Twitter:
@LIFE_telescope
@dan_anger

LIFE looks for life

Authors:

Daniel Angerhausen,
and the LIFE initiative

LIFE
LARGE INTERFEROMETER FOR EXOPLANETS

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Introduction of the LIFE mission

-What is LIFE?
-Sanity checks: does my mission get the minimum req.?
-Can we find life (as we don't know it)?
-What if we do not find anything?
-How you can contribute to LIFE

Authors:

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ETH zürich

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Can we find alien civilizations?

ETH zürich

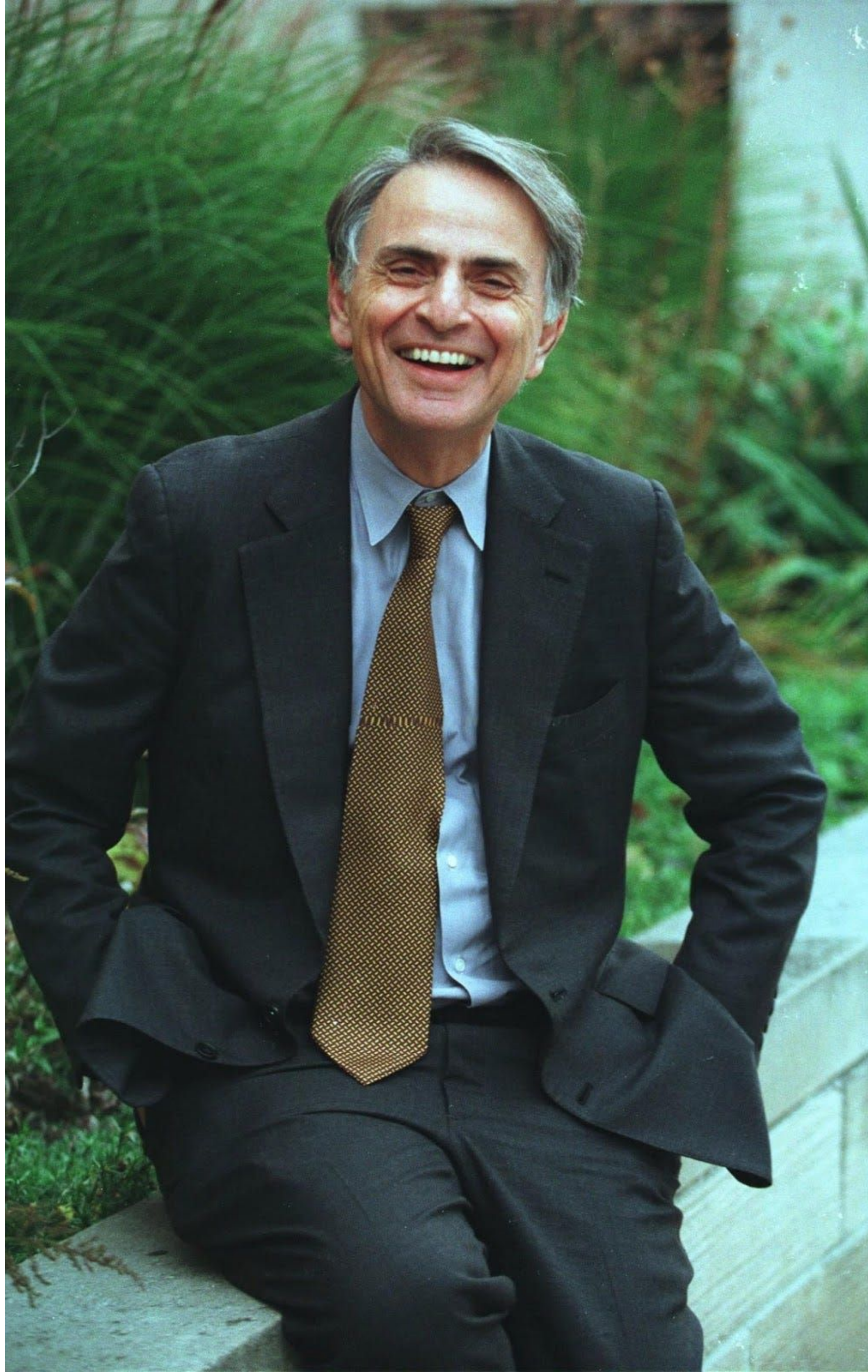
Life looks for life

Carl Sagan, Pale Blue Dot: A Vision of the Human Future in Space

As children, we fear the dark. Anything might be out. here. The unknown troubles us. Ironically, it is our fate to live in the dark. This unexpected finding of science is only about three centuries old. Head out from the Earth in any direction you choose, and—after an initial flash of blue and a longer wait while the Sun fades—you are surrounded by blackness, punctuated only here and there by the faint and distant stars. Even after we are grown, the darkness retains its power to frighten us. And so there are those who say *we should not inquire too closely into who else might be living in that darkness*. Better not to know, they say. There are 400 billion stars in the Milky Way Galaxy. Of this immense multitude, could it be that our humdrum Sun is the only one with an inhabited planet? Maybe. *Maybe the origin of life or intelligence is exceedingly improbable*. Or maybe civilizations arise all the time, but wipe themselves out as soon as they are able. Or, here and there, peppered across space, orbiting other suns, maybe there are worlds something like our own, on which other beings gaze up and wonder as we do about who else lives in the dark...Life is a comparative rarity. You can survey dozens of worlds and find that on only one of them does life arise and evolve and persist... If we humans ever go to these worlds, then, it will be because a nation or a consortium of them believes it to be to its advantage—or to the advantage of the human species... In our time we've crossed the Solar System and sent four ships to the stars...

But we continue to search for inhabitants.

We can't help it. Life looks for life.



SPASA 2011 – Astrobiology Summer School

My first lecture on origins of life

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My first lecture on origins of life

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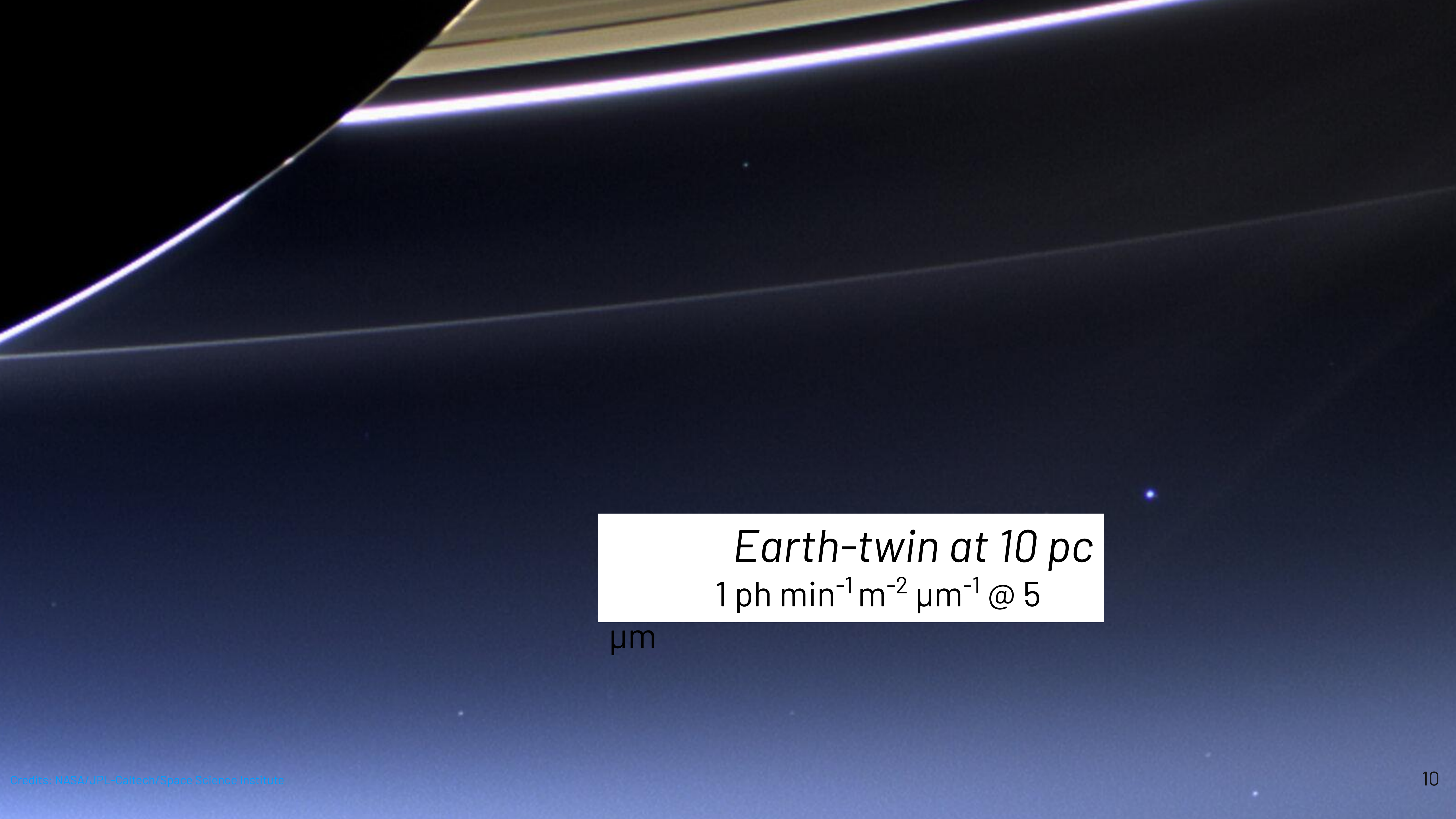
LARGE INTERFEROMETER FOR EXOPLANETS

Exoplanets are hard

We might have found 5000 in the past 25+ years ...
...but there is still so much to be discovered

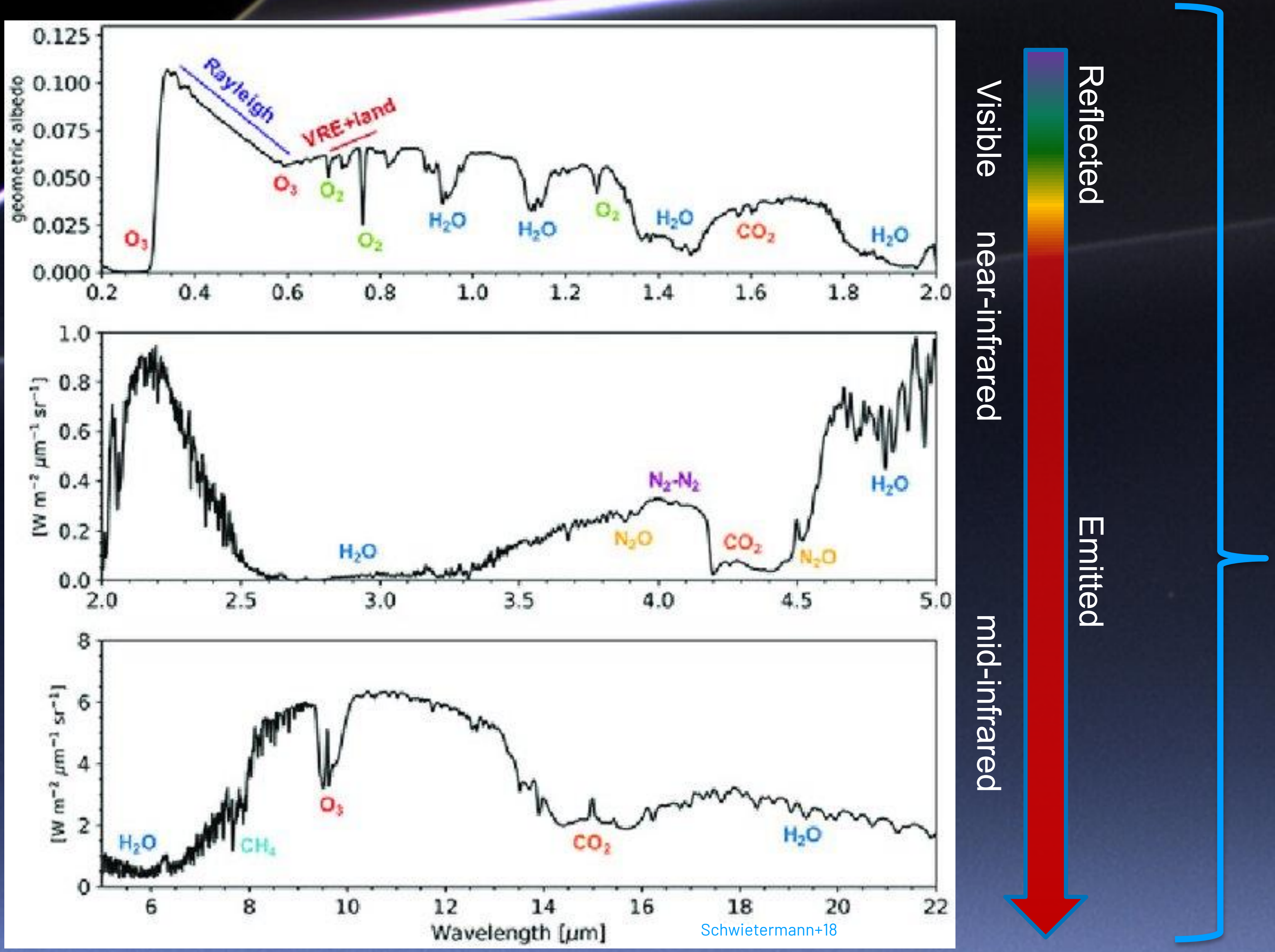
Credits: NASA/JPL-Caltech/Space Science Institute



Earth-twin at 10 pc

1 ph $min^{-1} m^{-2} \mu m^{-1}$ @ 5 μm

Credits: NASA/JPL-Caltech/Space Science Institute


geometric albedo
Rayleigh
VRE+land
O3
O2
H2O
CO2
[W m-2 μm-1 sr-1]
N2-N2
N2O
CH4
Wavelength [μm]
Schwietermann+18
Visible
near-infrared
mid-infrared
Reflected
Emitted

Roadmap

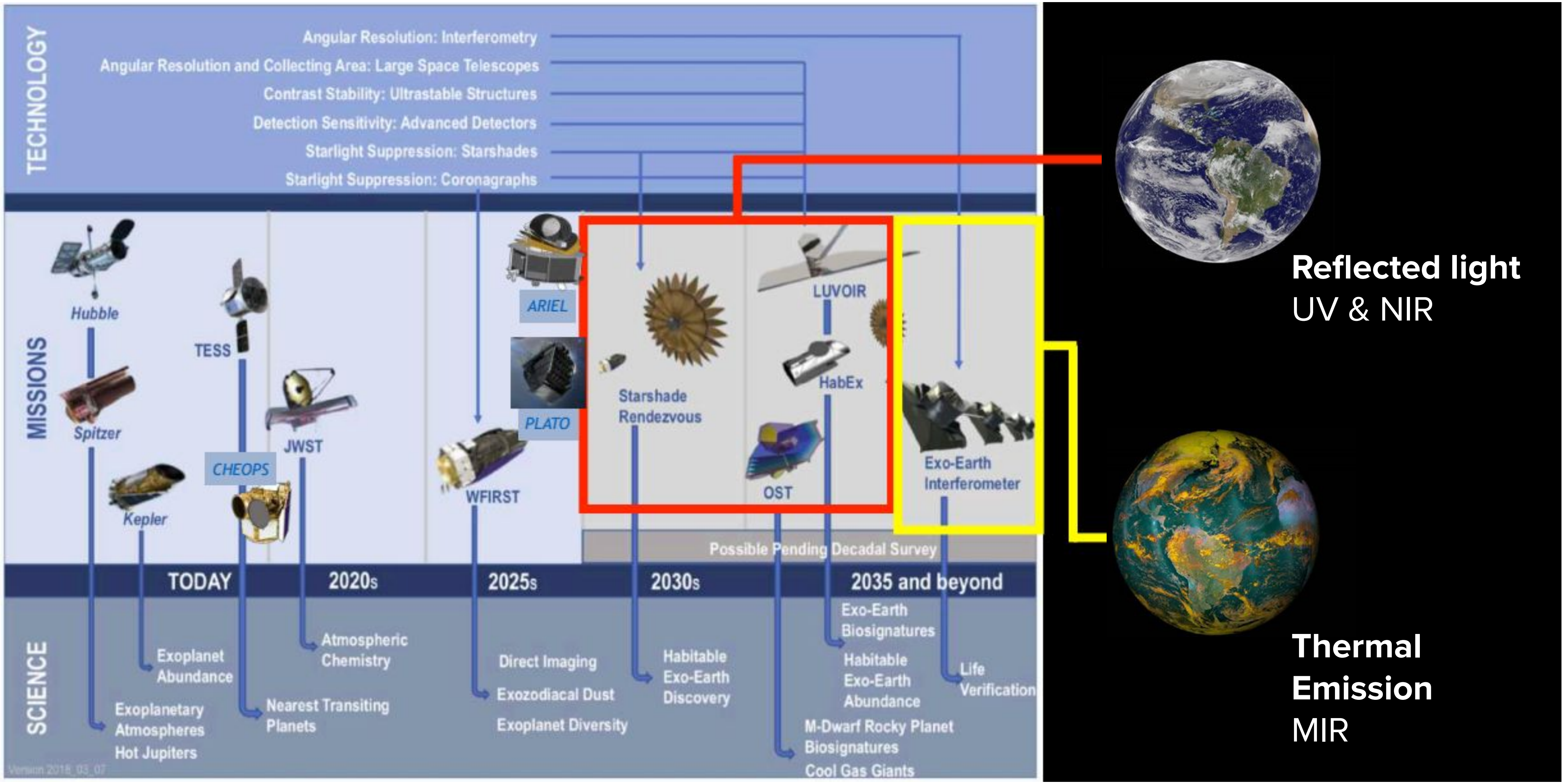


Image credit: (adapted from) NASA/JPL/Caltech; https://exoplanets.nasa.gov/exep/technology/technology-overview/ (accessed July 4, 2019)

Square One

What is the question we want to answer?

Start: Scientific Objective

ESA Voyage 2050 - European roadmap for future space exploration

SCIENCE & EXPLORATION

Voyage 2050 sets sail: ESA chooses future science mission themes

"Therefore, launching a Large mission enabling the characterisation of the **atmosphere of temperate exoplanets in the mid-infrared should be a top priority for ESA** within the Voyage 2050 timeframe."

"This would give ESA and the European community the opportunity to **solidify its leadership** in the field of exoplanets, [...]"

"Being the first to measure a spectrum of the direct thermal emission of a temperate exoplanet in the mid infrared **would be an outstanding breakthrough** that could lead to yet again another paradigm-shifting discovery."

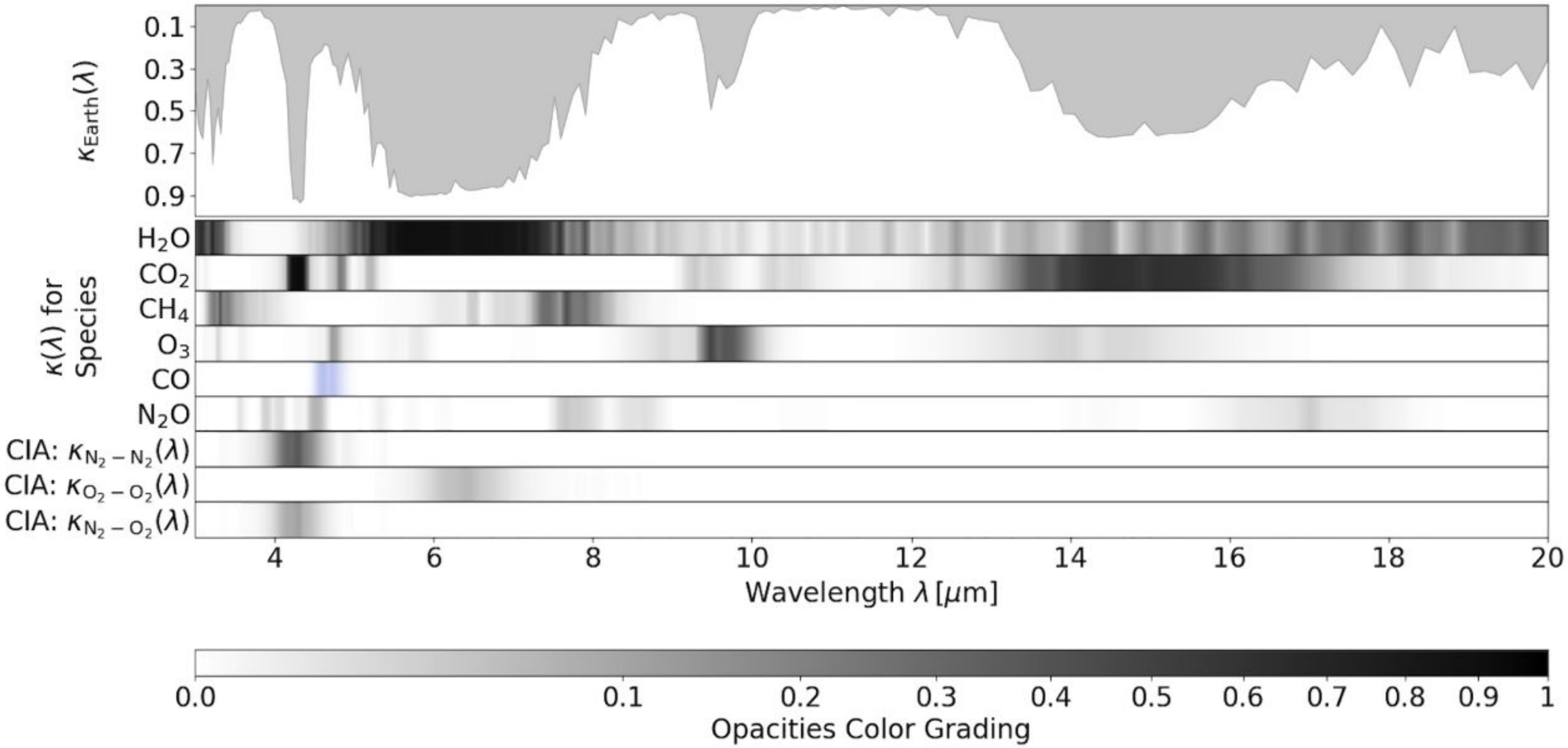
ESA Senior Committee Report

Why MIR?

