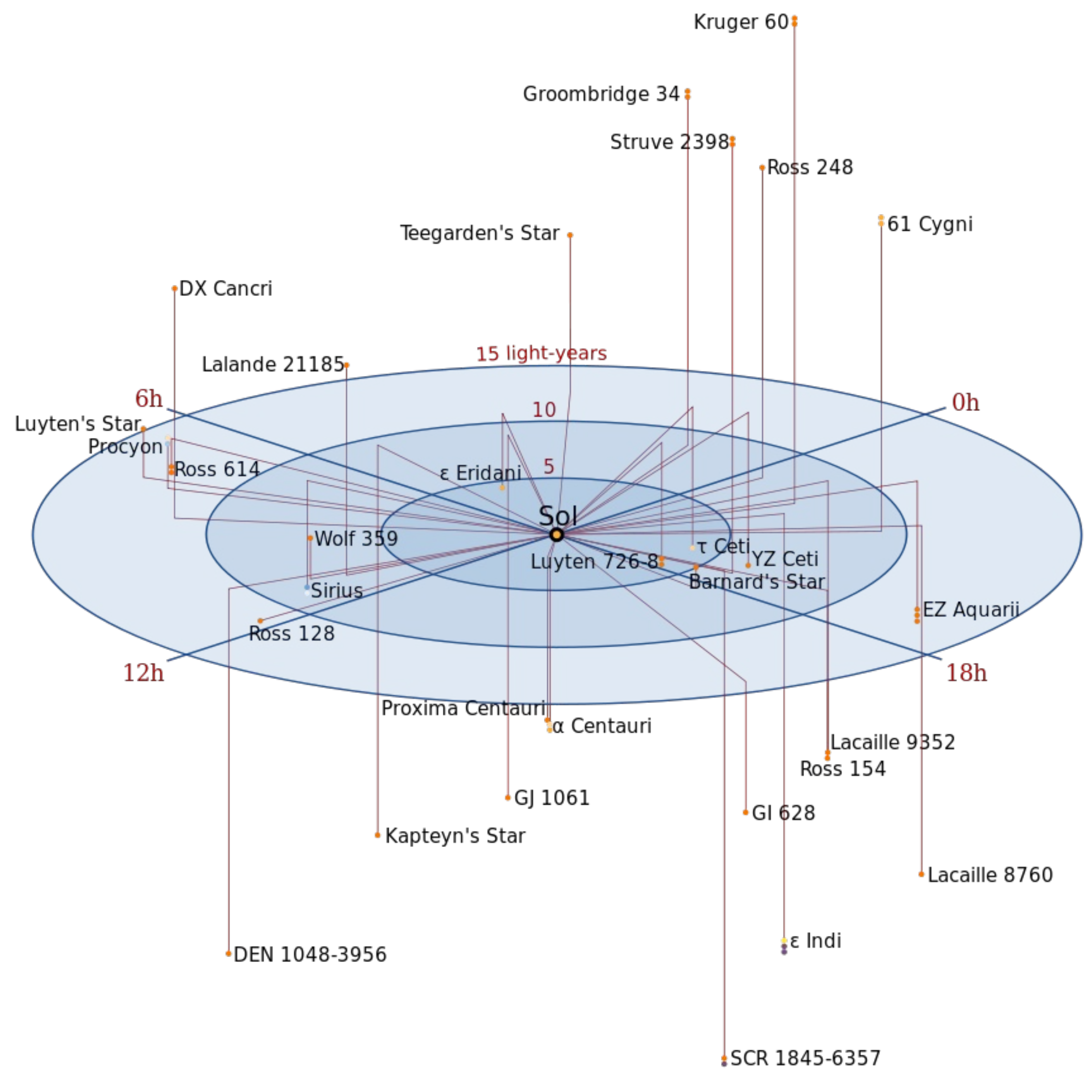
→ search for **biomarkers**

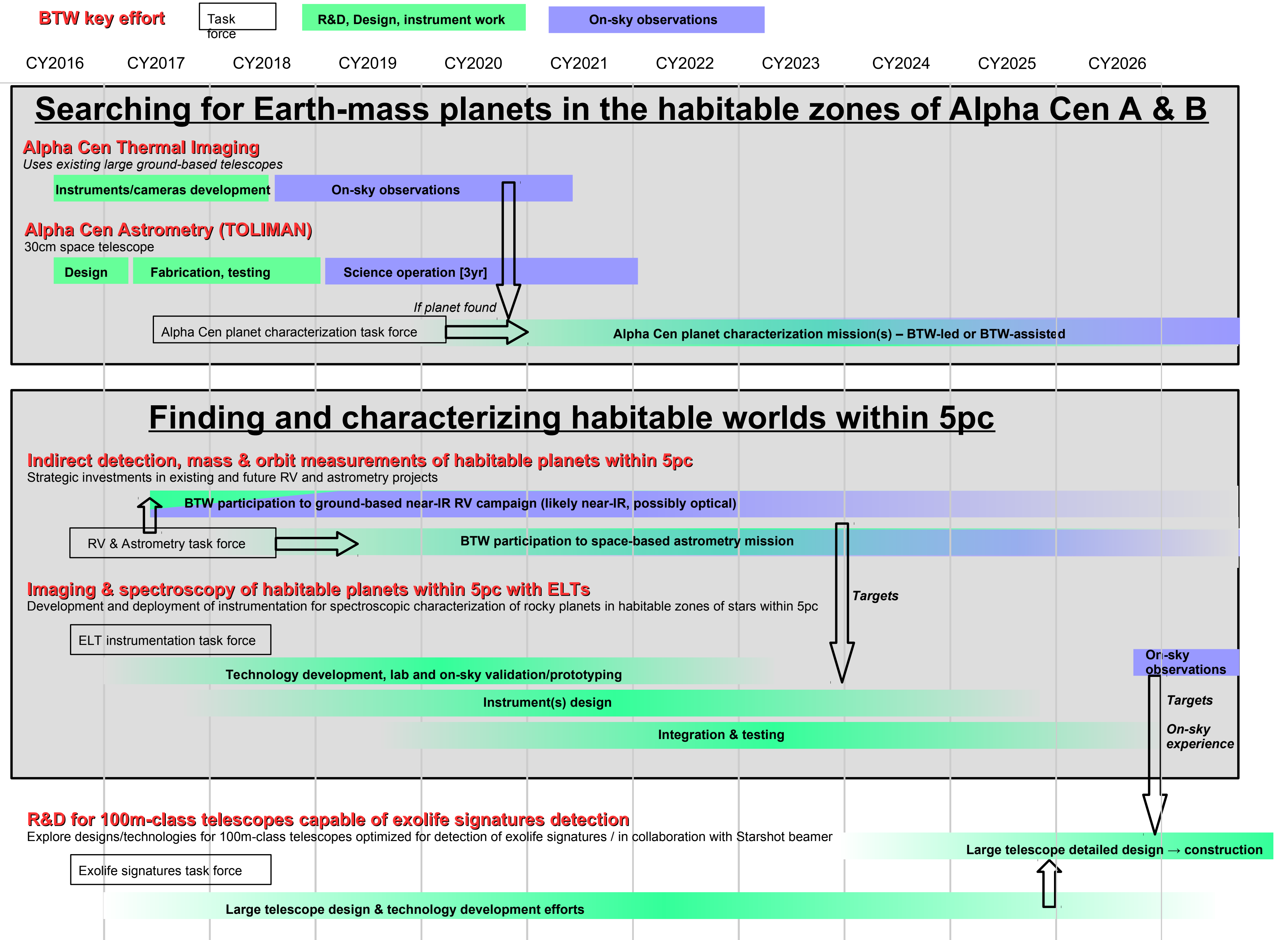
→ Future exploration (Starshot)

Approaches

Ground and space

Detection and spectroscopic characterization




BTW key effort
Task force
R&D, Design, instrument work
On-sky observations
CY2016
CY2017
CY2018
CY2019
CY2020
CY2021
CY2022
CY2023
CY2024
CY2025
CY2026
Searching for Earth-mass planets in the habitable zones of Alpha Cen A & B
Alpha Cen Thermal Imaging
Uses existing large ground-based telescopes
Instruments/cameras development
On-sky observations
Alpha Cen Astrometry (TOLIMAN)
30cm space telescope
Design
Fabrication, testing
Science operation [3yr]
If planet found
Alpha Cen planet characterization task force
Alpha Cen planet characterization mission(s) – BTW-led or BTW-assisted
Finding and characterizing habitable worlds within 5pc
Indirect detection, mass & orbit measurements of habitable planets within 5pc
Strategic investments in existing and future RV and astrometry projects
BTW participation to ground-based near-IR RV campaign (likely near-IR, possibly optical)
RV & Astrometry task force
BTW participation to space-based astrometry mission
Targets
Imaging & spectroscopy of habitable planets within 5pc with ELTs
Development and deployment of instrumentation for spectroscopic characterization of rocky planets in habitable zones of stars within 5pc
ELT instrumentation task force
On-sky observations
Technology development, lab and on-sky validation/prototyping
Instrument(s) design
Targets
Integration & testing
On-sky experience
R&D for 100m-class telescopes capable of exolife signatures detection
Explore designs/technologies for 100m-class telescopes optimized for detection of exolife signatures / in collaboration with Starshot beamer
Large telescope detailed design → construction
Exolife signatures task force
Large telescope design & technology development efforts

Recommendations

Phase #1 effort : Alpha Cen system

Key projects:
- 10um imaging with 8-m telescopes
- Dedicated space astrometry mission

+ support activities for RV, space visible imaging ?

Phase #2 effort: stars within ~5pc

Key project(s):
- Direct imaging with ELTs, 10um (Sun-like stars)
- Direct imaging with ELTs, near-IR (M-type stars)

+ astrometry for mass measurements (& target identification ?)

