Direct Imaging Searches for Planets Within Alpha Centauri

Kevin Wagner, University of Arizona

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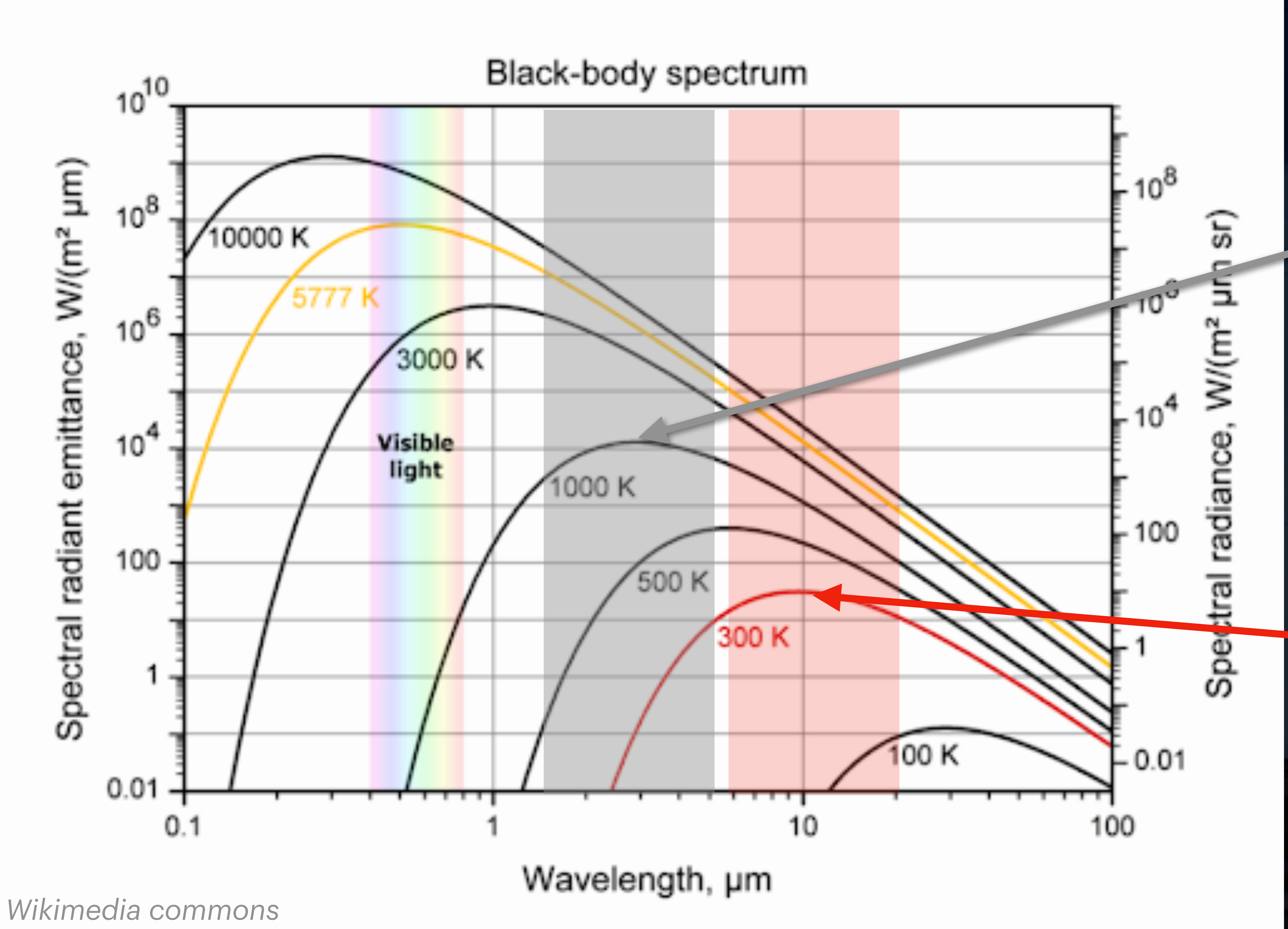
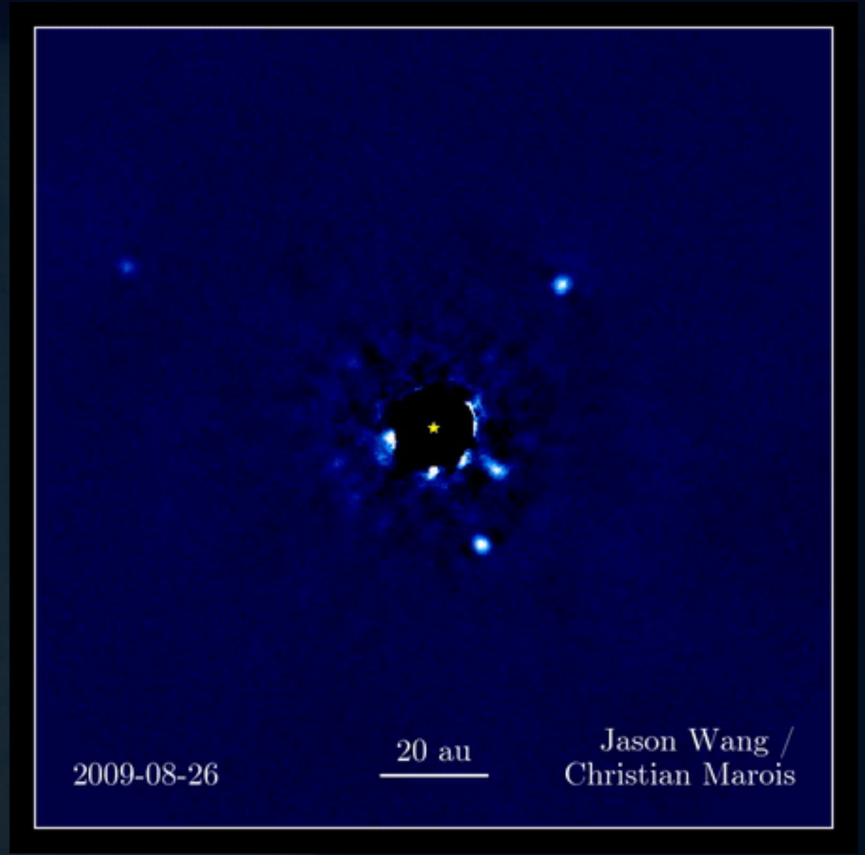
Thermal Emission: Habitable-Zone Exoplanets vs. Young Super-Jupiters



Young super-Jovian planets radiate primarily at ~2 μm



Note: present-day Jupiter is ~100K

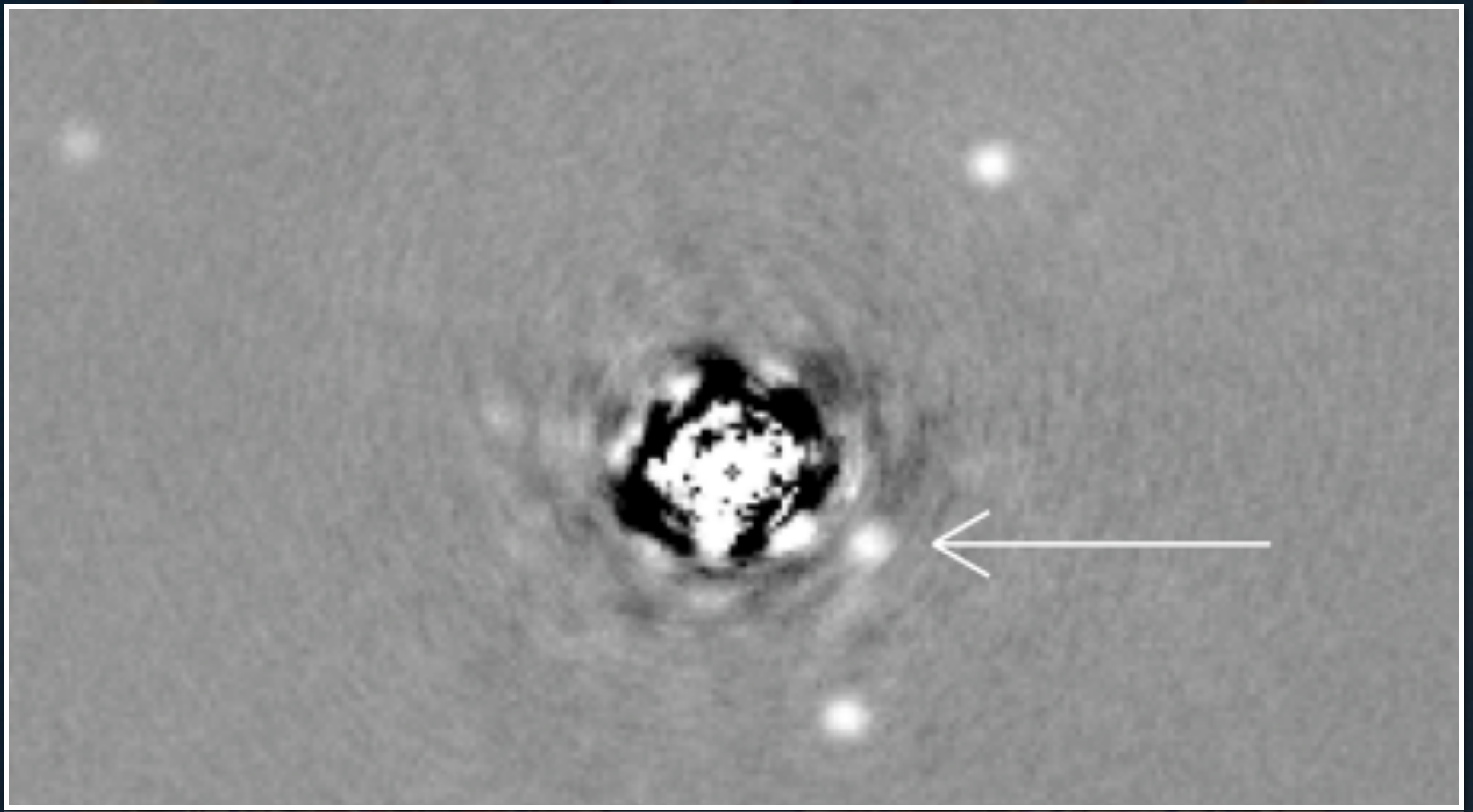
Mature, temperate (HZ) planets are best observed at ~10 μm

Image Credit: Apollo Earth/NEX55, Kornmesser NASA/ESA

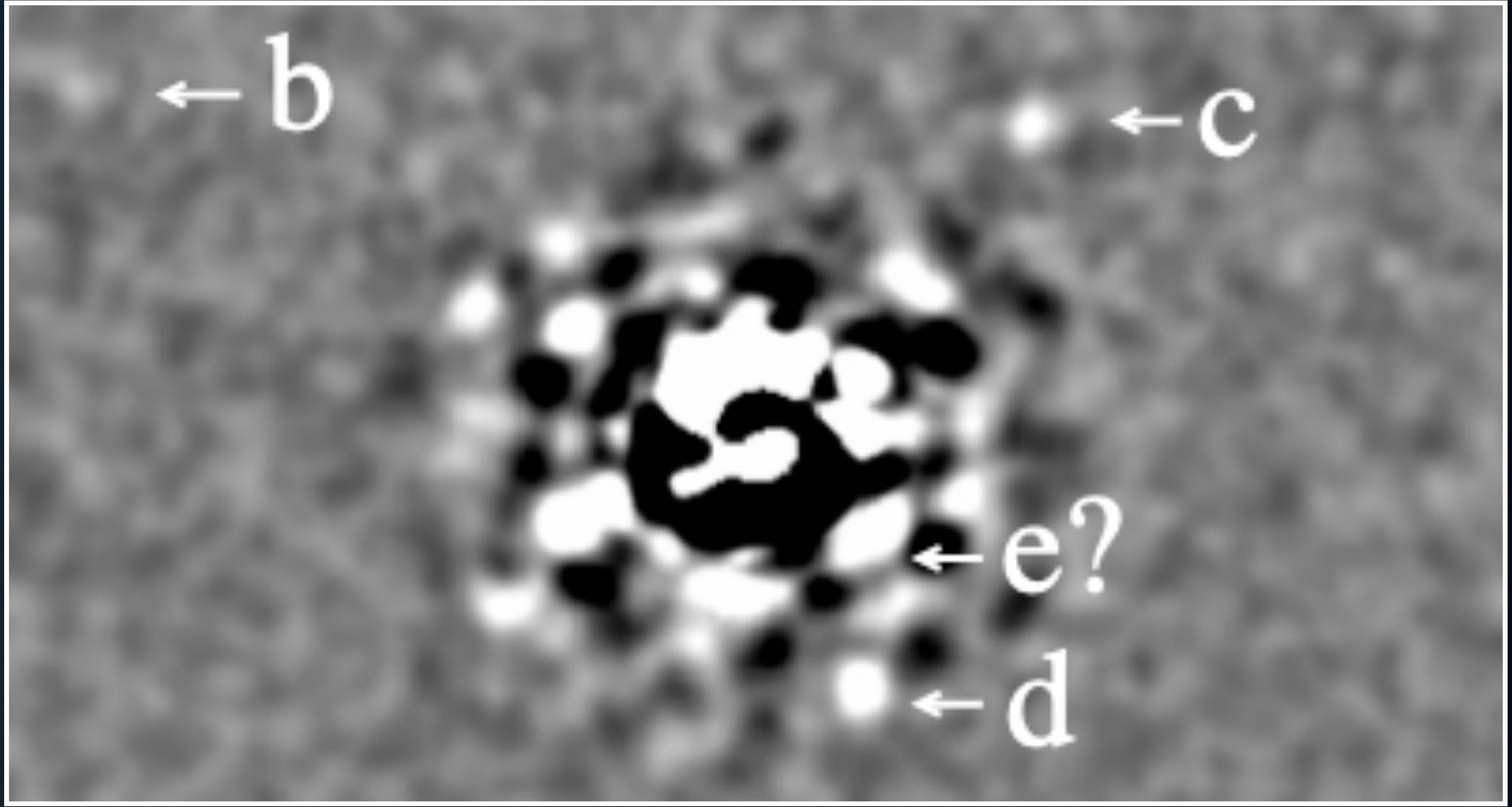
Difficulty of mid-IR: larger beam, higher background

