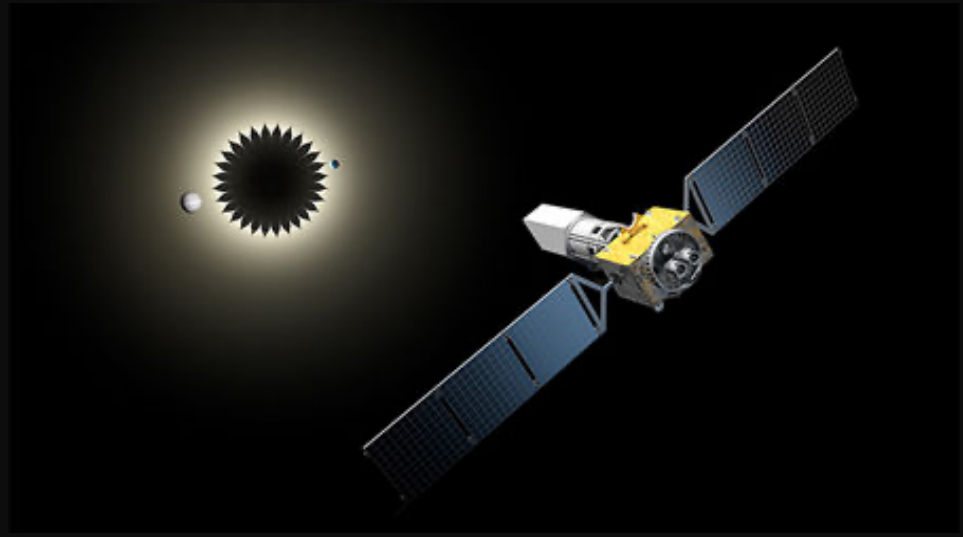
Jet Propulsion Laboratory
California Institute of Technology

Starshade Exoplanet Data Challenge
Simulated Data



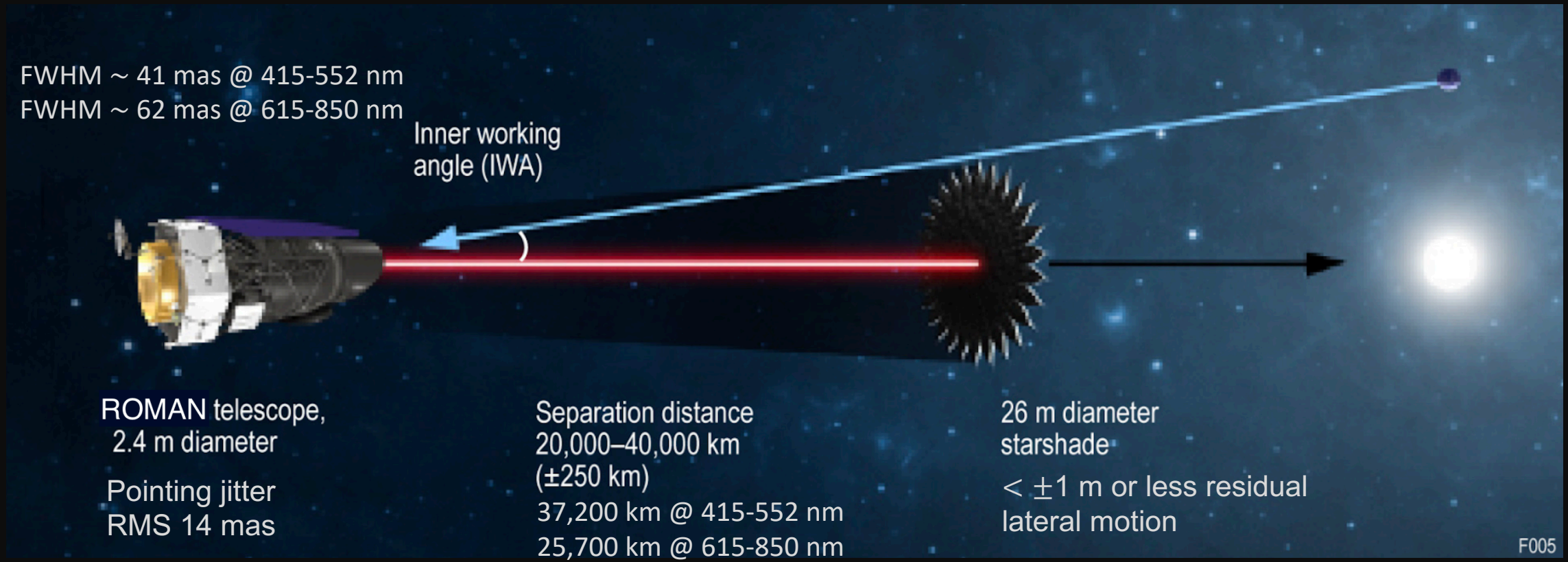
Sergi R. Hildebrandt, JPL/Caltech, on behalf of the SEDC team

