Improving Image Processing for Exoplanet Imaging with the Nancy Grace Roman Space Telescope Coronagraph Instrument (CGI)

Section 326, SIRI Internship Program
Presented by Kenneth Casimiro
Pronouns (He/Him/His)
Mentor/Co-Mentor: Dr. Marie Ygouf and Dr. Vanessa Bailey

May 24, 2021

Jet Propulsion Laboratory
California Institute of Technology

Introduction

Background Information

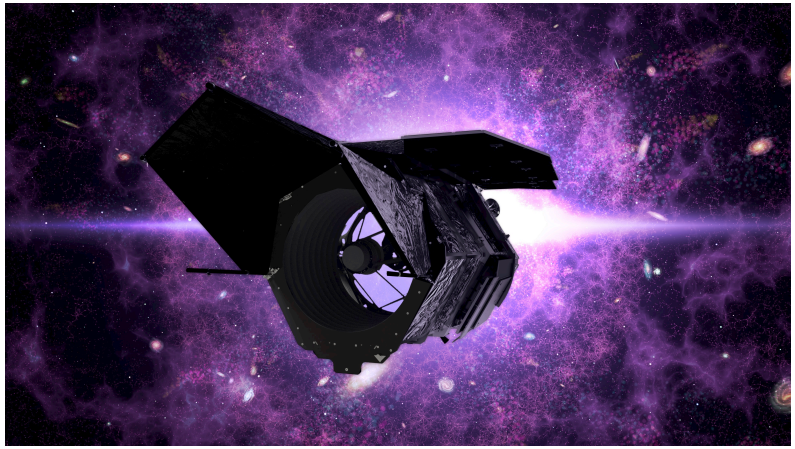
Direct Imaging: taking a picture of a planet next to its star.

- Contrast: Ratio of flux (starlight) between the star and the planet.

Rationale

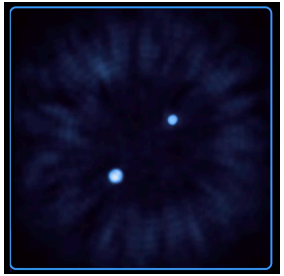
- Roman CGI capable of detecting and characterizing exoplanets.
- Technology demonstrator in preparation for future missions
- Process of direct imaging observations are not perfect, innovative post-processing techniques are being developed for the limitations of CGI.

Nancy Grace Roman Space Telescope



Before Post-Processing

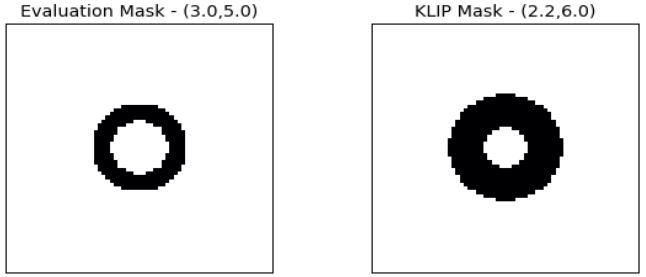
After Post-Processing

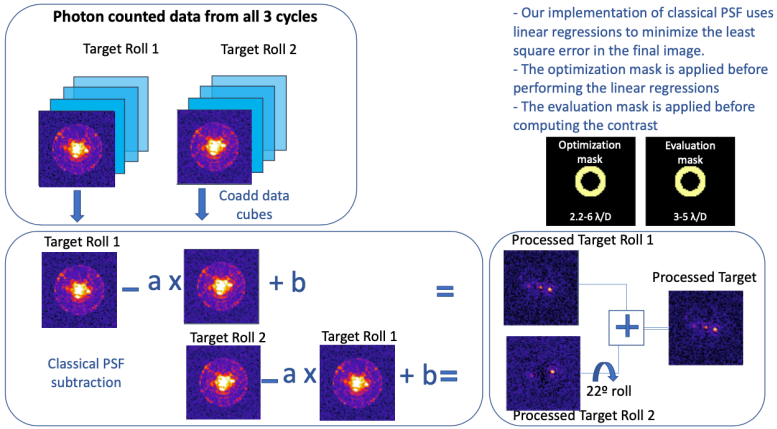


Introduction

Summary

- Develop post processing tools for the Roman Coronagraph Instrument (CGI) for Exoplanet Imaging
- Project: Improve contrast by region selection
- Post-Processing: Quality-improvement of images to return the most information possible.
- Post-Processing techniques:
  - Classical Reference Star Differential Imaging (cRDI)
  - Classical Angular Differential Imaging (cADI)
  - RDI-KLIP
- Units for contrast: 5 σ (sigma) sensitivity



