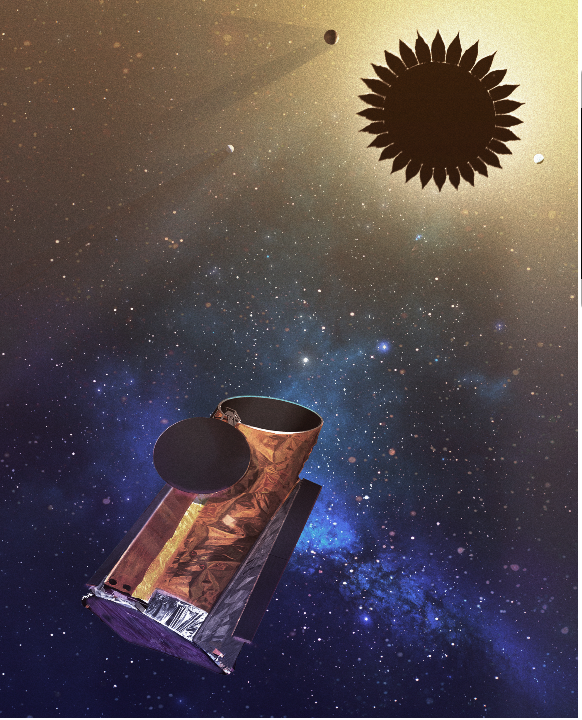

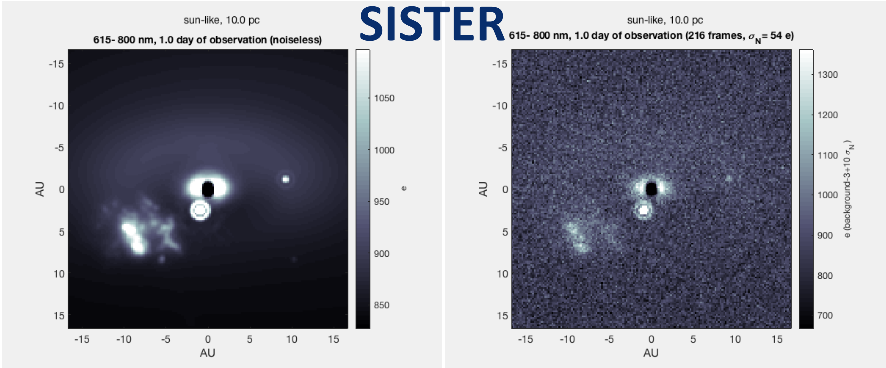

Virtual Research Presentation Conference

Orbit Determination via Image Simulation and Processing for Exoplanet Direct Imaging Missions

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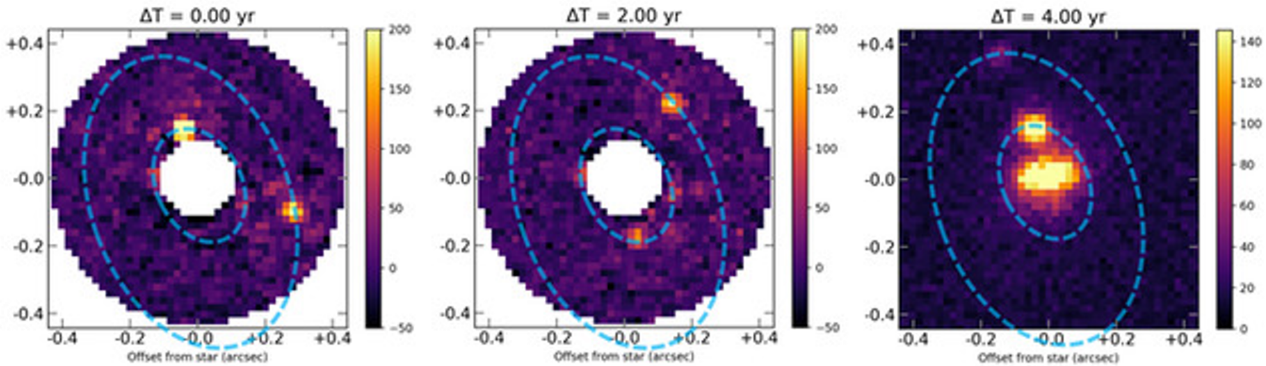
Program: SURP