BREAKTHROUGH
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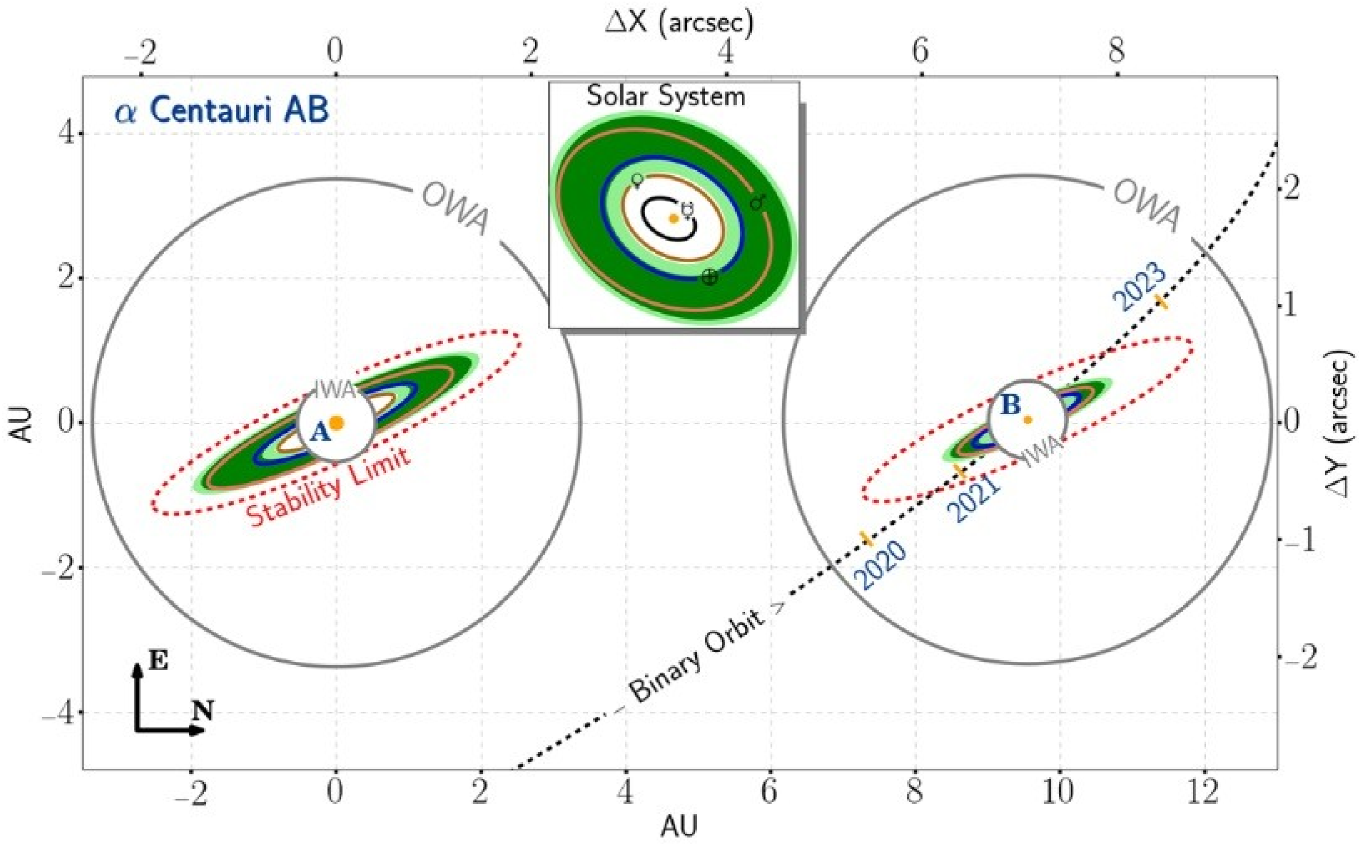
Space Astrometry Mission (TOLIMAN)



BREAKTHROUGH
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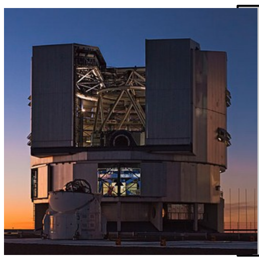
10um Ground Based Imaging

Phase 1 (Alpha Cen, VLT/Gemini/Magellan) 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 (CO_2, H_2O, O_3)
Overlap with space missions targets (reflected visible light) → Direct measurement of greenhouse effect and detailed characterization of atmospheres.



ESO VLT observation campaign

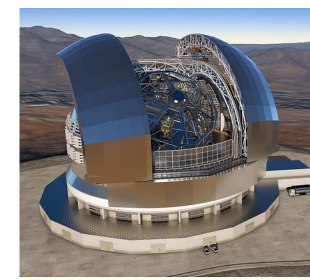
Gemini South observation campaign

Magellan Telescope Observation campaign

Detector development

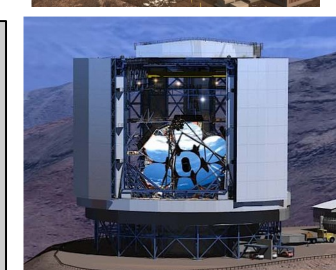
→

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



10um imaging and spectroscopy

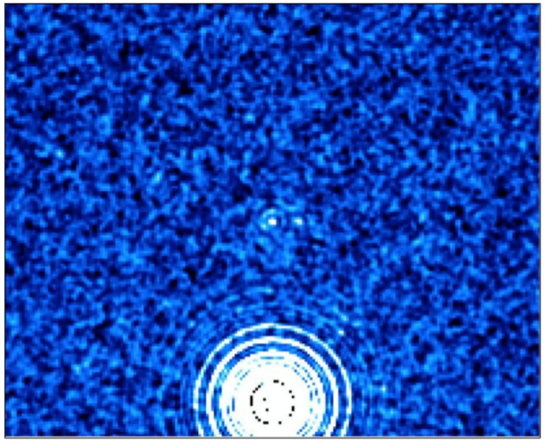


Fig. 1: A simulated 100h sequence of Alpha Cent at 10 microns for an 8m telescope. The target star (center) is hidden behind a coronagraph. A faint 4.5 sigma 1 Earth radius 288K planet is detected West of the star at 1 arcsec. The 2nd star of the system is visible South of the target star.

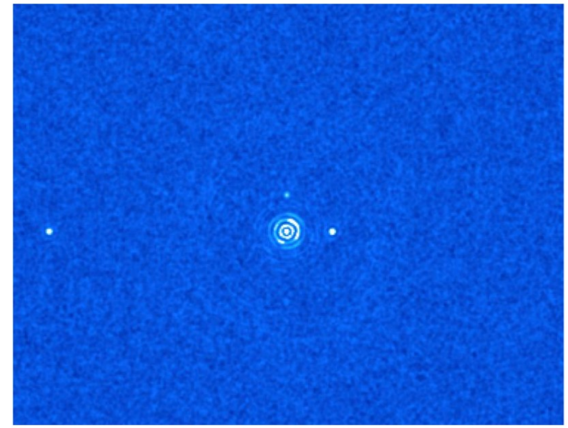


Fig. 2: Same as Fig.1, but for a 30m telescope. A bright 25 sigma 1 Earth radius 288K planet is detected West of the star at 1 arcsec. A Venus-like planet is detected North of the star, as a Jupiter-like planet is detected East.

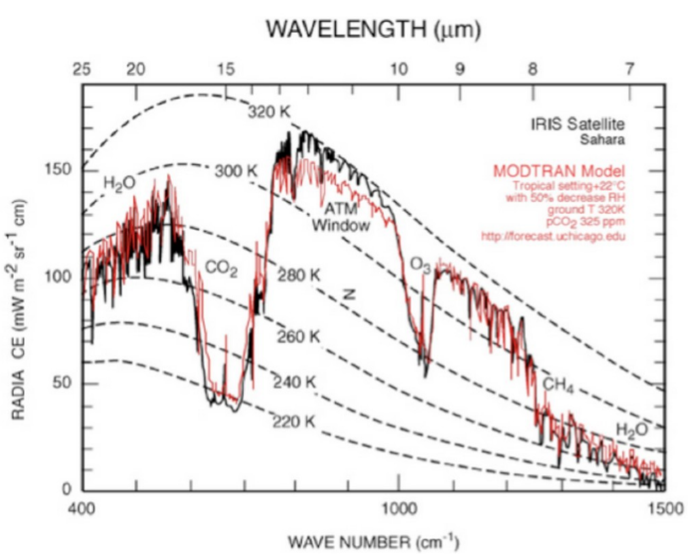
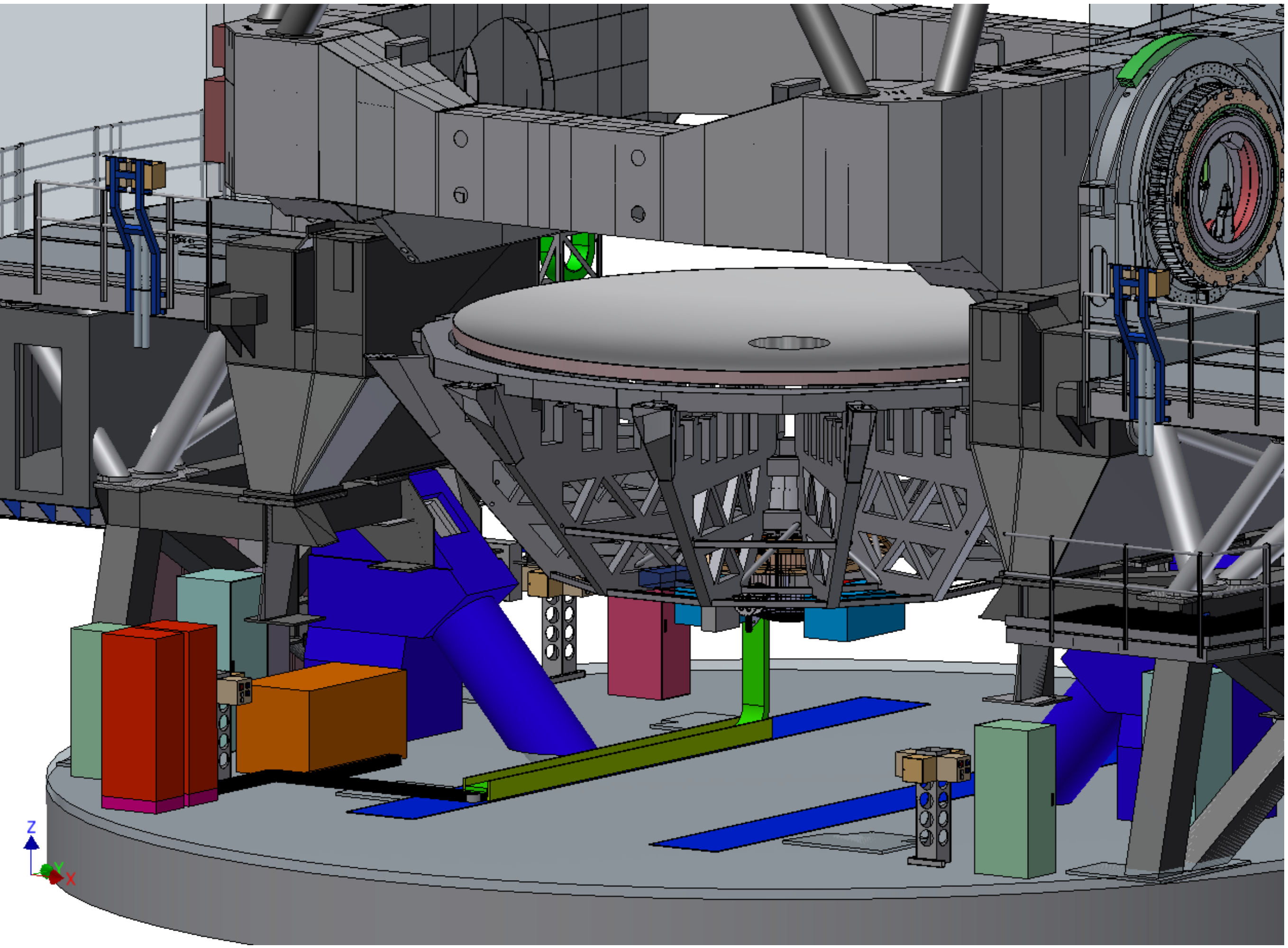