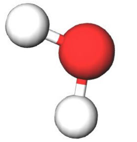
The mid-IR opportunity

Molecular abundances

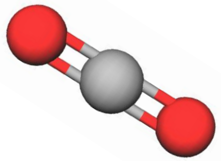
Konrad et al. 2022: LIFE III



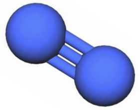
Major Constituents



H_2O

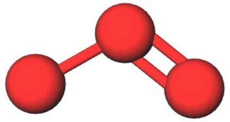


CO_2

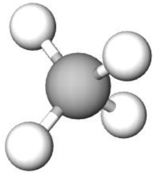


N_2

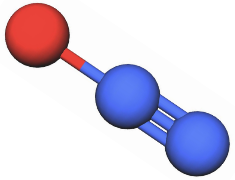
Earth-like Biomarkers



O_3

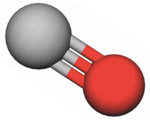


CH_4

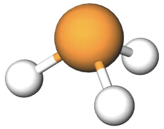


N_2O

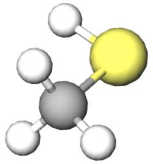
(Anti-) Biosignatures



CO



PH_3

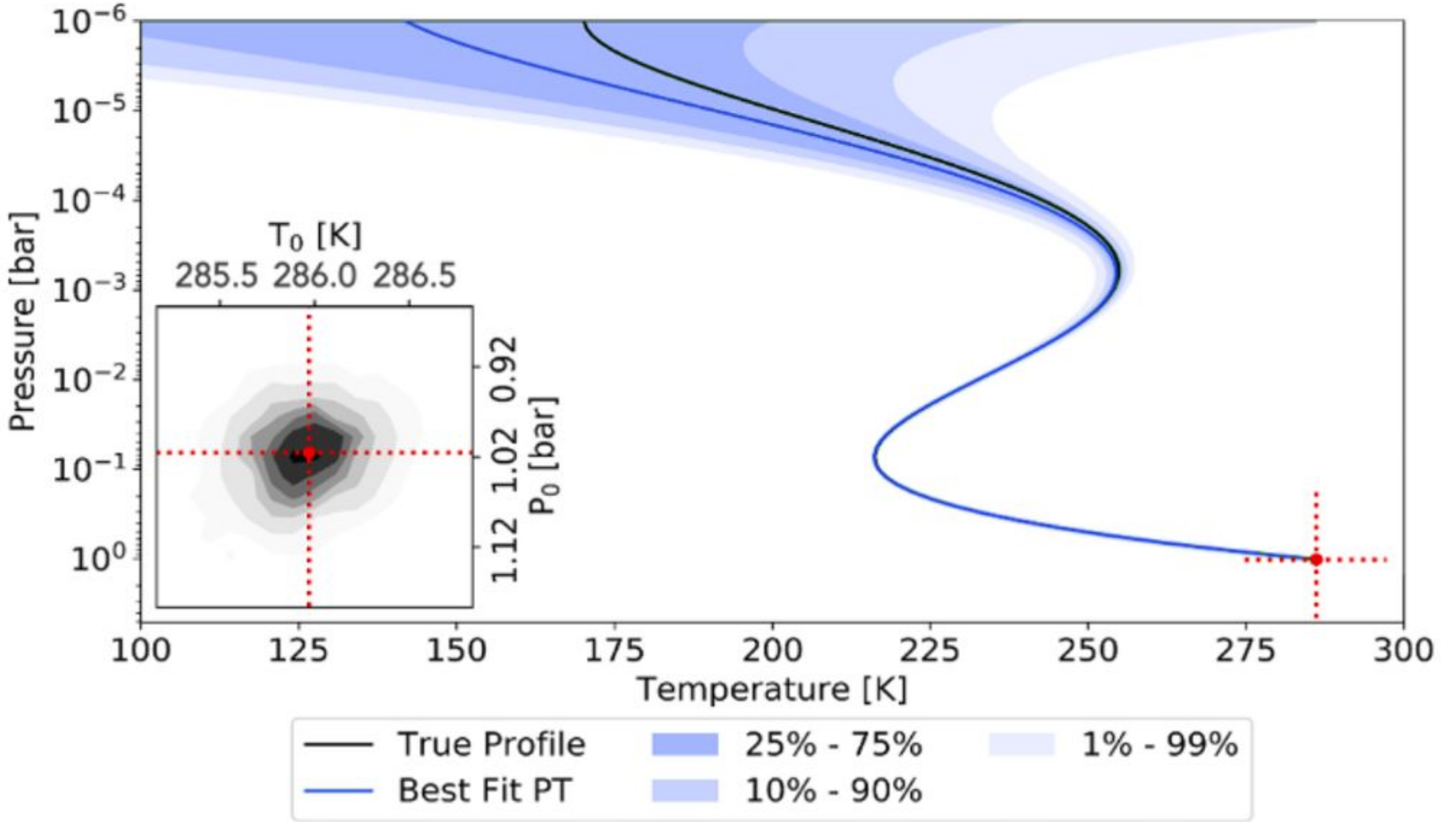


CH_3SH

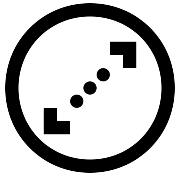
The mid-IR opportunity

Thermal emission

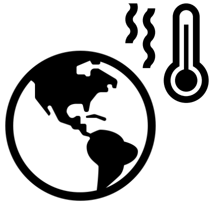
Konrad et al. 2022: LIFE III



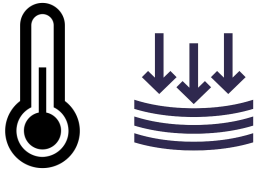
Signal extraction of synthetic terrestrial to sub-Jovian planets

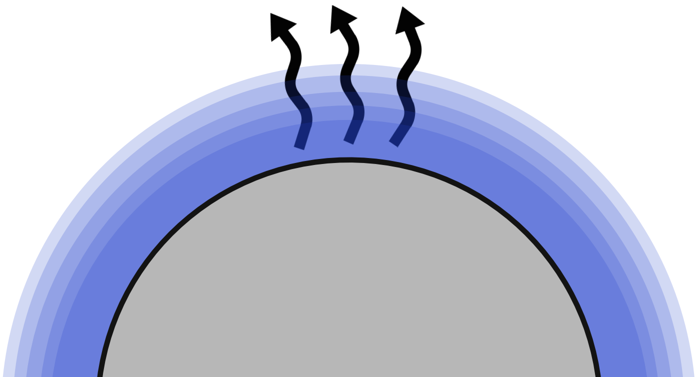


Planet radius



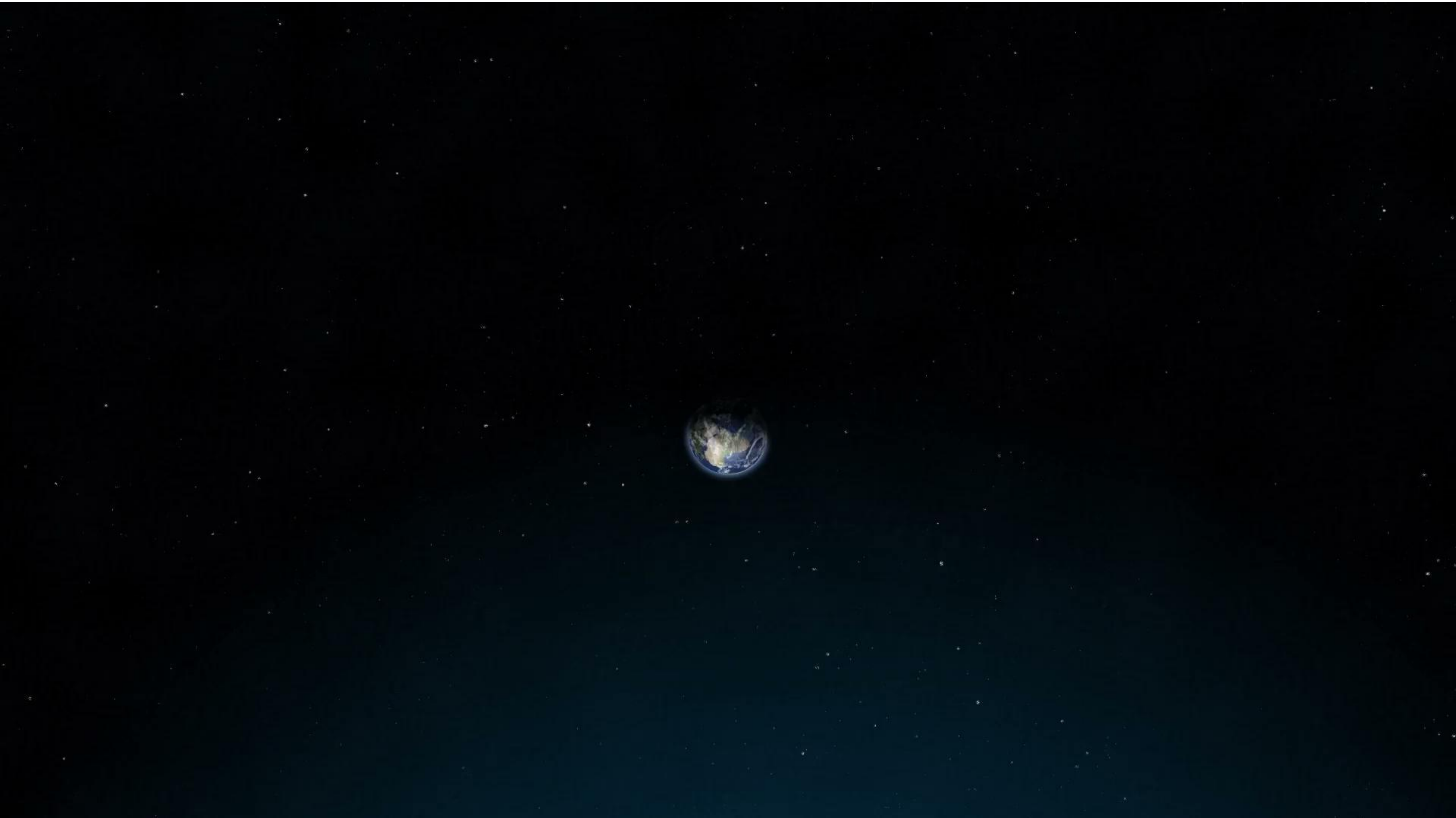
Effective temperature

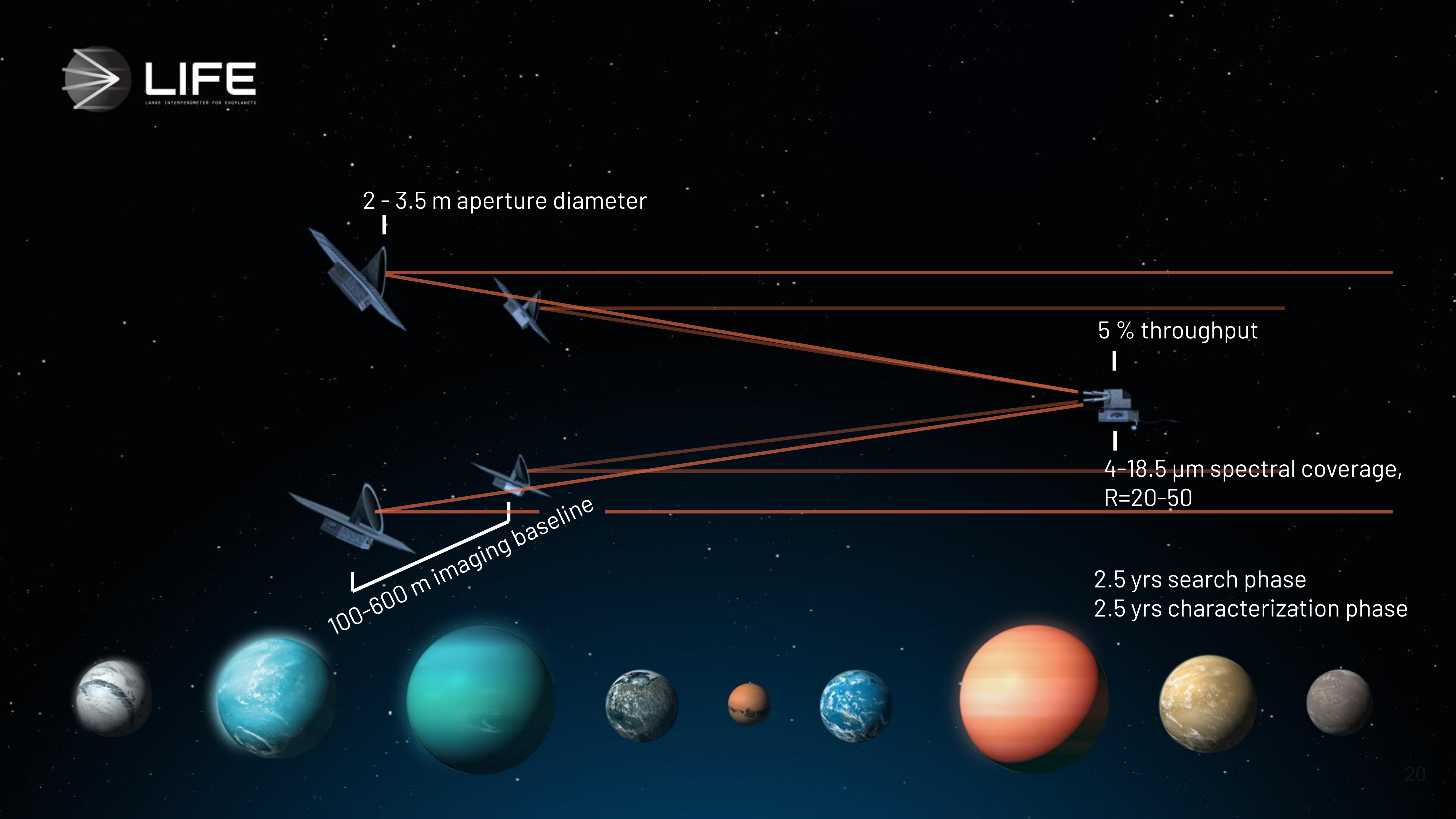




LIFE

The Large Interferometer For Exoplanets



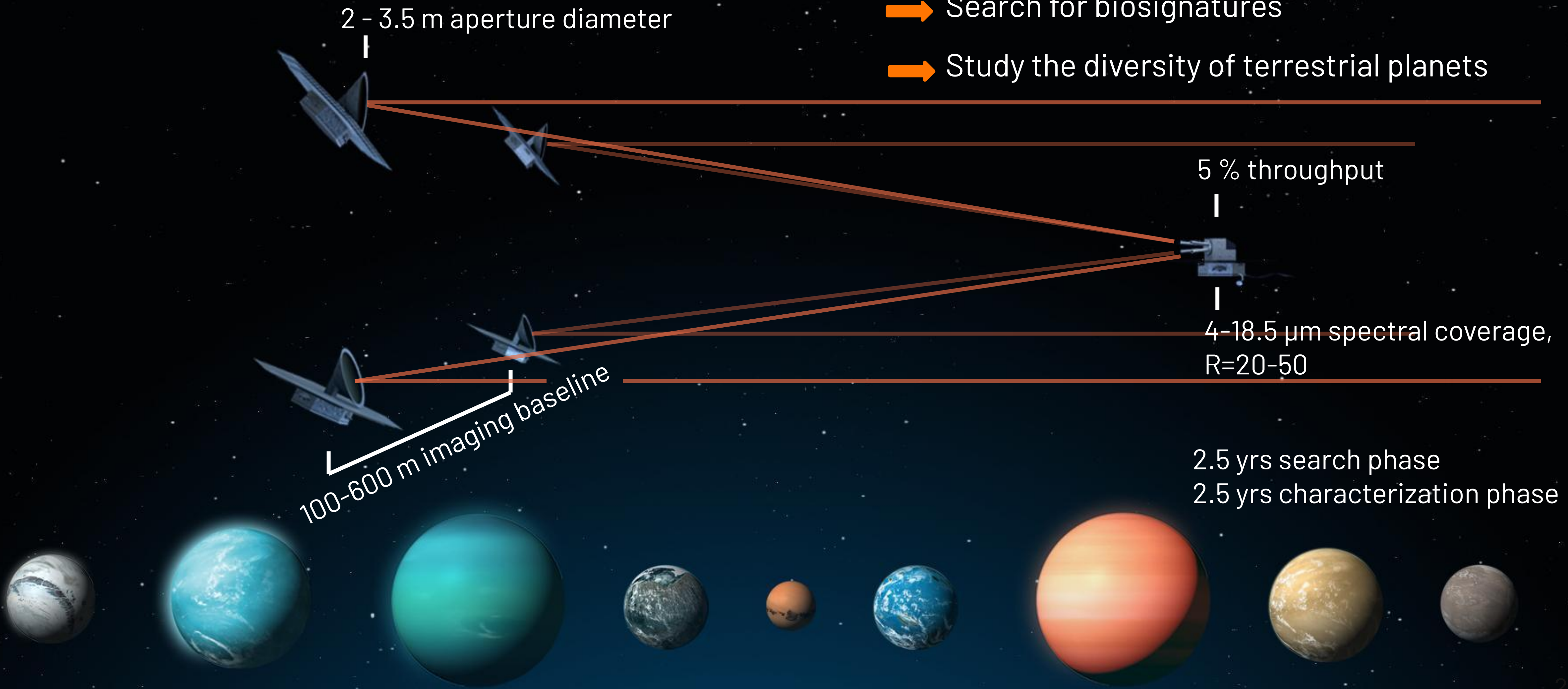

LIFE
LARGE INTERFEROMETER FOR EXOPLANETS
2 - 3.5 m aperture diameter
5 % throughput
4-18.5 µm spectral coverage,
R=20-50
100-600 m imaging baseline
2.5 yrs search phase
2.5 yrs characterization phase

LIFE

LARGE INTERFEROMETER FOR EXOPLANETS

Goals:

- Assess habitability
- Search for biosignatures
- Study the diversity of terrestrial planets

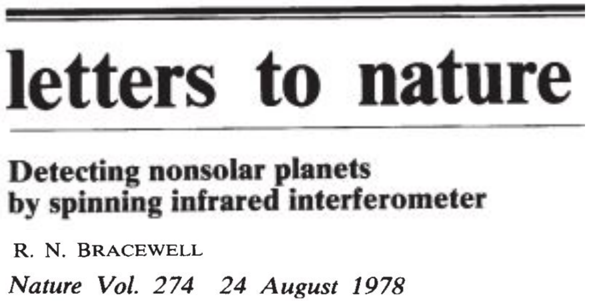


Heritage

Space based (MIR, nulling) interferometry is not a new idea, but:

We know exoplanet statistics much better with hundreds of terrestrial planets waiting to be discovered

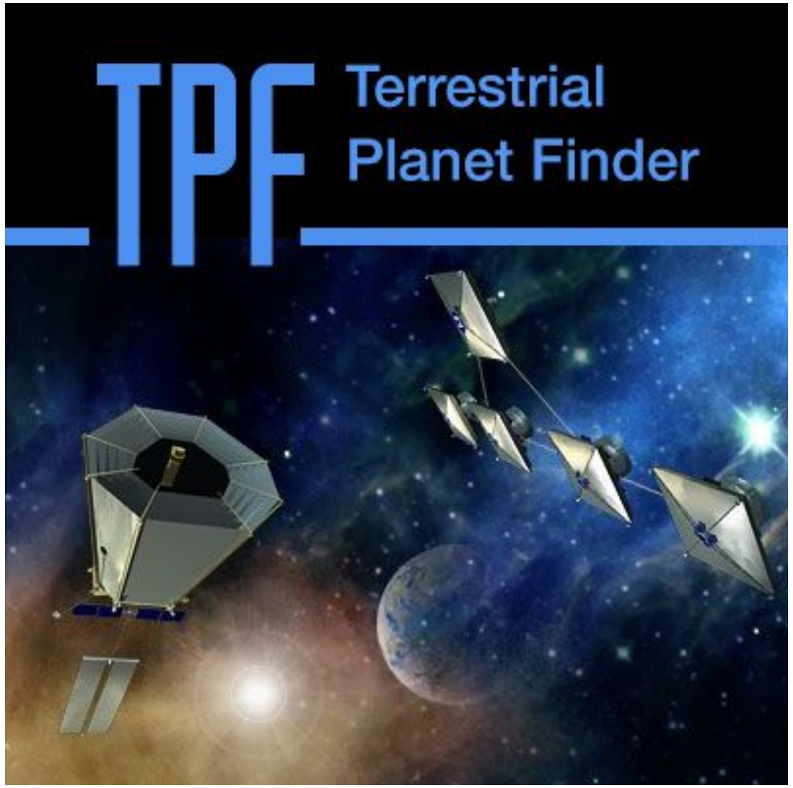
Progress was made in several key technologies


letters to nature

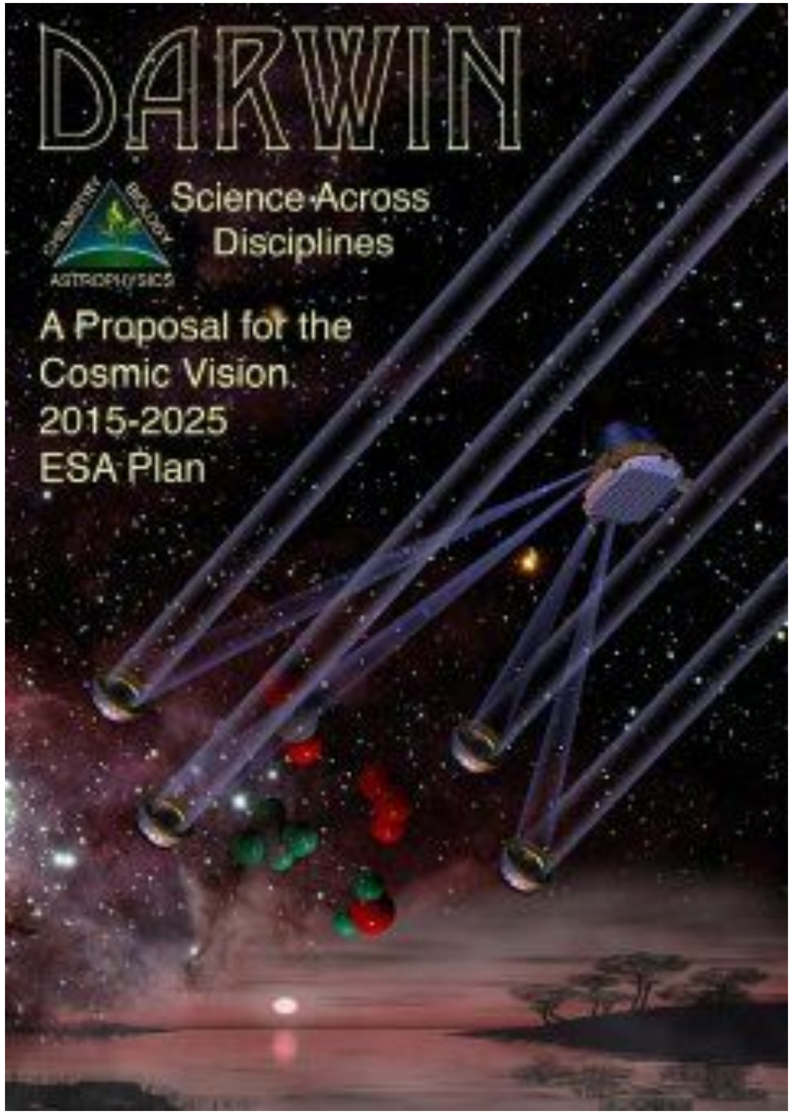
Detecting nonsolar planets by spinning infrared interferometer

R. N. BRACEWELL

Nature Vol. 274 24 August 1978



NASA TPF-I study



ESA Darwin Study

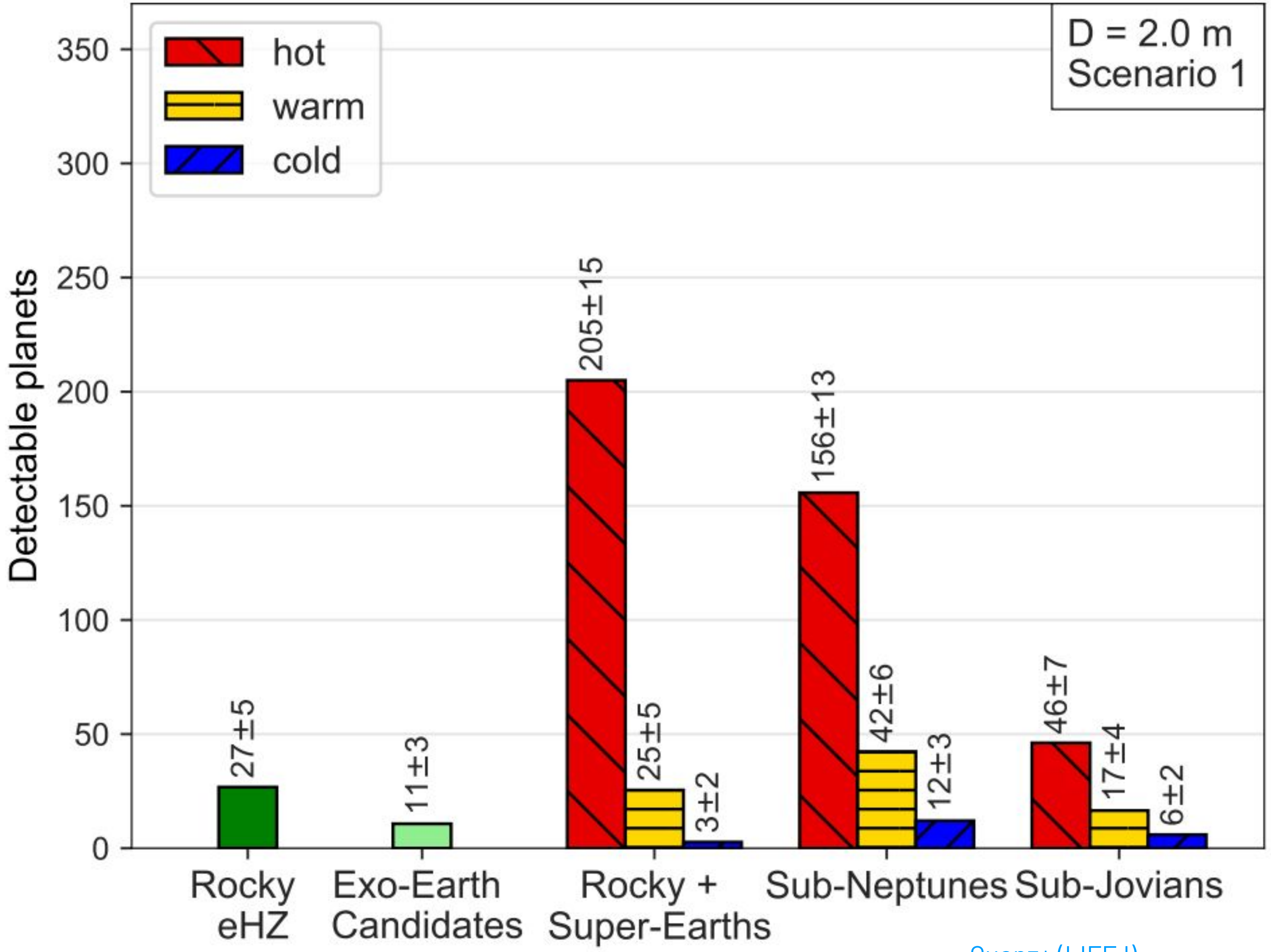

HOTEL

Does LIFE find planets?

