

**Jet Propulsion Laboratory**  
California Institute of Technology

# Starshade Exoplanet Data Challenge: Data Release #3

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# Data provided

- **For RST:**

- Simulated spectra of scenes with the starshade blocking the target star.
- Simulated spectra of the stars (starshade moved away from the scene).
- Line spread and dispersion function with 1 nm, 5 mas resolution.

- **For HabEX:**

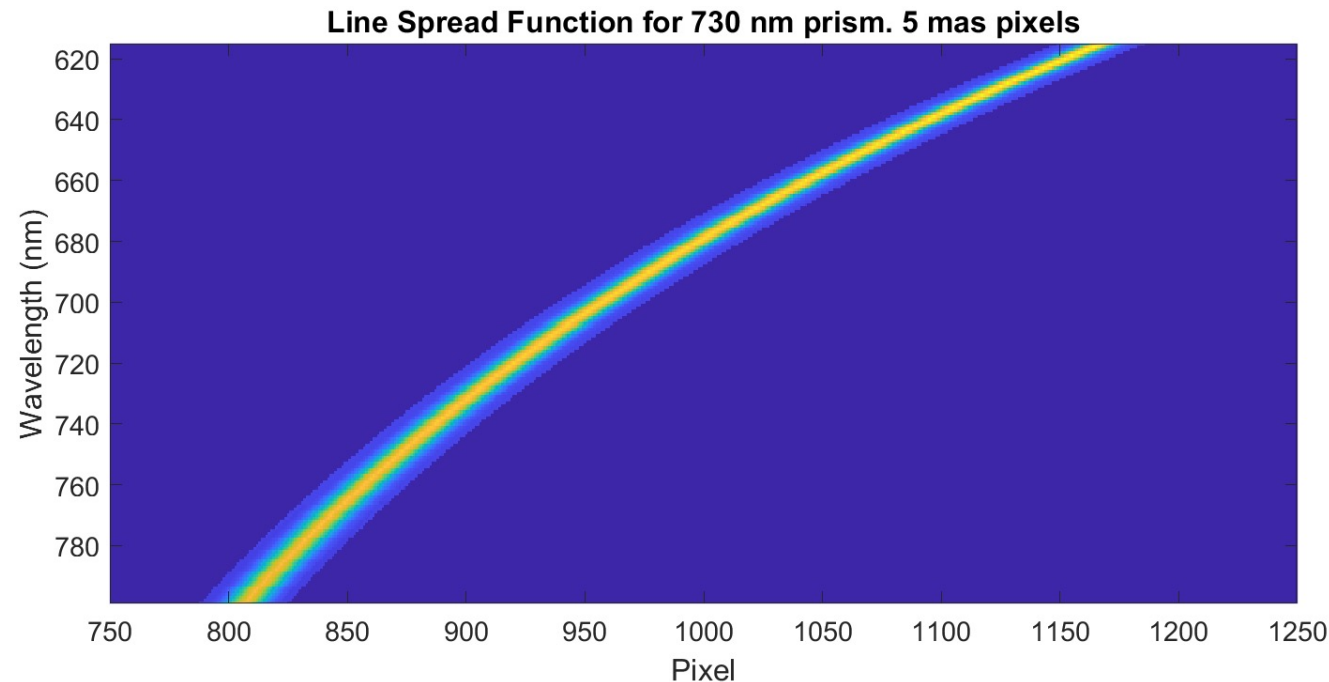
- Simulated IFS spectra of scenes with the starshade blocking the target star.
- Simulated IFS spectra of the stars (starshade moved away from the scene).
- Mapping arrays from lenslet positions to image plane positions with a wavelength resolution of 1 nm.

# RST Spectroscopy Modeling Methodology

- Follows the same approach that GSFC (N. Zimmerman) took for CGI:
  - Use a ray trace model of the prisms and lenses. Map Image plane  $(x,y,\lambda)$  to output plane  $(x',y',\lambda)$ .
    - But for speed, we use a 3<sup>rd</sup> order approximation to the distortion map, which has  $< 0.5$  mas error.
  - Treat the slit as a simple field stop: ignore diffraction since the slit is wide compared to the PSF
- Input image plane is computed with a 5 mas pixel pitch
  - Highly oversamples PSF
  - Highly oversampled compared to final CGI pixel pitch of 21.8 mas/pixel
- Map from input to output with 5 mas resolution
- Bin to 21.8 mas resolution using Matlab 'imresize' routine.
- Absolute position of spectra in image plane are not tracked, but relative position of spectra in the simulations are all consistent with the scenes.