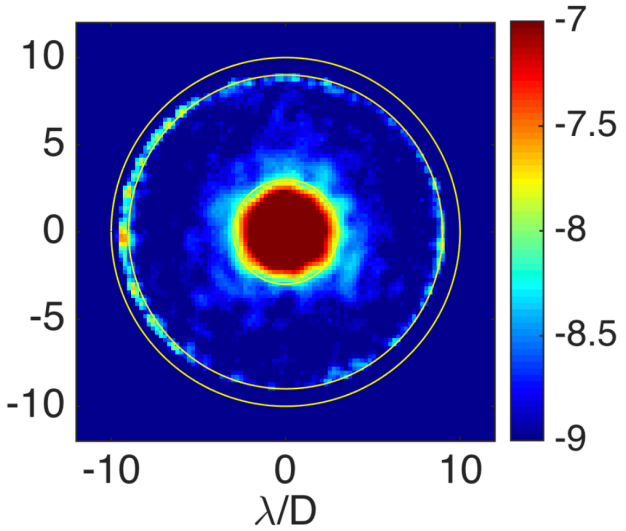


Performing classical angular differential imaging (cADI) PSF subtraction on OS9 Hybrid Lyot Coronagraph data

Introduction

Background Information

- Simulated Dataset: Will be using the simulated Observing Scenario (OS) 9 time series simulations for the Hybrid Lyot Band 1
- Model Uncertainty Factors (MUF): Imperfections and uncertainty that can factor into the data.
- The datasets that I worked with are:
  - Noiseless without planets with and without Model Uncertainty Factor (MUF)
  - Noiseless with planets with and without MUF
  - Noisy without planets with and without MUF
  - Noisy with planets with and without MUF
- Unprocessed datasets are publicly available at the Infrared Processing and Analysis Center (IPAC) website