01/27/21

Starshade Exoplanet Data Challenge
Simulated Data

- Missions in the SEDC
- SEDC Simulated data
- An example

Starshade Rendezvous Probe*



The 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). For the 615-850 nm (extended) passband, it is **104.3** mas.

(*) S. Seager, J. Kasdin, and the Starshade Rendezvous Probe team (2019) https://www.saraseager.com/wp-content/uploads/2020/07/Starshade2.pdf
A. Romero-Wolf et al. (2021). Accepted for publication in JATIS. https://arxiv.org/abs/2101.01272

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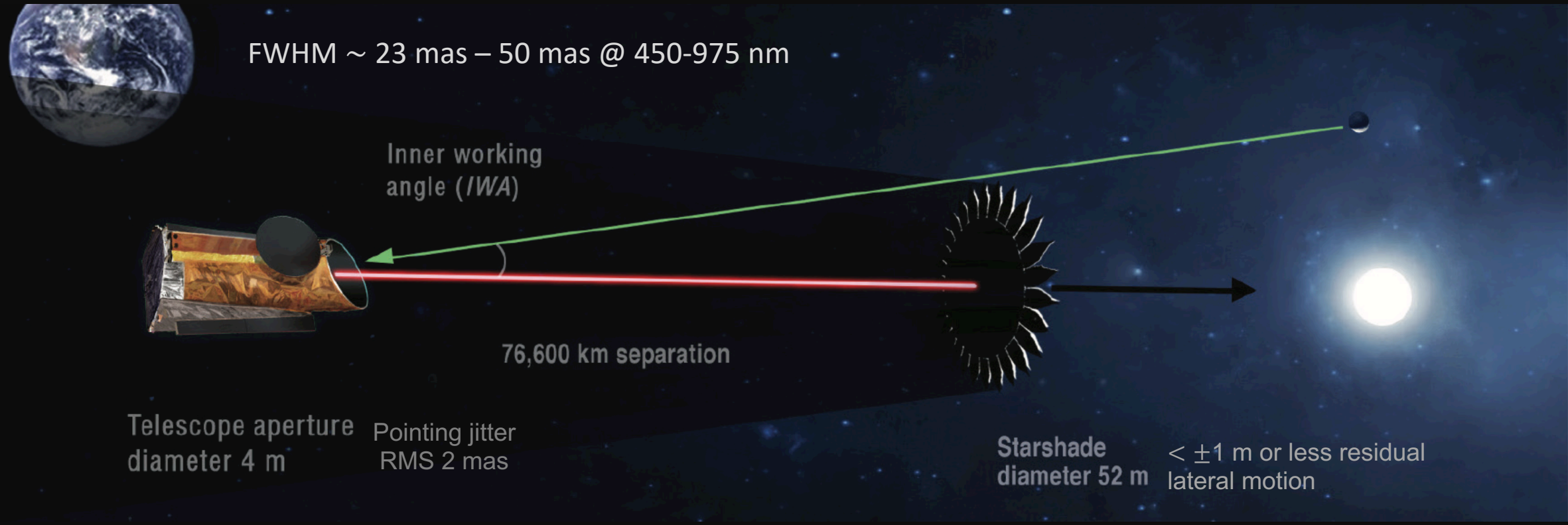
HabEx Starshade*



