Detectability of currently known exoplanets in direct imaging with notional designs of LIFE and HabWorlds

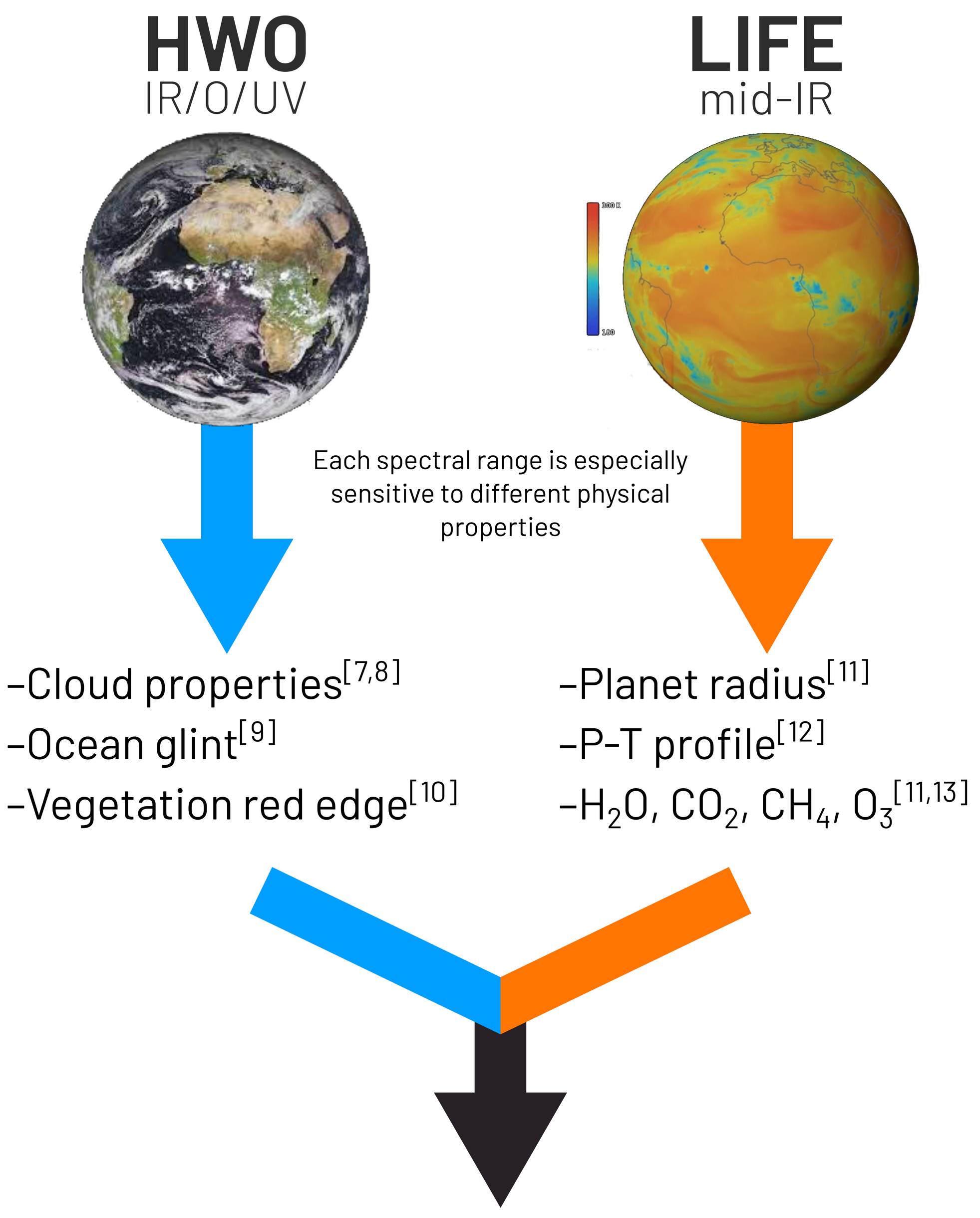
Ó. Carrión-González[1], J. Kammerer[2], D. Angerhausen[3], F. Dannert[3], A. García Muñoz[4], S. P. Quanz[3], O. Absil[5], C. A. Beichman[6], J. H. Girard[2], B. Mennesson[7], M. R. Meyer[8], K. R. Stapelfeldt[7], The LIFE Collaboration[9]