And if yes, how many?

Detection Yield

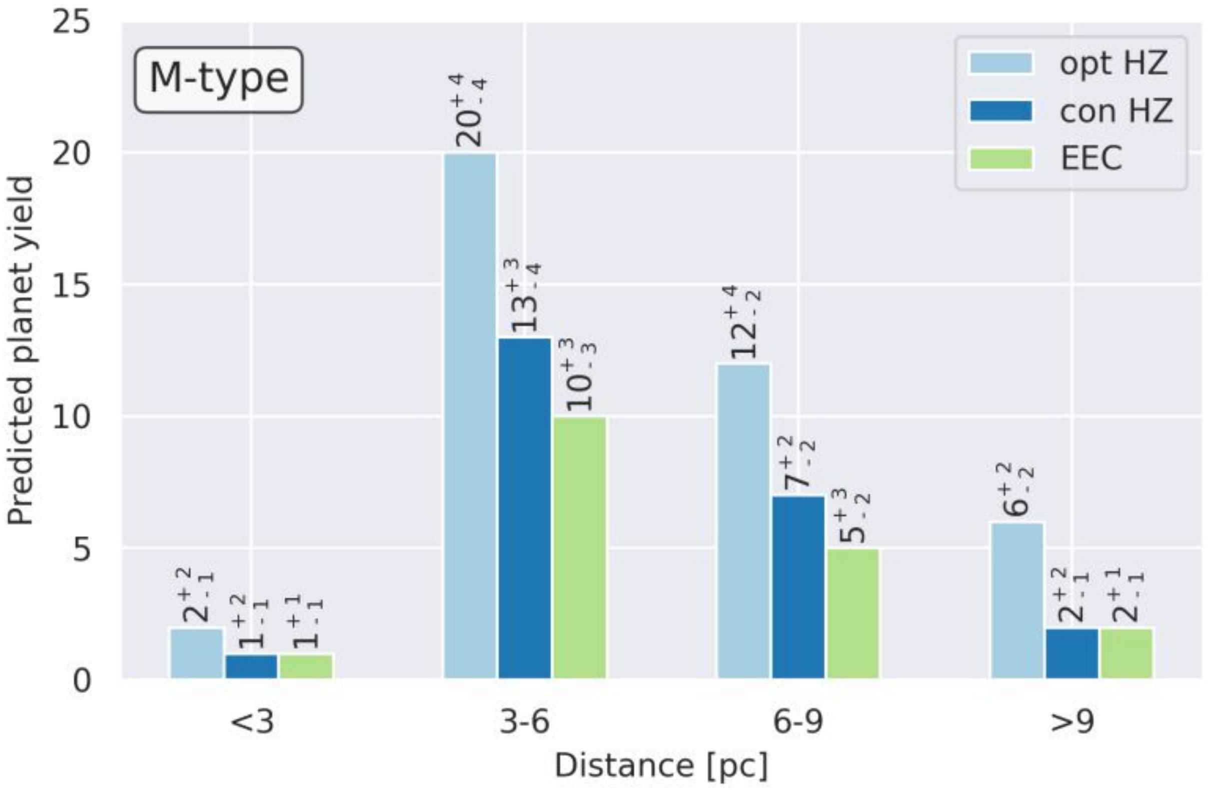
- hundreds of planets
- dozens of temperate rocky ones
- most of them only accessible with LIFE

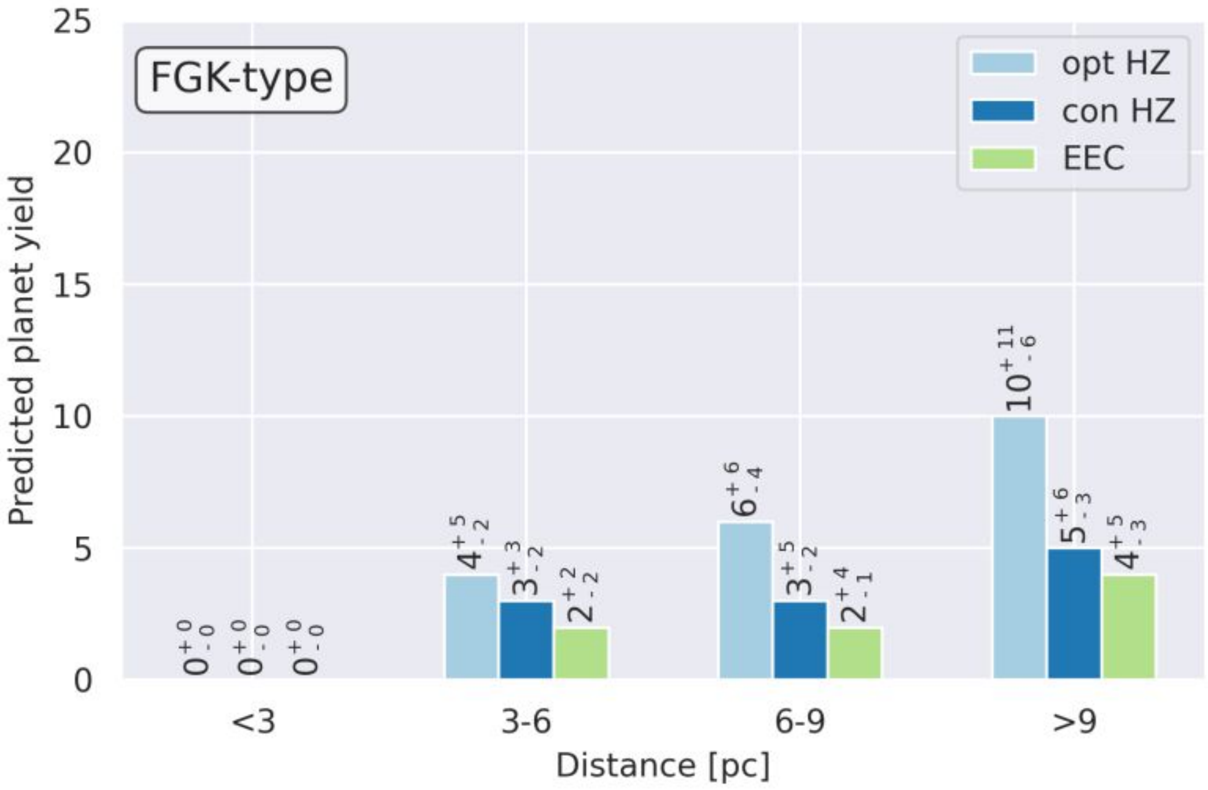


Quanz+ (LIFE I)

How far away are they?

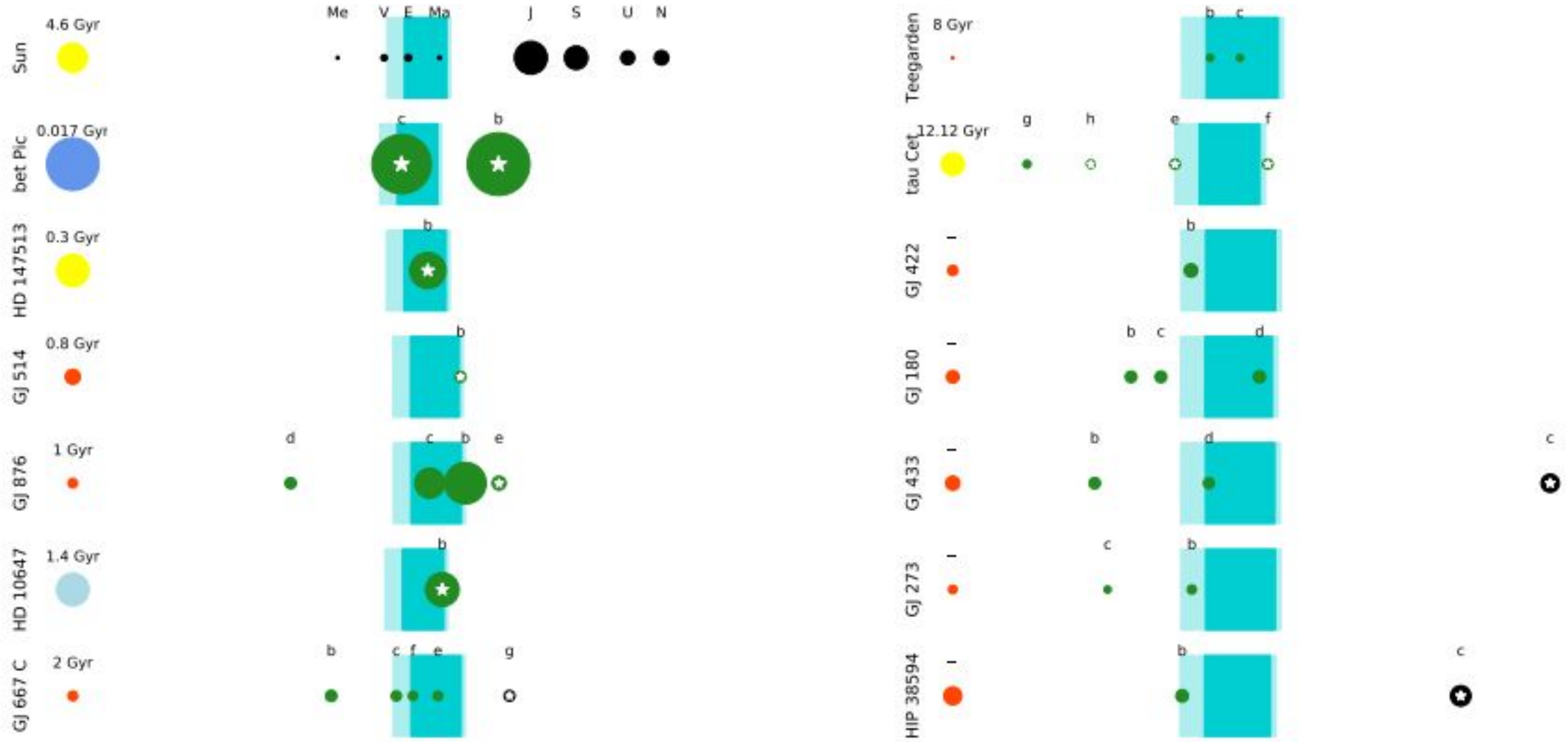
Angerhausen+ 2023, in rev.





What about already known planets?

LIFE X - Carrion-Gonzalez et. al 2023 - LIFE & HWO



[... 212 known exoplanets within 20 pc. Of these, 55 are also accessible to HWO]

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LARGE INTERFEROMETER FOR EXOPLANETS

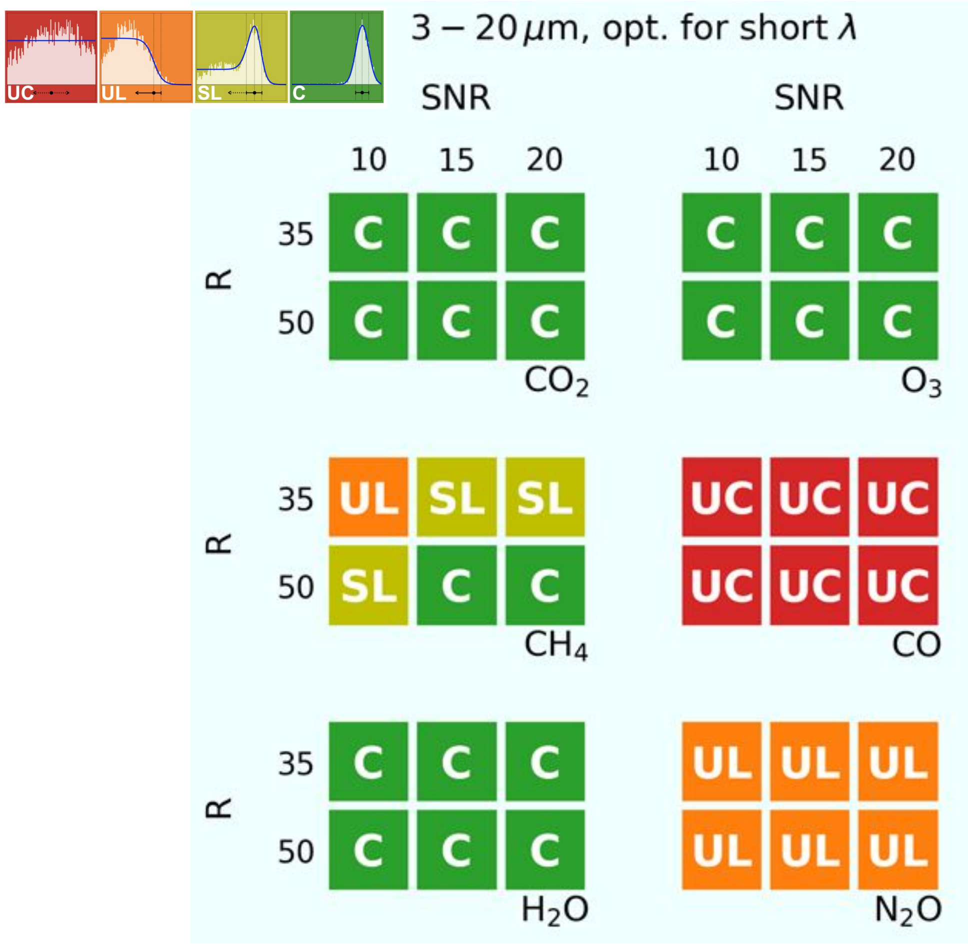
Sanity Check

Would we even find ourselves (in time)?

Credits: NASA/JPL-Caltech/Space Science Institute

LIFE III & V: Earth & Earth in time, science requirements

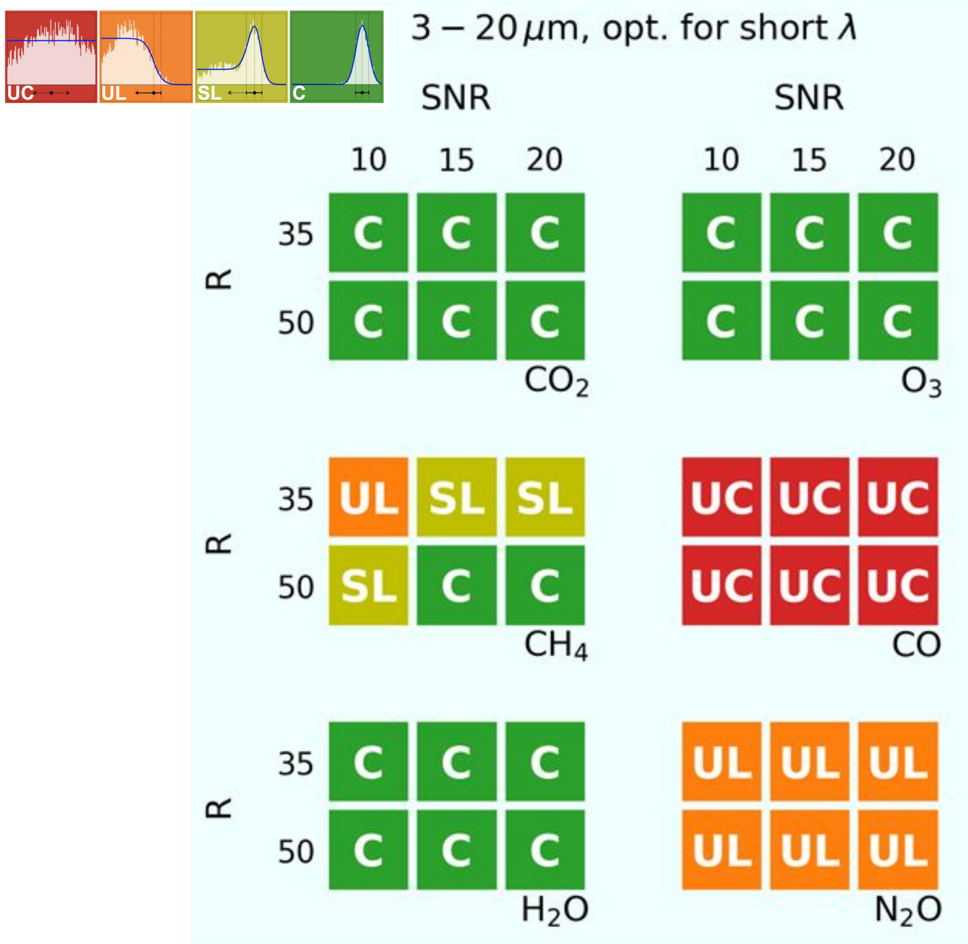
Konrad et al. 2022, Alei et al. 2022

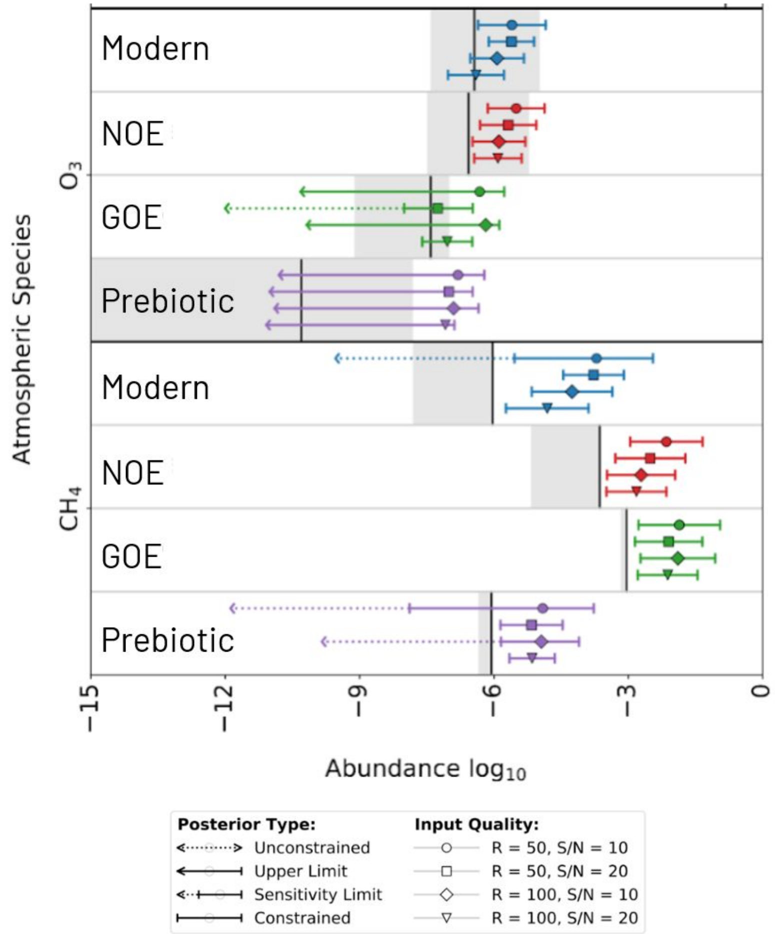


- What are the requirements to characterize an Earth twin?

LIFE III &V: Earth & Earth in time, science requirements

Konrad et al. 2022, Alei et al. 2022





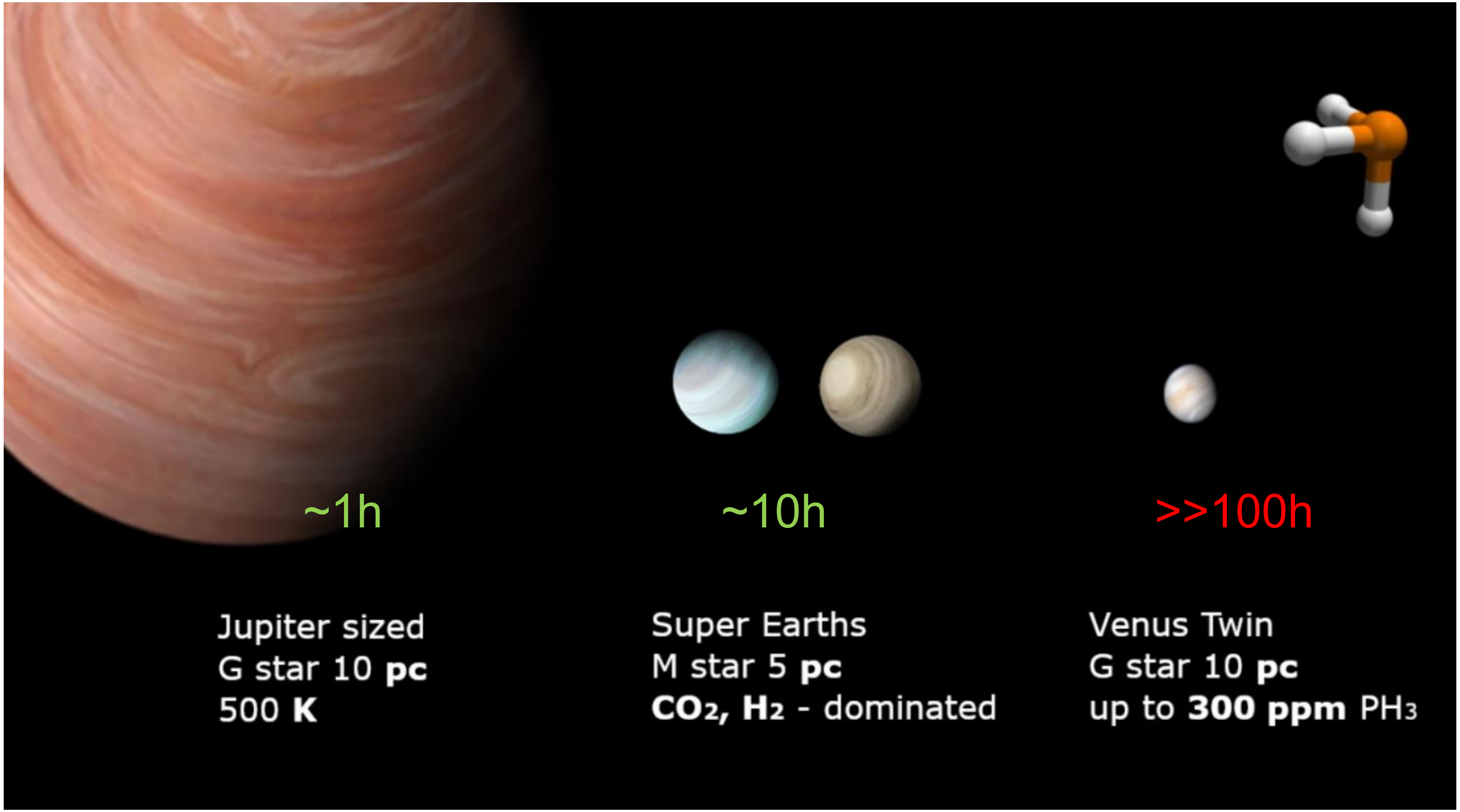
- What are the requirements to characterize an Earth twin?
- Can we distinguish different phases in Earths geological history?

