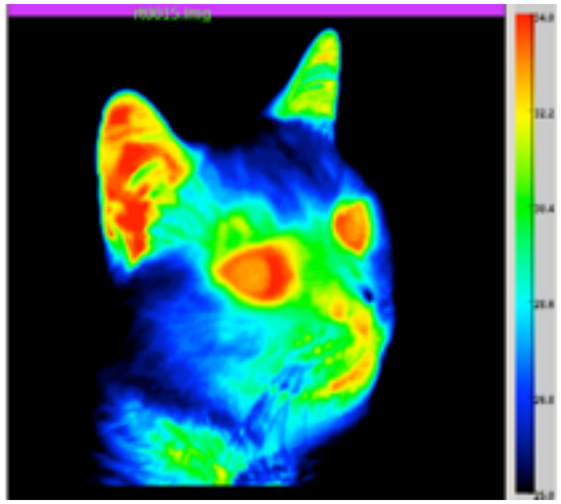


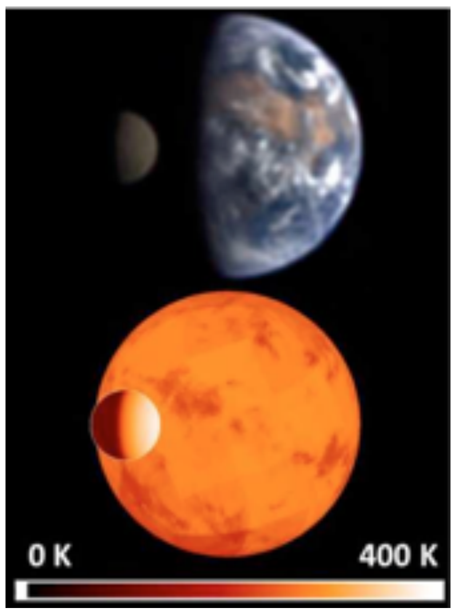
Ground-based **Thermal** imaging of Habitable Exoplanets

Christian Marois
NRC Astronomy & Astrophysics

Keck

KISS
Pasadena, USA
20161205

Why 10 microns?



Flux from the planet
(a closer look)

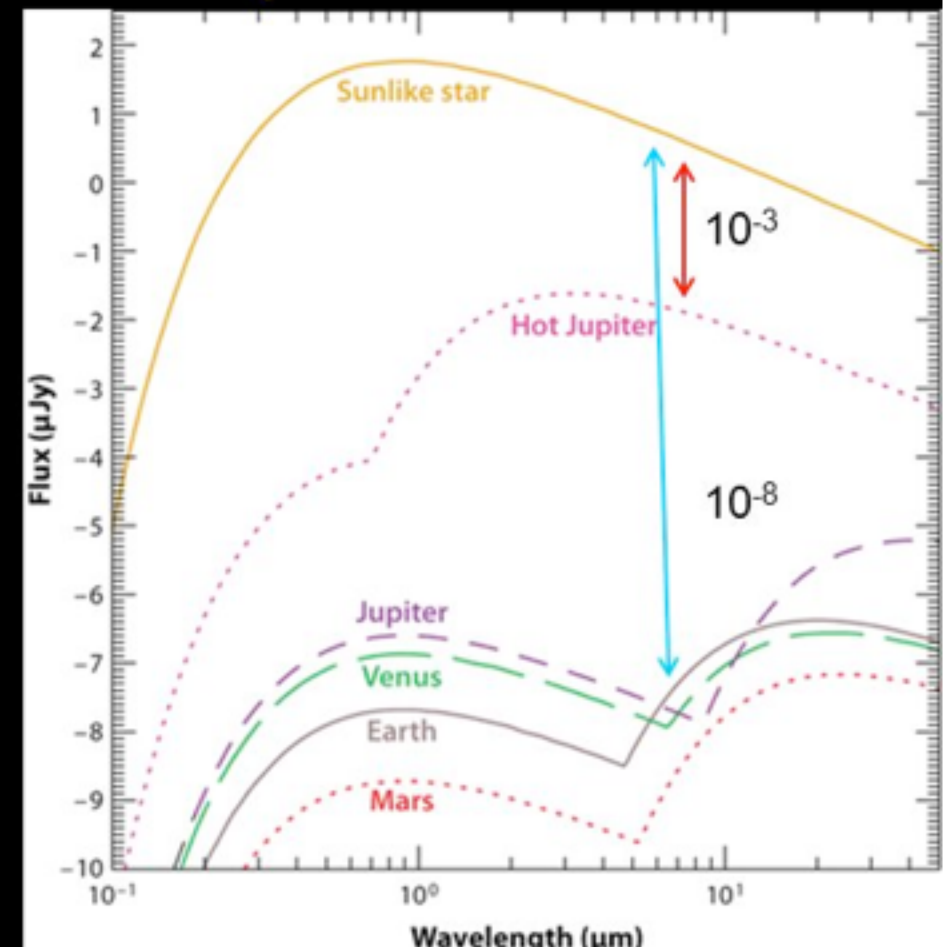
Peak flux:

Sun ~ 0.58 micron
Hot-Jupiter > 3 micron
Earth ~ 10 micron

Flux ratio (~ 8 micron):

Hot-jupiter/Sun ~ 10^{-3}
Earth/Sun ~ 10^{-8} !!!

Also, the flux ratio is favorable where the flux from the star & planet is high (more photons)



Seager S, Deming D. 2010.
Annu. Rev. Astron. Astrophys. 48:631–72

Ground-based observations/characterization of habitable planets around Sun-like stars.

Optimize instrument

- Higher QE detector
- No dither/chop
- AO with gold coated optics
- Coronagraph
- Dedicated campaign

Tab. 1 Exo-Earth sensitivity calculation table for 10-micron imaging spectroscopy

	T-RECS/ MICHELLE	8-m ExAO	30-m ExAO
On sky limit (5 sigma) 2h on sky	11.1	-	-
Detector QE	20%	80% (+0.75 mag)	80% (+0.75 mag)
FWHM (arcsec)	0.50 (70%-ile)	0.26 (+0.7 mag)	0.069 (+4.3 mag)
Time for orbit to move by l/D at 1 arcsec around Alpha Centauri	28 days	14 days	4 days
Obs. efficiency[1]	50%	90% (+0.32 mag)	90% (+0.32 mag)
Sequence length (hours)	2	100 (+2.12 mag)	30 (+1.47 mag)
Inst. throughput	50%	30% (-0.28 mag)	30% (-0.28 mag)
Warm low emissivity optics[2,3,4,5]	1 + 2 surfaces from telescope	1 + 3 at 5C + 2 surfaces from telescope (-0.12 mag)	1+ 3 at 5C + 3 surfaces from telescope (-0.12 mag)
Optimize 10-13 microns filter for detection	-	1.5x SNR (+0.44 mag)	1.5x SNR (+0.44 mag)
5 sigma limit Basic characterization	11.1	15.0	18.0
3 sigma limit Detection only	11.7	15.6	18.6

Earth at Alpha Cent
N=15.2

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	50	**0.17**	Y (30m)
Super-Earth (Kepler 22b)	2	288	13.7	**3**	**0.01**	Y
Warm Earth (Dune planet)	1	320	14.8	**23**	**0.08**	Y

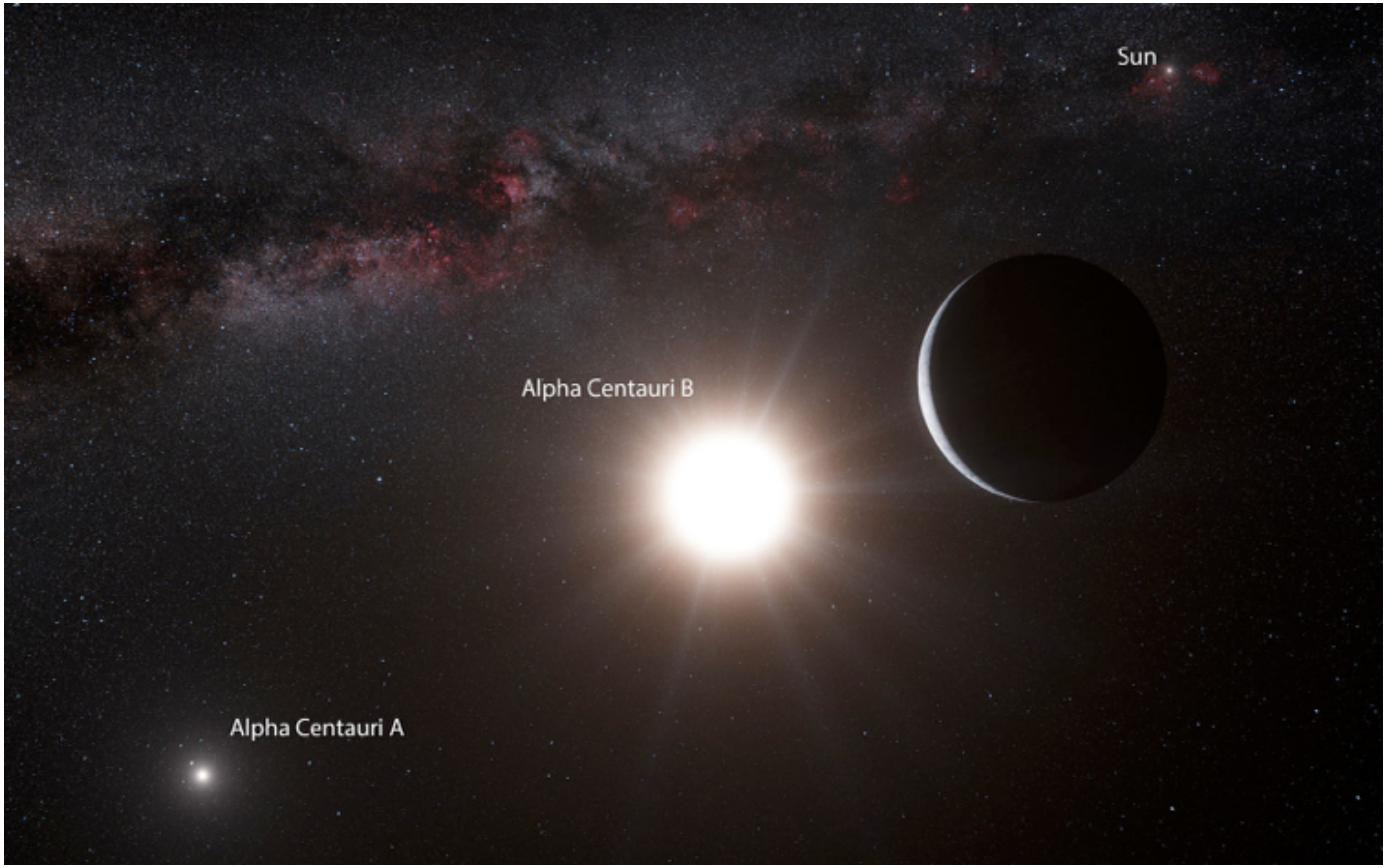
Tab. 3 Apparent magnitude and required time at 10-13 microns of exo-Earth planets at **5pc**

	Radius (Earth)	Temperature (K)	App. Mag. 10 microns	Time on 30m 5 sig. det. (h)	Charact ?
Earth	1	288	18.1	**36**	~Y
Super-Earth (Kepler 22b)	2	288	16.6	**2**	Y
Warm Earth (Dune planet)	1	320	17.7	**17**	Y

Tab. 4 Apparent magnitude and required time at 10-13 microns exo-Earth at **10pc**

