A Wider Perspective on Our World: Searching for Earth-like Planets

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Are planetary systems like our own common or rare in the Milky Way galaxy? This is a trick question because the answer depends on what one means by "like." Does it mean that an extra-solar planetary system must contain a rocky Earth-sized planet in the zone around its star where water is expected to be a liquid on a planet with an atmosphere? Does it mean that the system must contain a gas giant planet like Jupiter beyond the orbital radius where water exists as ice in the vacuum of space? No planetary system is exactly like the Solar System: at minimum we need to integrate over ranges of properties that we might care about. And the more properties of our own system that we require another galactic planetary system to have, the less likely it is that such systems are common in the galaxy.

To assess the prospects for life in the Universe, the real question is: which properties are critical for life to emerge? We have some rough ideas, but because we lack a robust theory for the biochemical origins of life, we cannot answer this question precisely. Let's start with the question of how common are rocky Earth-sized planets in the liquid water zone. NASA's Kepler Mission was designed to answer this question by detecting planets through the transit technique (measuring dips in observed brightness due to part of a star's emission being blocked by a planet), providing estimates of planet radius and orbital period (which we can convert to orbital radius knowing the mass of the star). While Kepler did not quite have the precision needed, nor the mission duration required, to measure large numbers of Earth-sized planets at orbital distances comparable to the mean Earth-Sun distance (1 AU) around Sun-like stars, new estimates from the mission are now available.

Considering both reliability and completeness of detections, researchers find that there is a 68% chance that anywhere from 16% to 85% (the best guess is 37%) of stars with masses between 0.75-1.25 that of the Sun, have planets between 0.5-1.5 Earth radii that receive 0.3-1.3 times the flux from their stars as the Earth does from the Sun (which dictates in part whether water could form pools thought to be helpful for life to emerge). This is not a precise answer, but we now know it is not a very small number.

These Kepler results have enabled us to predict the probability that the very nearest stars host Neptune-sized (~ 4 Earth radii) planets or smaller within 1.2 AU of their host stars, provided we assume they are consistent with the Kepler sample. The very nearest Sun-like stars (α Centari A & B), are clearly the best targets. Proxima Centari, the very low mass tertiary in the system, is known to host a small rocky planet near its liquid water zone. Such planets, like our Earth, emit the bulk of their radiation in the mid-infrared (wavelengths more than 10 times longer than the reddest thing your eyes can see). However, the star is so faint that the liquid water zone is too close to resolve from its host star without special interferometric techniques such as those developed by Prof. Monnier in our department.

In our laboratory in Randall Hall, Postdoc Dani Atkinson, Graduate Student Rory Bowens, and Engineer Eric Viges are working to characterize a new generation of mid-infrared detectors for use at the telescopes of the Magellan Observatory in which the University of Michigan is a key partner (Figure 1). With a new mid-infrared camera on the Magellan 6.5-meter telescopes utilizing adaptive optics to correct for blurring in the Earth's atmosphere, it might just be possible to directly detect a rocky planet, say twice the radius of Earth, around α Centari A. However, this would be extremely challenging, requiring dozens of observing nights (approximately the

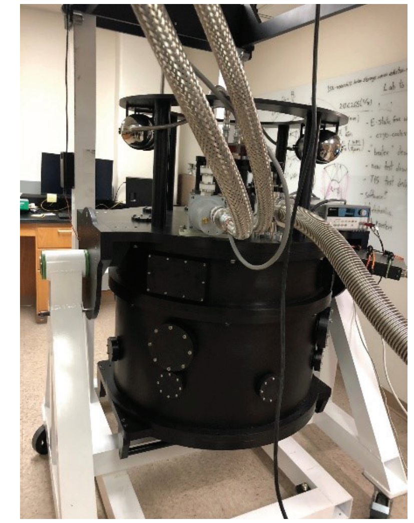

Figure 1 - A picture of the Michigan Infrared Thermal Test ELT N-band (MITTEN) Cryostat inside the lab in Randall Hall. The chamber is being used to characterize a new generation of mid-infrared detectors useful for current and future ground-based mid-infrared instrumentation (Bowens et al. 2020).

allocation our entire Department of Astronomy has on these facilities in a year), with no guarantee of success. Such an observation would not even be possible for the NASA-led international James Webb Space Telescope (JWST), set to launch in 2021. While JWST would have more than the required sensitivity, it was not designed to make extremely high contrast observations, detecting faint things near bright things at the level of one part in about five million within a few times the resolution limit of the telescope.