Starshade geometric IWA in the UV 300-450 nm and VIS 450-975 nm passbands is **70** mas.
For the NIR 975-1800 nm passband, the IWA is **126** mas and the nominal range is 42,600 km.

(*) S. Gaudi, S. Seager, B. Mennesson, A. Kiessling, K. Warfield, and the Habitable Exoplanet Observatory Study Team
https://www.jpl.nasa.gov/habex/

01/27/21

Simulated Data

- SISTER
- First Release

Jet Propulsion Laboratory
California Institute of Technology

SISTER: sister.caltech.edu

S. Hildebrandt, S. Shaklan, E. Cady & M. Turnbull (2021, JATIS, to be published)

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

Sign-up SISTER Handbook SISTER Imaging Basis GitHub

SISTER Examples

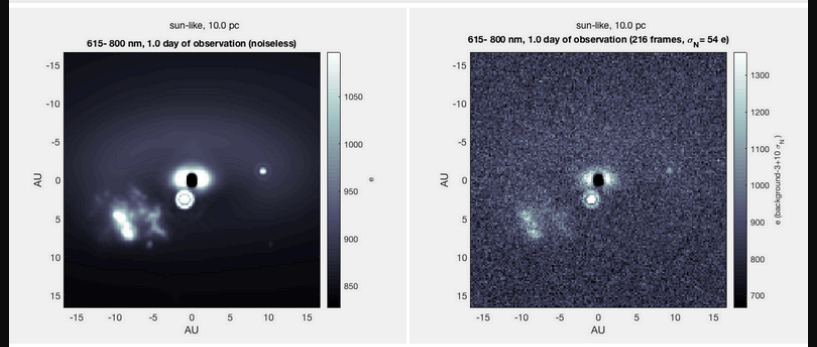


Figure 3.1: WFIRST RENDEZVOUS MISSION (GREEN BAND): Left: Noiseless simulation with SISTER of the solar system with some background objects at 10 pc and with an inclination of 60 degrees (Data from the Haystacks Project with local zodiacal light added). Right: Same as left, but including detector noise (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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SISTER: Starshade Imaging Simulation Toolkit for Exoplanet Reconnaissance

Sergi R. Hildebrandt[i,a,b], **Stuart B. Shaklan**[a], **Eric J. Cady**[a], **Margaret C. Turnbull**[c,a]
[a]Jet Propulsion Laboratory. 4800 Oak Grove Dr. La Cañada Flintridge, CA 91109, USA
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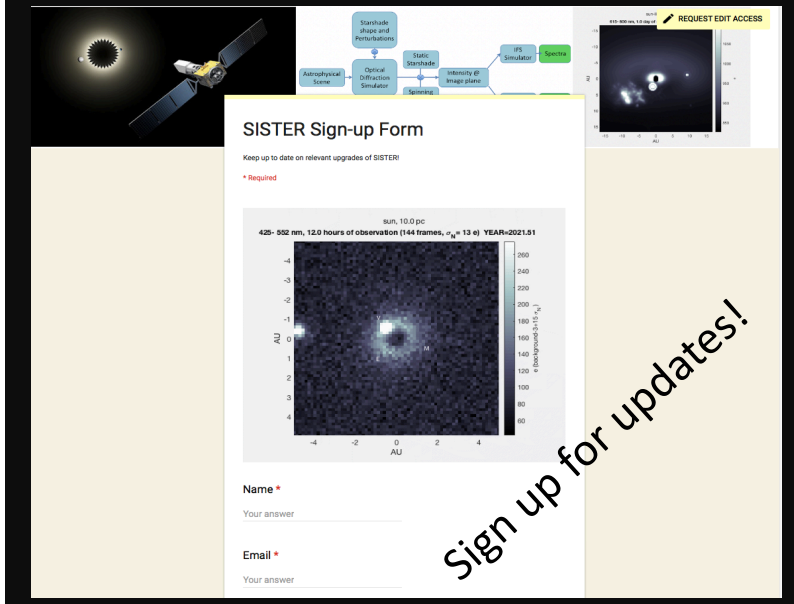
[c]SETI Institute, Carl Sagan Center for Life in the Universe. Off-Site: 2613 Waunona Way, Madison, WI 53713, USA