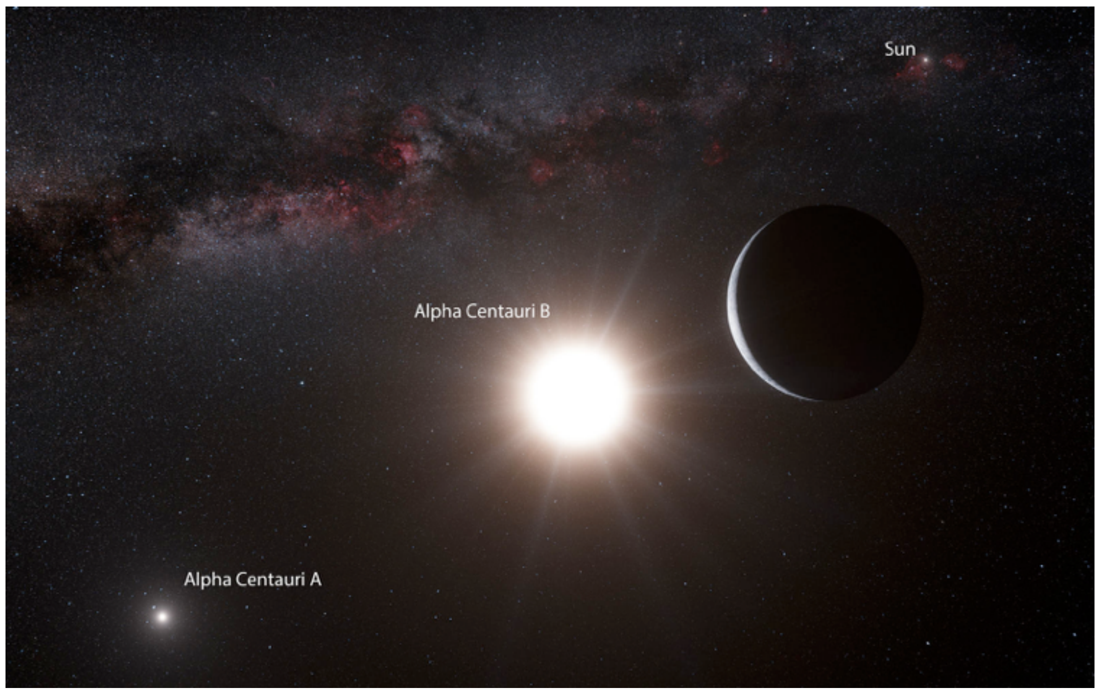
	Radius (Earth)	Temperature (K)	App. Mag. 10 microns	Time on 30m 5 sig. det. (h)	Charact ?
Earth	1	288	19.6	**571**	~Y
Super-Earth (Kepler 22b)	2	288	18.2	**43**	~Y
Warm Super-Earth (Kepler 22b)	2	320	17.7	**17**	Y

Thermal imaging of planets around Alpha Centauri A & B



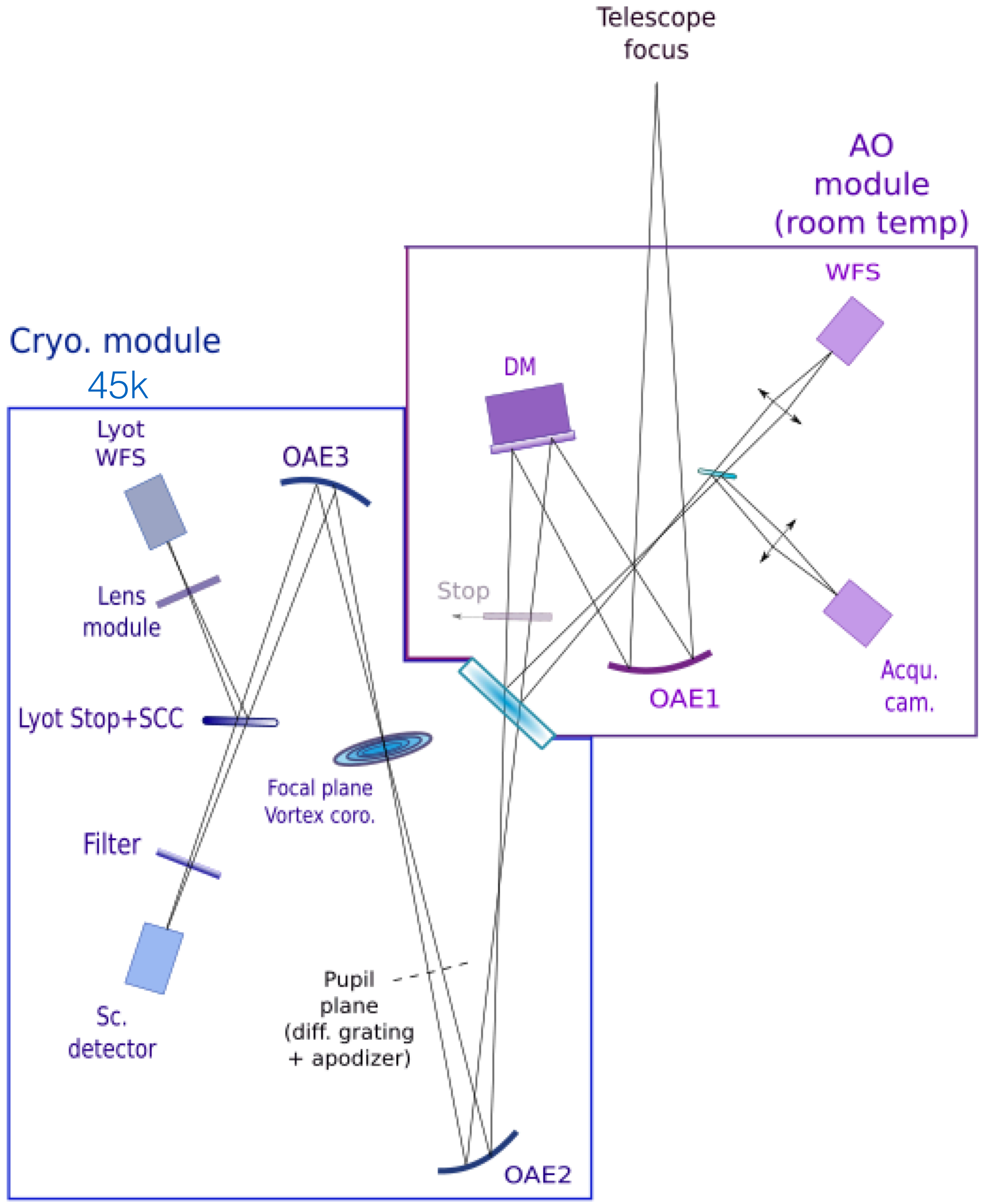
For Alpha Centauri, HZ rocky planet imaging at 10 microns requires a contrast comparable to GPI/SPHERE at similar separations.