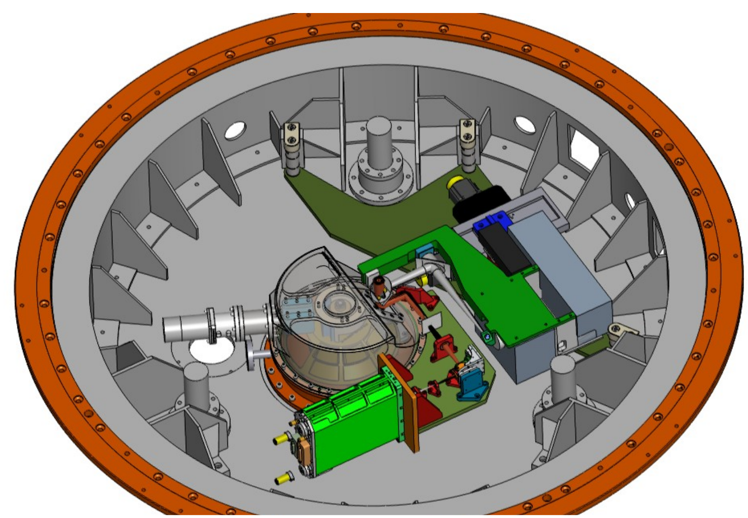
Fig. 3: Earth spectrum acquired from space for the Sahara. Note the peak emission between 10-13 microns. Biomarkers: CO2, O3, CH4 and water bands are visible in the N-band.

Credit: Christian Marois

VISIR at UT4 Cass, consolidated



- Main rack as in UT3
- He compressors on Azimuth
- He lines and cables routed from M1 cell (not through wrap)
- Test cables long enough
- Weight neutral



VISIR Flange Module (VFM)
Subcontracted to KT Optics, Munich

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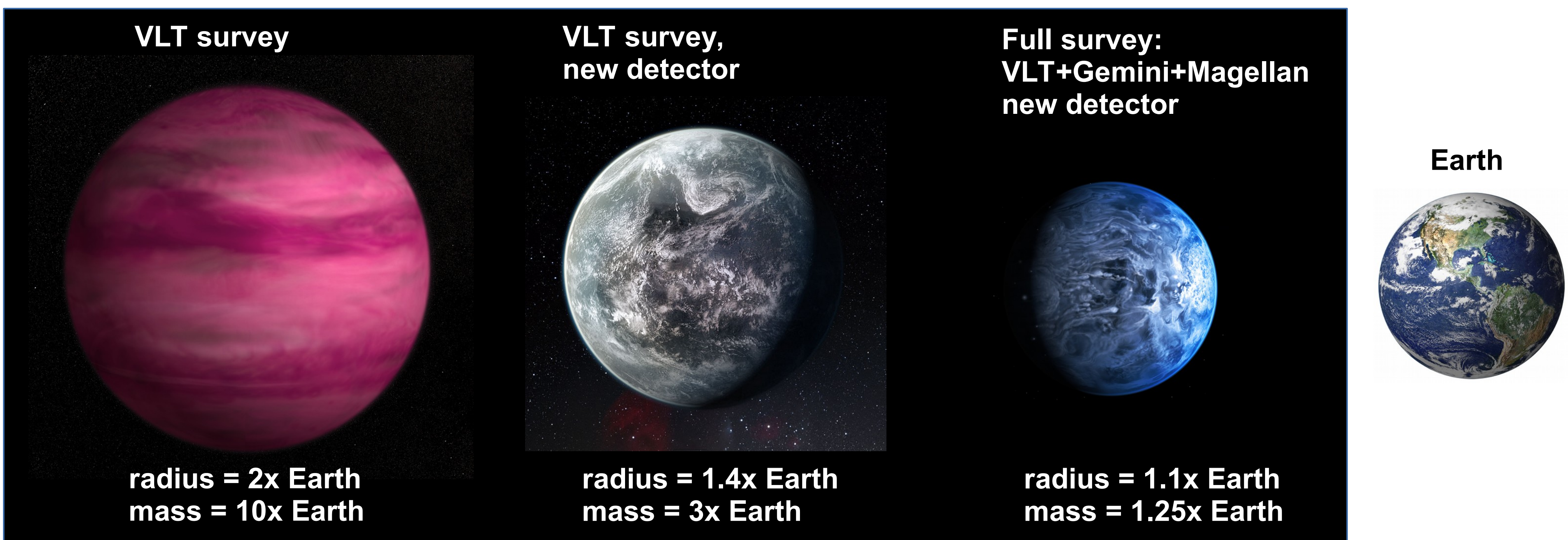
BTW 10um : current and future capabilities

VLT only survey, current camera:
Can detect ~2 Earth radius rocky planets = ~10 Earth mass in Alpha Cen A&B system

Full survey (VLT, Gemini, Magellan), new detector:

- detector alone brings 4x gain in efficiency (same observation requires ¼ of the time). At equal exposure time, 2x gain in sensitivity:
from 2 Earth radius / 10 Earth mass to 1.4 Earth radius / 3 Earth mass

- Adding Gemini and Magellan increases equivalent exposure time by x3 → additional 1.7x gain in sensitivity
from 1.4 Earth radius / 3 Earth mass to 1.1 Earth radius / 1.25 Earth mass



Recommendations

Phase #1 effort : Alpha Cen system

Key projects:
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+ support activities for RV, space visible imaging ?

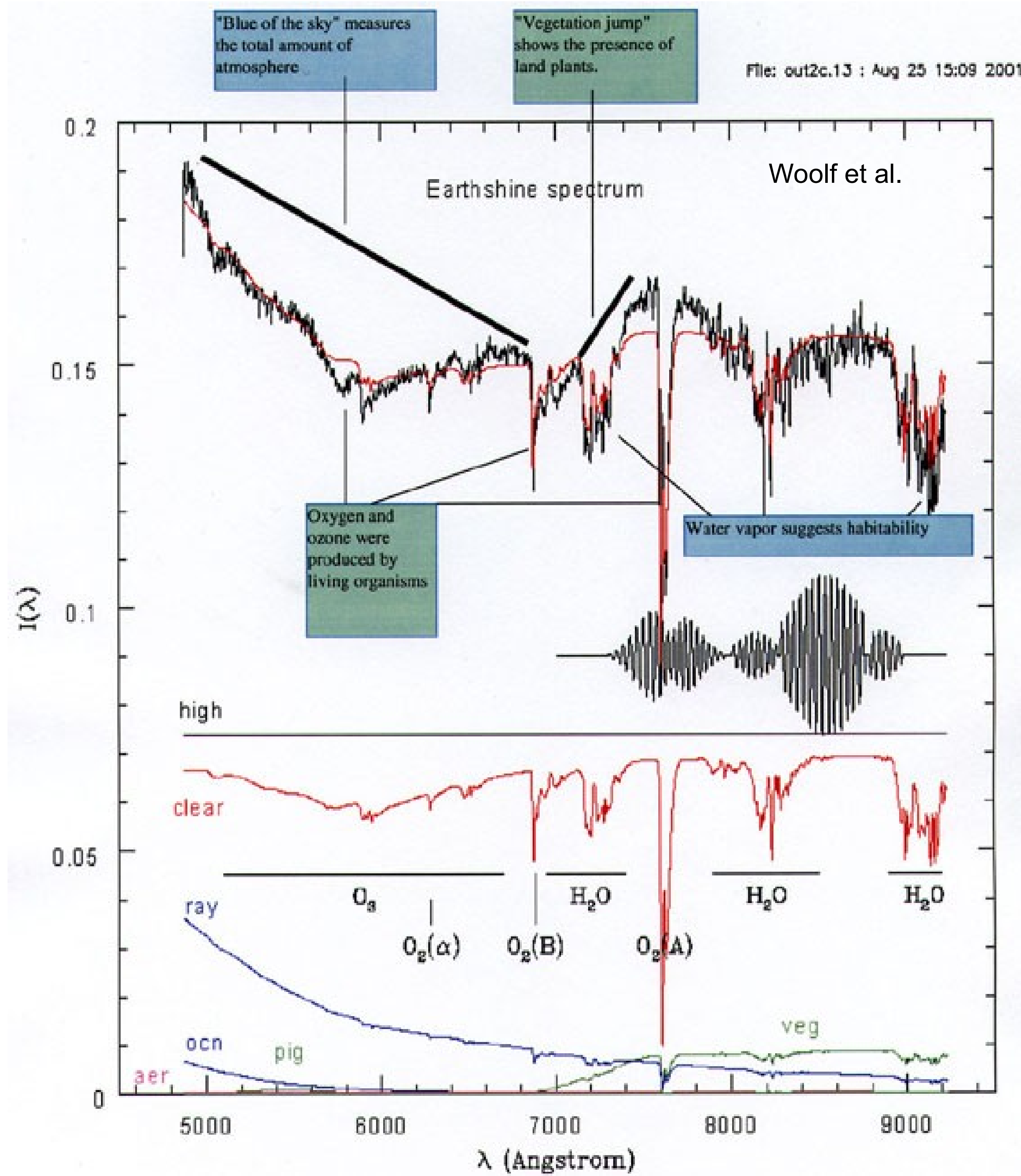
Phase #2 effort: stars within ~5pc

Key project(s):
- Direct imaging with ELTs, 10um (Sun-like stars)
- Direct imaging with ELTs, near-IR (M-type stars)