Biosignatures

Sniffing Alien Atmospheres

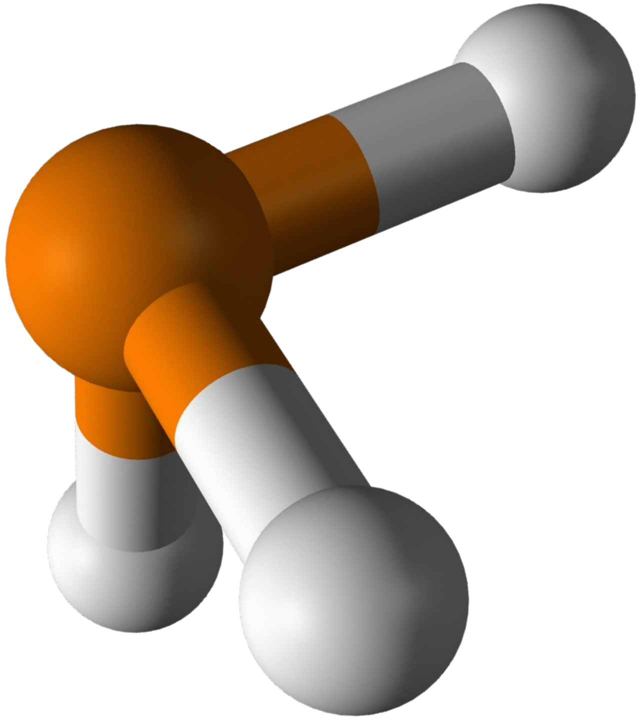
LIFE IV: Phosphine "survey"

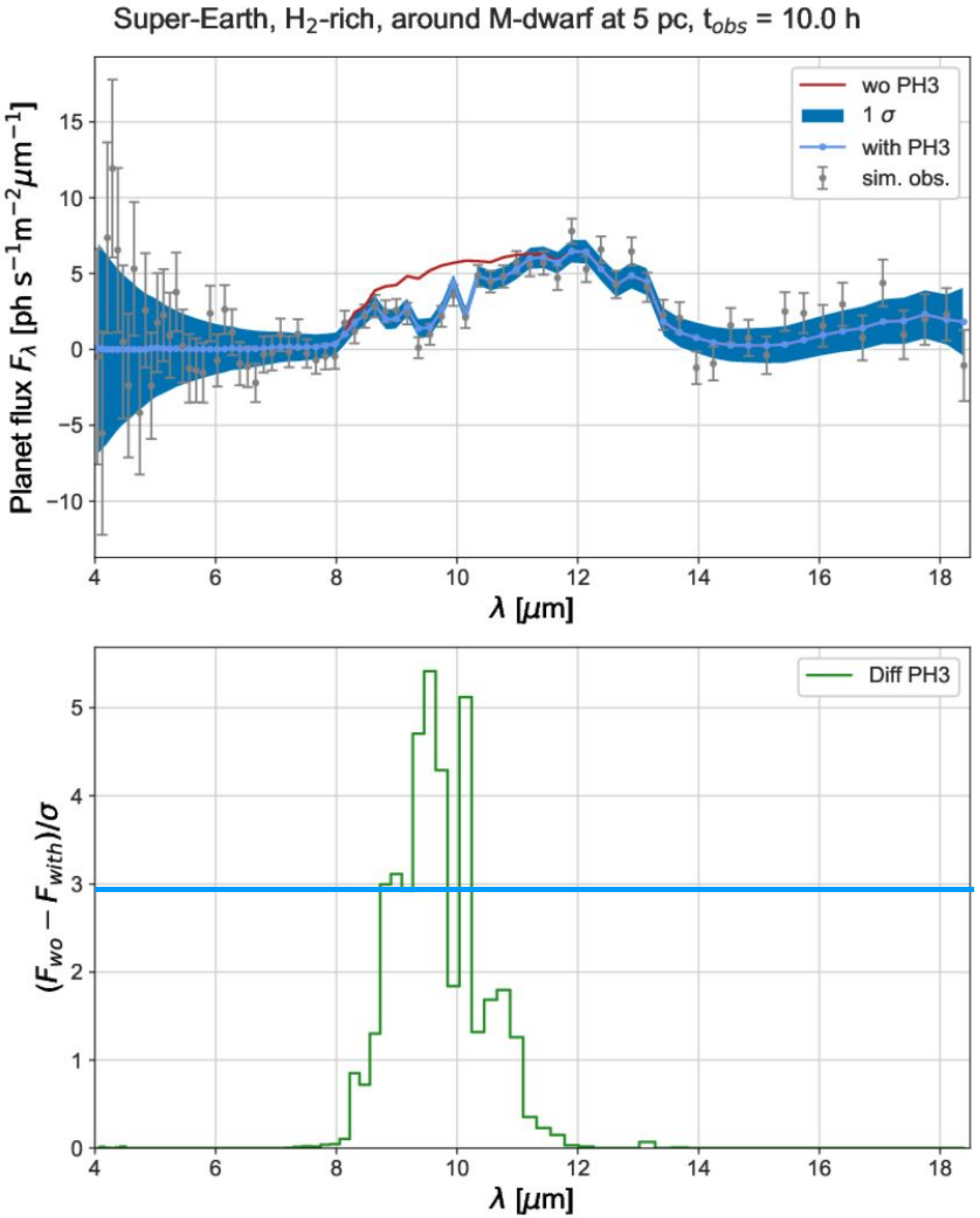
Angerhausen et al. 2023, *Astrobiology*



Phosphine

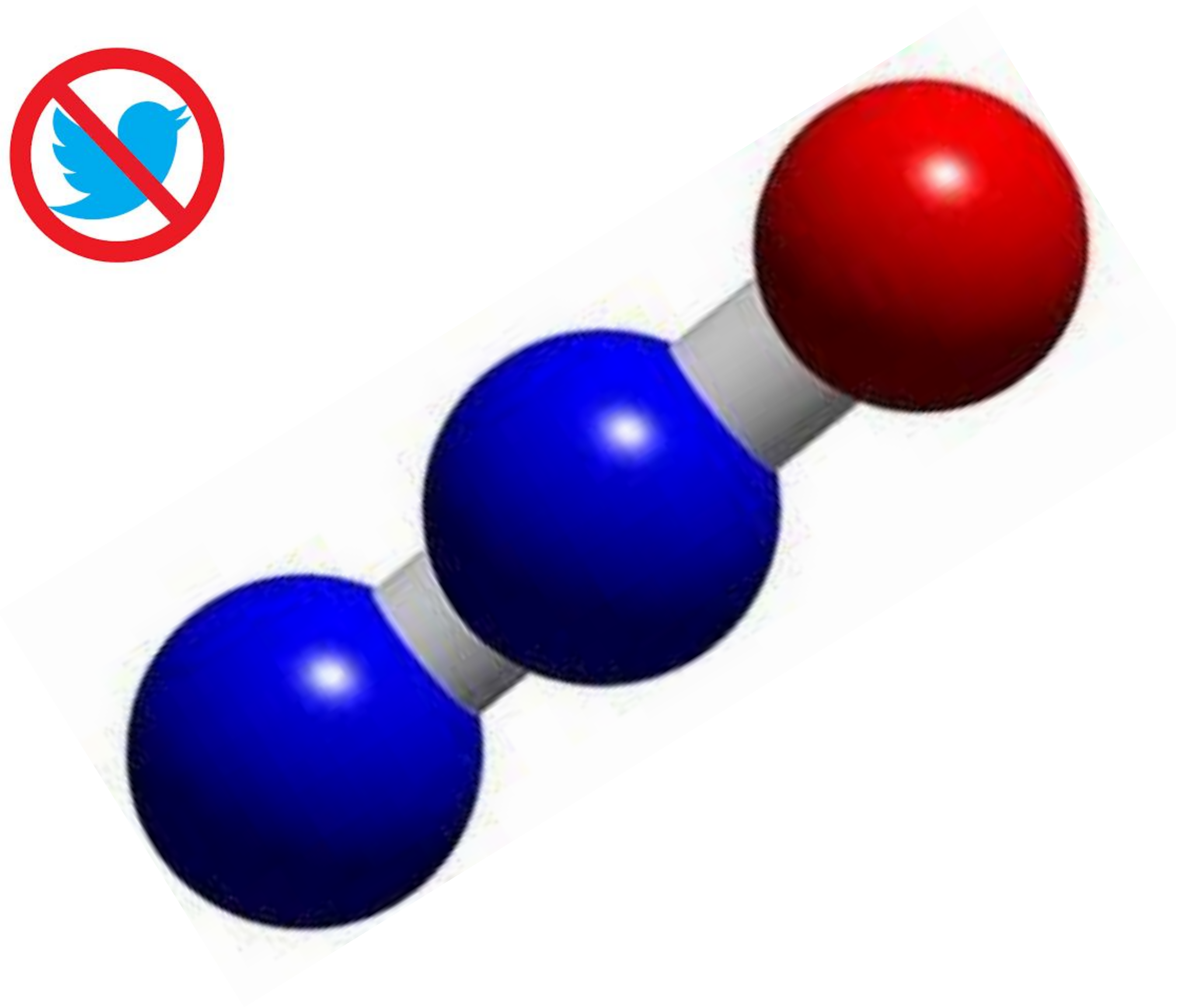
PH3 with LIFE

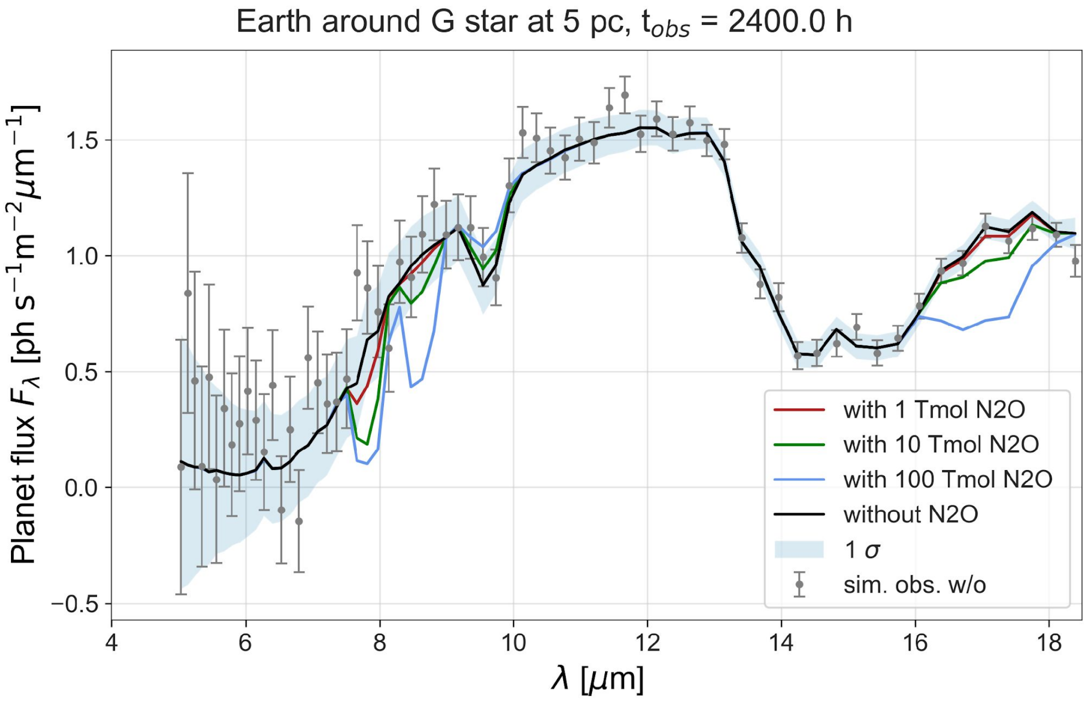


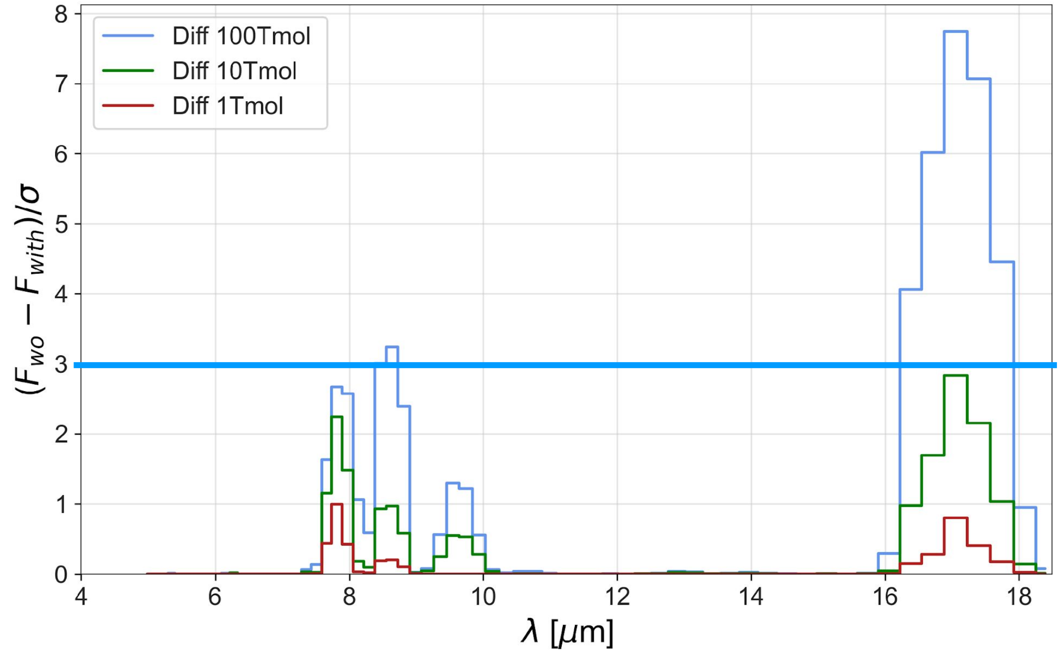


Nitrous Oxide

N2O with LIFE, work in progress, with E.Schwieterman (UCR)