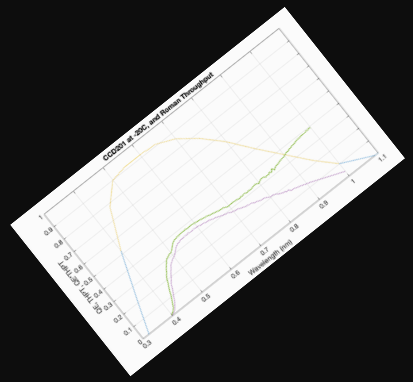
Abstract. SISTER (Starshade Imaging Simulation Toolkit for Exoplanet Reconnaissance, sister.caltech.edu[ii] is a versatile tool designed to provide accurate models of the images of exoplanet systems when observed with a starshade positioned to block the light from the host star. SISTER allows one to control a set of observational parameters including: (1) the Starshade design, position, orientation, and glint properties; (2) the telescope and optical system pupil, aberrations, bandpass, and throughput including a detector model; (3) the exoplanetary system, including stellar distance and spectral type, parallax and proper motion, planet size, reflection properties, orbital parameters, and exozodiacal dust; and (4) background objects. Additionally there is a substantial library of built-in plotting software added, but the simulations may be stored on disk and be plotted with any other software. This paper describes SISTER's algorithms, its operational modules, and presents several imaging examples.

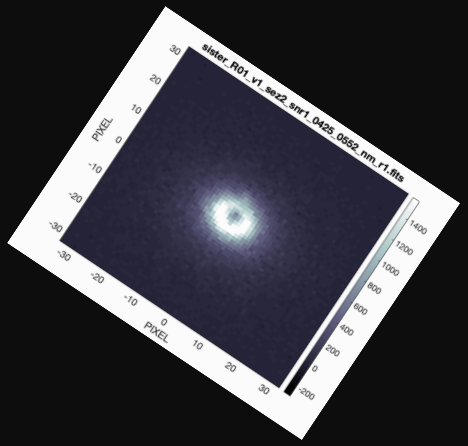
Keywords: Starshade, Exoplanets, Imaging Simulations.

