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Direct detection of hundreds of exoplanets with a space-based mid-infrared interferometer

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Abstract

One of the long-term goals of exoplanet research is the (atmospheric) characterization of a sizeable sample of small, terrestrial planets in order to assess their potential habitability. In this context it is important to quantitatively assess the scientific return of various mission concepts in order to derive robust science requirements. While transit and secondary eclipse spectroscopy may provide data on a few systems, it seems questionable whether a larger planet sample can be investigated given that most planets *do not* transit in front of their host stars. Hence, direct detection methods may be required.

Here we predict the exoplanet yield of a space-based mid-infrared nulling interferometer (akin to the Darwin mission concept) using Monte-Carlo simulations. Focusing solely on the scientific return we quantify the number and properties of detectable exoplanets and identify those target stars that have the highest or most complete detection rate. We further investigate how changes in the underlying technical assumptions (e.g., sensitivity, spatial resolution) and uncertainties in the underlying planet population impact the science return. As the primary goal of this work is to derive science requirements, technical challenges are not discussed.

We simulate 2000 exoplanetary systems around each of 326 nearby (d<20 pc) main-sequence stars based on planet occurrence statistics from Kepler. We put each exoplanet on a randomly oriented orbit and draw uniformly distributed Bond and geometric albedos. We calculate the apparent angular separation between exoplanets and host stars and the observed flux from each exoplanet assuming thermal equilibrium and that both planets and host stars are spherical blackbodies. We focus on fluxes at 5.6, 10, and 15 μm. By comparing the angular separation and the expected flux levels of the planets with our assumptions for the limiting spatial resolution and sensitivity we can quantify the number of detectable planets as a function of their radii and equilibrium temperatures.

We find that a mission with the technical specifications of Darwin could detect $>$300 exoplanets (with radii $0.5R_{\mathrm{Earth}} \leq R_{\mathrm{p}} \leq 6R_{\mathrm{Earth}}$) in at least one of the three bands and half of them in all bands. Roughly half of these planets is detected around M-stars, which have the highest planet yield per star, and the other half around FGK stars, that show overall a higher completeness in the detectability. $\sim$85 planets have $0.5\,R_{\mathrm{Earth}} \leq R_{\mathrm{p}} \leq 1.75\,R_{\mathrm{Earth}}$ and equilibrium temperatures $200\,\mathrm{K} \leq T_{\mathrm{eq}} \leq 450\,\mathrm{K}$ and are prime targets for spectroscopic follow-up observations in the second phase of the mission investigating their potential habitability. We further find that the expected planet yield depends strongly on the Bond albedos, but is quite robust with respect to the orbital eccentricities and the geometric albedos. Higher planet yields can be realized by further optimizing the observing strategy. We also compare the baseline planet yield of a space-based mid-infrared interferometer to that of a large space-based optical/IR telescope finding that the latter will overall detect fewer planets, has a significantly lower characterization potential, but might detect more "Earth-twins" even if only at the shortest wavelengths.

An optimized space-based interferometer operating in the mid-infrared would deliver an unprecedented dataset for the (atmospheric) characterization of (small) nearby exoplanets including dozens of potentially habitable planets. A *Darwin*-like mission concept should be put back on the long-term agenda of the exoplanet community and related space agencies.