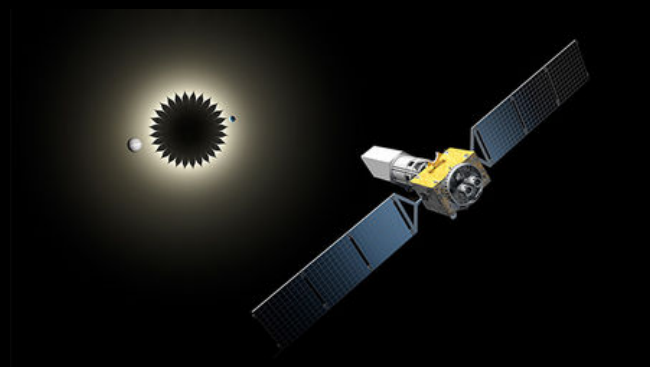
SISTER: Imaging Exoplanets with Starshade

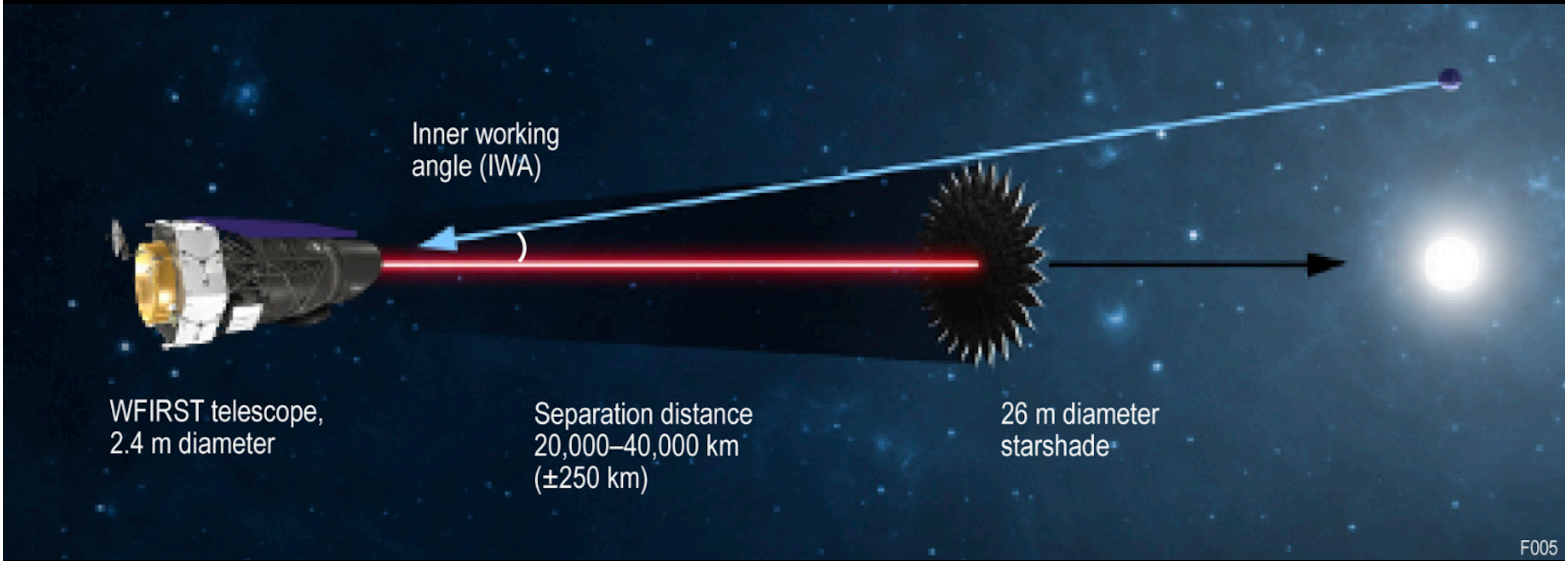


Science in our Own Backyard with WFIRST

Sergi R. Hildebrandt, JPL/Caltech

06/20/19

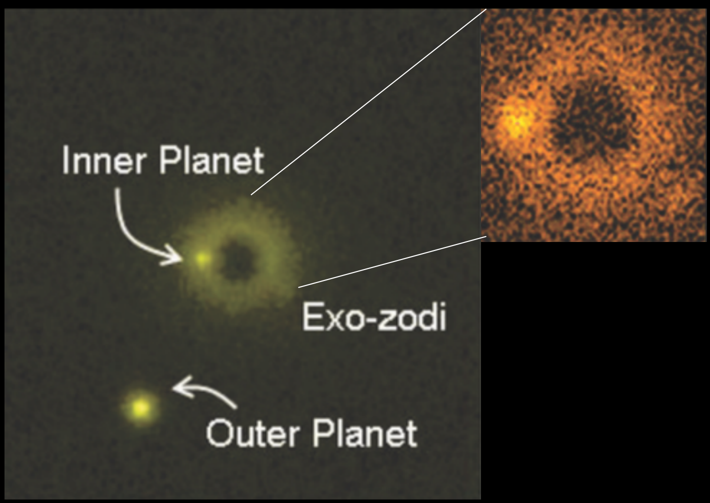
Starshade geometry



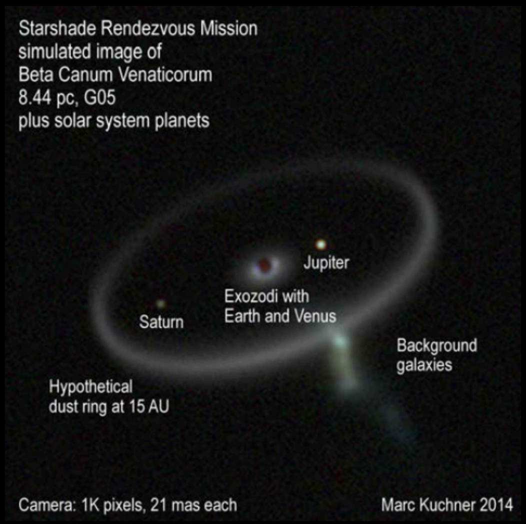
Starshade geometric IWA in the 425-552 nm band is **72** mas.
Same angular size as **1 AU** at **45.4** light years (**13.9** pc).