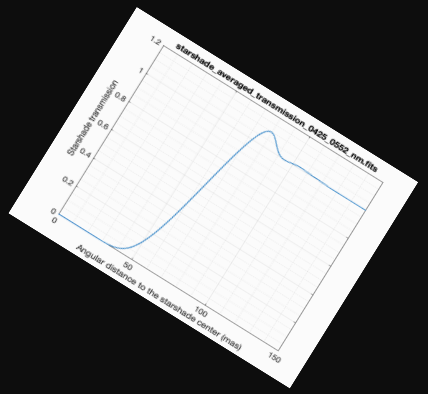


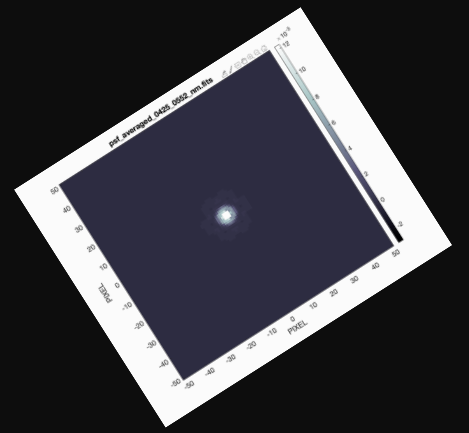
01/27/21

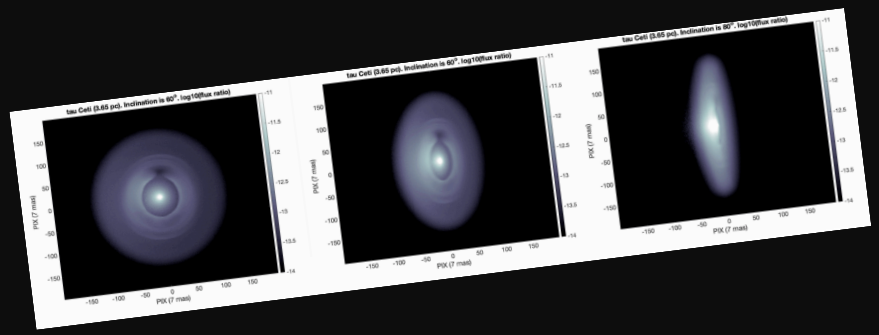
First Release

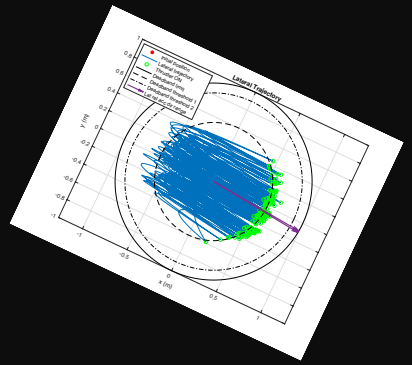












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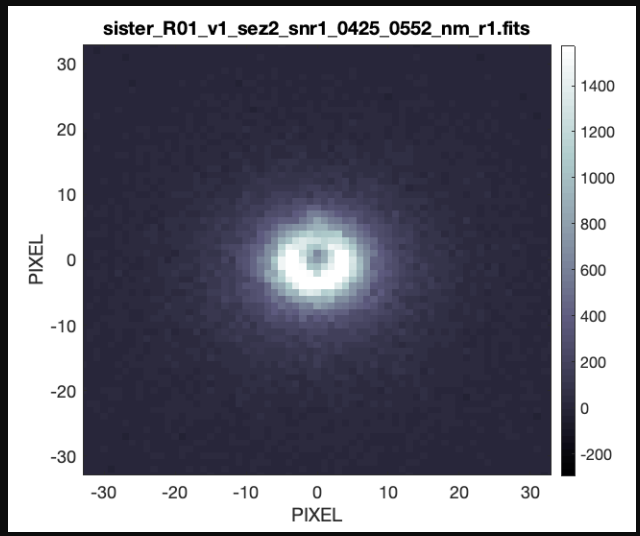
Instrumental Scenarios

- The Starshade Rendezvous 425-552 nm passband
- Imperfect starshade petals with a degraded performance within mission requirements (contrast at IWA=10^{-10})
- Residual motion from realistic formation flying simulations
- Solar glint: coated edges. Static: median orientation during observations
- Roman optical throughput
- Detector QE from vendor
- EMCCD parameters as defined in Roman's IPAC website
- Telescope's pointing jitter RMS 14 mas
- Three integration times to produce low, medium and high SNR

- Other effects that will be included in the next release that were dimmer than the previous effects are straylight from micrometeorite, Earth, Jupiter, and Milky Way shine