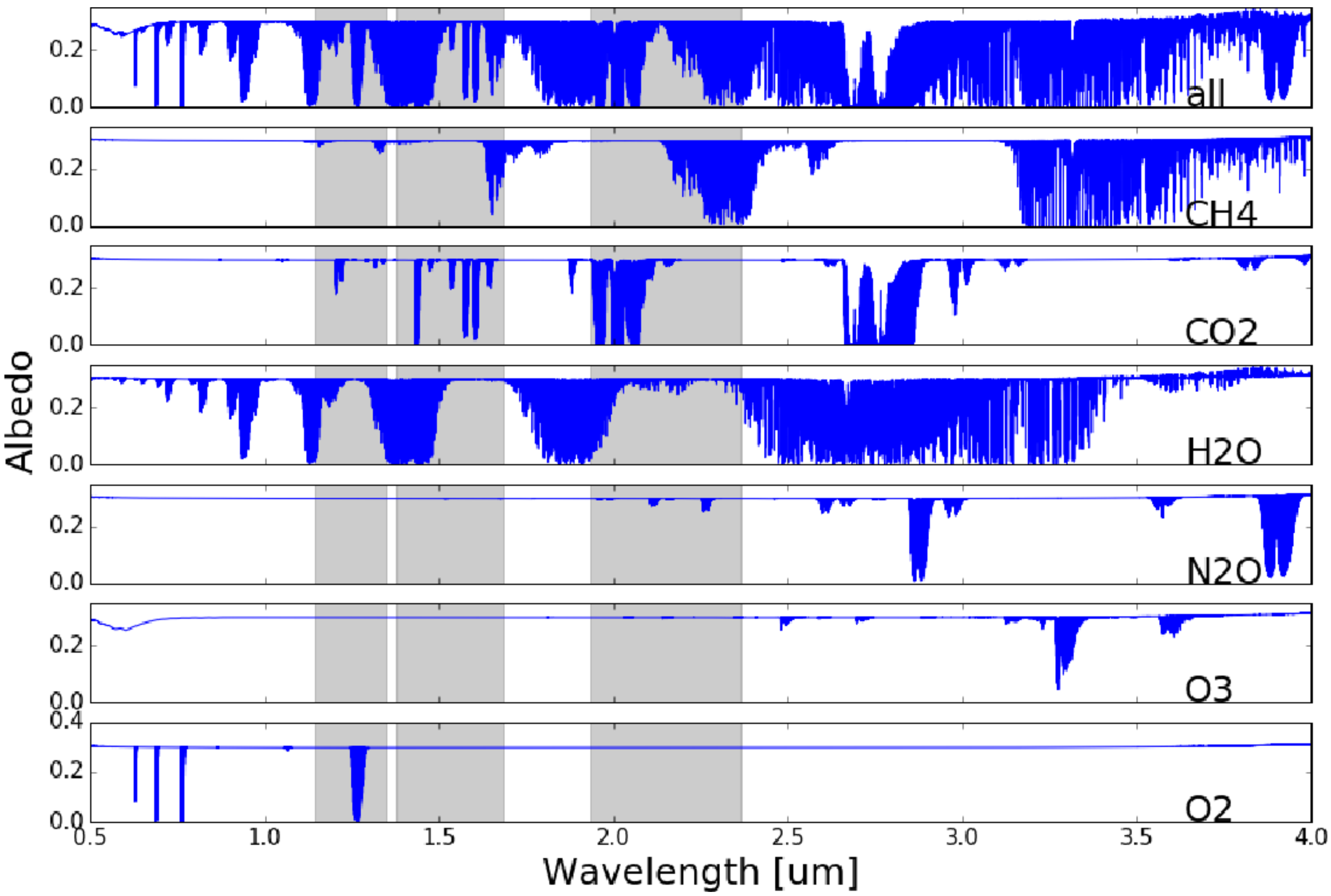
+ astrometry for mass measurements (& target identification ?)

Why directly imaging ?

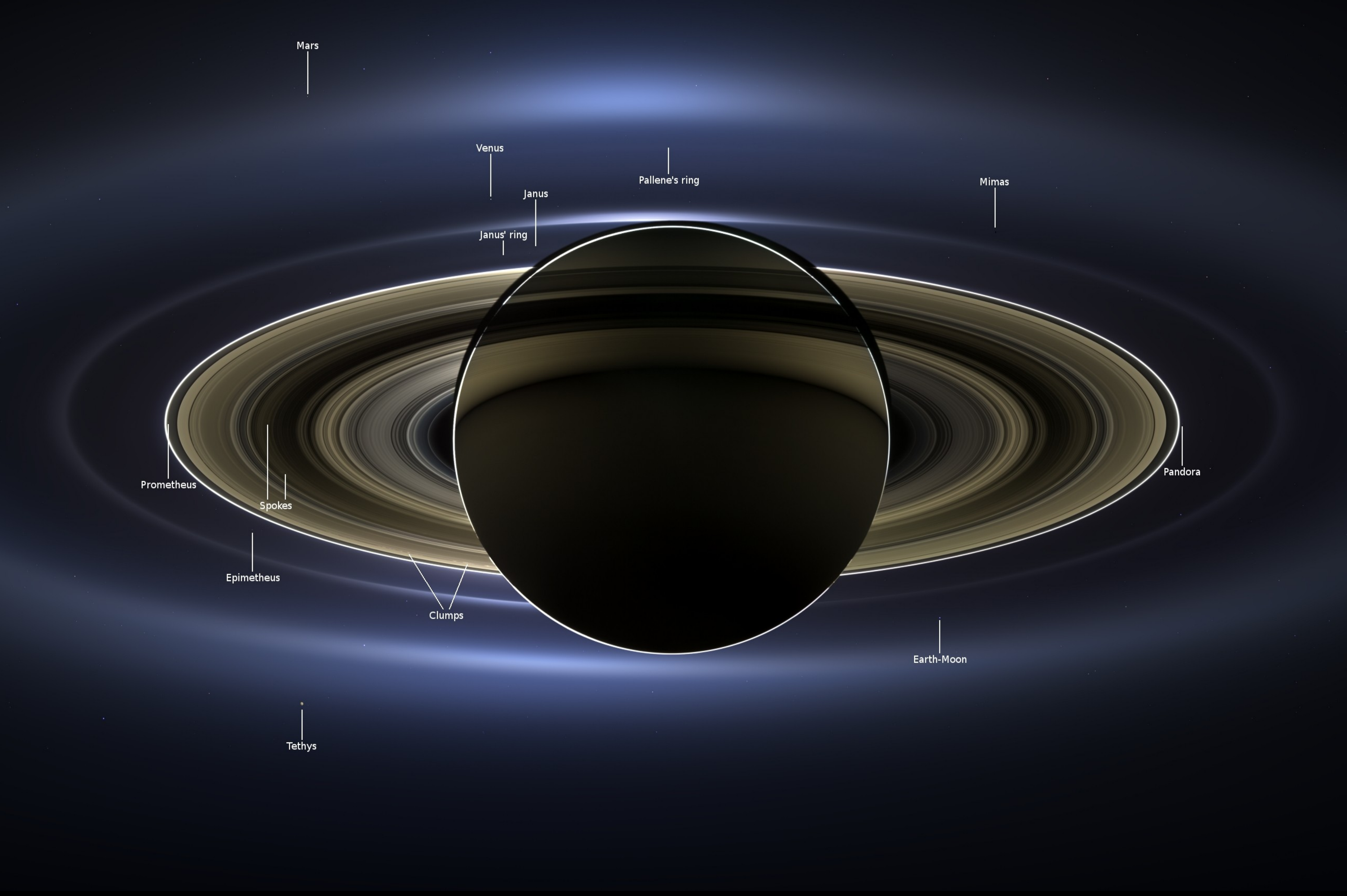
Spectra of Earth (taken by looking at Earthshine) shows evidence for life and plants



Biomarkers in Near-IR: O2 + CH4 + H2O

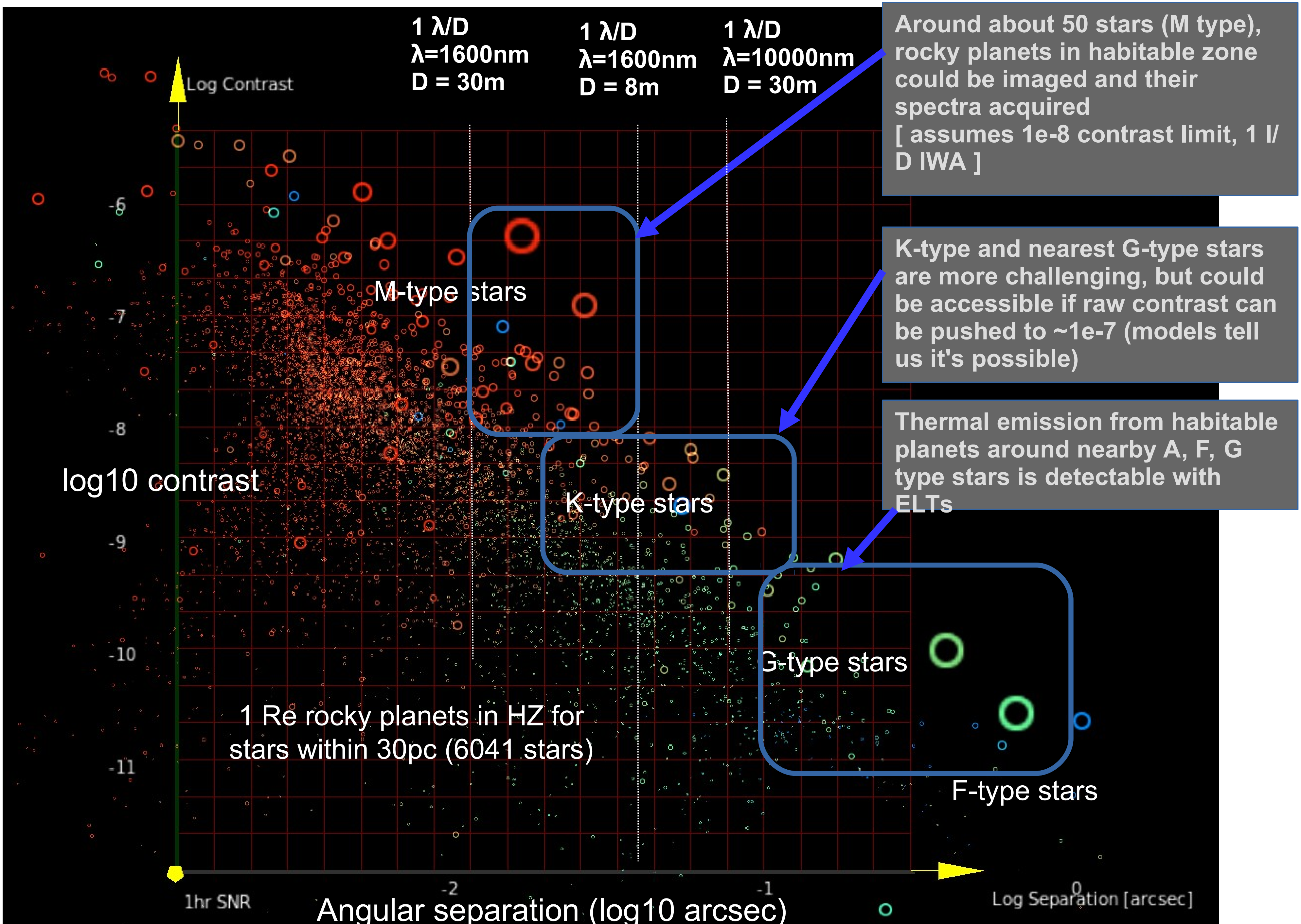


Taking images of exoplanets: Why is it hard ?