Keck telescope on Mauna Kea, Hawaii

HR 8799 - Keck telescope - 4 μm image - Marois+2010



HR 8799 - Keck telescope - 5 μm image - Galicher+2011



Benefit: brightness of HZ planets peaks in the mid-IR

Mid-IR imaging's niche: nearby temperate planets

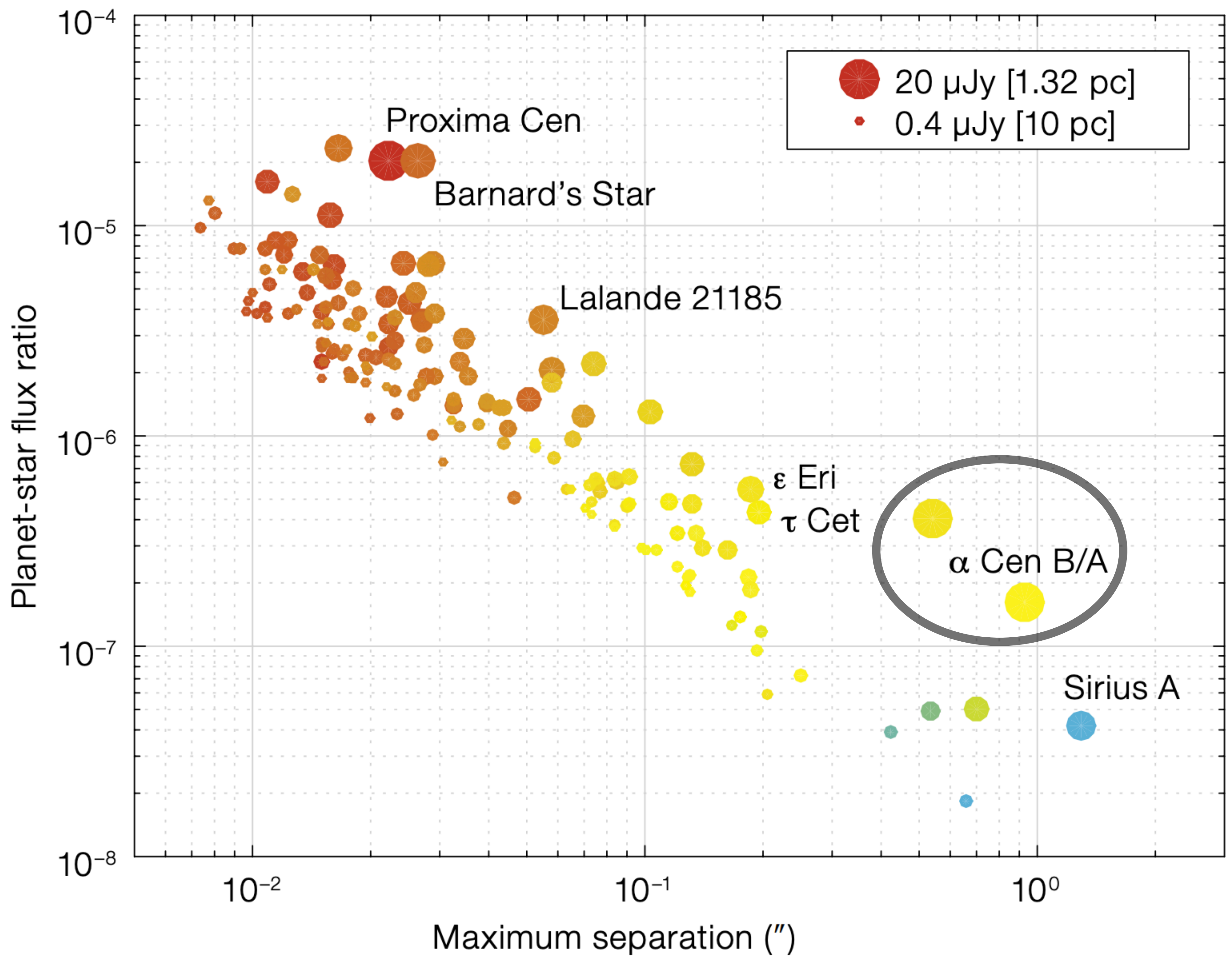
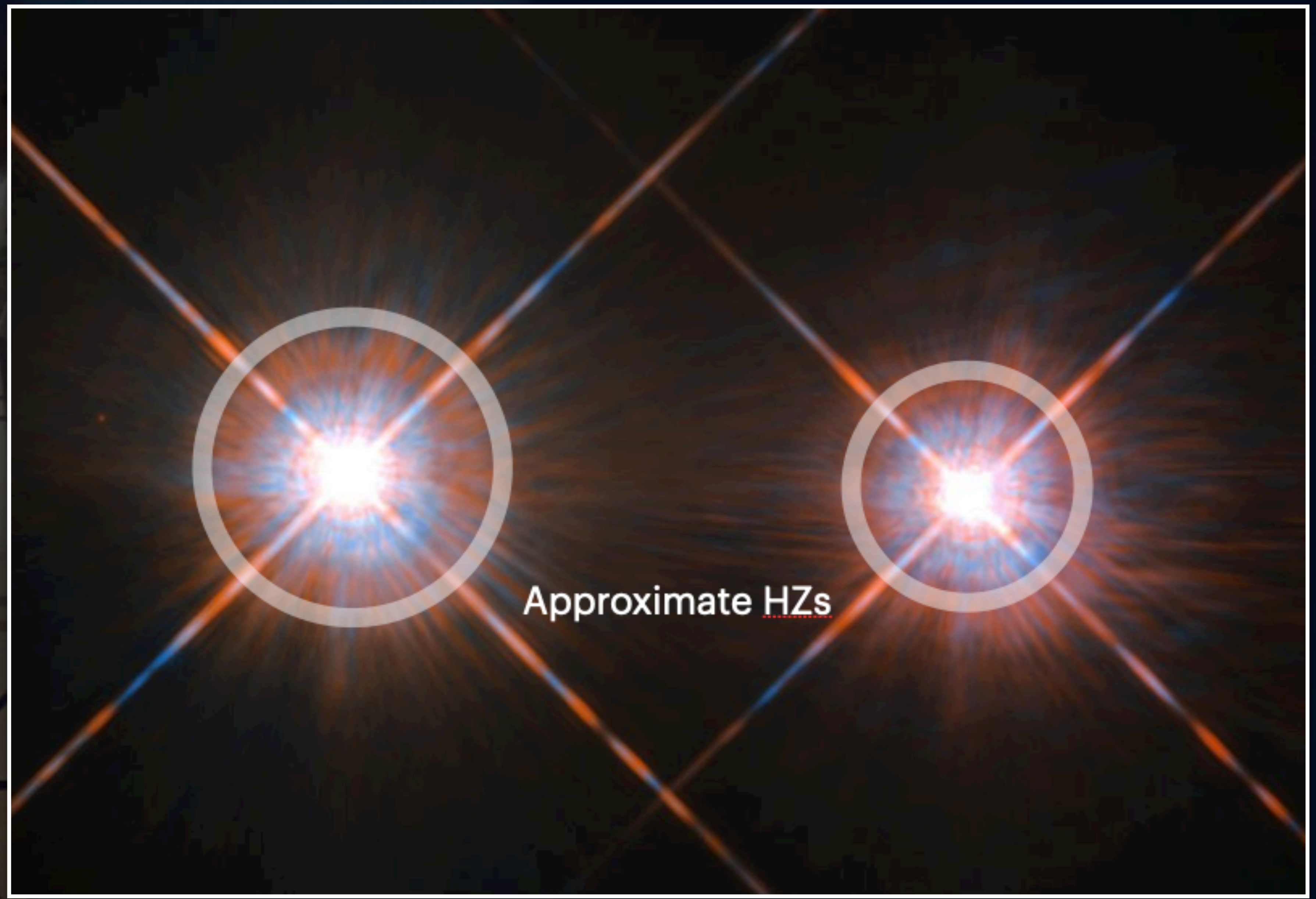


Figure 1. *N*-band flux ratio between Earth-analogue planets and parent stars within 10 pc (from the Hipparcos catalogue). The size of the symbol indicates the planet's apparent brightness, and the colours approximately match those of the stars.

$$\lambda = 10 - 12.5\ \mu m$$

Kasper+2017, *ESO Messenger*



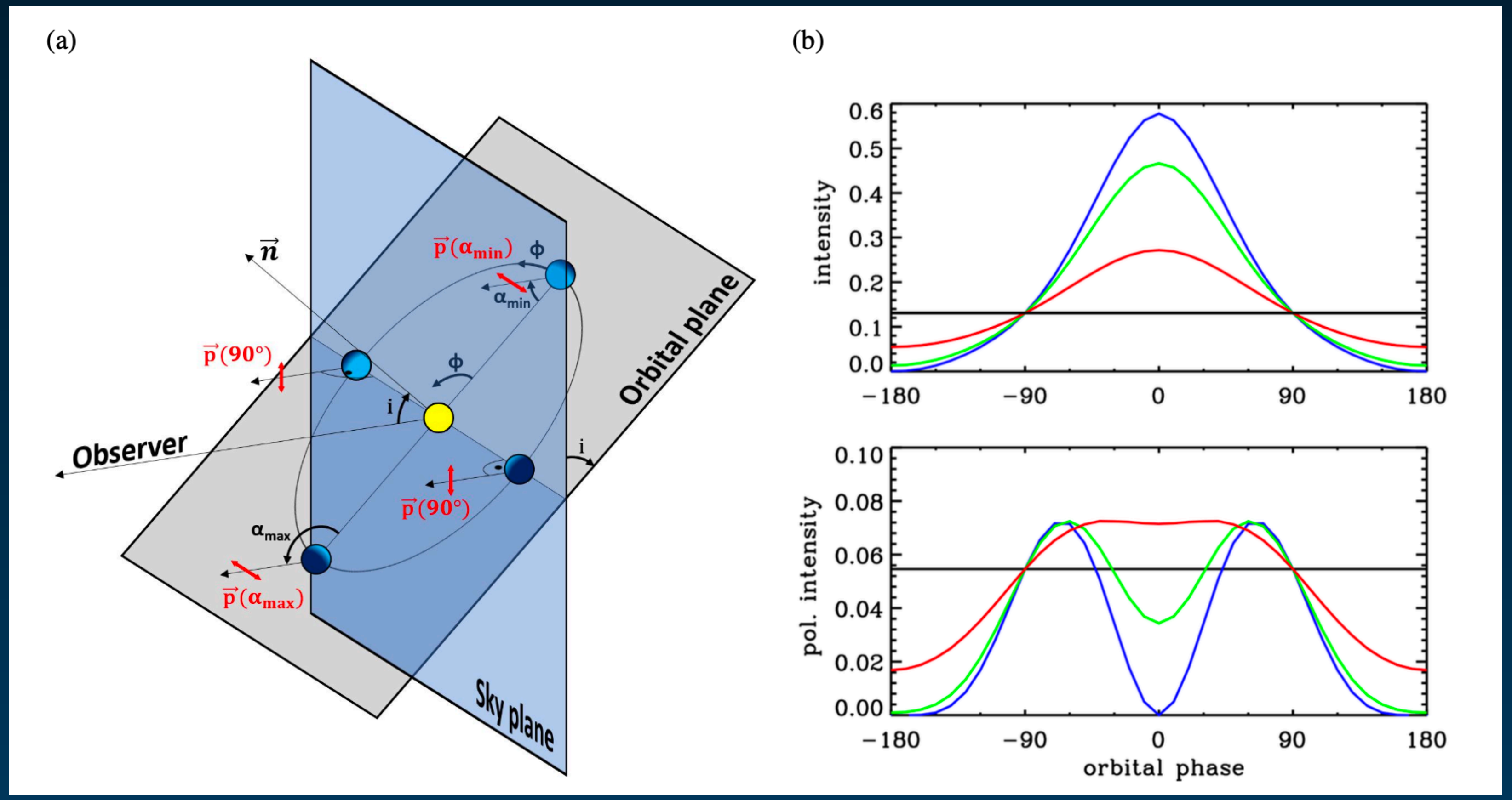
Alpha Cen with HST (similar resolution to VLT @ 10 μm)

Reflected Light Imaging

Image Credit: Alien Earths/NExSS, Kornmesser NASA/ESA

RefPlanets: Search for reflected light from extrasolar planets with SPHERE/ZIMPOL★

S. Hunziker[1], H. M. Schmid[1], D. Mouillet[3,4], J. Milli[5], A. Zurlo[17,18,15], P. Delorme[3], L. Abe[12], H. Avenhaus[13,1],



Hunziker et al. 2020

PI: Hans Martin Schmid (ETH)

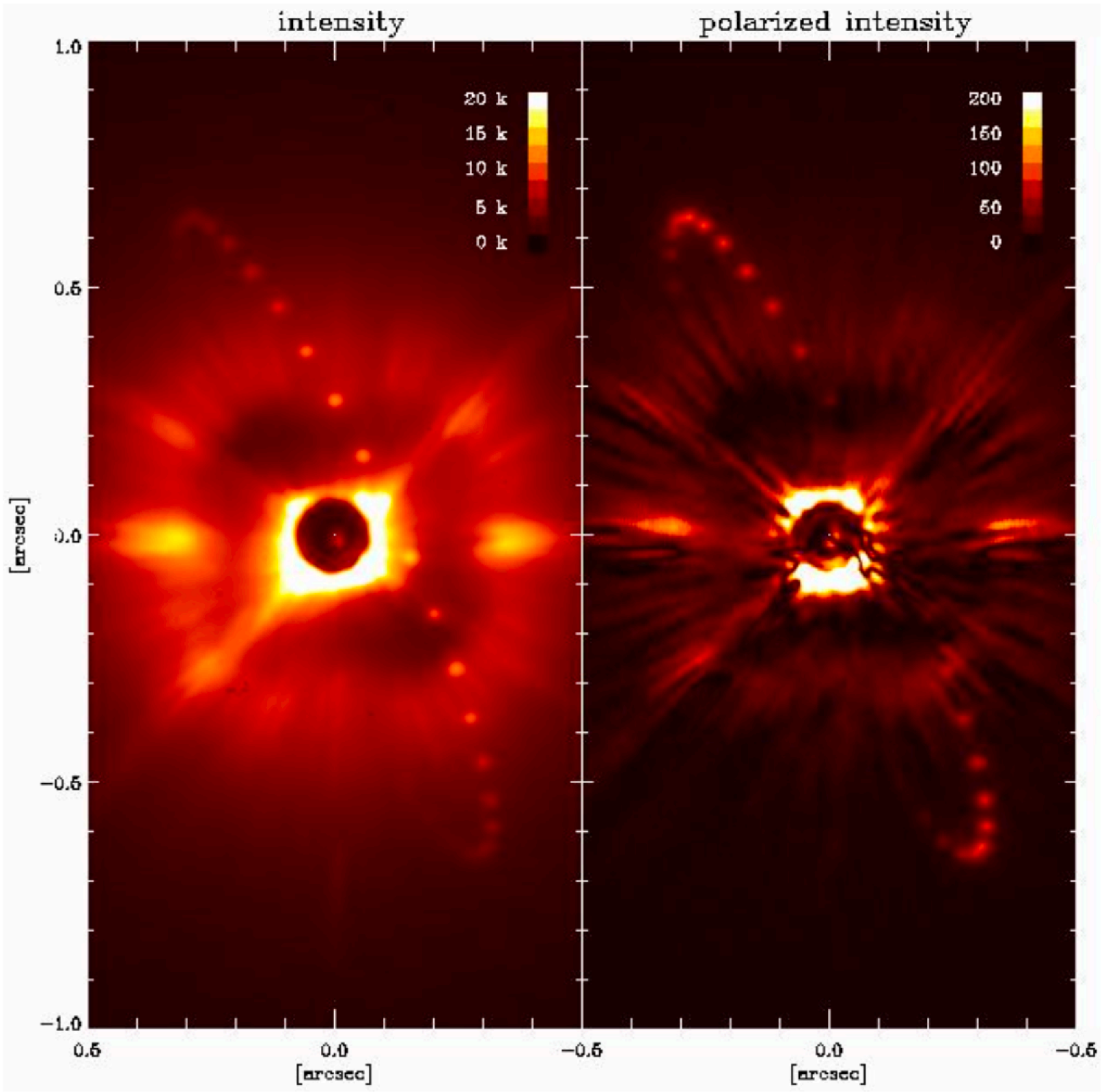


Fig. 2. Apparent positions of a model planet on a circular 80° inclined orbit with r = 1 AU around α Cen A in a typical coronagraphic intensity (*left*) and polarisation frame (*right*) at ten-day intervals. The brightness of the planet signal with respect to α Cen A is exaggerated by a factor of 10^4 for the intensity and 10^3 for the polarisation. The relative brightness of the point for different phases is according to the model presented in Fig. 1.

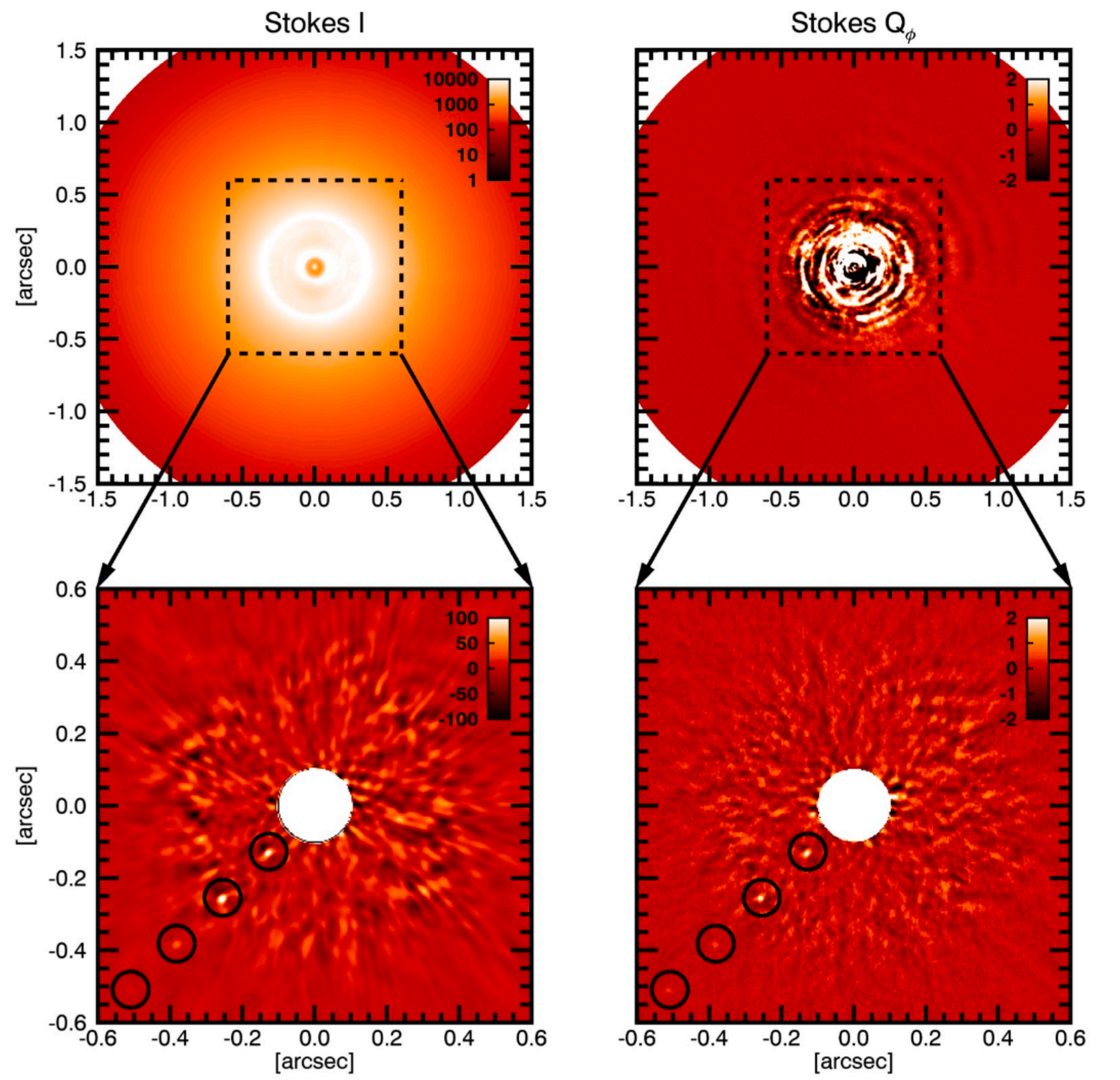


Fig. 4. Total intensity (Stokes I) and polarised intensity (Stokes Q_ϕ) for the complete dataset of α Cen A in the N_R filter. The frames in the bottom row show a closer look at the speckle-dominated region closer to the star after injecting artificial point-sources (black circles) and applying PCA-ADI with 20 PCs.

