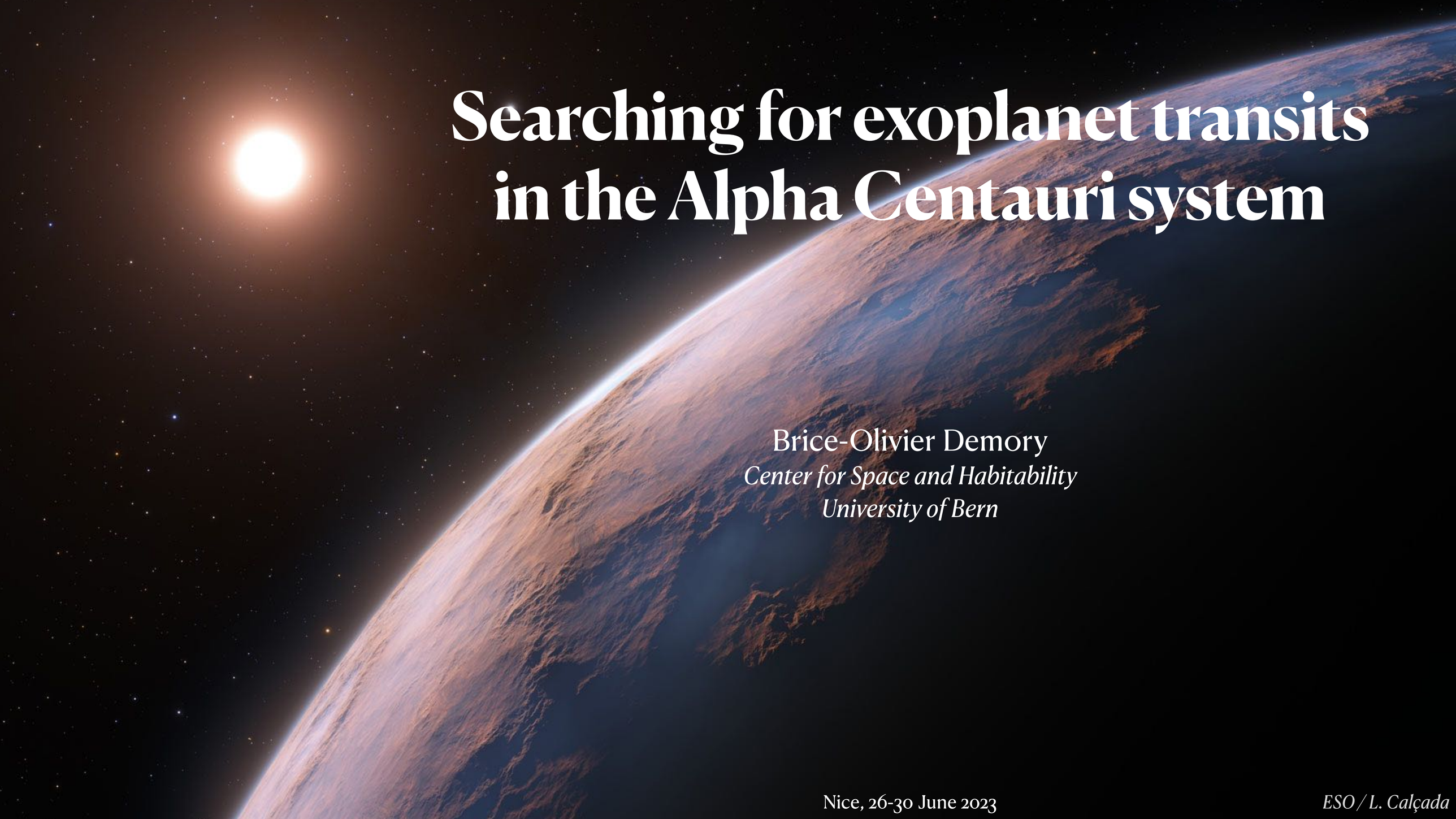
Searching for exoplanet transits in the Alpha Centauri system

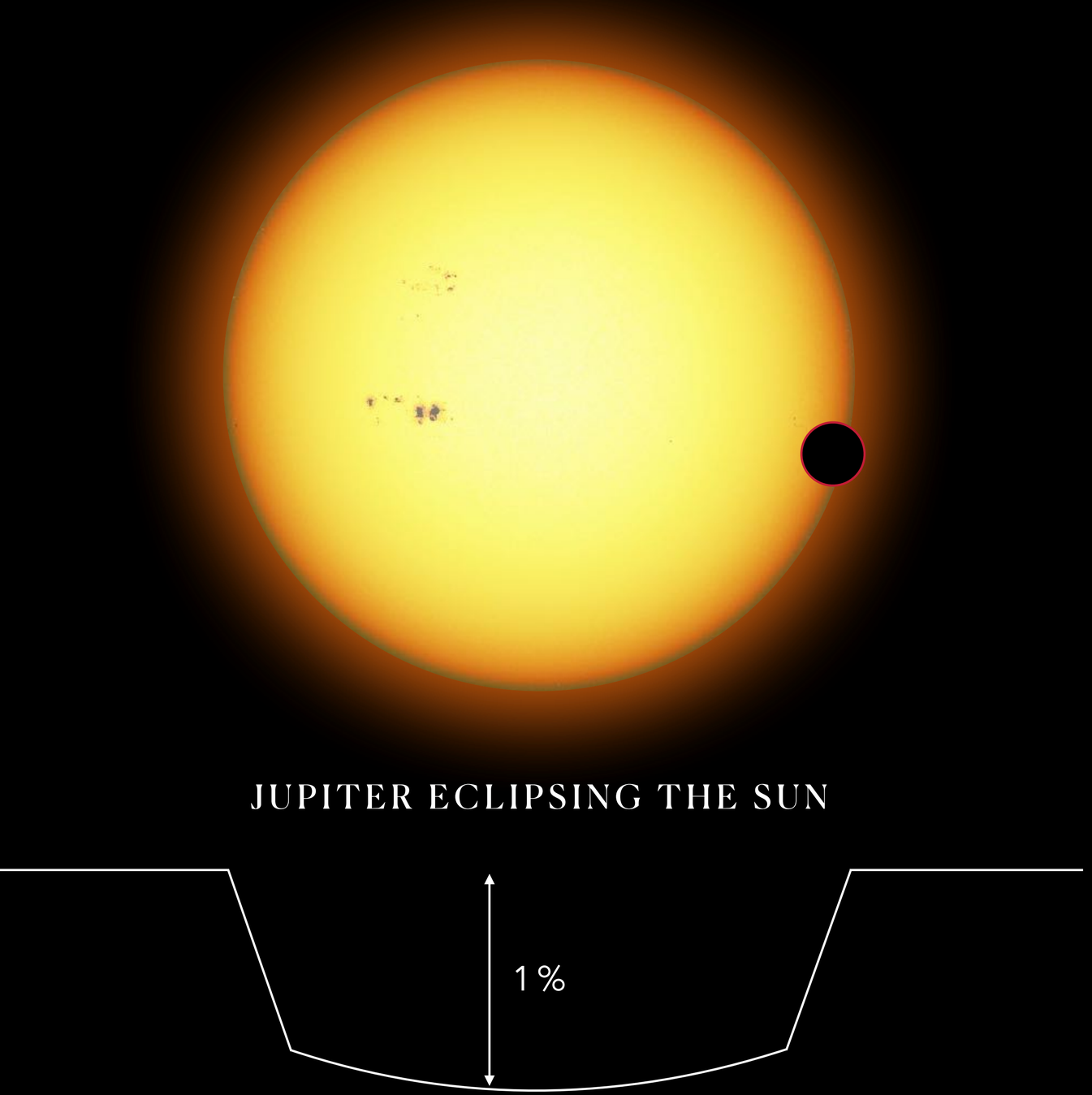
Brice-Olivier Demory
Center for Space and Habitability
University of Bern

Nice, 26-30 June 2023



ESO / L. Calçada

JUPITER ECLIPSING THE SUN



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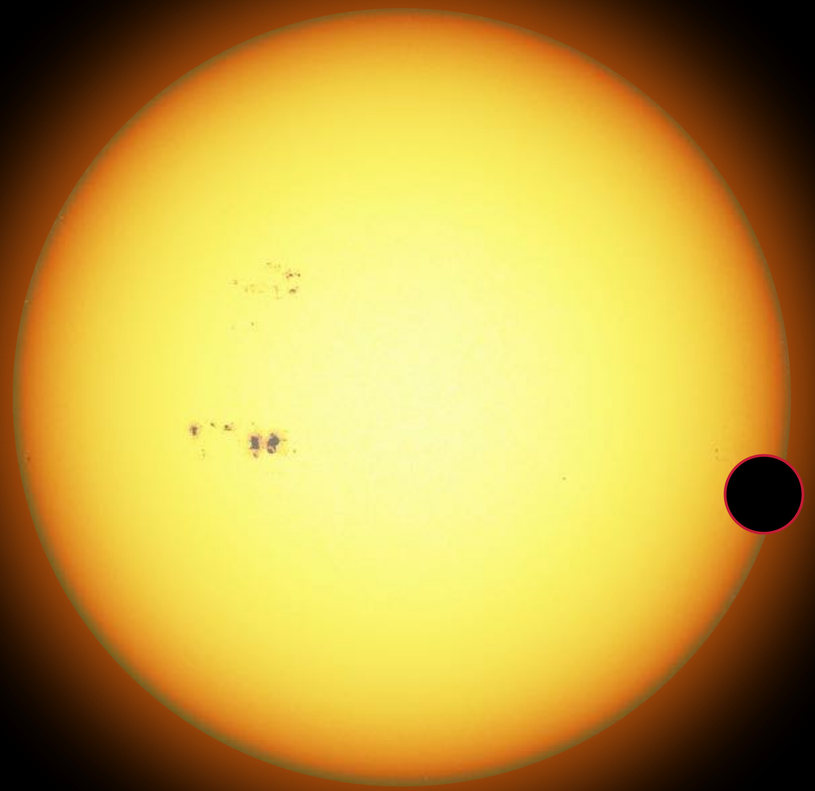

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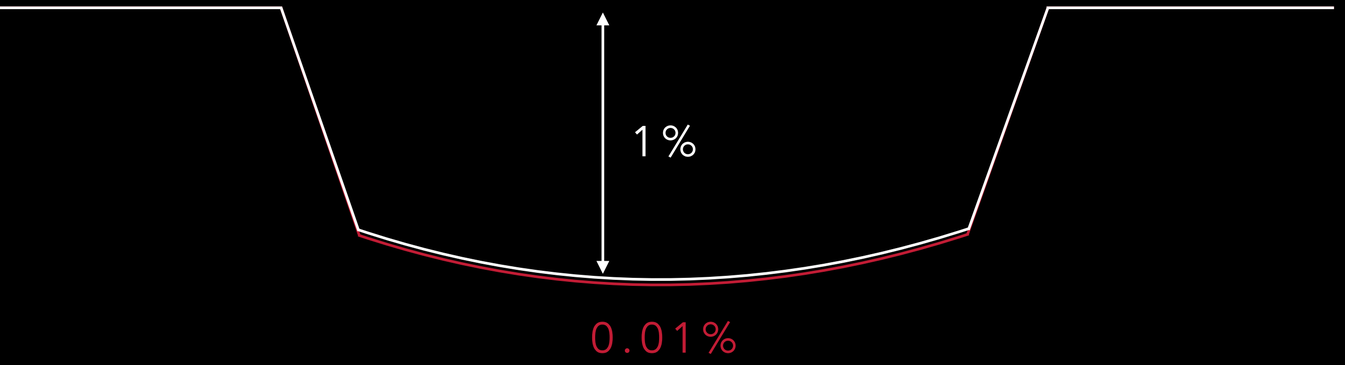

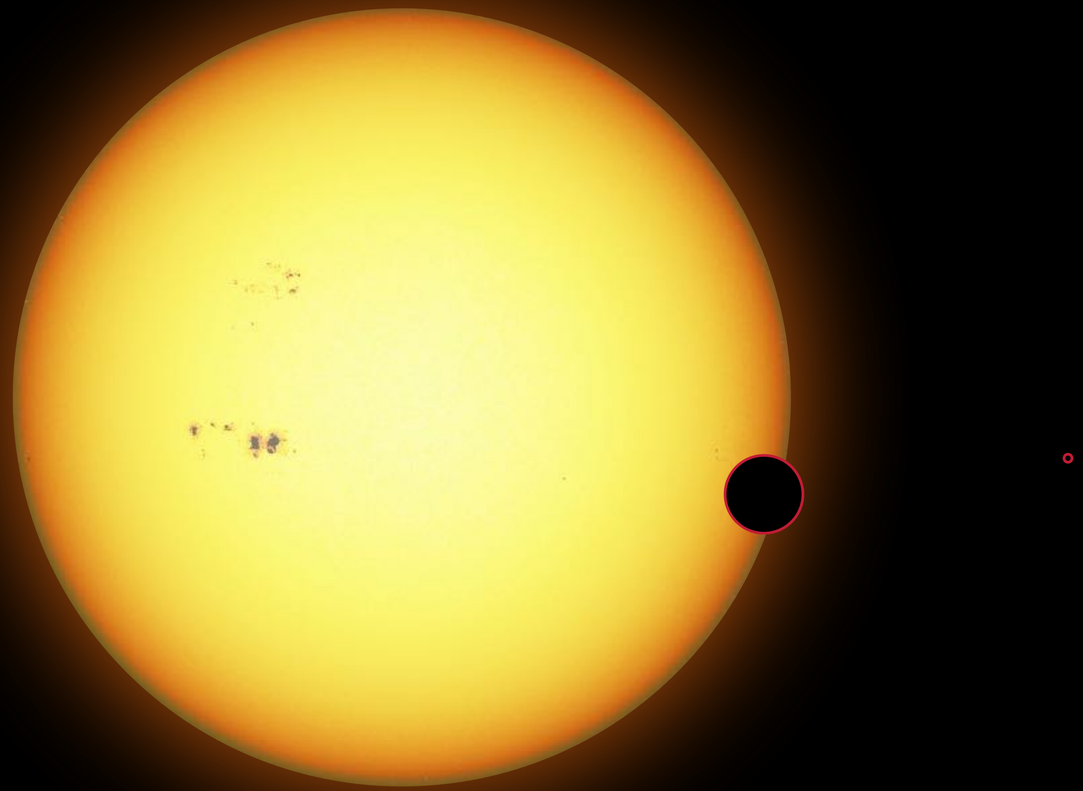

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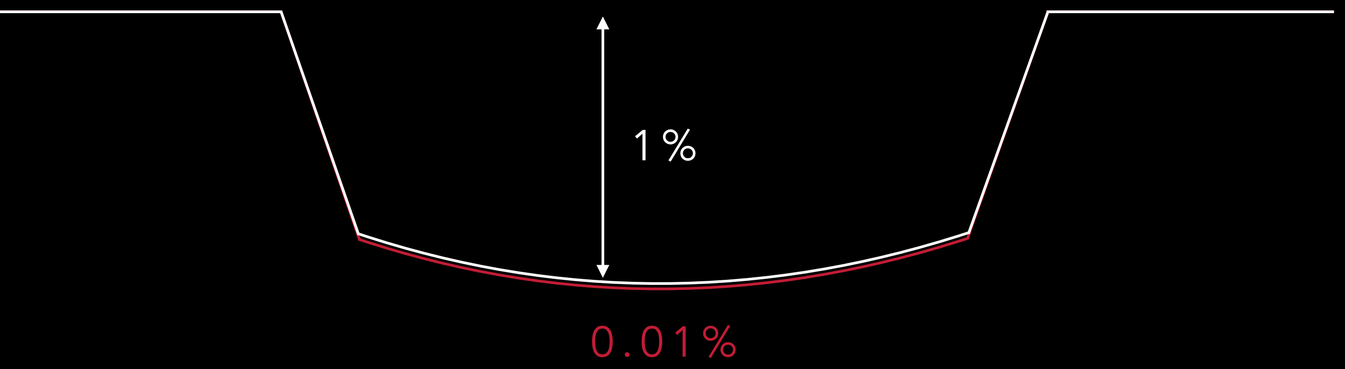
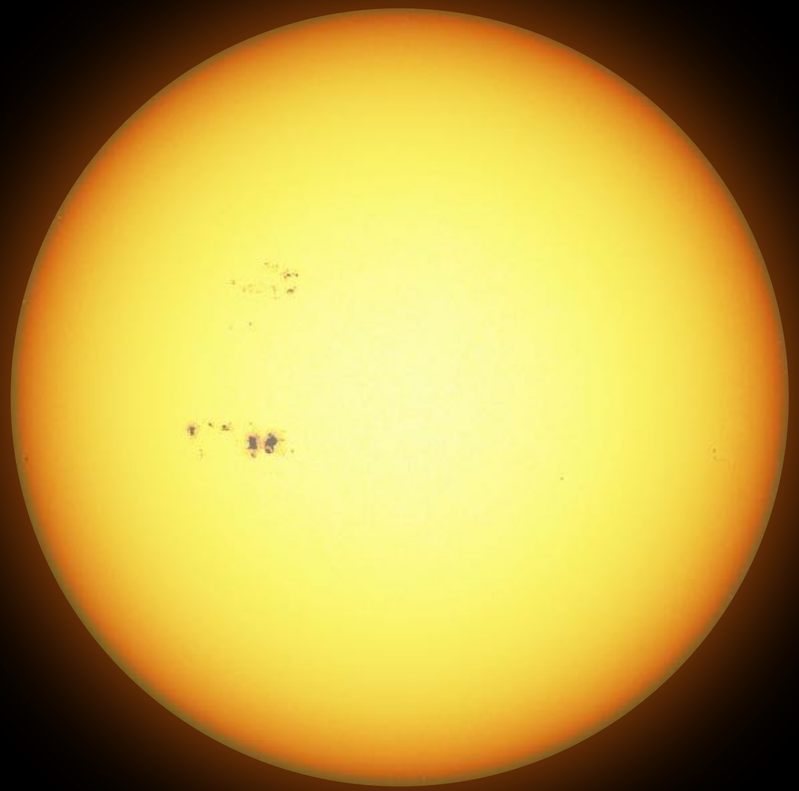
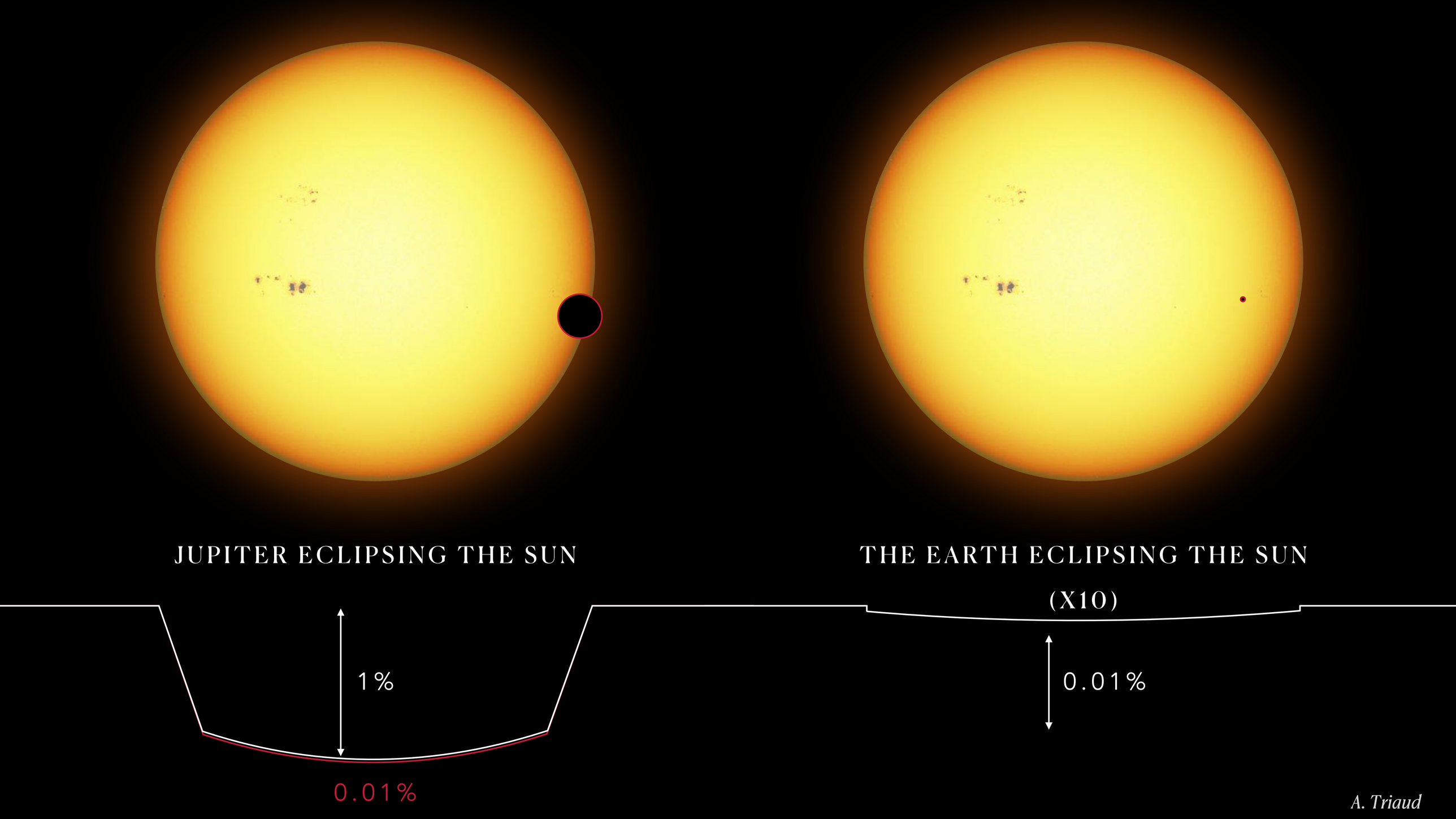
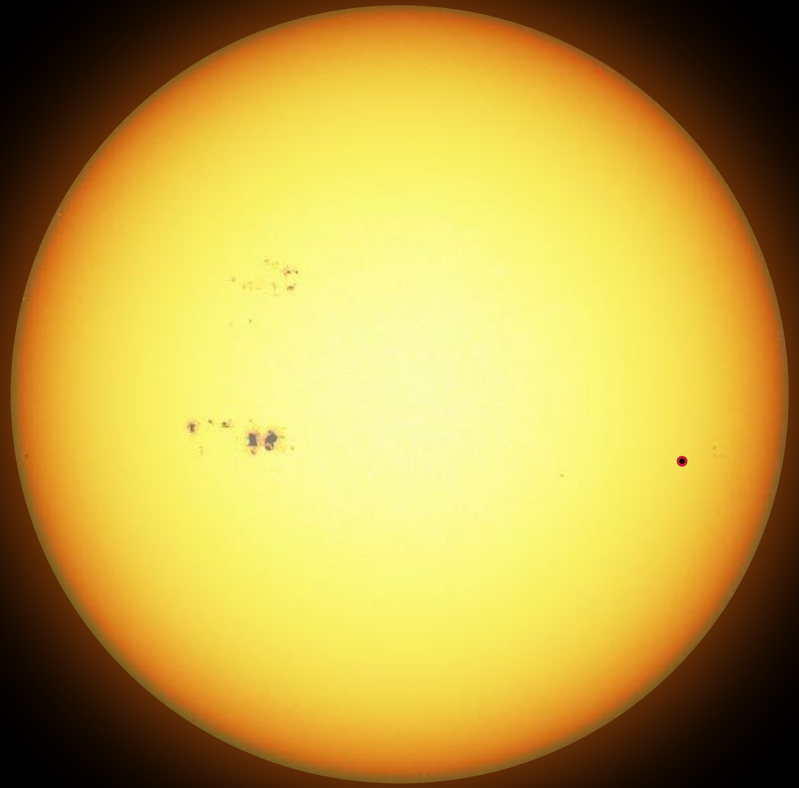
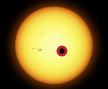