[1]Observatoire de Paris (France), [2]STScI (USA), [3]ETH Zurich (Switzerland), [4]CEA-Saclay (France), [5]Université de Liège (Belgium), [6]NExScI, JPL, Caltech (USA), [7]JPL, Caltech (USA), [8]University of Michigan (USA), [9]www.life-space-mission.com

Abstract

The atmospheric characterization of low-mass temperate exoplanets was identified as a scientific priority for the coming decades, both by the US Astro2020 Decadal Survey[1] and by the European Space Agency's Voyage 2050 Senior Committee report[2]. The Astro2020 Decadal Survey recommended a segmented 6-m telescope -now named Habitable Worlds Observatory (HWO)- to directly image exoplanets in reflected starlight (IR/O/UV wavelengths). On the other hand, ESA's Voyage 2050 report gave high priority to analysing the thermal emission of exoplanets (mid-IR). The Large Interferometer For Exoplanets (LIFE[3]) is a mission proposed to directly image low-mass temperate exoplanets in the mid-IR. The mission concept consists of multiple free-flying telescopes operating together as a nulling interferometer in space. In this work[4] we use the NASA Exoplanet Archive[5] and a pre-existing statistical method[6] to compute which of the currently-known exoplanets are potential targets for LIFE and HWO. We discuss the complementary approaches of HWO and LIFE, and how the science output increases if both IR/O/UV and mid-IR measurements are available.

Science approach



HWO

- Cloud properties[7,8]
- Ocean glint[9]
- Vegetation red edge[10]

LIFE

- Planet radius[11]
- P-T profile[12]
- H_2O, CO_2, CH_4, O_3[11,13]

Combining observations in both spectral ranges results in:

- Breaking the radius-albedo degeneracy[14]
- Deriving the wavelength-dependent albedo and the planet's full energy budget
- Detecting eventual greenhouse effect

Exoplanet detectability

For each confirmed exoplanet in the NASA Exoplanet Archive, we ran 1000 orbital simulations with the methodology of [6] for the 259 known exoplanets within 20 pc.

- An exoplanet is considered **accessible with HWO** if there are orbital positions that verify simultaneously: an angular separation ($\Delta\theta$) such that $IWA<\Delta\theta<OWA$, and a planet-to-star contrast ratio $F_p/F_*>C_{min}$. We assume a notional design of HWO with D=6 m, IWA=$3\lambda/D$, OWA=$64\lambda/D$, λ=575 nm, and $C_{min}=10^{-10}$.

- An exoplanet is considered **detectable with LIFE** if it can be detected with S/N=7 in less than 100h (computed with the LIFEsim[15] software). We assume a LIFE configuration with 4 telescopes of 2-m diameter, total 5% throughput, λ={4-18.5 μm}, and R=50.[11]