RefPlanets: Search for reflected light from extrasolar planets with SPHERE/ZIMPOL★

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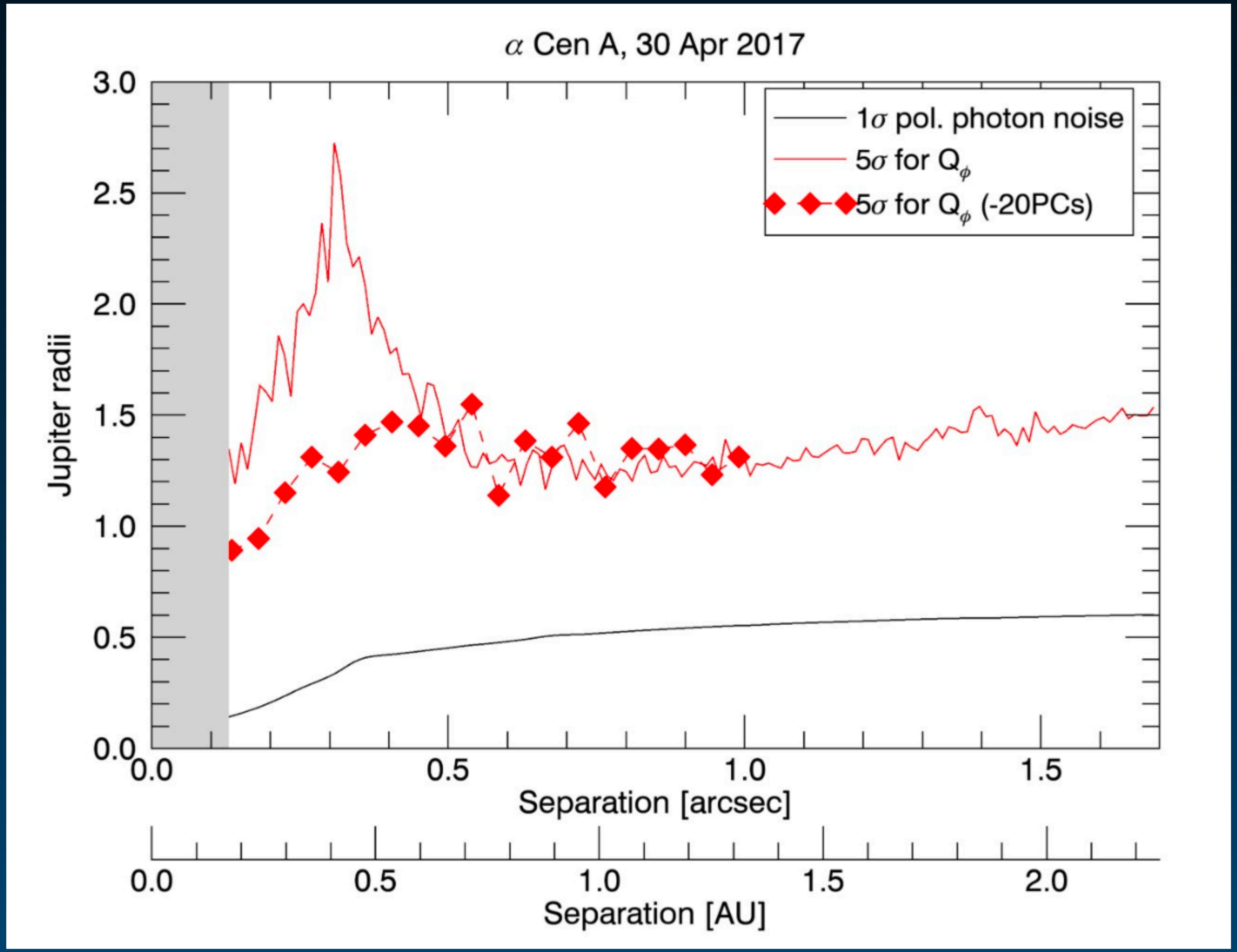

RefPlanets: Search for reflected light from extrasolar planets with SPHERE/ZIMPOL★

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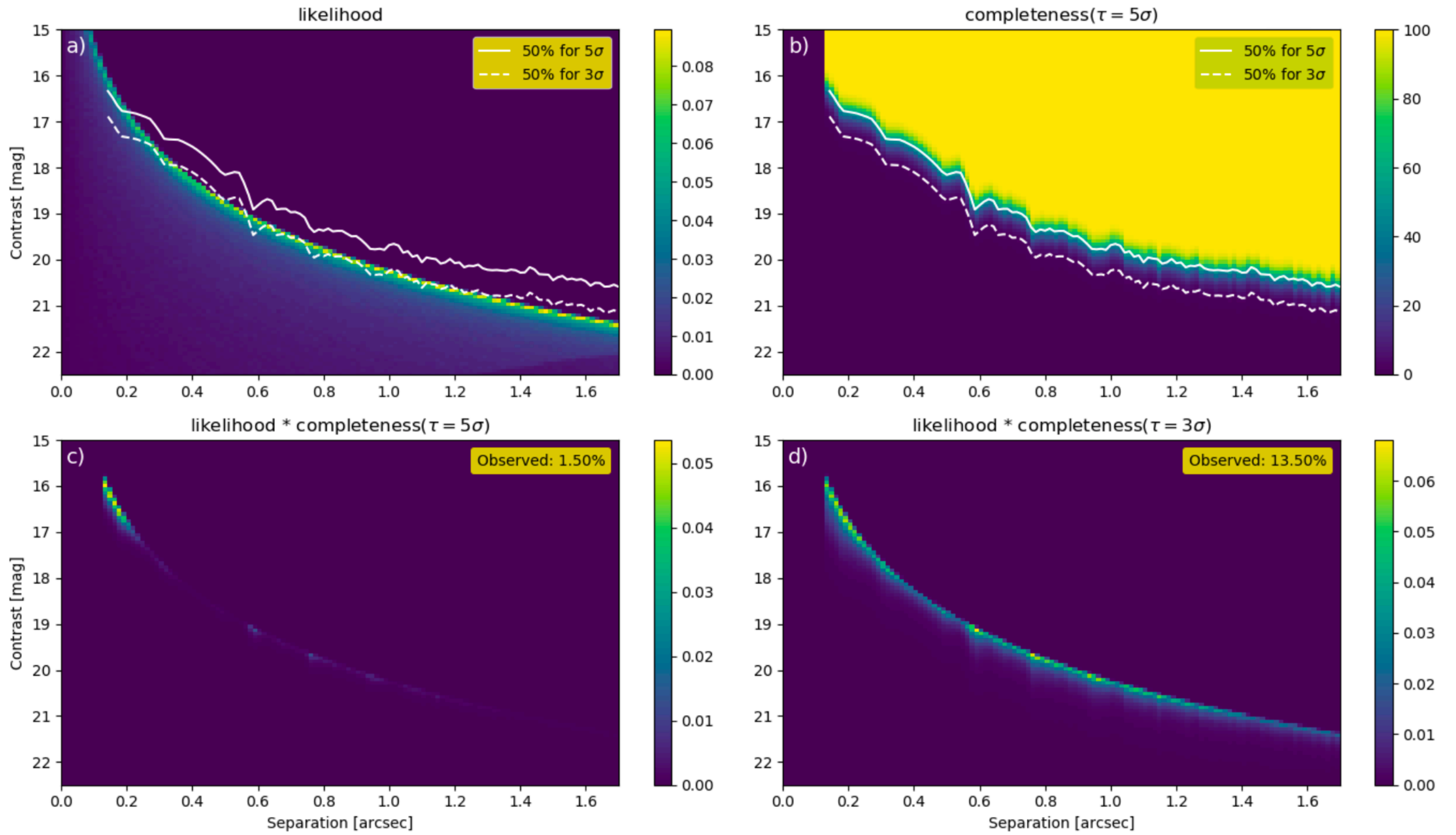
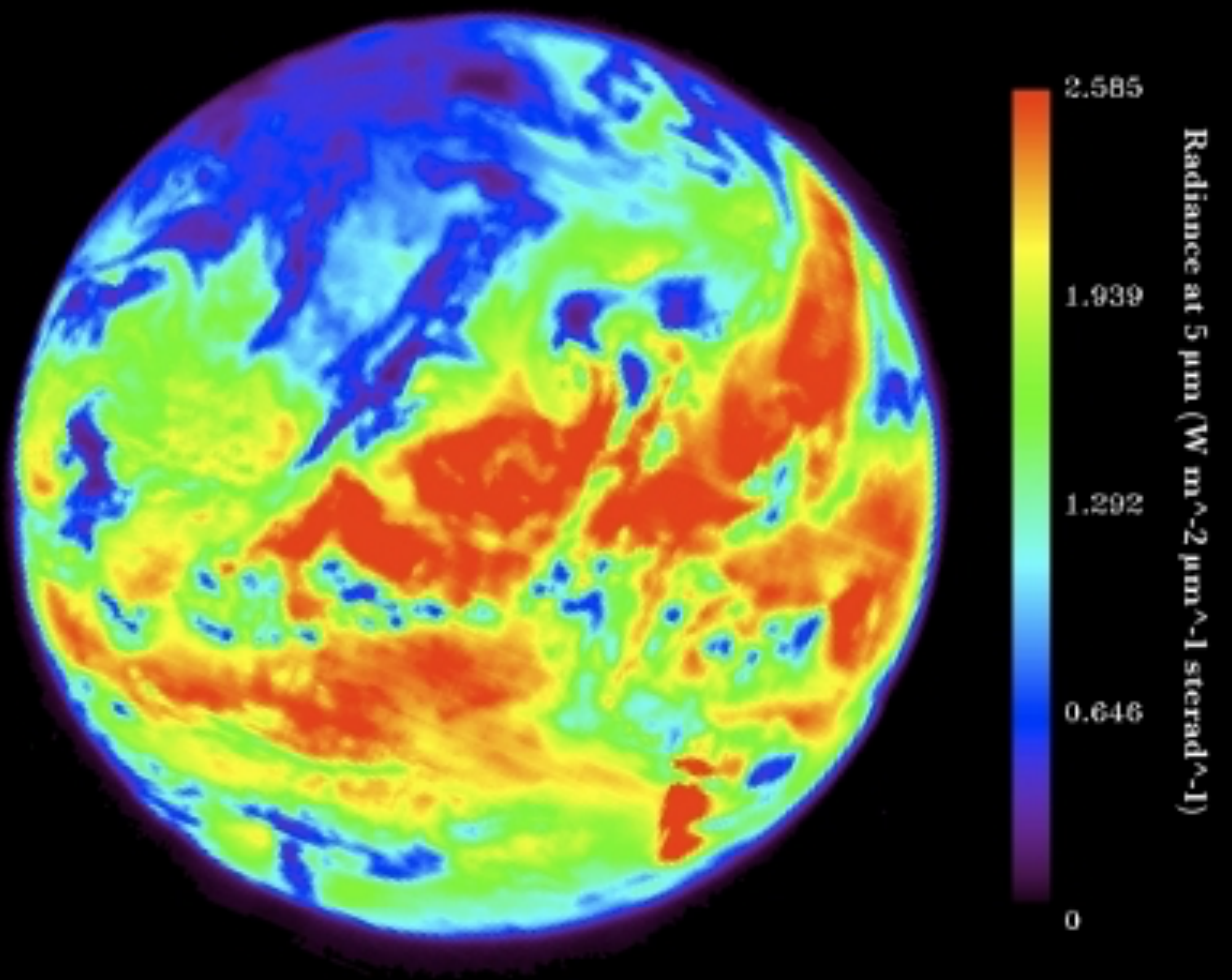


Fig. 9. Results of the Monte-Carlo sampling of 5 000 000 Jupiter-sized planets on circular orbits around α Cen A. *Panel a*: fraction of samples (in percent) that end up at a certain apparent separation and polarised intensity contrast at all times. *Panel b*: full performance map for a certain detection threshold $N\tau$. This figure shows the probability of detecting an existing planet for all separations and contrasts with an S/N of N. *Panels c and d*: combination of the likelihood and the performance map gives the fraction of planets at each separation and contrast that are detected as either $S/N = 5$ or $S/N = 3$ signals depending on the detection threshold.