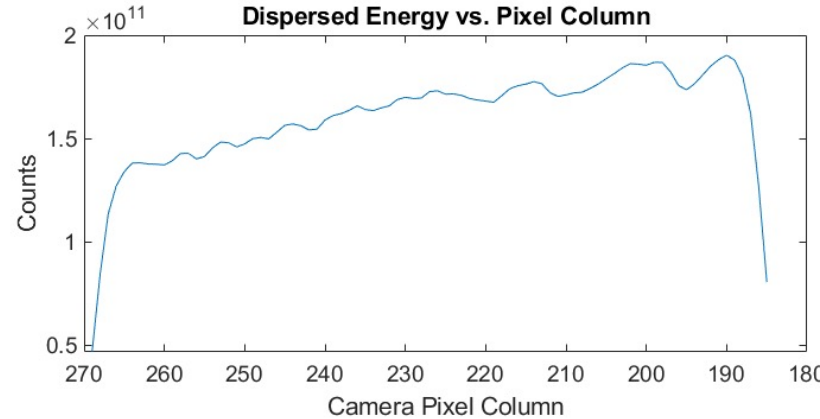
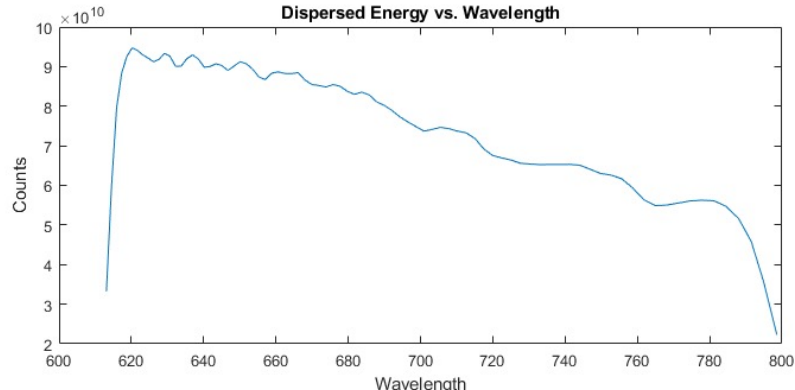
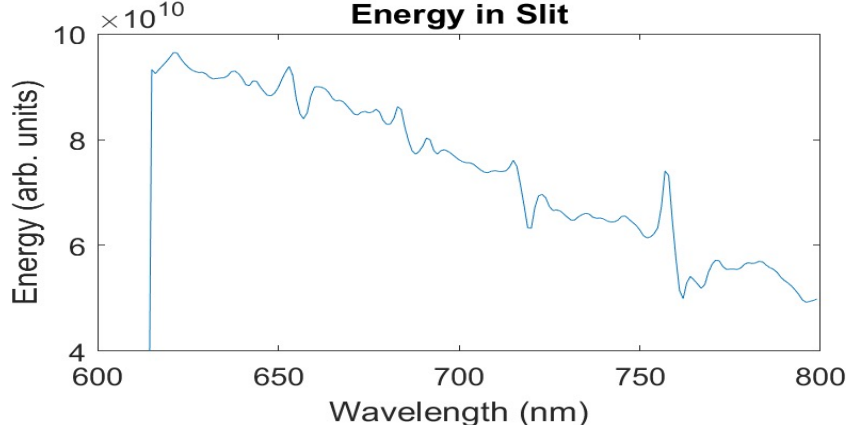
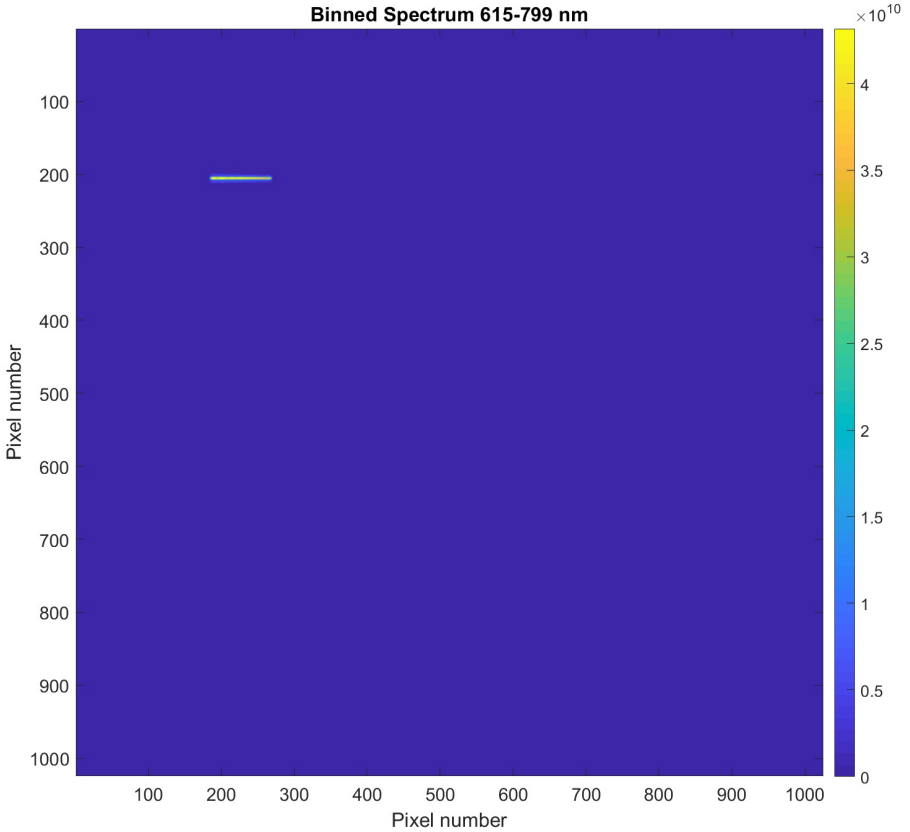
# Line Spread Function and Dispersion

- The dispersion is calculated every nm, and on a 5 mas pixel grid (compared to 21.8 mas pixels in the camera).
- Wavelength range 615 (first row) – 799 nm (last row)
- Array size is 185 (wavelengths) x 4465 (5-mas pixels)
- Absolute pixel values have no relevance.
- Each row is the summed signal of the normalized PSF at each wavelength. Since the PSF grows with wavelength, and the slit blocks some of the sidelobes, the integrated LSF power decreases slightly with wavelength.
- The LSF assumes that the star is centered in the slit.



# Example: Tau Ceti Spectrum

Spectrum with starshade removed, on 21.8 mas pixel pitch.