Alpha Centauri

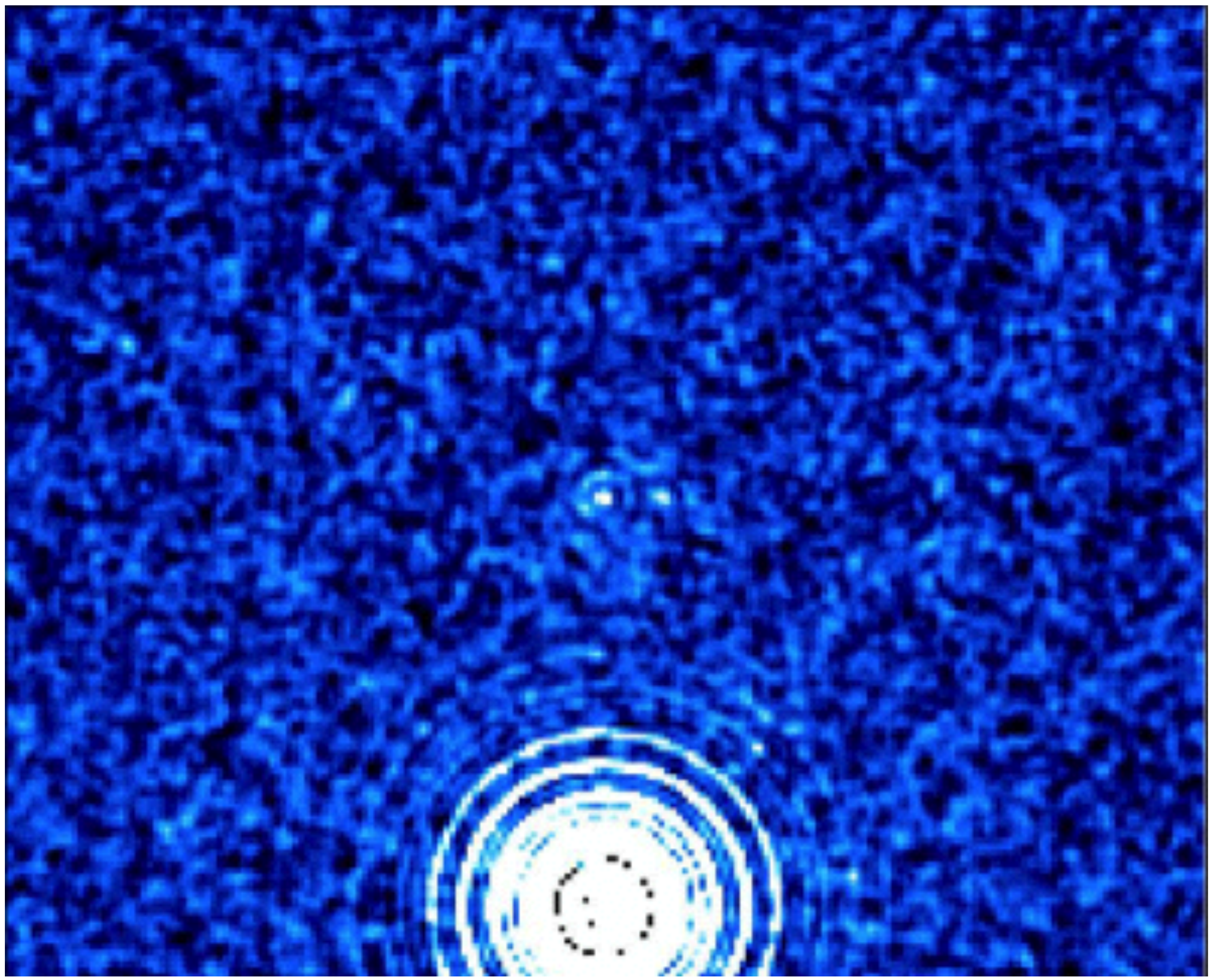



Tiki

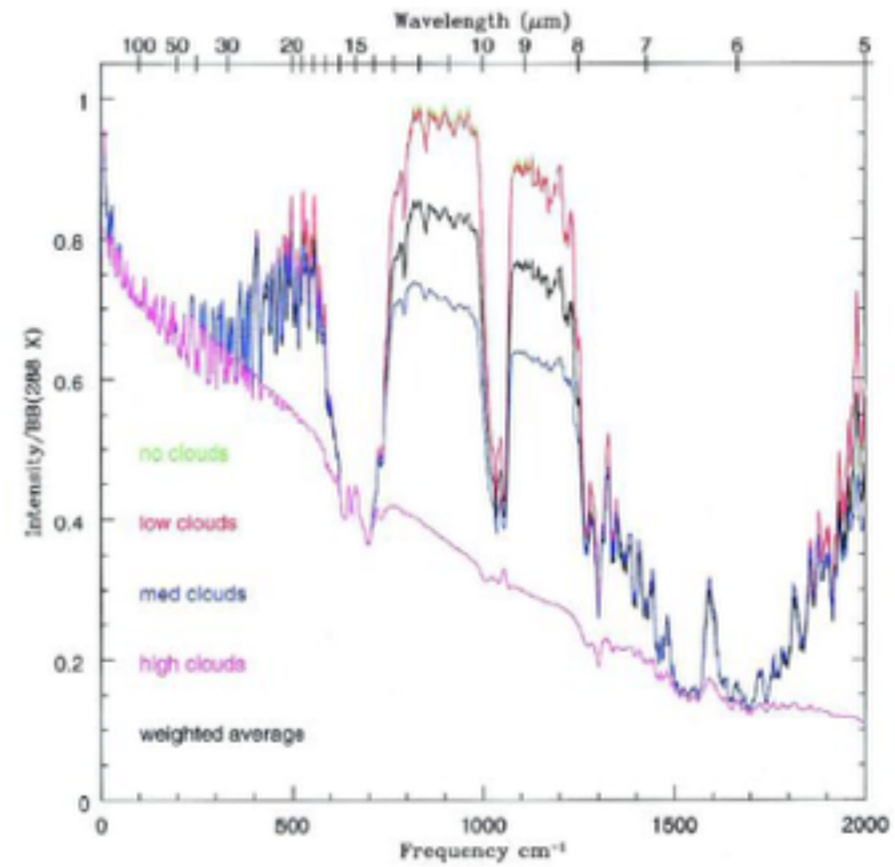
TIKI preliminary optical design



Alpha Centauri @ 10 microns

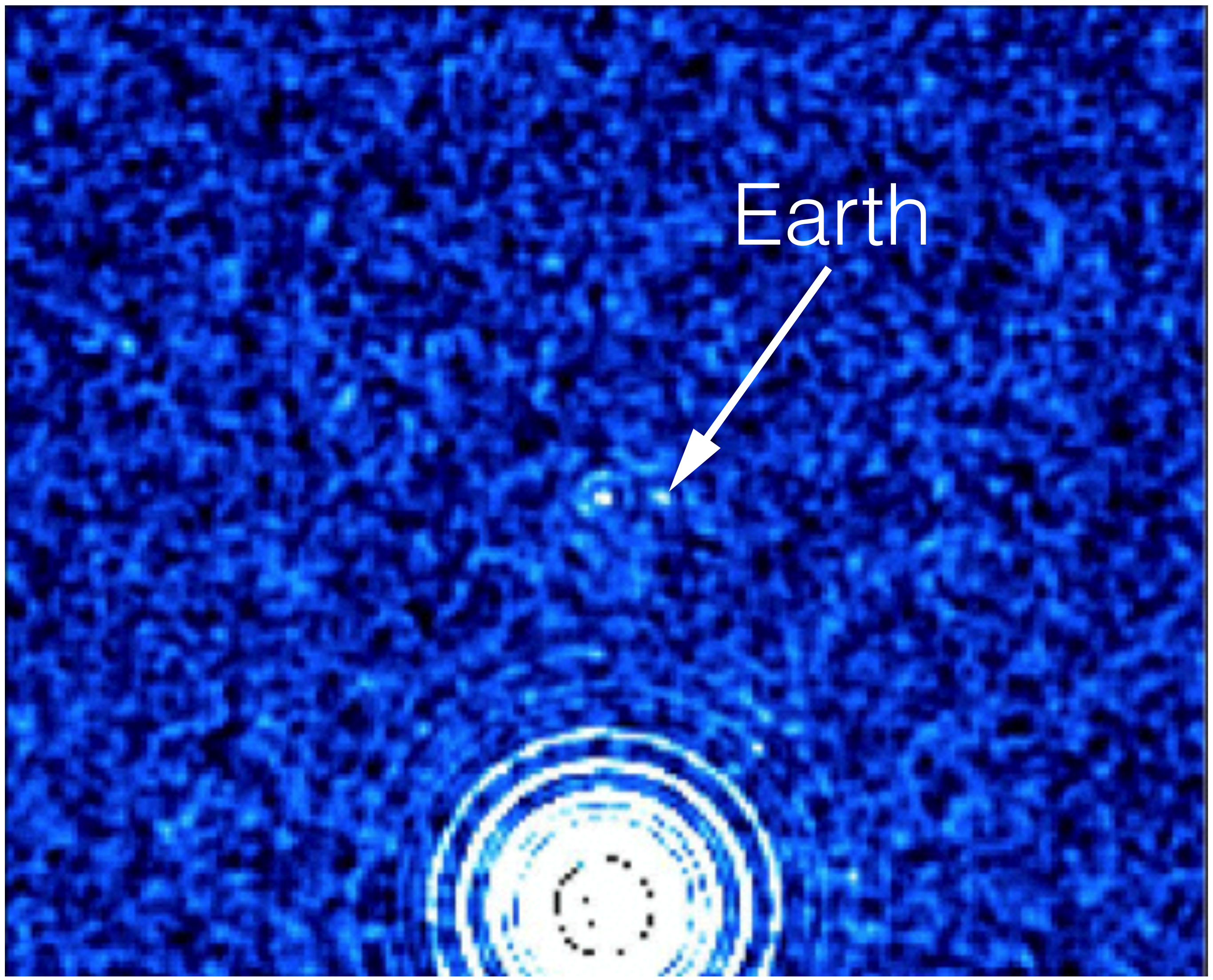


Tiki @ Gemini South
~2019, ~50h

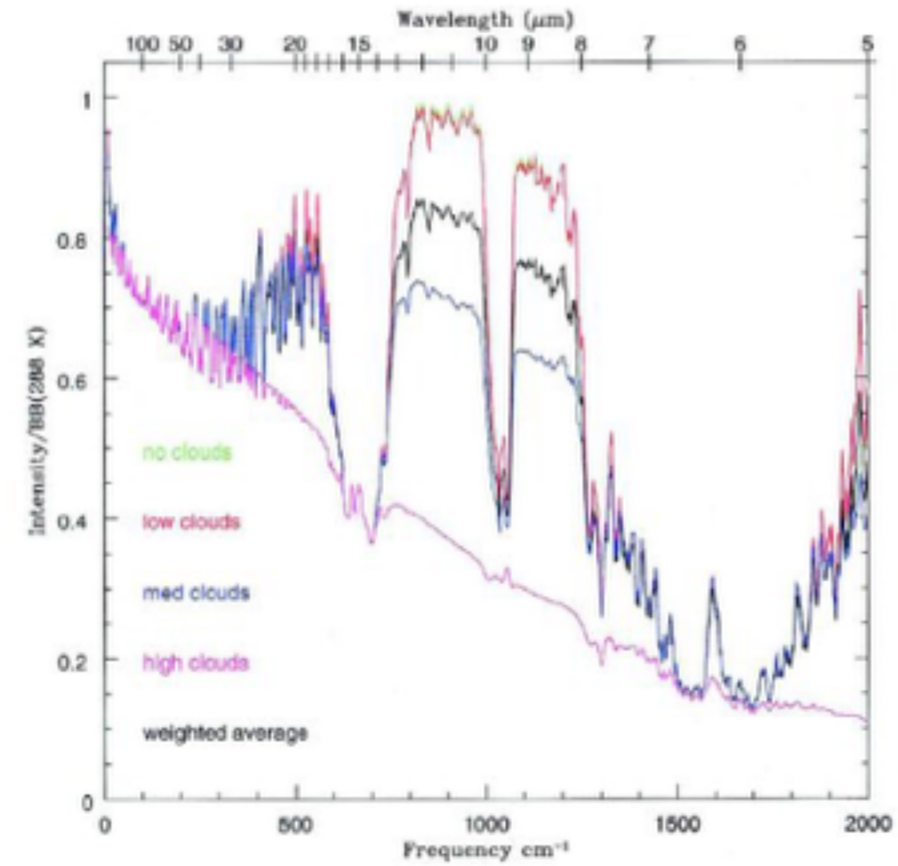


Des Marais et al. (2002)

Alpha Centauri @ 10 microns

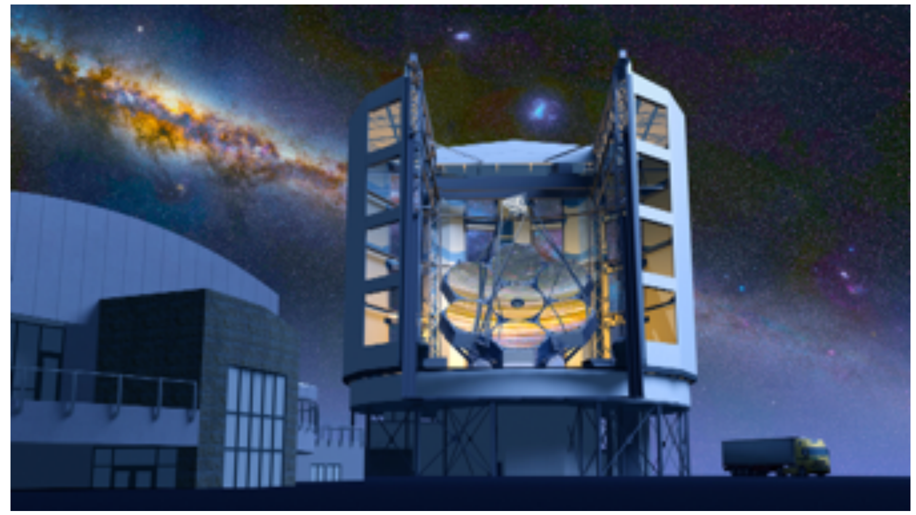


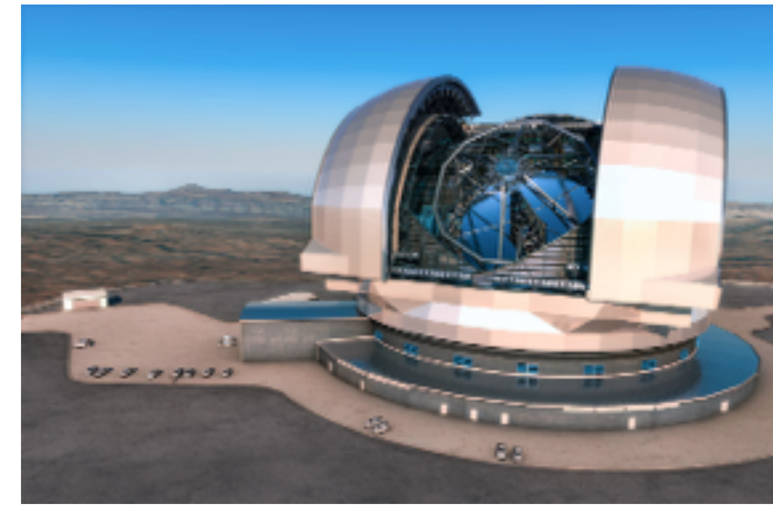
Tiki @ Gemini South
~2019, ~50h



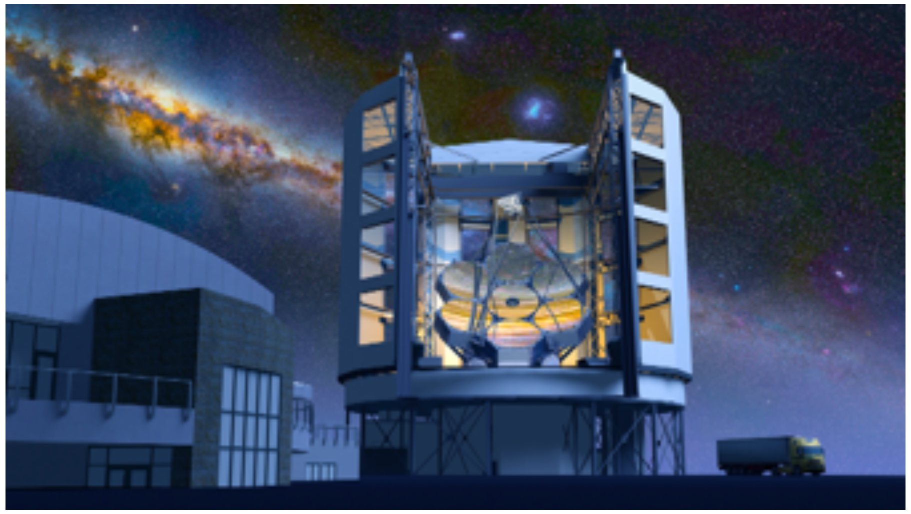
Des Marais et al. (2002)