Back to Thermal Emission

Earth - ROSETTA/VIRTIS



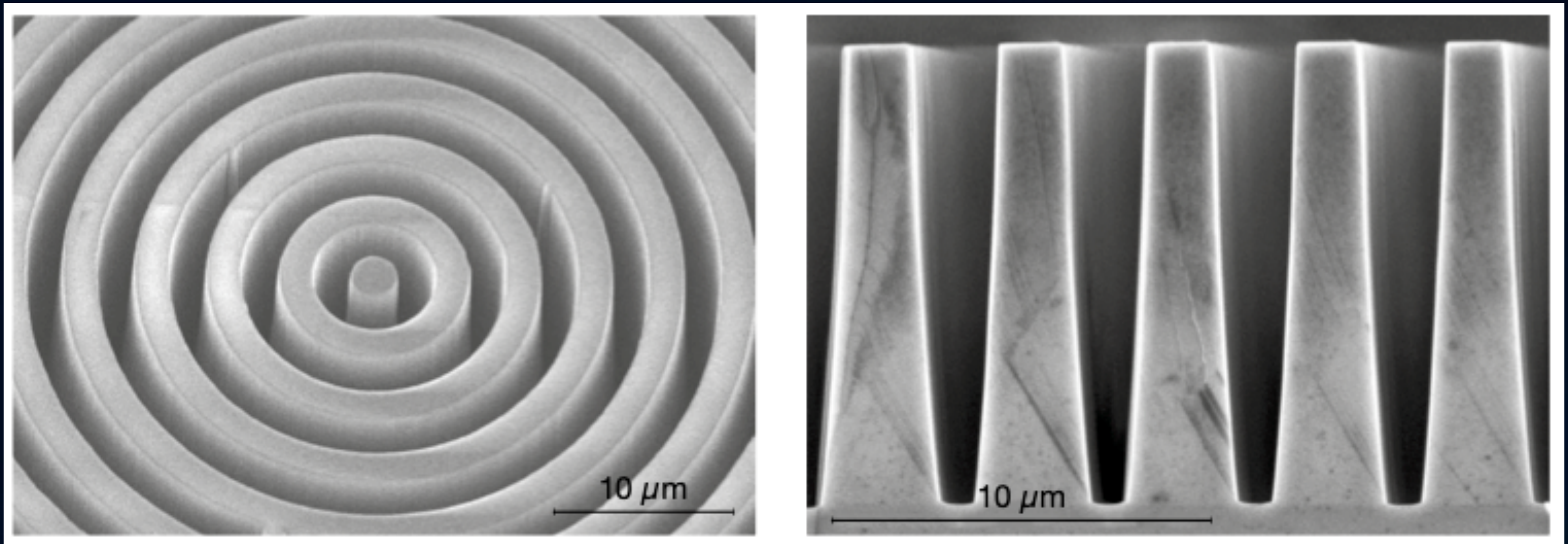
IR-2

Image Credits: INAF-IFSI, INAF-IASF, ASI

Deformable Secondary Mirror (DSM) enables AO without additional warm optics

Image Credit: ESO

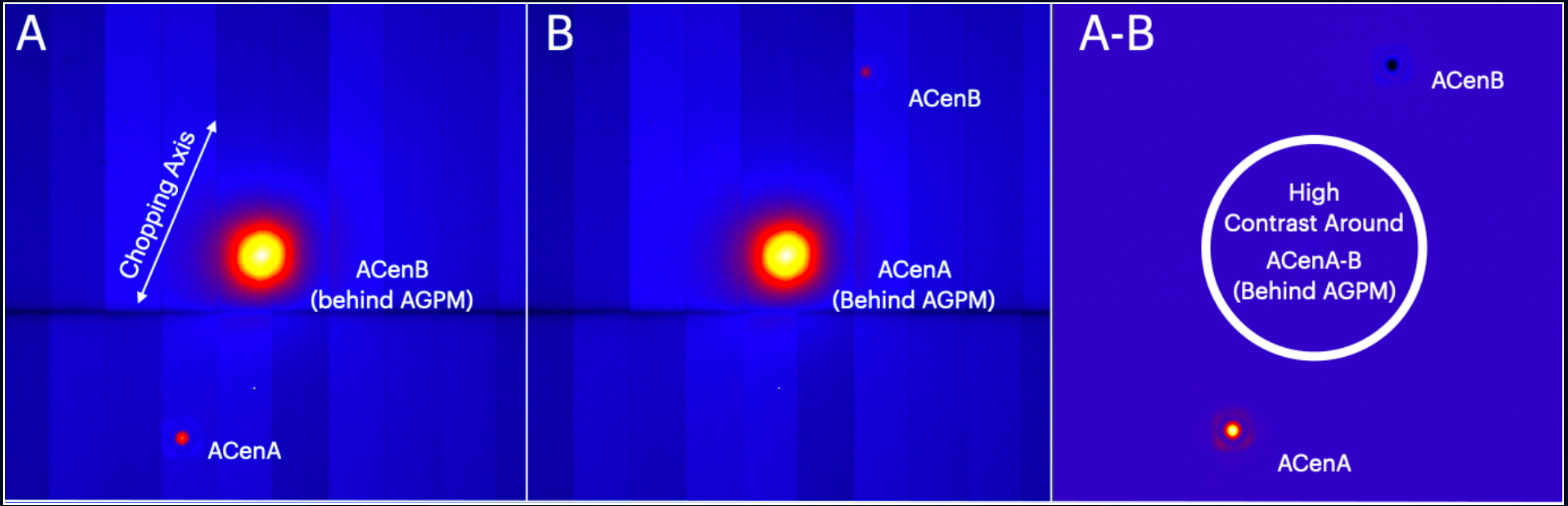
Mid-IR optimized coronagraph



Kasper+2017 Annular Groove Phase Mask (AGMP): Mawet+2005

See also Delacroix+2013, Ruane+2015, Absil+2016, Maire+2020

Observing Strategy: Fast (10 Hz) Chopping



Wagner, NEAR team + 2021

Wagner, Ertel+2021 SPIE

The NEAR Experiment:

a 100-hour campaign to directly image low-mass planets within α Centauri

NEAR Team:

A. Boehle, P. Pathak, M. Kasper (PI), R. Arsenault, G. Jakob, U. Käufl, S. Leveratto, A.-L. Maire, E. Pantin, G. Zins, R. Siebenmorgen, O. Absil, N. Ageorges, D. Apai, A. Carlotti, É. Choquet, C. Delacroix, K. Dohlen, P. Duhoux, E. Fuenteseca, S. Gutruf, O. Guyon, E. Huby, D. Kampf, M. Karlsson, P. Kervella, J.-P. Kirchbauer, P. Klupar, J. Kolb, D. Mawet, M. N.´ Diaye, G. de Xivry, S. Quanz, A. Reutlinger, G. Ruane, M. Riquelme, C. Soenke, M. Sterzik, A. Vigan, and T. de Zeeuw

Partner institutions:

Breakthrough Watch, ESO, CEA-Paris, ETH Zürich, Univ. Liege, Univ. Uppsala, Univ. Arizona, Kampf Telescope Optics, Caltech, others

Published in: Wagner Boehle, Pathak, Kasper, et al. 2021, Nature Communications

NEAR: *New Earths in the α Centauri Region*, a project jointly sponsored by Breakthrough Watch and ESO

The NEAR Experiment:

a 100-hour campaign to directly image low-mass planets within α Centauri

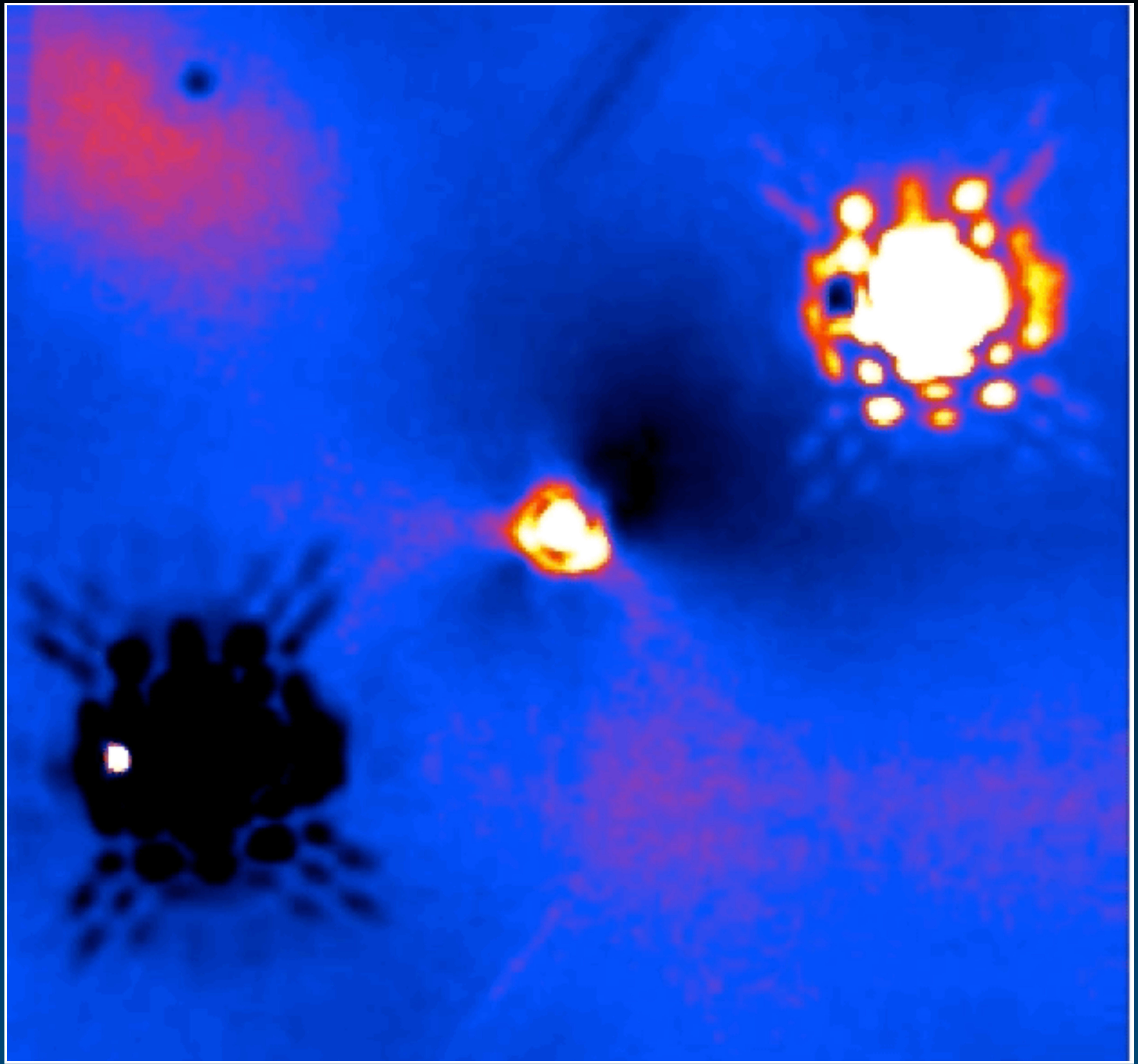
NEAR Commissioning team:

Markus Kasper (NEAR PI, right)

NEAR: *New Earths in the α Centauri Region*, a project jointly sponsored by Breakthrough Watch and ESO

Image Credit: ESO/A.Panizza.

Observing Strategy: Angular Differential Imaging



~5 million images

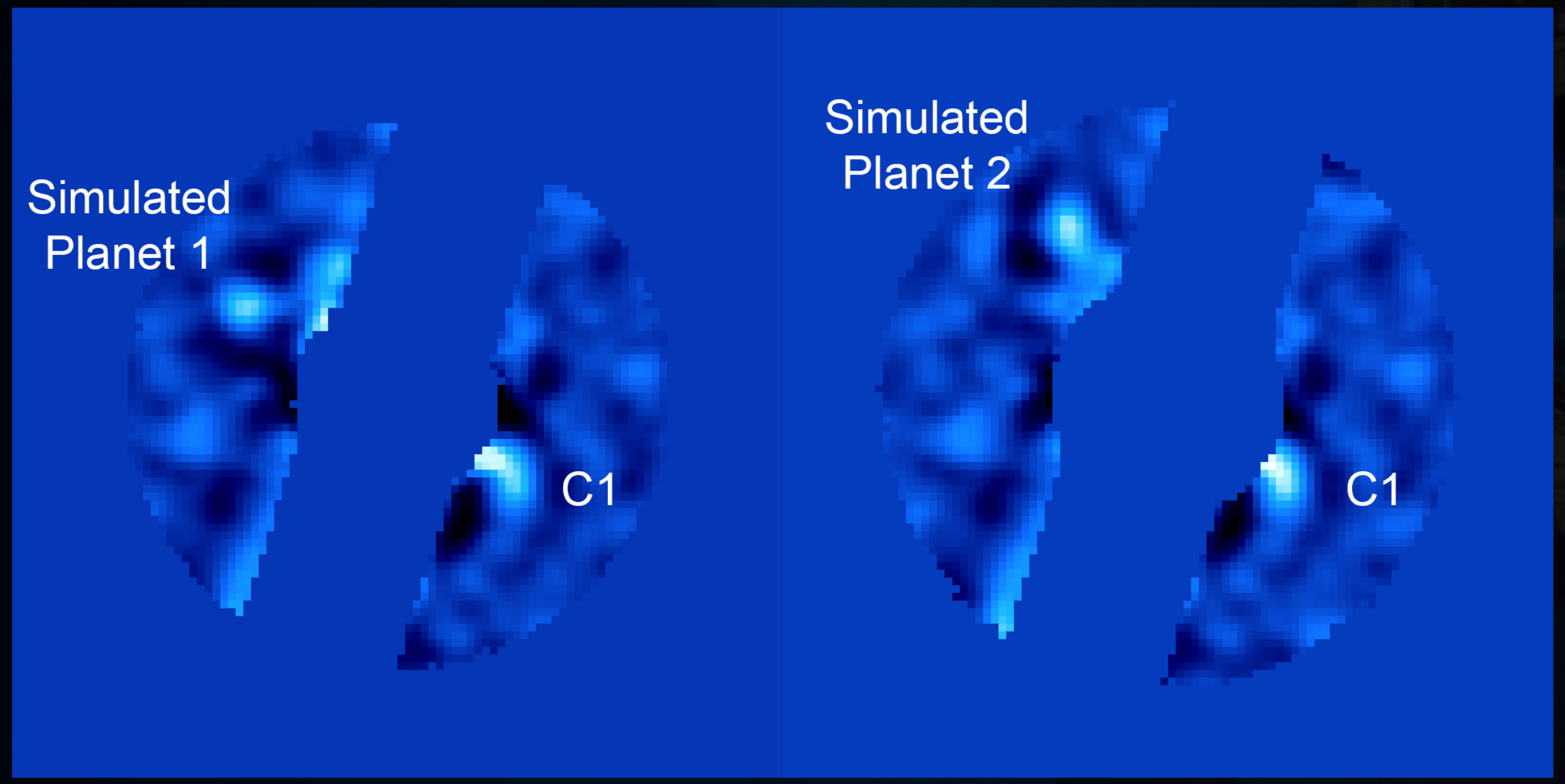
7 TB of data

All publicly available at archive.eso.org

Breakthrough Watch/NEAR

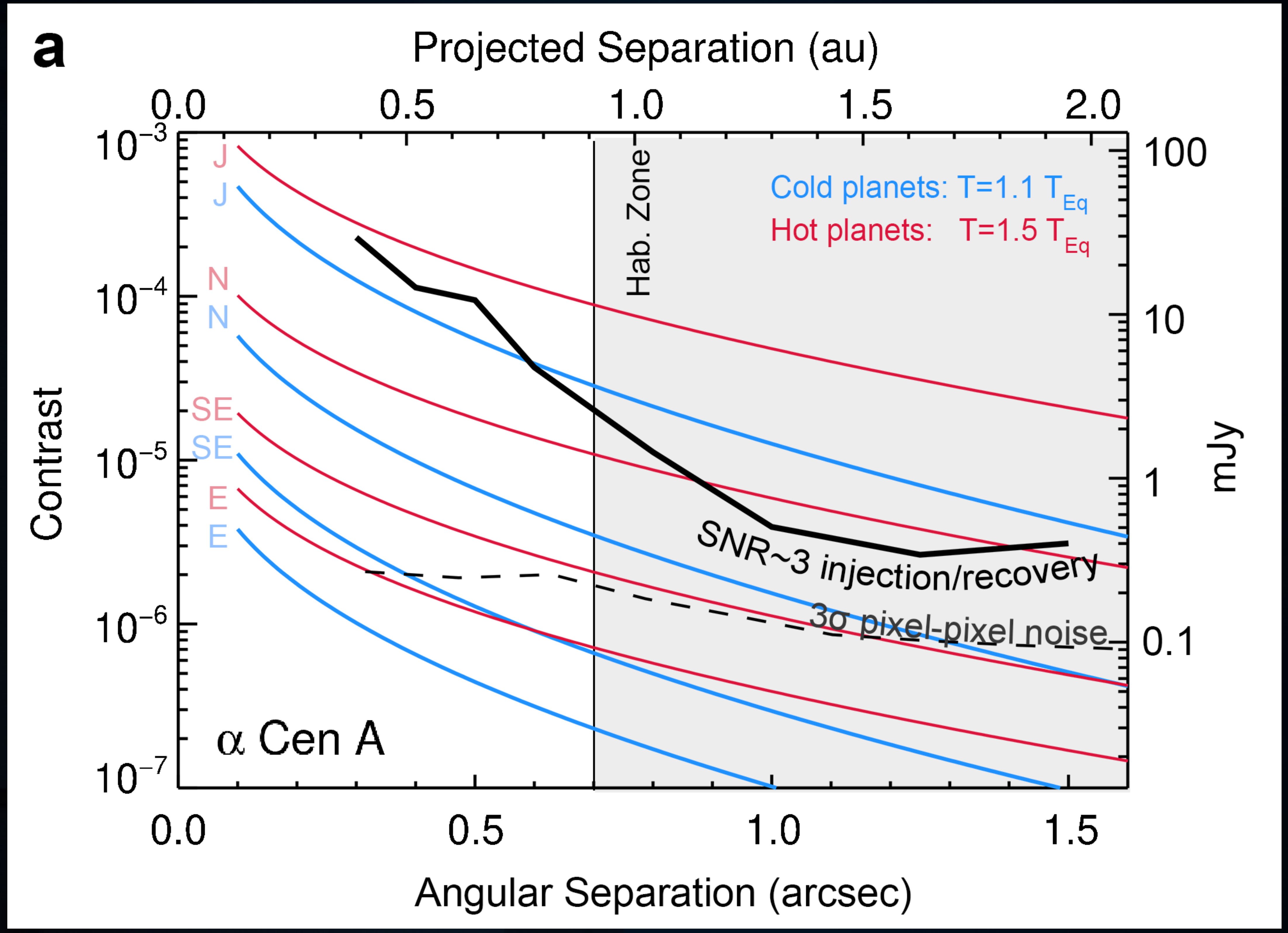
- Unique privately/publicly funded partnership
- 100 hr Search for habitable-zone planets within α Cen
- Established sensitivity beneath HZ Saturn-sized planets
  - between warm super-Earths and sub-Neptunes
- Revealed a planet candidate (α Cen A C1, or BTW-C1)
- Confirmed that exo-Earths are possible for ELTs!