Assigned Presentation RPC-021

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

Exoplanet Direct Imaging missions will generate images of exoplanet systems observed by using some method of occulting the host star.



source: https://roman.ipac.caltech.edu/sims/Exoplanet_Data_Challenges.html

Problem Description

Question 1) What is the best way to process images of exoplanets taken with a Starshade?

- How robust is this image processing to detector noise?
- What happens if there are exoplanets observed using a Starshade that are at an angular separation from their host star that is between the tips of the Starshade petals?

Question 2) What observations do we need to be able to understand a multi-planet system? We will have multiple planets in several epochs and there will likely be confusion in knowing which is which.

Methodology

Task 1:

- Use JPL “SISTER” software to simulate observations of exoplanets and process the results:
  - Assess impact of diffraction on exoplanets observed between Starshade petals
  - Assess impact of detector noise on exoplanet detection and characterization

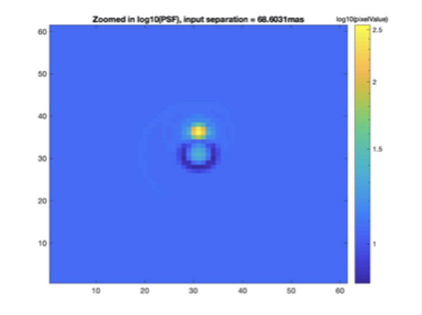
Task 2:

- Evaluate current tools for exoplanet orbit-fitting
- Develop new methods to manage likely confusion in not knowing which planet is which in different image epochs

Results - Task 1, Starshade image simulation

Goals:

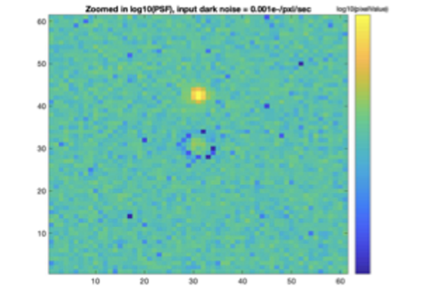
- Image simulation and processing for Starshade Image
- Starshade Image Simulation Tool parameterization incorporated into EXOSIMS
- Trade study of image processing approaches
- Image processing parameterization incorporated into EXOSIMS



Accomplishments:

• Used JPL SISTER tool to simulate Starshade images
• Tested different methods to detect planet location
• Tested image processing methods robustness to detector noise, planet location between Starshade tips

Significance: We determined through simulation that a matched filter is an effective and robust way to process Starshade observation data. We found that this image processing approach is robust to detector noise levels that are expected throughout the mission. We also found that Starshade observations are not significantly affected when the exoplanet is observed between the tips of the Starshade petals.



Next steps: Summarize the likely knowledge obtained per Starshade observation based on SISTER simulations, parameterize result and incorporate into mission simulation software (descoped due to shorter time of grant vs proposal)

Results - Task 2, Multi-Planet Orbit Fitting

a) Accomplishments versus goals

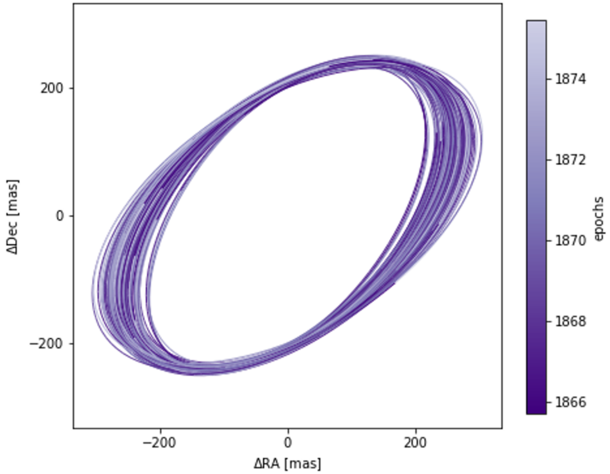
Goals: Expand EXOSIMS to handle multi-planet systems and understand its performance