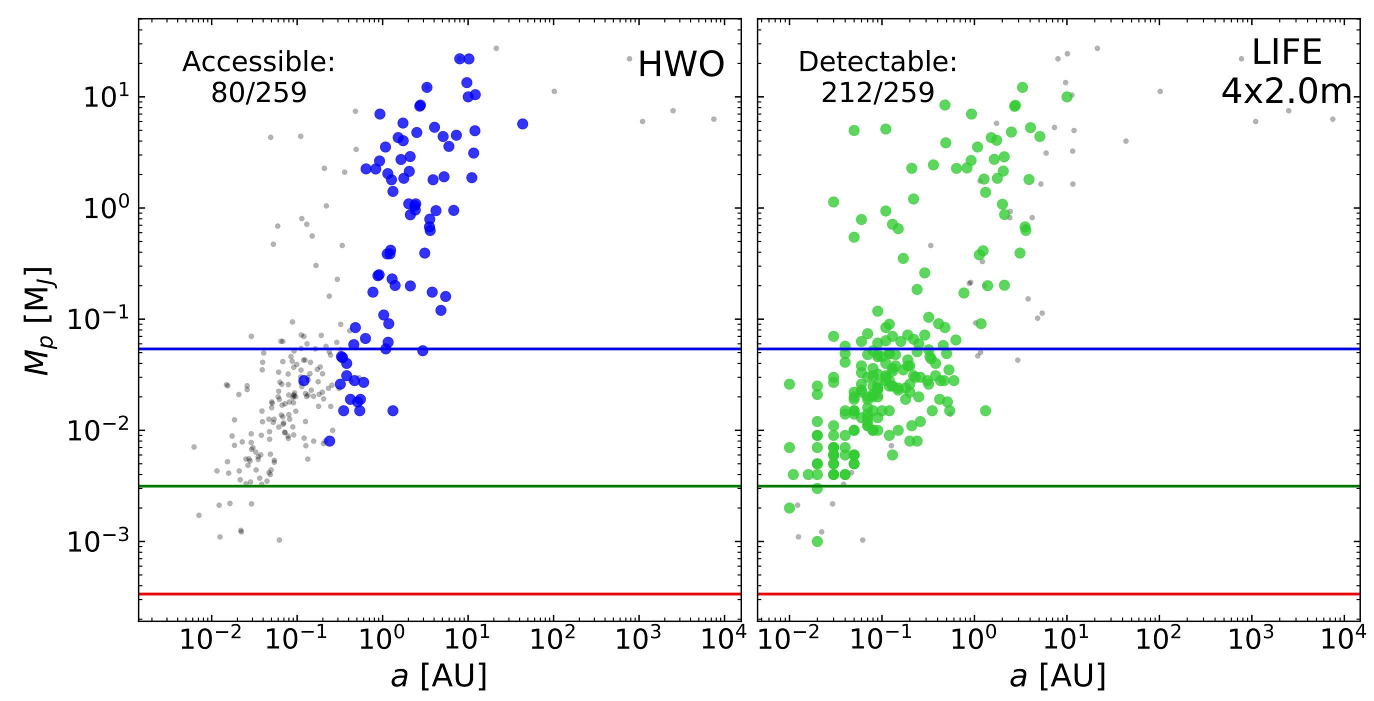


Figure 1: Known exoplanets potentially detectable with LIFE and HWO (coloured circles) compared to the total population of known exoplanets within 20 pc (grey dots). The value of M_p reported for the potential targets is the output of our statistical methodology. For non-detectable planets we plot either M_p or $M_p\sin(i)$ as reported in the NASA Archive. Horizontal lines indicate the mass of Neptune (blue), Earth (green), and Mars (red).

We find that LIFE's reference configuration (4x2m telescopes with total 5% throughput) can detect 38 known habitable-zone (HZ) planets, 13 of which have $M_p<5M_\oplus$. HWO can detect a total of 13 HZ planets, one of which has $M_p<5M_\oplus$. This is due to current observational biases, which favour the discovery of low-mass planets around M stars. Fig. 2 shows the common HZ targets for LIFE and HWO. Planet population statistics predict hundreds of additional HZ planets to be discovered within 20 pc[3,16].