Saturn
Earth

Contrast and Angular separation



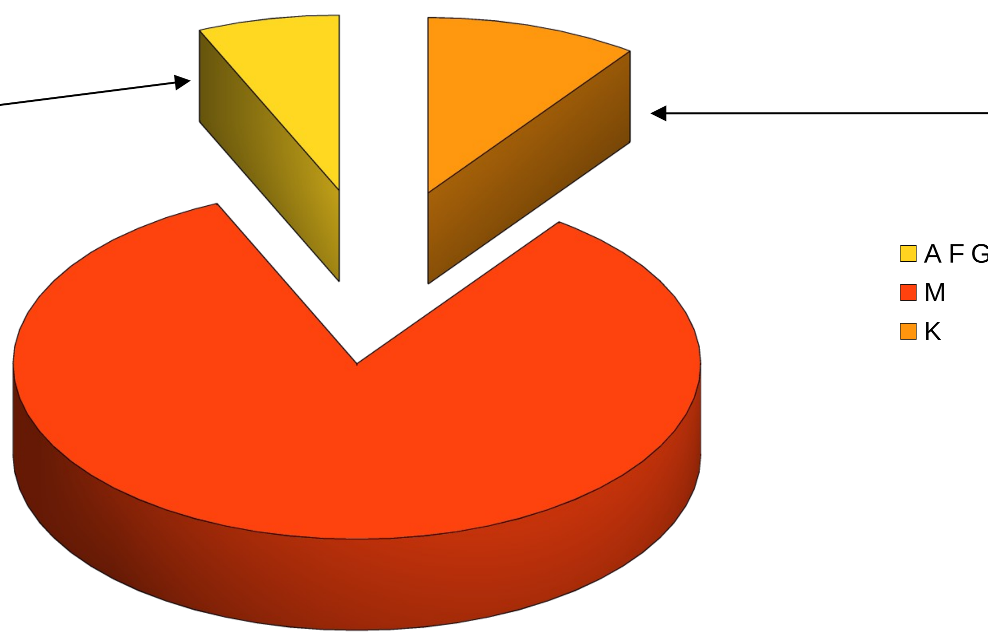
What is so special about M stars ?

They are **abundant**: >75% of main sequence stars are M type

Class	Effective temperature[1][2][3]	Vega-relative "color label"[4][nb 1]	Chromaticity[5][6][7][nb 2]	Main-sequence mass[1][8] (solar masses)	Main-sequence radius[1][8] (solar radii)	Main-sequence luminosity[1][8] (bolometric)	Hydrogen lines	Fraction of all main-sequence stars[9]
O	≥ 30,000 K	blue	blue	≥ 16 $M_\odot$	≥ 6.6 $R_\odot$	≥ 30,000 $L_\odot$	Weak	~0.00003%
B	10,000–30,000 K	blue white	deep blue white	2.1–16 $M_\odot$	1.8–6.6 $R_\odot$	25–30,000 $L_\odot$	Medium	0.13%
A	7,500–10,000 K	white	blue white	1.4–2.1 $M_\odot$	1.4–1.8 $R_\odot$	5–25 $L_\odot$	Strong	0.6%
F	6,000–7,500 K	yellow white	white	1.04–1.4 $M_\odot$	1.15–1.4 $R_\odot$	1.5–5 $L_\odot$	Medium	3%
G	5,200–6,000 K	yellow	yellowish white	0.8–1.04 $M_\odot$	0.96–1.15 $R_\odot$	0.6–1.5 $L_\odot$	Weak	7.6%
K	3,700–5,200 K	orange	pale yellow orange	0.45–0.8 $M_\odot$	0.7–0.96 $R_\odot$	0.08–0.6 $L_\odot$	Very weak	12.1%
M	2,400–3,700 K	red	light orange red	0.08–0.45 $M_\odot$	≤ 0.7 $R_\odot$	≤ 0.08 $L_\odot$	Very weak	76.45%

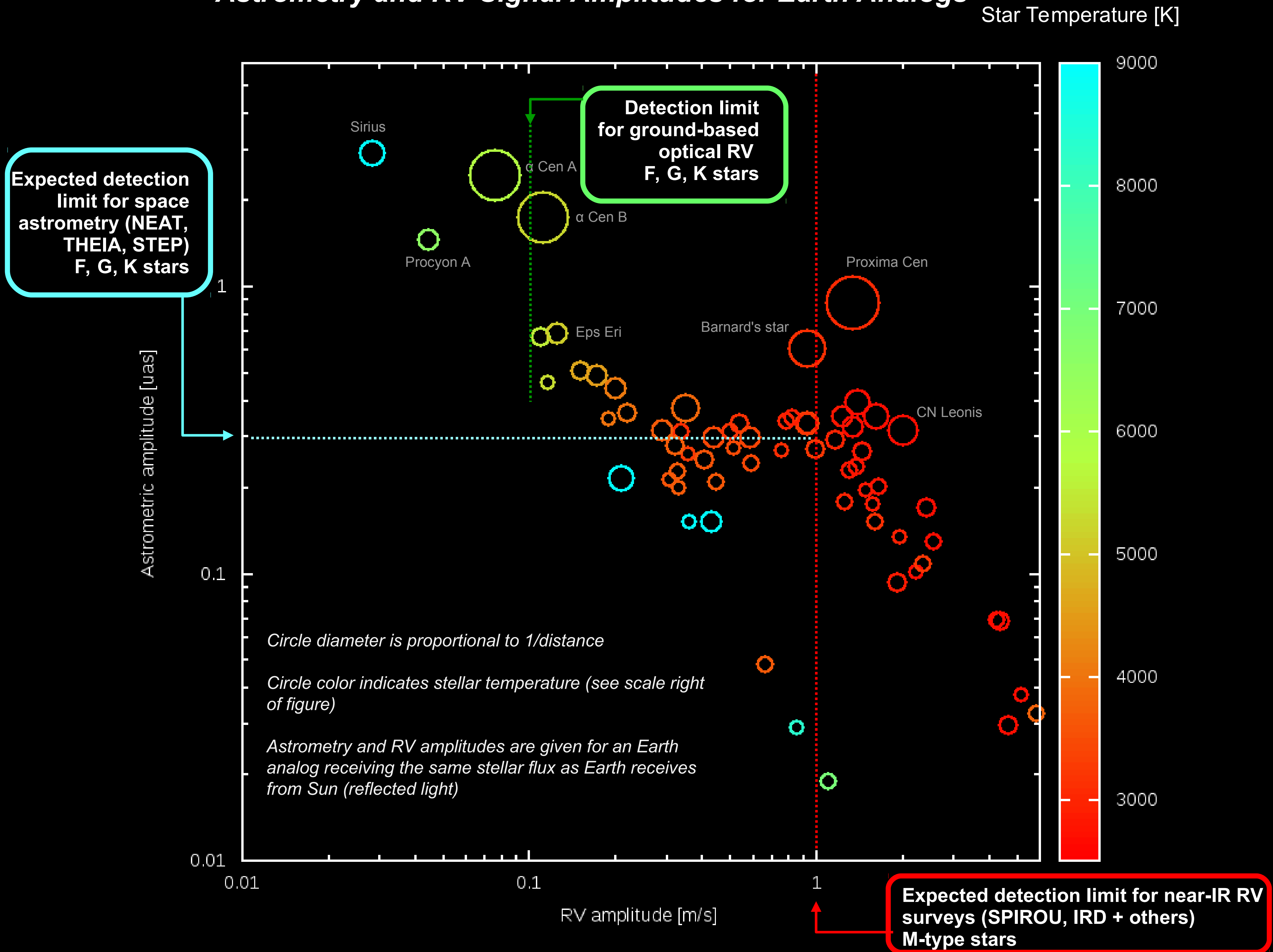
Within 5pc (15ly) : 60 hydrogen-burning stars, 50 are M type, 6 are K-type, 4 are A, F or G

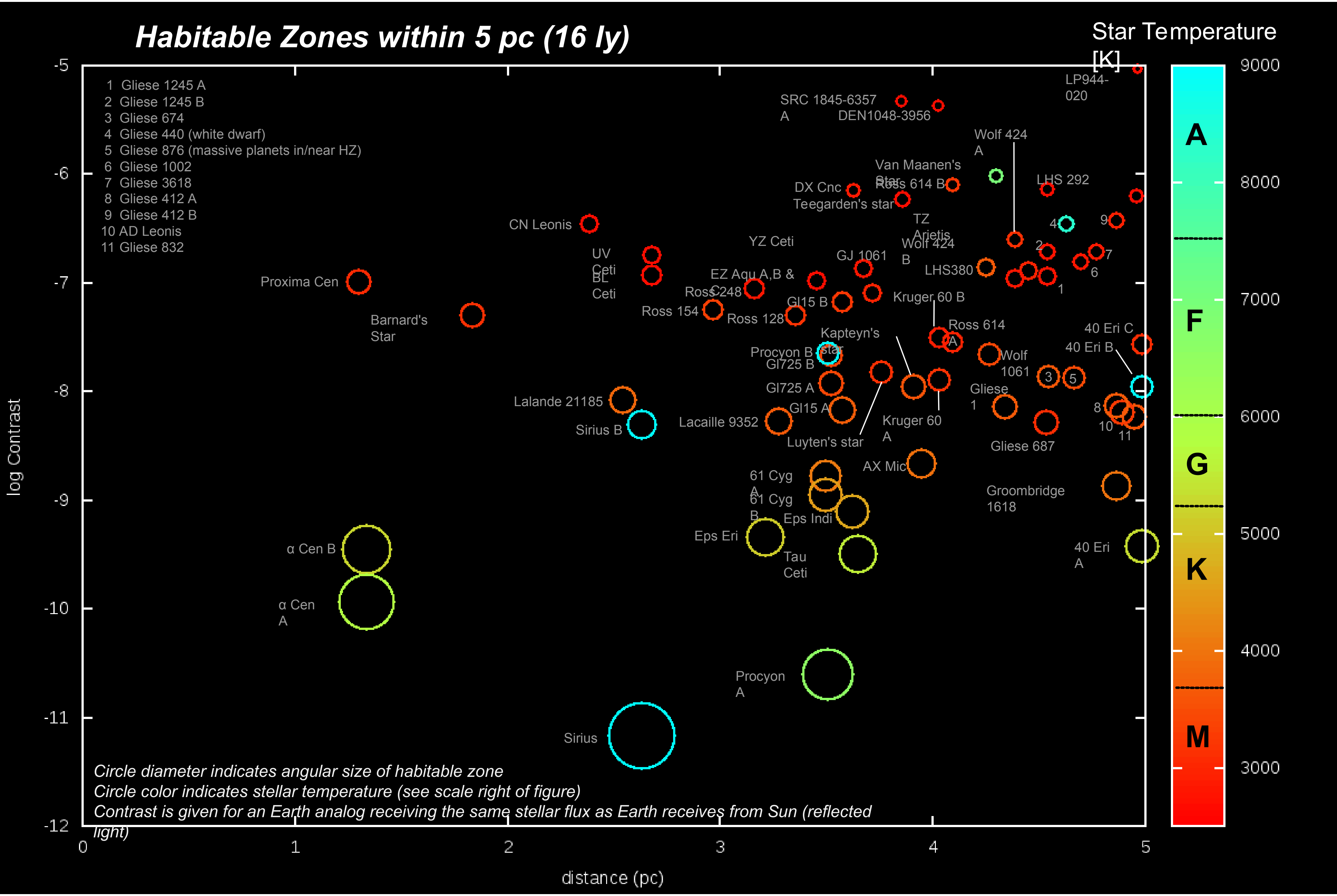
4.36 Alpha Cen A
8.58 Sirius A
11.40 Procyon A
11.89 Tau Ceti