Starshade: previous simulations

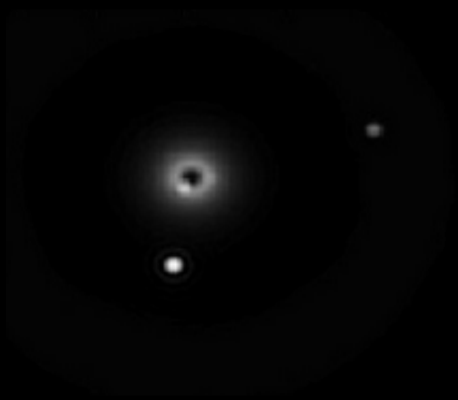
A few, specific examples. No general user interface.



Lillie et al. SPIE News 2008



Exo-S Mission Study 2014

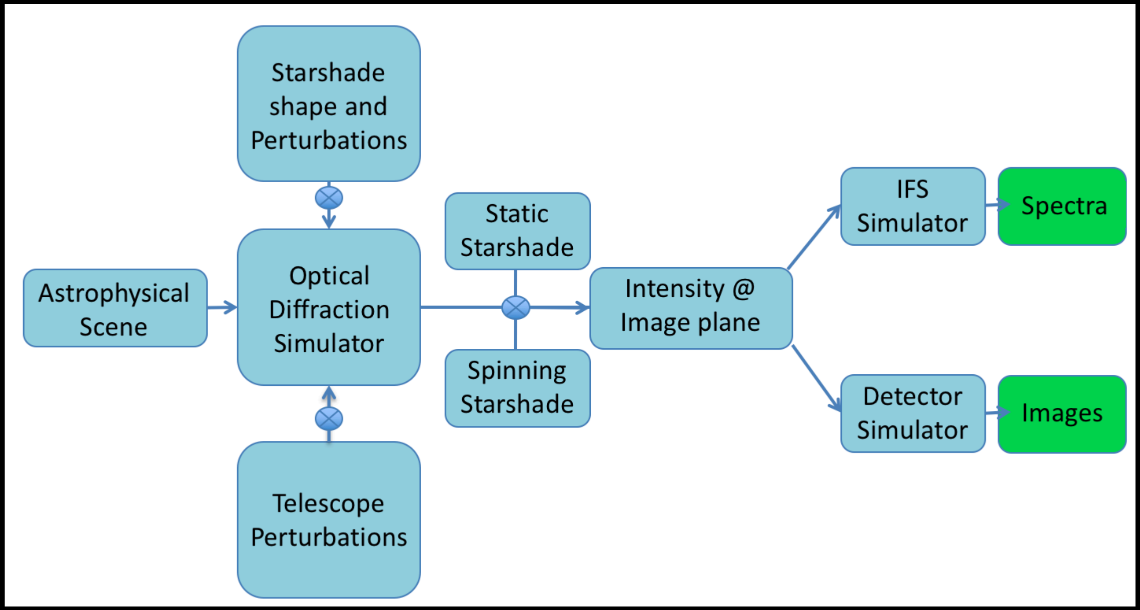


M. Hu,, A. Harness,and
N. J. Kasdin SPIE 2017

SISTER

SISTER (Starshade Imaging Simulation Toolkit for Exoplanet Reconnaissance) is a versatile tool designed to provide enough accuracy and variety for starshade astrophysical simulations.*

SISTER is a Matlab, open source project: sister.caltech.edu



(*) **S.R. Hildebrandt**[1] **S.B. Shaklan**[1], **E.J. Cady**[1], and **M.C. Turnbull**[2,1]. (1) Jet Propulsion Laboratory, California Institute of Technology (2) SETI Institute, Carl Sagan Center for Life in the Universe

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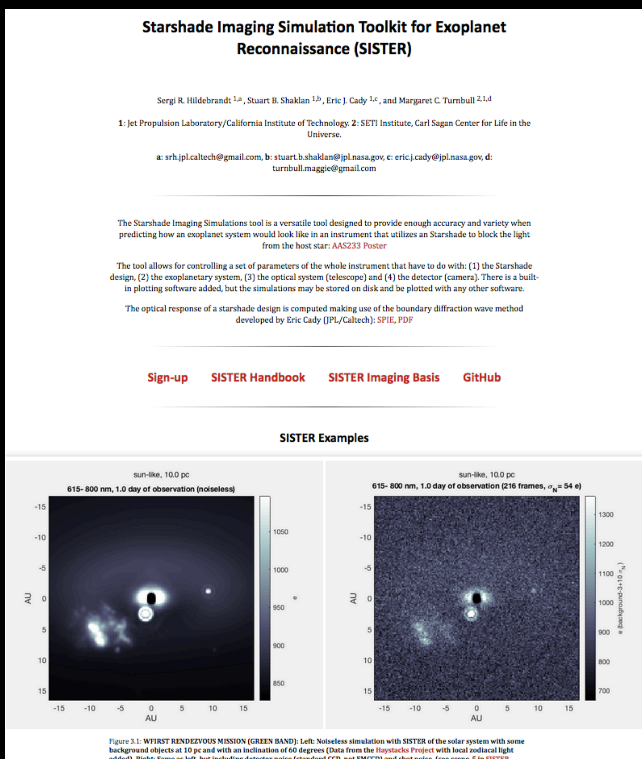

Starshade Imaging Simulation Toolkit for Exoplanet Reconnaissance (SISTER)