Integral along columns 185 – 268

21.8 mas pix

# RST Observational Configurations, all with 730 nm prism

- **case 1** ;% tau ceti SCENE 1
- load('C:\Users\shaklan\Documents\MATLAB\starshade\SISTER\config\sister\_R01\_v1\_sez1\_snr3\_0615\_0800\_nm\_r2.mat');
- outn = 'tau\_ceti\_config\_1'
- slit\_name = 'R4C6';
- disp\_pos\_mas = 110; % slit horizontal position (in the direction of the dispersion)
- orthog\_pos\_mas = 0; % slit vertical position (along the length of the slit)
- scene\_rotation\_deg = 90;
- **case 2** ;% tau ceti SCENE 2
- load('C:\Users\shaklan\Documents\MATLAB\starshade\SISTER\config\sister\_R01\_v1\_sez1\_snr3\_0615\_0800\_nm\_r2.mat');
- outn = 'tau\_ceti\_config\_2'
- slit\_name = 'R4C6';
- disp\_pos\_mas = 0;
- orthog\_pos\_mas = -400;
- scene\_rotation\_deg = 90;
- **case 3** ;% sigma draconis planets epoch 1 SCENE 1
- load('C:\Users\shaklan\Documents\MATLAB\starshade\SISTER\config\sister\_R05\_v2\_sez2\_snr3\_0615\_0800\_nm\_r2.mat');
- outn = 'sigma\_draconis\_config\_3'
- slit\_name = 'R4C6';
- disp\_pos\_mas = 80;
- orthog\_pos\_mas = 0;
- scene\_rotation\_deg = 40;
- **case 4** ;% sigma draconis planets epoch 2 SCENE 2
- load('C:\Users\shaklan\Documents\MATLAB\starshade\SISTER\config\sister\_R06\_v2\_sez2\_snr3\_0615\_0800\_nm\_r2.mat');
- outn = 'sigma\_draconis\_config\_4'
- slit\_name = 'R4C6';
- disp\_pos\_mas = 0;
- orthog\_pos\_mas = 0;
- scene\_rotation\_deg = 90;

# Observational Parameters

- Instrument components are the same as in Releases 1 and 2:
  - Imperfect starshade ( $1e-10$  at IWA), formation flying, solar glint, Roman throughput, Detector QE and EMCCD parameters and noise in analog mode with gain = 200, Roman jitter of 14 mas.
  - Does not include dimmer effects such as stray light from micrometeoroids, Earth-shine, Jupiter reflection, Milky Way reflection. These are estimated to be dimmer than solar glint.
  - We are currently investigating solar scatter arising from non-planarity of the starshade. This may prove to be comparable to solar glint.
  - Same for HabEx, except we use 2 mas jitter.
- Slit “R4C6” is 127 mas wide (dispersion direction) and 382 mas long.