Deliverables:

- Adaptation of universe simulator to produce dynamically feasible multi-planet systems
- Adaptation of "orbitize!" [1] output to account for interplanetary interactions
- Study speed and performance of orbit fitting algorithms for multi-planet systems

Accomplishments:

- Performed trade study between OFTI [2] and MCMC [3] for single planet and multiplanet systems



a) Significance: Capabilities for fitting orbits of multiplanet systems that will aid in determining future observation times and observation cadence

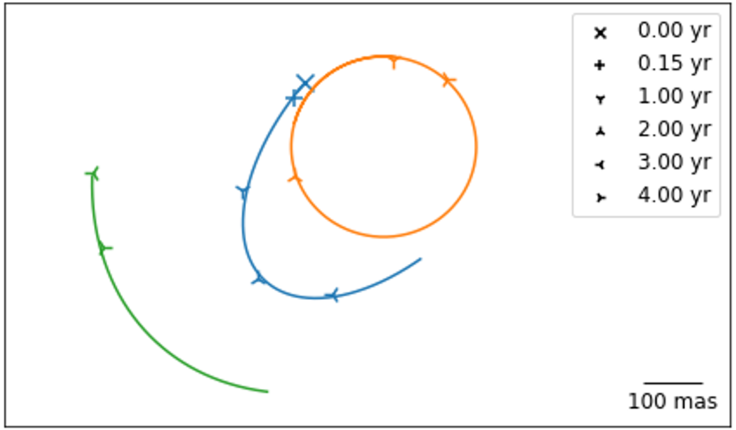
b) Next steps

- Further testing of multiplanet fitting capabilities in "orbitize!"
- Incorporate interplanetary interactions into the orbit fitting algorithms
- Incorporate planet deconfusion techniques into software package

Results - Task 2, Planet Deconfusion

Goal: Automatically match detection across multiple observations to planets in a multiplanetary system.

Accomplishments: Proof on concept algorithm working on Roman CGI data challenge.



a) Significance

Deconfusing planet detections, missing detections and false positives is a necessary step before fine trajectory fitting (e.g. using OFTI).

a) Next steps

A Monte Carlo study of various planetary systems and observation schedules to determine the minimal number of observations and their spacing to successfully characterize a multi-planet system.

Publications and References

[1] Blunt, S., Wang, J. J., Angelo, I., Ngo, H., Cody, D., De Rosa, R. J., Graham, J. R., Hirsch, L., Nagpal, V., Nielsen, E. L., Pearce, L., Rice, M., & Tejada, R. (2020). orbitize!: A Comprehensive Orbit-fitting Software Package for the High-contrast Imaging Community. The Astronomical Journal, 159, 89. https://doi.org/10.3847/1538-3881/ab6663

[2] Blunt, S., Nielsen, E. L., De Rosa, R. J., Konopacky, Q. M., Ryan, D., Wang, J. J., Pueyo, L., Rameau, J., Marois, C., Marchis, F., Macintosh, B., Graham, J. R., Duchêne, G., & Schneider, A. C. (2017). Orbits for the Impatient: A Bayesian Rejection-sampling Method for Quickly Fitting the Orbits of Long-period Exoplanets. The Astronomical Journal, 153, 229. https://doi.org/10.3847/1538-3881/aa6930

[3] Foreman-Mackey, D., Hogg, D. W., Lang, D., & Goodman, J. (2013). emcee: The MCMC Hammer. Publications of the Astronomical Society of the Pacific, 125, 306. https://doi.org/10.1086/670067

SISTER software documentation/source code available at: sister.caltech.edu