Astrophysical Scenarios

- 4 host stars: tau Ceti, eps Indi A, sig Draconis, beta CVn between 3.5 and 9 pc.
- A total of 10 astrophysical scenarios with these 4 host stars that have some exoplanets with some visual inclination (undisclosed)
- Realistic atmospheric models in the 425-552 nm band (undisclosed)
- First of two visits (every few months)
- Smooth exozodiacal cloud model (~solar system) with some forward scattering (undisclosed)
- Extragalactic background (undisclosed)
- Local zodiacal light (undisclosed)
- Total of 30 files: 10 scenarios x 3 integration times/each.
- Public: anyone can download and publish their results

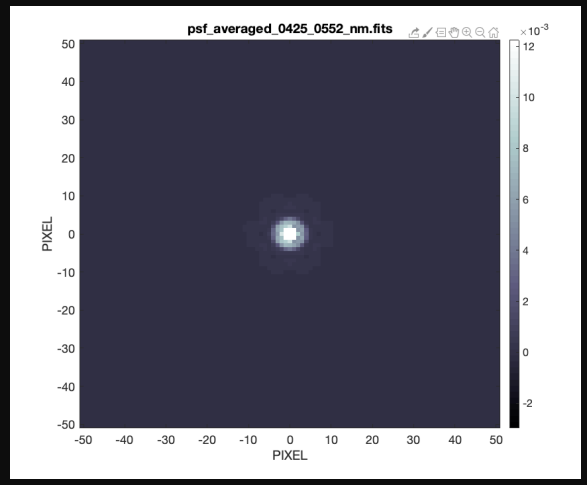


Example scenario with low SNR

- Other components that will be included in forthcoming releases are additional passbands for Starshade Rendezvous and HabEx, two complete visits for each astrophysical scenario, resonant cloud exozodiacal models, and some specific scenarios with a further degraded instrumental performance. See *Renyu Hu's* presentation on logistics.

Calibration Data

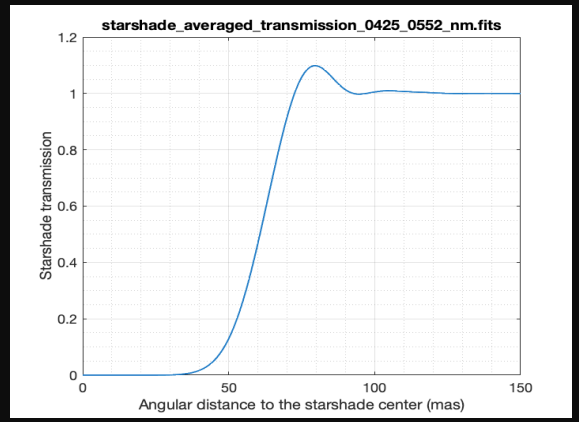
- **PSF response at different angular distances from the starshade:**



PSF at IWA

FWHM ~ 41 mas

- **Starshade average transmission:**



Calibration data are helpful to estimate the astrometry and photometry of the data.

- **Similar files will be included for the other passbands in Starshade Rendezvous and HabEx as more data are released.**

Data files

- 30 data FITS files + 2 Calibration FITS files. Open to anyone interested
- Detailed public documentation available at the SIP website
- Each file has a complete set of Keywords with all the relevant instrumental and astrophysical (disclosed) information, e.g., star's flux (STARFLX)