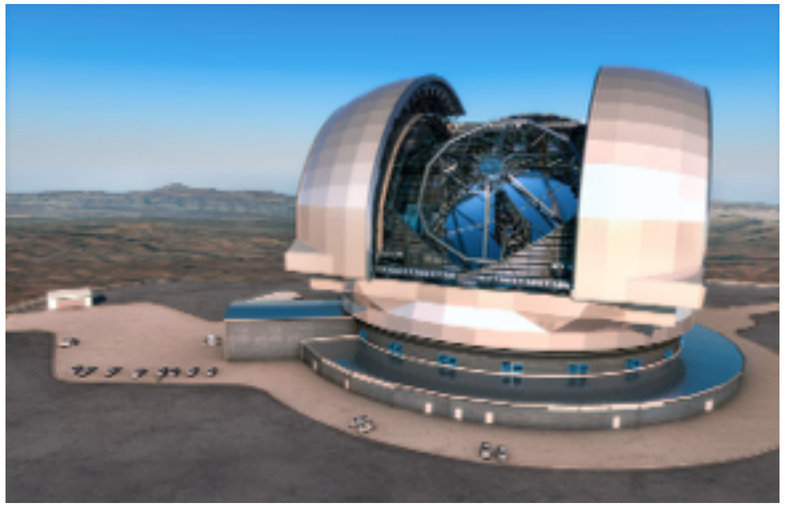
Alpha Cent A & B with ELTs

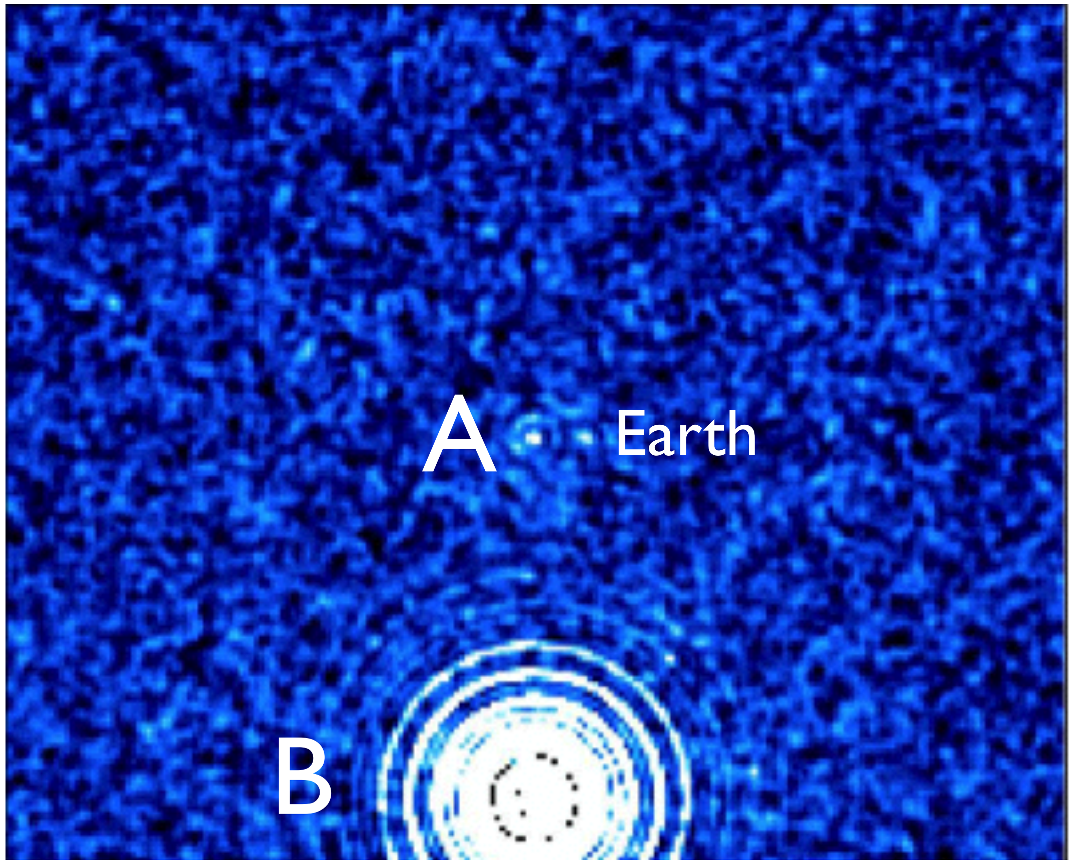




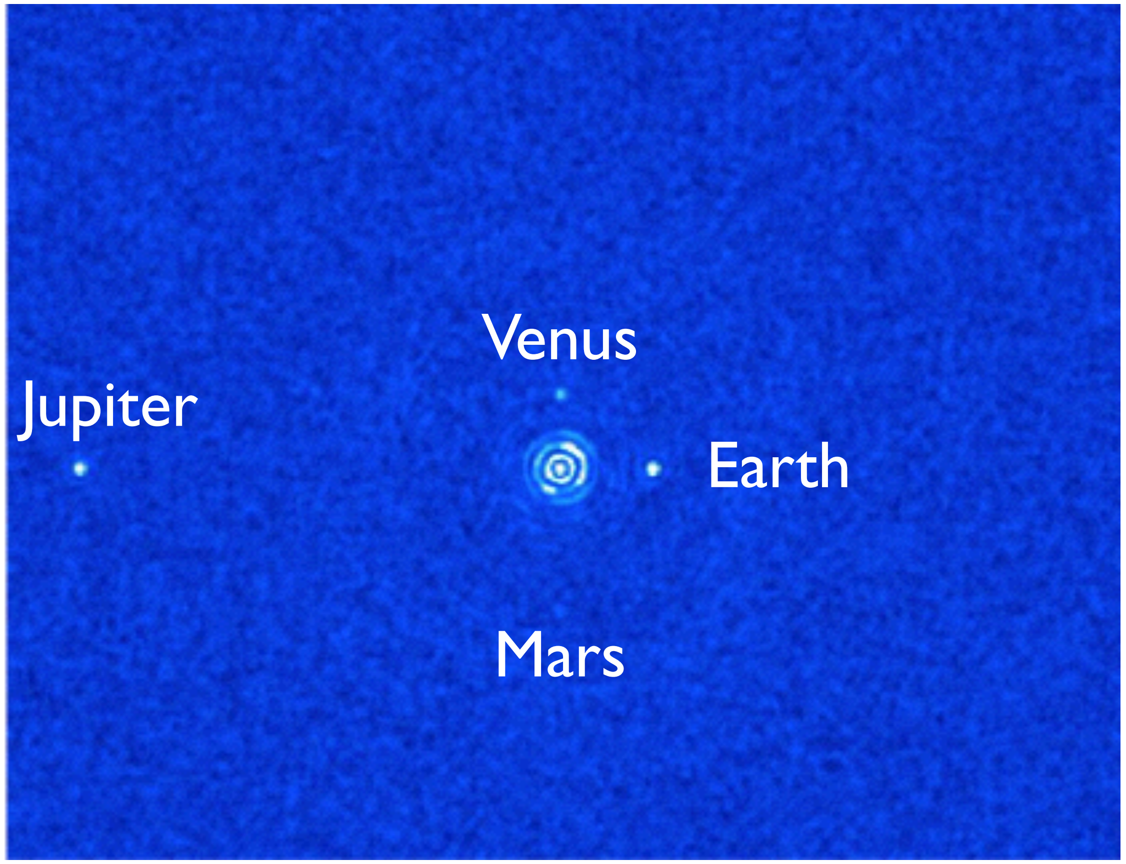
Alpha Cent A & B with ELTs







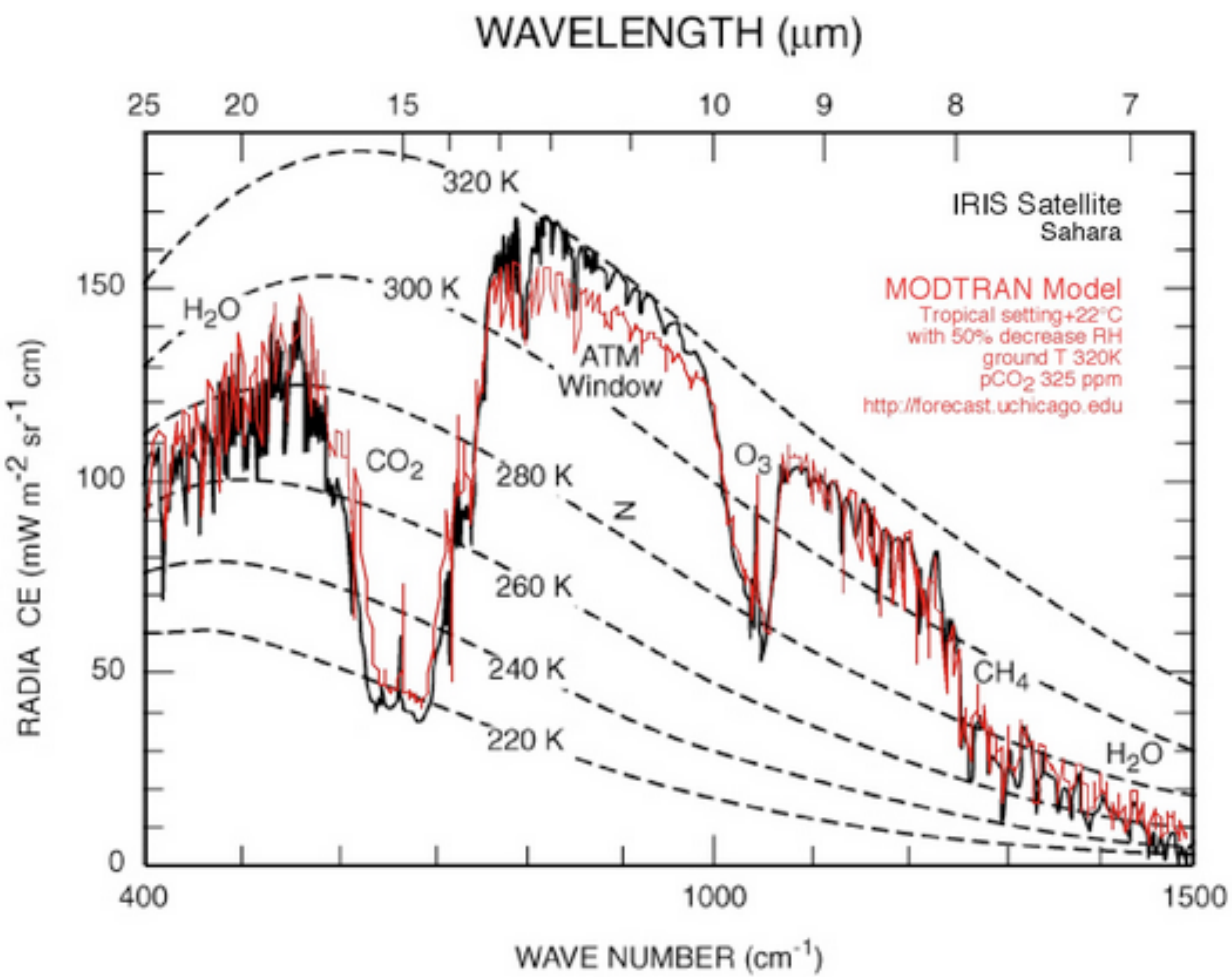
50h 8m



25h TMT

What IF we find something?