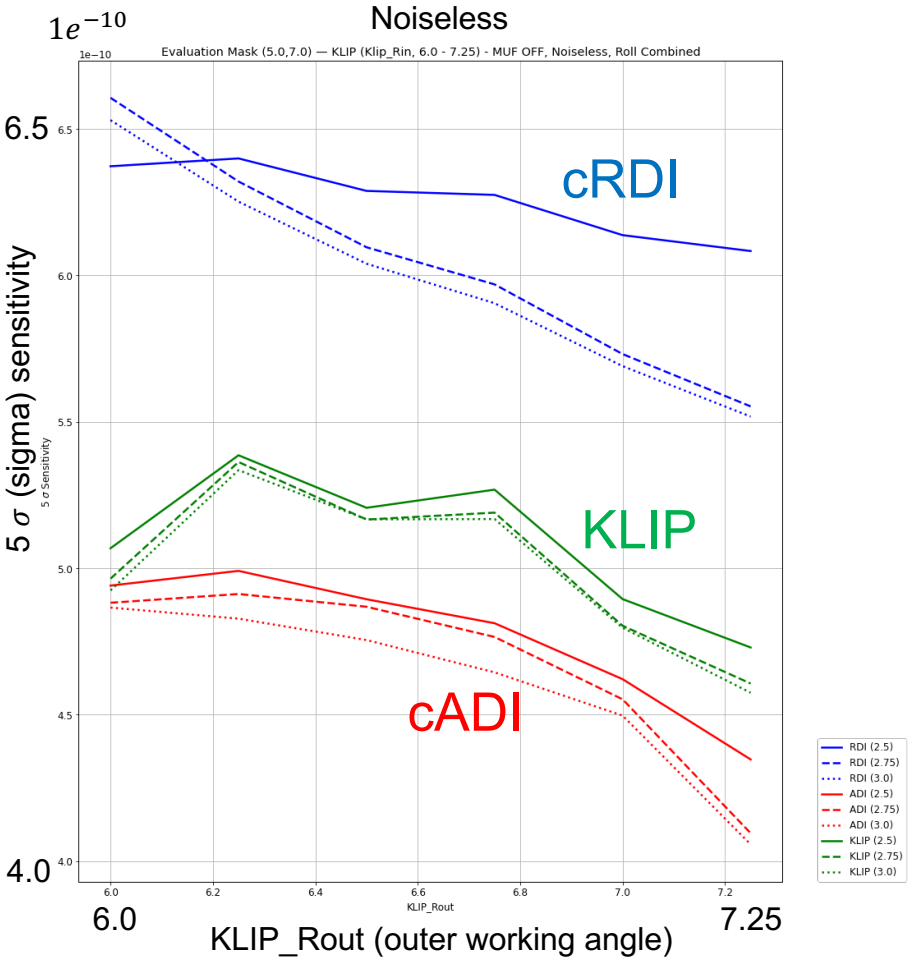


(a) Hybrid Lyot

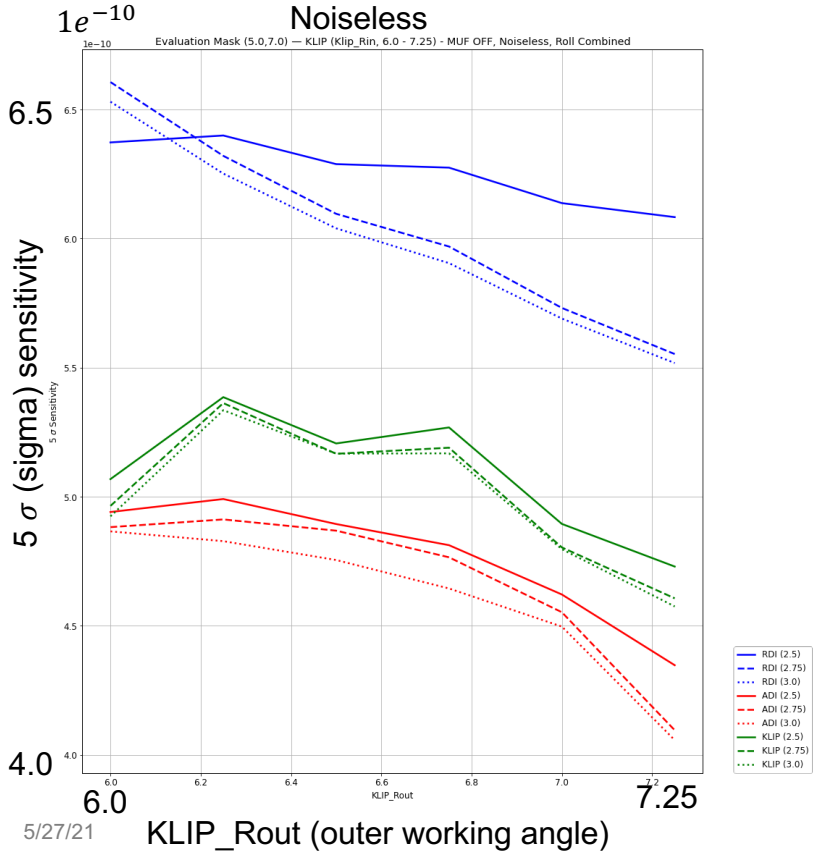
Method

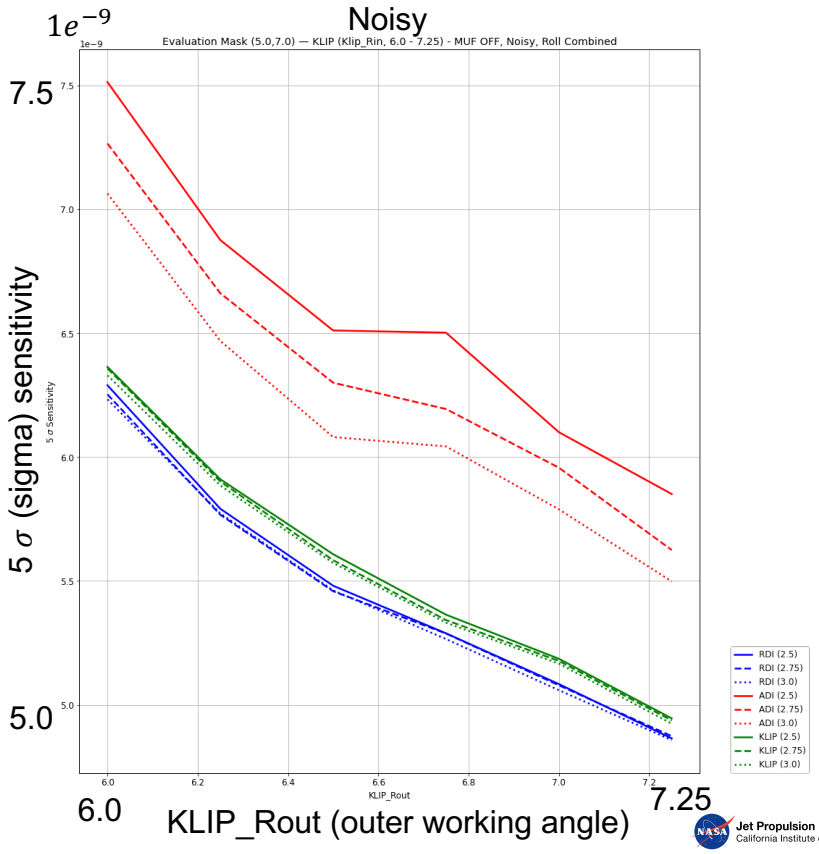
Data Visualization and analysis of optimal regions for post-processing techniques

- Primary method will be to produce graphs with the Matplotlib library in the Python program.
- Created iterations in the program to run through each dataset.
- Store each plotted post-processing technique.
- Produce the graphs that show the relationship between the increase of the outer angle of the KLIP mask (x-axis), and the contrast calculated for respective post-processing technique (y-axis, 5 σ sensitivity) .



Results — Data Visualization
Evaluation Mask (5 — 7 λ/D) – MUF OFF