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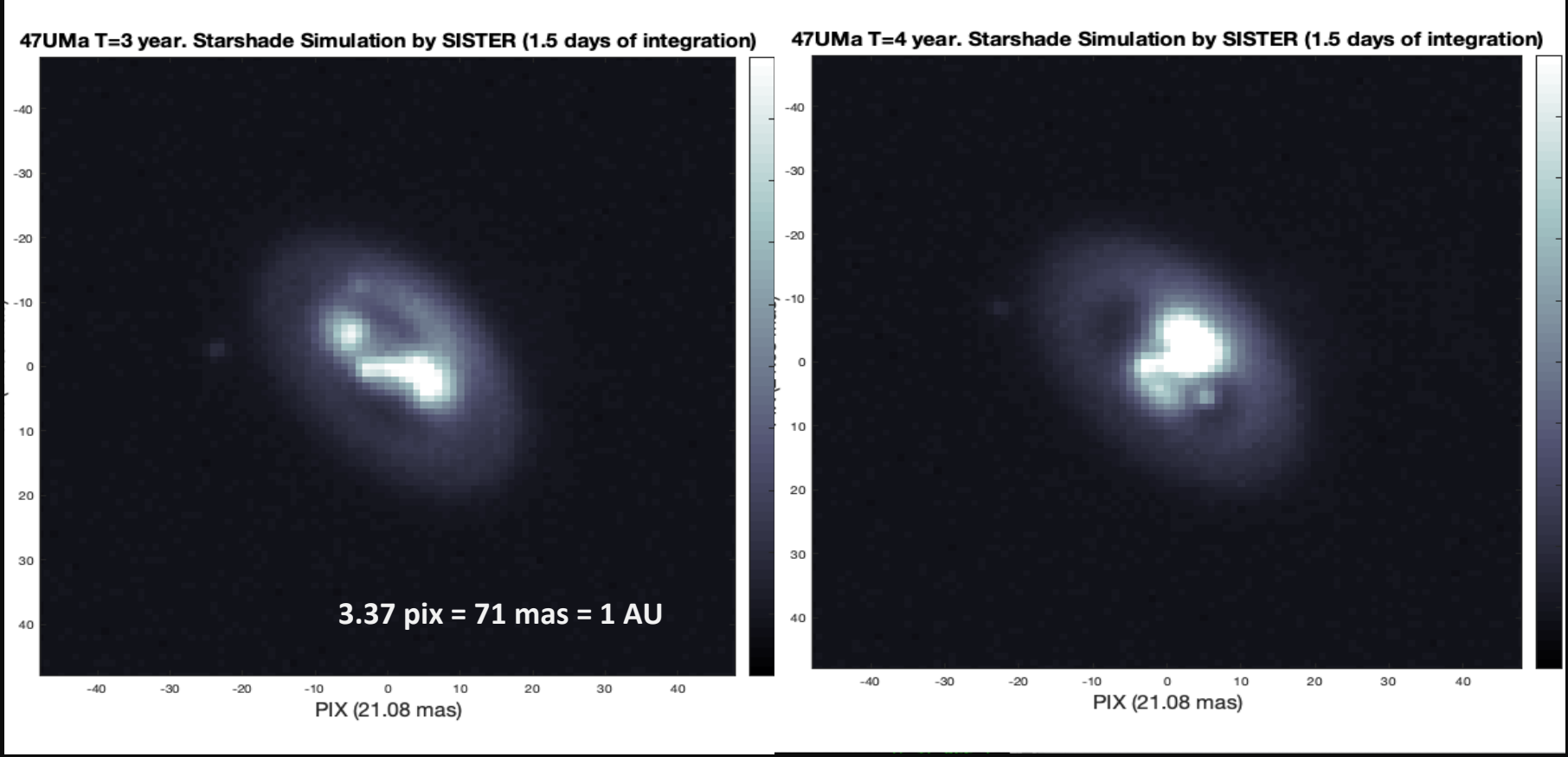
An Example