Earth like



10 microns remote sensing

- Orbit
- Surface temperature
- O3
- Water
- CO2
- CH4
- Clouds/radius

Not Earth-like

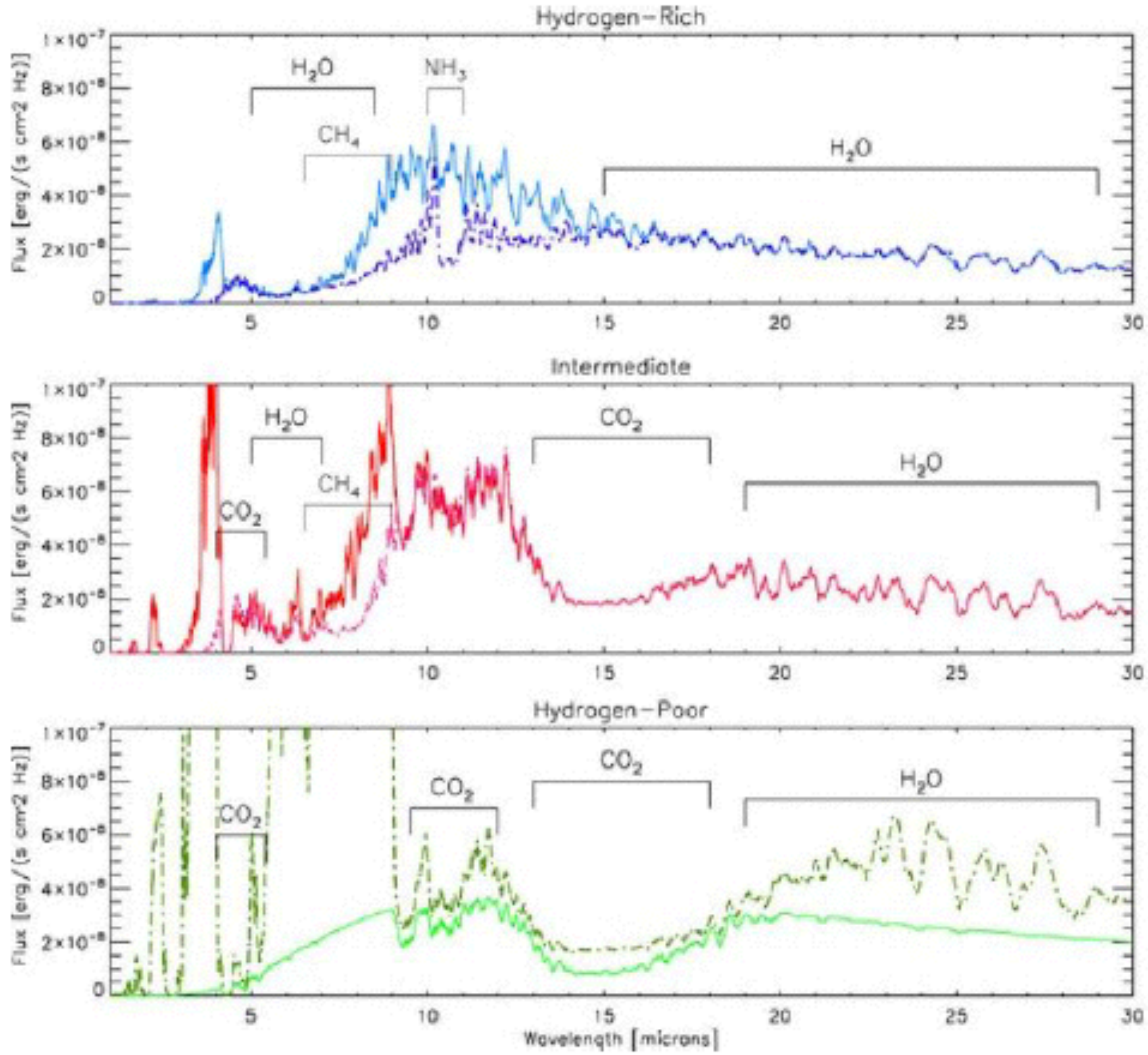
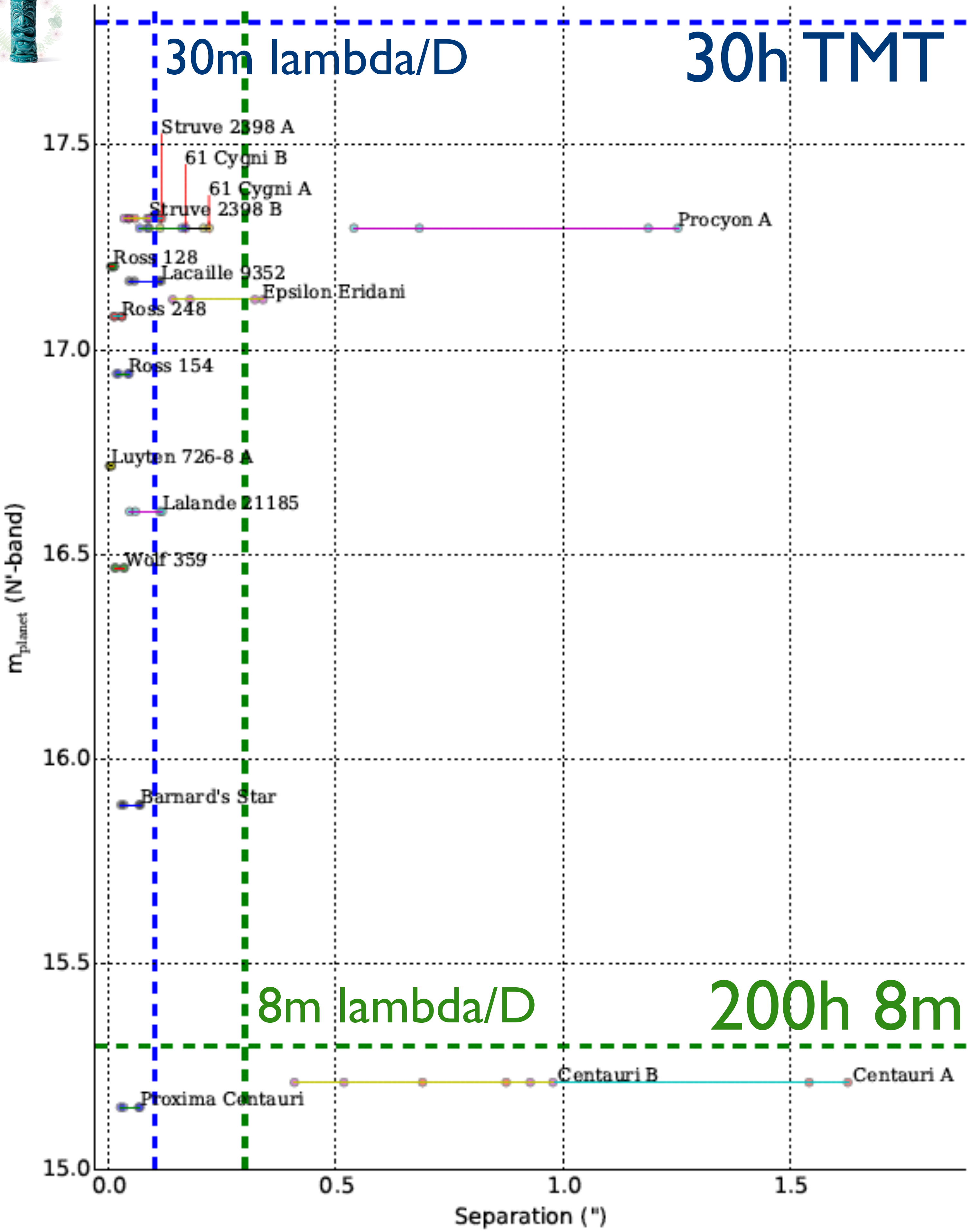
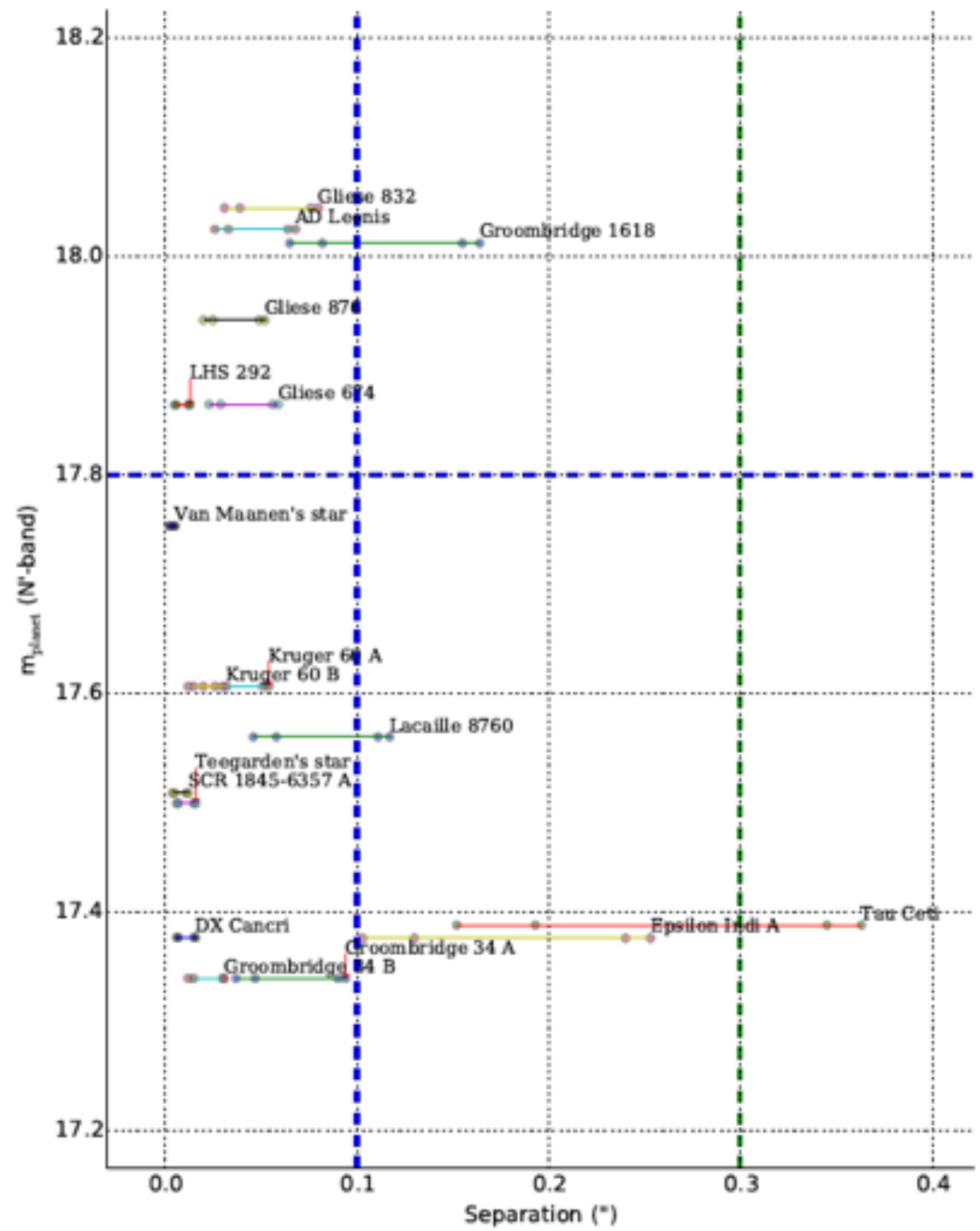


Fig. 8. Expected spectrum for exo-Earth having various types of atmospheres. From Kempton et al. 2009