Fortunately, the future looks bright for this type of work. In partnerships with member states of the European Southern Observatory (ESO), the University of Michigan is participating in the development of new instrumentation for the 39-meter ESO Extremely Large Telescope (ELT; Figure 2). This behemoth, under construction with first light planned for late in this decade, will make revolutionary discoveries in many areas of astronomy. It will have both the fineness of imaging detail and light-gathering power to spatially resolve and detect small rocky planets in the liquid-water zones of the very nearest stars.

Simulations of the contrast and sensitivity expected with the mid-infrared camera (METIS) under development for the ELT and its adaptive optics systems, suggest that there is about a 90% chance we would detect at least one planet with size between that of Earth and Neptune from a survey of the nearest stars. We might even be able to detect one of these planets in multiple wavelengths, enabling us to estimate its temperature. And if future ground- or space-based capabilities are able to detect such a world in reflected light, we can compare the implied radius (modulated by the albedo) to that inferred from its temperature and luminosity in thermal emission.

The amount of power absorbed by a planet from its star equals the amount of power received from the star (set by the star's luminosity, the planet's radius as well as its orbital distance) minus the fraction reflected. The power emitted by the planet in thermal emission should roughly equal the amount received from the star. Thus, knowing the flux available from the star at the orbit of the planet, as well as the radius, albedo, and surface temperature of the planet, we can search for signs of an active greenhouse effect, trapping energy in ^the^ atmosphere and heating up the planet. This sort of detailed characterization would be a first step on the way to understanding potential biosignatures in the atmosphere of another world. It may be that the only thing harder than proving a planet harbors life, is proving that it doesn't!

Our group (https://sites.lsa.umich.edu/feps/) is involved in a number of other research projects focused on: (a) estimating the frequency of Jupiter-like planets beyond the ice-line around sun-like stars (with Undergraduate Student Seth Greenfield and U-M Alumnus Avery Peterson); (b) developing and testing models of planet formation (Postdoc Arthur Adams); and (c) studying the context of planet formation in multiple star systems and star clusters (Graduate Student Matthew DeFurio, Undergraduate Student Christopher Liu, and U-M alumnus Nicholas Susemiehl). Much of this work is done in collaboration with the broad departmental expertise in star and planet formation and exoplanets here at UM (https://lsa.umich.edu/astro/research/stars-exoplanets.html). Our work often involves use of large ground-based telescopes (such as Magellan) equipped with adaptive optics and other instrumentation. And soon, we look forward to utilizing JWST with its extraordinary infrared sensitivity for a variety of complementary studies.

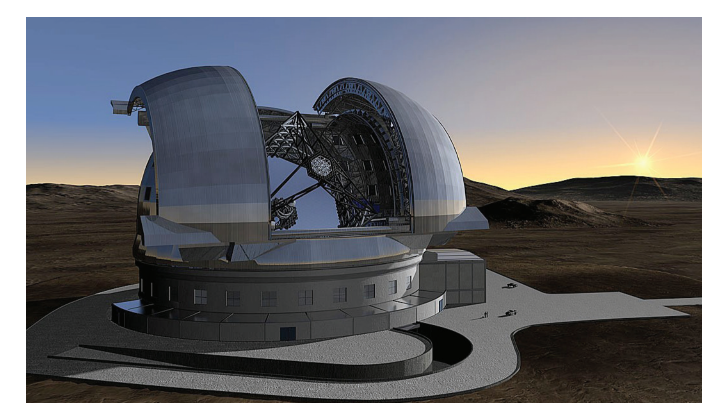

Figure 2 - An artist's conception of the 39-meter diameter ESO Extremely Large Telescope under construction in Chile, with first light as early as 2027.