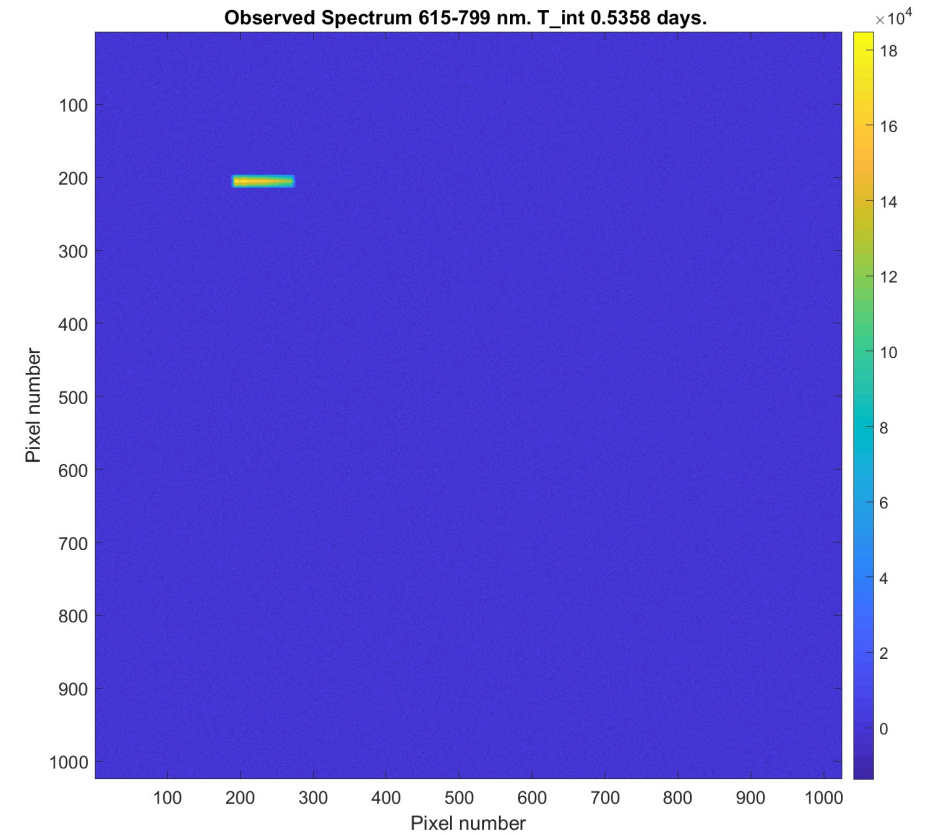
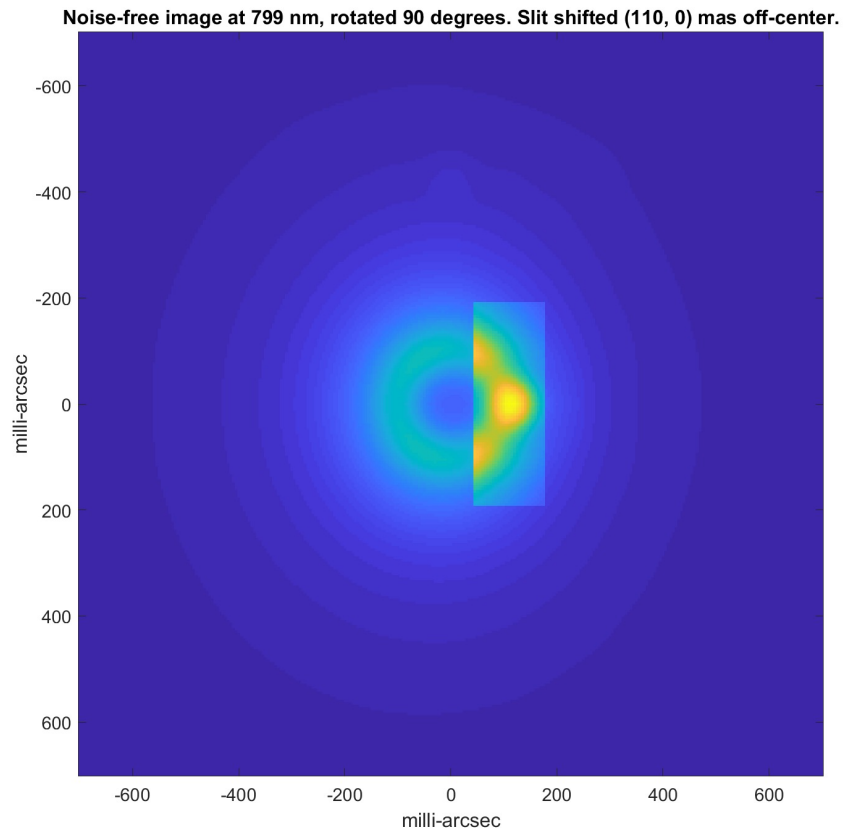
# Slit list

```

      Name  width length angle
           (mas) (mas) deg
slit_list = { 'R1C2', 127, 765, 0;  % SPC major-FWHM vertical slit band 3; tall
              'R2C2', 64, 1083, 30; % SPC minor-FWHM rotated slit band 3; tall
              'R2C3', 63, 346, 30;  % HLC FWHM vertical slit Band 2
              'R2C4', 360, 1000, 0; % starshade slit #3
              'R2C5', 115, 346, 0;  % SPC major-FWHM vertical slit band 2; short
              'R3C1', 243, 728, 0;  % SPC ~1st null vertical slit; tall
              'R3C2', 243, 364, 0;  % SPC ~ 1st null vertical slit; short
              'R4C2', 64, 382, 30;  % SPC minor-FWHM rotated slit band 3; short
              'R4C3', 58, 979, 30;  % SPC minor-FWHM rotated slit band 3; tall
              'R4C4', 58, 346, 30;  % SPC minor-FWHM rotated slit band 2; short
              'R4C5', 70, 382, 0;   % HLC FWHM vertical slit Band 3
              'R4C6', 127, 382, 0;  % SPC major-FWHM vertical slit band 3; short
              'R5C1', 70, 500, 0;  % HLC FWHM curved slit band 3  NOTE CURVED SLIT NOT
IMPLEMENTED IN THIS CODE
              'R6C3', 300, 1000, 0; % starshade slit #2
              'R6C4', 180, 1000, 0; % starshade slit #1
              'R6C5', 115, 691, 0;  % SPC major-FWHM vertical slit band 2; tall
              };
```