Earth-size 280K





Bialek & Marois in prep

University of Victoria

C. Bradley PM/coPI
C. Blain
(Masen Lamb)
Ben Gerard
(J. Kennedy)
(D. Gamroth)
(J. Reynolds)

NRC·CNRC

C. Marois PS/coPI
O. Lardiere
J. Pazder
J.-P. Veran

SETI INSTITUTE

F. Marchis
(Jeff Chilcote)

California Institute of Technology 1891

D. Mawet

JPL Jet Propulsion Laboratory

G. Serabyn

The University of Texas at Austin

C. Packham

université PARIS DIDEROT PARIS 7

R. Galicher

University of California San Diego

C. Melis

Université Laval

S. Thibault

Institute for Astronomy University of Hawai'i

M. Chun

ULg Université de Liège

O. Absil

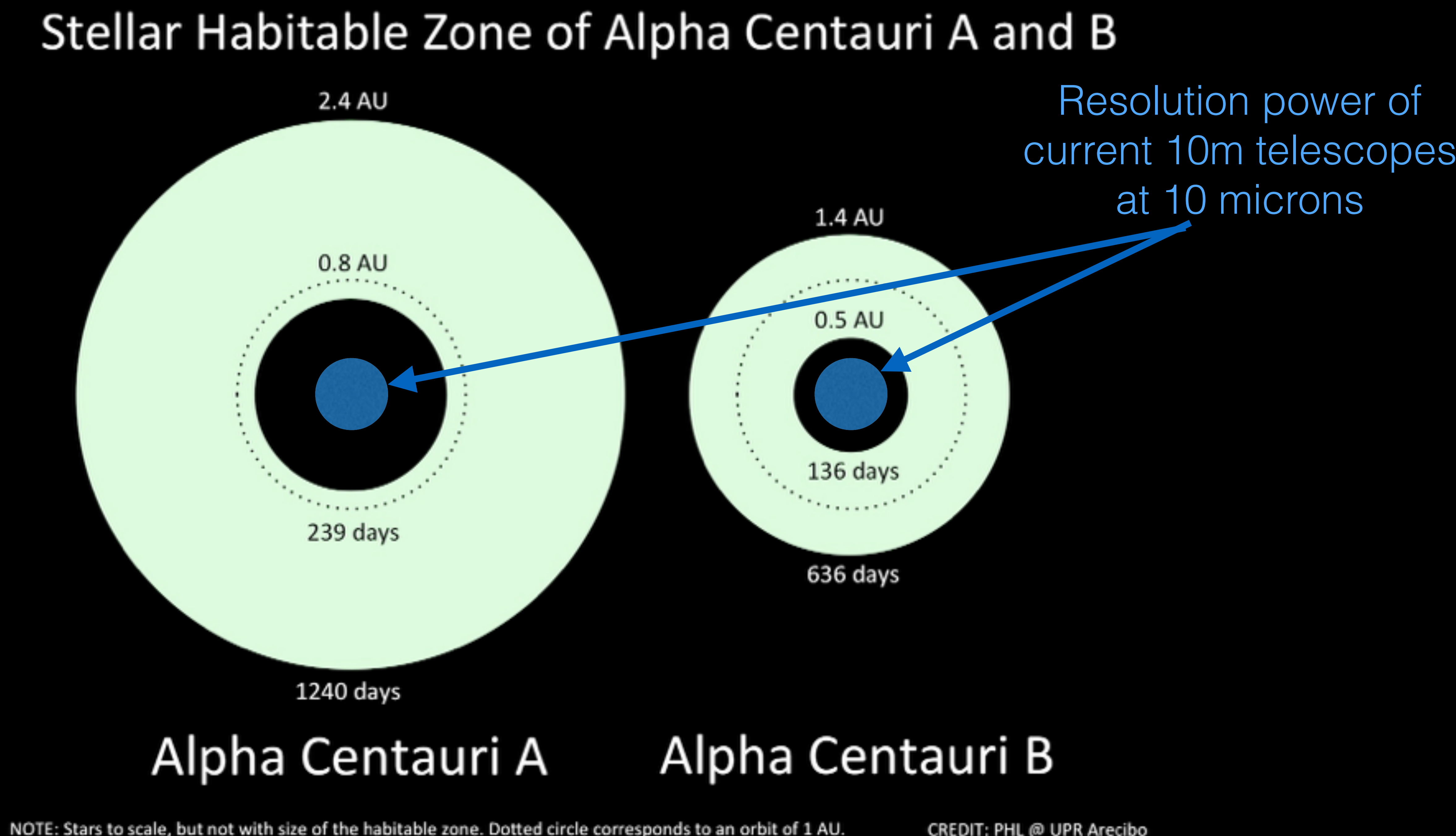
University of California Santa Cruz

A. Skemer

Gemini Observatory Exploring the Universe, Sharing its Wonders

T. Hayward

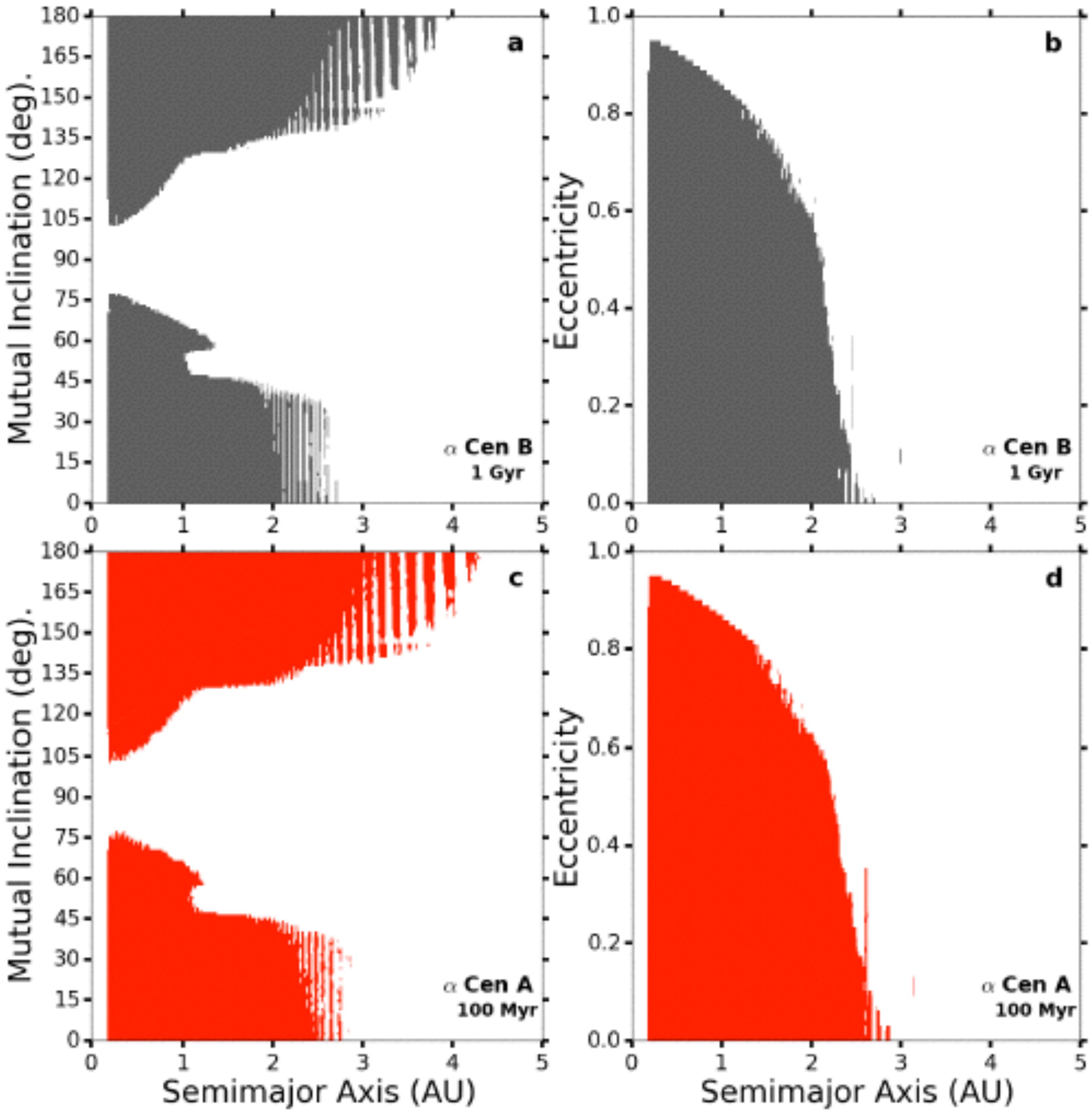
Are 10m telescopes big enough?



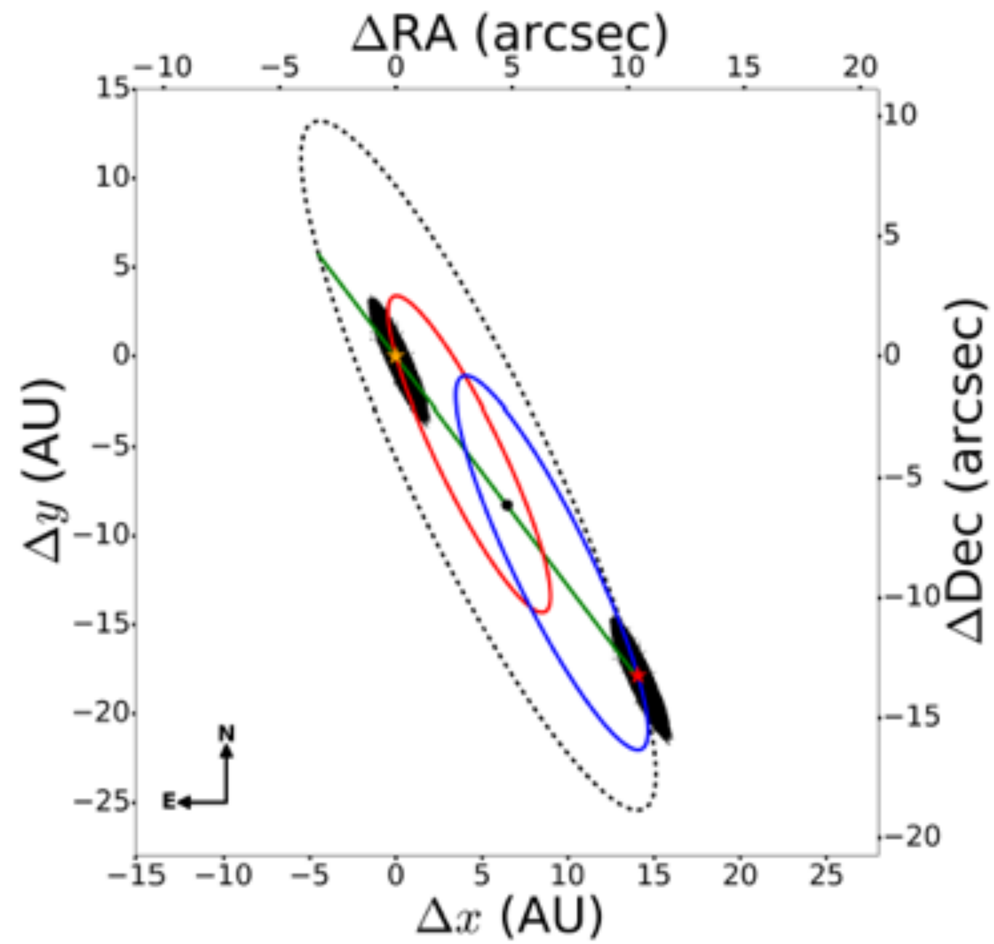
Two stars in the sky that we can do this NOW (not 0…)!

Stable orbits?

Quarles & Lissauer 2016 (astroph April 17, 2016)



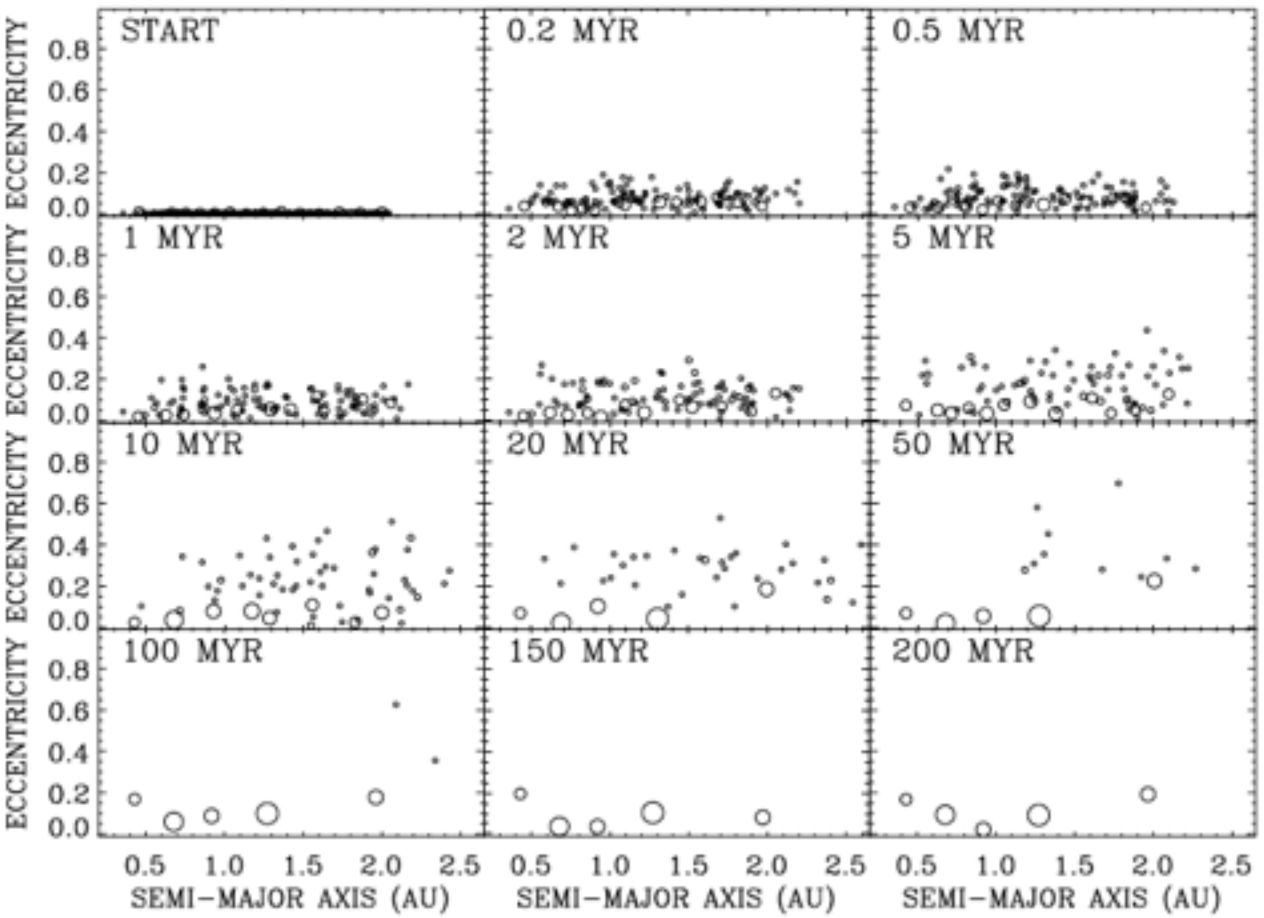
B HZ: 0.5-1.4 AU



A HZ: 0.8-2.4 AU

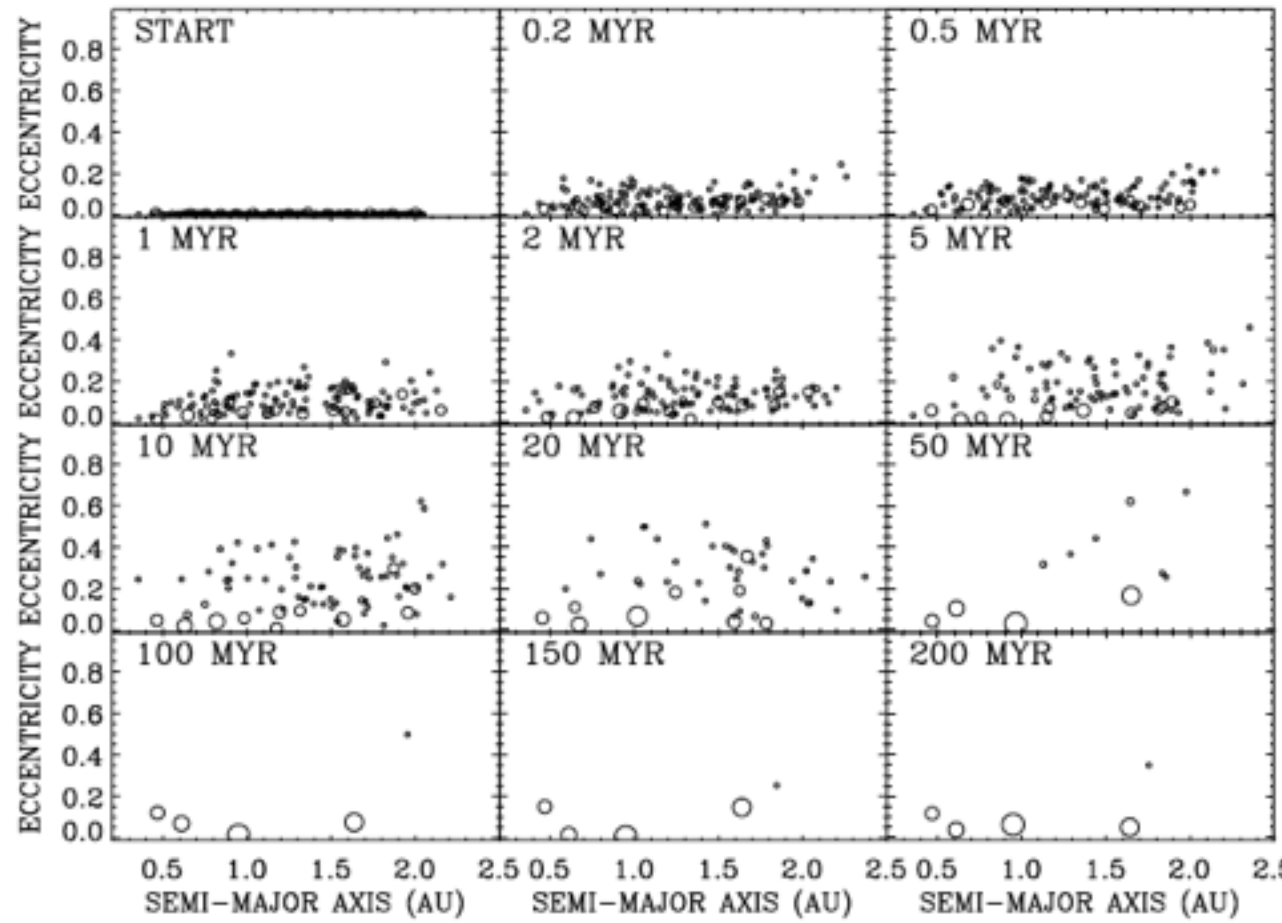
Planet formation in a binary?

