Cool Planets, New Science
Exoplanet Science with Starshade

Renyu Hu, Ph.D.
Starshade Scientist, NASA Exoplanet Exploration Program
Jet Propulsion Laboratory
California Institute of Technology

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Exoplanet Demography

>25% nearby stars have Earth-sized planets in their habitable zone

![Graph showing the distribution of exoplanet masses and semi-major axes. The graph indicates the presence of Earth-like planets in the habitable zone of their stars.]
Exoplanet Detection with Starshade
From the instrument contrast to planetary S/N

\[
S/N = \frac{N_P}{\sqrt{N_P + 2(N_{SC} + N_E + N_Z)}}
\]

- “Speckles” from starshade \(<\) exozodiacal light for \(<4\)-m telescope
- To detect the spectral features, for a reasonable integration of \(~20\) days, a \(1-R_{\oplus}\) planet requires a \(5.2\)-m telescope, and a \(2-R_{\oplus}\) planet only requires a \(2.6\)-m telescope

Hu et al. 2019, White Paper of the Astro2020 Decadal Survey
Family Portraits of Nearby Planetary Systems

Planetary characterization enabled by starshade spectroscopy

HabEx Final Report, 2019
Cloud and Gas Abundance
Characterizing Giant Exoplanets

Damiano & Hu 2019

Simulated Data

$\tau = 1$
$\tau = 10$
$\tau = 100$
$\tau = 1000$

$\log(NH_3) = -2.5$, $\log(D_{cld}) = 5.5$, $\log(CR_{NH3}) = -8.0$

$\log(NH_3) = -0.01$, $\log(D_{cld}) = 6.0$, $\log(CR_{NH3}) = -10.5$
Characterizing Sub-Neptunes and Super Earths

- Is there a surface?
  - Cloud, liquid, or solid
- What is the composition of the atmosphere?
  - H\(_2\)-dominated or non-H\(_2\)-dominated
- What are the formation and evolution pathways?

Seager et al. 2015
Detecting an Earth-like Atmosphere
Water, Oxygen, and Carbon Dioxide

Turnbull et al. 2006
From Earths to super-Earths
Diversity in the spectral appearance of rocky planets

HabEx Final Report, 2019
Detecting Earths

Bare-Rock Exoplanets

- Rocky exoplanets without atmospheres have spectral features in reflection.

- Signature absorption features in 1-2 μm are characteristic of water ice and hydrated minerals.

Hu et al. 2012
Detecting Earths
Land and Sea

Cowan et al. 2009
Rotation Period and Hydrological Cycle
What we learned from DSCOVR observations of Earth

Jiang et al. 2018, Fan et al. 2019
We could not guess how different from us they (extraterrestrials) might be.

Carl Sagan, Contact, 1985