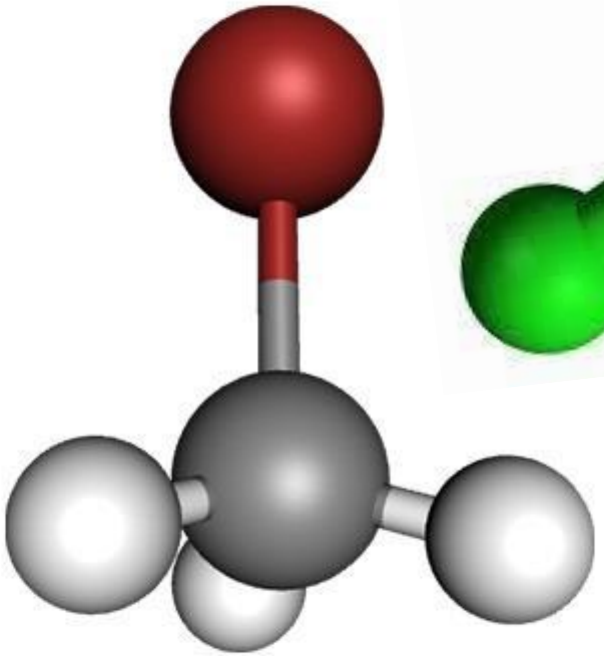


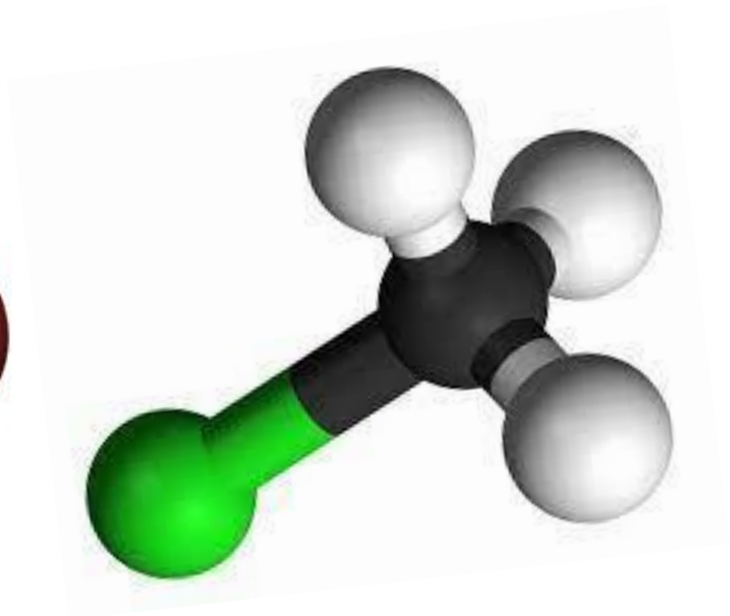


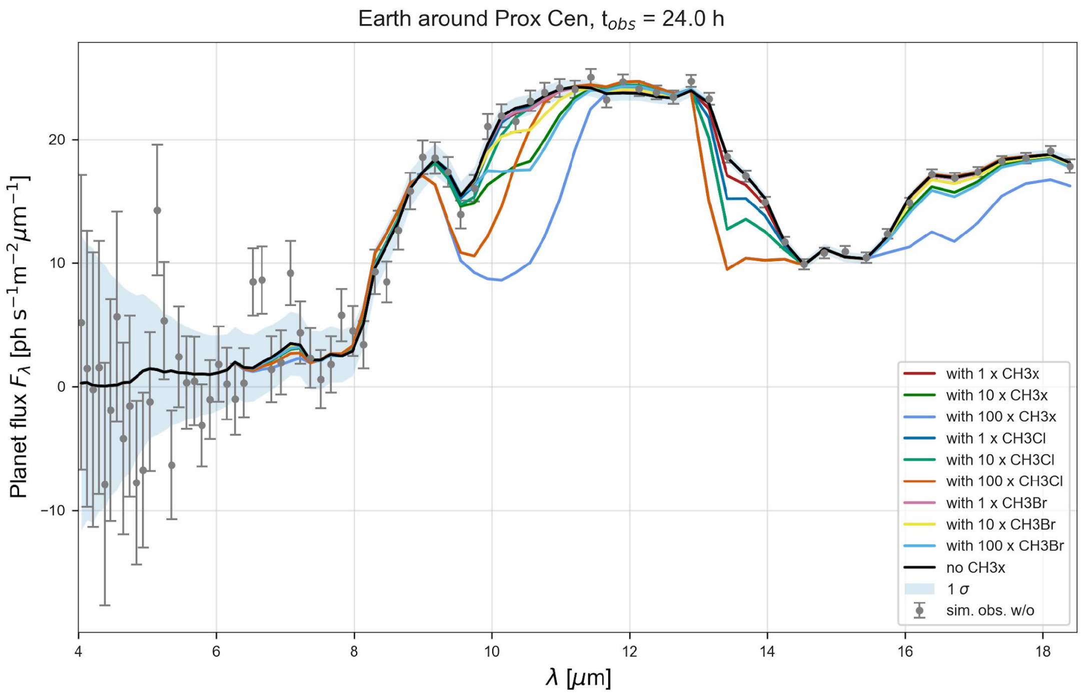


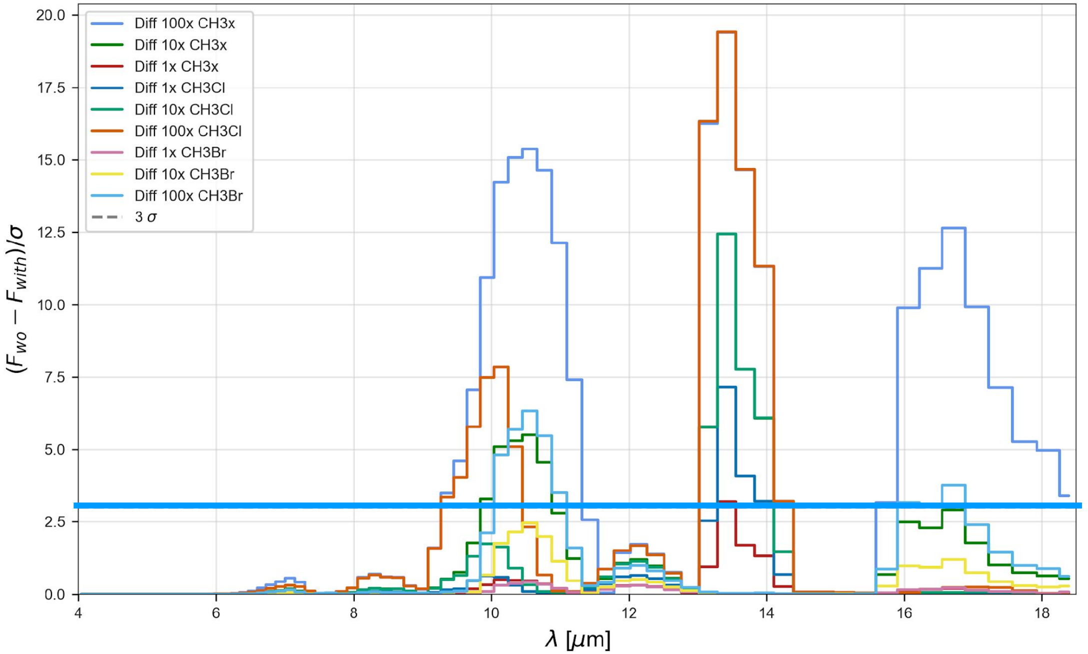
Methylated Halogens

CH3x with LIFE, work in progress



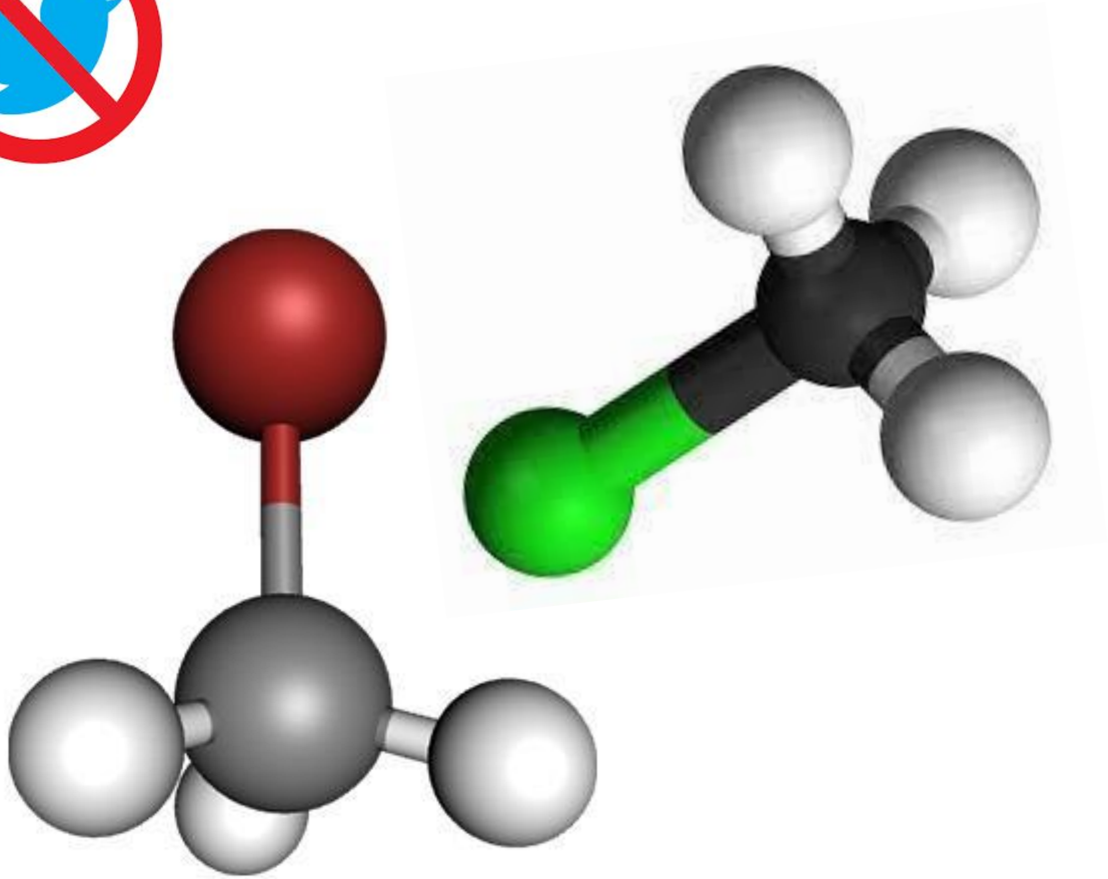


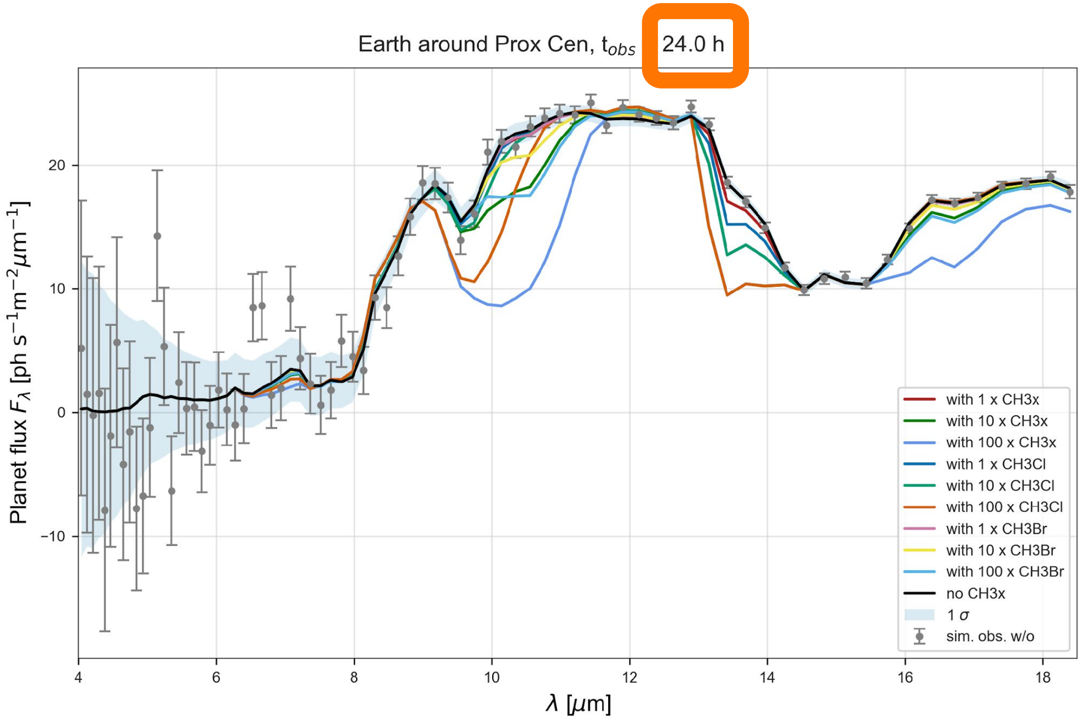


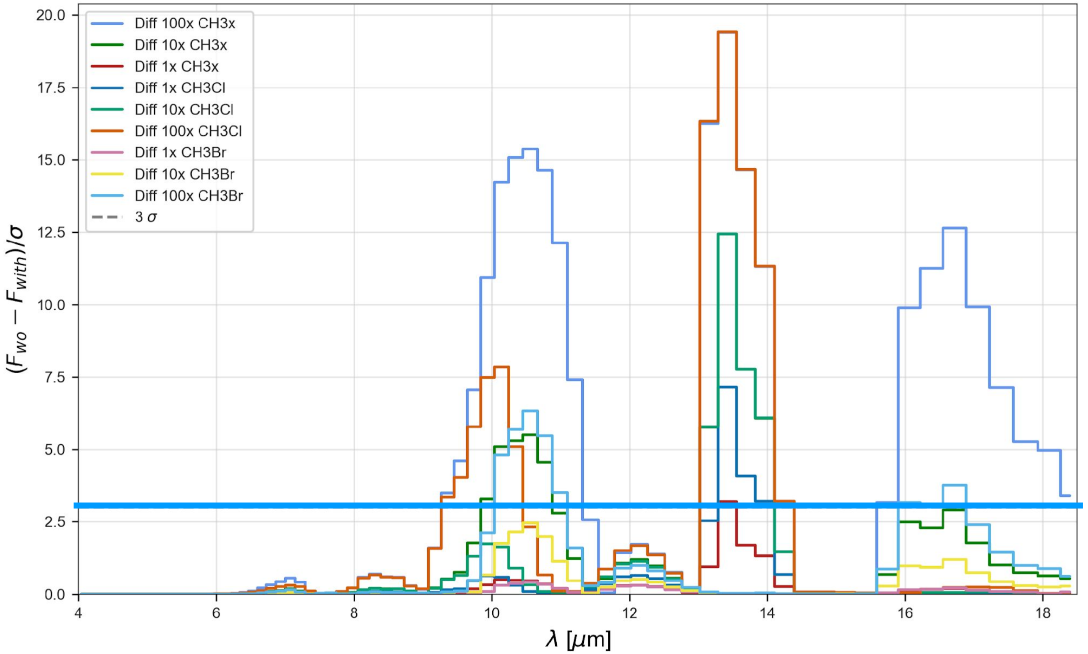


Methylated Halogens

CH3x with LIFE, work in progress

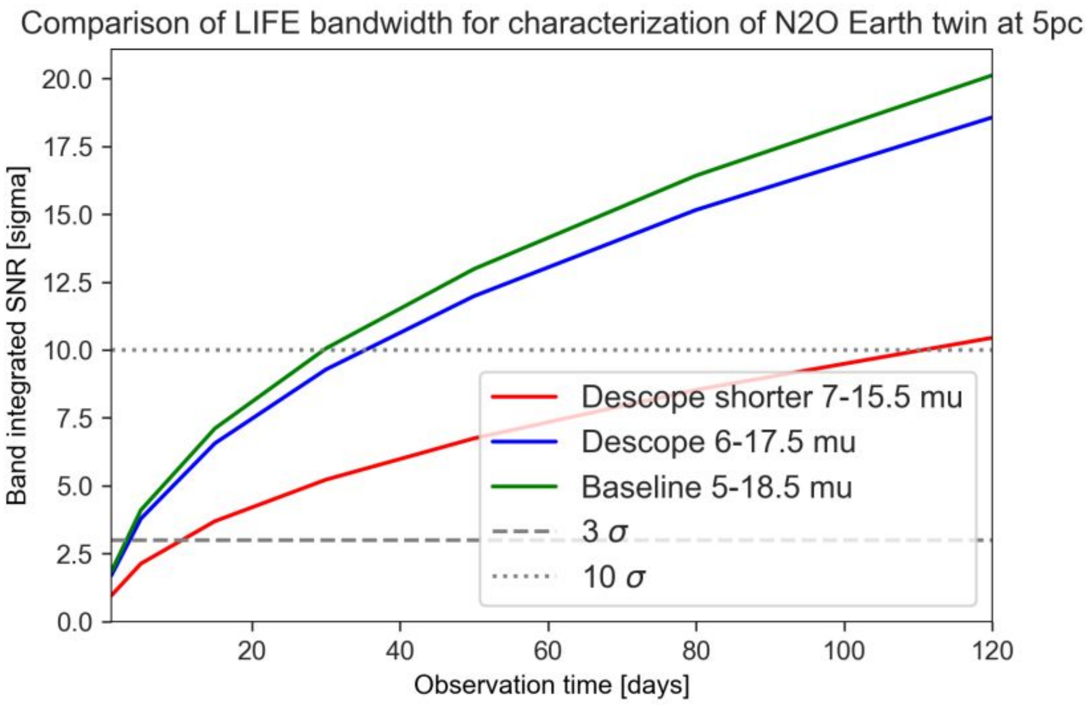


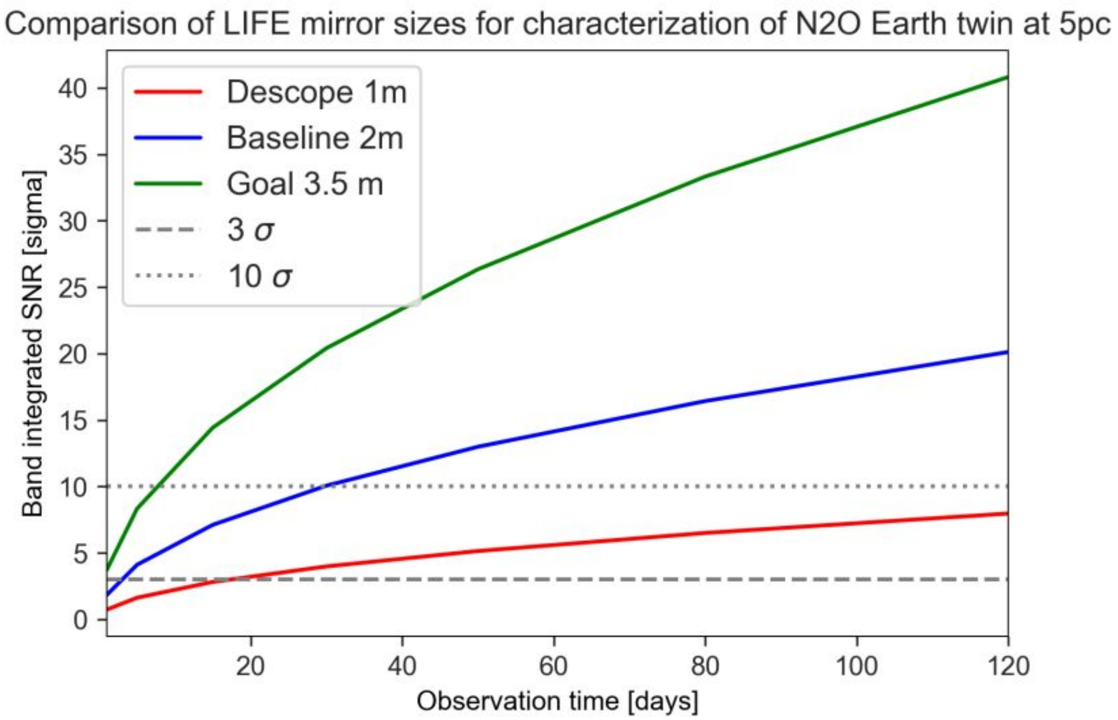




How does it scale? Trade offs

Angerhausen et al. 2023, in rev.





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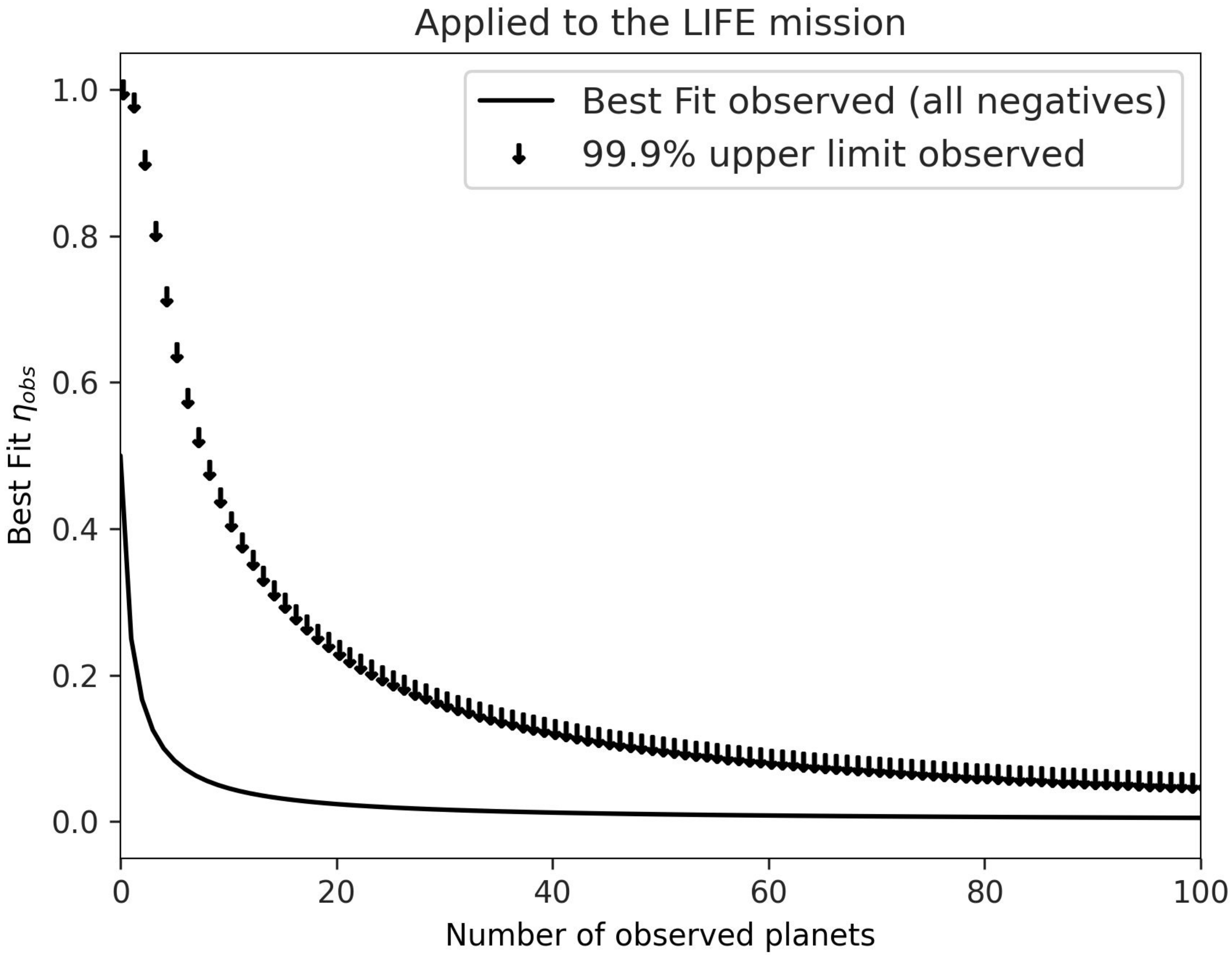
What if we don't find anything?

How significant is a null result?

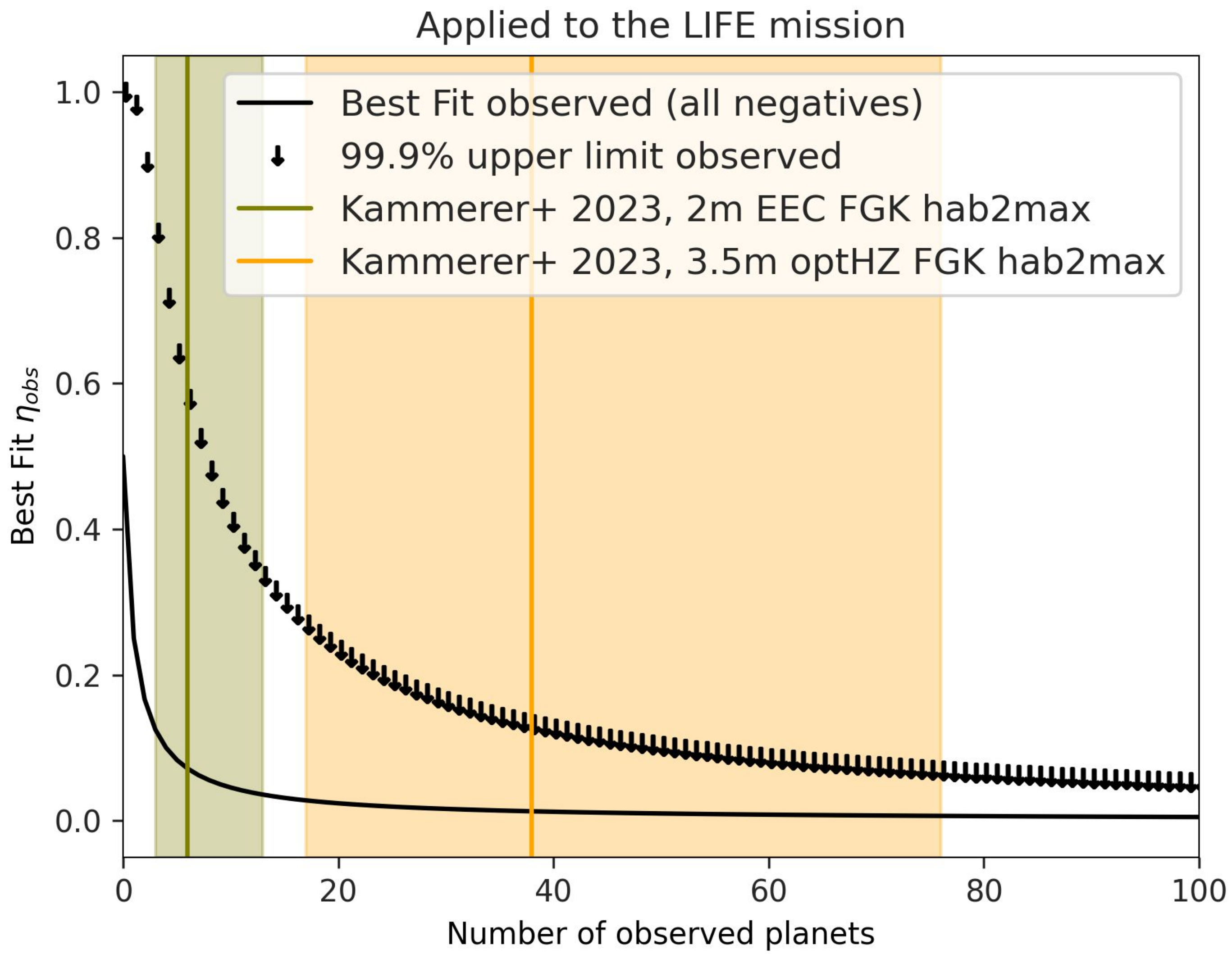
Upper limit on η_life

After observing a survey of N planets, Angerhausen+ 2023, in prep



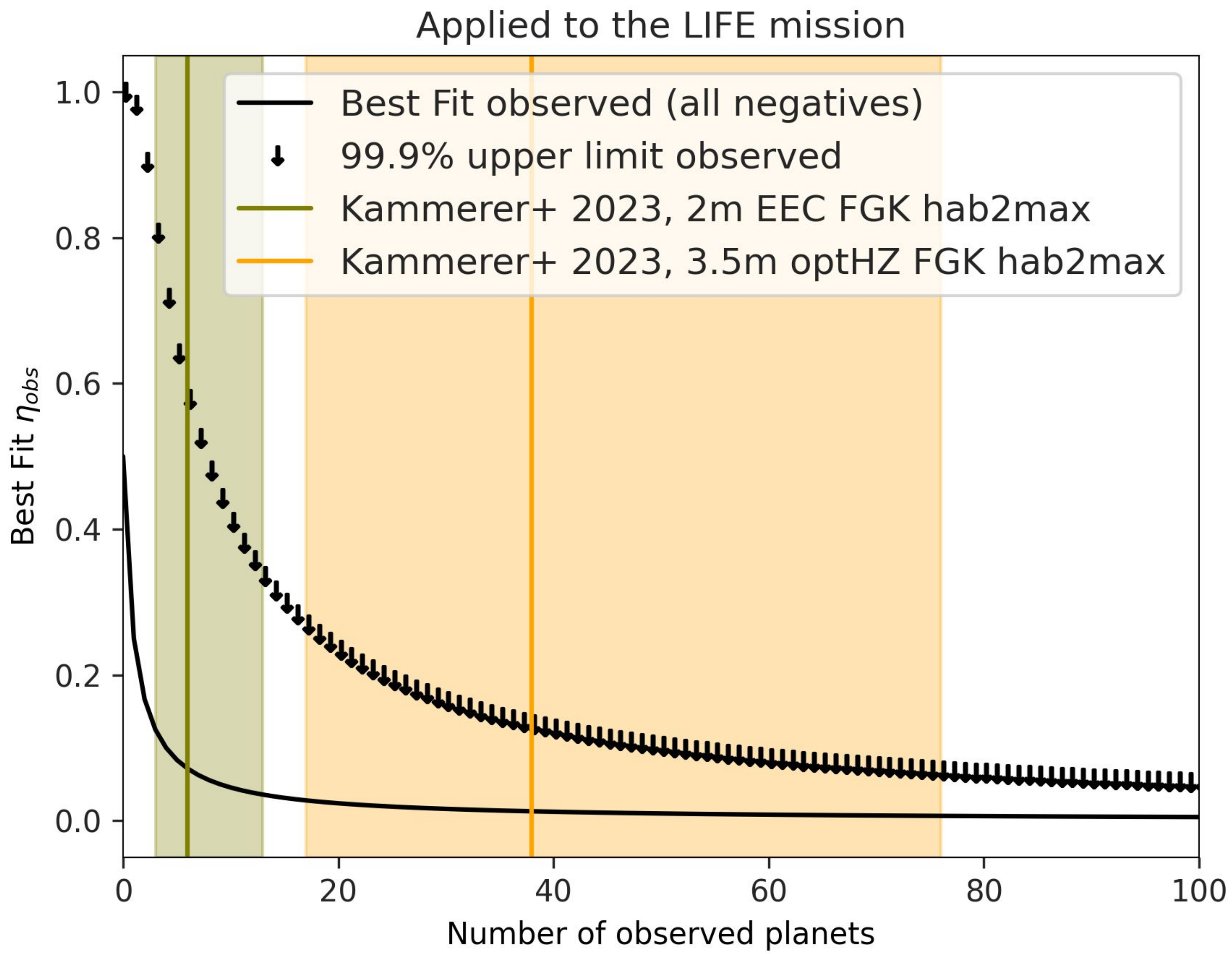
Upper limit on η_life

After observing a survey of N planets, Angerhausen+ 2023, in prep



Upper limit on η_life

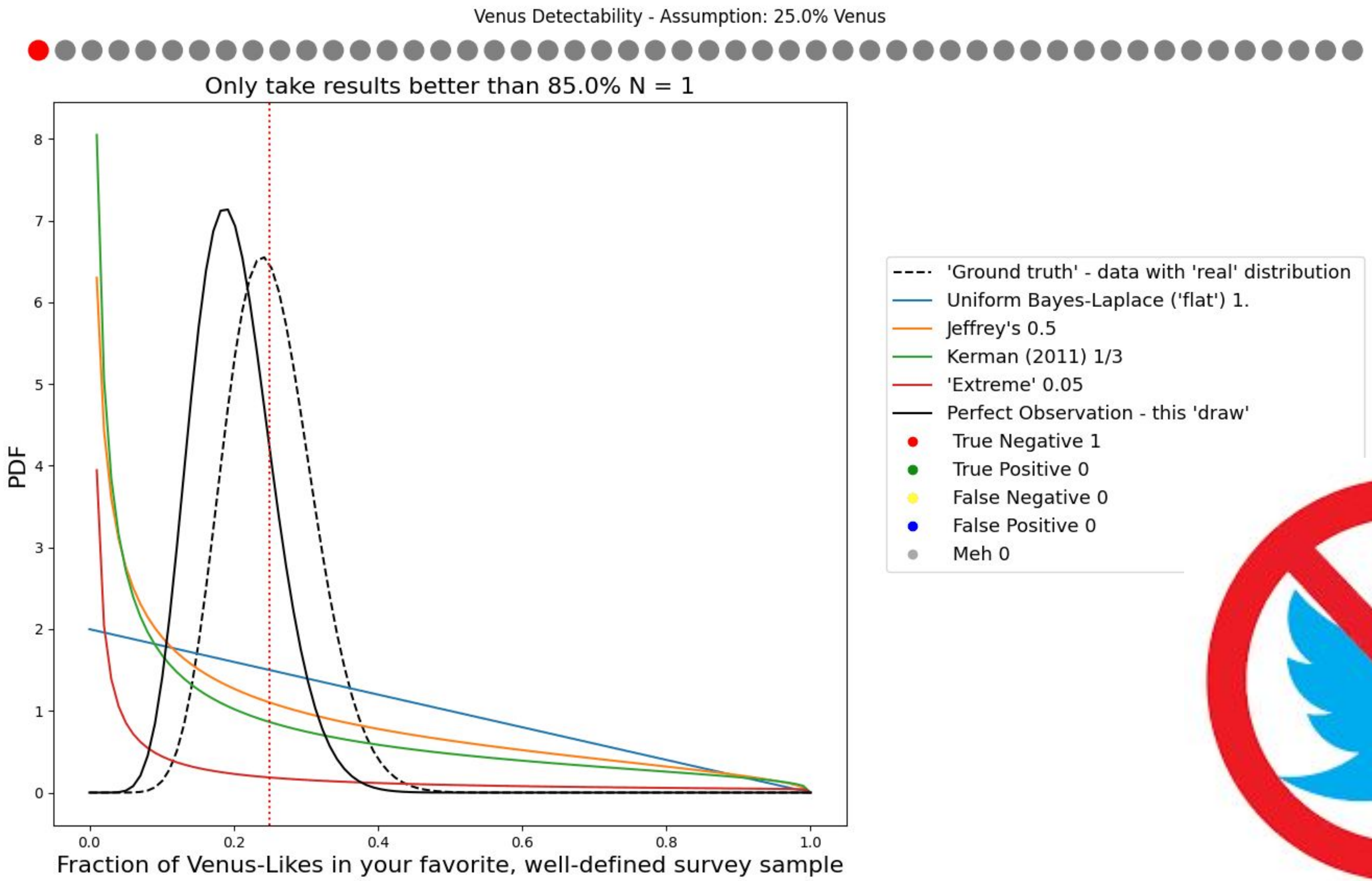
After observing a survey of N planets, Angerhausen+ 2023, in prep