Qintana et al. 2002



Alpha Cent A

Qintana et al. 2003

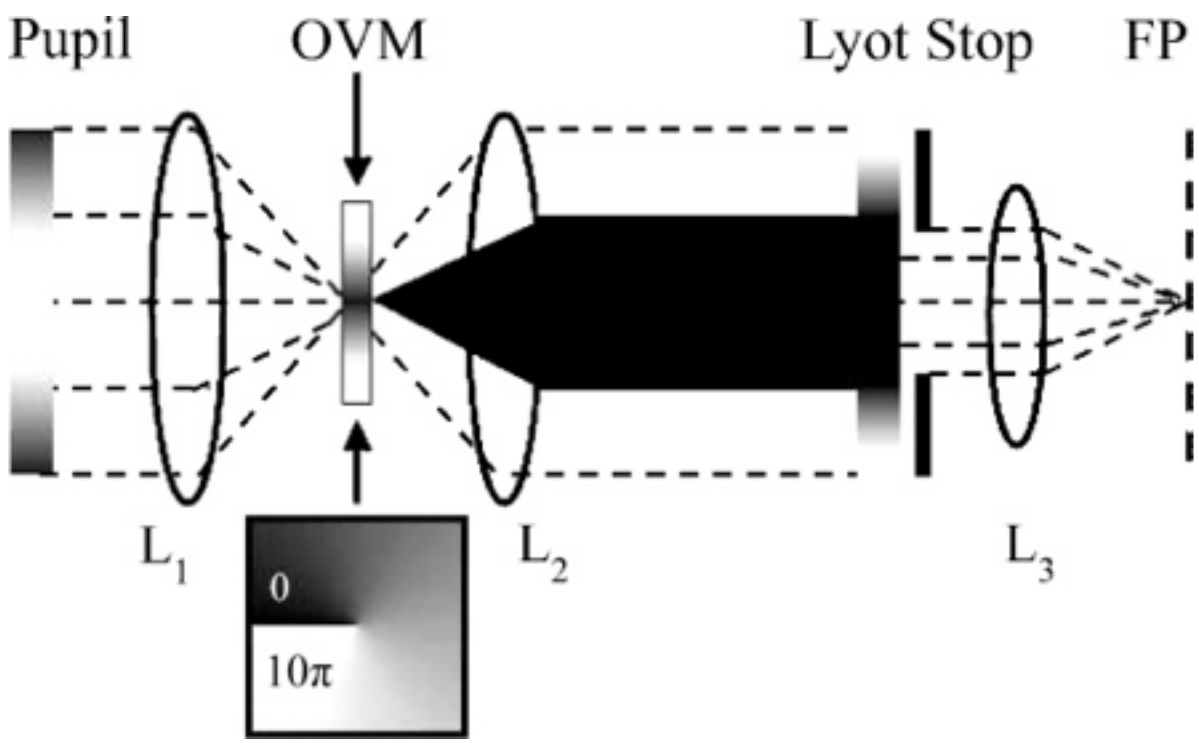


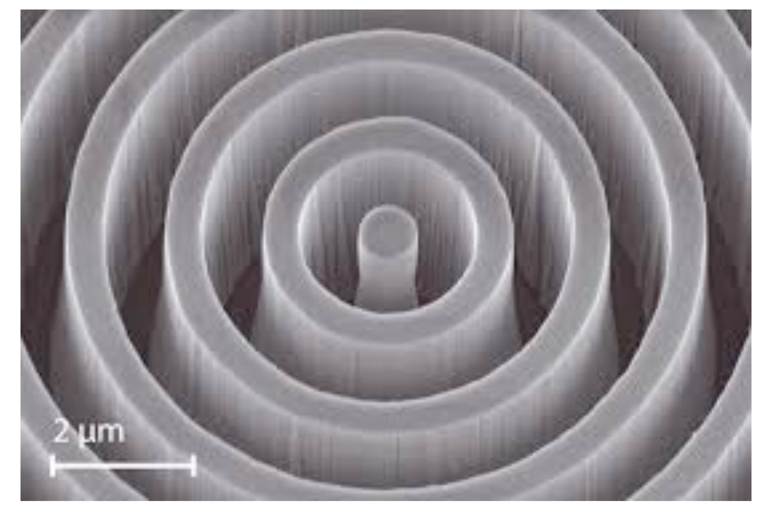
Alpha Cent B

Kepler statistics:

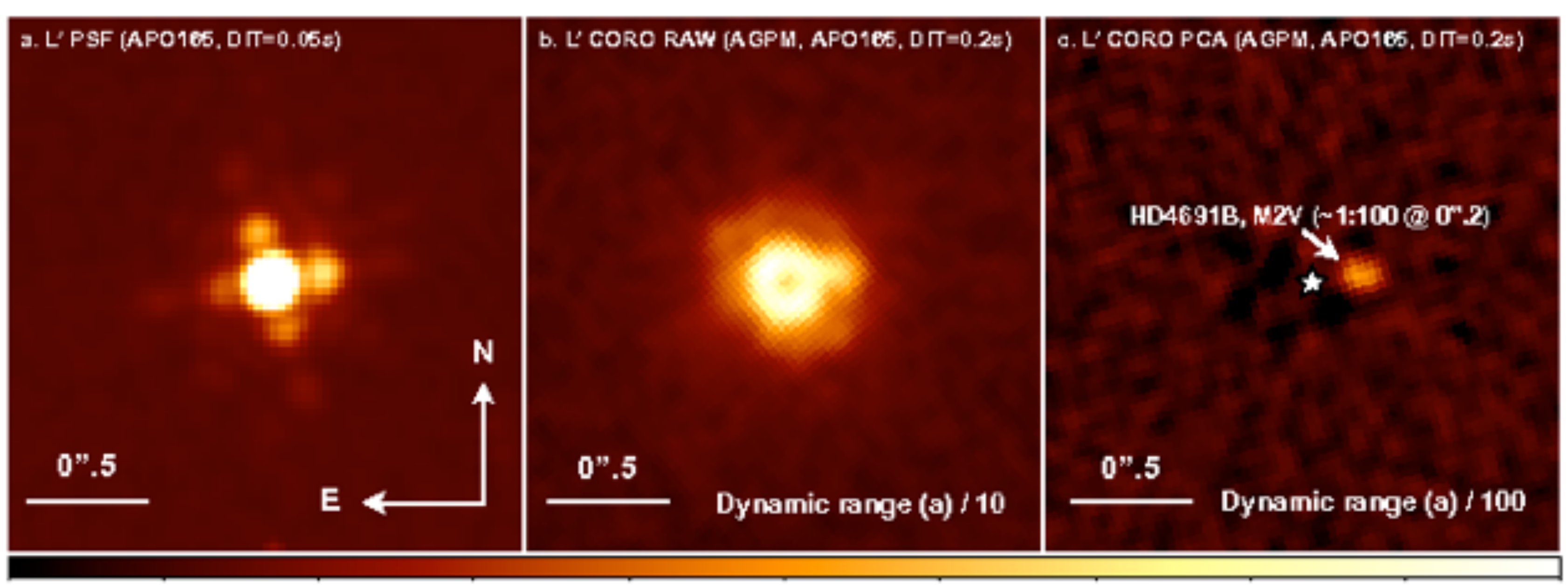
"Our findings do not suggest that inner transiting exoplanets are rare in binary systems"