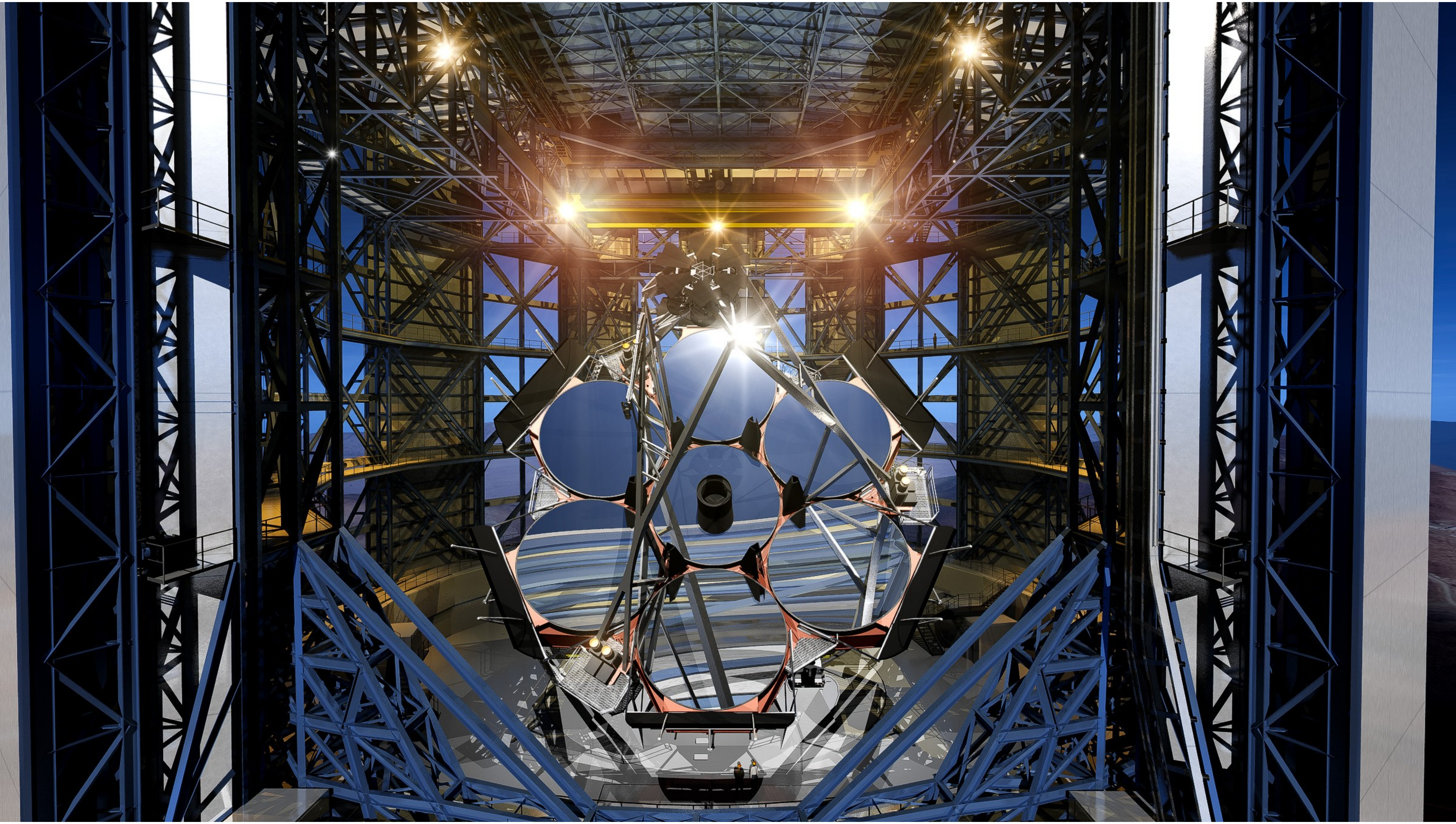


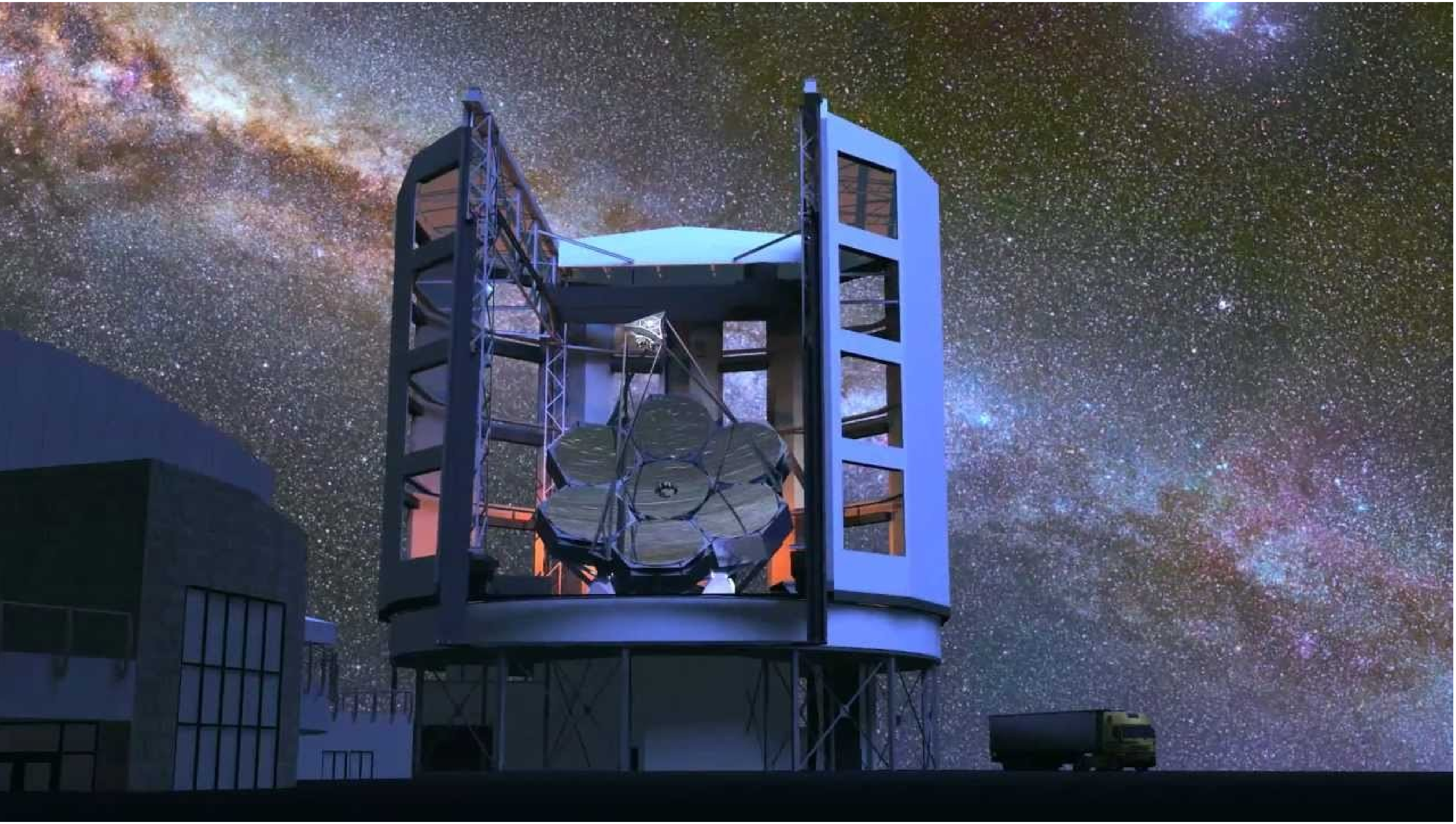
4.36 Alpha Cen B
10.52 Eps Eri
11.40 61 Cyg A
11.40 61 Cyg B
11.82 Eps Ind A
15.82 Gliese 380