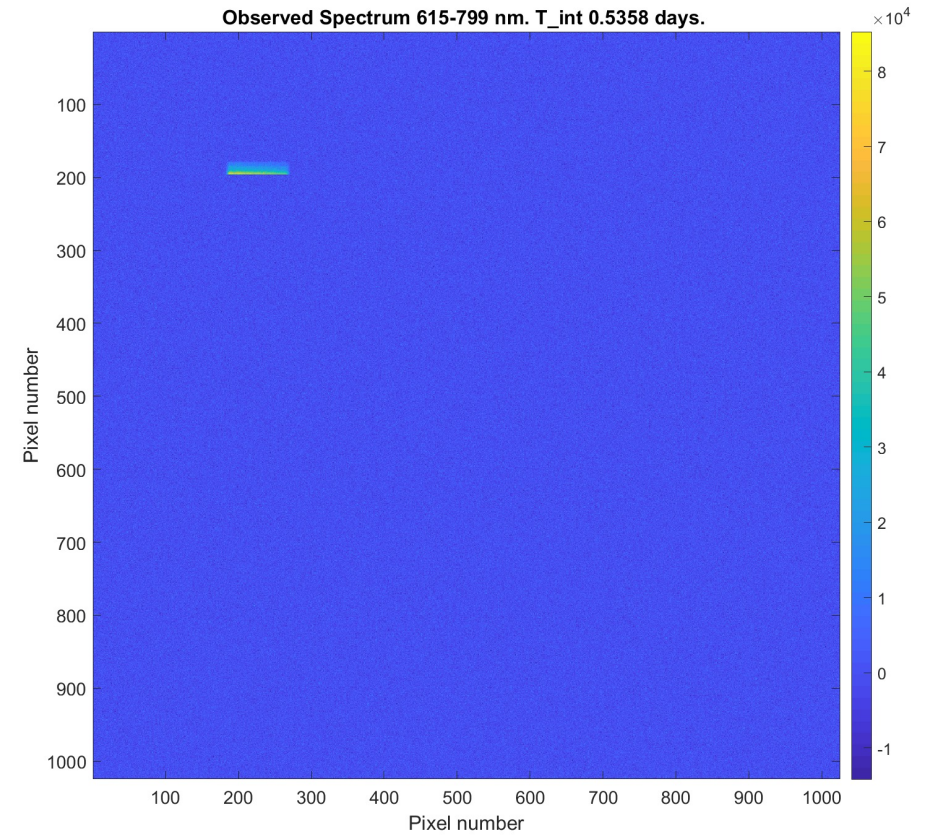
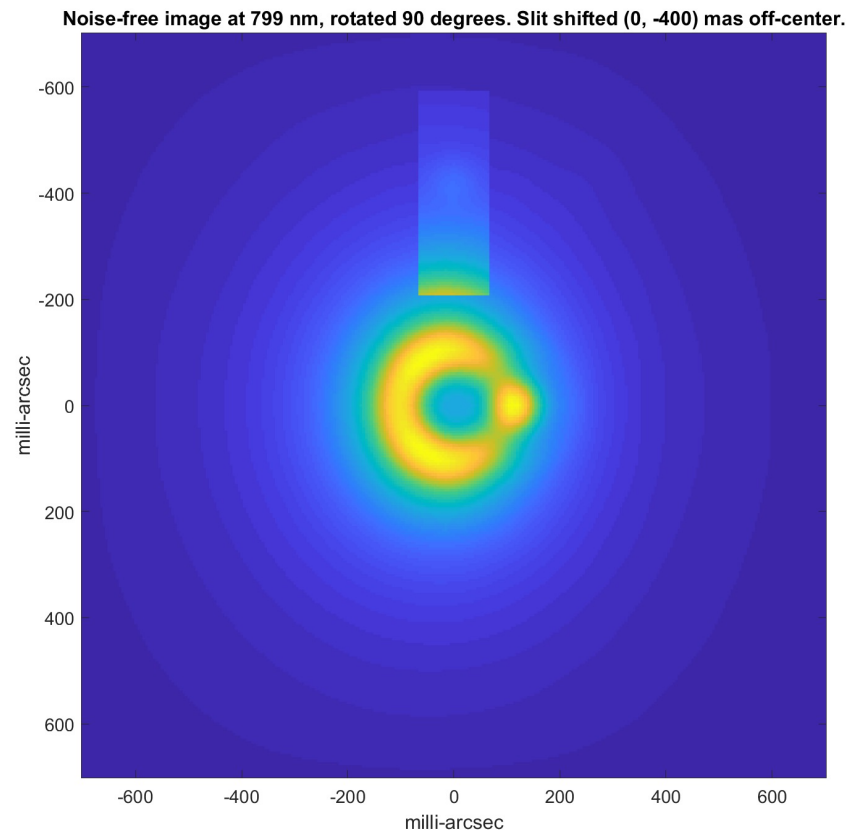


# RST Configuration 1: Tau Ceti Scene 1

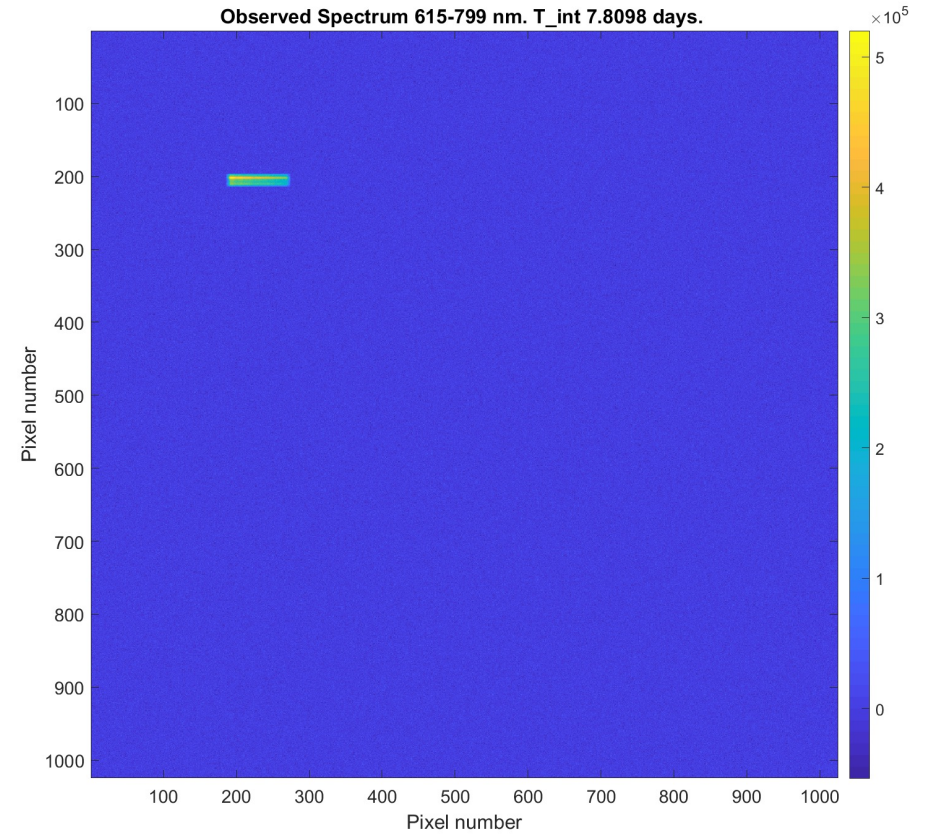
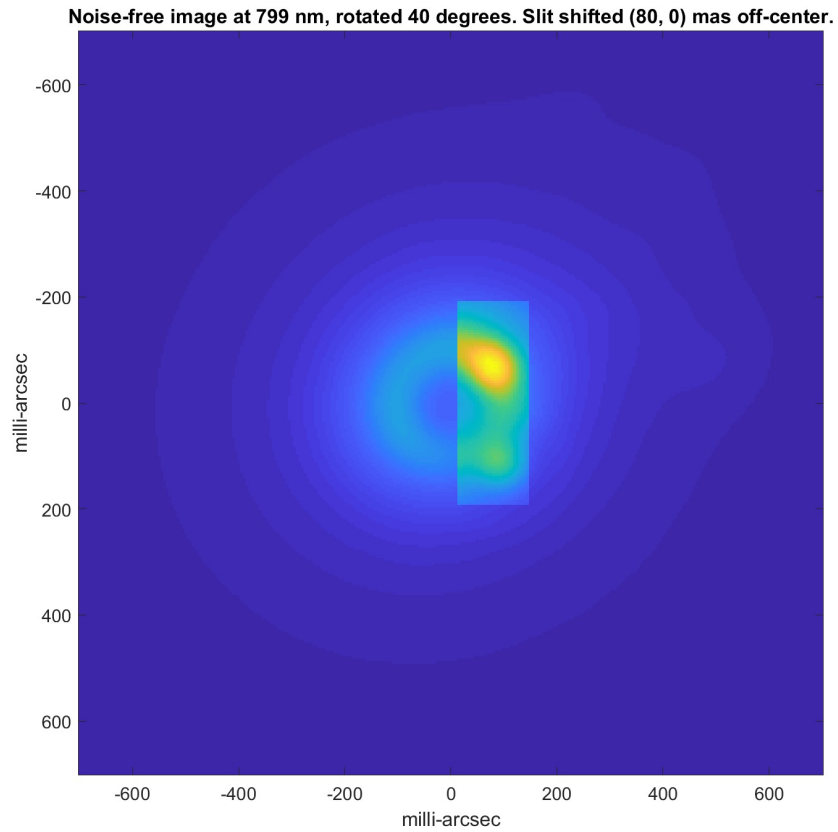