Images of α Centauri



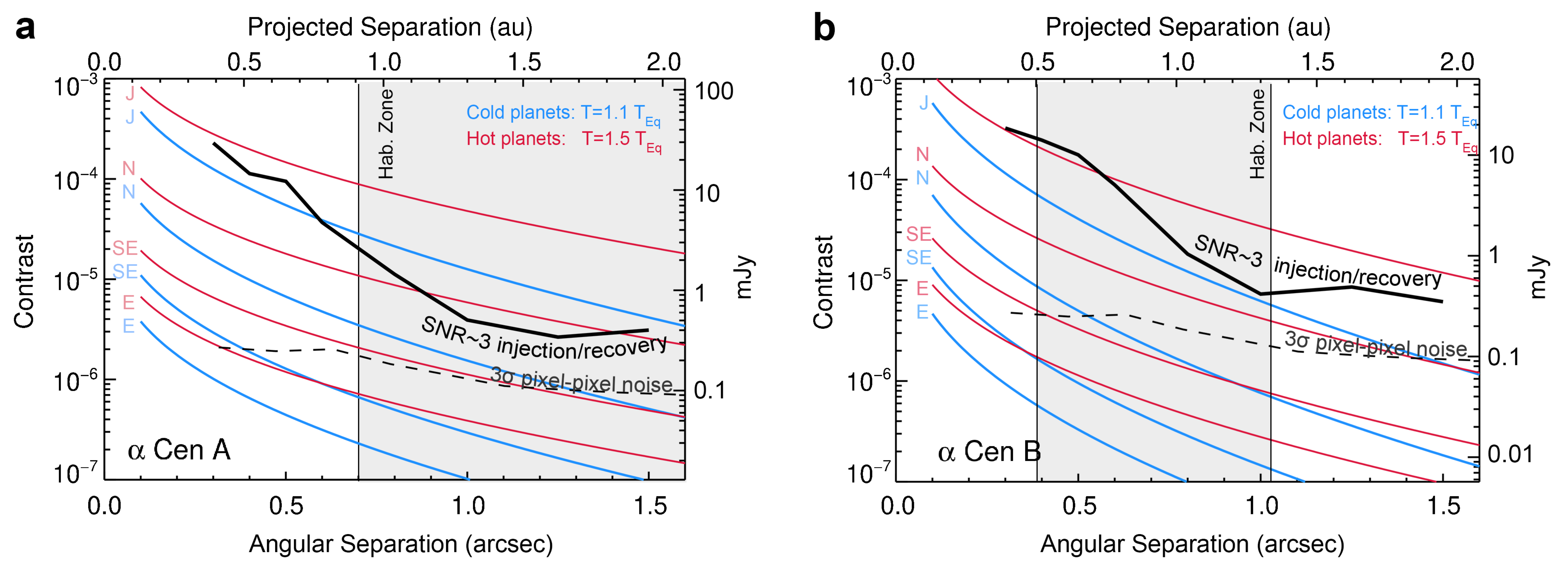
Long (100 hr) Exposures

Sensitivity to Habitable-Zone Planets



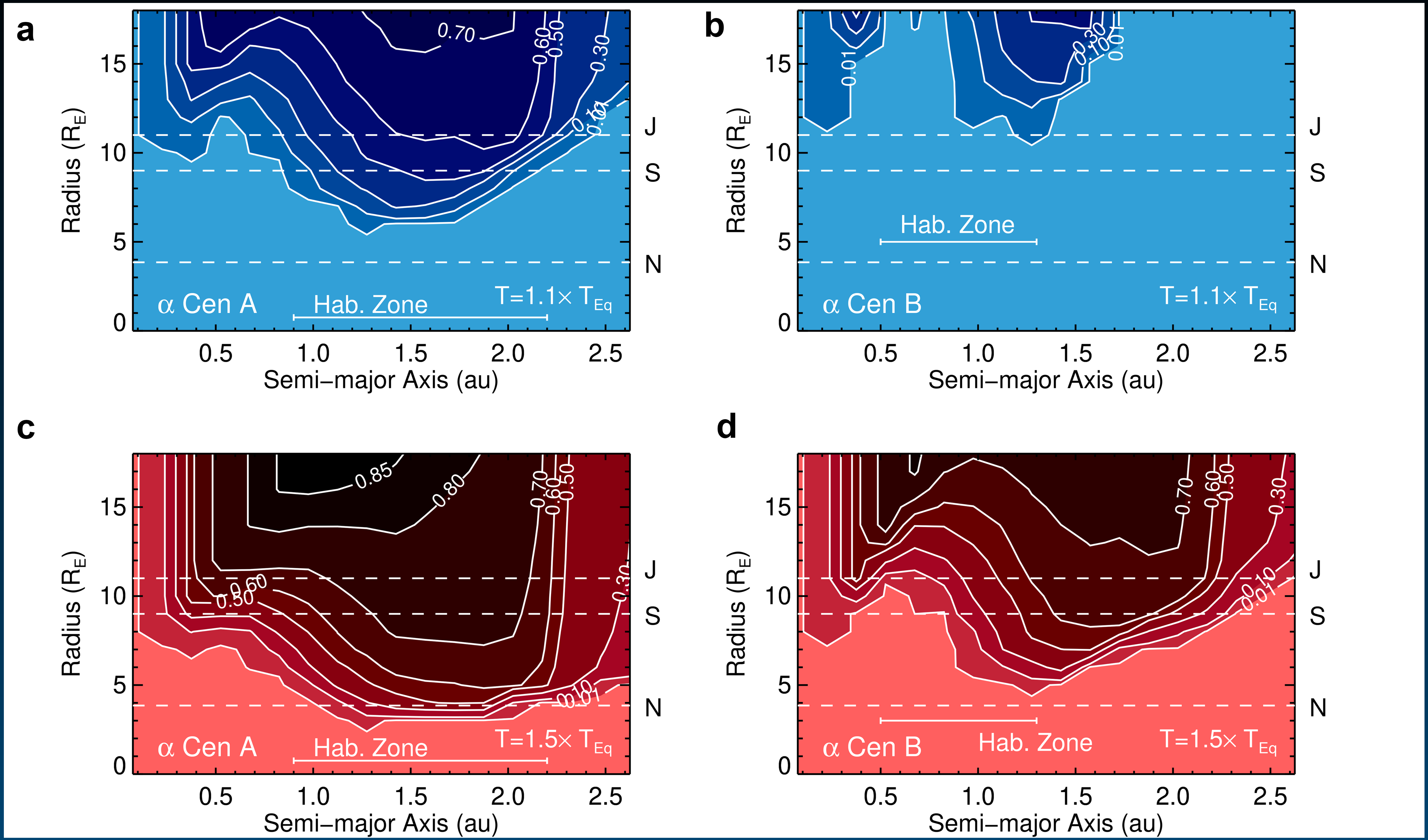
Wagner, NEAR team et al. 2021, Nature Communications

NEAR Campaign Sensitivity: HZ Neptune– to Saturn-sized planets around A



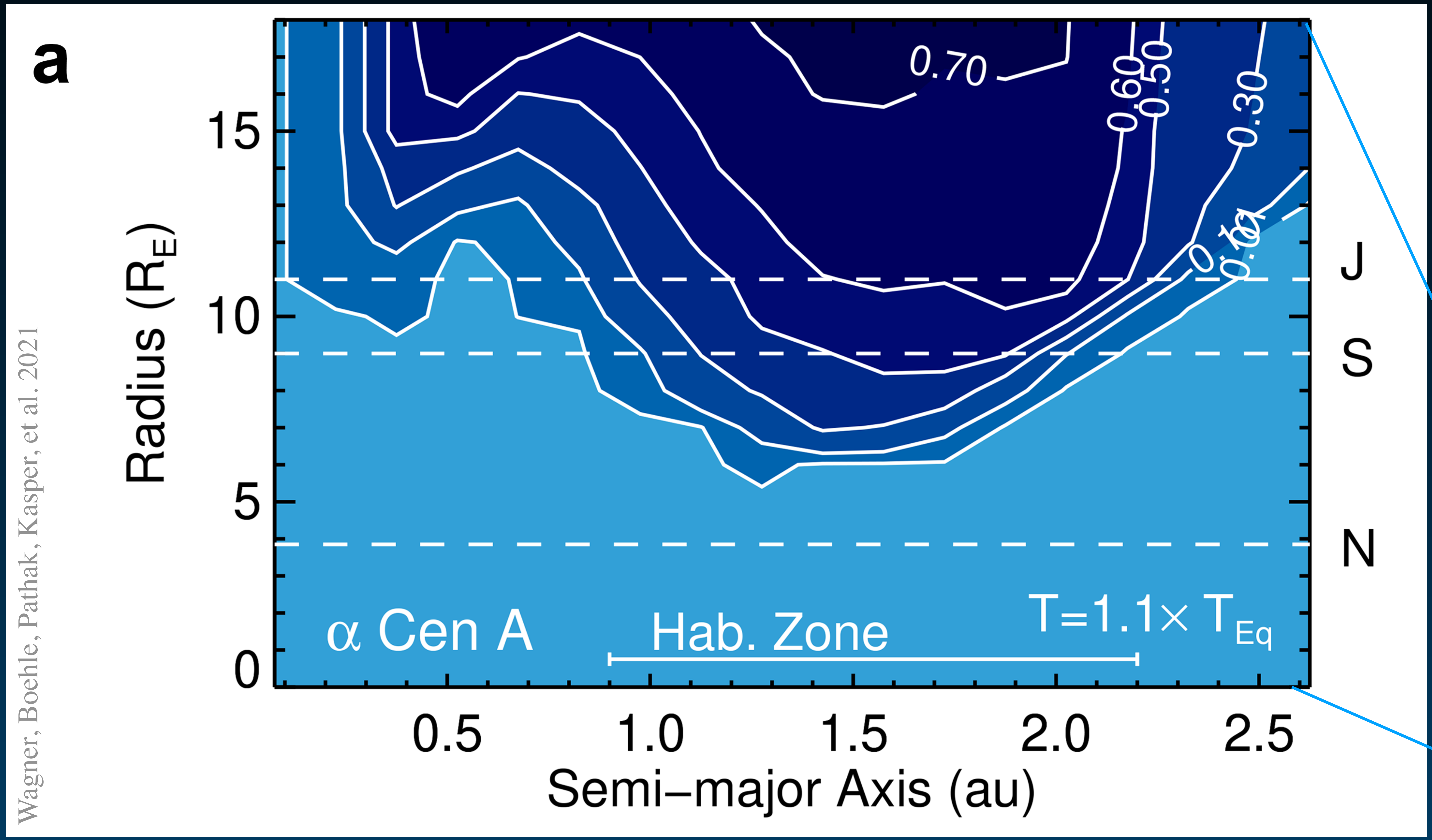
Wagner Boehle, Pathak, Kasper, et al. 2021

NEAR Campaign Sensitivity: Completeness from Monte Carlo simulations



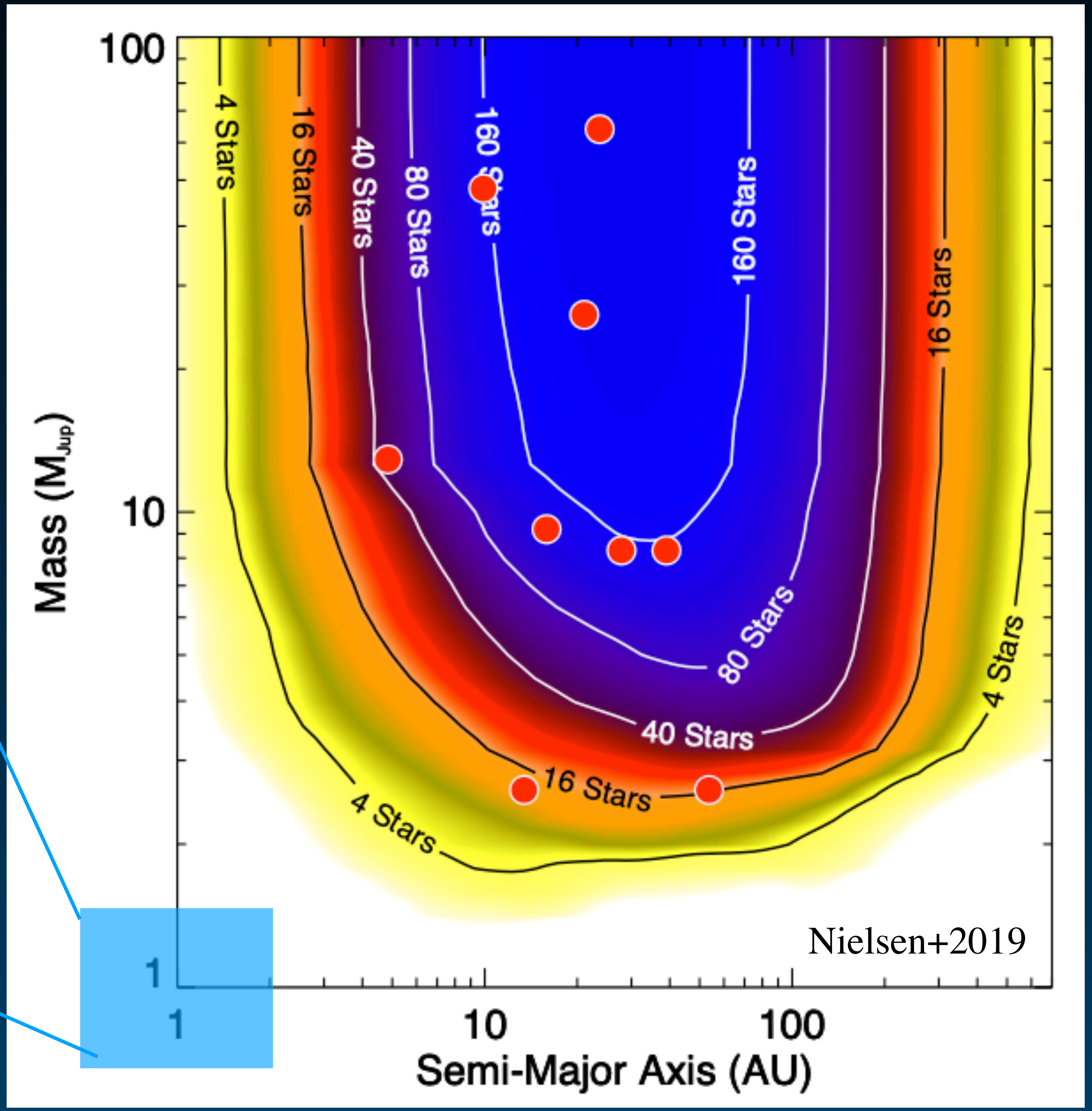
Wagner Boehle, Pathak, Kasper, et al. 2021

Comparison to Exoplanet Imaging Around Young Stars



HZ planets close to radiative thermal equilibrium, Alpha Cen A, 100 hours, 10 μm

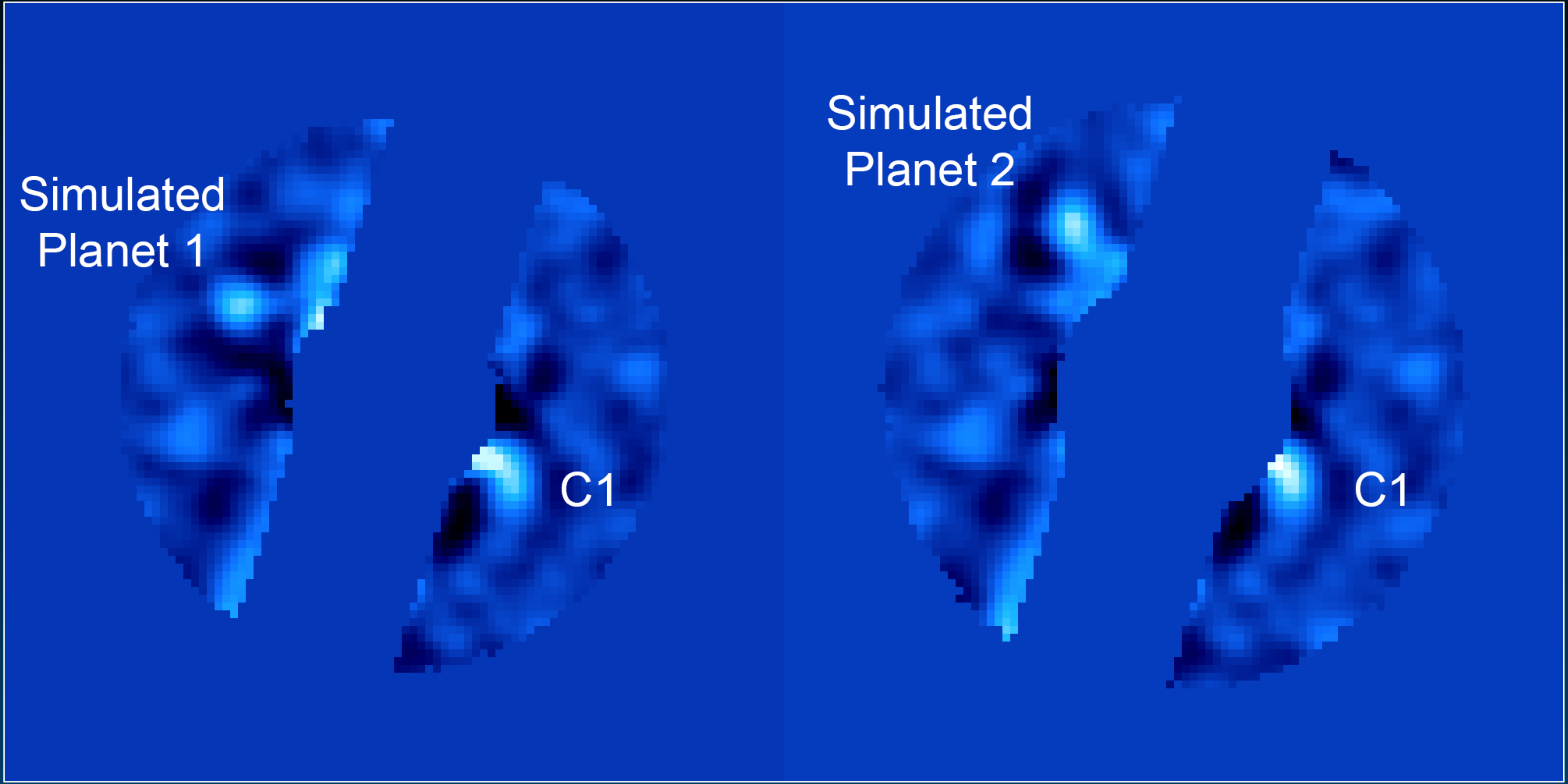
Distance to Alpha Cen = 1.3 pc



GPIES, Nielsen+2019, 300 young stars, ~200 hours, 1.6 μm

Average target distance = 30-50 pc

Possible Explanations for C1



Wagner, Boehle, Pathak, Kasper, et al. 2021

Overstated:

Astronomers Directly Image Habitable-Zone Planet around Alpha Centauri A

Feb 11, 2021 by News Staff / Source « Previous | Next »

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Astronomy
Featured

Tagged as
Alpha Centauri
Alpha Centauri A
Alpha Centauri AB
Breakthrough Initiatives
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Gas giant
Habitable zone
Solar-type star
Star
sub-Neptune
Sun-like star
Triple star
VLT

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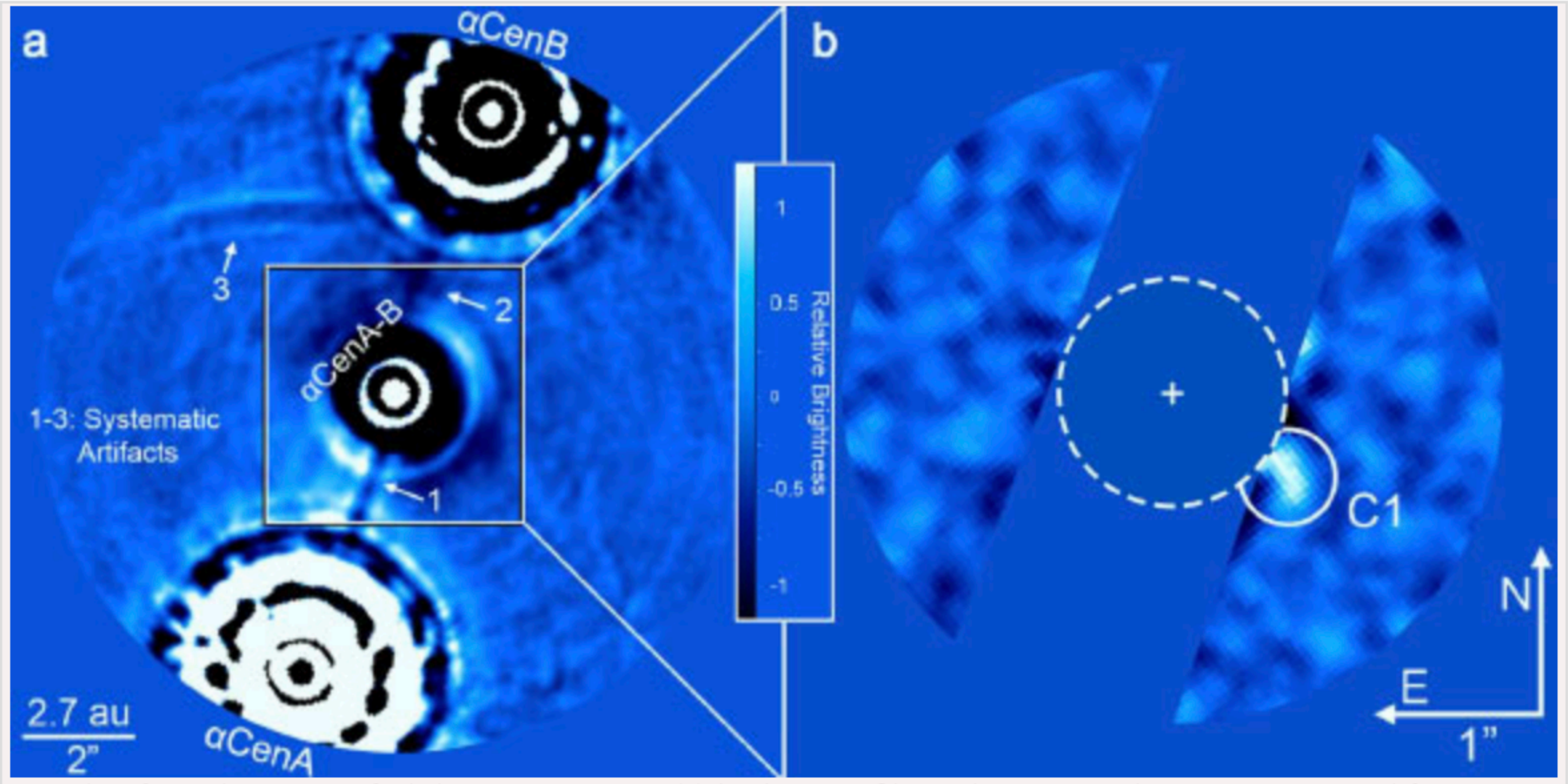
Using a newly developed system for mid-infrared exoplanet imaging, astronomers from the Breakthrough Watch Initiative say they can now use ground-based telescopes to directly capture images of exoplanets about three times the size of Earth within the habitable zones of nearby stars. Their initial observations, made with ESO's Very Large Telescope at the Paranal Observatory in Chile as part of the NEAR (New-Earths in the AlphaCen Region) program, resulted in the detection of a warm sub-Neptune-sized planet in the habitable zone of Alpha Centauri A, part of the star system nearest to Earth.



Proper skepticism:

Is It a Planet? Astronomers Spy Promising Potential World around Alpha Centauri

The candidate could be a "warm Neptune" or a mirage. Either way, it signals the dawn of a revolution in astronomy

By Lee Billings on February 10, 2021

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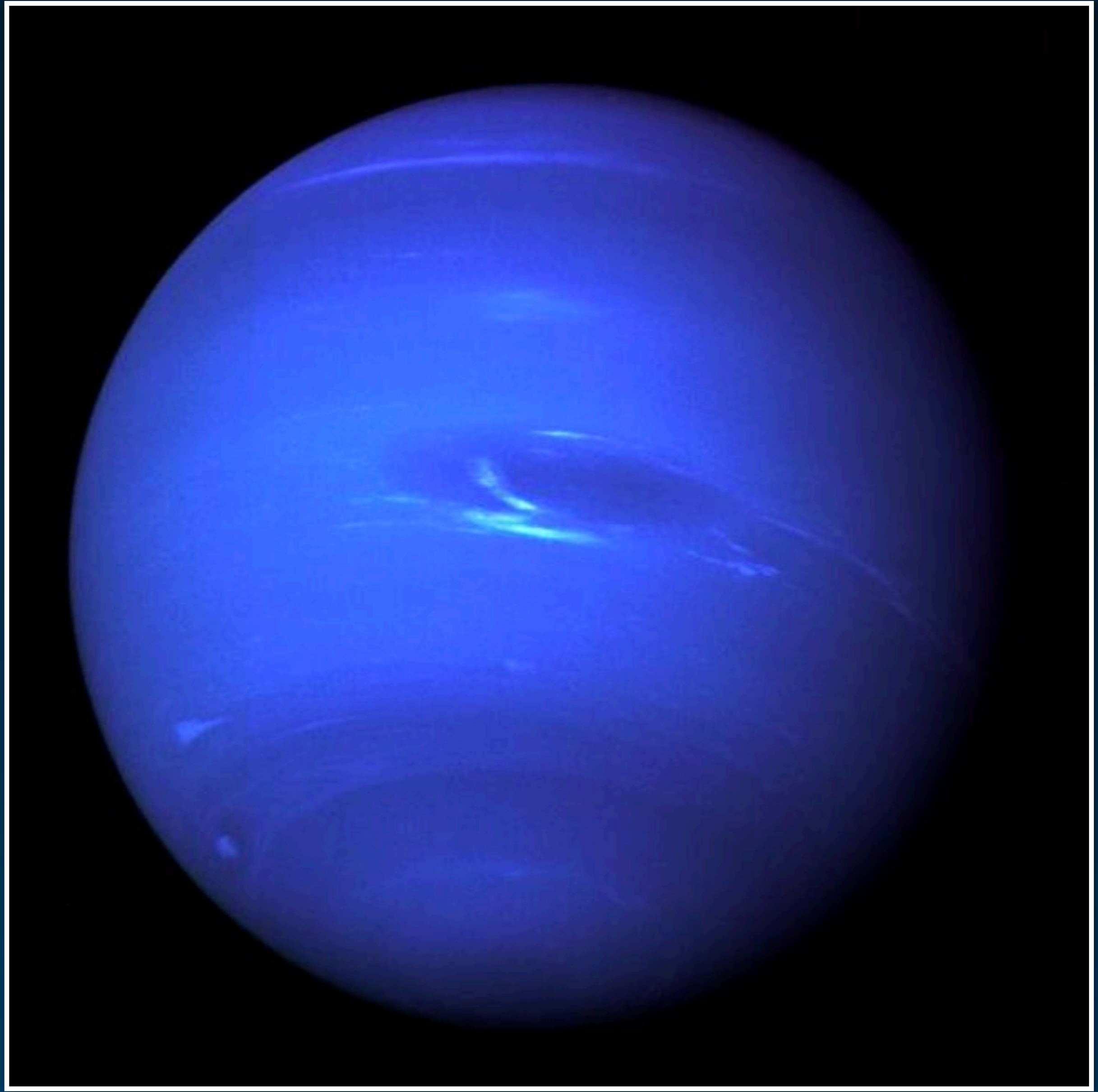
Possible Explanations for C1

Background source? Eliminated by 2009 images (Kervella+2016)

Planet



Voyager 2, NASA/JPL

Exozodiacal Dust Disk

ESO/ Y. Beletsky

Unknown Artifact

?

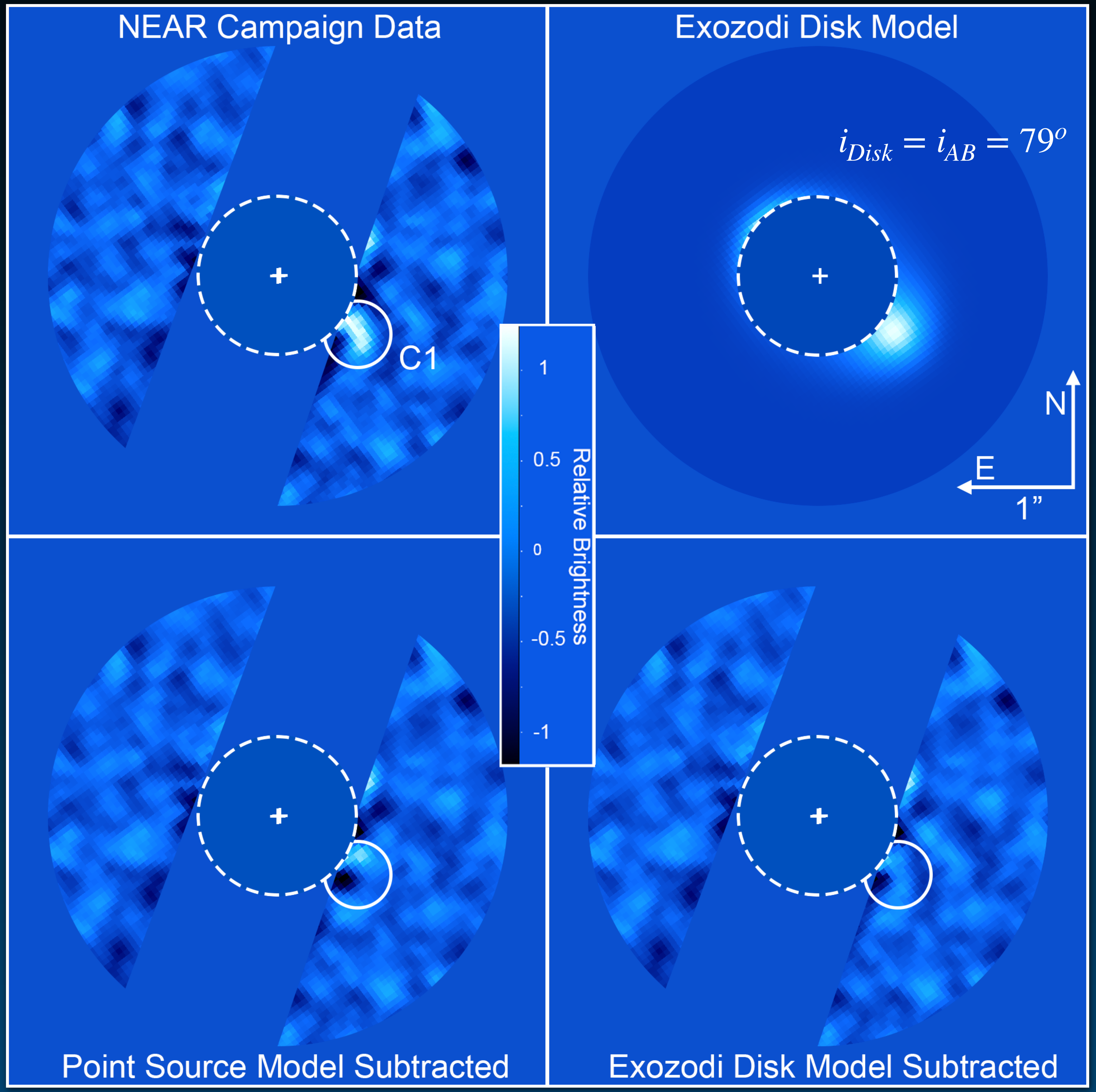
Something else?

Planet or Disk?

- Planet model: R_{C1} ~ 3.3–7 Earth radii, a~1.1 au
  - roughly Neptune– to Saturn-sized
  - consistent with RV-limits (Zhao+2018)

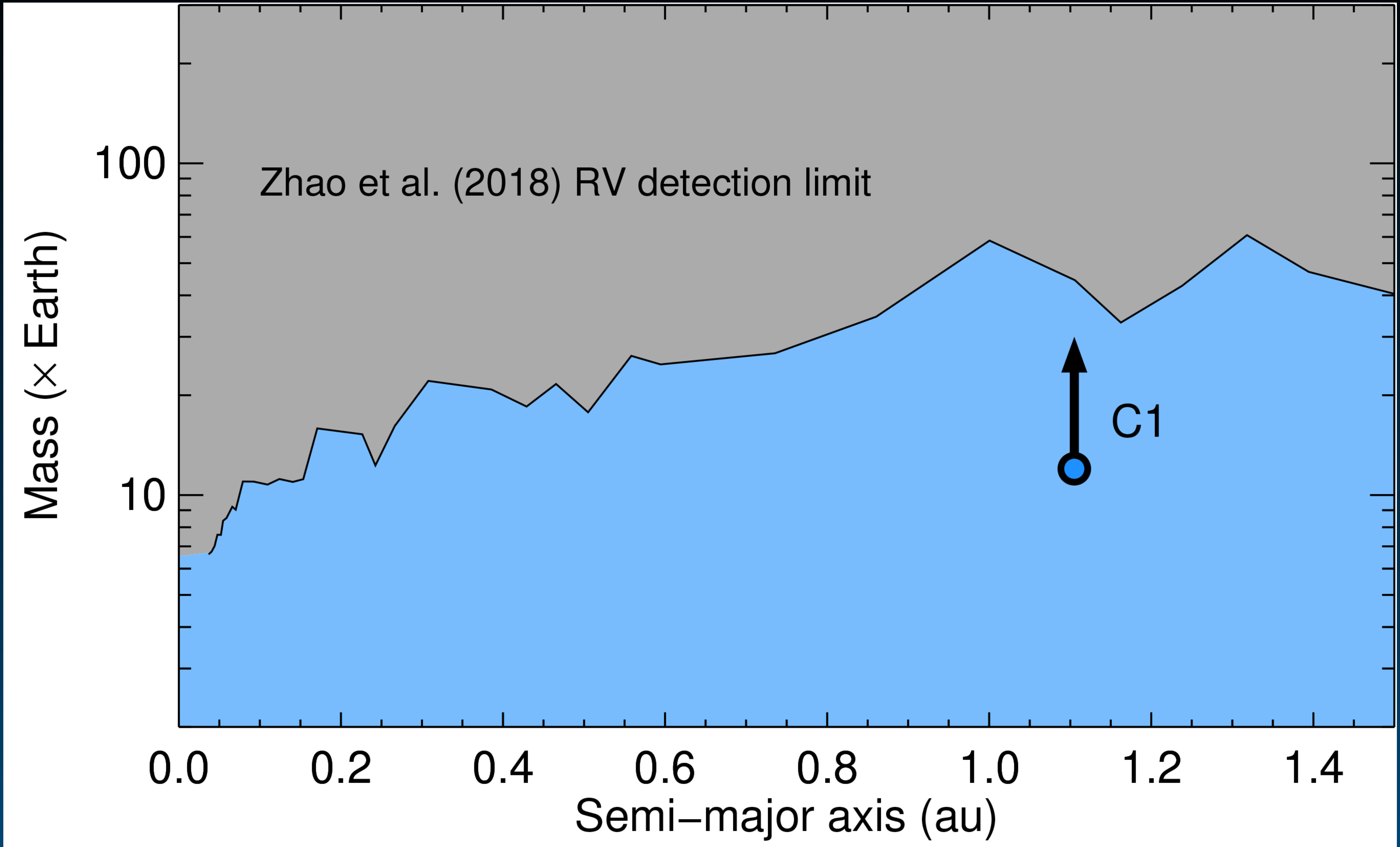
- Disk model generated by zodipic (Kuchner+2012)
  - large amount of dust: 60 zodis
    - higher than 95% of sun-like stars (Ertel+2020) but not unprecedented (e.g., ϵ Eri)
  - Eccentricity of e~0.3, could possibly induced by the e=0.5 binary.