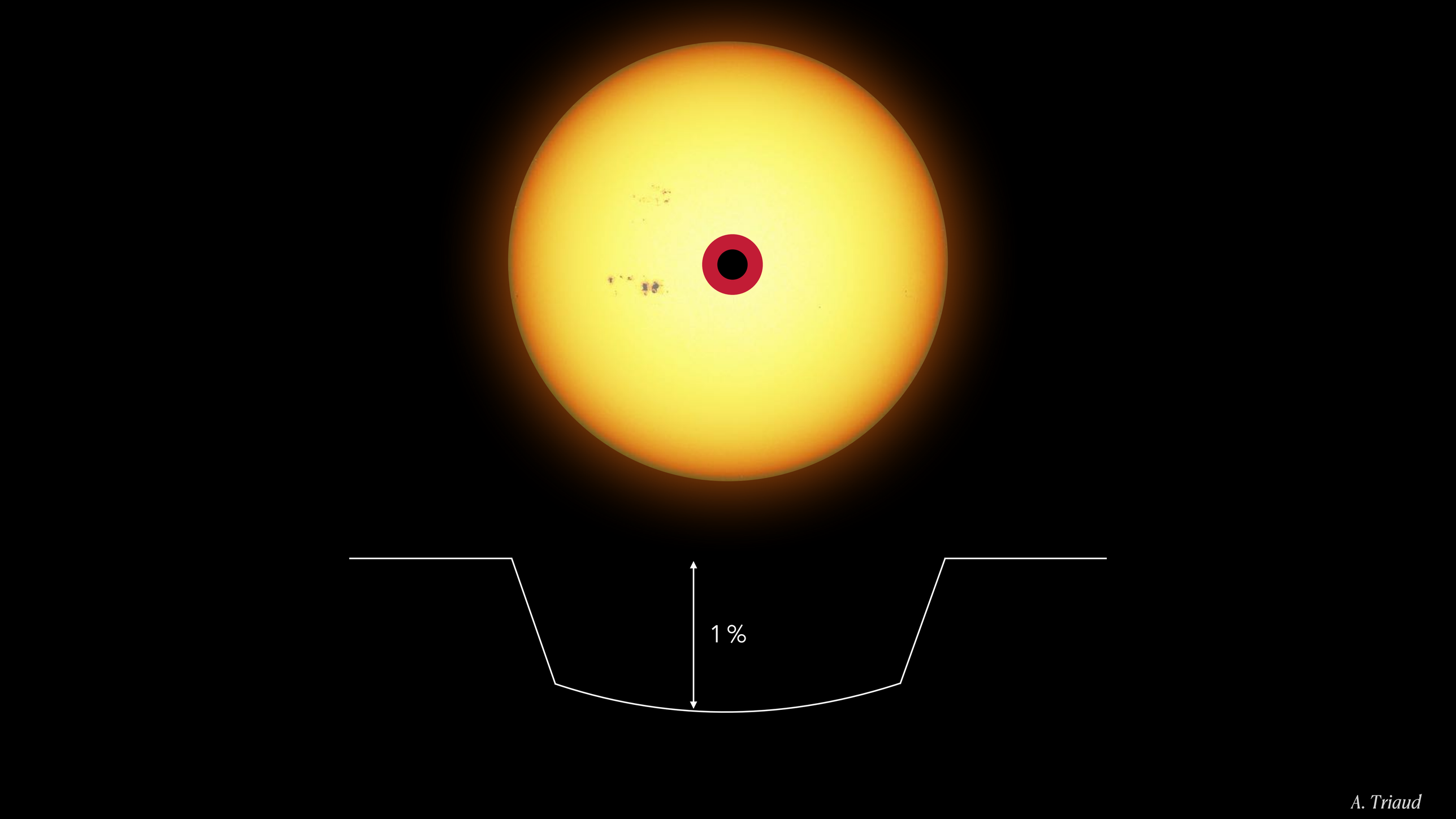


THE EARTH ECLIPSING THE SUN

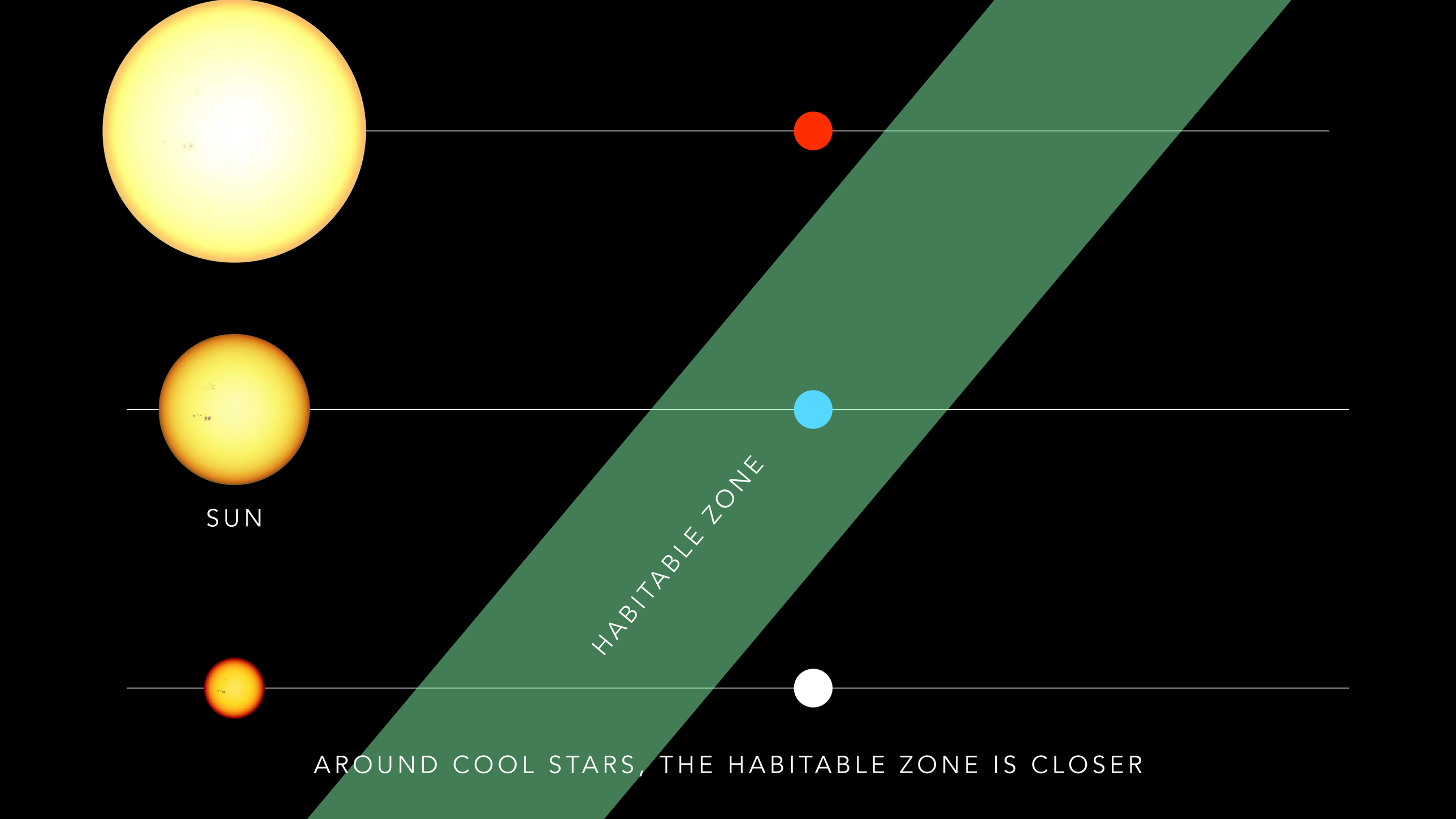

JUPITER ECLIPSING THE SUN
THE EARTH ECLIPSING THE SUN
(X10)
1%
0.01%
0.01%
A. Triaud

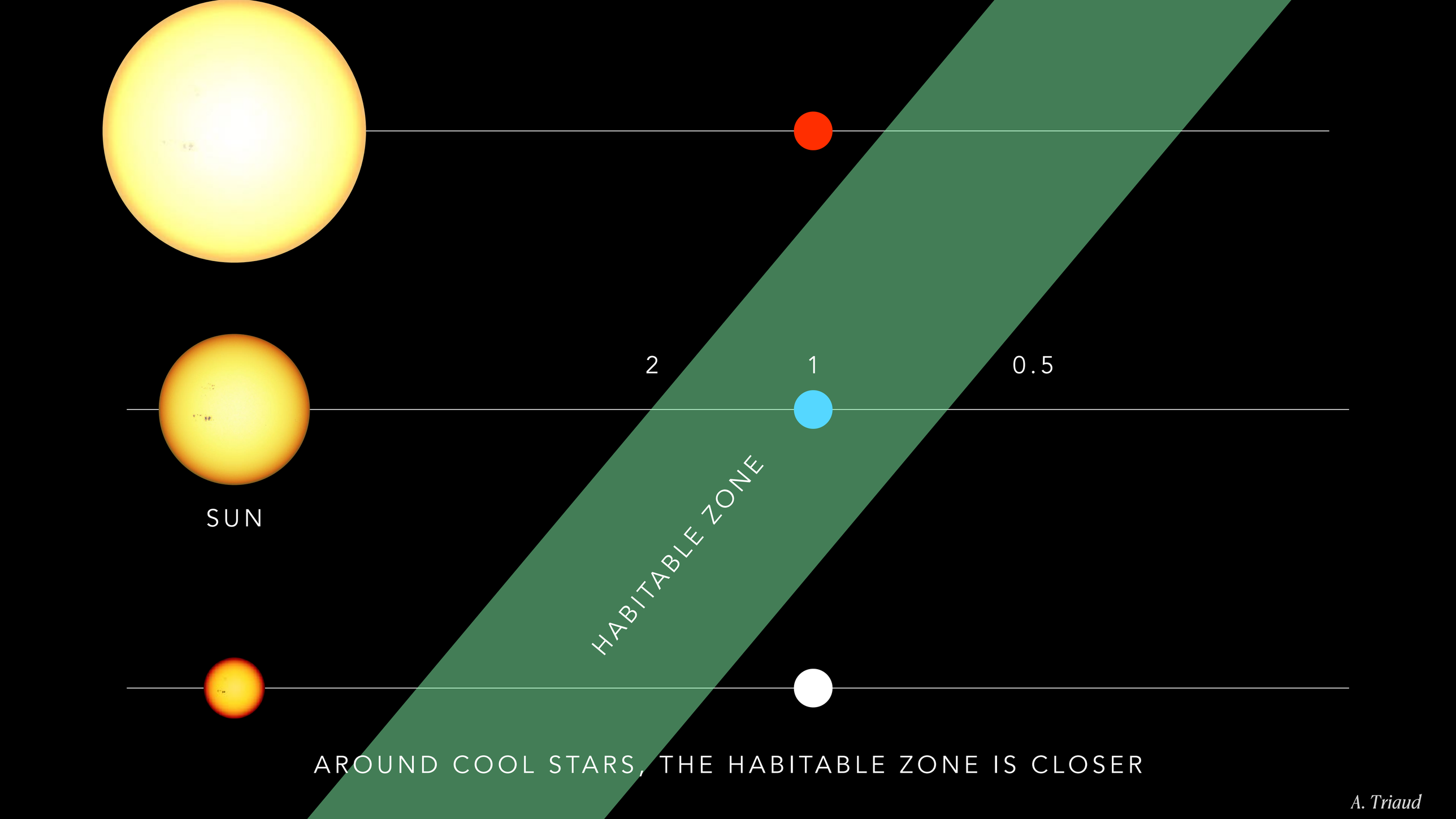


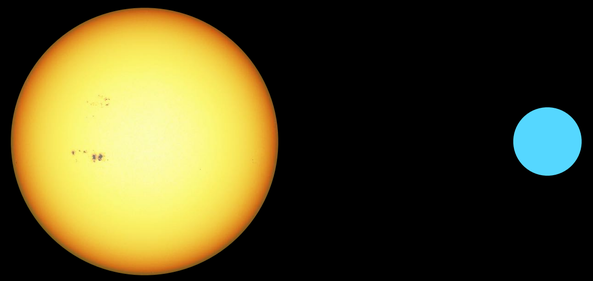




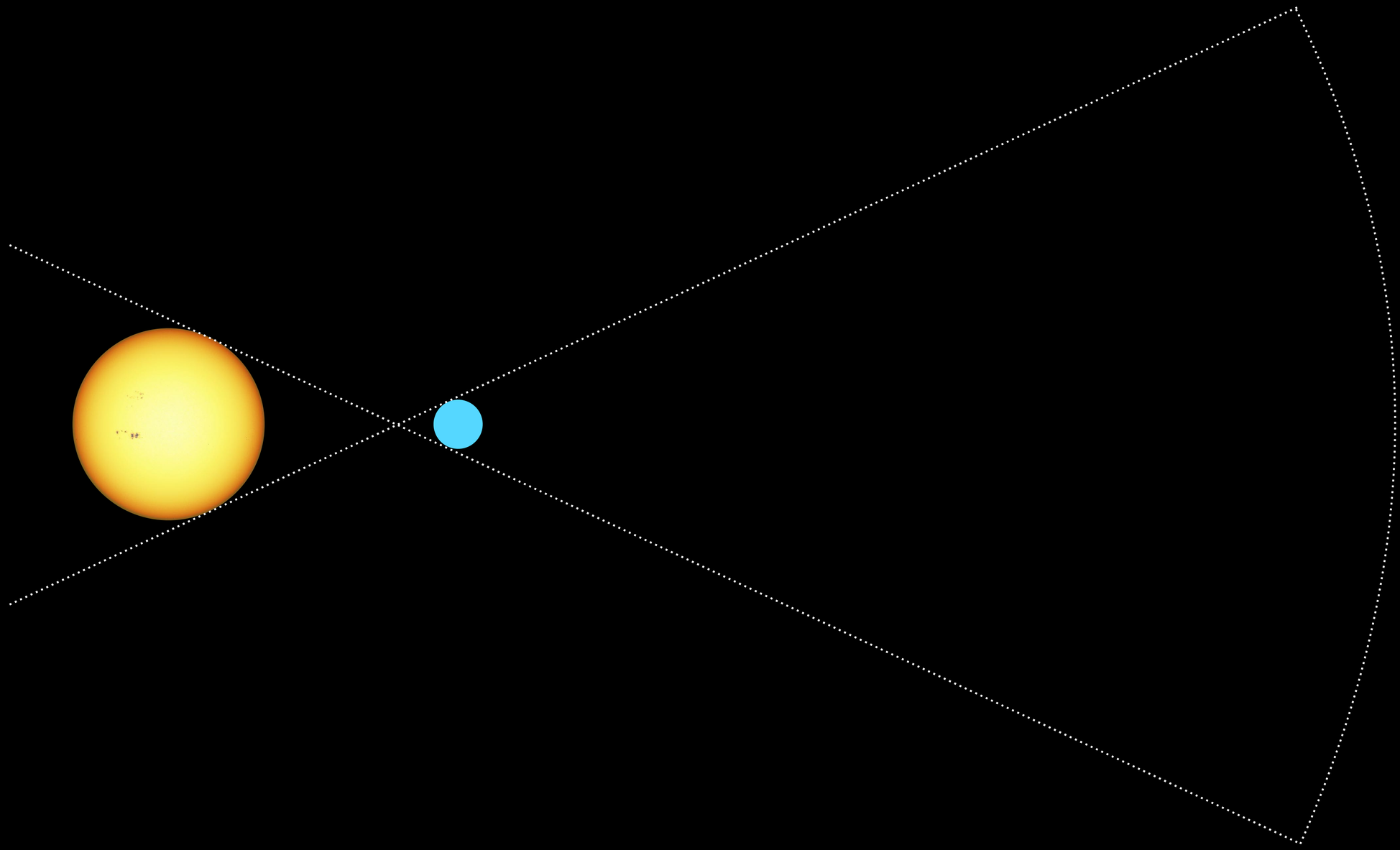
A. Triaud


SUN
HABITABLE ZONE
AROUND COOL STARS, THE HABITABLE ZONE IS CLOSER


2
1
0.5
SUN
HABITABLE ZONE
AROUND COOL STARS, THE HABITABLE ZONE IS CLOSER
A. Triaud



THE PROBABILITY TO OBSERVE A TRANSIT DECREASES WITH ORBITAL SEPARATION



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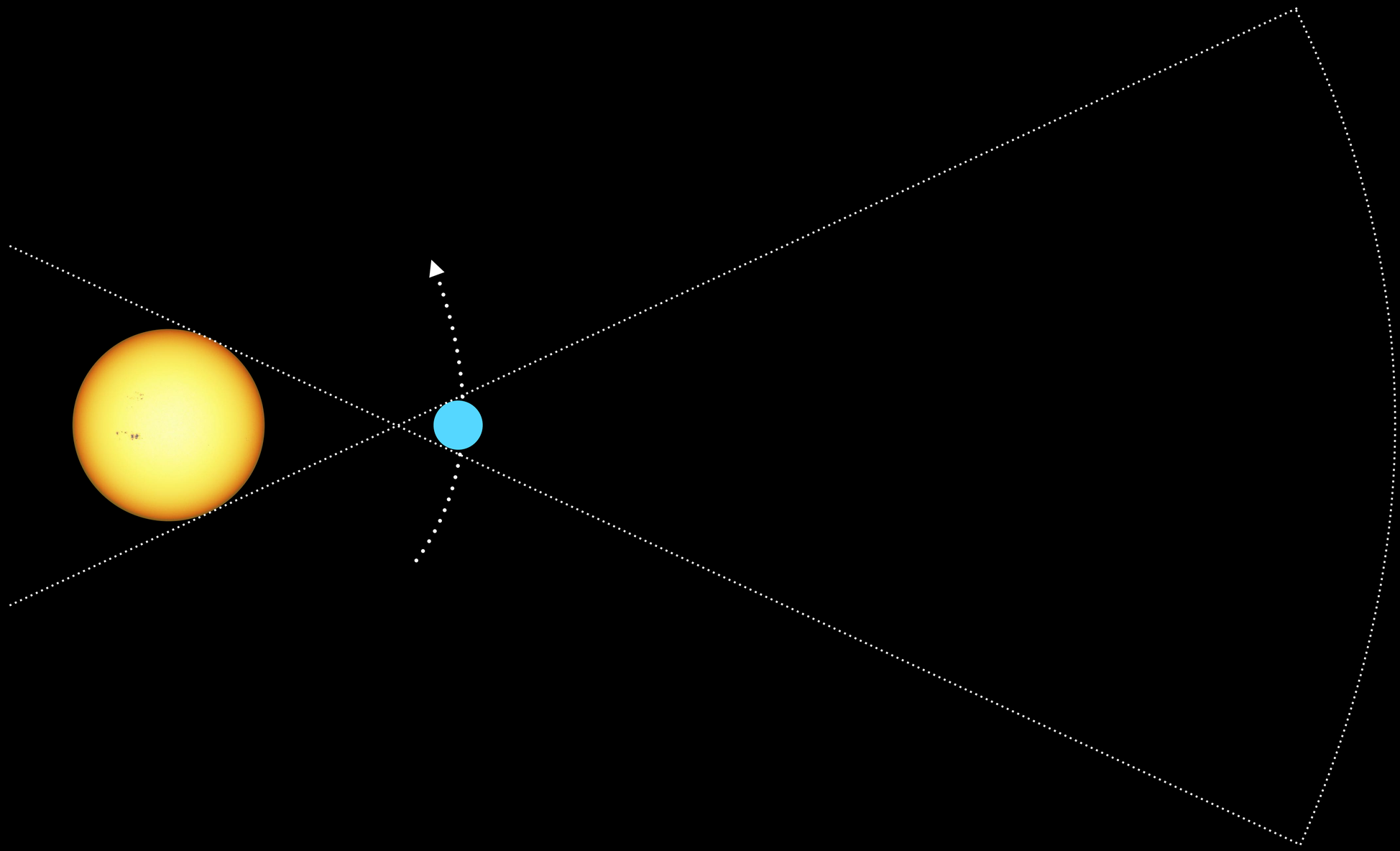

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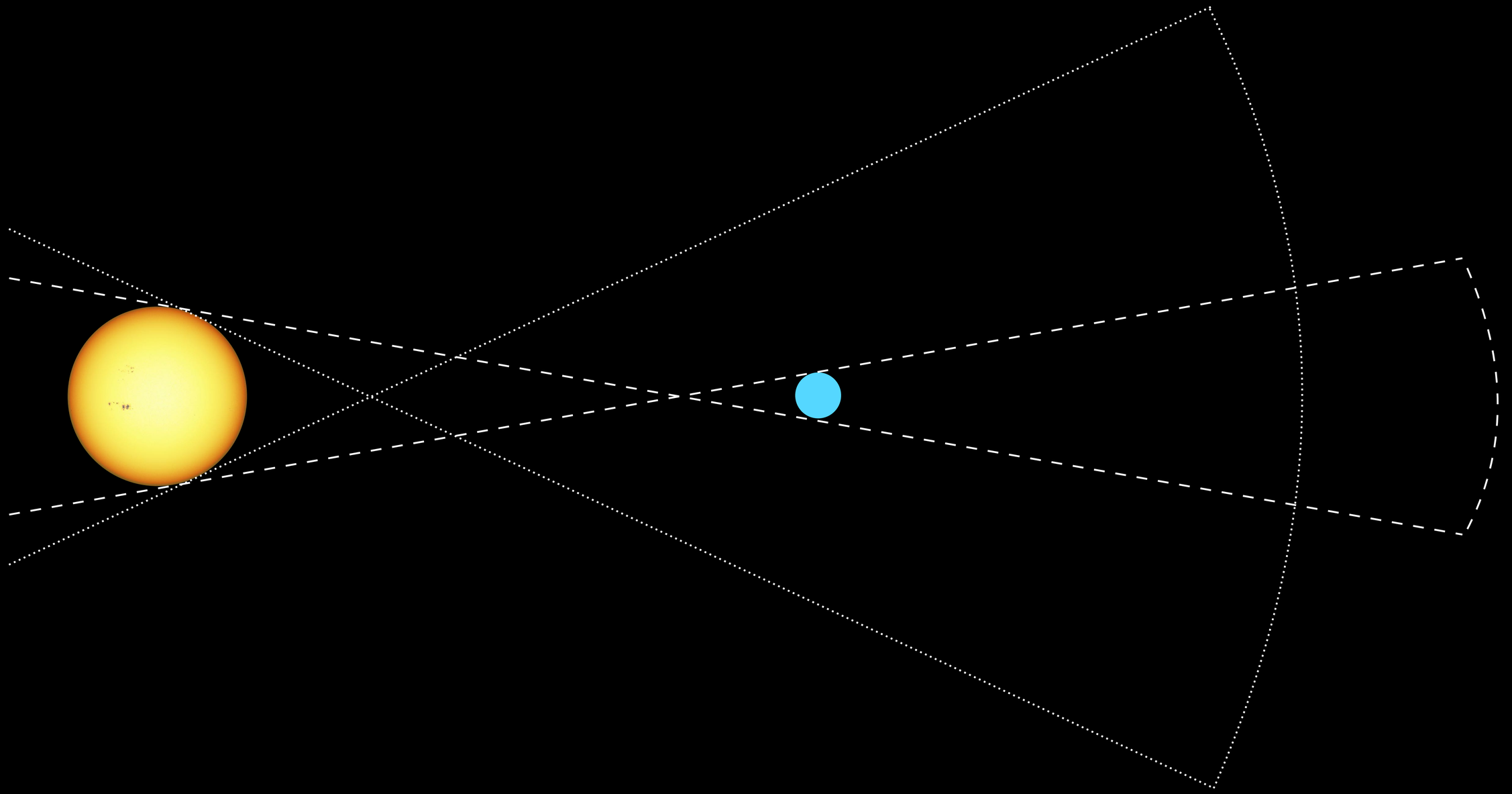

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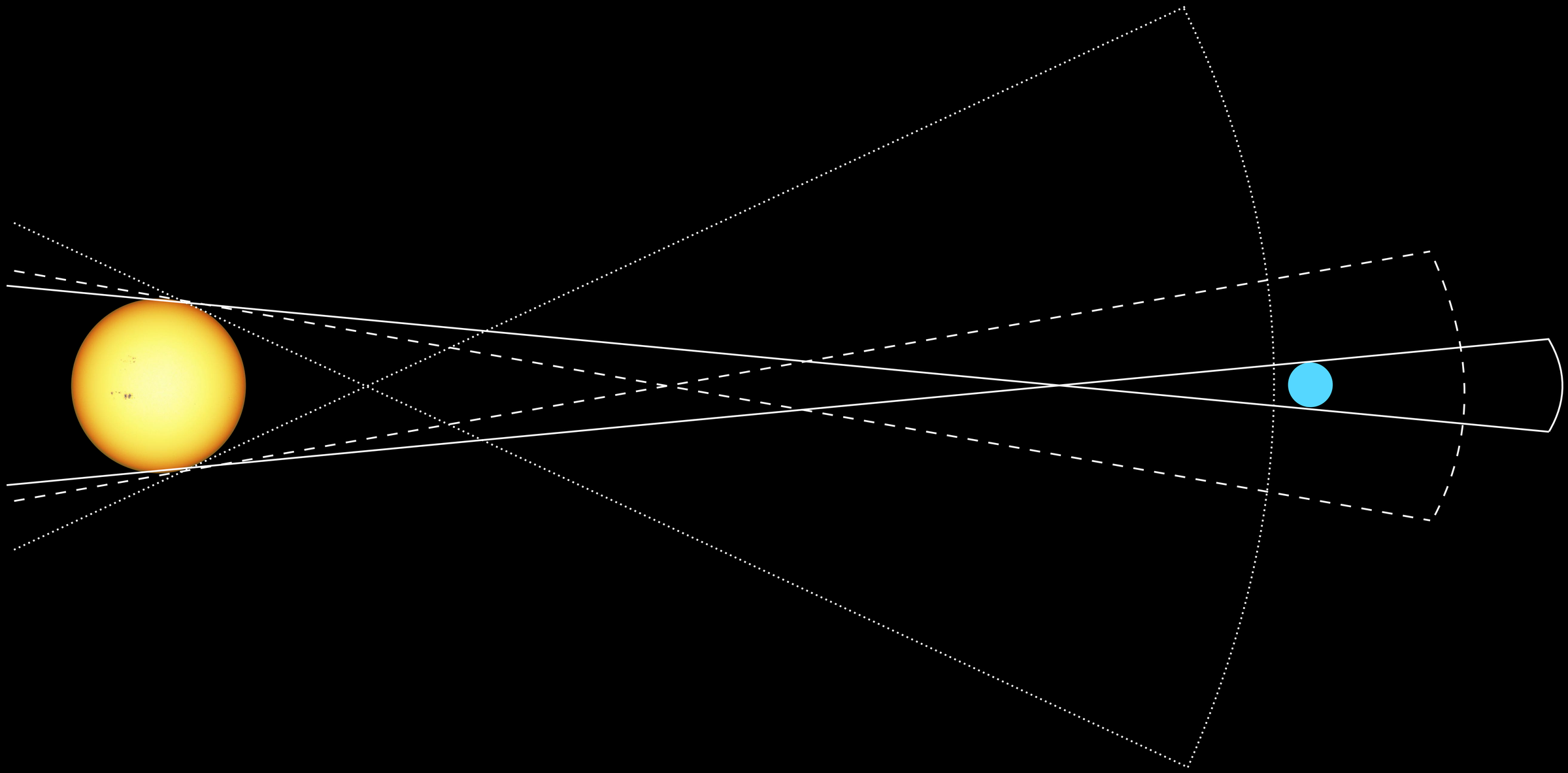

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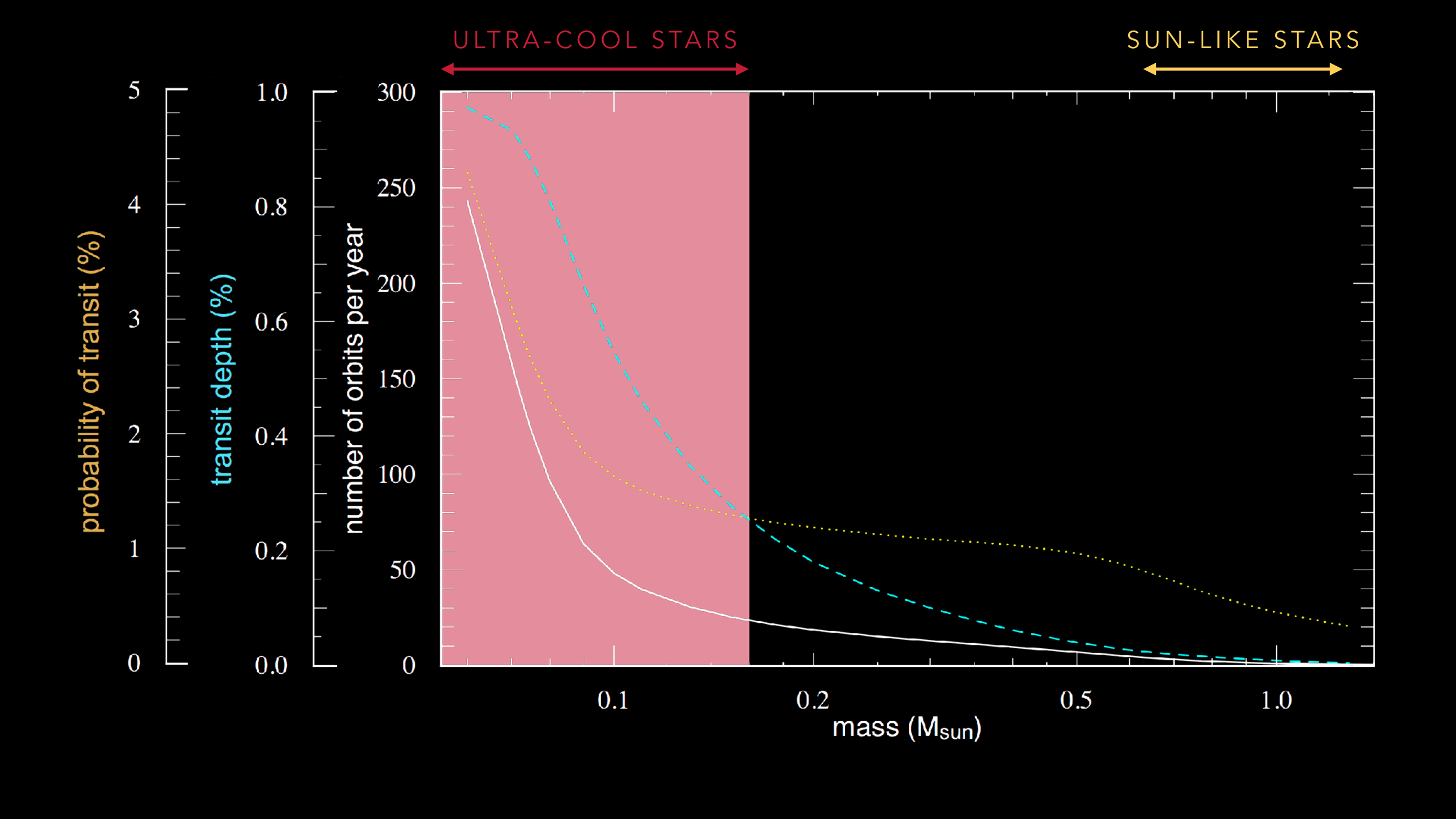
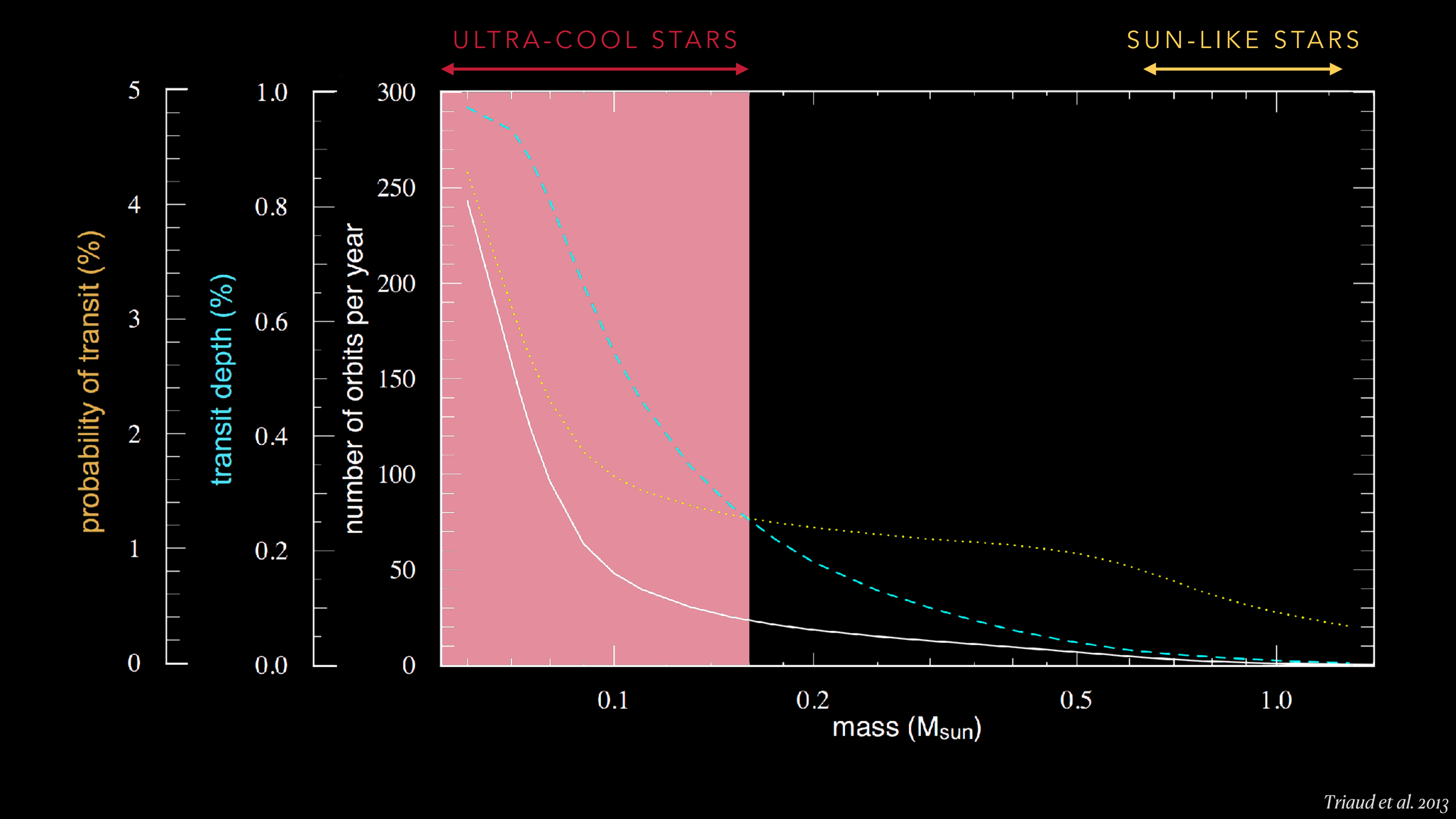

ULTRA-COOL STARS
SUN-LIKE STARS
probability of transit (%)
transit depth (%)
number of orbits per year
mass (Msun)
0
1
2
3
4
5
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
250
300
0.1
0.2
0.5
1.0



Triaud et al. 2013

The case of Alpha Cen Bb

ARTICLE

Published: 17 October 2012

doi:10.1038/nature11572

An Earth-mass planet orbiting α Centauri B

Xavier Dumusque[1,2], Francesco Pepe[1], Christophe Lovis[1], Damien Ségransan[1], Johannes Sahlmann[1], Willy Benz[3], François Bouchy[1,4], Michel Mayor[1], Didier Queloz[1], Nuno Santos[2,5] & Stéphane Udry[1]

Exoplanets down to the size of Earth have been found, but not in the habitable zone—that is, at a distance from the parent star at which water, if present, would be liquid. There are planets in the habitable zone of stars cooler than our Sun, but for reasons such as tidal locking and strong stellar activity, they are unlikely to harbour water–carbon life as we know it. The detection of a habitable Earth-mass planet orbiting a star similar to our Sun is extremely difficult, because such a signal is overwhelmed by stellar perturbations. Here we report the detection of an Earth-mass planet orbiting our neighbour star α Centauri B, a member of the closest stellar system to the Sun. The planet has an orbital period of 3.236 days and is about 0.04 astronomical units from the star (one astronomical unit is the Earth–Sun distance).