Highlighted area shows position and size of slit.

# RST Configuration 2: Tau Ceti Scene 2

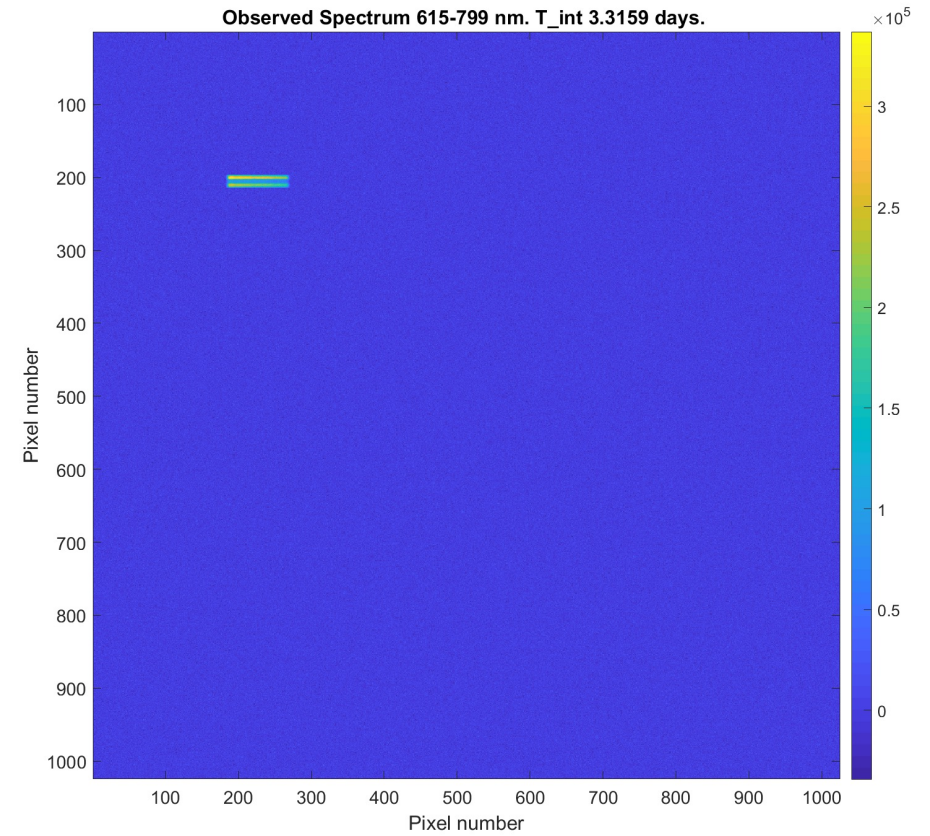
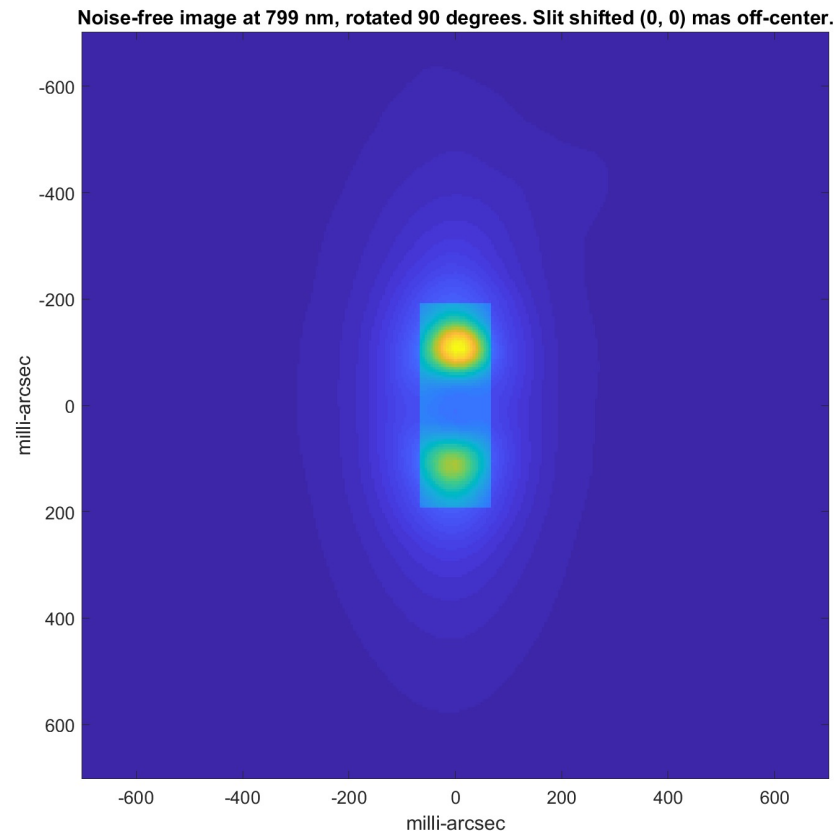