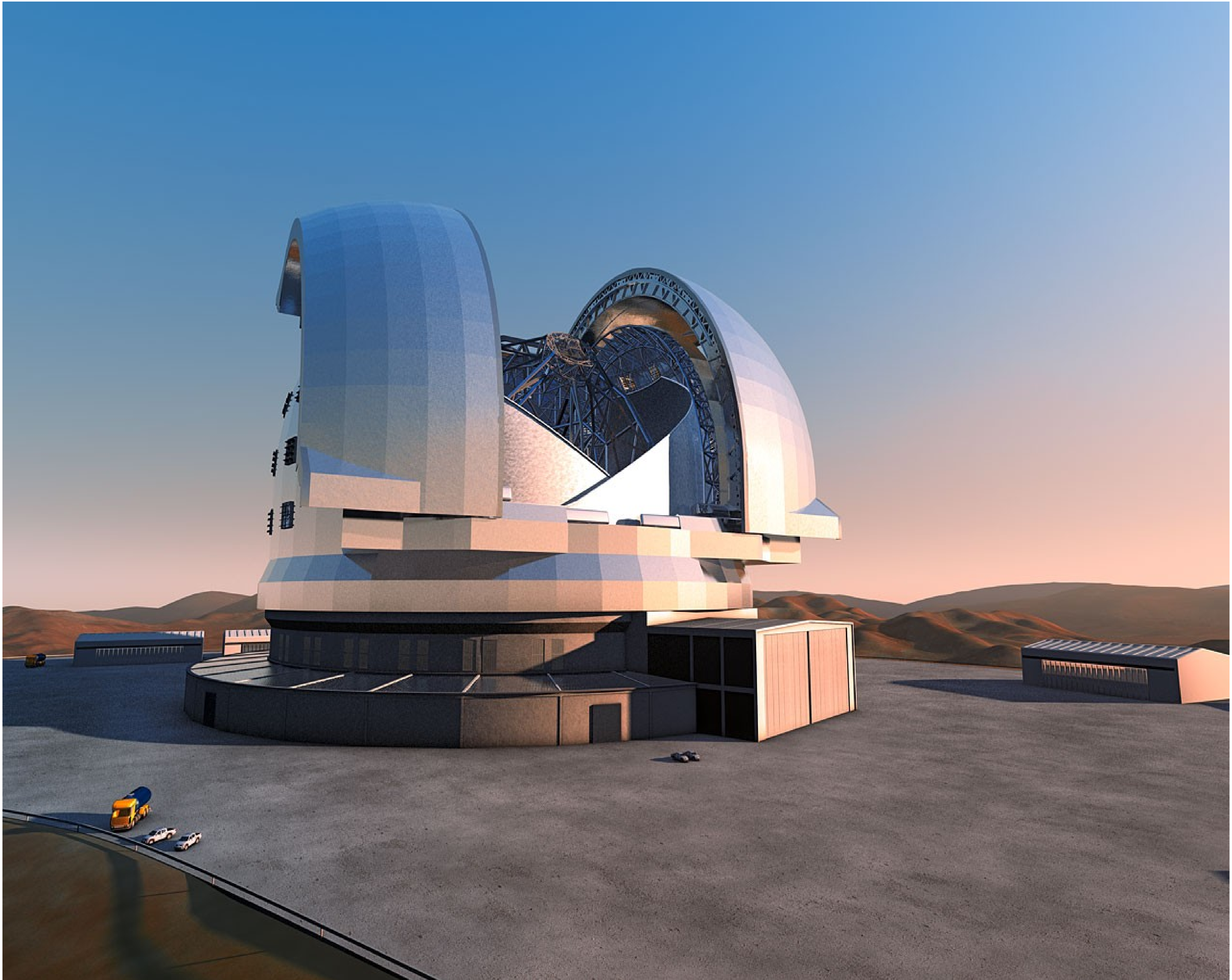
Habitable Zones within 5 pc (16 ly): Astrometry and RV Signal Amplitudes for Earth Analogs




Habitable Zones within 5 pc (16 ly)
Star Temperature [K]
1 Gliese 1245 A
2 Gliese 1245 B
3 Gliese 674
4 Gliese 440 (white dwarf)
5 Gliese 876 (massive planets in/near HZ)
6 Gliese 1002
7 Gliese 3618
8 Gliese 412 A
9 Gliese 412 B
10 AD Leonis
11 Gliese 832
Proxima Cen
Barnard's Star
CN Leonis
UV Ceti
BL Ceti
Ross 154
Ross 248
EZ Aqu A,B &
YZ Ceti
Ross 128
Gl15 B
GJ 1061
SRC 1845-6357 A
DEN1048-3956
DX Cnc
Teegarden's star
Van Maanen's Star
Ross 614 B
Wolf 424 A
Wolf 424 B
TZ Arietis
LHS380
LHS 292
LP944-020
Kruger 60 B
Ross 614 A
Kapteyn's star
Procyon B
Gl725 B
Gl725 A
Gl15 A
Lalande 21185
Sirius B
Lacaille 9352
Luyten's star
Kruger 60 A
Wolf 1061
Gliese 1
Gliese 687
40 Eri C
40 Eri B
40 Eri A
AX Mic
61 Cyg A
61 Cyg B
Eps Indi
Eps Eri
Tau Ceti
Groombridge 1618
α Cen B
α Cen A
Procyon A
Sirius
Circle diameter indicates angular size of habitable zone
Circle color indicates stellar temperature (see scale right of figure)
Contrast is given for an Earth analog receiving the same stellar flux as Earth receives from Sun (reflected light)
log Contrast
distance (pc)
A
F
G
K
M

