#140.48

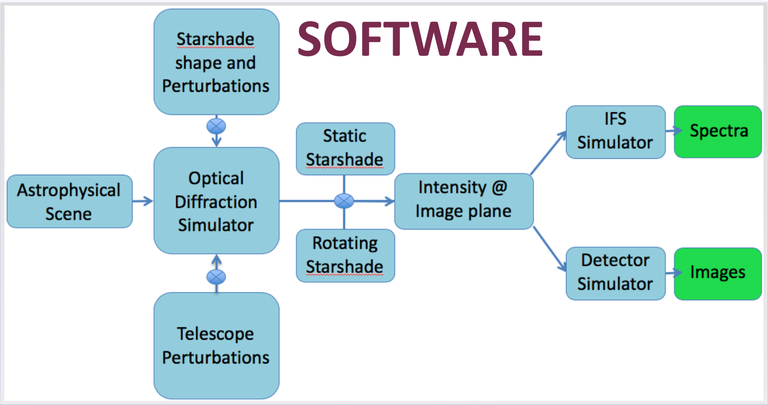
Starshade Imaging Simulations

Margaret Turnbull [1,2], Sergi Hildebrandt [2], and Stuart Shaklan [2]

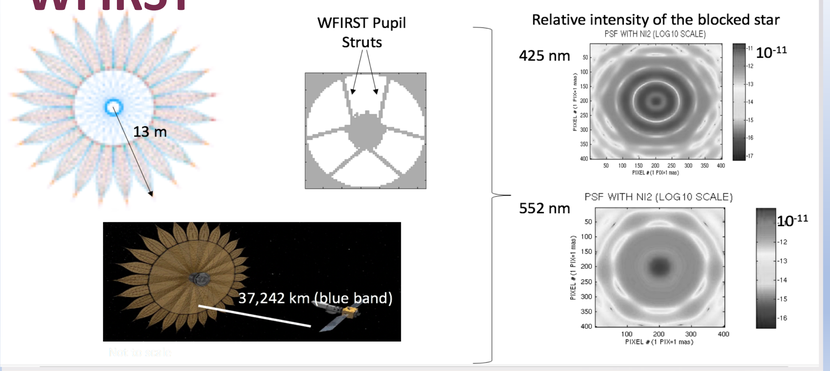
We have developed a suite of matlab-based ***software***[3], intended for distribution to community, forming an end-to-end ***starshade imaging*** tool that produces images of an arbitrary user-defined ***exoplanetary system*** and background as observed by a starshade and a telescope. The starshade imaging characteristics include both the optical model ***diffraction***[4] from a nominal or distorted starshade, as well as ***solar glint*** from the starshade edges, the largest source of local instrument scatter. The telescope model assumes an ideal ***telescope*** with a user-defined obscured pupil (e.g. secondary obstruction and struts). It incorporates a vanilla ***detector model*** with read noise and dark current. Finally, the astrophysics scenario incorporates ***Keplerian*** orbits, phase angles, geometric ***albedo***, different atmospheric scattering/absorption laws, any kind of ***host star*** (by default the user can choose among any of the +10,000 stars from ***ExoCat***) and a large variety of ***extragalactic background*** fields (galaxies, Quasars). ***Exo-dust*** emission is accurate for a solar system and flexible for an arbitrary elliptical user-defined profile in the inner habitable zone. ***Proper motion*** and ***parallax*** are also taken into account when background fields are added to the simulated images. There are some default systems, like the Solar System at any distance from us. We have employed the tool to support WFIRST-S, HabEx mission probe studies, as well as other investigations for using the starshade in ground telescopes.

NOTE: A subset of these images will be used for the WFIRST CGI Exoplanet Data Challenge, for which our team is actively seeking participants. Please contact the author at turnbull.maggie@gmail.com, for details.