# RST Configuration 3: Sigma Draconis Scene 1

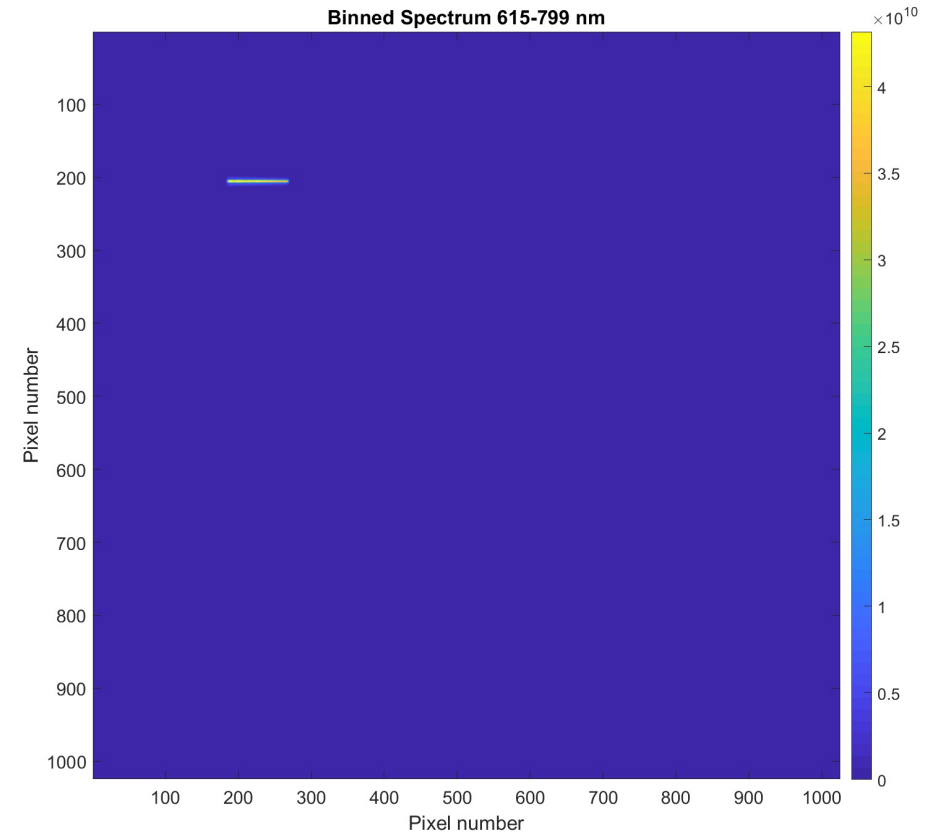
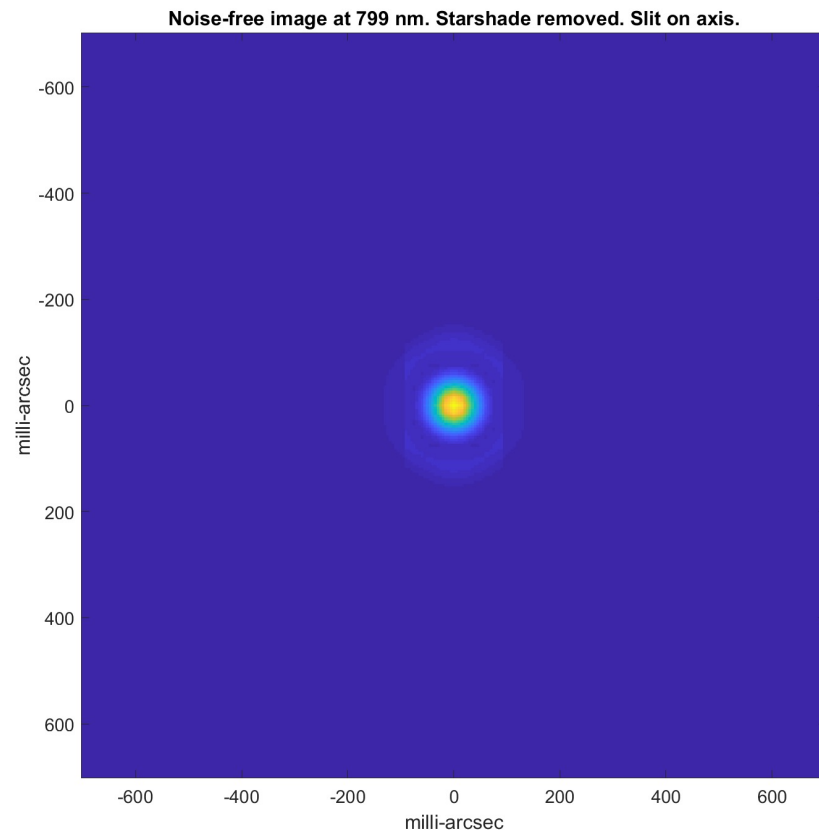