Jet Propulsion Laboratory
California Institute of Technology

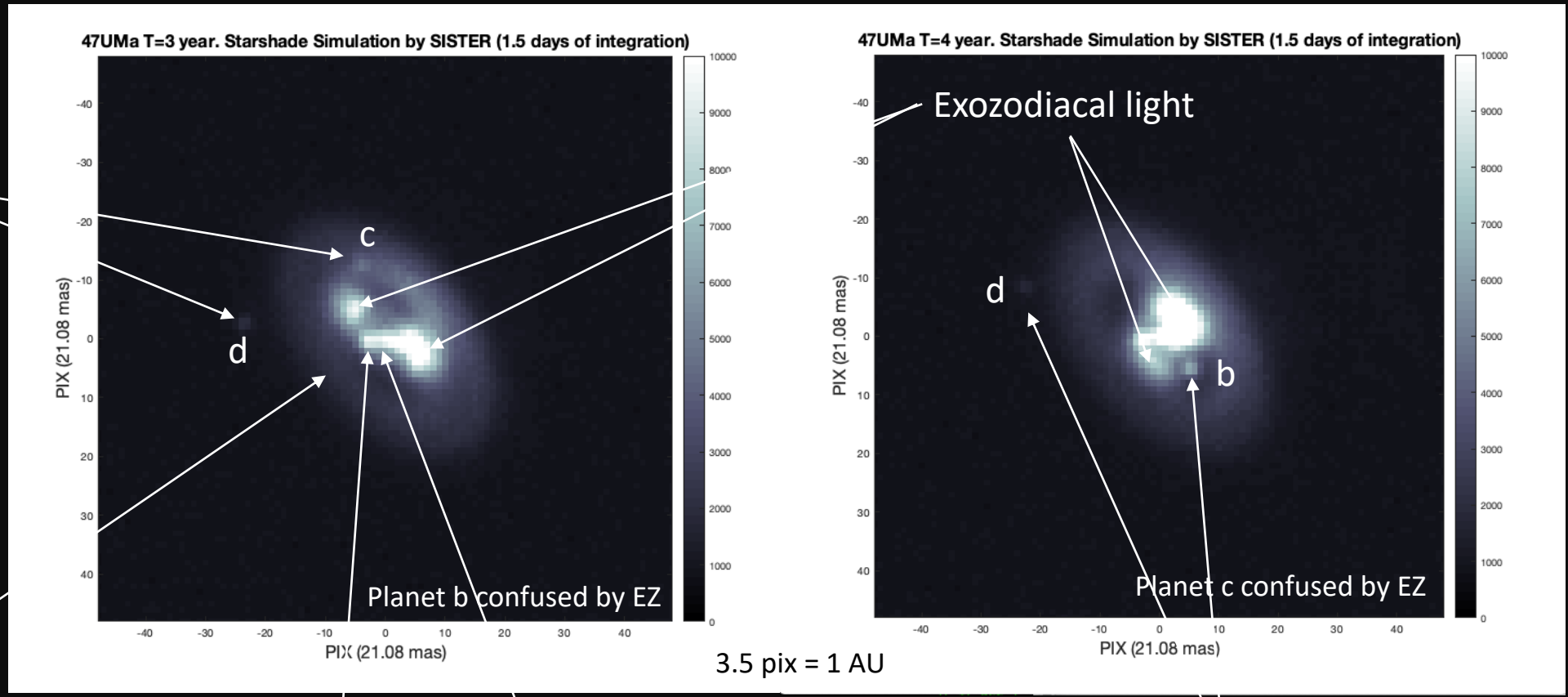
Starshade Epochs in the Roman CGI Exoplanet Data Challenge 2019-20*
Blind search of exoplanets for one scenario with 4 Roman CGI images and 2 Starshade Rendezvous images and precursor RV data. Goal: detection, orbit determination and photometry. Papers submitted and/or to be submitted.



01/27/21 (*) https://www.exoplanetdatachallenge.com PI: M. Turnbull, CGI SIT

An Example

Starshade Epochs in the Roman CGI Exoplanet Data Challenge 2019-20*



Exoplanets
FR_c=5.6x10 ^{10},
FR_d=6.9x10 ^{10}

3.5 pix = 1 AU

Remaining Starlight

Solar Glint (10x than nominal)

Exoplanets
FR_b=2.4e-9, FR_d=4.8e-10

01/27/21

https://www.exoplanetdatachallenge.com PI: M. Turnbull, CGI SIT

Questions …

Mario Damiano will later introduce the communication channels between the SEDC team and the participants