Results — Recommendations for Optimal Regions.

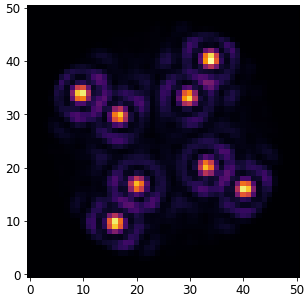
	MUF OFF, Noiseless	MUF OFF, Noisy	MUF ON, Noiseless	MUF ON, Noisy
cADI	3 — 4 λ/D	5 — 6 λ/D	5 — 6 λ/D	5 — 6 λ/D
cRDI	5 — 6 λ/D	4 — 5 λ/D	5 — 6 λ/D	5 — 6 λ/D
RDI-KLIP	4 — 5 λ/D	4 — 5 λ/D	5 — 6 λ/D	5 — 6 λ/D

Method

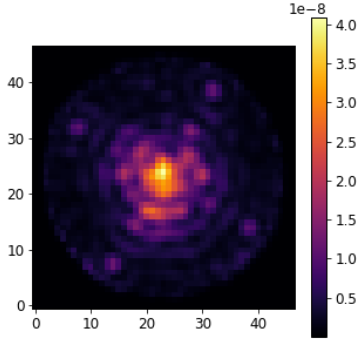
Throughput Correction

- Correcting how much of the planet light has been subtracted from the Point Spread Function (PSF) subtraction.
- Need to implement for Classical Angular Differential Imaging and (cADI) and Classical Reference Star Differential Imaging (cRDI).
- KLIP throughput correction has already been implemented
- Required to finalize the post-processed data.