SOFTWARE

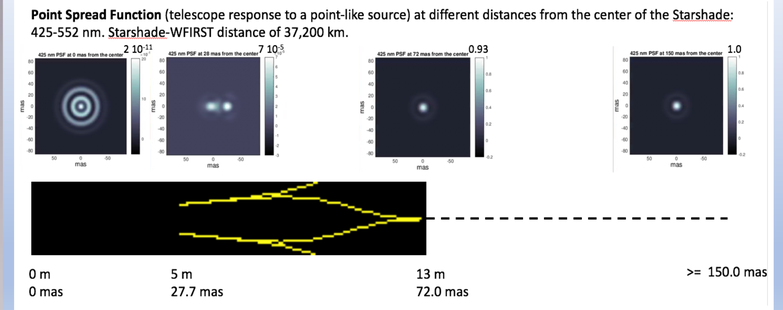


WFIRST



NON-STATIONARY PSF RESPONSE

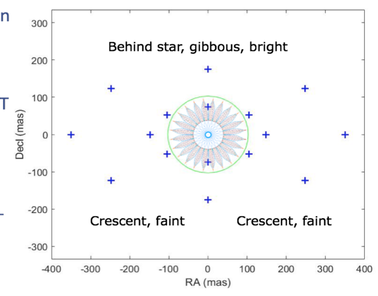
Point Spread Function (telescope response to a point-like source) at different distances from the center of the Starshade: 425-552 nm. Starshade-WFIRST distance of 37,200 km.

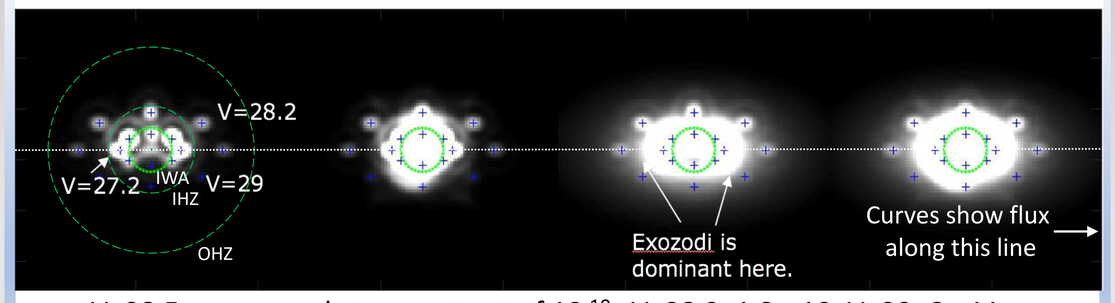


Each starshade design has its own PSF computed before imaging

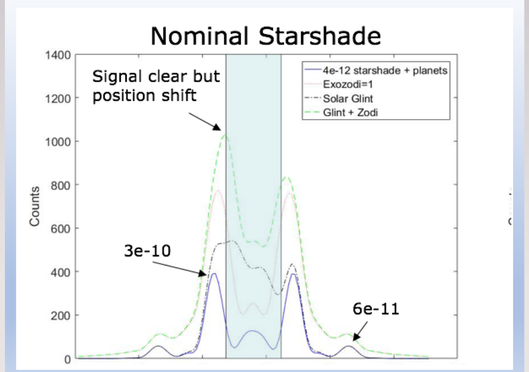
EXAMPLE: Tau Ceti

- Distance 3.65 pc, V=3.5, L = 0.52, inclination 60o
- Band 606-787 nm
- Pixel size 11.9 mas
- IWA 103 mas (starshade outer tips), WFIRST starshade designated NI2 (26 m, 24 petal)
- No noise added.
- Planets at Luminosity-scaled IHZ=0.75 AU and OHZ = 1.77 AU
- Planet flux Luminosity-scaled to Earth = 1e-10 at quadrature
- Planets have Lambertian phase function