Vortex coronagraph



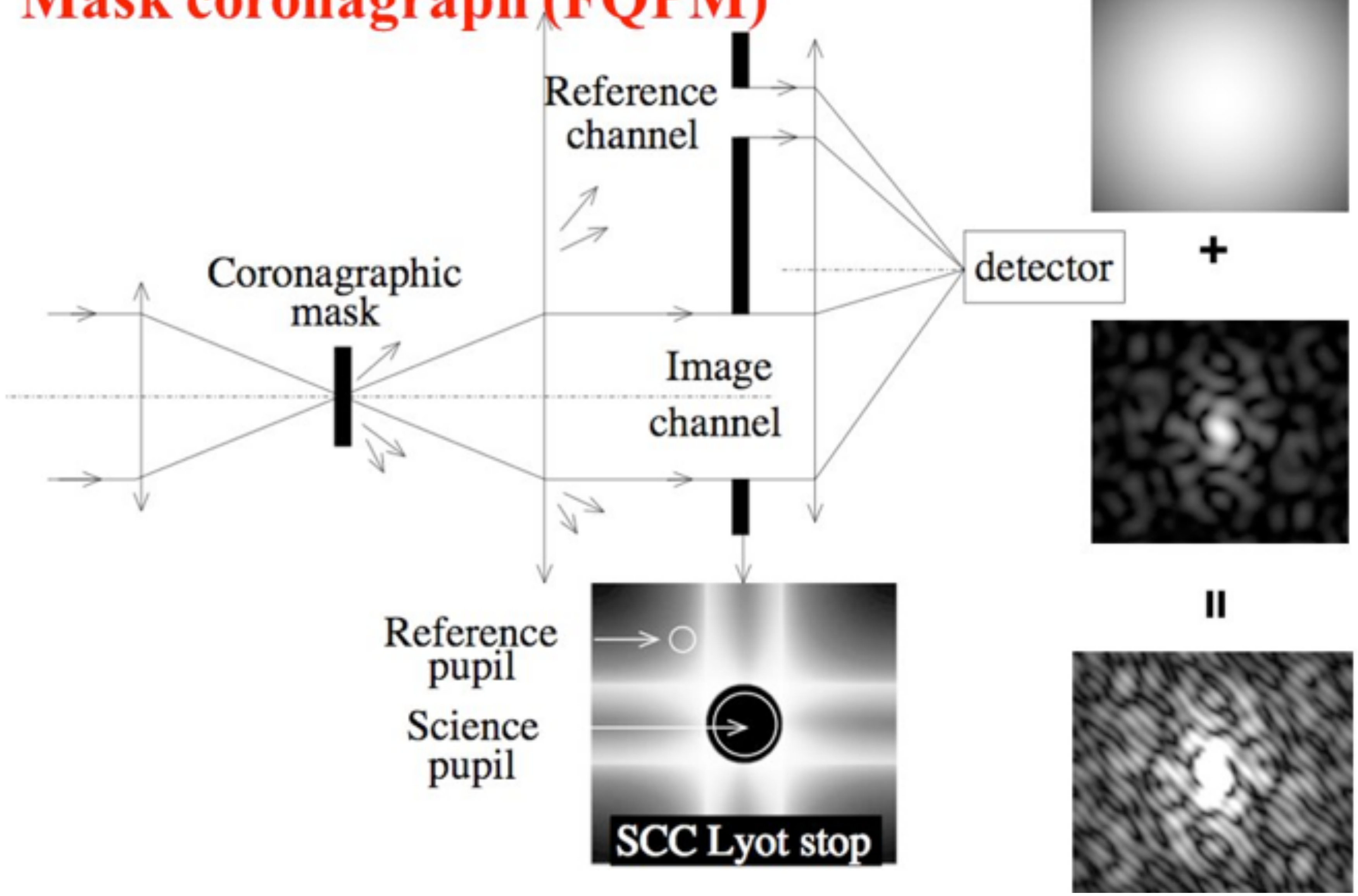


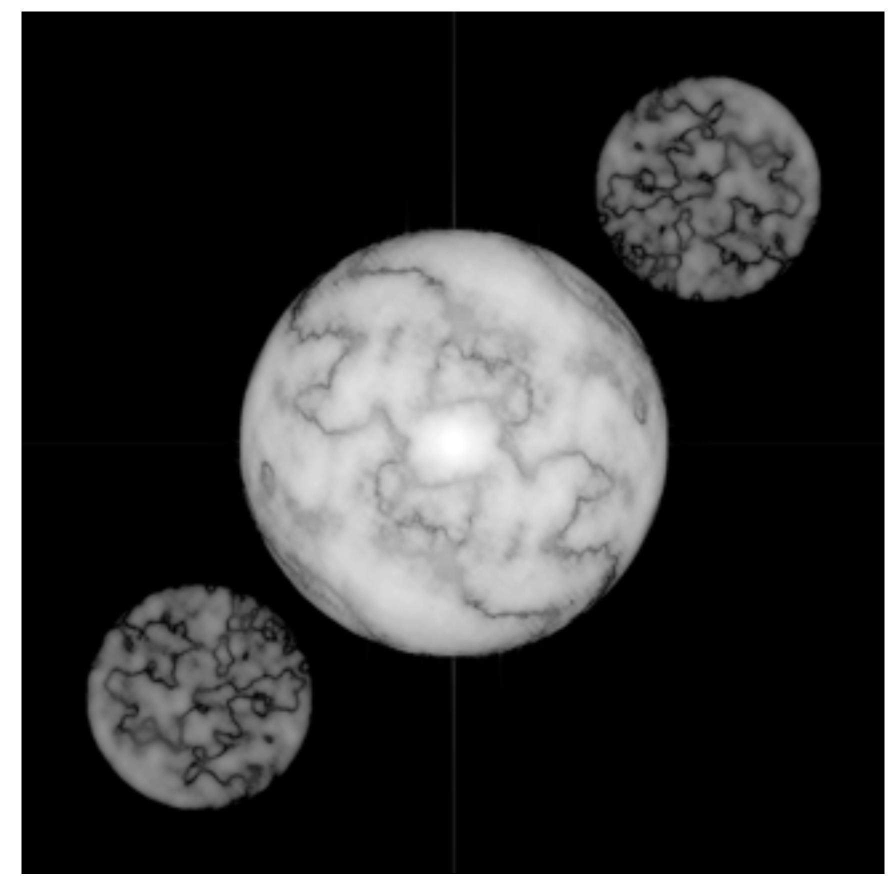
VLT NACO



Self coherent camera

Simple set-up : SCC + Four Quadrant Phase Mask coronagraph (FQPM)





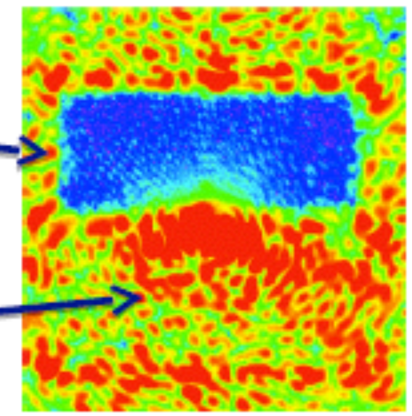
Examples of Performance

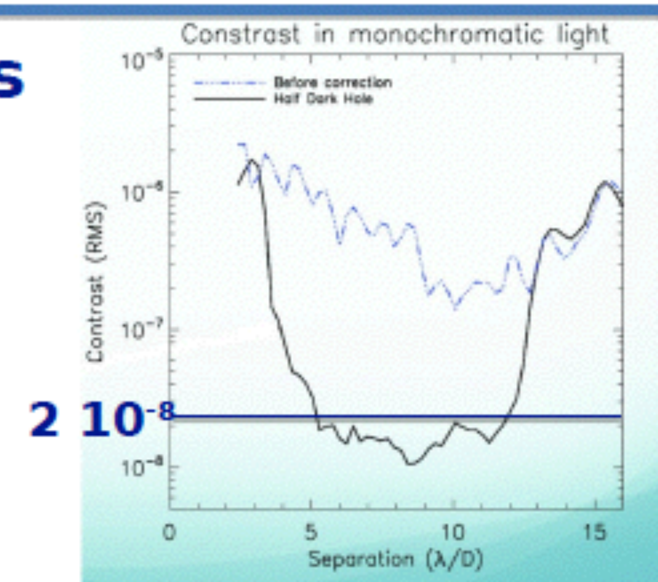
More than 15 Publications (5 refereed or accepted papers)

Monochromatic (bandwidth <10 nm) results

Contrast: < 2 10^{-8} between 5 /D and 12 /D

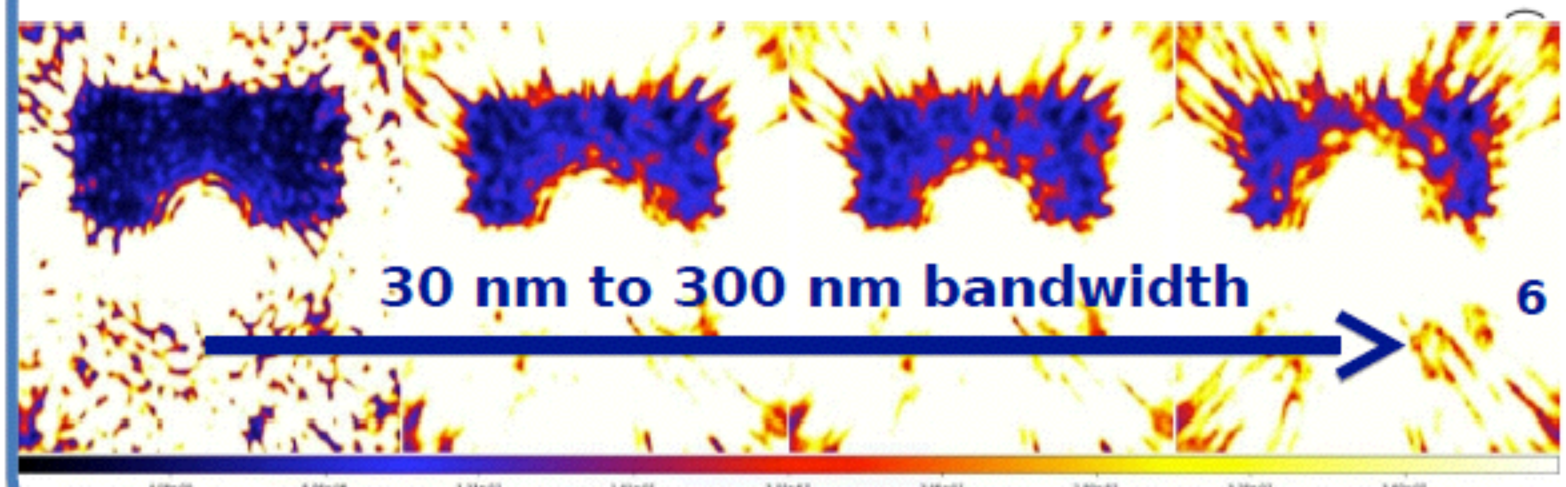
THD1 Limitation = amplitude errors
Reduced by a factor >20 on THD2

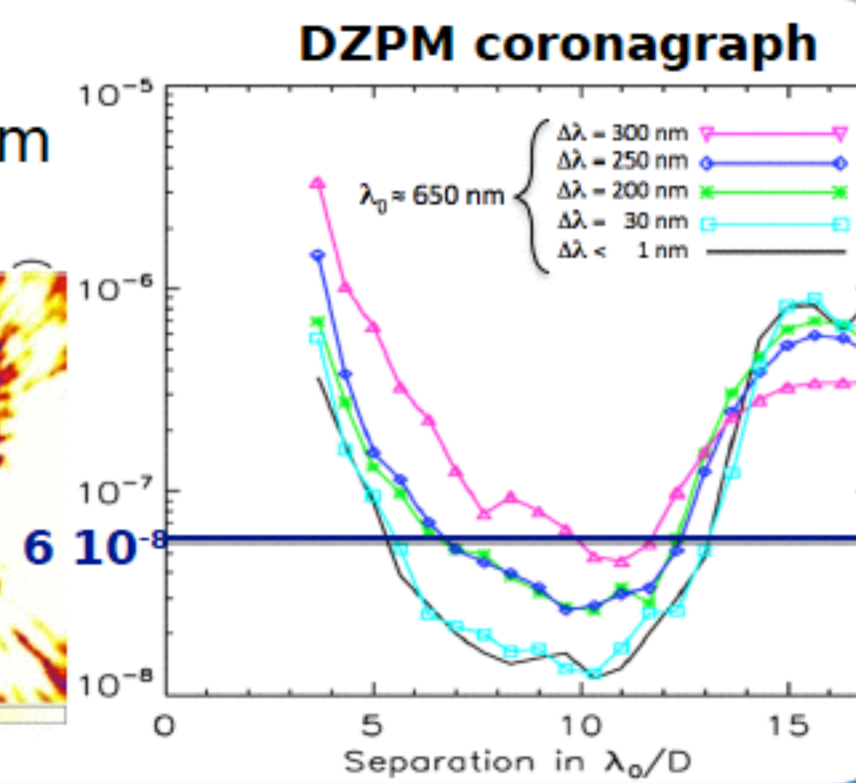




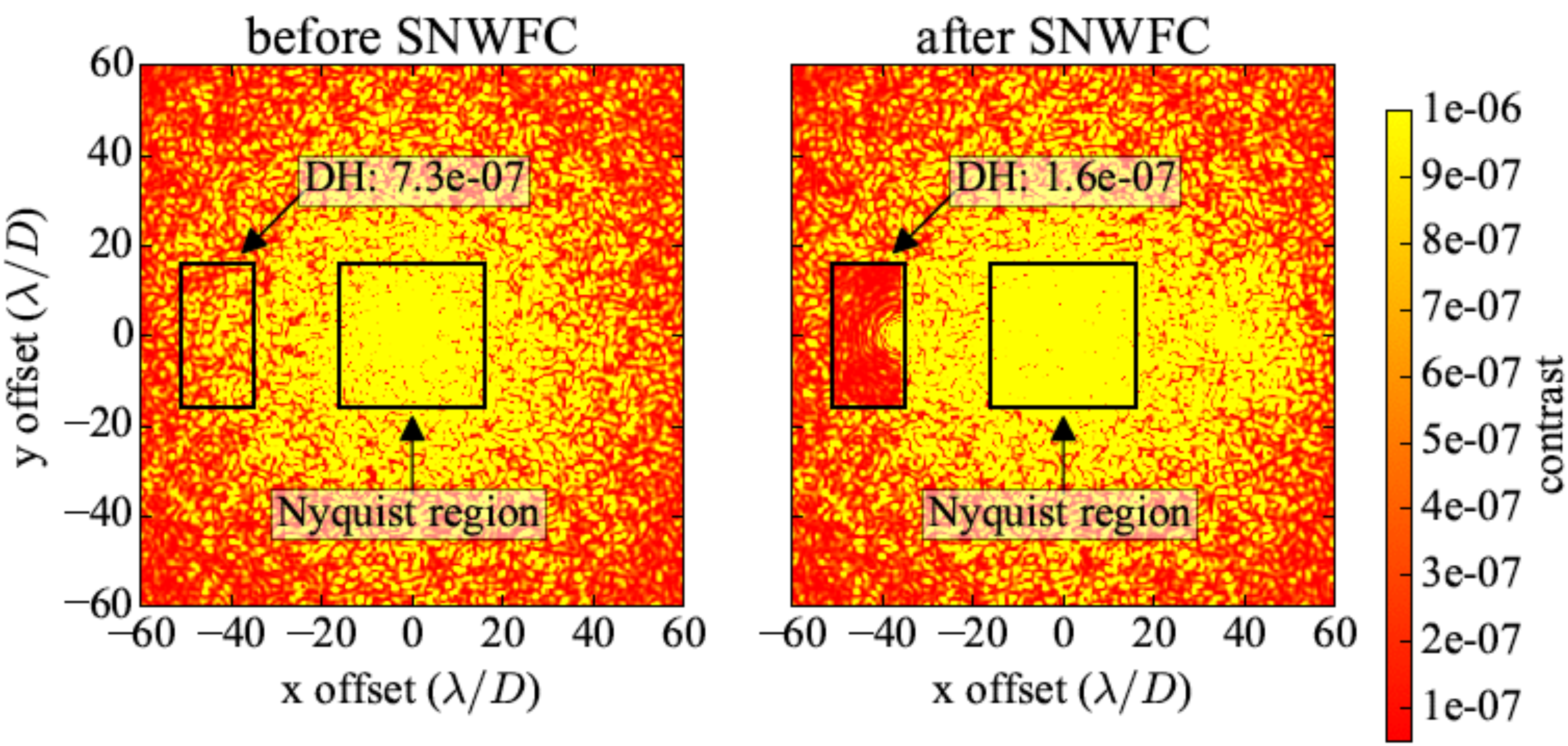
Achromaticity of the testbed

Contrast degrades by only a factor 3 for 250 nm bandwidth (37%)





SCC simulations @ UVic



Sky background Post-Processing