Sergi R. Hildebrandt [1,a], Stuart B. Shaklan [1,b], Eric J. Cady [1,c], and Margaret C. Turnbull [2,1,d]

1: Jet Propulsion Laboratory/California Institute of Technology. **2**: SETI Institute, Carl Sagan Center for Life in the Universe.

a: srh.jpl.caltech@gmail.com, **b**: stuart.b.shaklan@jpl.nasa.gov, **c**: eric.j.cady@jpl.nasa.gov, **d**: turnbull.maggie@gmail.com

The Starshade Imaging Simulations tool is a versatile tool designed to provide enough accuracy and variety when predicting how an exoplanet system would look like in an instrument that utilizes an Starshade to block the light from the host star: AAS233 Poster

The tool allows for controlling a set of parameters of the whole instrument that have to do with: (1) the Starshade design, (2) the exoplanetary system, (3) the optical system (telescope) and (4) the detector (camera). There is a built-in plotting software added, but the simulations may be stored on disk and be plotted with any other software.

The optical response of a starshade design is computed making use of the boundary diffraction wave method developed by Eric Cady (JPL/Caltech): SPIE, PDF

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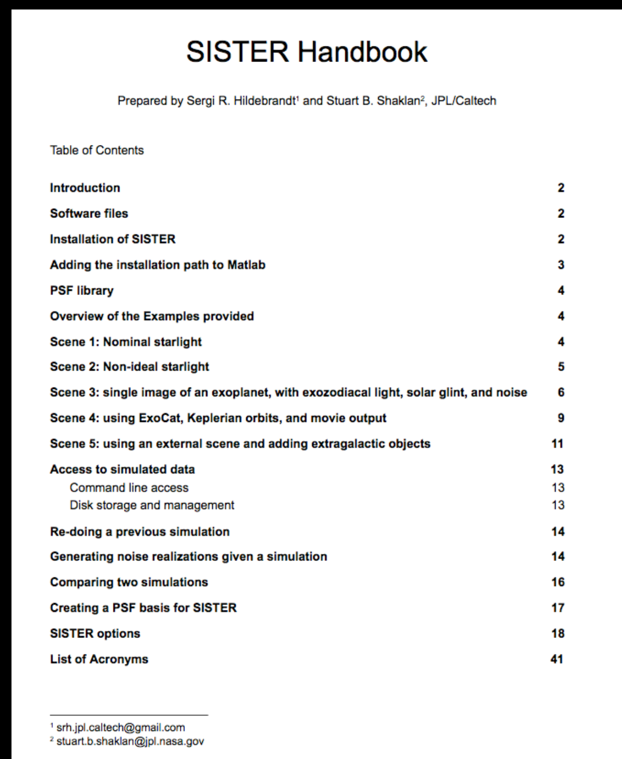
Figure 3.1: **WFIRST RENDEZVOUS MISSION (GREEN BAND): Left: Noiseless simulation with SISTER of the solar system with some background objects at 10 pc and with an inclination of 60 degrees (Data from the Haystacks Project with local zodiacal light added). Right: Same as left, but including detector noise (standard CCD, not EMCCD) and shot noise. (see scene_5 in SISTER**



SISTER Handbook

Prepared by Sergi R. Hildebrandt[1] and Stuart B. Shaklan[2], JPL/Caltech

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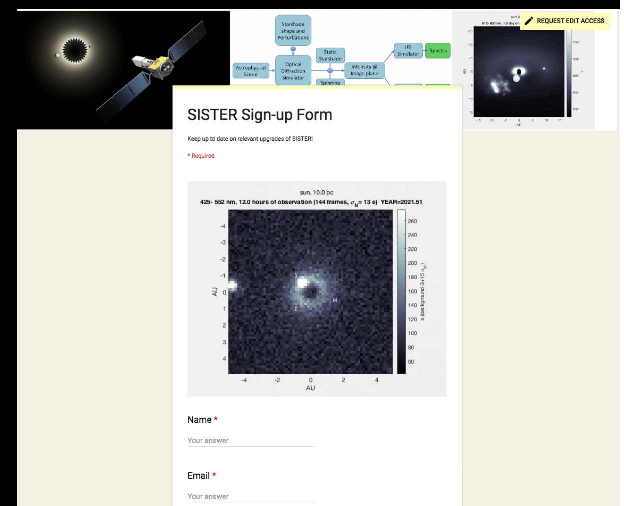
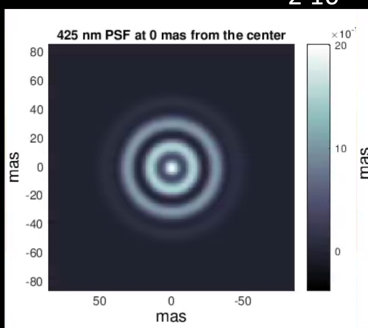
[2] stuart.b.shaklan@jpl.nasa.gov



SISTER Optical Response

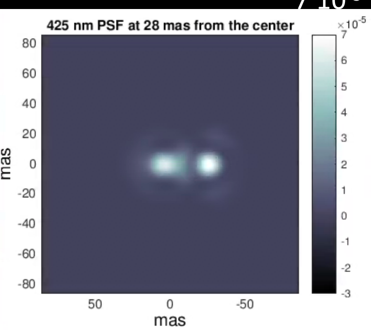
Point Spread Function (telescope response to a point-like source) at different distances from the center of the Starshade: 425-552 nm. Starshade-WFIRST distance of 37,200 km. Spinning starshade. Diameter of 26 meters, 24 petals.