See also Rajpaul et al., 2016

Poor track record of detecting transits of RV planets

A&A 601, A117 (2017)
DOI: 10.1051/0004-6361/201629270

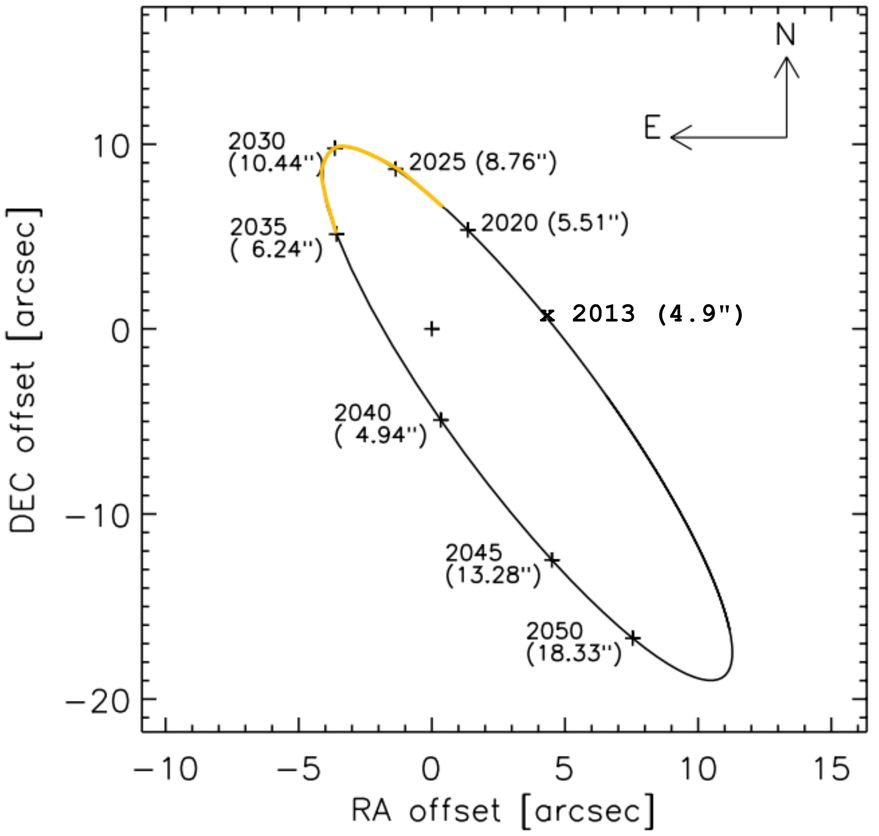
Astronomy & Astrophysics

The *Spitzer* search for the transits of HARPS low-mass planets

II. Null results for 19 planets★

M. Gillon[1], B.-O. Demory[2,3], C. Lovis[4], D. Deming[5], D. Ehrenreich[4], G. Lo Curto[6], M. Mayor[4], F. Pepe[4], D. Queloz[3,4], S. Seager[7], D. Ségransan[4], and S. Udry[4]

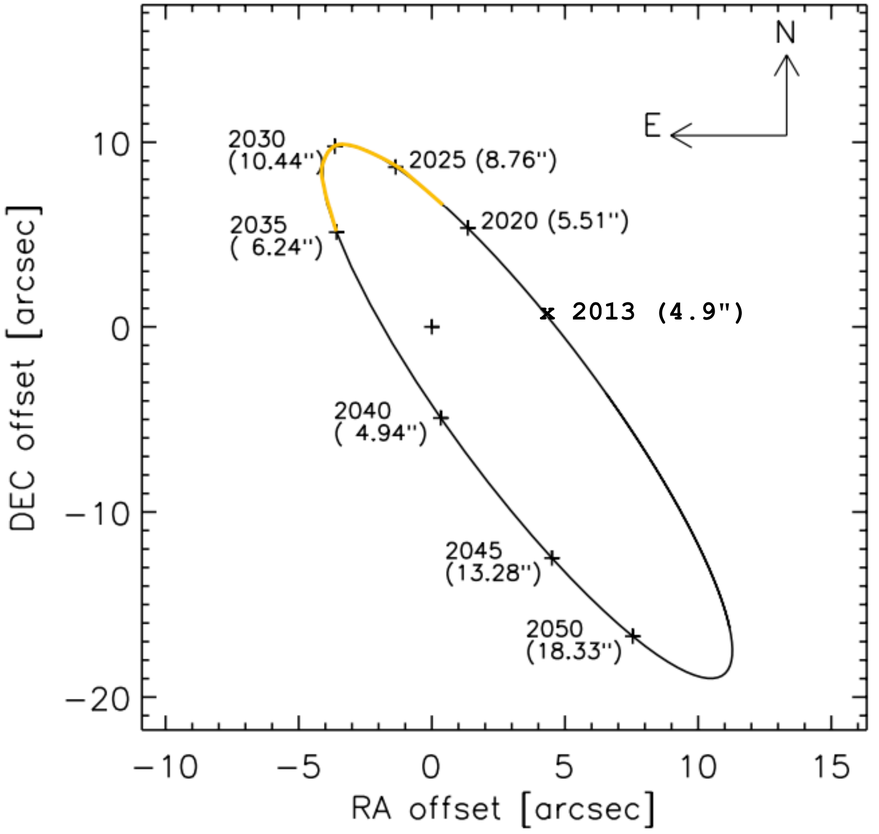
What is the *a priori* transit probability of Alpha Cen Bb ?



Wang et al., 2022

What is the *a priori* transit probability of Alpha Cen Bb ?

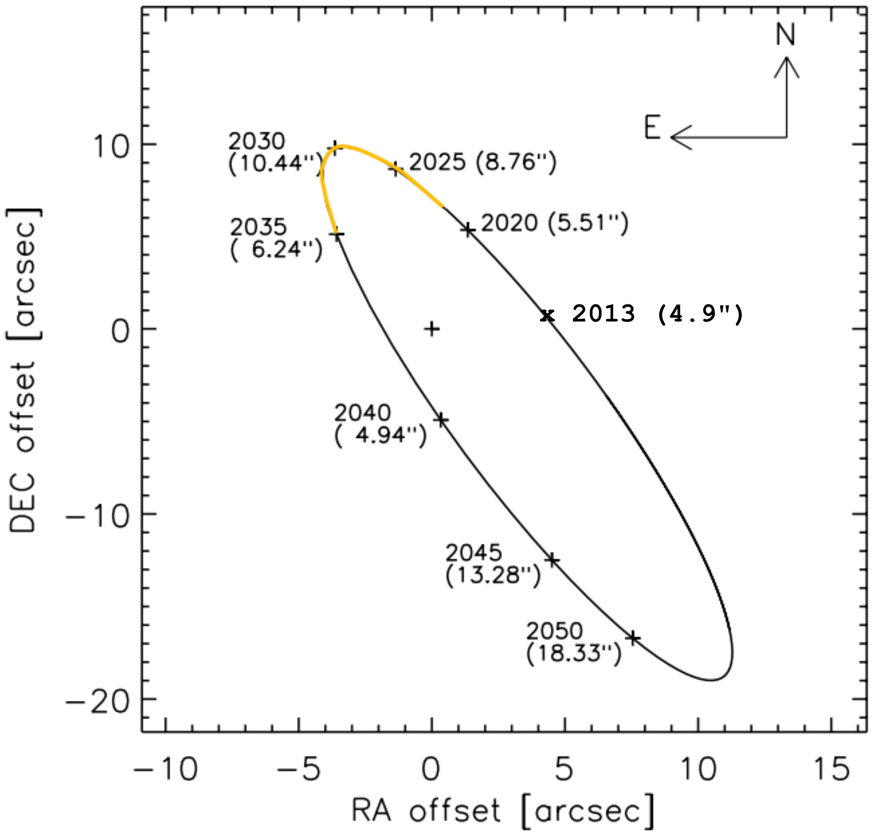
- A priori geometric transit probability: ~10% (0.04 AU from B)



Wang et al., 2022

What is the *a priori* transit probability of Alpha Cen Bb ?

- A priori geometric transit probability: ~10% (0.04 AU from B)
- Alpha Cen AB orbital plane inclination ~11°



Wang et al., 2022

What is the *a priori* transit probability of Alpha Cen Bb ?

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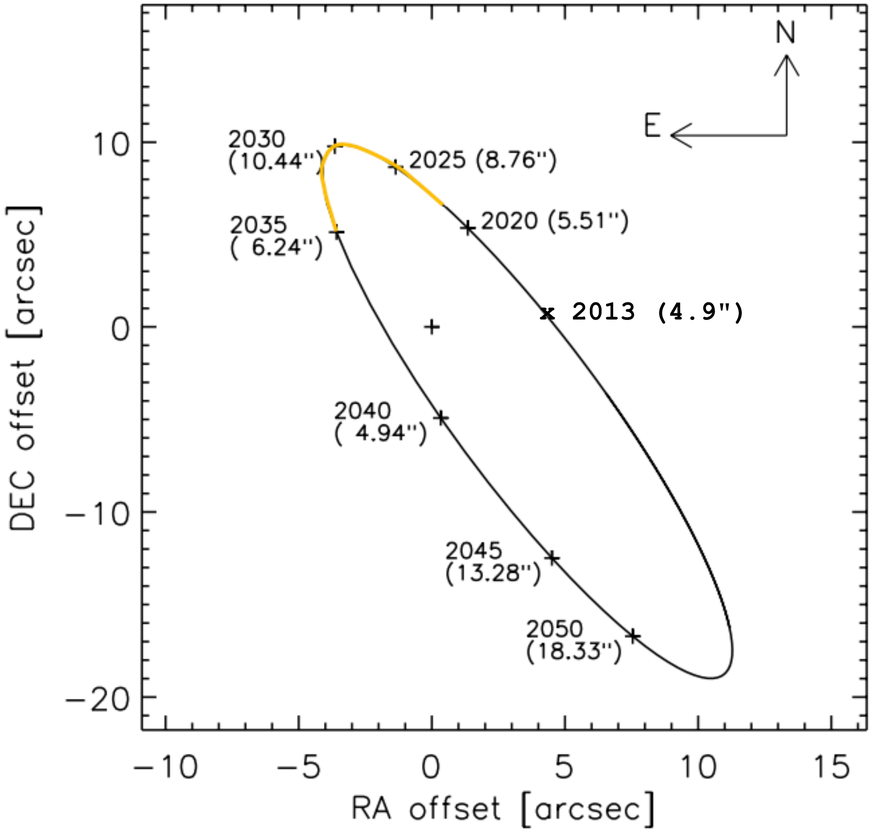
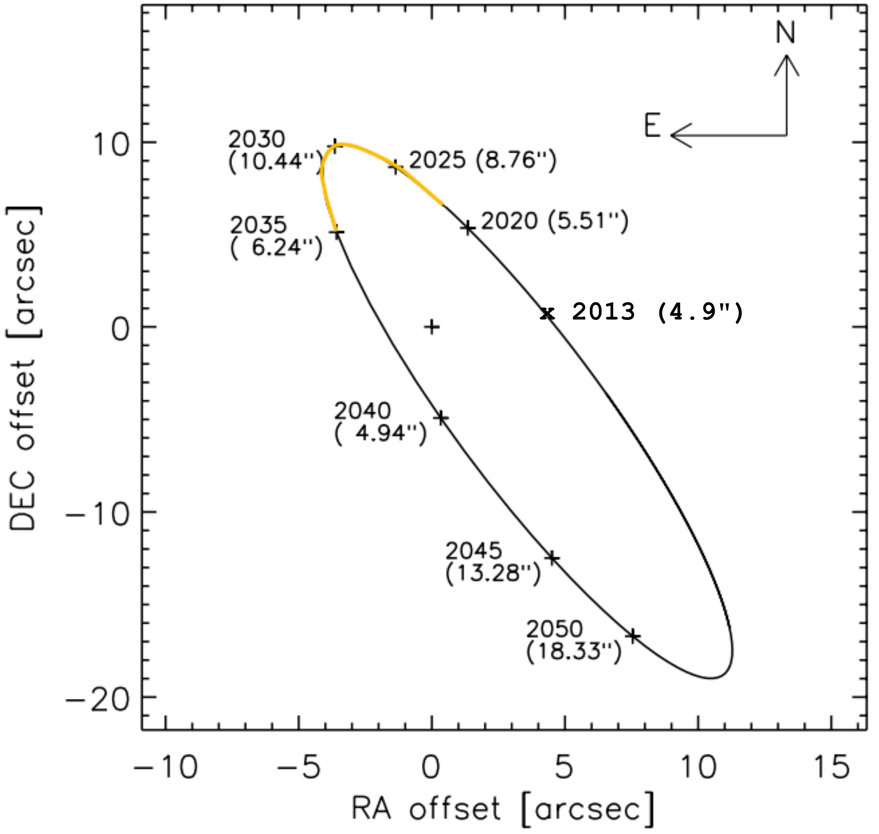
- Alpha Cen AB orbital plane inclination ~11°
- How easy to form planets in the orbital plane of Alpha Cen AB ? (Quintana et al. 2002, Thébault et al. 2009)



Wang et al., 2022

What is the *a priori* transit probability of Alpha Cen Bb ?

- A priori geometric transit probability: ~10%
  (0.04 AU from B)
- Alpha Cen AB orbital plane inclination ~11°
- How easy to form planets in the orbital plane of Alpha Cen AB ? (Quintana et al. 2002, Thébault et al. 2009)
- Difficult to form planets in orbits > 40° relative to Alpha Cen AB orbital plane
  (Quintana et al. 2002, Xie et al. 2010)



Wang et al., 2022

A 100-ppm transit in a 26-hour window?

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- **Ground**
  - cannot monitor continuously for 26 hours
  - cannot reach 30 ppm over 2.5 hours

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  - x10 above saturation level for ch1 and 2.

A phone call from STScI...

Hubble Space Telescope Cycle 20 GO/DD Proposal **3010**

High-precision search for transits of the Earth-mass exoplanet Alpha Centauri Bb

Principal Investigator: Dr. David Ehrenreich
Institution: Observatoire de Geneve
Electronic Mail: david.ehrenreich@unige.ch
Scientific Category: EXTRA-SOLAR PLANETS
Scientific Keywords: Extra-Solar Planets, Main Sequence Stars, Terrestrial Planets
Instruments: STIS

Proprietary Period: 0

Orbit Request	Prime	Parallel
Cycle 20	15	0

Hubble Space Telescope Cycle 20 GO/DD Proposal **3011**

Search for a Transit of Alpha Centauri Bb, the First Earth-mass Exoplanet Orbiting a Sun-like Star

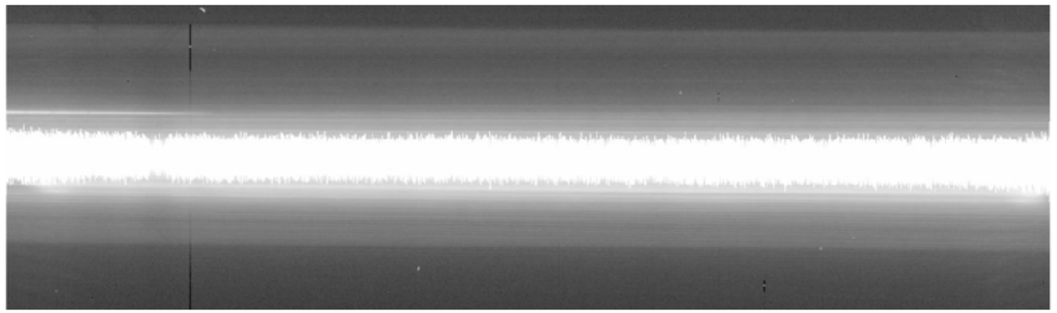
Principal Investigator: Dr. Brice-Olivier Demory
Institution: Massachusetts Institute of Technology
Electronic Mail: demory@mit.edu
Scientific Category: EXTRA-SOLAR PLANETS
Scientific Keywords: Extra-Solar Planets, Planetary Atmospheres, Terrestrial Planets
Instruments: STIS

Submitted: 23 October 2012

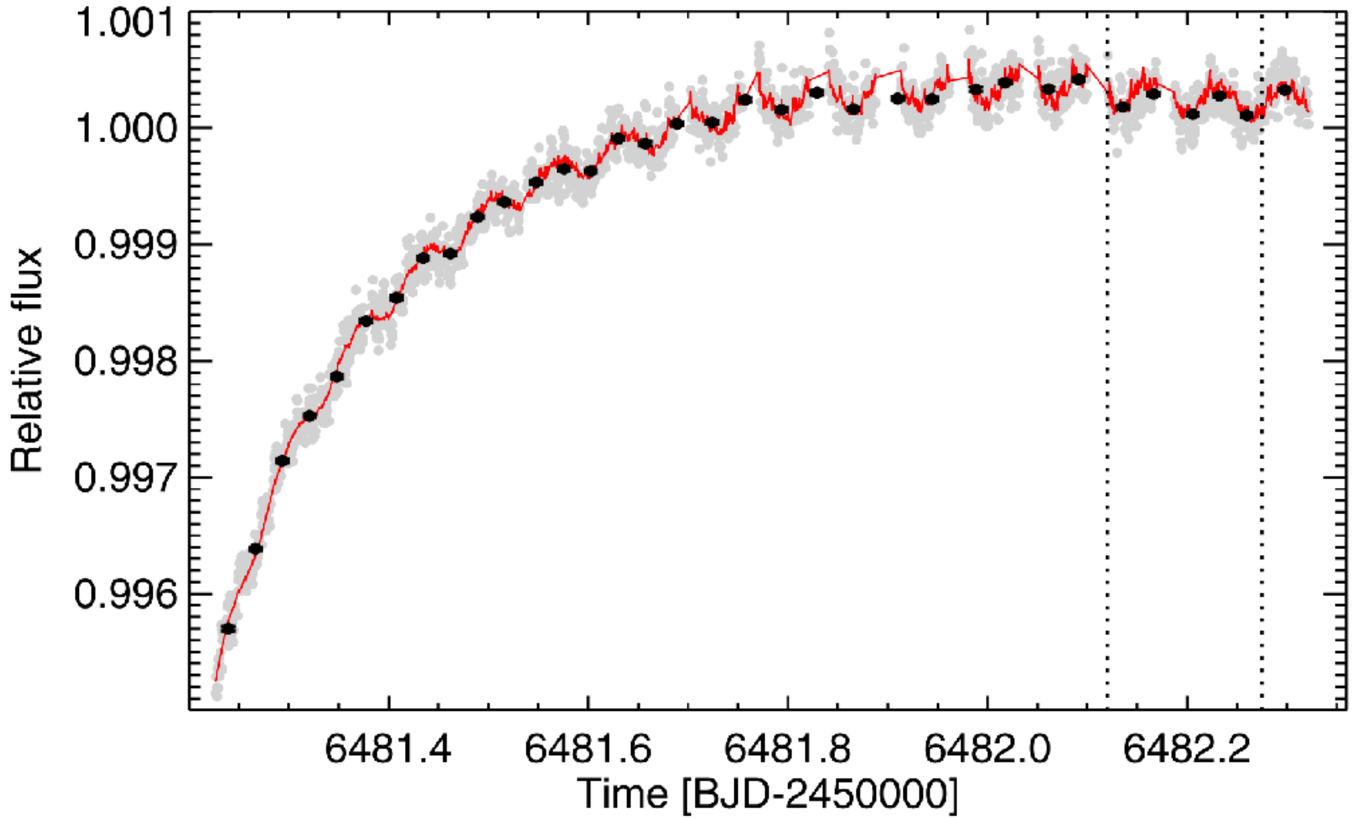
Proprietary Period: 0

Orbit Request	Prime	Parallel
Cycle 20	16	0

Despite saturation, getting to 115 ppm/6s



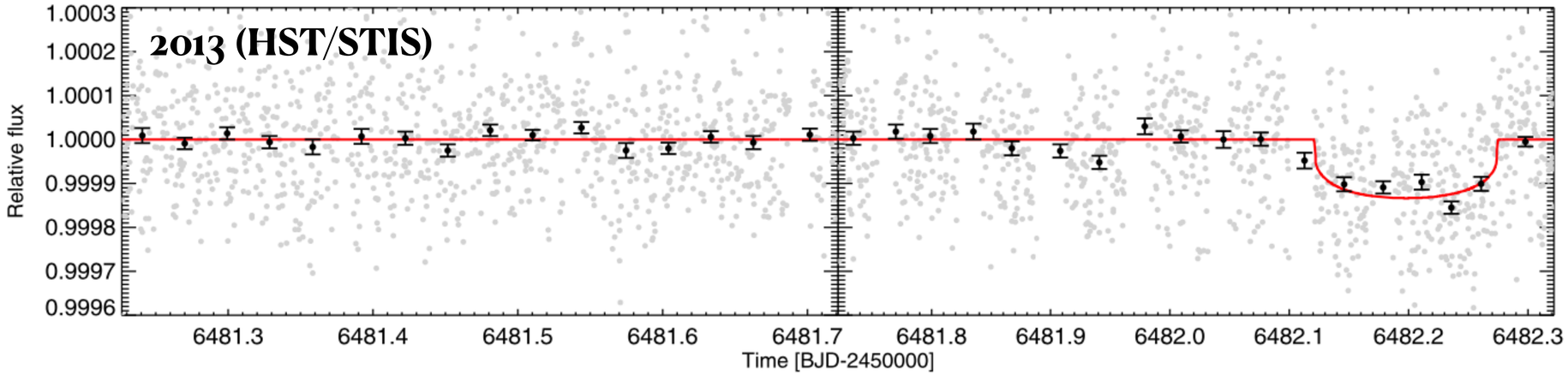
Raw STIS/G750L spectrum



Flux time-series with best-fit model

Demory et al., 2015

Possible transit pattern in the expected window?