3rd hypothesis: unknown artifact?

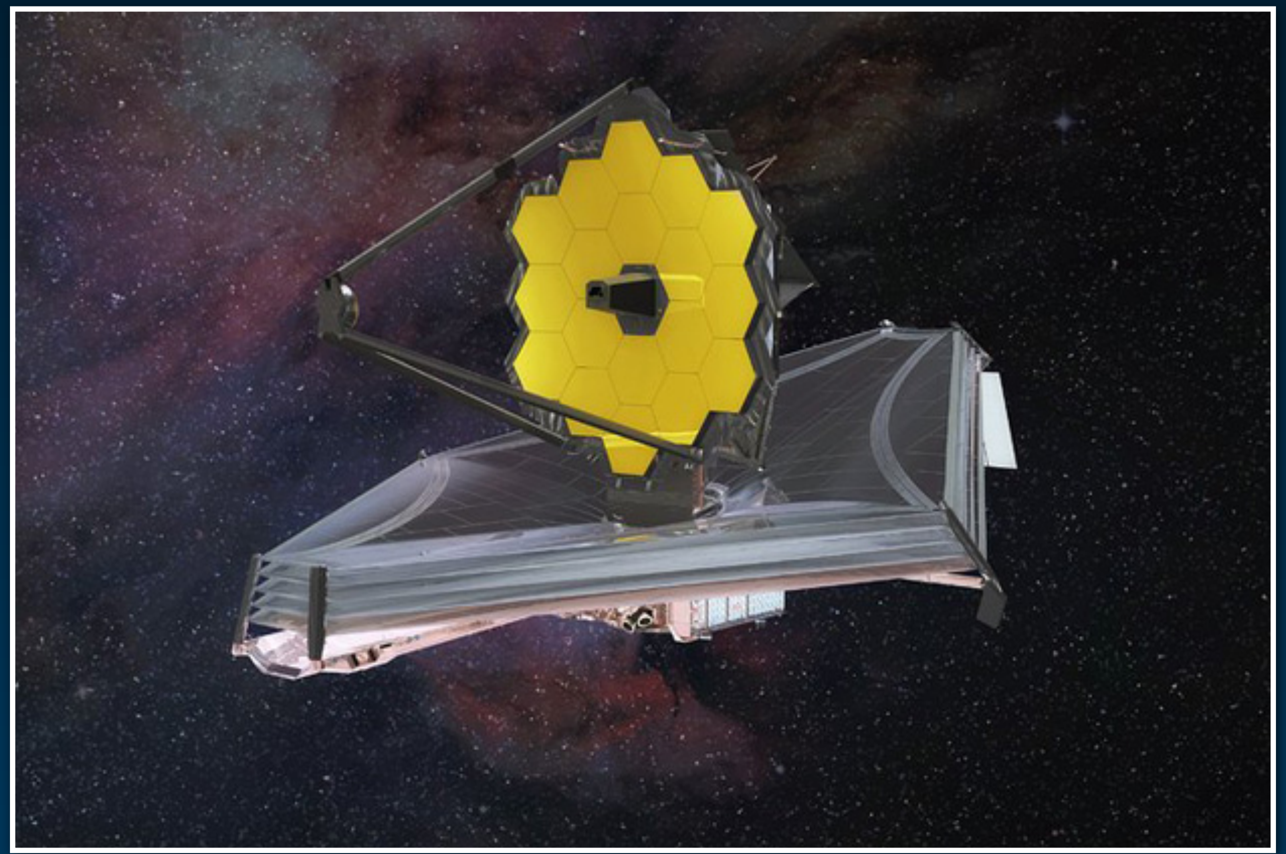


Wagner Boehle, Pathak, Kasper, et al. 2021

Comparison to existing RV detection limits from HARPS



Verifying C1: imaging (JWST or ELT), astrometry (ALMA or a new space telescope), RV (ESPRESSO)



Searching for Planets Orbiting α Cen A with the James Webb Space Telescope

Charles Beichman,[1] Marie Ygouf,[2] Jorge Llop Sayson,[3] Dimitri Mawet,[3] Yuk Yung,[3]

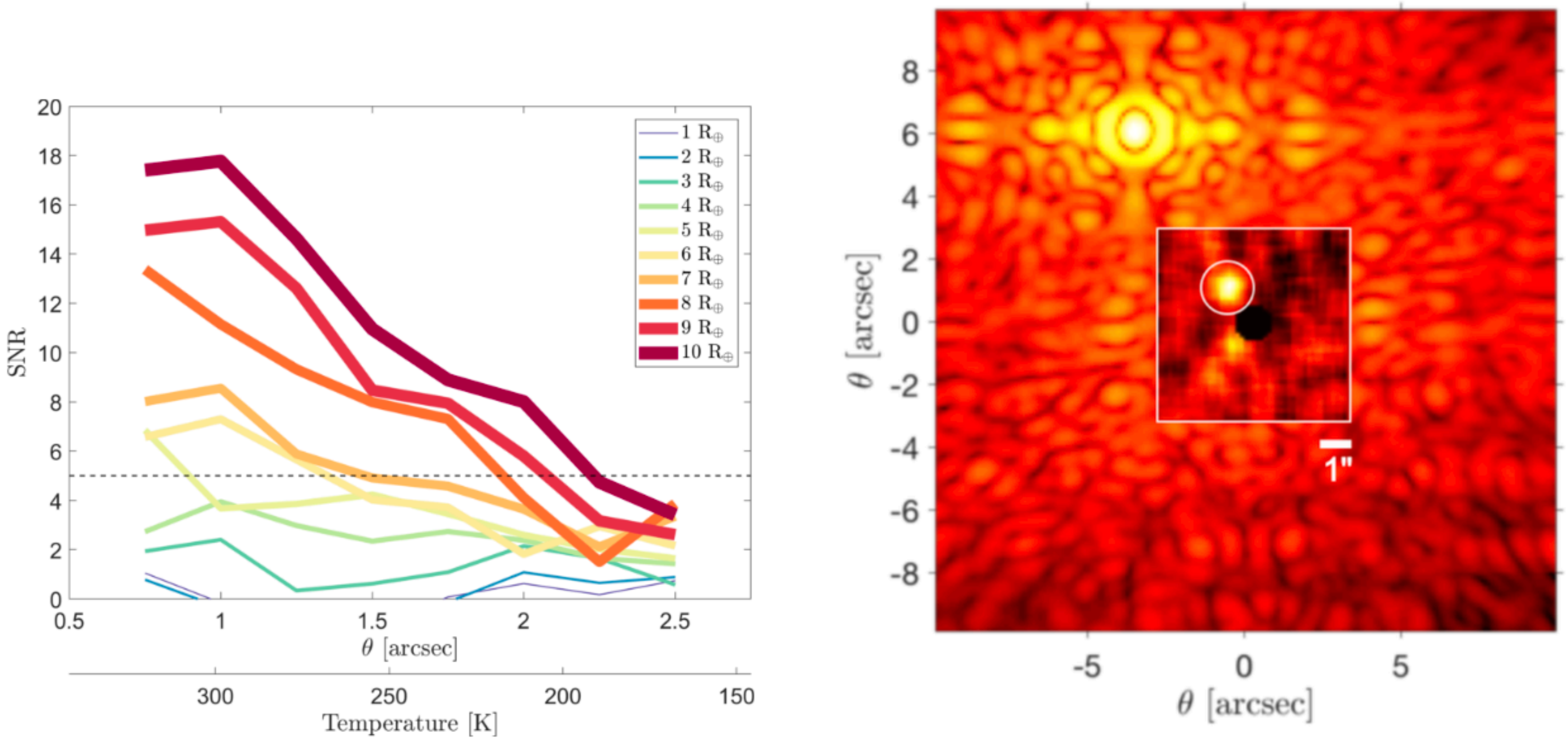


Figure 12. a,left) The sensitivities for different planet sizes at the expected angular separation range of detection were computed for a slow thermal varying wavefront error of 2 nm RMS (*left*). b,right) Simulation for the 2 nm case (left) for the α Cen system with the F1550C filter centered on α Cen A, with α Cen B on the top left, 7 arcseconds away. The PCA reduction of the data is done on a $5'' \times 5''$ central portion of the full image (white square, the scales inside the square are different from outside). A 10 $R_\oplus$ planet is detected at $1.5''$ (white circle).

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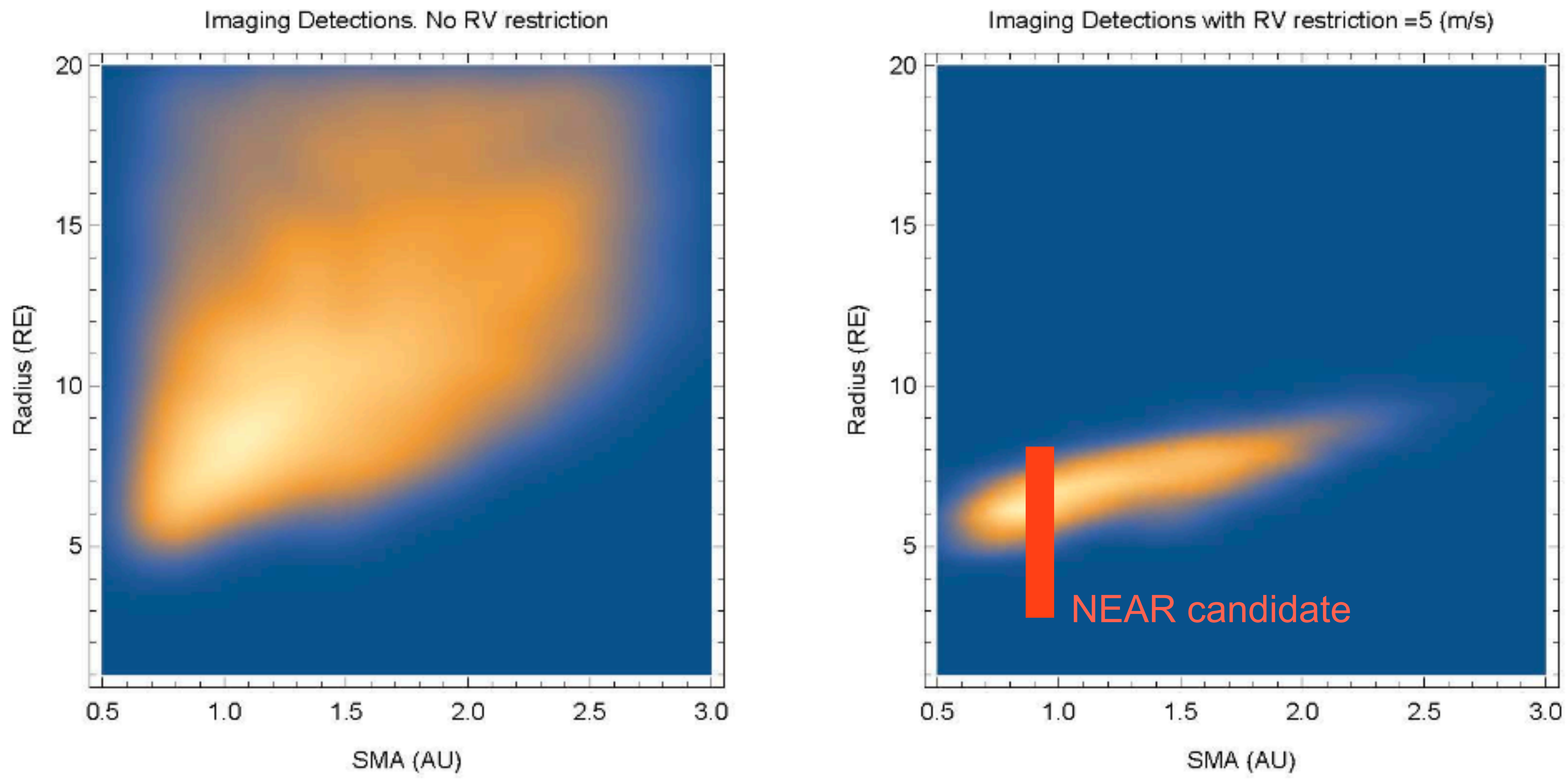


Figure 15. a,left) The locus of all potentially detectable planets in (Radius-SMA) space similar to Figure 14b. b, right) the locus of all detected planets subject to the RV limit of 5 m s^{-1}. The intensity scale is arbitrary.

Searching for Planets Orbiting α Cen A with the James Webb Space Telescope

Charles Beichman,[1] Marie Ygouf,[2] Jorge Llop Sayson,[3] Dimitri Mawet,[3] Yuk Yung,[3]

Scheduled for July 22-29

Challenges:

1) Positioning behind the coronagraph is critical

2) Alpha Cen and reference are too bright to acquire directly on the MIRI coronagraph

3) Blind offset from a nearby reference star will be necessary

4) Motion of Alpha Cen (orbit, proper motion, parallax yield 10 mas/day)
   (final position via ALMA DDT from Ed Fomalont, Rachel Akeson, and Pierre Kervella)

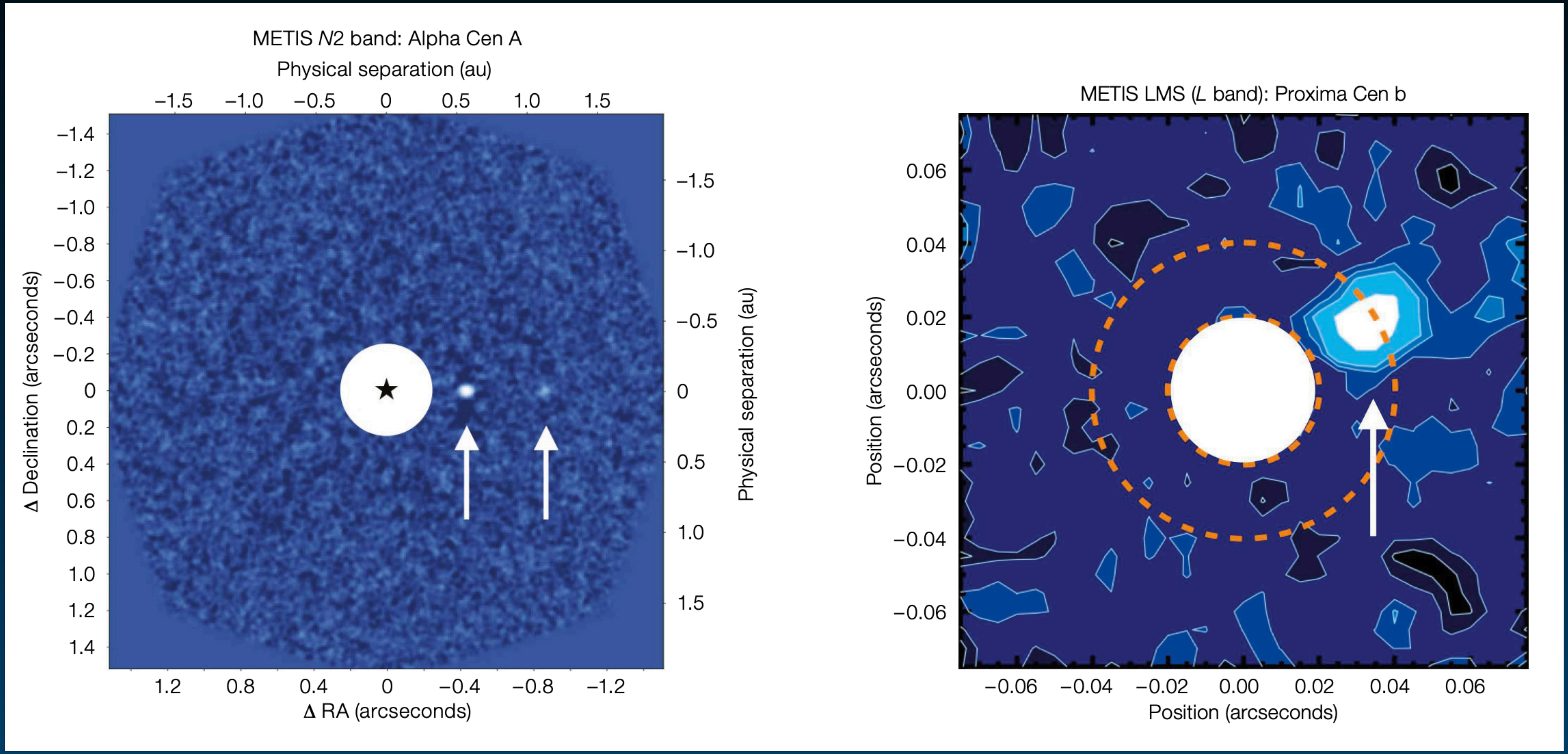
5) Even with all of the above, planets may be at unfavorable orbital phase