$2\ 10^{-11}$



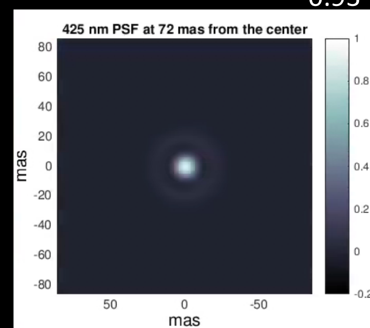
0 m, 0 mas

$7\ 10^{-5}$



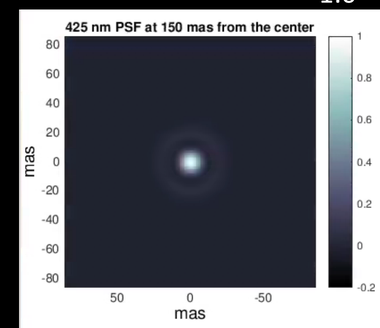
5 m, 27.7 mas

0.93



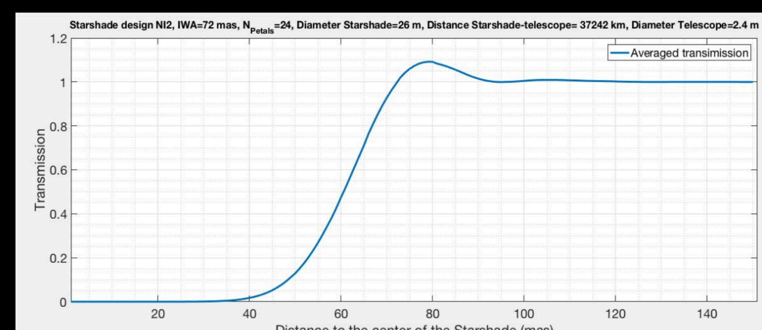
13 m, IWA 72.0 mas

1.0



>= 150.0 mas

WFIRST SS Petal



SISTER Astrophysical and Instrumental Scenes

1. **Telescope:** primary, secondary mirror, pupil, optical efficiency, pointing jitter.
2. **Detector model:** read noise, dark current, Filters, QE. For WFIRST, a full EMCCD simulator* can be run externally to SISTER, including CIC, aging, and other effects.
3. **Starshade mode:** spinning, or non-spinning.
4. **Non-ideal Starshade:** shape deformations –very many.
5. **Solar glint:** target Star-Starshade-Sun angle, and Sun angle about the orbital plane. Different petal edges depending on the starshade mode: razor, stealth.
6. **Local Zodiacal light:** surface brightness model from STSCI, helio-centric coordinates.
7. **Star:** the user may define any star (its sub-spectral type will be approximated by either 0 or 5, e.g. G3 will be G5). Or one may choose among any of the 2,347 stars from ExoCat (M. Turnbull, 2015).

*EMCCD simulator developed by P. Morryssey, JPL.

SISTER Astrophysical and Instrumental Scenes

7. **Exo-dust emission:** any external model (for instance, from the Haystacks Project*, or a very simple, scaled, rotated and resized solar model from one run of Zodipic**. Not an easy element to simulate.
8. **Planets and Keplerian orbits:** direct location, or 2-body motion with independent Keplerian parameters. No integrity evaluation.
9. **Reflected light from planets:** phase angle, phase functions (Lambert, Rayleigh, or user defined).
10. **Extragalactic background:** any external field. SISTER uses by default a deep field prepared by the Haystacks Project*.
11. **Proper motion and parallax:** given star coordinates, distance and proper motion.

* Haystacks Project A. Roberge, M. Rizzo et al. (2017)
** Zodipic by M. Kushner, GFSC.

SISTER Contributions
STARSHADE RENEDEZVOUS PROBE*

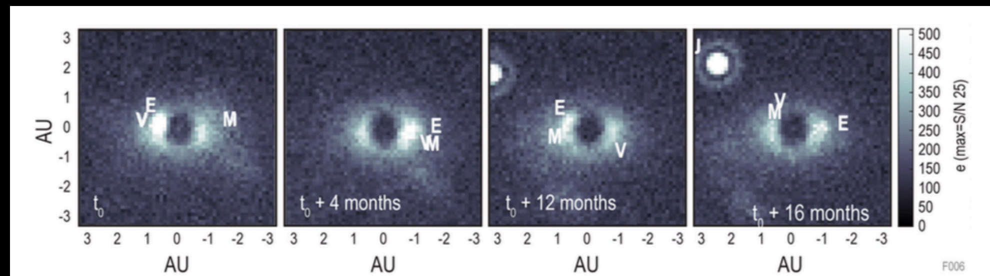


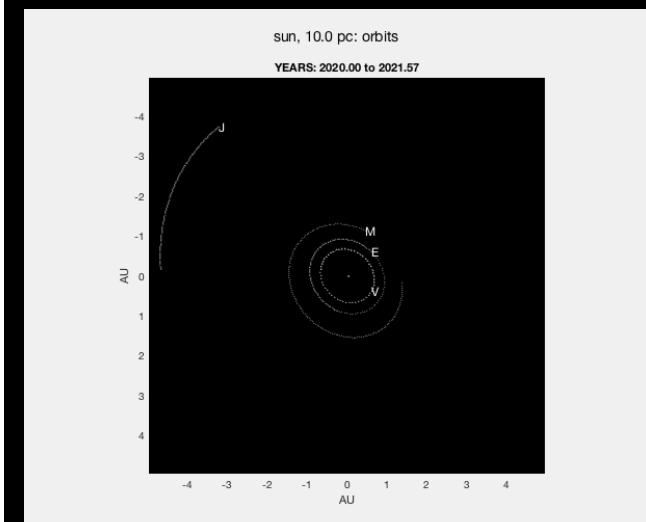
FIGURE 2-2. Multiple observations enable the tracking of habitable zone exoplanets. Image simulations of the solar system (inclination angle 60°) at a distance of 6 pc observed with a starshade and WFIRST CGI camera show the presence of Venus (V), Earth (E), and Mars (M) in a zodiacal dust cloud of 1 zodi. Jupiter (J) appears in the last two frames. Each image is obtained with 1 day of integration time. The color scale indicates the number of detector counts with the highest value being equivalent to signal to noise ratio of 25. Credit: Sergi Hildebrandt