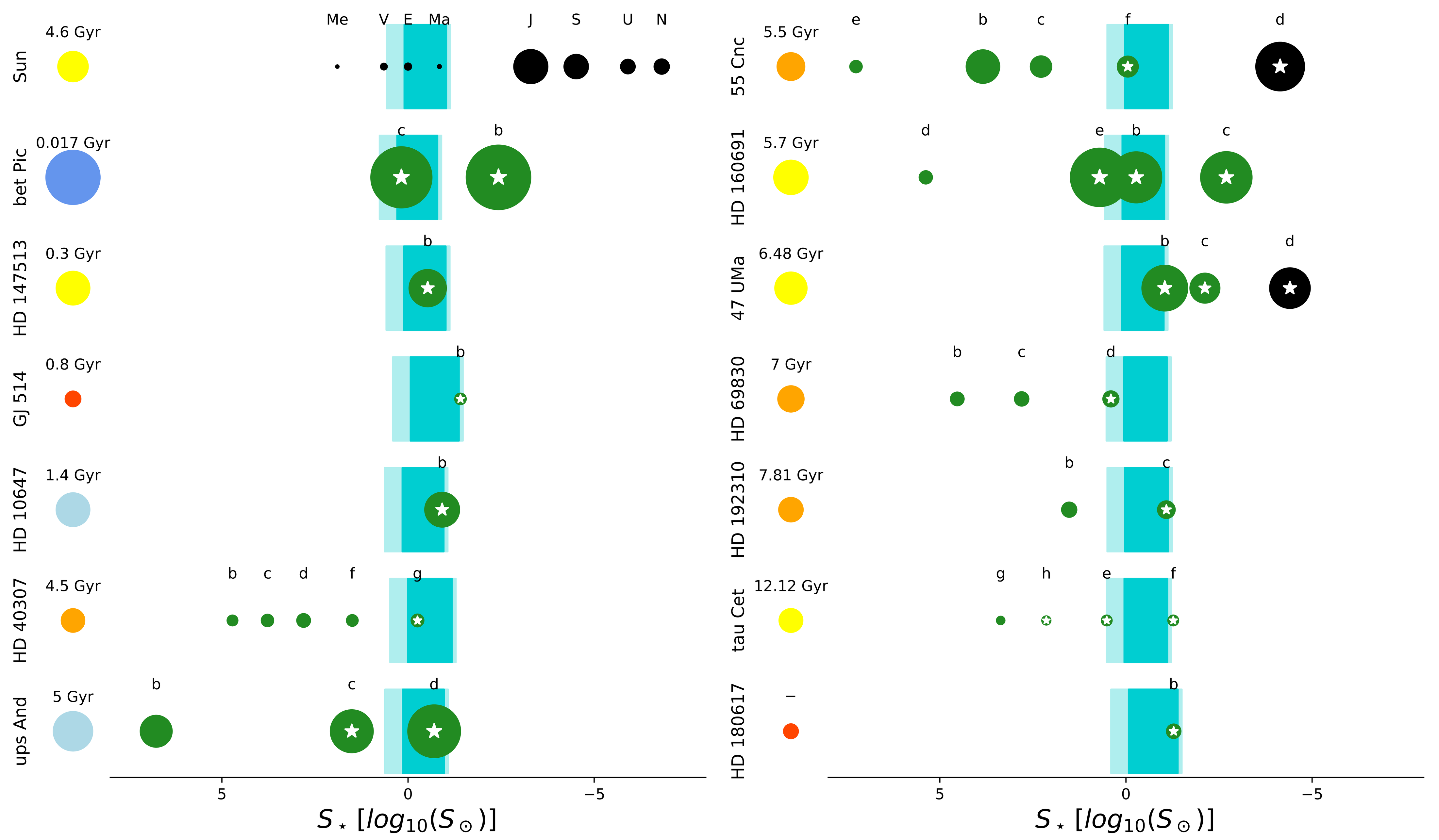


Figure 2: Planetary systems within 20 pc with habitable-zone planets potentially detectable both with LIFE and with HWO. Planets detectable with LIFE are shown by green circles, and those which are not, by black circles. Inscribed white-star markers indicate planets that are accessible with HWO in reflected starlight. Blue-shaded regions show the conservative HZ of each star, with lighter-blue regions being the optimistic HZ zone[17]. The sizes of the markers both for host-stars and planets are proportional to their masses. Stars are color-coded red, orange, yellow, blue-grey and light blue for M, K, G, F and A stars resp. The Solar System is included for reference. Not shown in this plot are 22 additional planetary systems with HZ planets detectable with LIFE but not accessible with HWO.

In addition, the list of HZ planets detectable with LIFE but not with HWO includes low-mass planets around M stars such as: Proxima Cen b, Teegarden's Star b and c, Ross 128 b, GJ 1061 d, GJ 273 b, Wolf 1061 c, GJ 3323 b, GJ 667 C c, e and f or Ross 508 b. See [4] for the complete target list.

Get the paper here

A&A 678, A96 (2023)

oscar.carrion@obspm.fr

Conclusions

- LIFE's approach can detect temperate exoplanets around stars of any spectral type, including M dwarfs. LIFE can detect 38 known exoplanets within 20 pc wihch orbit in the habitable zone.
- Despite current observational biases favouring the detection of planets around M stars, we find 55 common targets for HWO and LIFE – 13 of them in the HZ.
- If optical and mid-IR measurements are combined, the science output is much greater than the sum of the parts. Excitingly, the list of common targets for HWO and LIFE will just keep growing.

References

[1] National Academies of Sci. Eng. & Med. (2021)
[2] www.cosmos.esa.int/web/voyage-2050
[3] Quanz et al., A&A 664, A21 (2022)
[4] Carrión-González et al., A&A 678, A96 (2023)
[5] Akeson et al., PASP 125, 989 (2013)
[6] Carrión-González et al., A&A 651, A7 (2021)
[7] Lupu et al., AJ 152, 217 (2016)
[8] Damiano & Hu, AJ 159, 175 (2020)
[9] Lustig-Yaeger et al., AJ 156, 301 (2018)
[10] Seager et al., Astrobiology 5, 3 (2005)
[11] Konrad et al. A&A 664, A23 (2022)
[12] Konrad et al., A&A 673, A94 (2023)
[13] Alei et al., A&A 665, A106 (2022)
[14] Carrión-González et al., A&A 640, A136 (2020)
[15] Dannert et al., A&A 664, A22 (2022)
[16] Kammerer & Quanz, A&A 609, A4 (2018)
[17] Kopparapu et al., ApJ 787, L29 (2014)