Exoplanet Science with a Starshade: Exo-S, WFIRST, and Hab-Ex
**PRO:** Contrast and IWA decoupled from telescope aperture size

**PRO:** No outer working angle

**PRO:** Few reflections = high throughput, broad wavelength bandpass

**PRO:** Starlight does NOT enter telescope
  - High quality telescope not required, wavefront correction unnecessary

**CON?** Retargeting requires long starshade slews (days to weeks)
Are We Really Alone?
What We Can Learn from a Dot?
Maggie’s Dream
Earthshine spectrum
Spectroscopic signatures indicate the possible conditions conducive to life

- **Blue of the sky** measures total amount of atmosphere
- **Vegetation jump** indicates presence of land plants
- **Carbon dioxide** suggests possible volcanic activity
- **Methane** indicates presence of anaerobic bacteria
- **Oxygen and ozone** were produced by living organisms
- **Water vapor** suggests habitability

Brightness vs. Wavelength:
- Optical
- Visible
- Near
The Many Faces of Earth: continents, oceans, weather, seasons
Maggie’s Nightmare
Observing Sequence

1. Schedule known giant planet observations
2. Fill in gaps on sky with highest priority blind search target
3. Repeat with lower priority targets until fuel or time limit reached
4. Reserve 3rd year for follow-up / additional characterization revisits

Rendezvous mission, 2-year sequence, 55 stars visited, $\Delta v = 1266$ m/s
12 known giant planets. Blind search targets: 28 Earths, 7 sub-Neptunes, 8 Jupiters
Yield By Planet Type & Temperature

Exo-S 2.4-m Planet Discovery Yield
"Habitable Zones" Program
\(<N> = 26\) Total New Planets in 2 years
Hot -- Warm -- Cold

Plus 12 known RV planets characterized at up to R~70

For Planet Occurrence Rates:
Hot/Warm/Cold Earths, 16%
All Others, 10%
R = 9, SNR = 7, 600-850nm

Exo-S Final Report to NASA APS - March 18, 2015
WFIRST and a Starshade
WFIRST Starshade Accommodation Study

- The Mission is in Phase A
  - exoplanets imaging: “tech demo”
  - this could be our only chance to prove the concept
  - formulation of science and engineering requirements
  - validation of technological milestones
  - starshade off ramp

- Phase B due to begin in one year
- Launch in 2024/25
WFIRST Starshade Accommodation Study

- 10-50x Faster Exposure times
- Smaller inner working angle (70 mas)
- Deeper contrast ($10^{-10}$)

→ No outer working angle
→ Can point off axis while in shadow for mosaics

HZ EARTHS.

DISKS AND WHOLE SYSTEMS.
Discovery Targets

Minimum Detectable Planet Size (Earth Radii)

Separation, in units of Earth-Equivalent Insolation Distance

Traditional Habitable Zone

planets at quadrature, $A_{\text{B}}=0.3$, 100 mas IWA, 1.6" OWA

Image Credit: M. Turnbull
Starshade Lab at JPL
Habitable Exoplanet Imaging Mission (HabEx)

- One of four mission concepts under study for 2020 Decadal Survey
- Four concepts under study, reports due 2019
- Hab-Ex focus is on habitable worlds
- Chairs Sara Seager, Scott Gaudi, managed by JPL
- 4-6.5 m telescope, coronagraph, starshade
- Studies began in Spring 2016, currently investigating high readiness technologies, tall poles, and formulating the science “story”
Creating the Hab-Ex “Story”:

Hopefully Detecting/Characterizing Some Planets vs. Exploring Our Unique and Amazing Neighboring Planetary Systems

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