Demory et al., 2015

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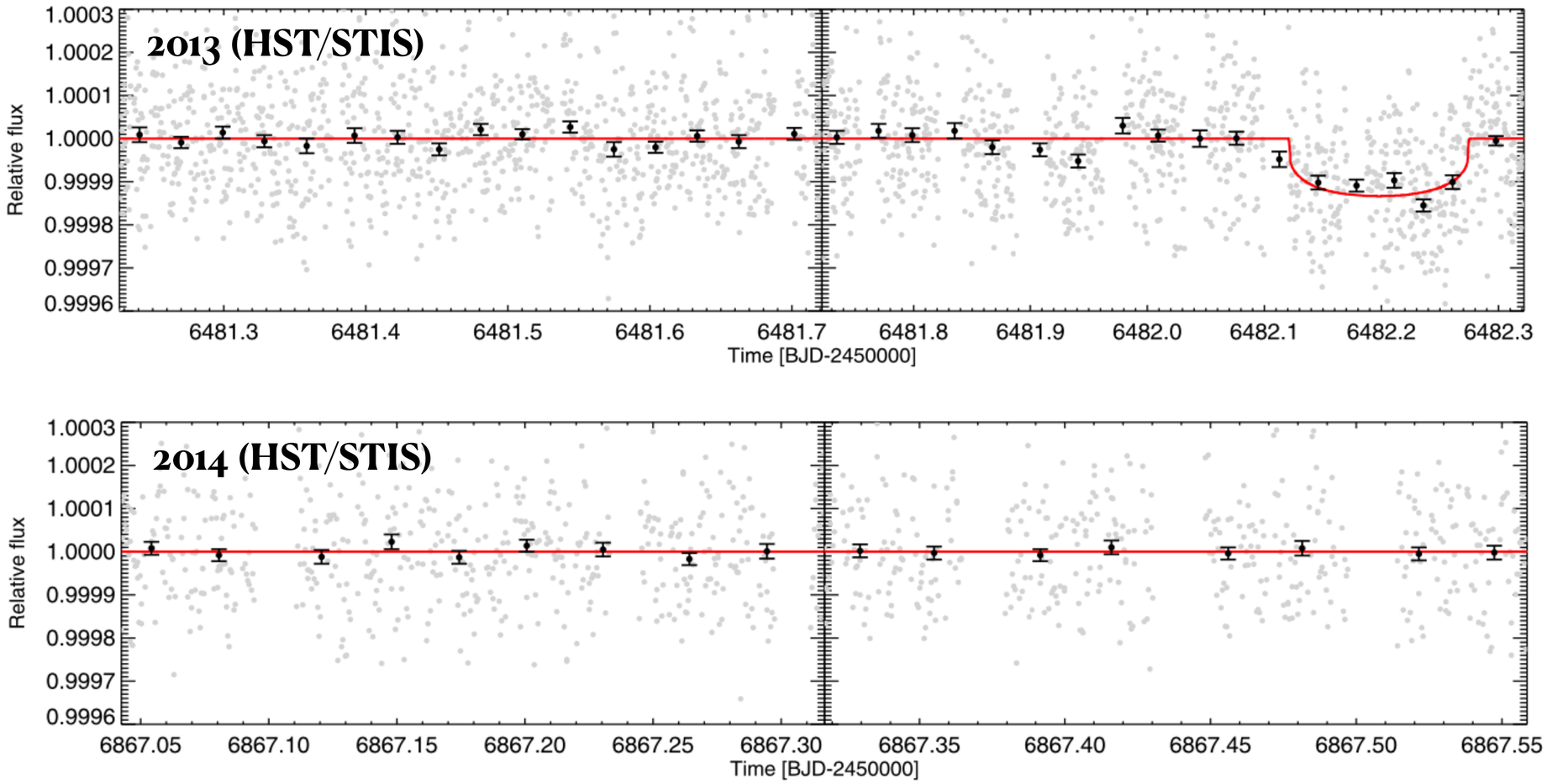
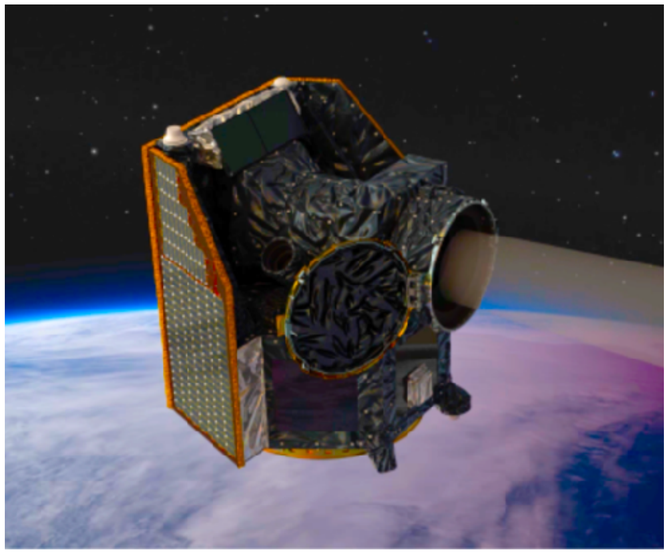


Alpha Cen Bb (Dumusque et al. 2012) is not transiting

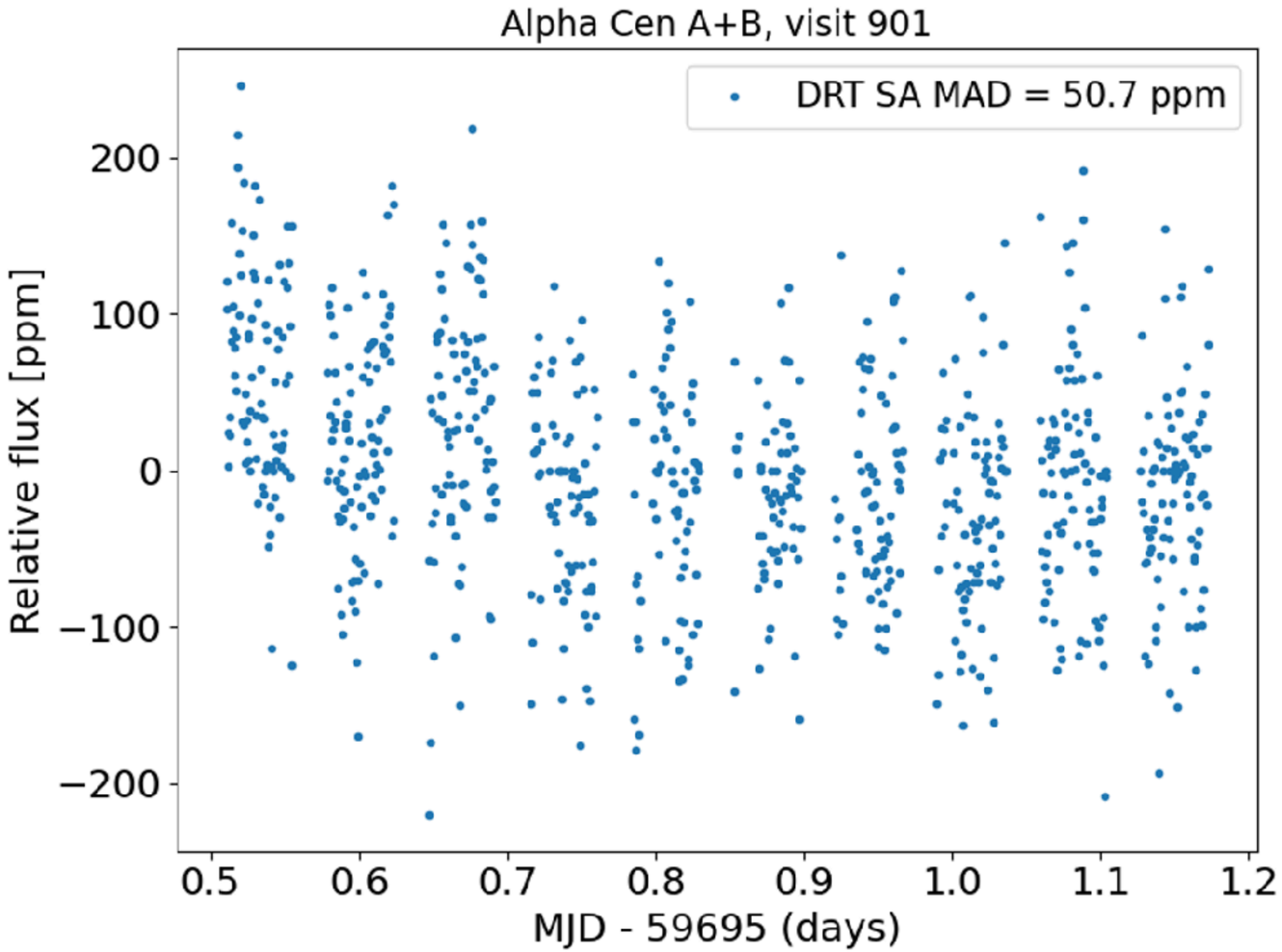
Demory et al., 2015

CHEOPS to Alpha Cen B's rescue



Courtesy of V. Van Grootel & D. Gandolfi

CHEOPS to Alpha Cen B's rescue



Courtesy of V. Van Grootel & D. Gandolfi

The cases of Proxima b, c and d

Published: 25 August 2016

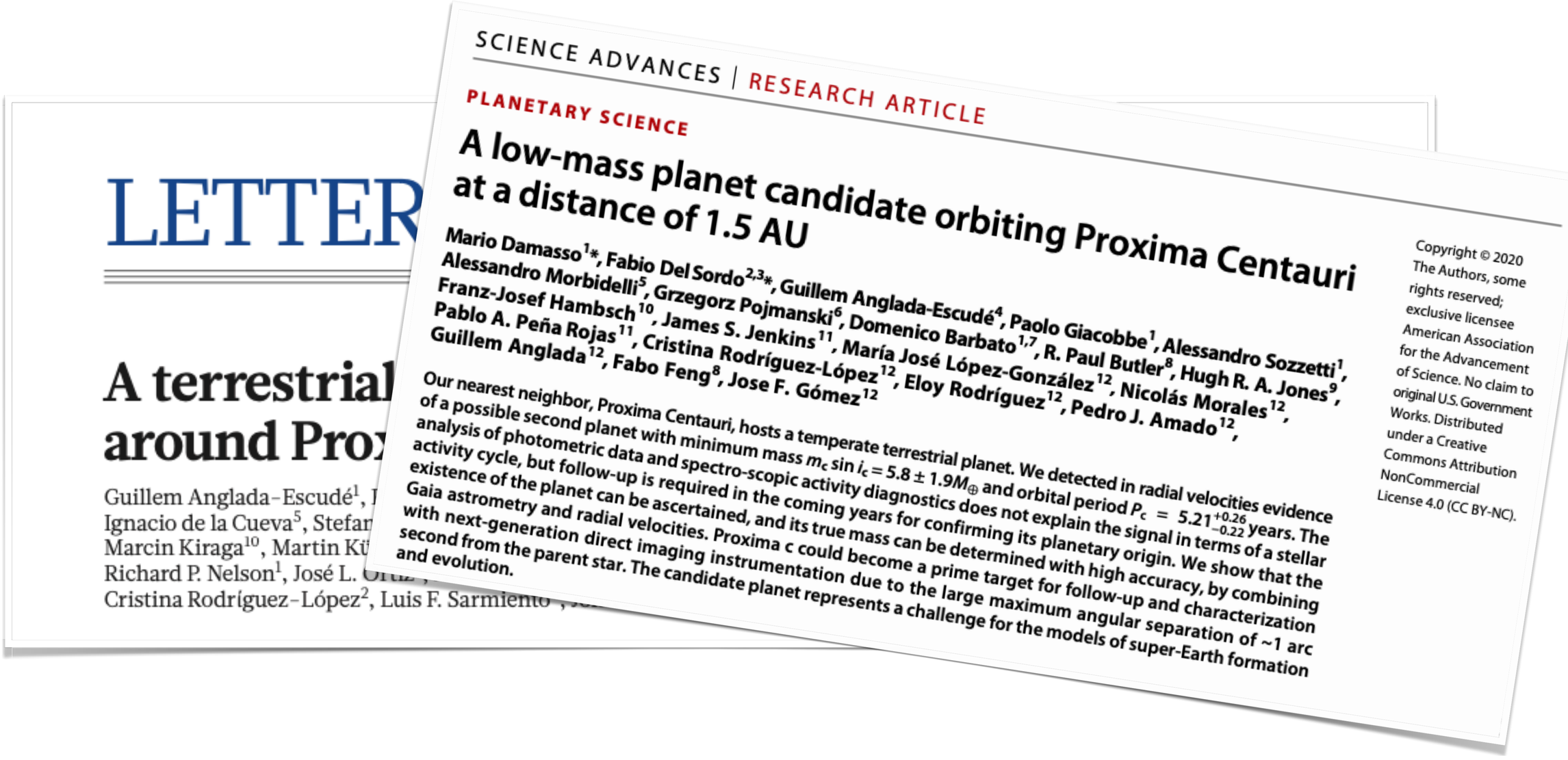
LETTER

doi:10.1038/nature19106

A terrestrial planet candidate in a temperate orbit around Proxima Centauri

Guillem Anglada-Escudé[1], Pedro J. Amado[2], John Barnes[3], Zaira M. Berdiñas[2], R. Paul Butler[4], Gavin A. L. Coleman[1], Ignacio de la Cueva[5], Stefan Dreizler[6], Michael Endl[7], Benjamin Giesers[6], Sandra V. Jeffers[6], James S. Jenkins[8], Hugh R. A. Jones[9], Marcin Kiraga[10], Martin Kürster[11], María J. López-González[2], Christopher J. Marvin[6], Nicolás Morales[2], Julien Morin[12], Richard P. Nelson[1], José L. Ortiz[2], Aviv Ofir[13], Sijme-Jan Paardekooper[1], Ansgar Reiners[6], Eloy Rodríguez[2], Cristina Rodríguez-López[2], Luis F. Sarmiento[6], John P. Strachan[1], Yiannis Tsapras[14], Mikko Tuomi[9] & Mathias Zechmeister[6]

The cases of Proxima b, c and d



LETTER

A terrestrial
around Prox

Guillem Anglada-Escudé[1], I
Ignacio de la Cueva[5], Stefan
Marcin Kiraga[10], Martin Kü
Richard P. Nelson[1], José L. Ortiz
Cristina Rodríguez-López[2], Luis F. Sarmiento

SCIENCE ADVANCES | RESEARCH ARTICLE

PLANETARY SCIENCE

A low-mass planet candidate orbiting Proxima Centauri at a distance of 1.5 AU

Mario Damasso[1]*, Fabio Del Sordo[2,3]*, Guillem Anglada-Escudé[4], Paolo Giacobbe[1], Alessandro Sozzetti[1], Alessandro Morbidelli[5], Grzegorz Pojmanski[6], Domenico Barbato[1,7], R. Paul Butler[8], Hugh R. A. Jones[9], Franz-Josef Hambsch[10], James S. Jenkins[11], María José López-González[12], Nicolás Morales[12], Pablo A. Peña Rojas[11], Cristina Rodríguez-López[12], Eloy Rodríguez[12], Pedro J. Amado[12], Guillem Anglada[12], Fabo Feng[8], Jose F. Gómez[12]

Our nearest neighbor, Proxima Centauri, hosts a temperate terrestrial planet. We detected in radial velocities evidence of a possible second planet with minimum mass $m_c \sin i_c = 5.8 \pm 1.9 M_\oplus$ and orbital period $P_c = 5.21^{+0.26}_{-0.22}$ years. The analysis of photometric data and spectro-scopic activity diagnostics does not explain the signal in terms of a stellar activity cycle, but follow-up is required in the coming years for confirming its planetary origin. We show that the existence of the planet can be ascertained, and its true mass can be determined with high accuracy, by combining Gaia astrometry and radial velocities. Proxima c could become a prime target for follow-up and characterization with next-generation direct imaging instrumentation due to the large maximum angular separation of ~1 arc second from the parent star. The candidate planet represents a challenge for the models of super-Earth formation and evolution.