***PI**: S. Seager, J. Kasdin (2019)
JPL POC: A. Romero-Wolf, A. Gray, J. Booth, S. Shaklan, D. Lisman, et al.

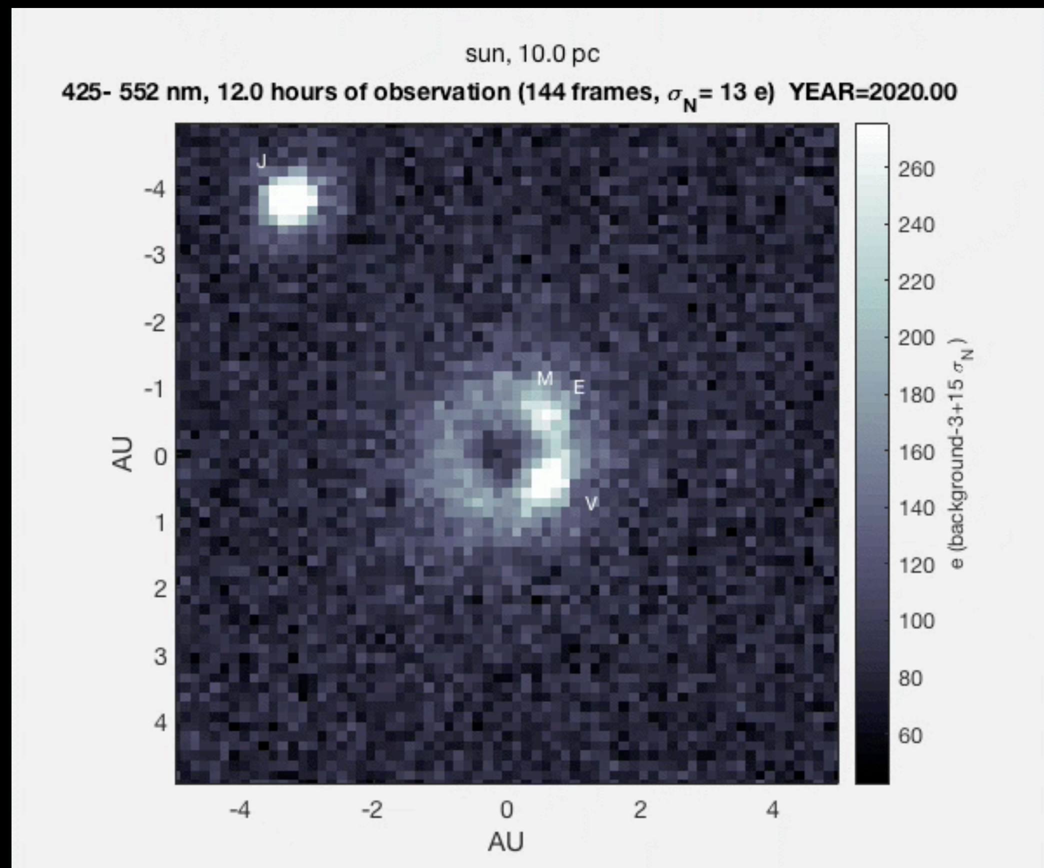
STARSHADE RENEDEZVOUS PROBE

Solar system at 10 pc, accurate EMCCD noise , QE detector and optical loses

SISTER



30º inclination and position angle of 45º



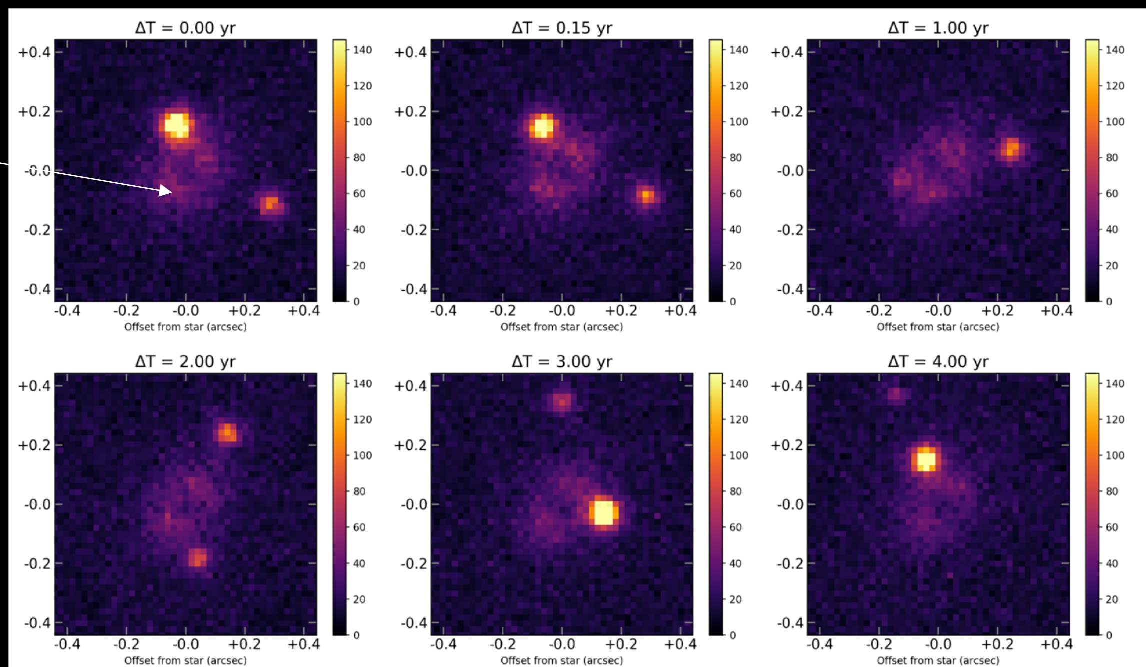
Good signal to noise ratios for J, V and E