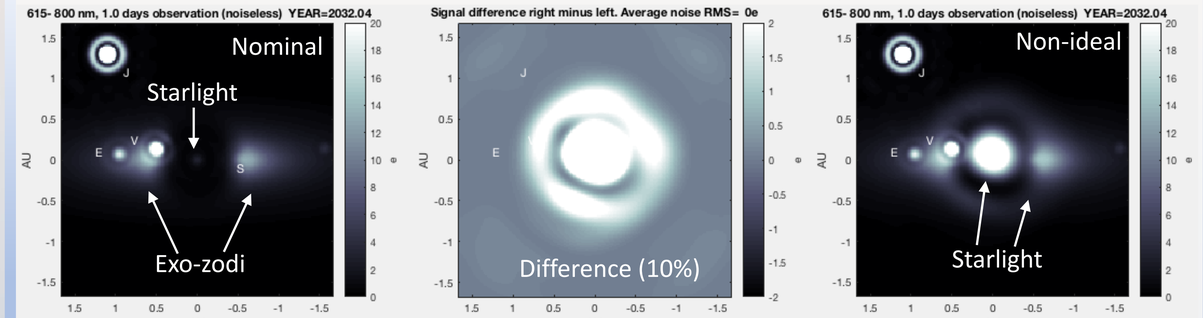




V=28.5 corresponds to a contrast of $10^{-10.}$. V=28.2, 1.3e-10. V=29, 6e-11.

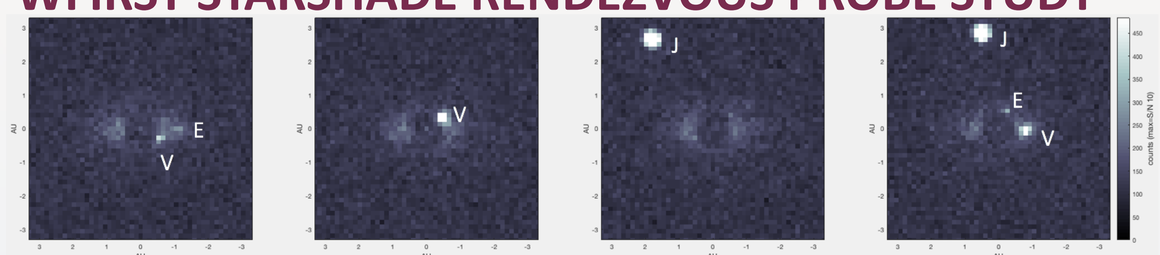


NON-IDEAL STARSHADE: WFIRST REQUIREMENTS



Solar system planets (true albedos) at 6 pc, 5x exo-zodi, and system inclination of 75º

WFIRST STARSHADE RENDEZVOUS PROBE STUDY[6]



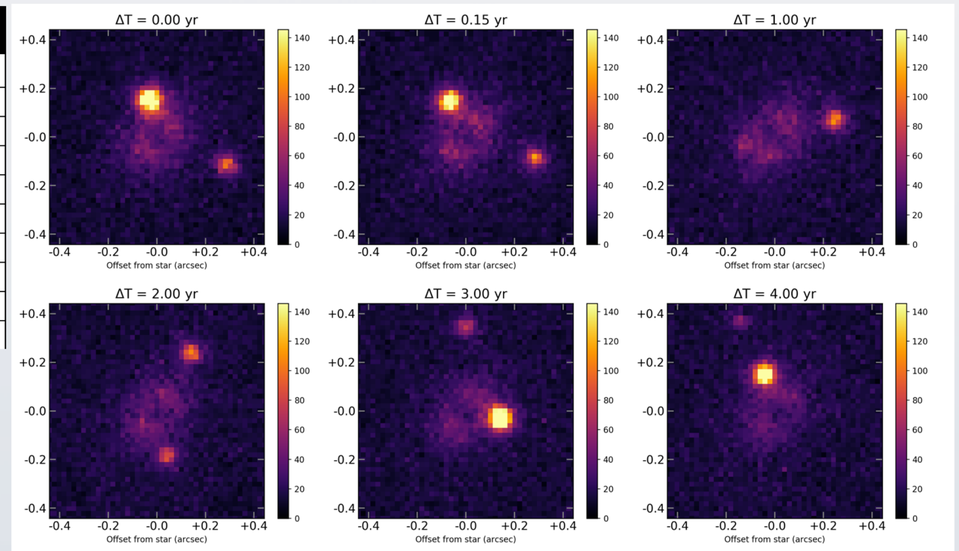
Four images of the imaging band 615-800 nm with 1 day integration time and realistic EMCCD detector readout[5] for our solar system as seen at 6 pc, with an inclination of 60º, and same exo-zodiacal light emission as the solar system. The color scale is linear and clipped at a signal to noise (S/N) of 10. Earth is observed with a S/N~3 in favorable phases. True albedos and Lambertian phase function are used.