The cases of Proxima b, c and d

A&A 658, A115 (2022)
https://doi.org/10.1051/0004-6361/202142337

Astronomy & Astrophysics

A candidate short-period sub-Earth orbiting Proxima Centauri★

J. P. Faria[1,2], A. Suárez Mascareño[3,4], P. Figueira[5,1], A. M. Silva[1,2], M. Damasso[6], O. Demangeon[1,2], F. Pepe[7], N. C. Santos[1,2], R. Rebolo[8,4,3], S. Cristiani[9], V. Adibekyan[1], Y. Alibert[10], R. Allart[11,7], S. C. C. Barros[1,2], A. Cabral[12,13], V. D'Odorico[9,14,15], P. Di Marcantonio[9], X. Dumusque[7], D. Ehrenreich[7], J. I. González Hernández[4,3], N. Hara[7], J. Lillo-Box[16], G. Lo Curto[17,5], C. Lovis[7], C. J. A. P. Martins[1,18], D. Mégevand[7], A. Mehner[5], G. Micela[19], P. Molaro[9,14], N. J. Nunes[12], E. Pallé[3,4], E. Poretti[20], S. G. Sousa[1,2], A. Sozzetti[6], H. Tabernero[21], S. Udry[7], and M. R. Zapatero Osorio[21]

(Affiliations can be found after the references)

Received 30 September 2021 / Accepted 24 December 2021

...ng Proxima Centauri

...o Giacobbe[1], Alessandro Sozzetti[1], ...R. Paul Butler[8], Hugh R. A. Jones[9], ...ález[12], Nicolás Morales[12], ...[2], Pedro J. Amado[12],

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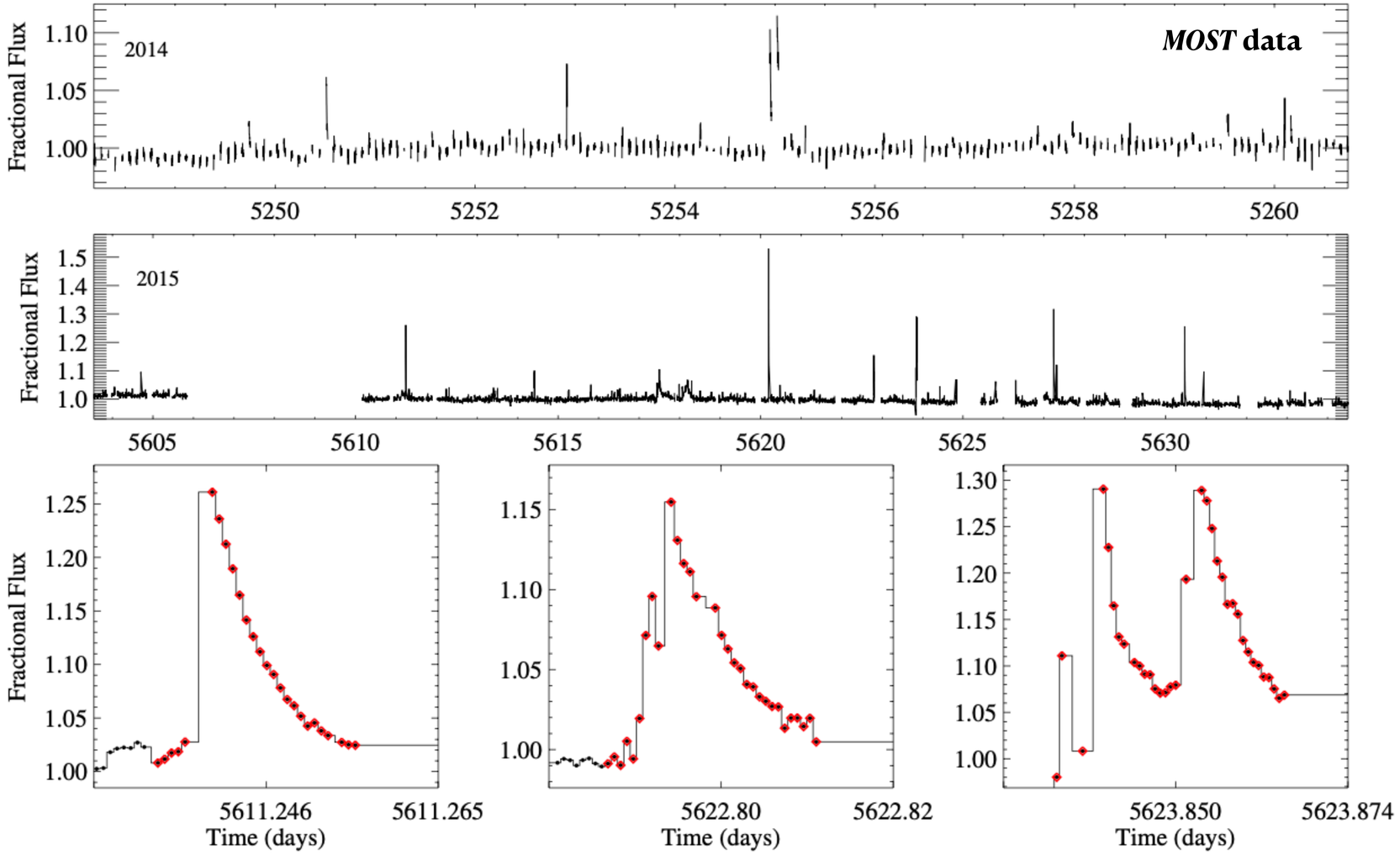
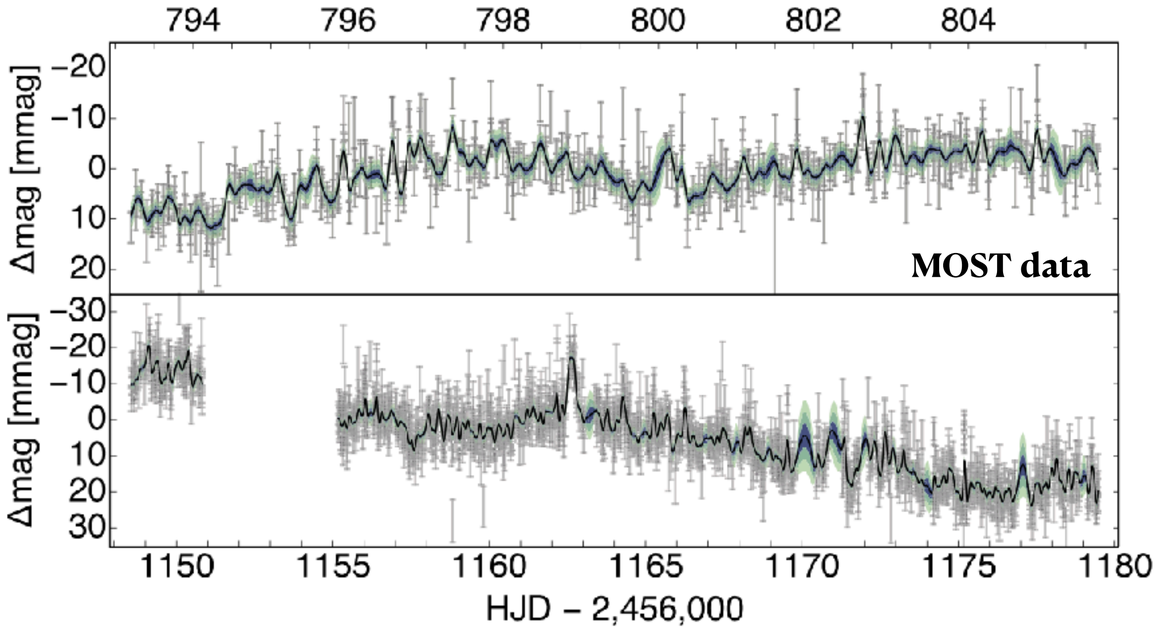
Strong modulation and high-amplitude flares



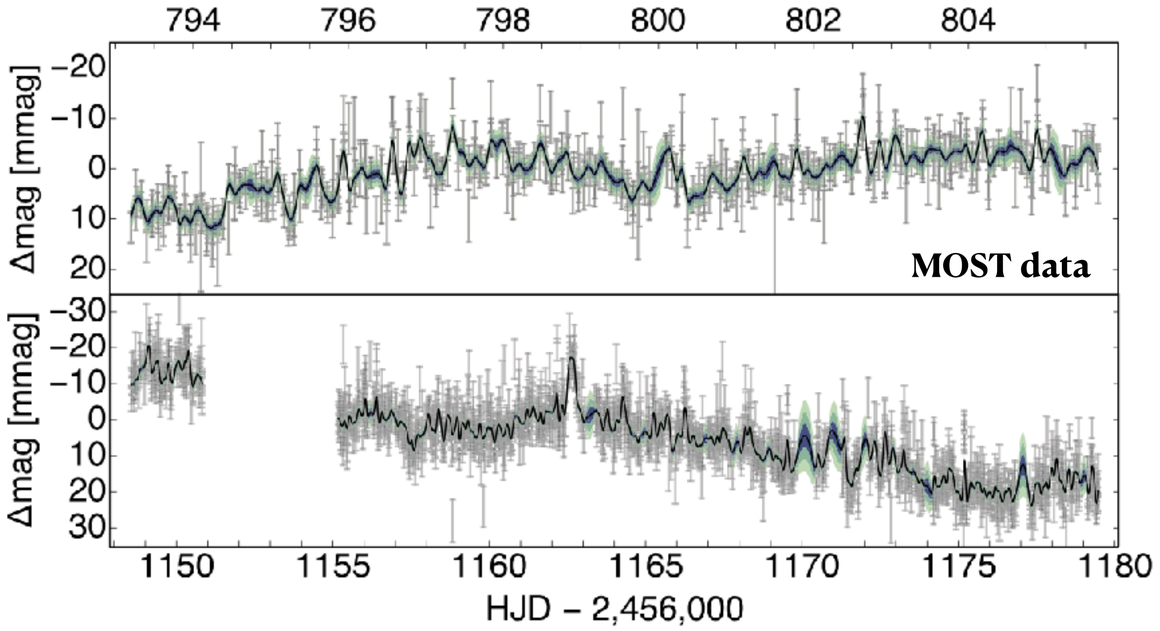
Davenport et al. 2014

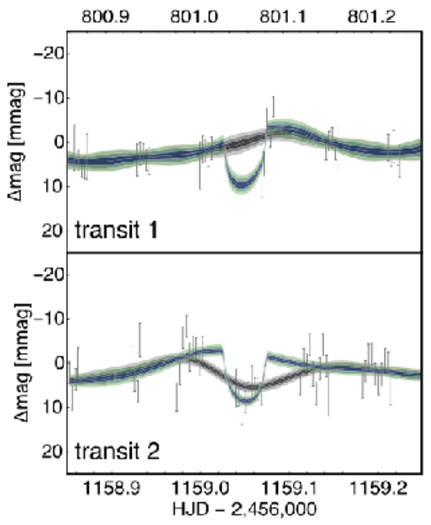
43.5-day continuous monitoring with MOST

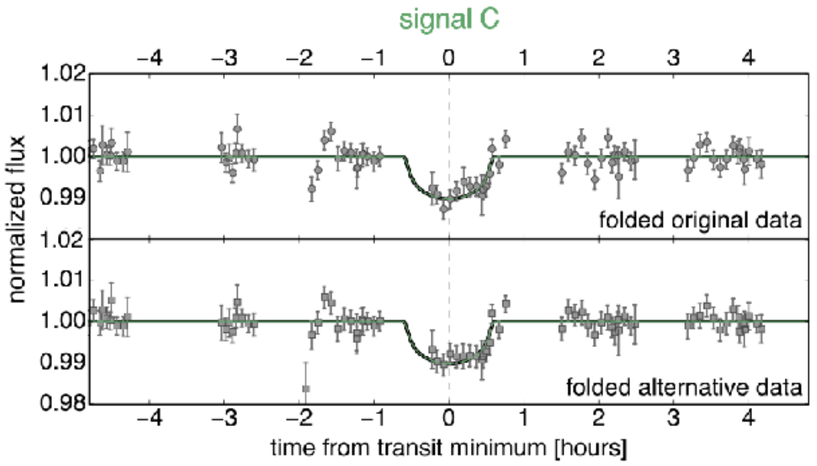


Kipping et al. 2017

43.5-day continuous monitoring with MOST

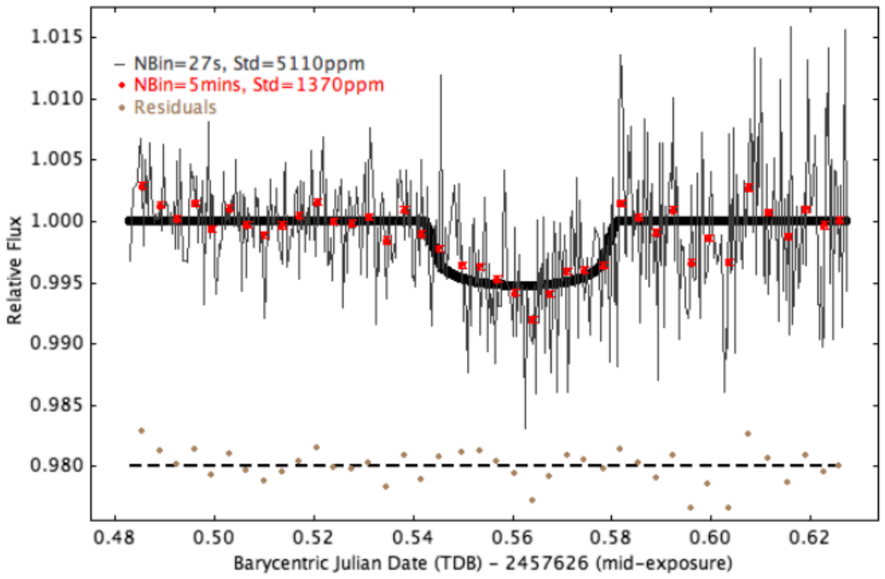


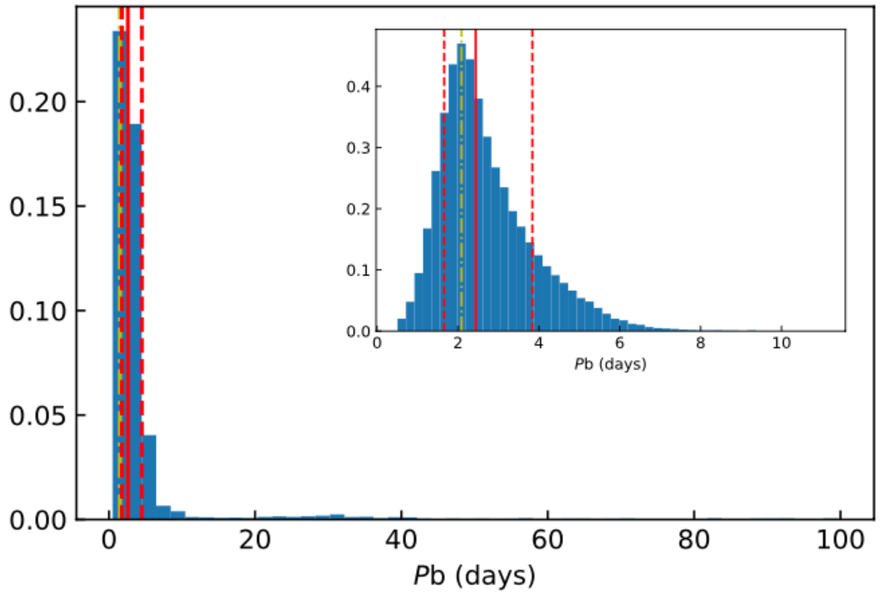




Kipping et al. 2017

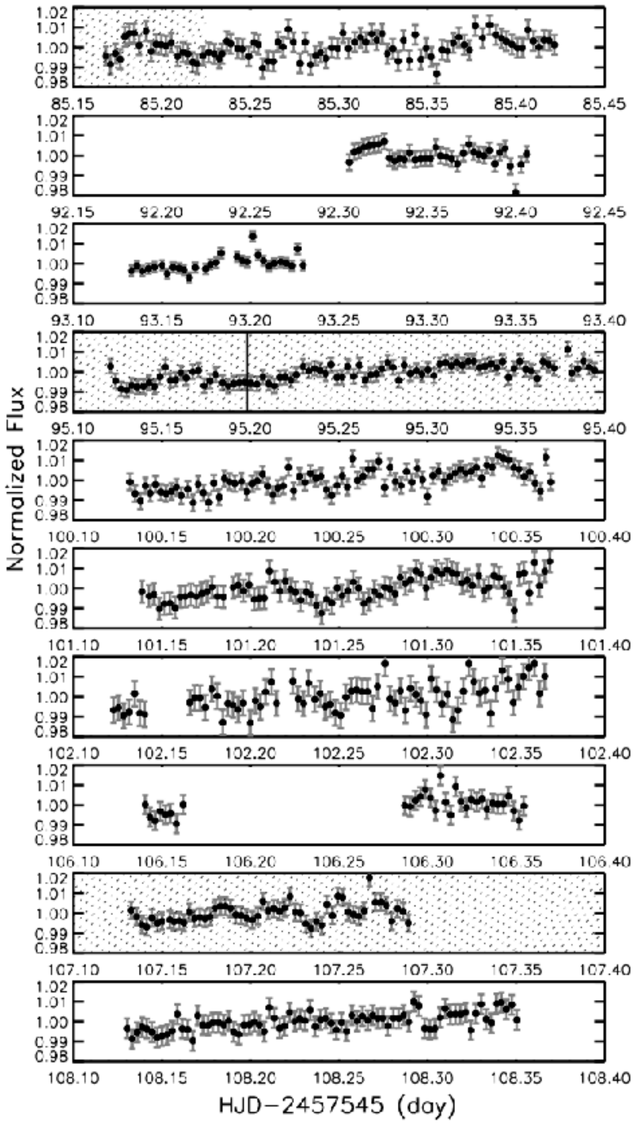
23 nights from Las Campanas (30 cm)