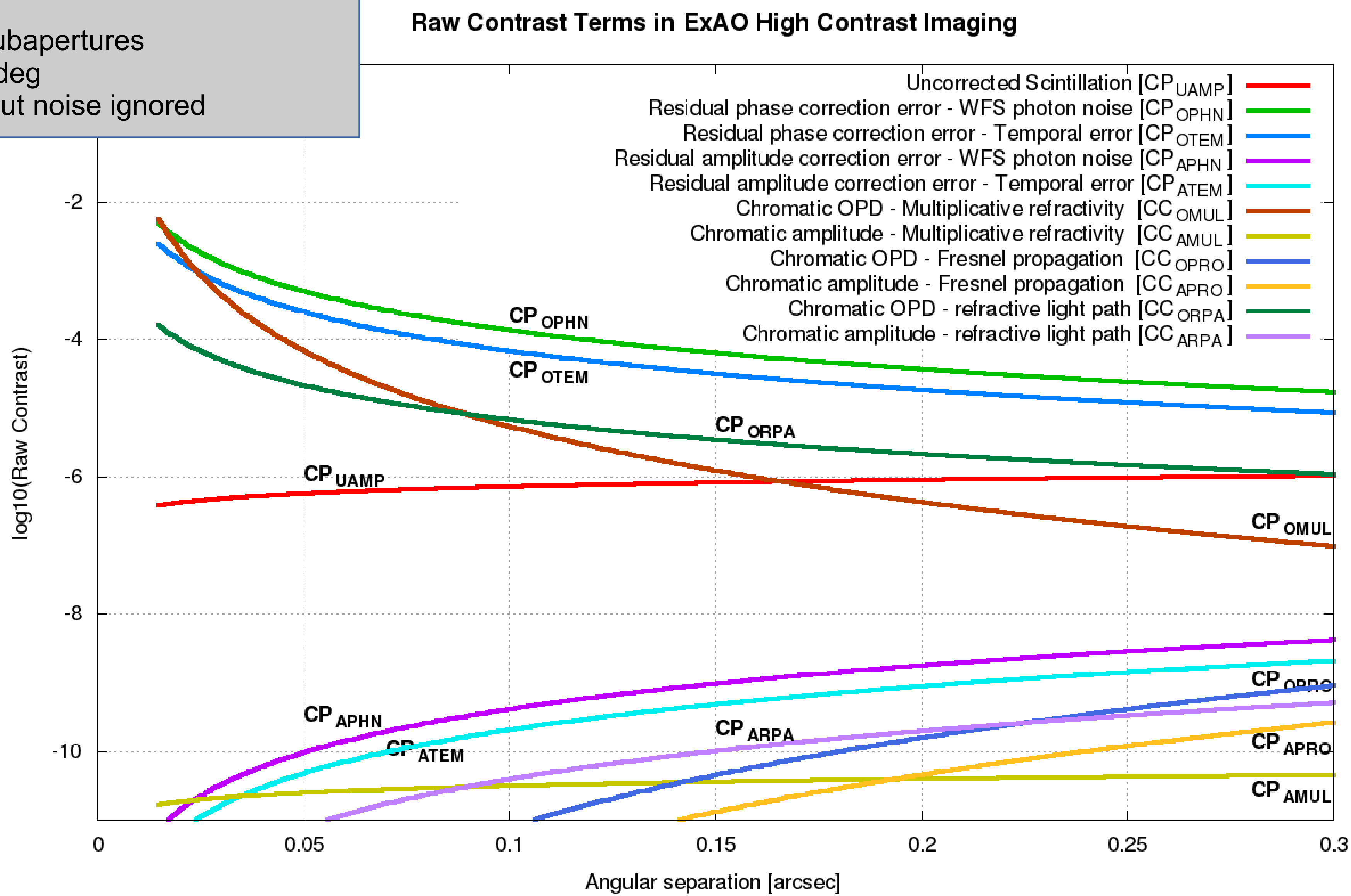




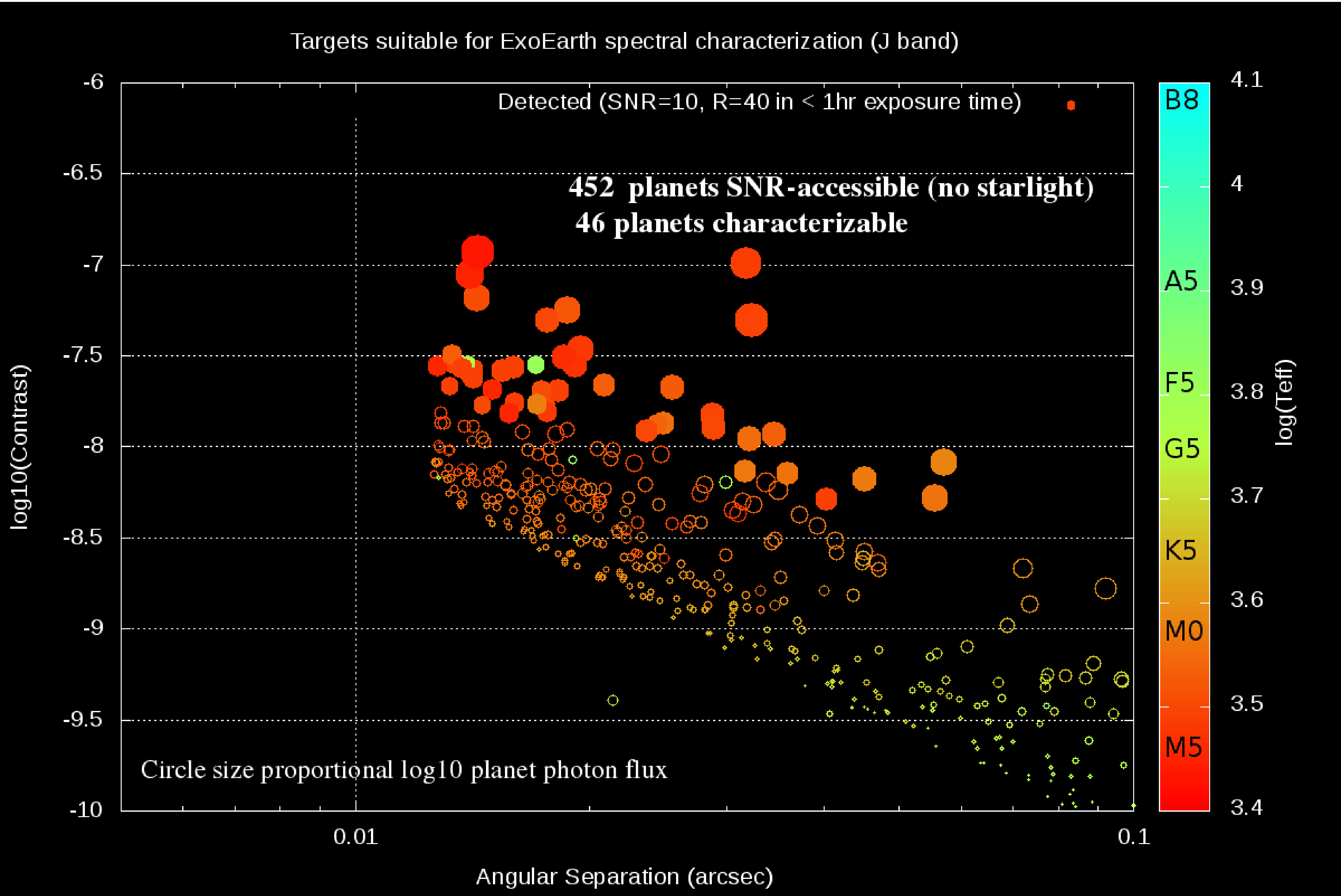


Contrast Error Budget
→ 1e-6 raw contrast

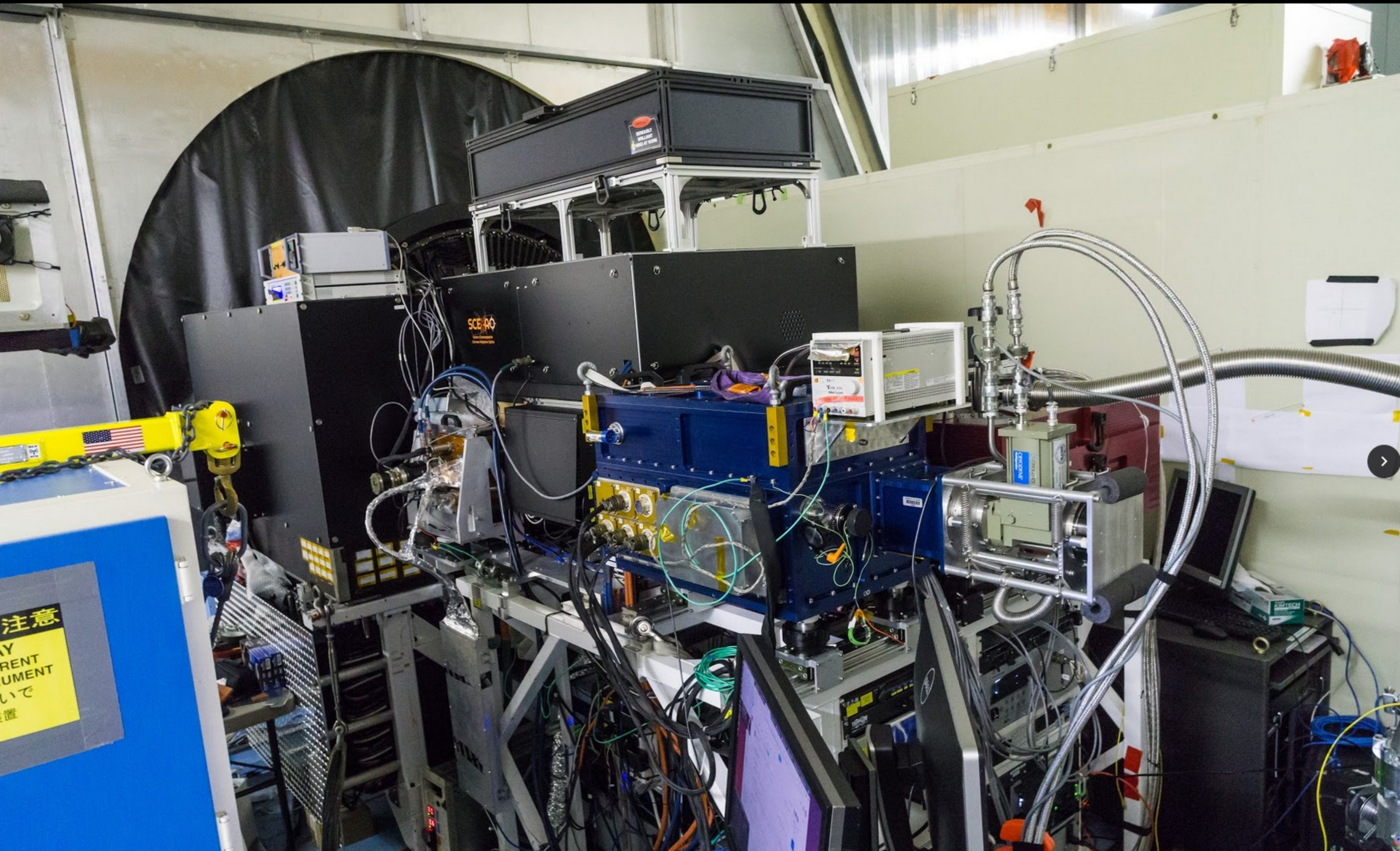
D=30m telescope
High contrast imaging at 1.6 um
Wavefront sensing at 0.8 um
30% efficiency WFS
40% wide WFS spectral band
5 kHz WFS frame rate
Integrator controller with optimal gain setting
Wind speed = 10 m/s
Fried parameter r_0 = 0.15 m at 0.5 um
m_I = 8 target
SHWFSm 15cm subapertures
Zenith angle = 40 deg
Aliasing and readout noise ignored



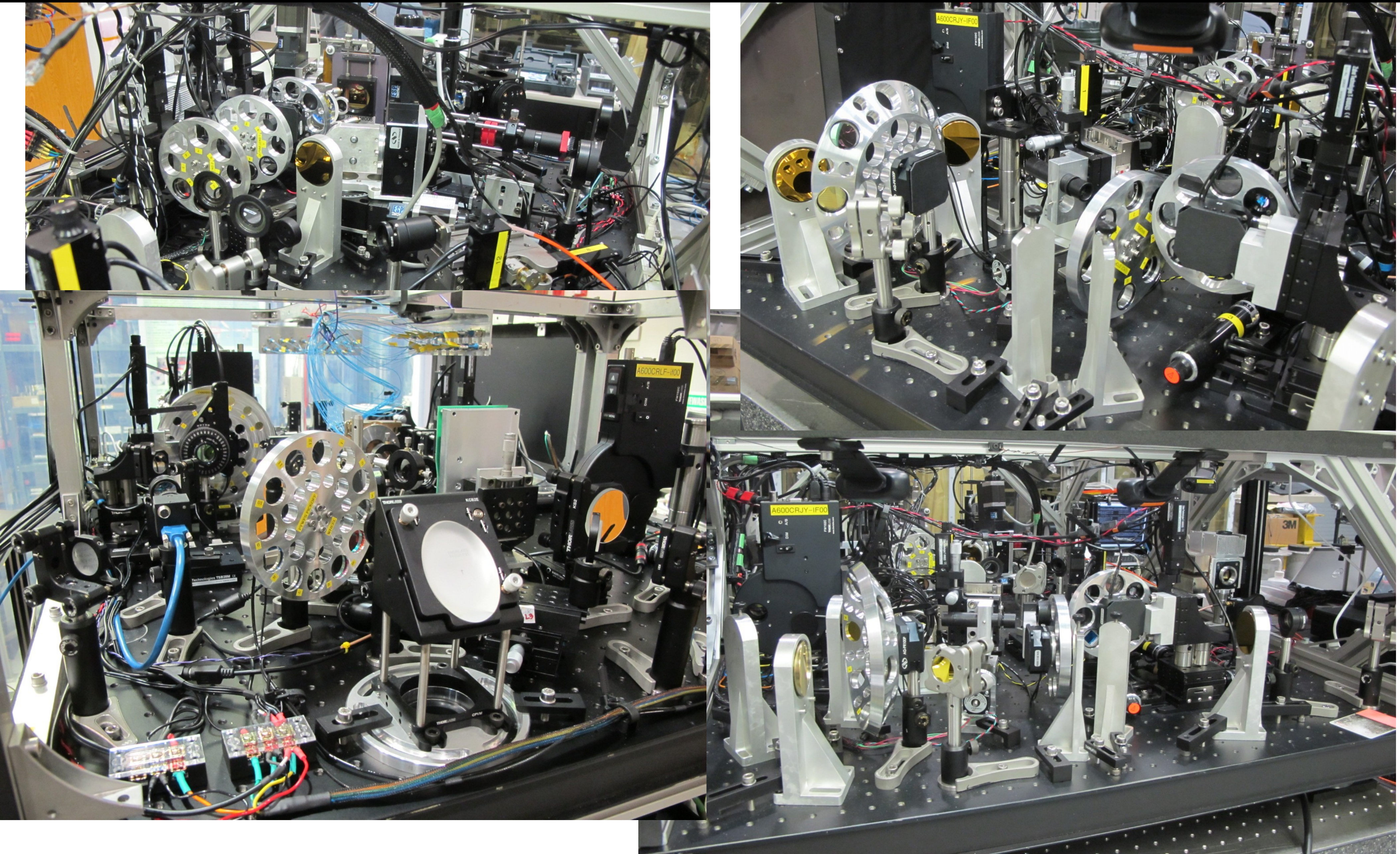
Photon-noise limited detections (1e-6 raw contrast at 1um)



Subaru Coronagraphic Extreme Adaptive Optics



Subaru Coronagraphic Extreme Adaptive Optics



Characterizing nearby habitable planets - future highlights

Now: Apha Cen system

TOLIMAN program + Thermal imaging from ground + Small space-based coronagraph

→ Mass, orbit, temperature, albedo, colors

Soon (~5-10yr): Nearby M-type stars (NIR) + few Sun-like Stars

Large Ground-based telescopes (currently in construction)

→ Focus on M-type stars: biomarkers in Near-IR

→ Thermal imaging of hab planets around few nearby Sun-like stars

Later (~10-20yr): Nearby Sun-like stars

Large (4m+) space telescopes

→ Visibe light high contrast imaging, spectroscopy

Important note: Transit spectroscopy may get lucky