SISTER Contributions

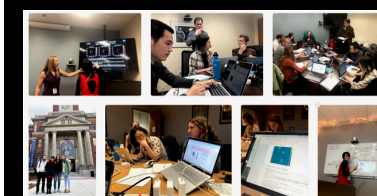
WFIRST CGI DATA CHALLENGE*

47 Uma, 14 pc, planets b & c. Imaging + RV data. Orbital, albedo and planet discovery challenge.

Exozodi



SS 6 hours of integration



1st Session at STSCI 03/18-19/19

***PI:** M. Turnbull. turnbull.maggie@gmail.com, contact us to participate

Next session at IPAC, June 20th, 2019

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THANK YOU!

Starshade Imaging Simulation Toolkit for Exoplanet Reconnaissance (SISTER)

Sergi R. Hildebrandt [1,a], Stuart B. Shaklan [1,b], Eric J. Cady [1,c], and Margaret C. Turnbull [2,1,d]

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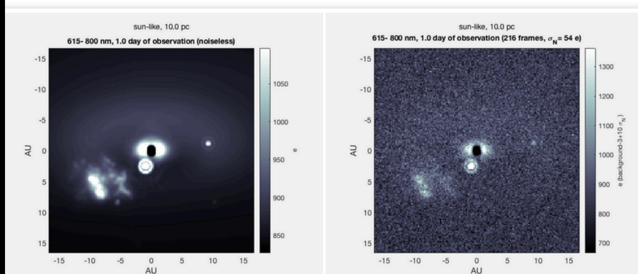

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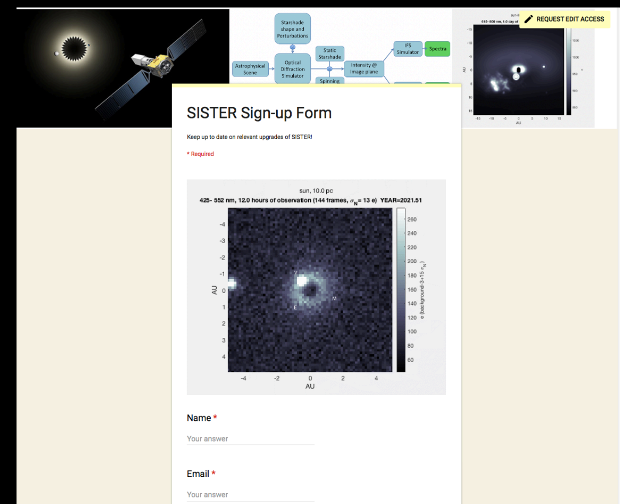
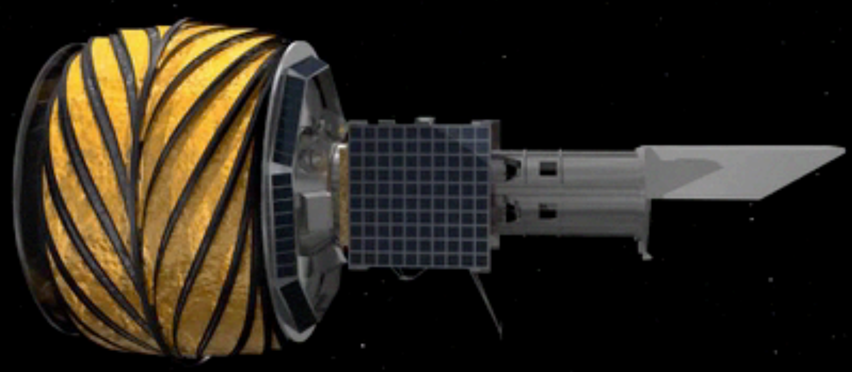


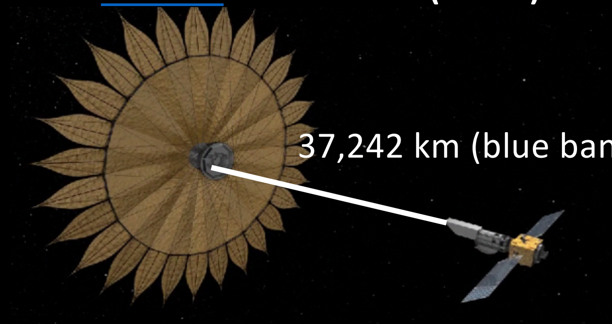
Backup Slides

Starshade in a movie



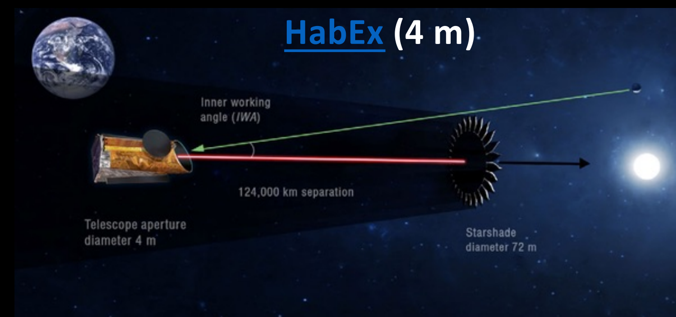
Starshade: Mission Studies

WFIRST Rendezvous (2.4 m)