- "Independent" (i.e. diff <5%) of priors
- ~20-80 to constrain to upper limits below 0.2/0.1
- Caveat: assuming 100% confidence in each observation

Statistical Evidence

More generalized for surveys and actual detections

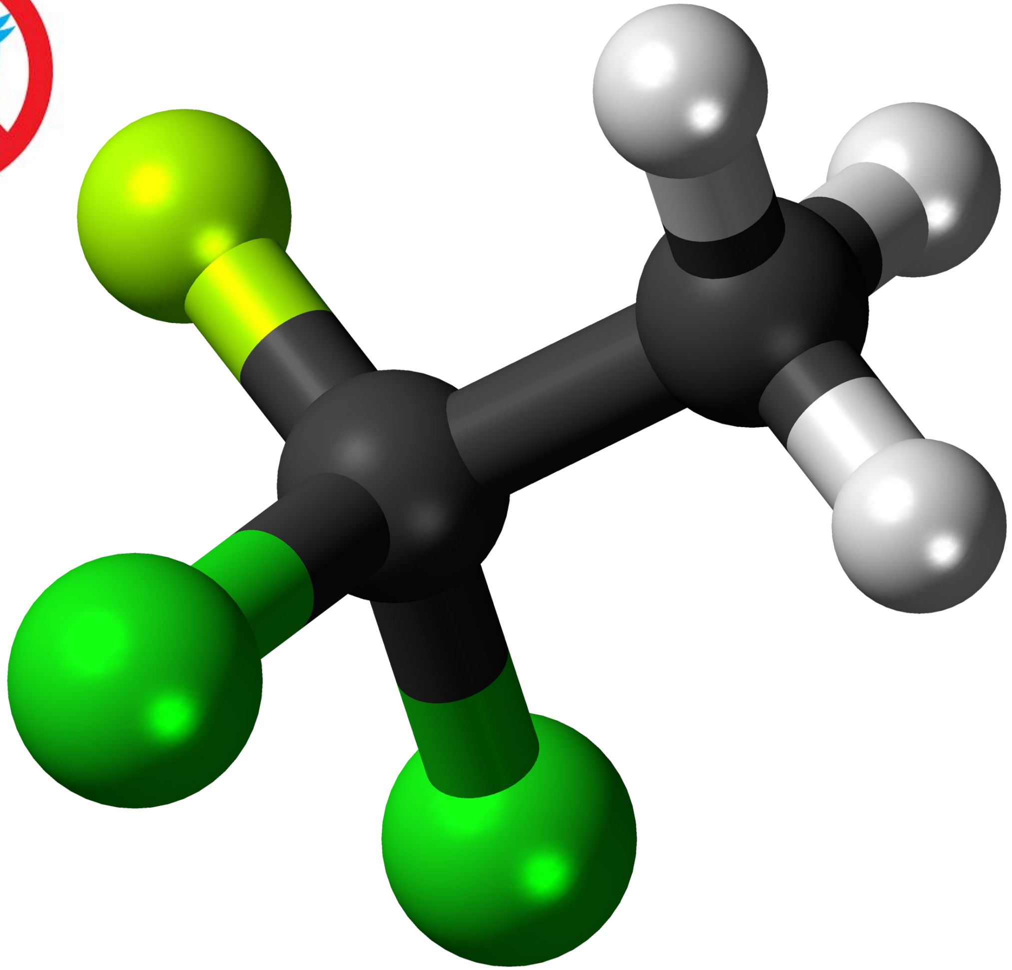


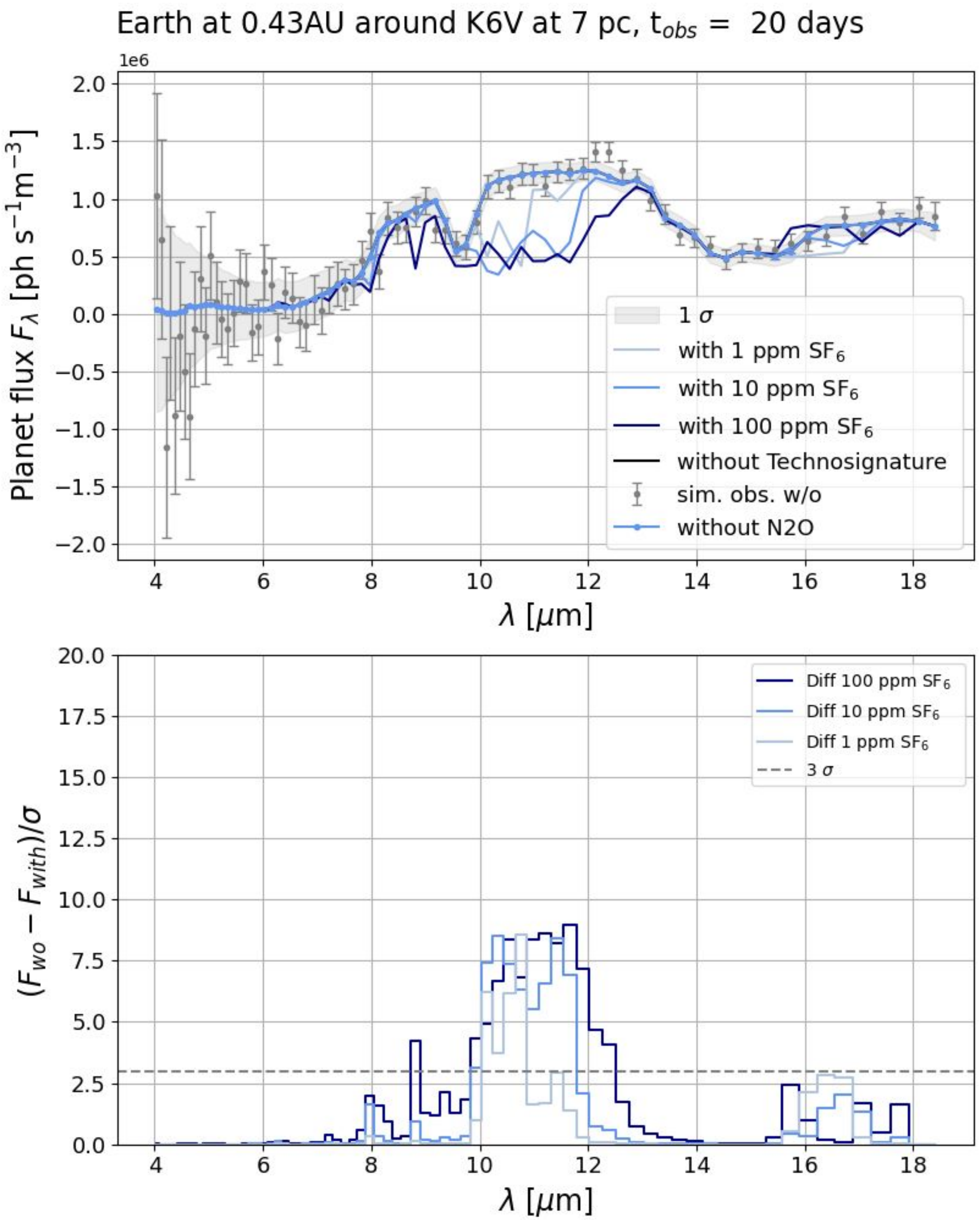
Can it find Aliens?

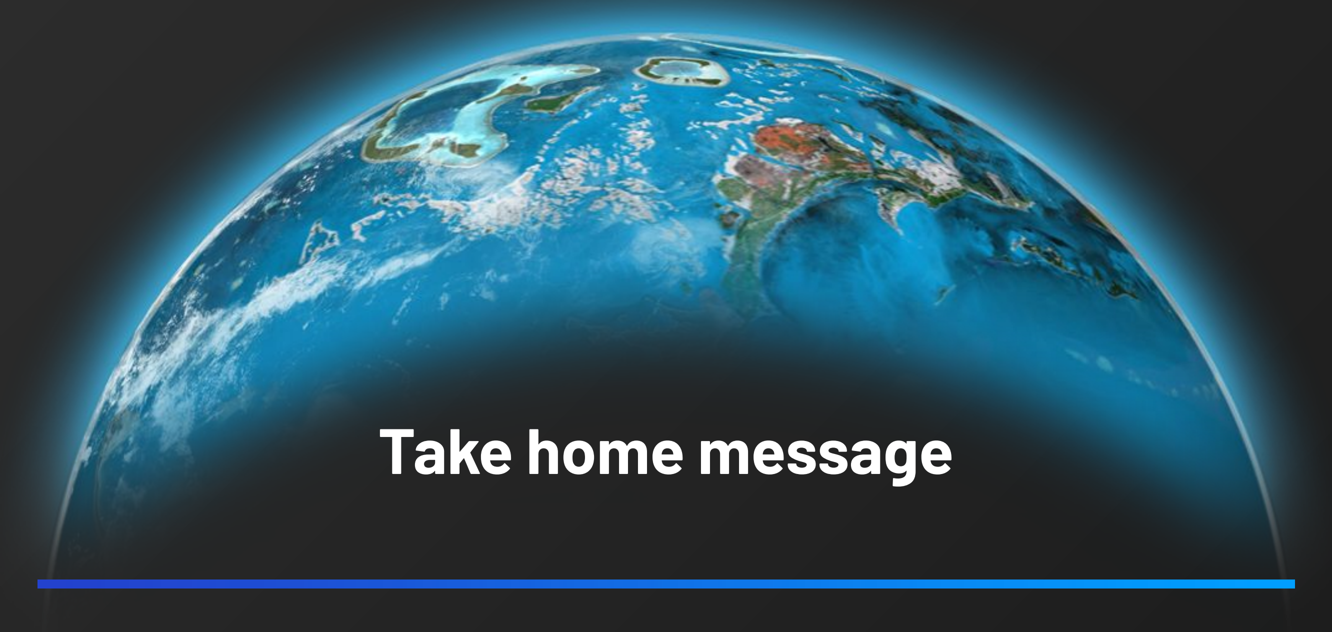
Technosignatures with LIFE

Atmospheric Technosignatures

CFCs, SF6 etc., with R. Kopparapu, J. Haqq Misra, E.Schwietermann



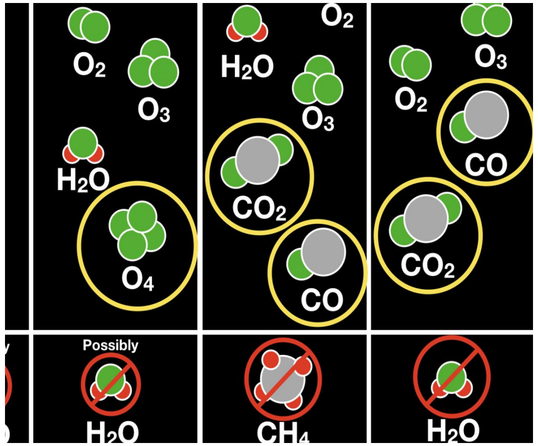


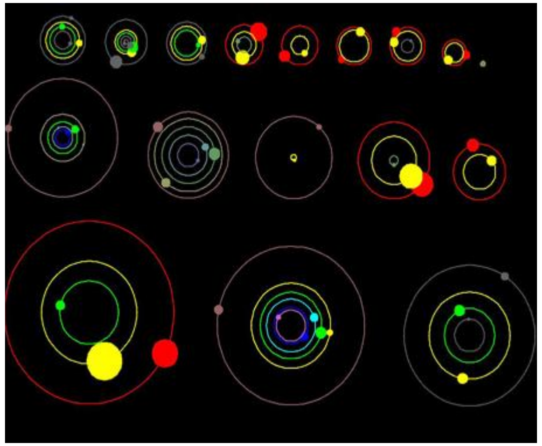


Take home message

Reasons you should love LIFE

What you can do for LIFE





-models of interesting exoplanets or trends >> LIFEsim
-temporal/dynamic changes, e.g. reaction to flares
-from individual planets to demographics

-many other “jobs”: project office, (sub)-WG/project leads, student-/master projects, ...

LIFE take home message

In the next decades we will have the technologies to systematically search for potential biosignatures in our neighbourhood.

LIFE is a European lead initiative and one of the most promising concepts in this field.

If you want to know more:
Check our webpage: **www.life-space-mission.com**
Sign up for newsletter: **life@phys.ethz.ch**
Twitter: **@LIFE_telescope**

LIFE take home message

In the next decades we will have the technologies to systematically search for potential biosignatures in our neighbourhood.

LIFE is a European lead initiative and one of the most promising concepts in this field.

If you want to know more:
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Twitter: **@LIFE_telescope**

Online All-hands meeting
Today & Tomorrow
15-18 CET

LIFE mission concept

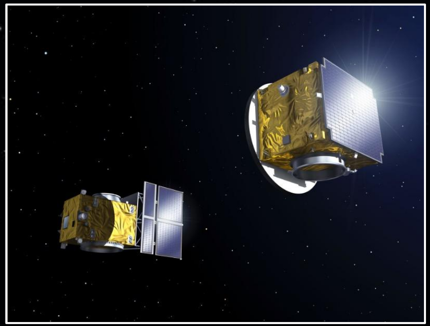
Executive summary

- LIFE is an ambitious space mission with unparalleled scientific capabilities optimized for the **direct detection and atmospheric characterization of hundreds of exoplanets**, dozens of which will be terrestrial, temperate and possibly hospitable to life as we know it
- As a **formation-flying mid-infrared (nulling) interferometer** LIFE is located in L2 and consists of 4 collector spacecraft with 2-3.5 m apertures and a combiner spacecraft
- The observing wavelength range is 4-17.5 μm (requirement) / **3-20 μm** (goal) and the required **spectral resolution** is 35 (req.) / **50** (goal)
- The total **mission lifetime is 5-6 years** (requirement)
  - **Search phase (2.5 years)**: detection of hundreds of planets
  - **Characterization phase (up to 3.5 years)**: detailed investigation of atmospheric diversity and search for biosignatures
  - Other science (up to 20%; tbc.)
- Significant progress has been made in relevant key technologies since mid-2000s (incl. ESA's Proba-3 mission, Herschel, and JWST/MIRI) and additional R&D is currently ongoing

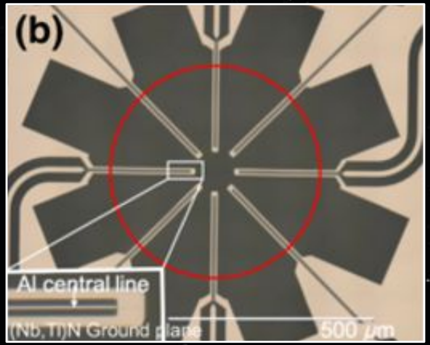
LIFE
LARGE INTERFEROMETER FOR EXOPLANETS

Backup Slides

Technology (gaps)

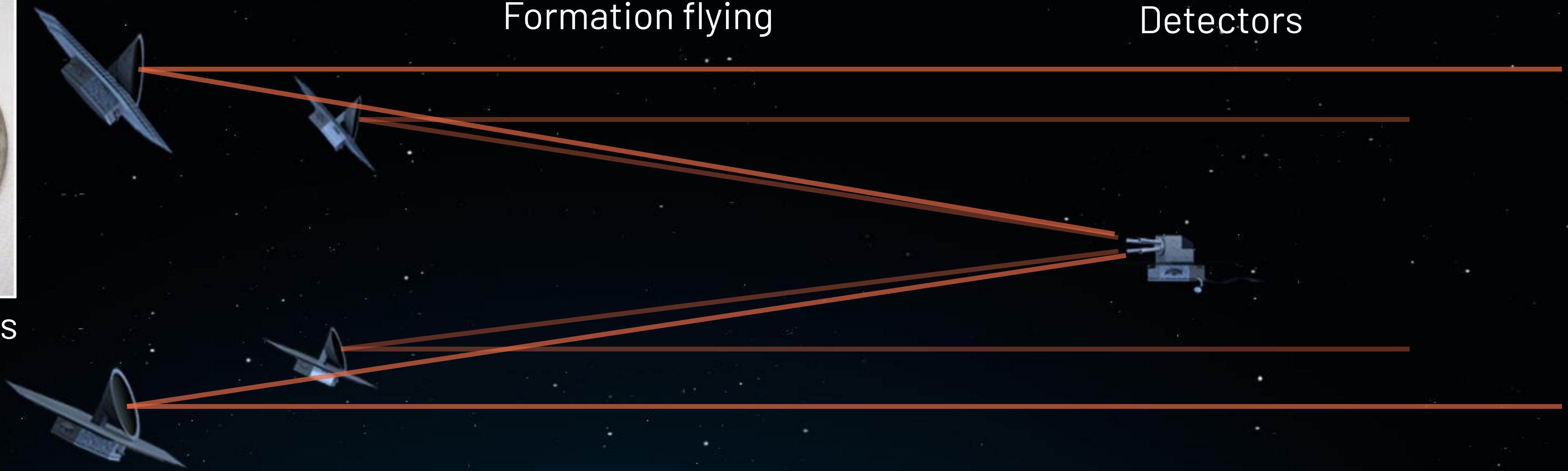


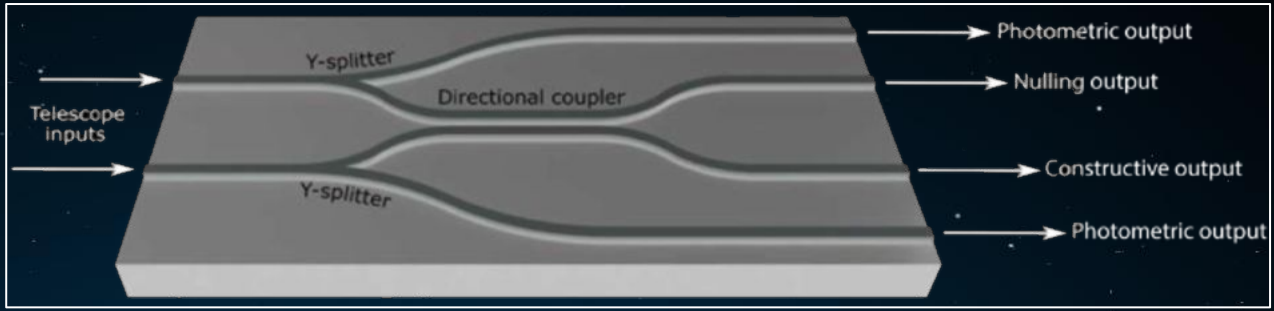
Formation flying



Detectors

Cryogenic components



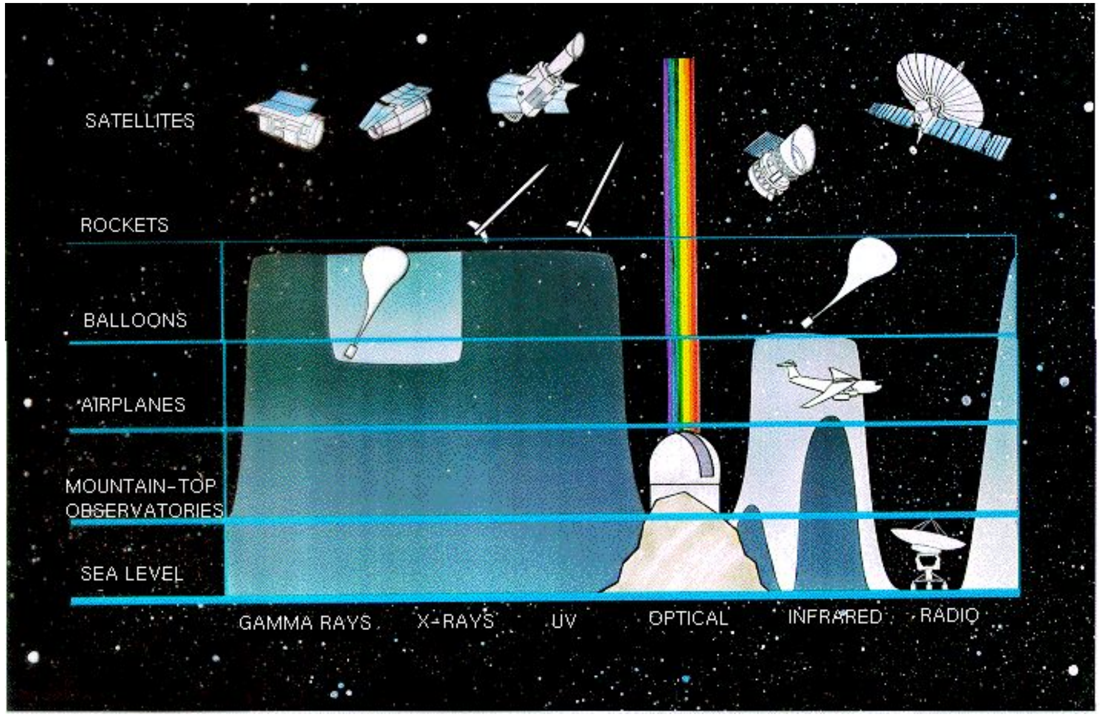


High sensitivity beam combination

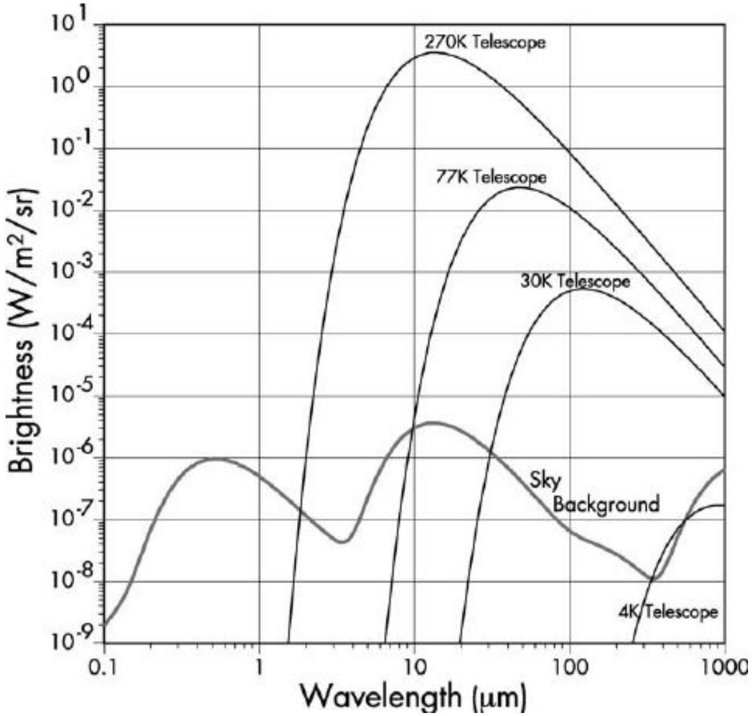
Why Space?

Why do we need a space mission?