6) Wavefront error (2nm optimistic, 5 nm worst case)

METIS: The Mid-infrared ELT Imager and Spectrograph

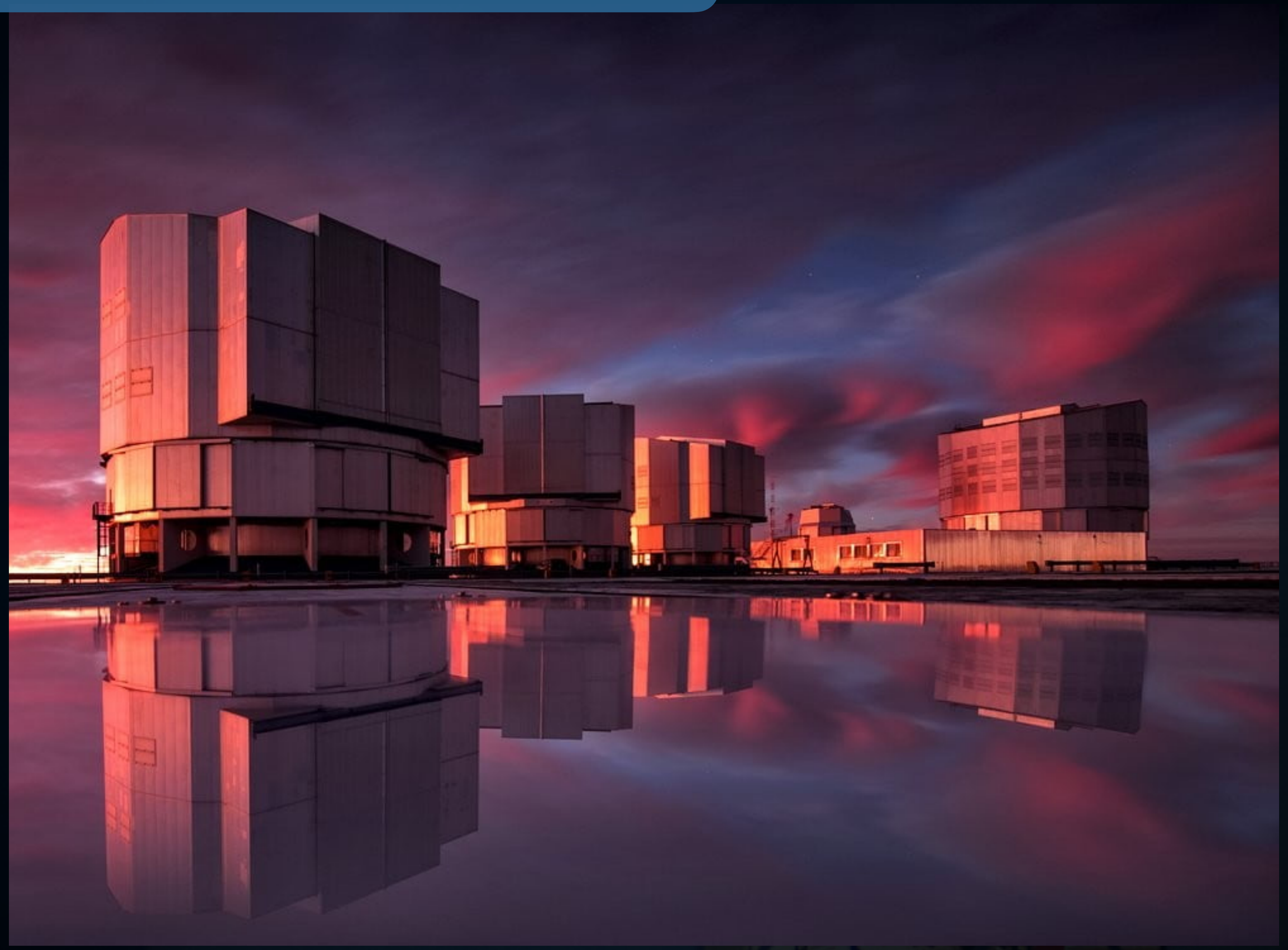
2028?

Bernhard Brandl[1, 2]
Felix Bettonvil[1]
Roy van Boekel[3]
Adrian Glauser[4]
Sascha Quanz[4]
Olivier Absil[5]
António Amorim[6]
Markus Feldt[3]
Alistair Glasse[7]
Manuel Güdel[8]
Paul Ho[9]
Lucas Labadie[10]
Michael Meyer[11]
Eric Pantin[12]
Hans van Winckel[13]
and the METIS Consortium[a]



A Bridge Between Generations

NEAR (decommissioned) – 8.2m VLT



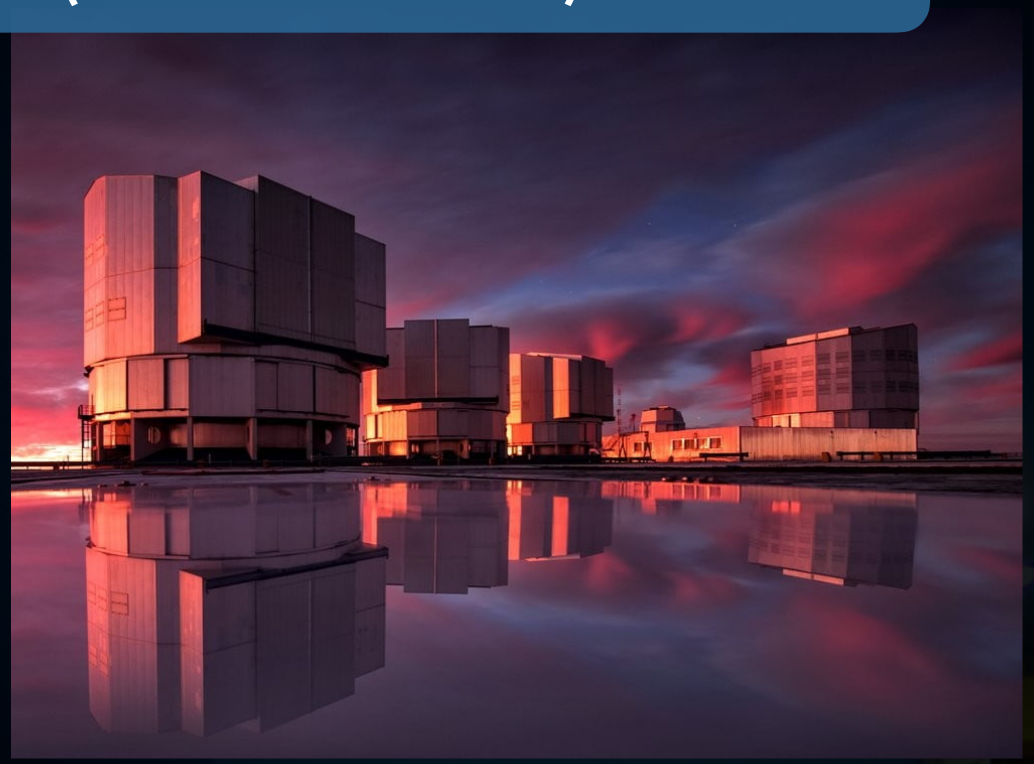
2019

39m ELT

2030s

A Bridge Between Generations

NEAR (decommissioned) – 8.2m VLT



2019

2020s

22.7m LBT

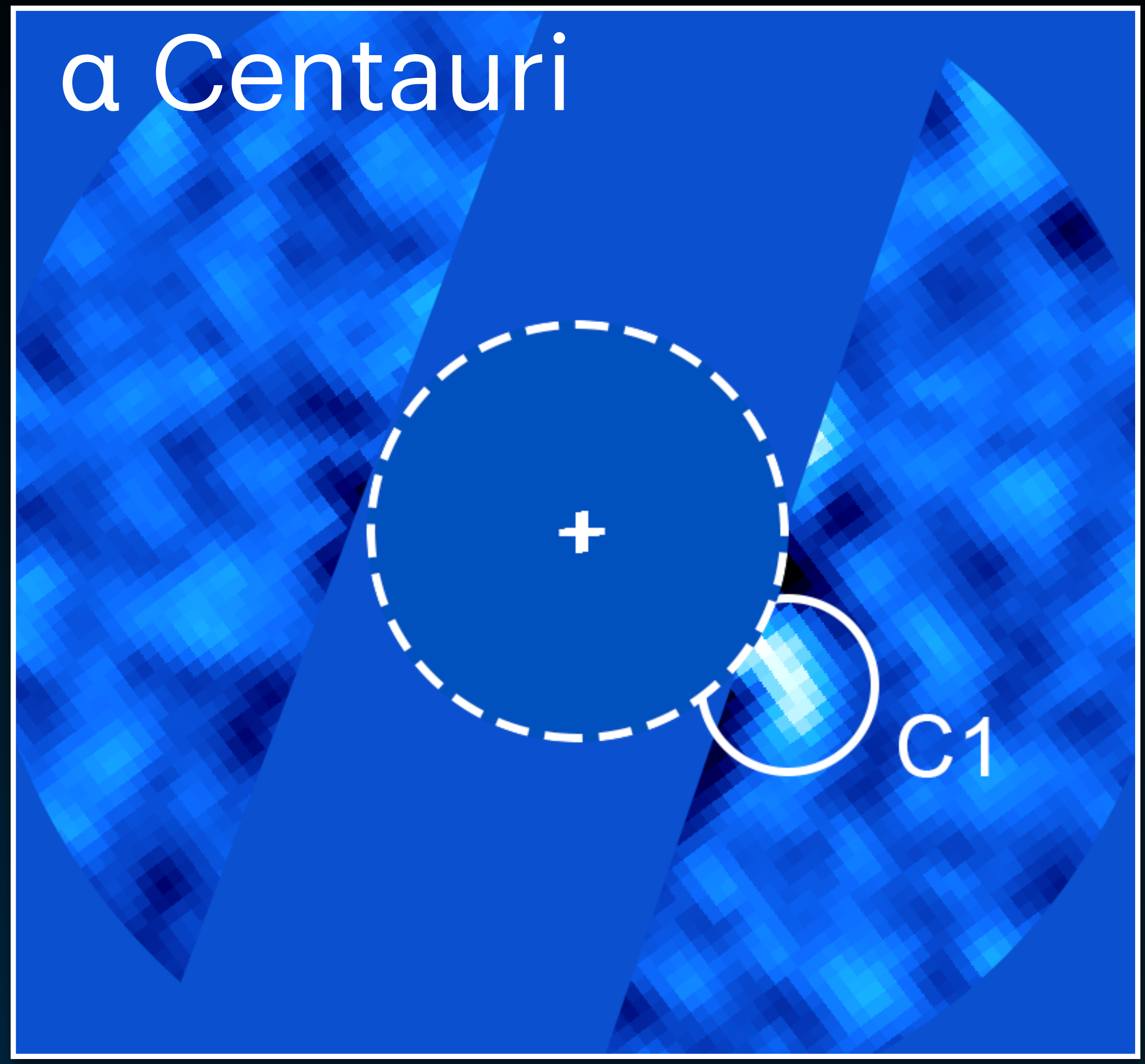
39m ELT

2030s

Conclusions:

1. RefPlanets established sensitivity to Jovian planets (13% completeness: Hunziker+2020, Tschudi et al. in prep.)
2. NEAR established thermal-IR sensitivities to warm sub-Neptunes (30% completeness) and cold giant planets (50-60% completeness: Wagner, NEAR team 2021)
3. NEAR detected a potential exoplanet or exozodiacal disk candidate that will soon be followed up by JWST (in ~1 month!) and ELTs in the coming years.

7 TB of public data on the ESO archive; have fun!



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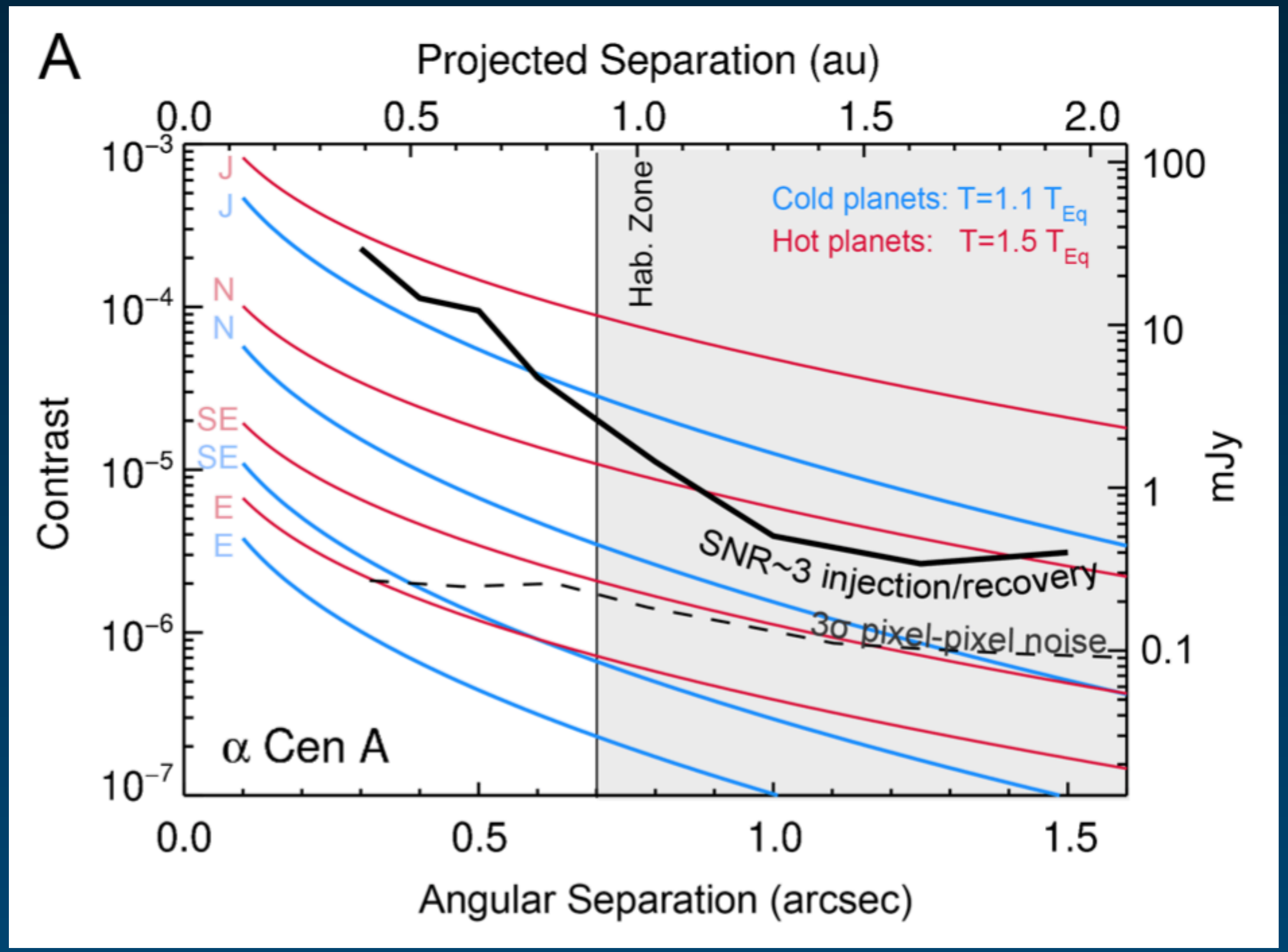

Kevin Wagner | U. Arizona, Sagan Fellow | Nice, France – June 2023 | kevinwagner@arizona.edu | @AstroWagner

Bonus Slide: Jupiter at 10 μm from NEAR commissioning