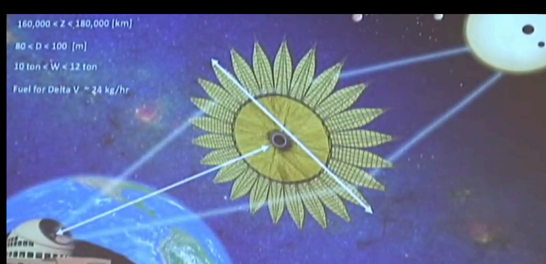


Not to scale

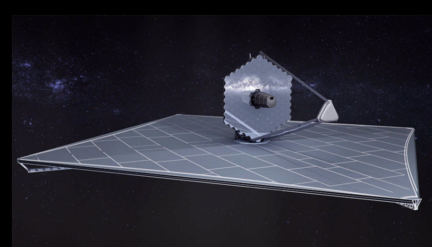
HabEx (4 m)



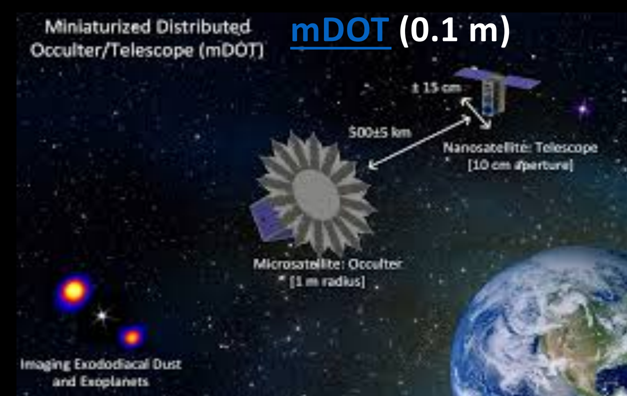
Ground telescopes (30-40 m)



LUVOIR B (8 m)



mDOT (0.1 m)



Optical Diffraction

Boundary diffraction wave integrals for diffraction modeling of external occulters

Eric Cady*

Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA, 91109 USA

*eric.j.cady@jpl.nasa.gov

Abstract: An occulter is a large diffracting screen which may be flown in conjunction with a telescope to image extrasolar planets. The edge is shaped to minimize the diffracted light in a region beyond the occulter, and a telescope may be placed in this dark shadow to view an extrasolar system with the starlight removed. Errors in position, orientation, and shape of the occulter will diffract additional light into this region, and a challenge of modeling an occulter system is to accurately and quickly model these effects. We present a fast method for the calculation of electric fields following an occulter, based on the concept of the boundary diffraction wave: the 2D structure of the occulter is reduced to a 1D edge integral which directly incorporates the occulter shape, and which can be easily adjusted to include changes in occulter position and shape, as well as the effects of sources—such as exoplanets—which arrive off-axis to the occulter. The structure of a typical implementation of the algorithm is included.

OCIS codes: (050.1940) Diffraction; (050.1970) Diffractive optics; (070.7345) Wave propagation; (120.6085) Space instrumentation; (350.6090) Space optics.

References and links

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#168276 - $15.00 USD Received 9 May 2012; revised 1 Jun 2012; accepted 5 Jun 2012; published 21 Jun 2012
(C) 2012 OSA 2 July 2012 / Vol. 20, No. 14 / OPTICS EXPRESS 15196

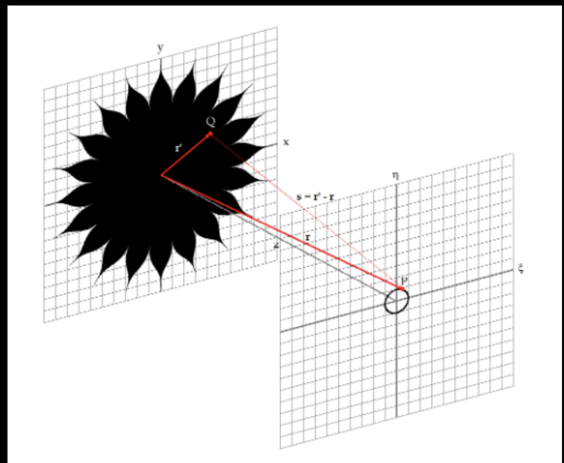
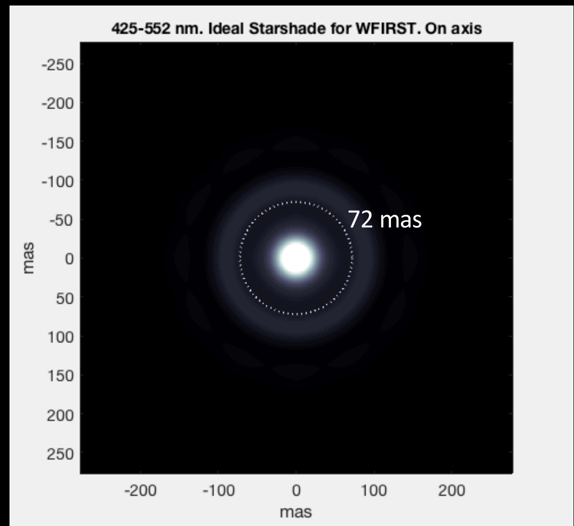


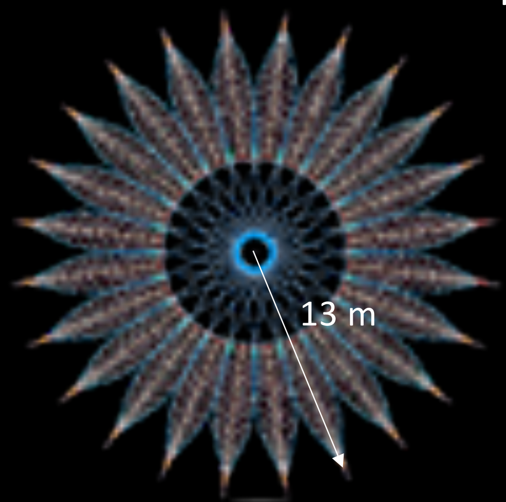
Fig. 2. A diagram of the points, coordinate systems, and vectors used in this paper. The left grid is in the plane of the occulter, and the right grid in the plane of the telescope aperture.