(for MIR)



Atmospheric transmission



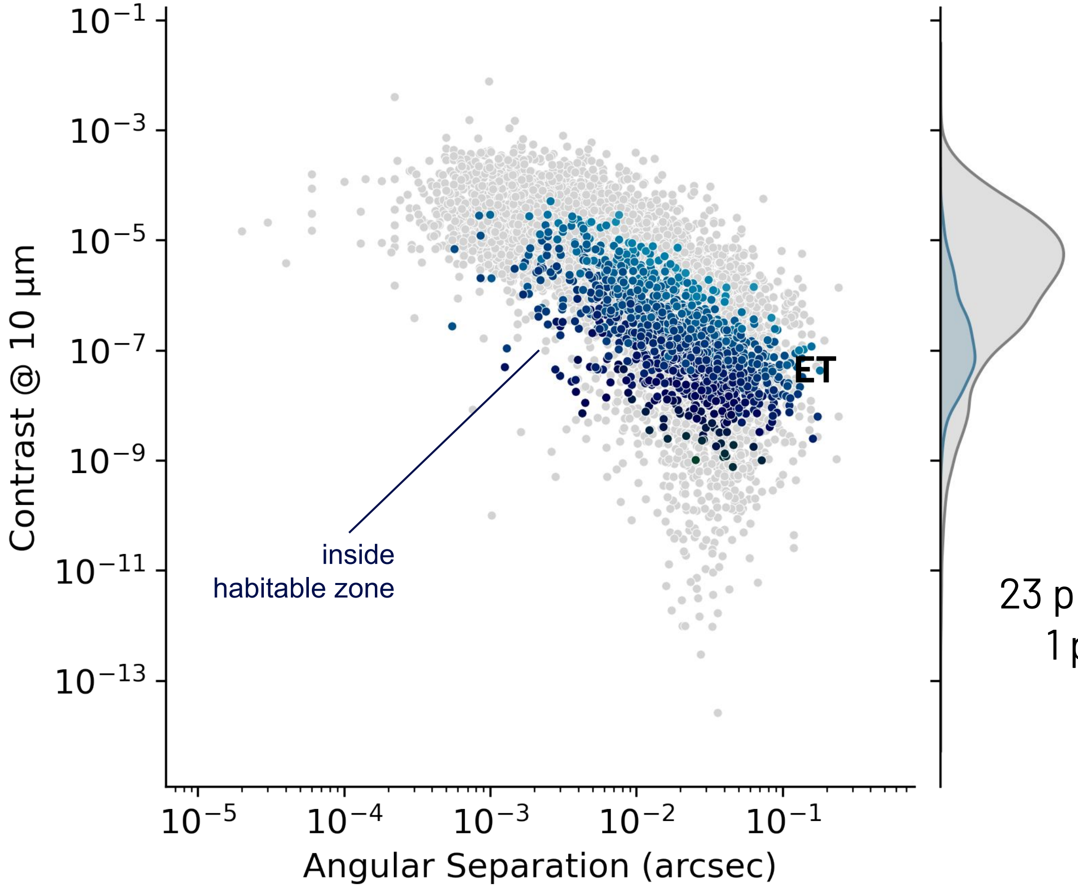
Background

LIFE
LARGE INTERFEROMETER FOR EXOPLANETS

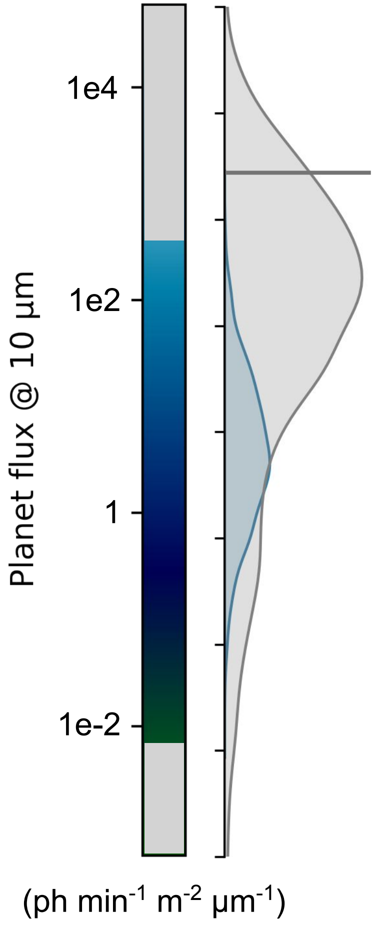
Why Nulling Interferometry?

And how does it work?

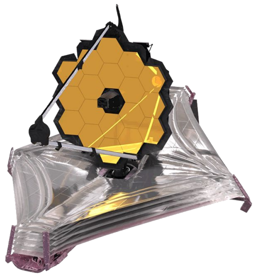
$1.8 \cdot 10^9$ ph min^{-1} m^{-2} µm^{-1}
Subaru (GJ 504 b) in L'
in 1.5h



Earth-twin at 10 pc
23 ph min^{-1} m^{-2} µm^{-1} @ 10 µm
1 ph min^{-1} m^{-2} µm^{-1} @ 5 µm



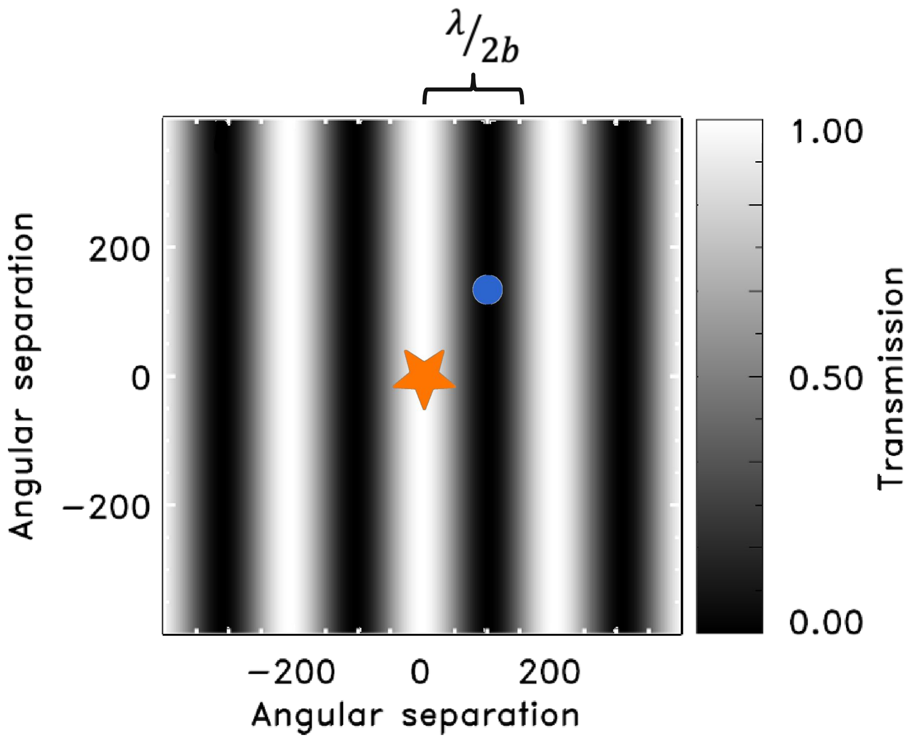
$4 \cdot 10^3$ ph min^{-1} m^{-2} µm^{-1}
JWST in 3h



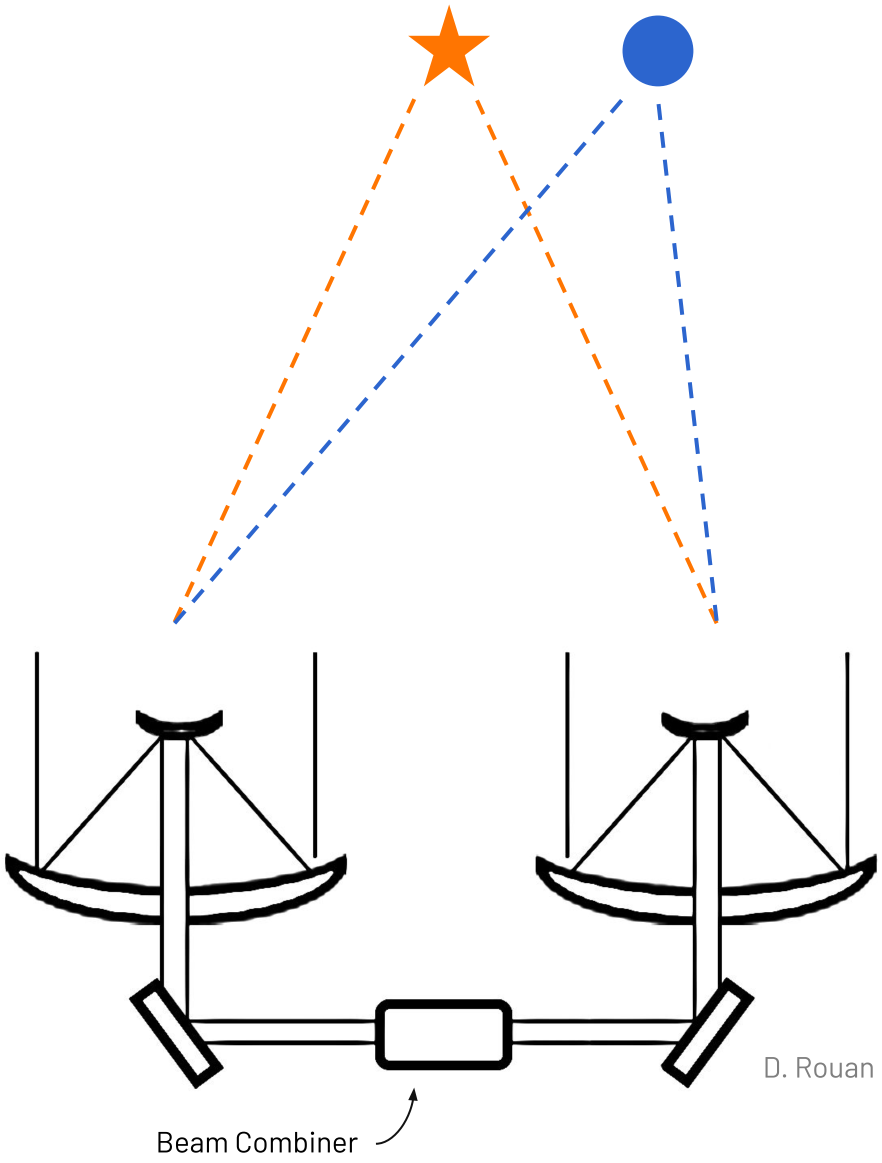
Images: ESO, NASA Wikipedia: SiOwl,, Denys

Nulling Interferometry

in a Nutshell

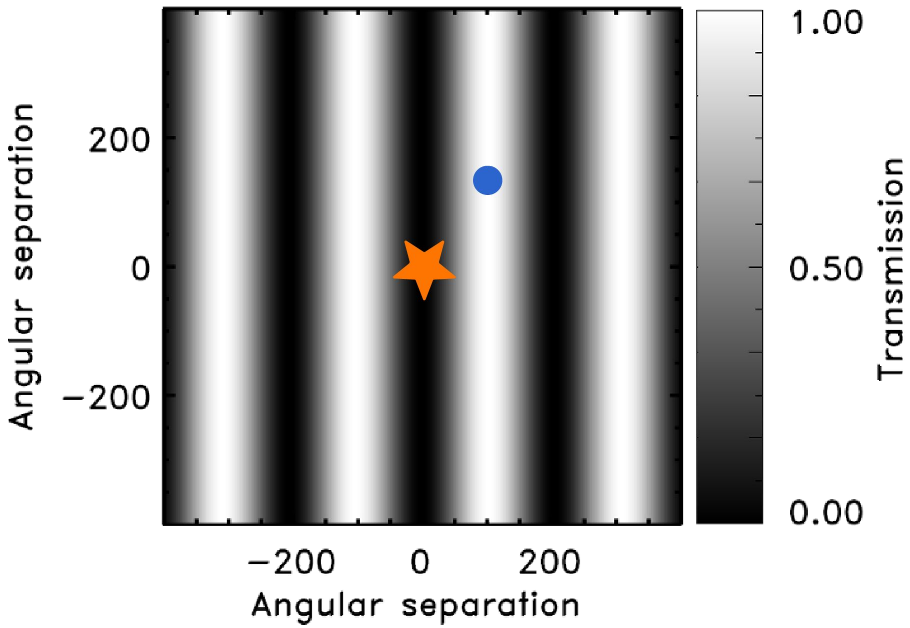


Imaging Interferometer

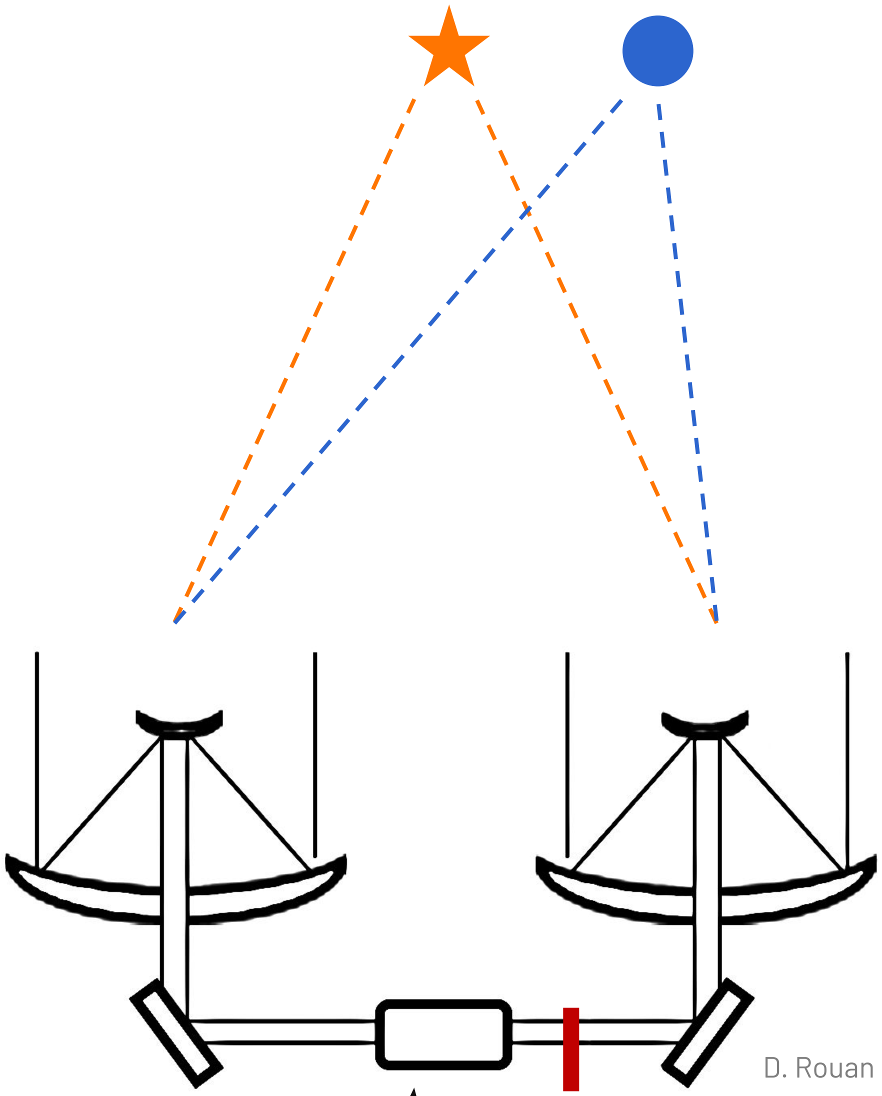


Nulling Interferometry

in a Nutshell

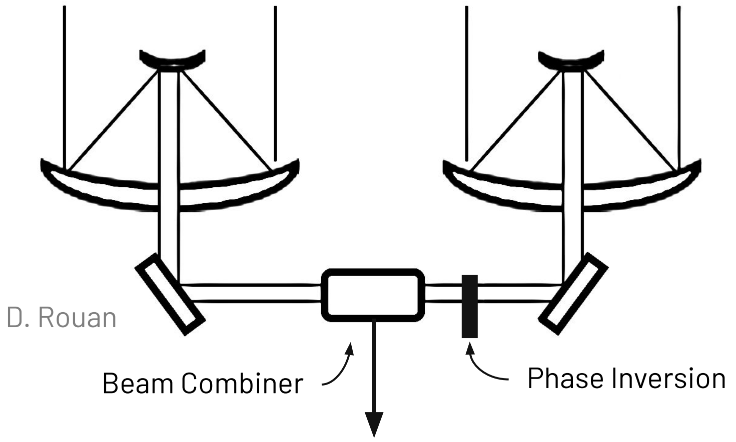


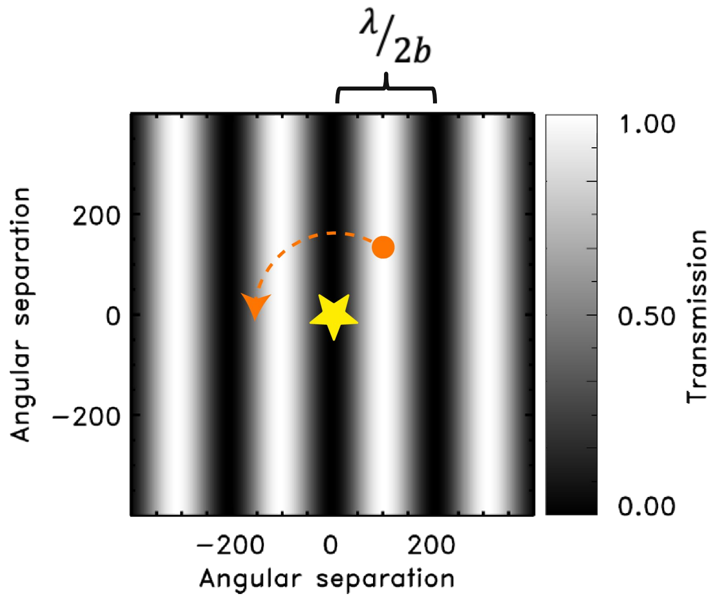
Nulling Interferometer

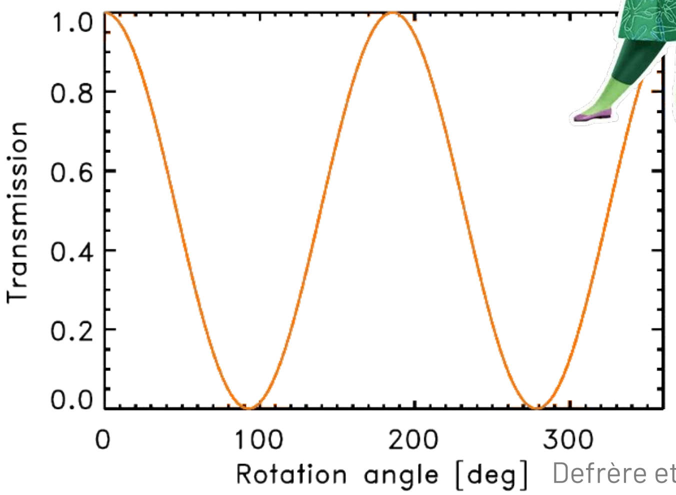


Nulling Interferometry Level 2

in a Nutshell







Defrère et al. (2018)

Starlight Rejection

- 10^{-4} with single Bracewell
- Increased by more apertures and post-processing

Angular Resolution

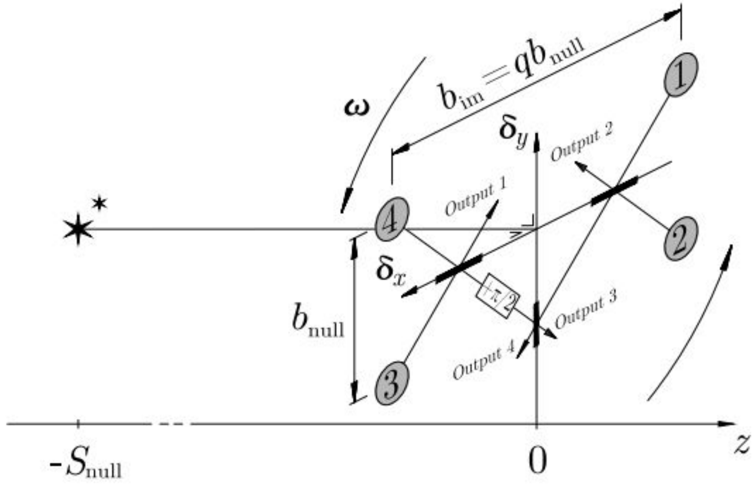
- Scales with baseline
- Reduces rejection

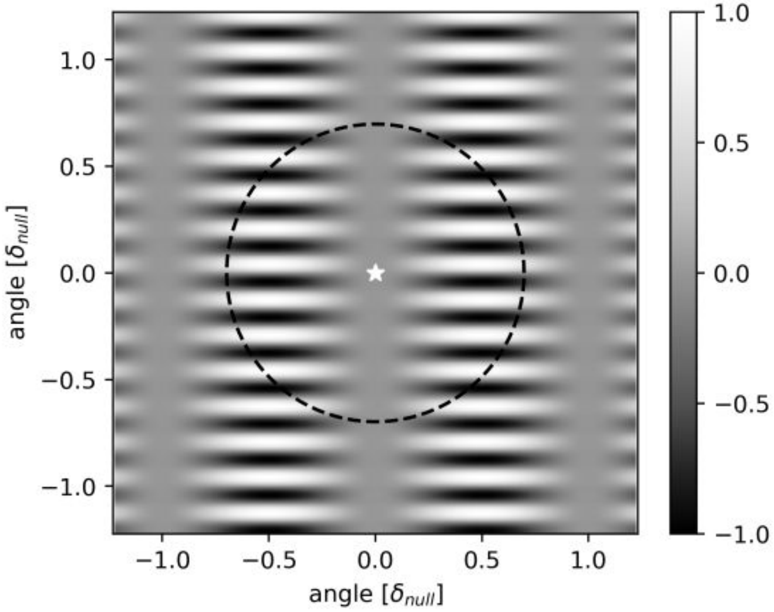
Synthesis Interferometry

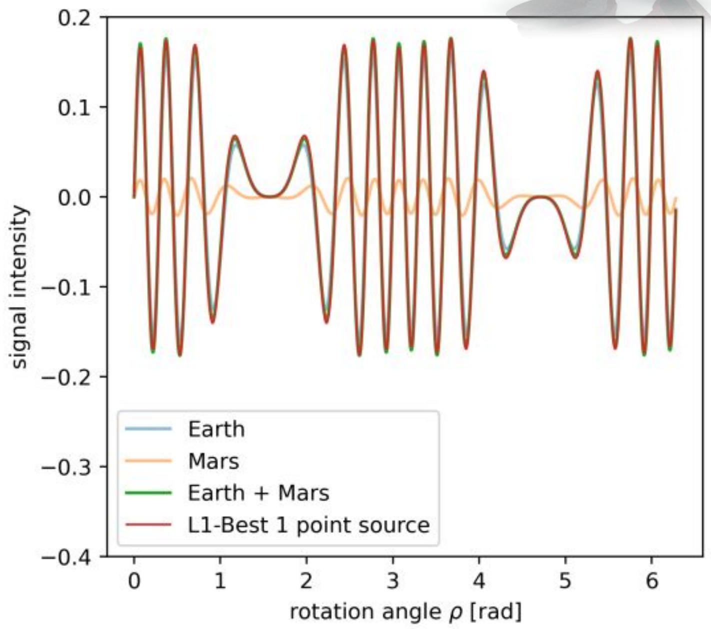
- Single spatial mode
- Deconvolve with modulation to identify source

Nulling Interferometry Level 3

in a Nutshell







Nulling Interferometry Level 4

Adding more apertures

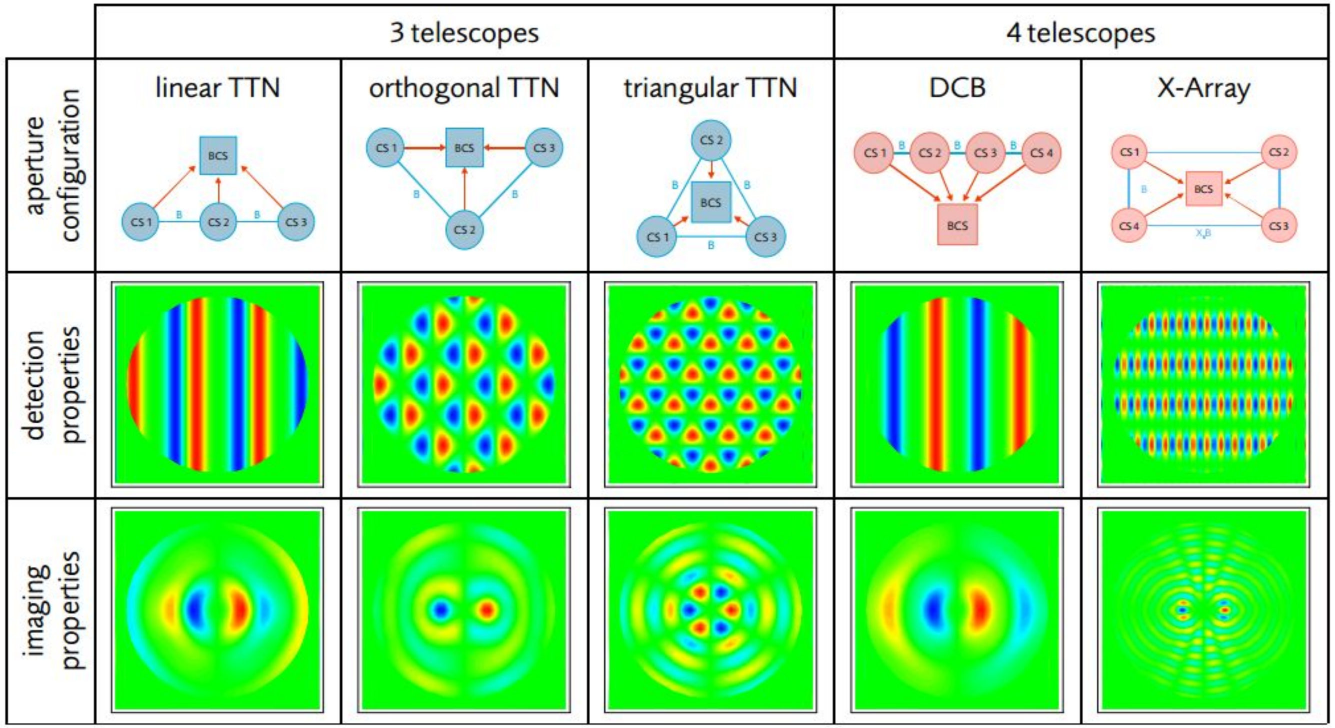
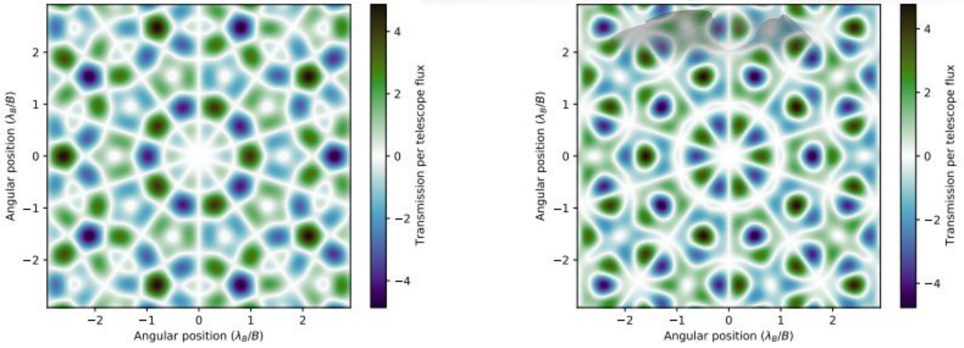


Fig. 4-1 Detection and imaging properties of three and four telescope configurations. The first row shows the aperture configuration, the second row the receive characteristic of the instrument after applying phase chopping and the third row the correlation map for image reconstruction.