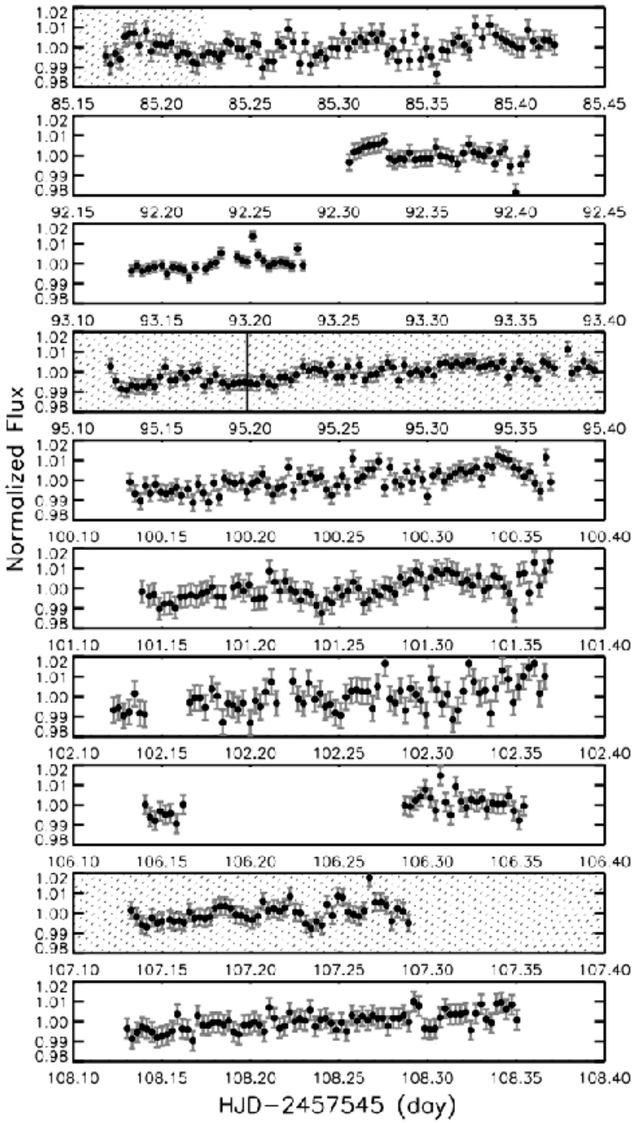
Li et al. 2017

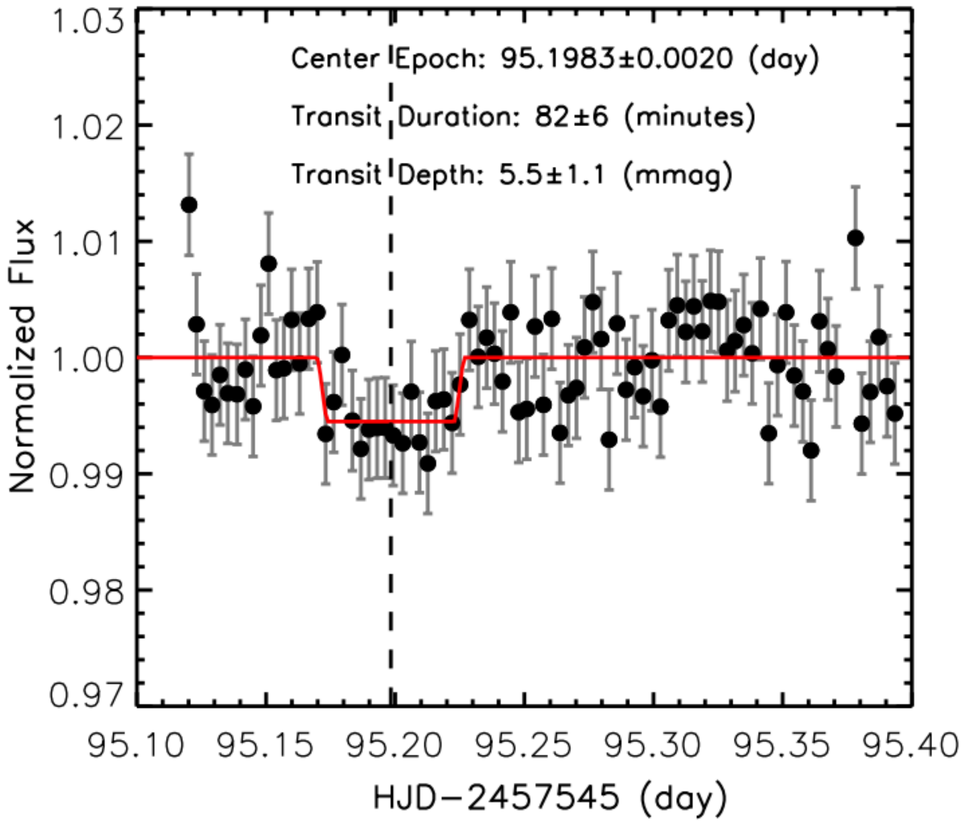
10-day campaign from Antarctica



Liu et al. 2018

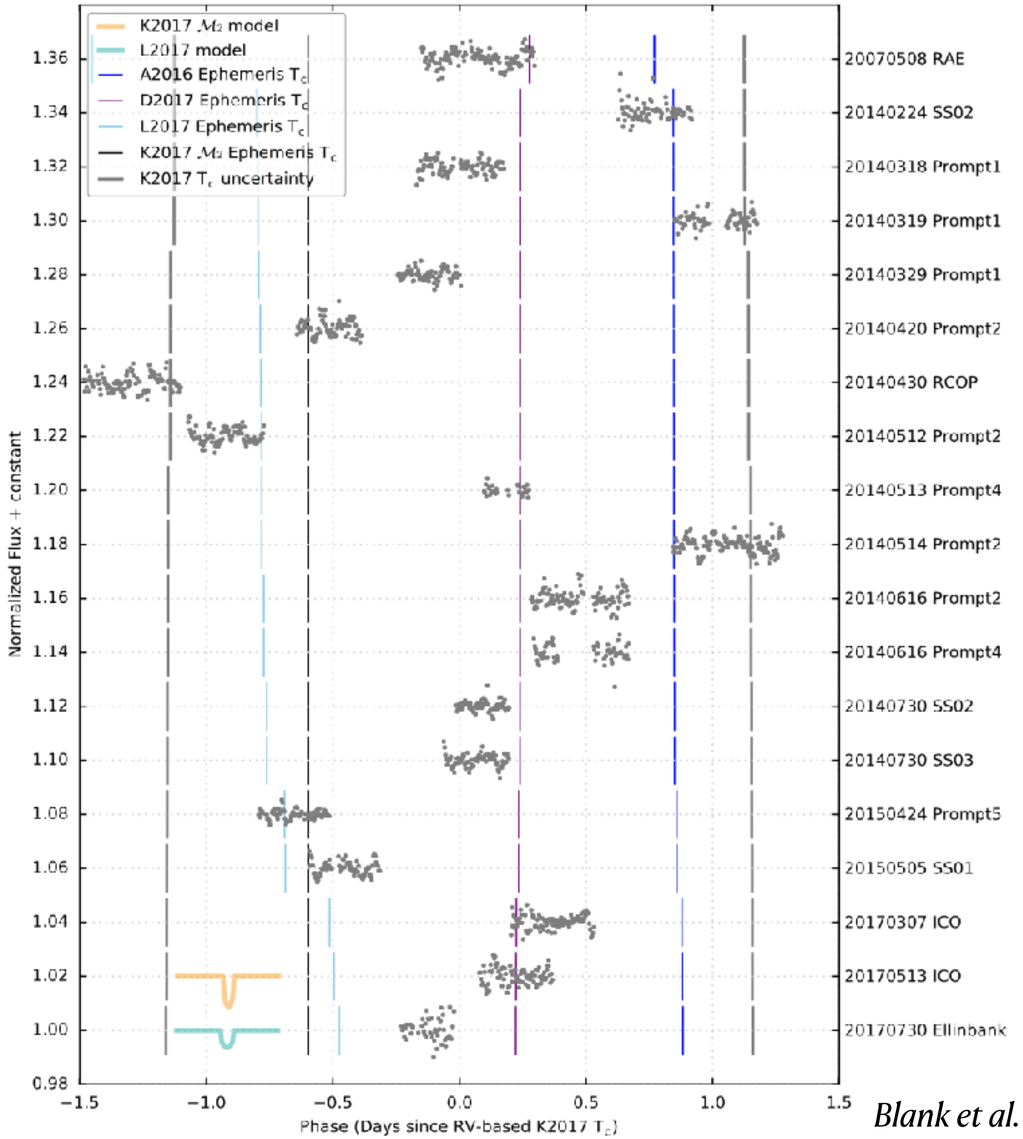
10-day campaign from Antarctica





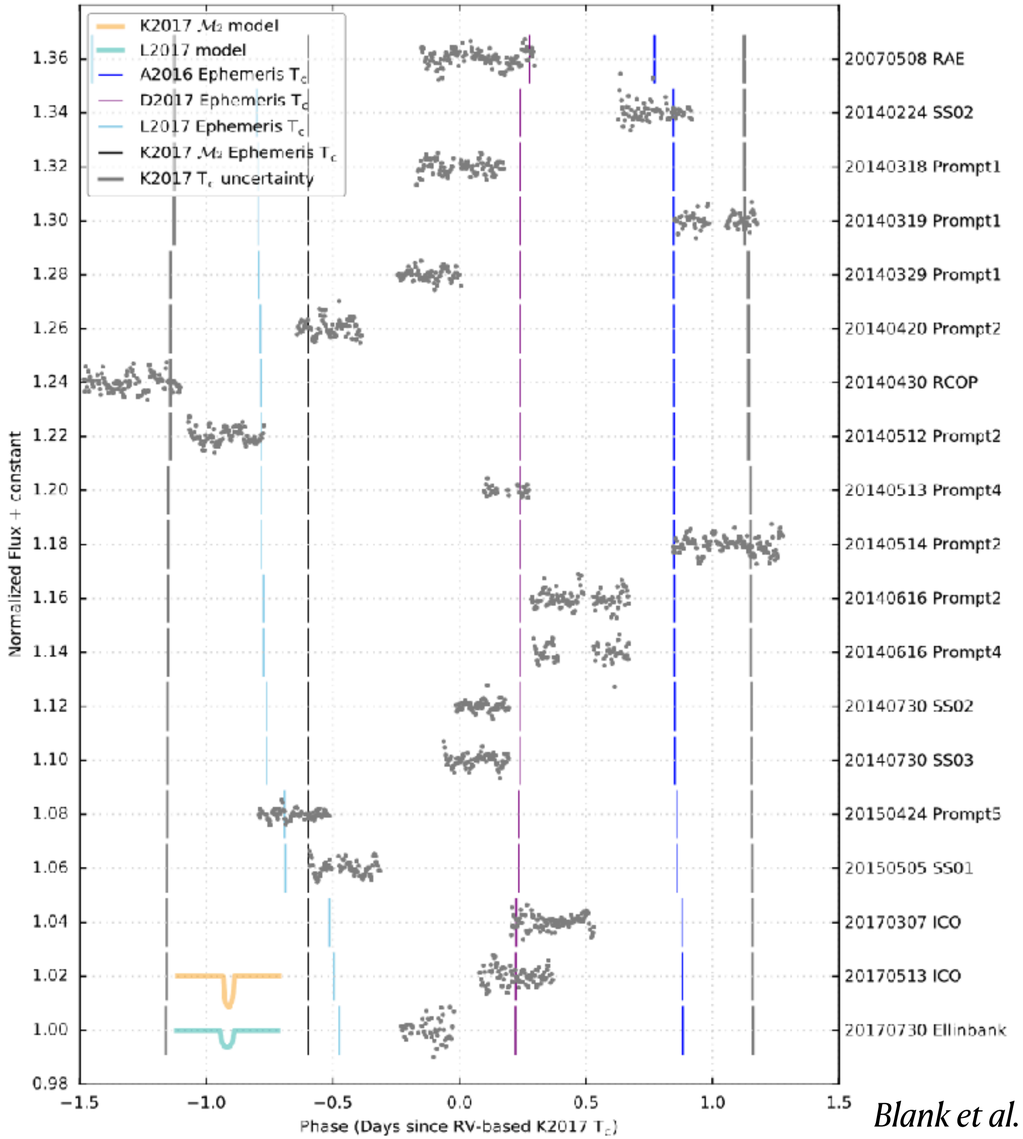
Liu et al. 2018

Multi-site ground-based observations

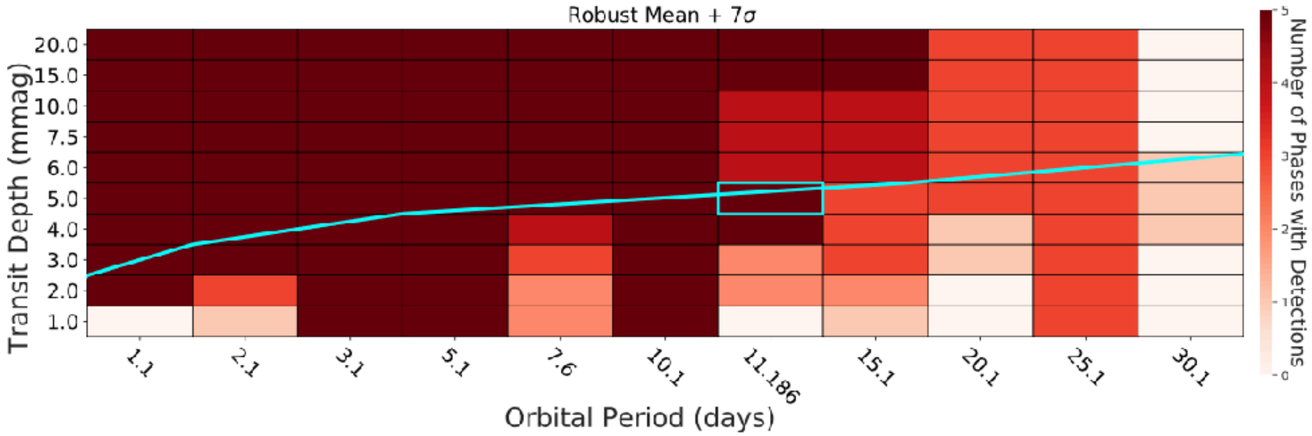


Blank et al. 2018

Multi-site ground-based observations

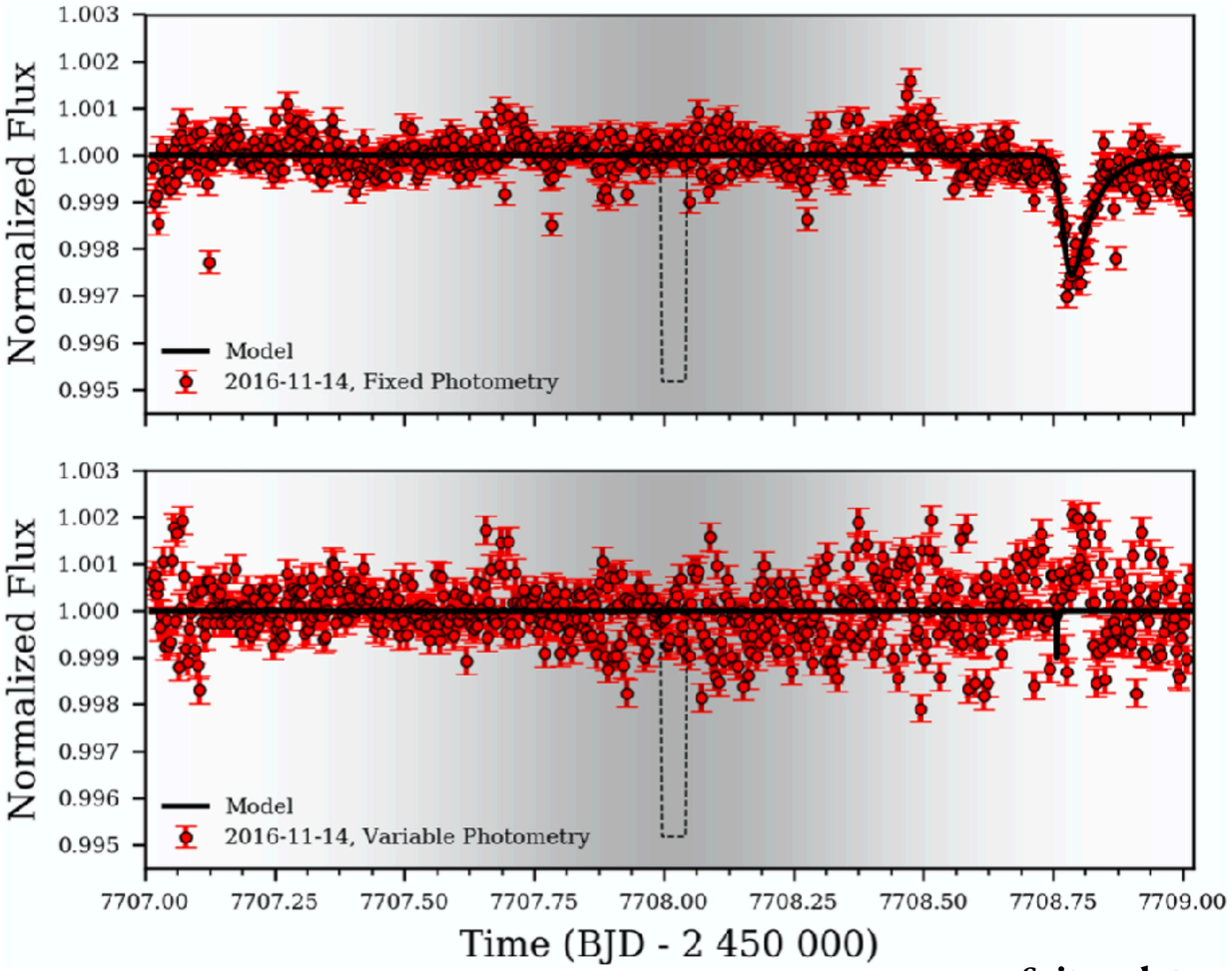


Blank et al. 2018



Feliz et al. 2019

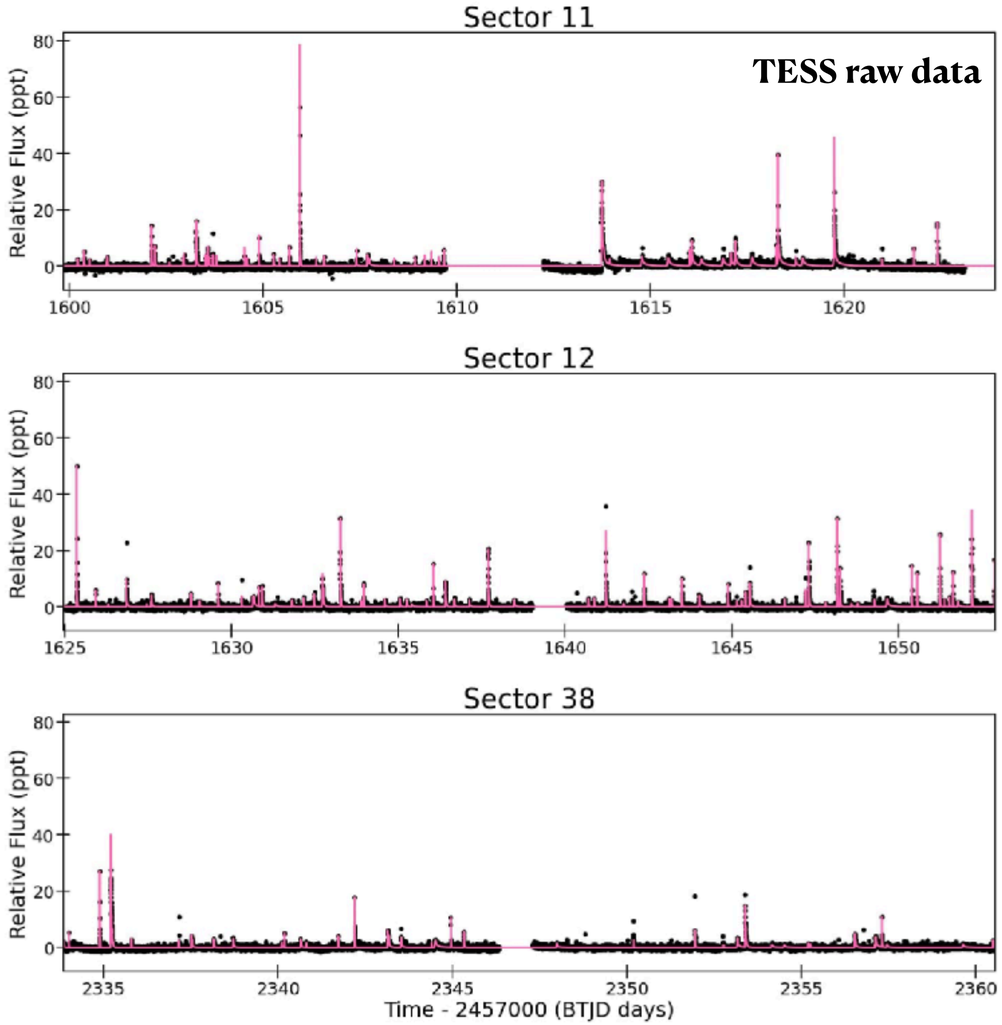
Spitzer space telescope: 48 hours continuous monitoring