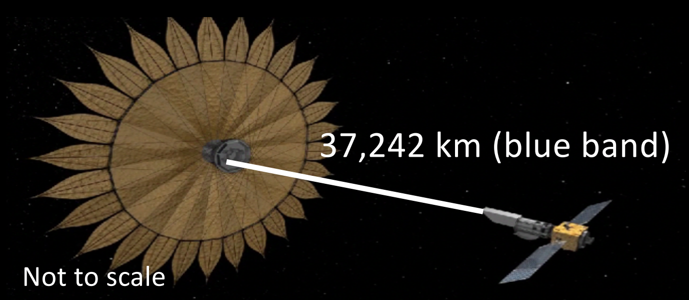


Eric's approach: the 2D structure of the occulter is reduced to a 1D edge integral using Stokes's theorem and a vector potential.

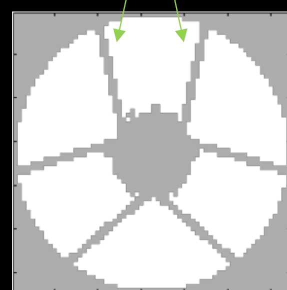
SISTER PSF Basis

Ideal WFIRST Starshade of 24 petals



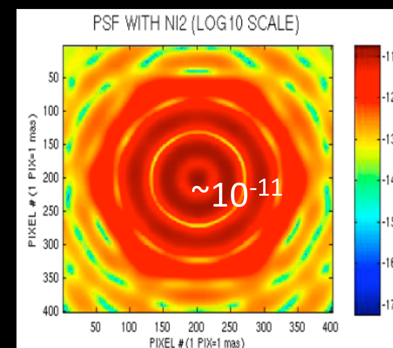


WFIRST Pupil
Struts

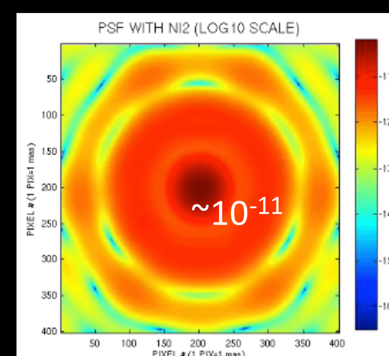


Relative intensity of the blocked star.
Non-spinning starshade

425 nm

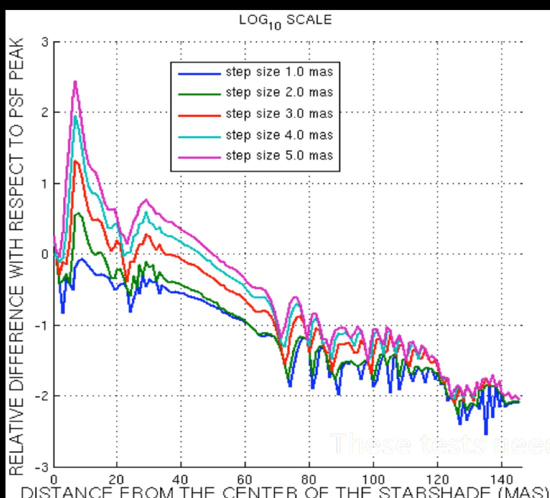


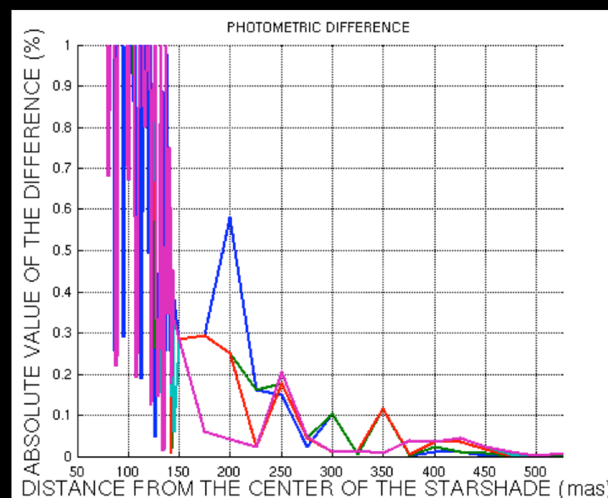
552 nm

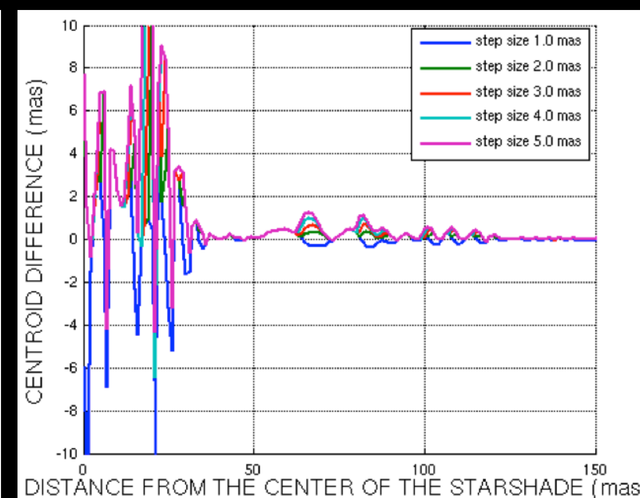


SISTER PSF Basis

The PSF basis consists of a library that depends on the spatial location on the image plane, pixel scale, and wavelength step*.
Example: testing precision with the spatial step on the image plane







These tests need to be done for each starshade-telescope-filter combination

* S.R. Hildebrandt, S.B. Shaklan, E.J. Cady, and M.C. Turnbull (2019). In preparation.