WFIRST CGI EXOPLANET DATA CHALLENGE

Planets (fictitious)	b	c
semi-major axis	2.5 AU	5.5 AU
period	3.95 yr	12.89 yr
radius	1.0 jupiterRad	1.0 jupiterRad
albedo	[0.3]	[0.4]
albedo_wavelens	[<Quantity 575. nm>]	[<Quantity 575. nm>]
eccentricity	0.10	0.05
arg periastron	155.0 deg	50.0 deg
inclination	45.0 deg	48.0 deg
long. ascending node	300.0 deg	300.0 deg

Star (47 UMa-like)	
mass	1.0 solar mass
spec type	G0V
distance	14.0 pc
apparent V mag	5.0

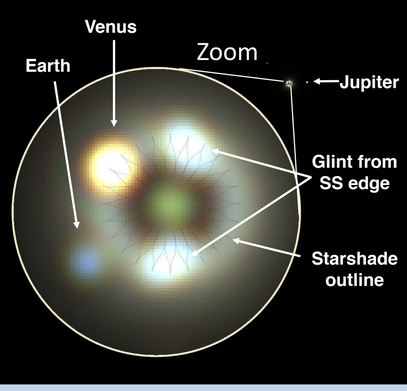
Realistic EMCCD detector[5] and noise used, band 425-552 nm. 1 exo-zodi, 20 mas telescope jitter.

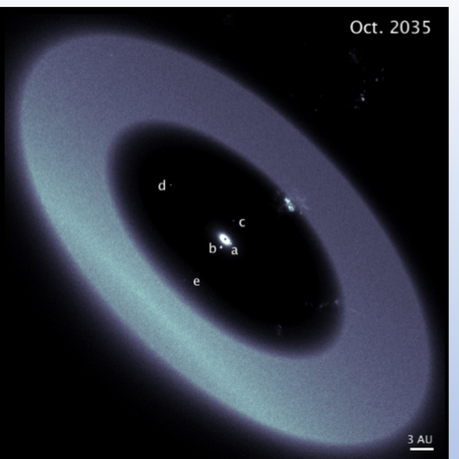


Our team is actively seeking participants. Please contact the author at turnbull.maggie@gmail.com, for details.

HabEx

Our solar system as seen at 10 pc, face-on, for a starshade only HabEx 3.2 m mission with true color 400-700 nm (**see D. Redding et al. poster**)





A solar system analog as seen from 5 pc by HabEx 4m + Starshade[7]
(a) an exoEarth
(b) a sub-Neptune
(c) Jupiter, (d) Saturn, (e) Neptune
- **Inner dust belt (3x zodiacal dust within 1 AU)**
- **Outer dust belt (3x Kuiper belt extending 22 to 33 AU)**
- **FoV = 12x12 arcsec**

(1) SETI Institute, Carl Sagan Center for Life in the Universe
(2) Jet Propulsion Laboratory & California Institute of Technology Pasadena, California

(3) Hildebrandt, S., Shaklan, S., & Turnbull, M.C. 2019, in prep
(4) Eric Cady, "Boundary diffraction wave integrals for diffraction modeling of external occulters," Opt. Express 20, 15196-15208 (2012)
(5) EMCCD detector noise simulations were generated using the *mkemccd* software by Patrick Morryssey (JPL/Caltech)
(6) *Starshade Rendezvous Probe Study Report*, S. Seager, J. Kasdin, et al (2019) to be submitted.
(7) *The Habitable Exoplanet Observatory (HabEx) Mission Concept Study Interim Report*; Gaudi, B. Scott; Seager, Sara; Mennesson, Bertrand, et al. 2018arXiv180909674G

National Aeronautics and Space Administration

Copyright 2018. All rights reserved.