(a) Kernel 1 (b) Kernel 2

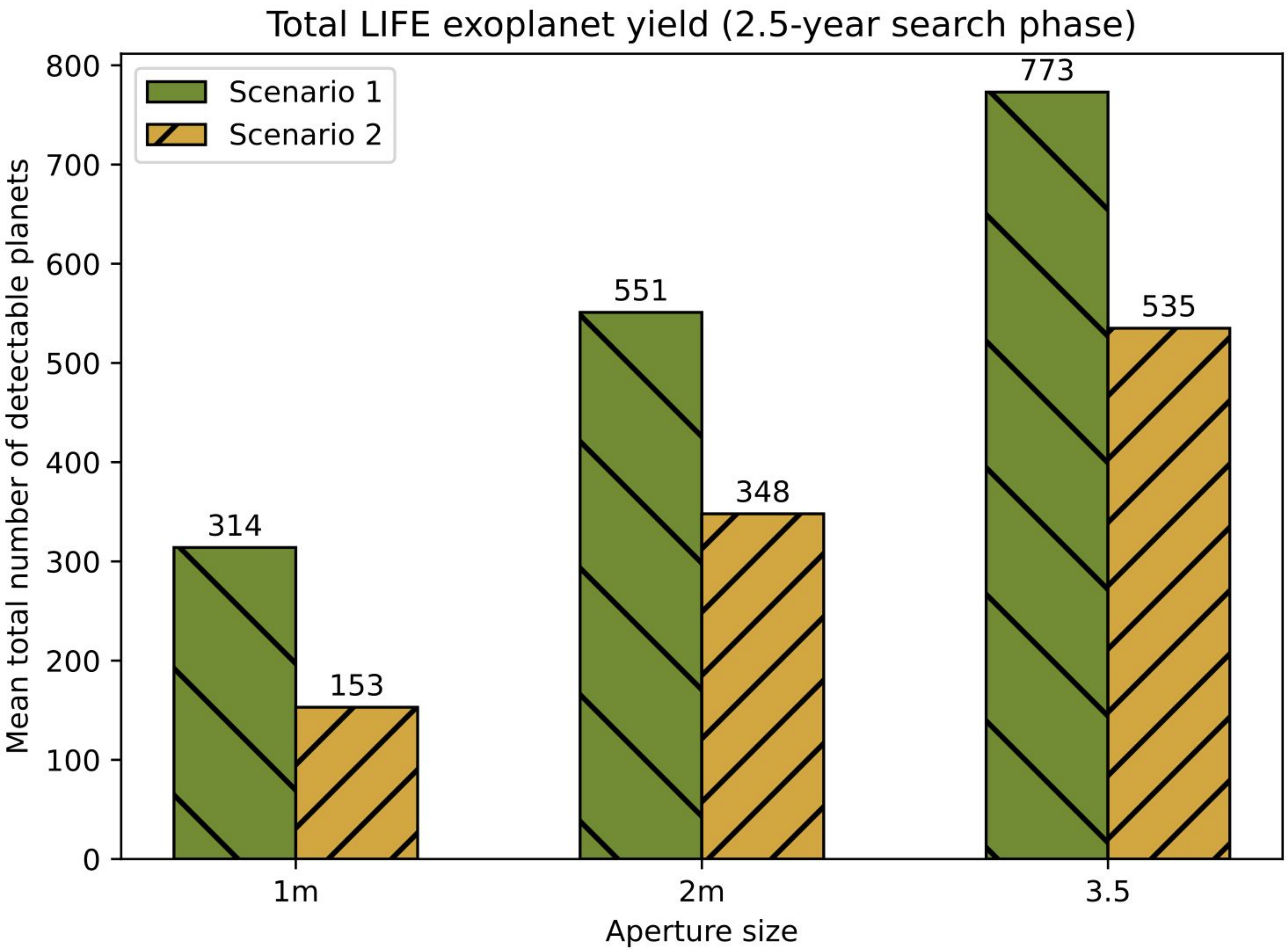
Fig. 8: Response maps of the Kernel-5 kernel nulls, given in units of λ_B/B.

DARWIN system assessment study - EADS Astrium

Hansen et al. 2022, LIFE IV

Exoplanet Detection Yield

- Monte Carlo simulations based on Kepler statistics (SAG13) and stars within ~20 pc
- Assuming
  - 2.5 years total search phase
  - 5% total instrument throughput
  - 10 h slew between targets
  - 20% general overhead

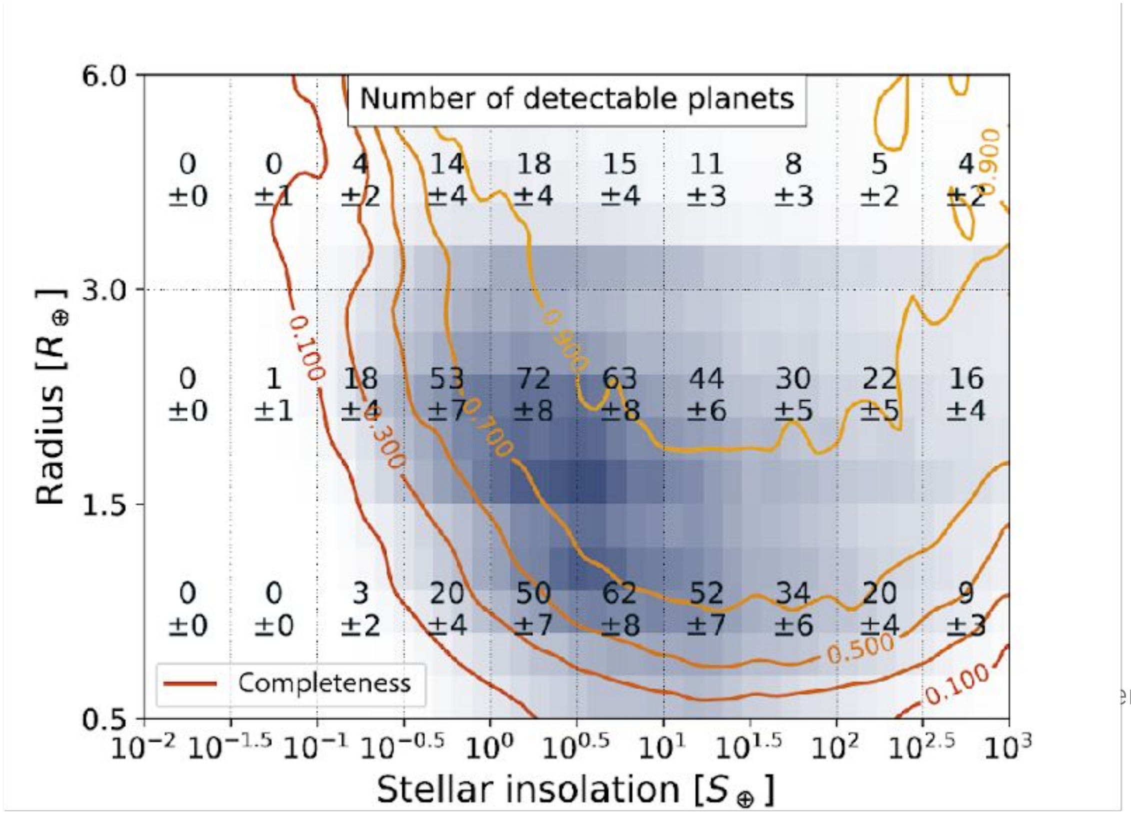


Exoplanet yield predictions

Parameter space coverage

Simulation Parameters	
Number of collector spacecraft	4
Mirror diameter	2 m
Baseline length	10 – 600 m
Wavelength coverage	4 – 18.5 μm
Mission duration	2.5 yrs (search phase) + 2.5 yrs (char. phase)
Noise Sources	Astrophysical only (star, exo- and local-zodiacal dust)

Total number of detectable exoplanets: **550**



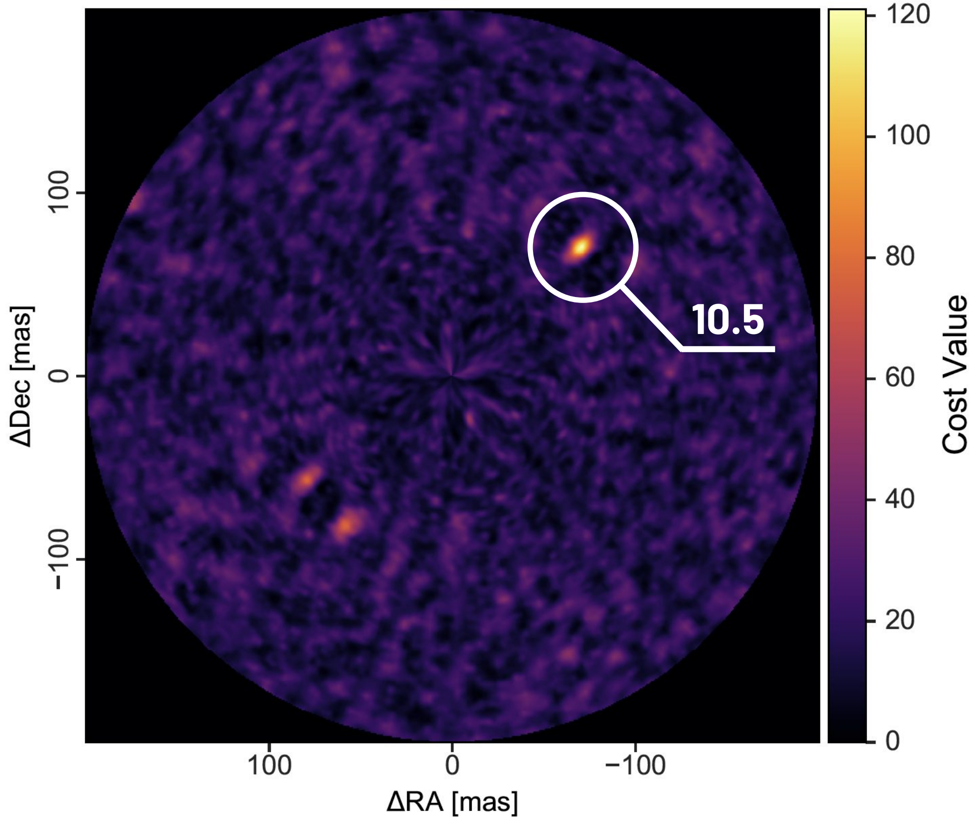
Completeness = Pr(detection | target observed)

Exoplanet yield predictions

A question of sensitivity?

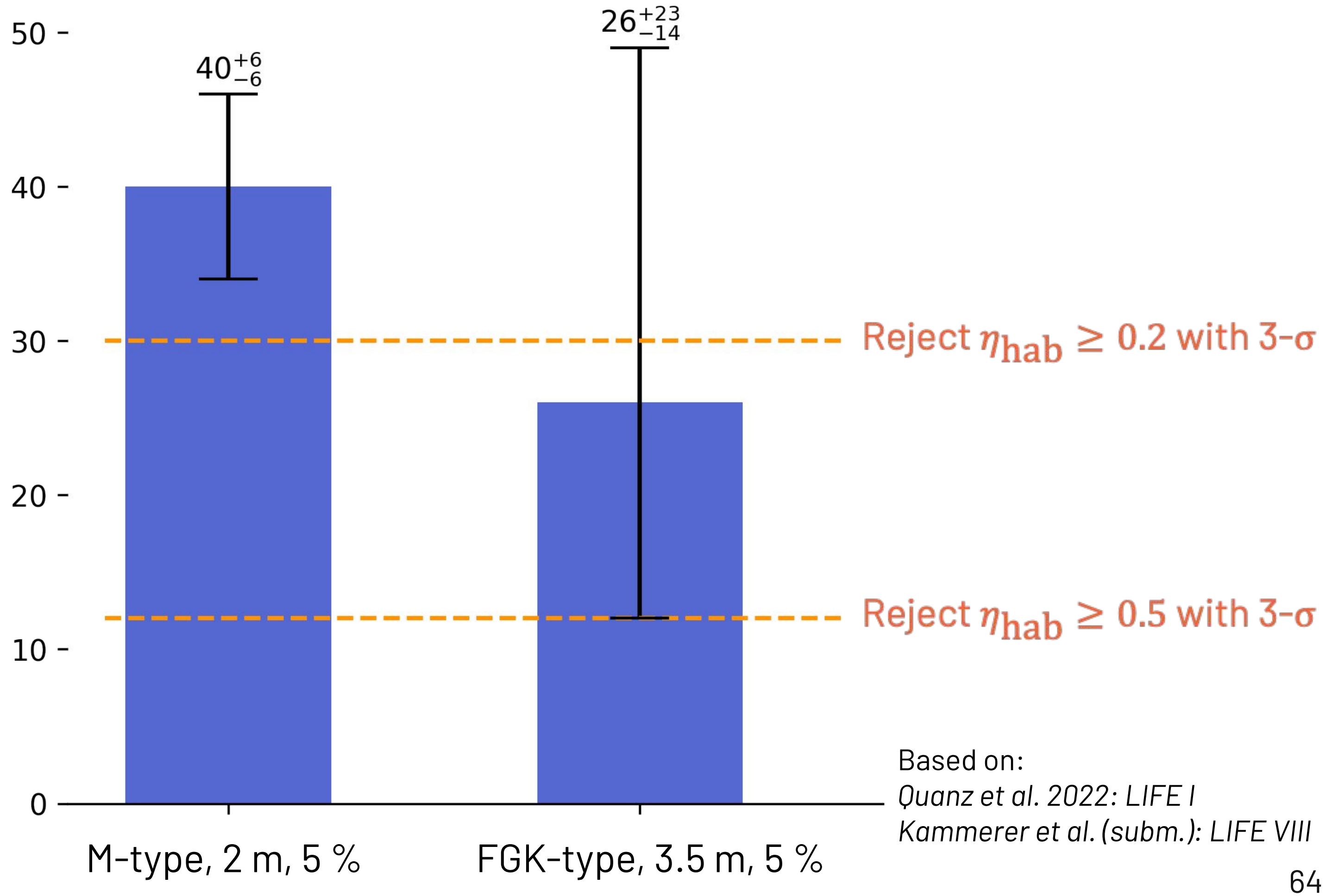
Signal extraction

Dannert & Ottiger et al. 2022: LIFE II



For Earth-analogue at 10 pc,
56 h integration time

Detected number of planets in the eHZ



Based on:
Quanz et al. 2022: LIFE I
Kammerer et al. (subm.): LIFE VIII

Exoplanet Detection Yield

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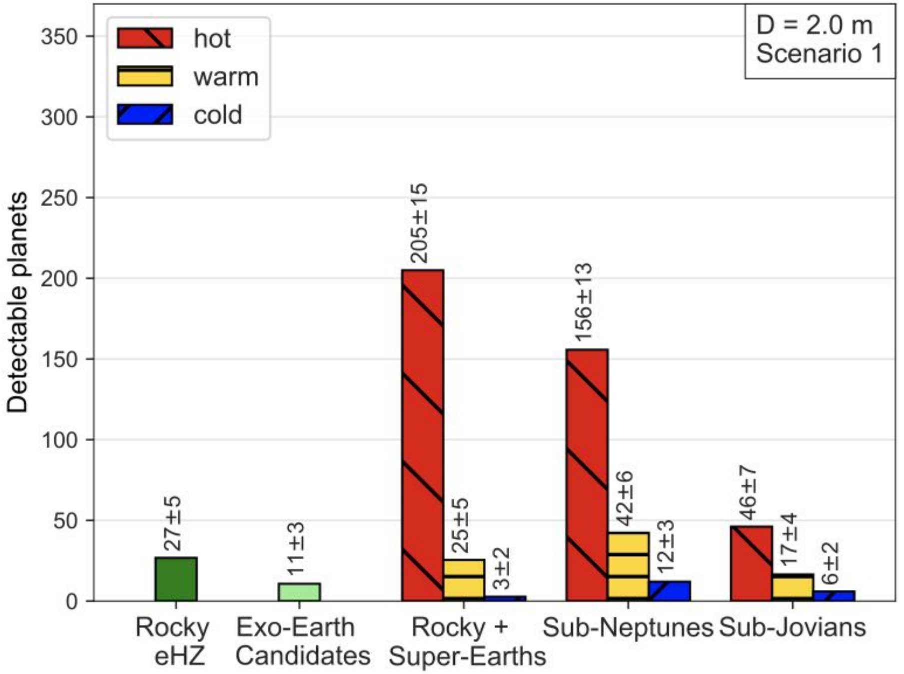
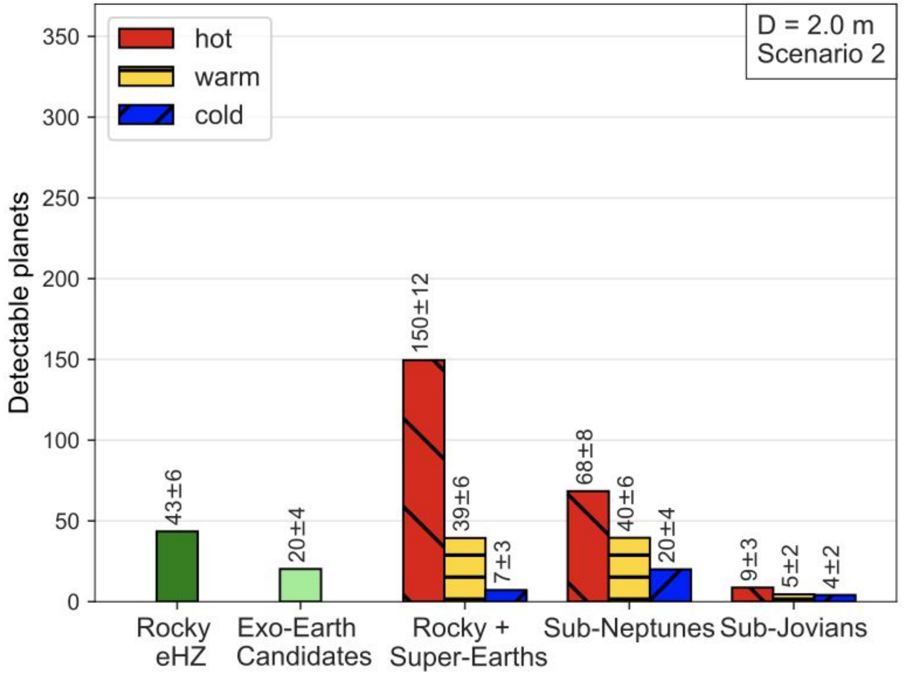
- Assuming
  - 2m apertures
  - 2.5 years total search phase
  - 5% total instrument throughput
  - 10 h slew between targets
  - 20% general overhead



Maximizing total number of detected exoplanets



Maximizing number of rocky, HZ exoplanets

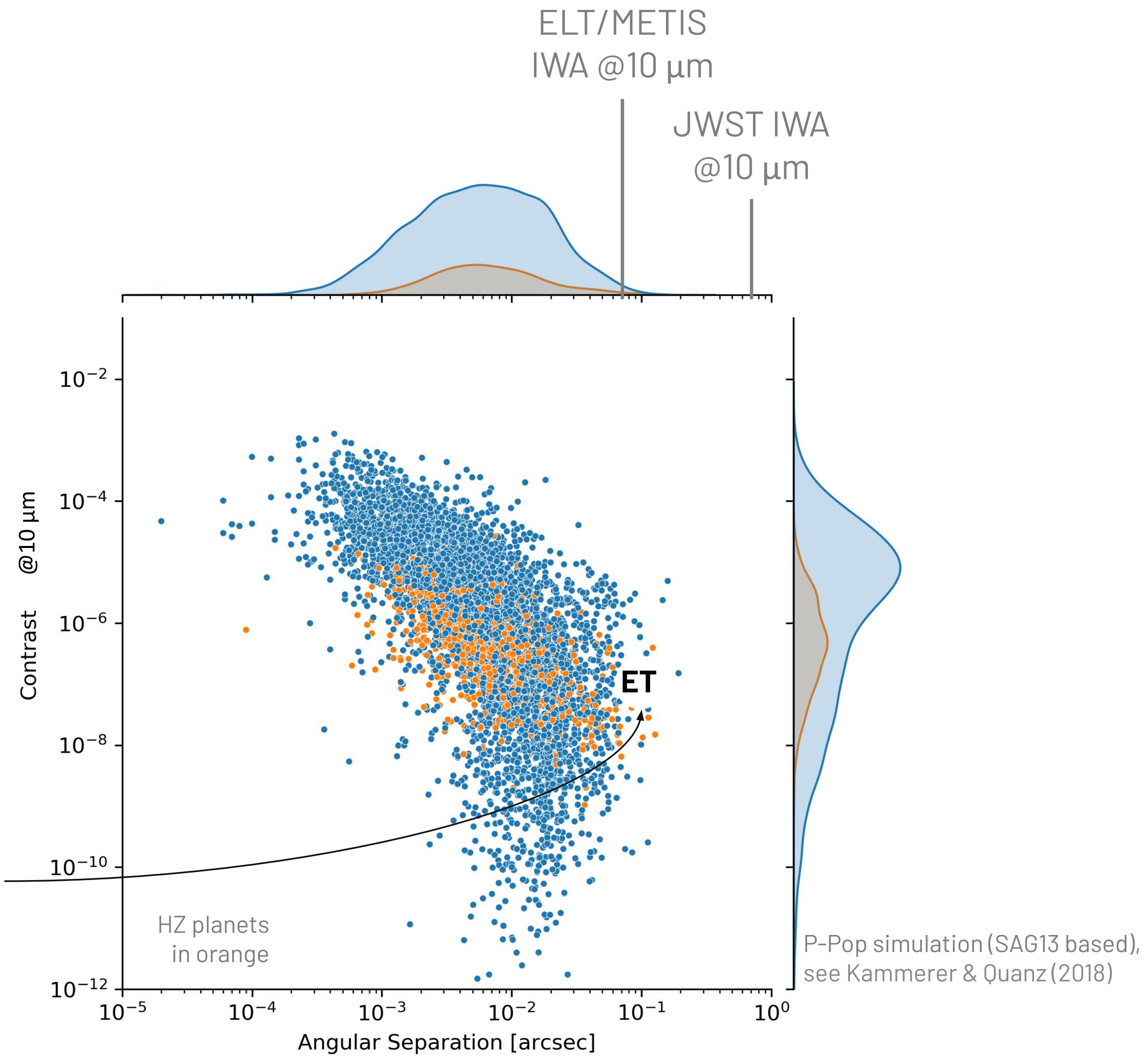
A Challenging Sample

Small Angular Resolution

High contrast to star

Low total flux

Earth-twin at 10 pc
23 ph min^{-1} m^{-2} µm^{-1} @ 10 µm
1 ph min^{-1} m^{-2} µm^{-1} @ 5 µm



LIFE IX: Venus and clouds

Konrad+ 2022, accepted