***Spitzer* data**

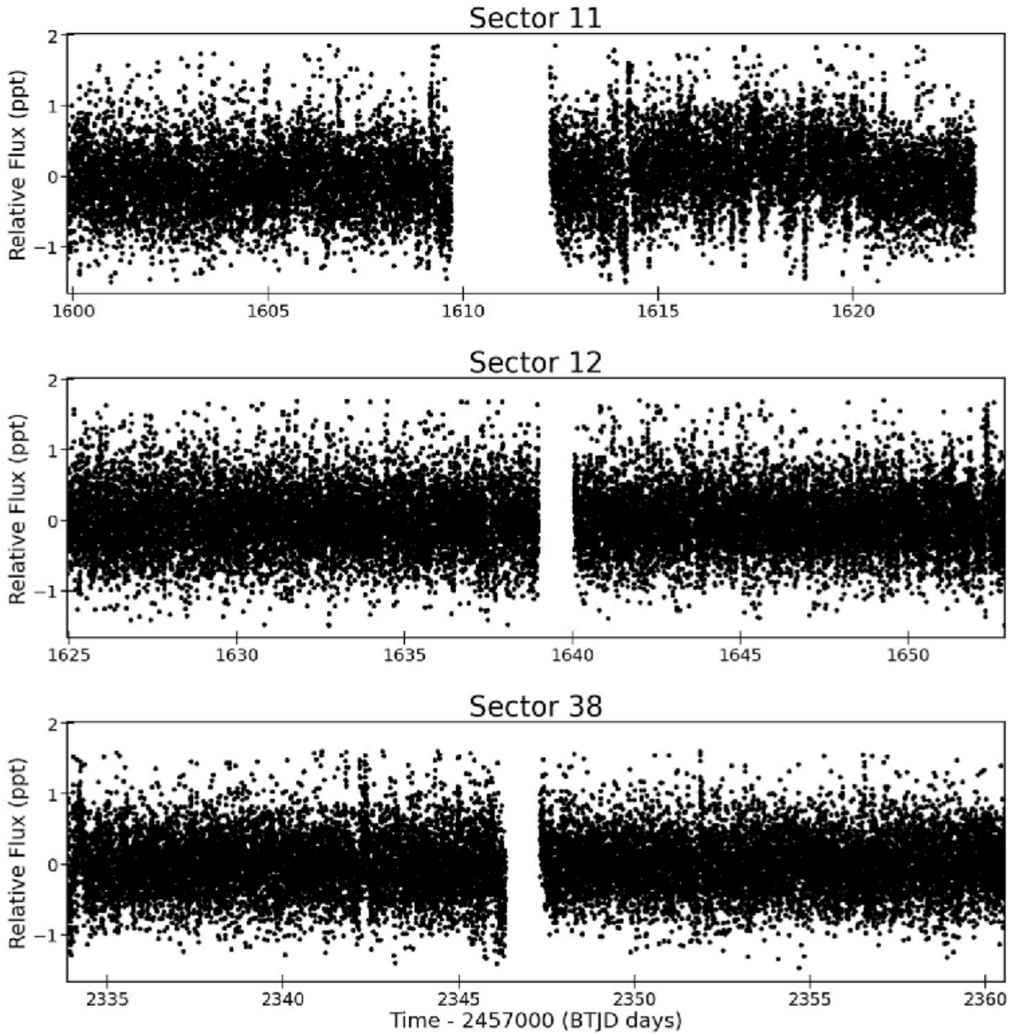
Jenkins et al. 2019

Multi-sector monitoring with TESS



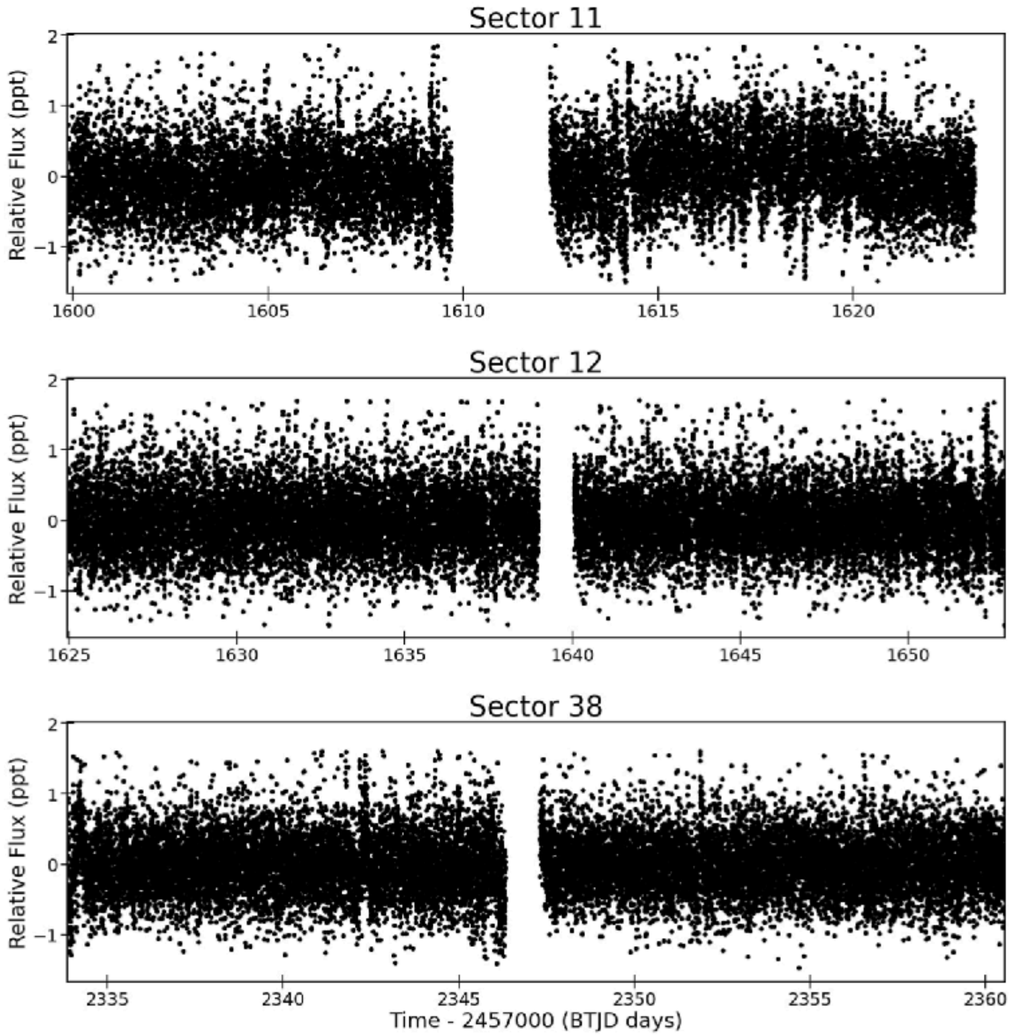
Gilbert et al. 2021

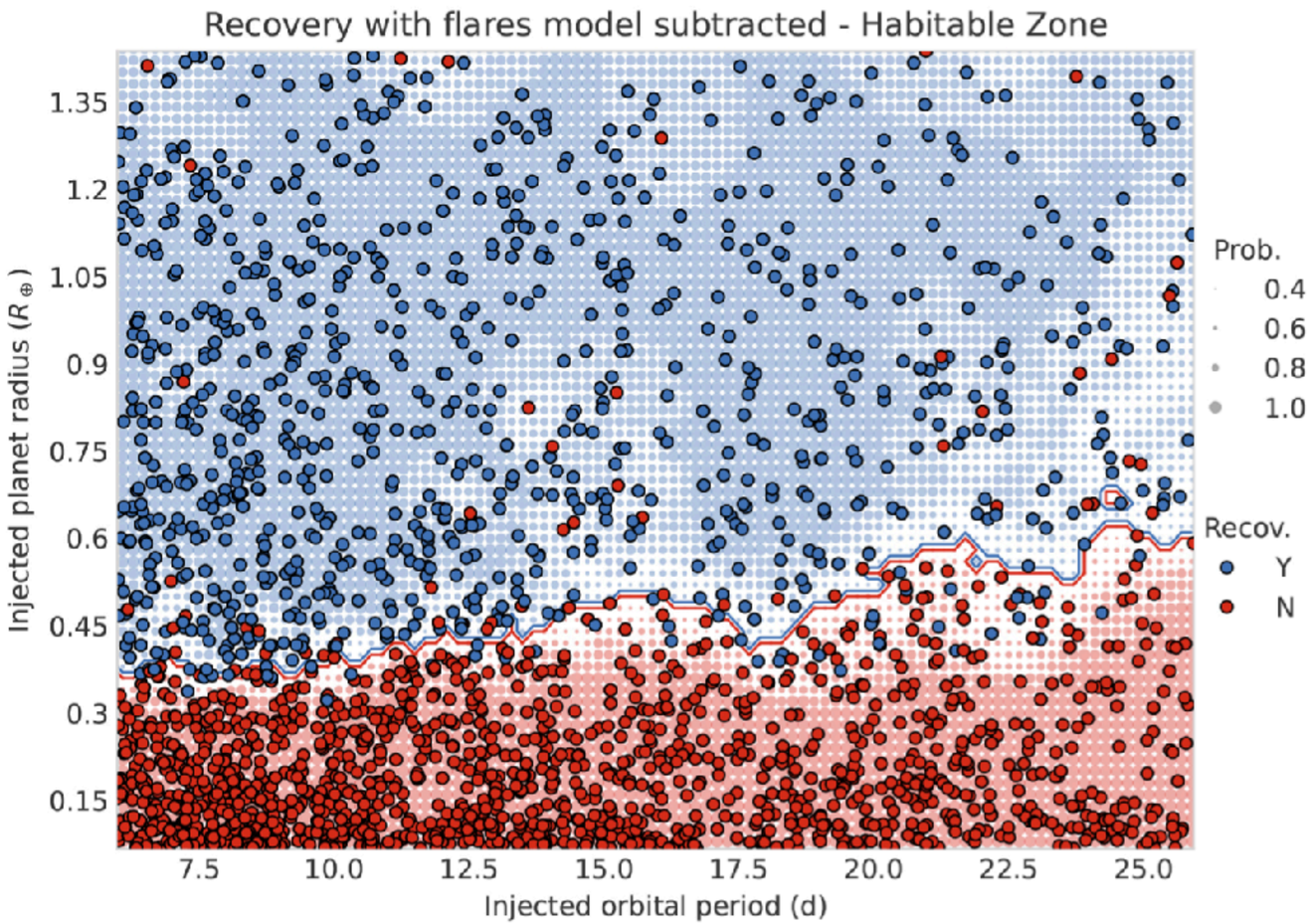
Multi-sector monitoring with TESS



Gilbert et al. 2021

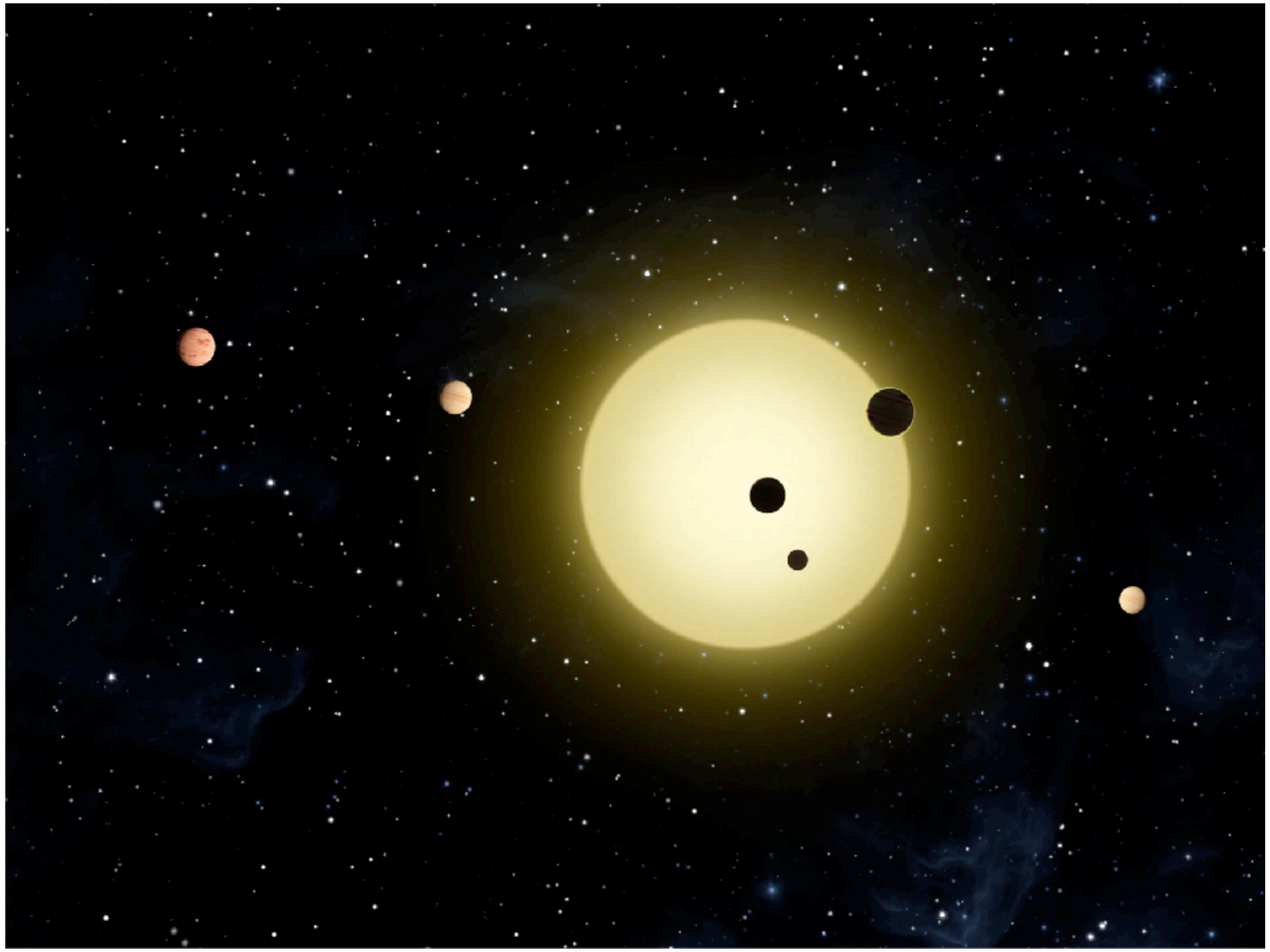
Multi-sector monitoring with TESS





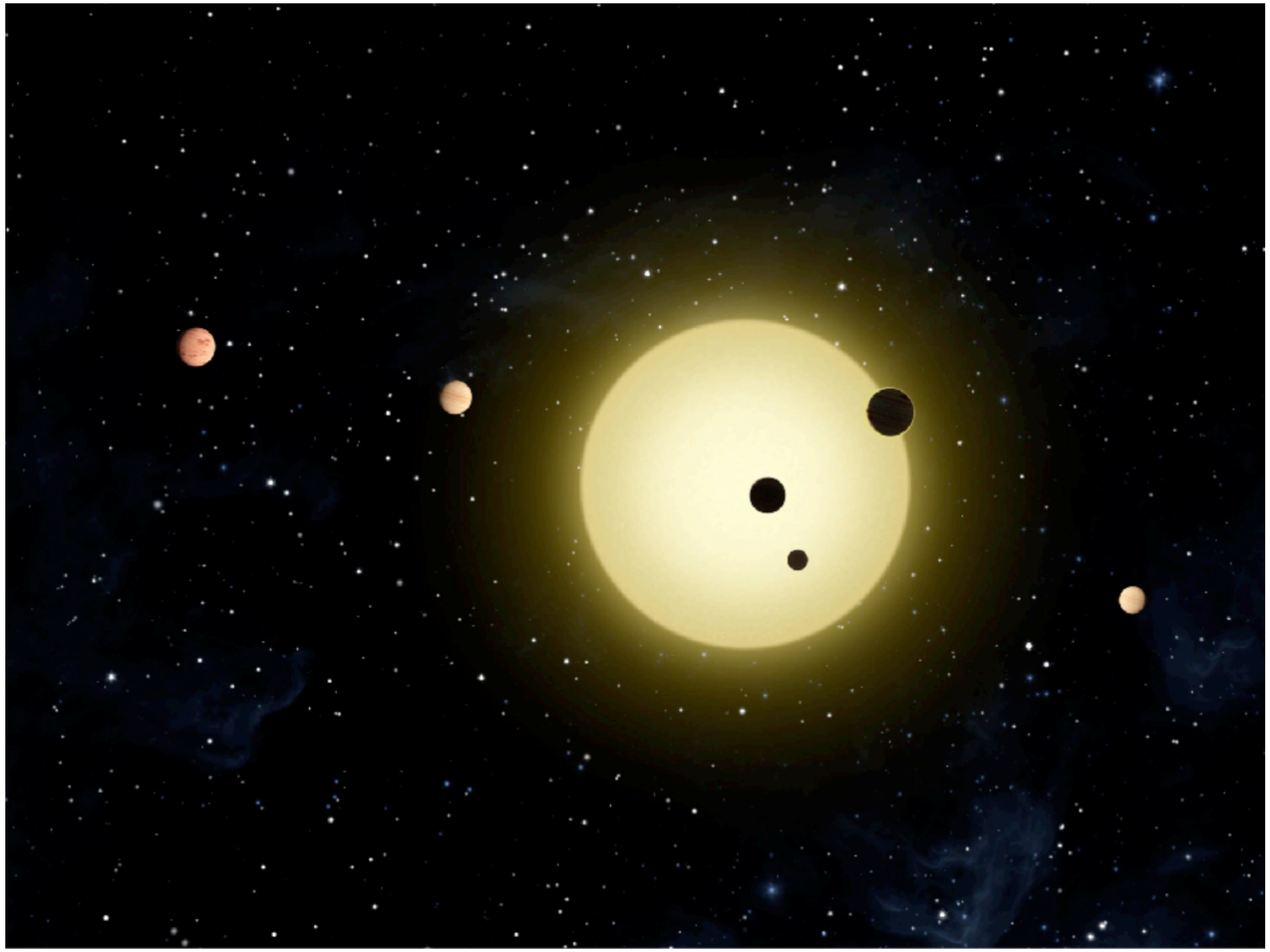
Gilbert et al. 2021

Searching for transits in Alpha Cen system is hard!



Searching for transits in Alpha Cen system is hard!

- **Alpha Cen A/B**
  - Very bright
  - Dilution



Searching for transits in Alpha Cen system is hard!

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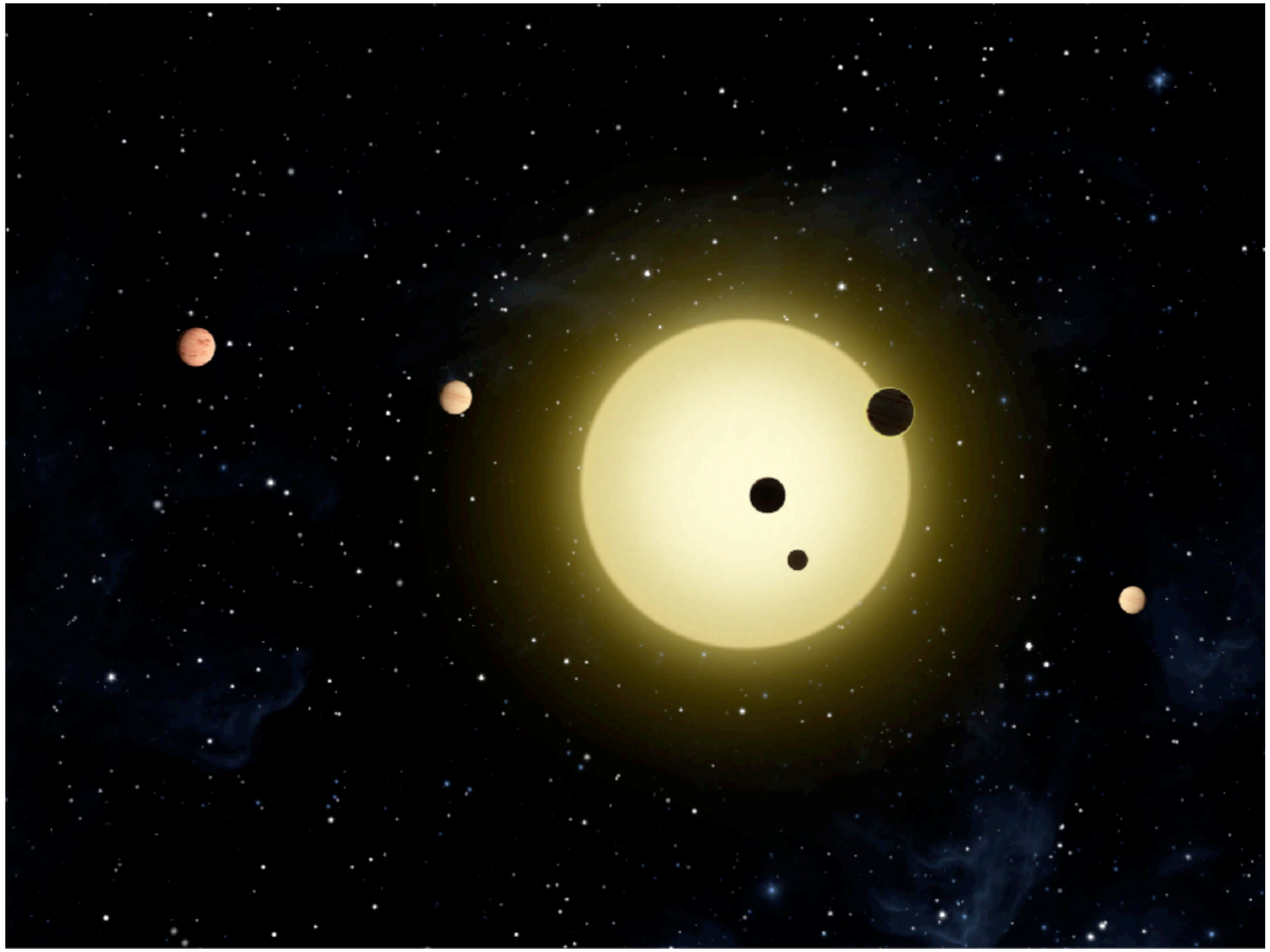
- **Proxima**
  - Flares
  - Photometric modulation



Searching for transits in Alpha Cen system is hard!

- **Alpha Cen A/B**
  - Very bright
  - Dilution

- **Proxima**
  - Flares
  - Photometric modulation

- Next opportunity: **CHEOPS**