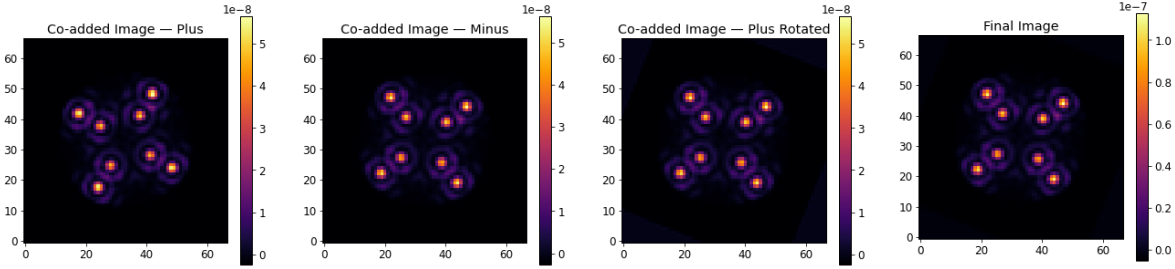
Fake Planets



Fake Planets Injection



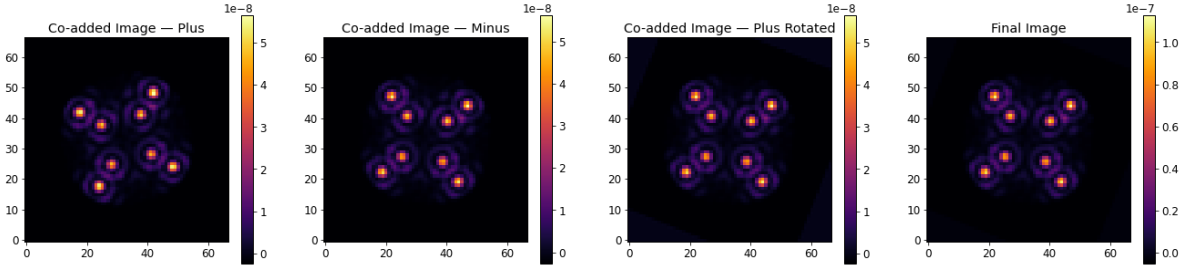
Example — Noisy Datasets



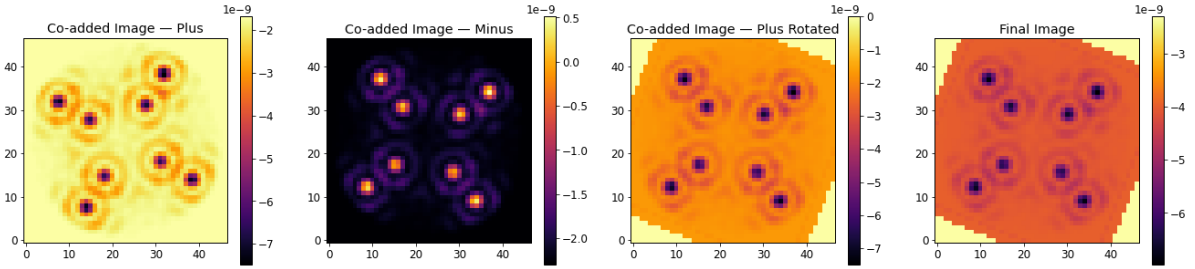
Results — Throughput Correction

- Implementation for throughput correction is working for noisy datasets but not for noiseless datasets
- Need to understand the section of the code that results in negative contrast for noiseless datasets
- Will need to be further investigated.

Noisy Datasets



Noiseless Datasets



Conclusion

- Implemented visualization of the data to show optimal region for each dataset and post-processing technique.
- Confirmed the behavior of cADI, cRDI, and KLIP in noisy and noiseless datasets.
- Recommendation to continue the project: Further implementation and investigation of the cADI and cRDI throughput correction to finalize the optimal region recommendations.
- Received hands-on experience in a professional research environment.
- Learned about high-contrast direct imaging and how software is being developed for image processing related to exoplanet research.

Acknowledgements

Thank you to Dr. Marie Ygouf and Dr. Vanessa Bailey for mentoring me and guiding me throughout this internship and allowing me to have first-hand experience in exoplanet research and software development.

Thank you to Jenny Tieu and Jessica Parker at the JPL Education Office for managing the Student Independent Research Intern (SIRI) program which allowed me to have this experience.

Dr. Marie Ygouf

Dr. Vanessa Bailey

Jet Propulsion Laboratory
California Institute of Technology