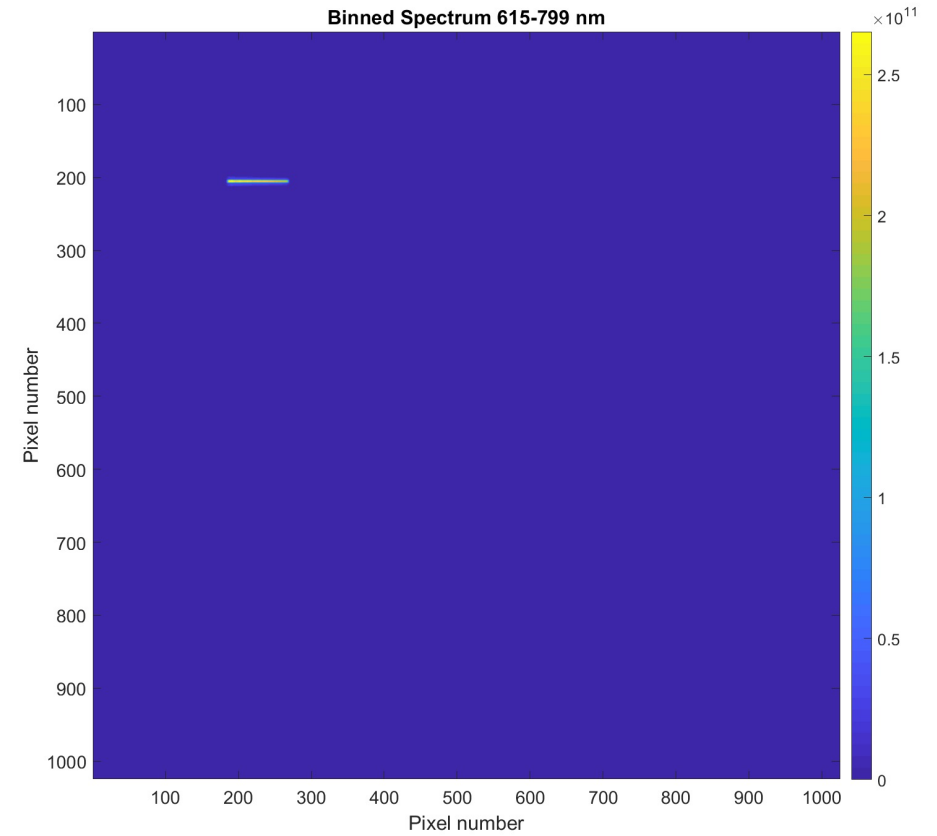
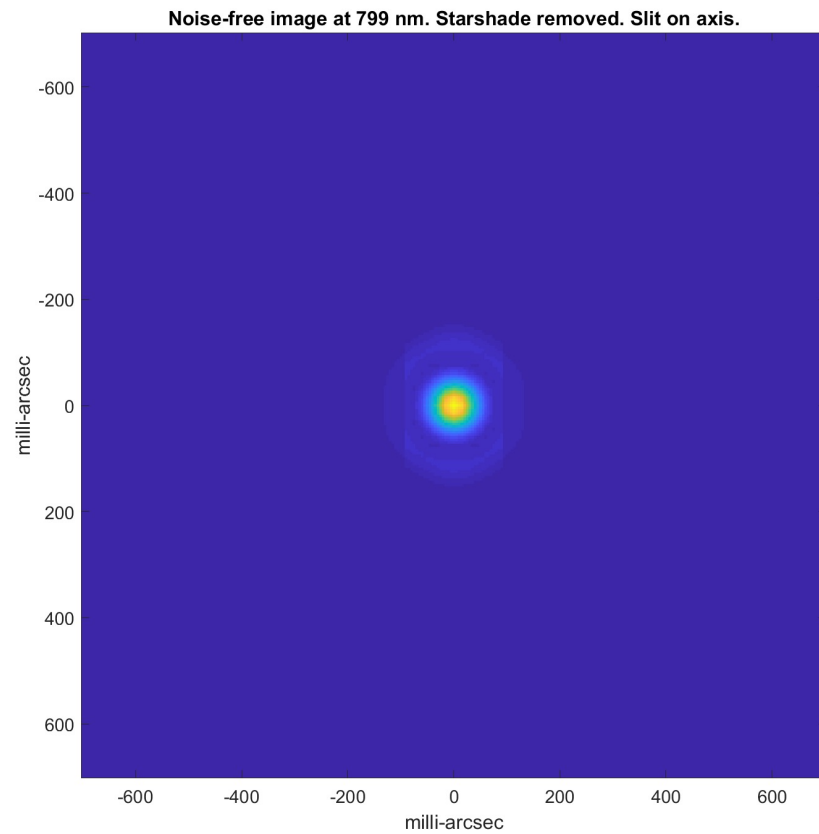
# RST Configuration 4: Sigma Draconis Scene 2



# RST Spectrum of Tau Ceti (starshade removed)



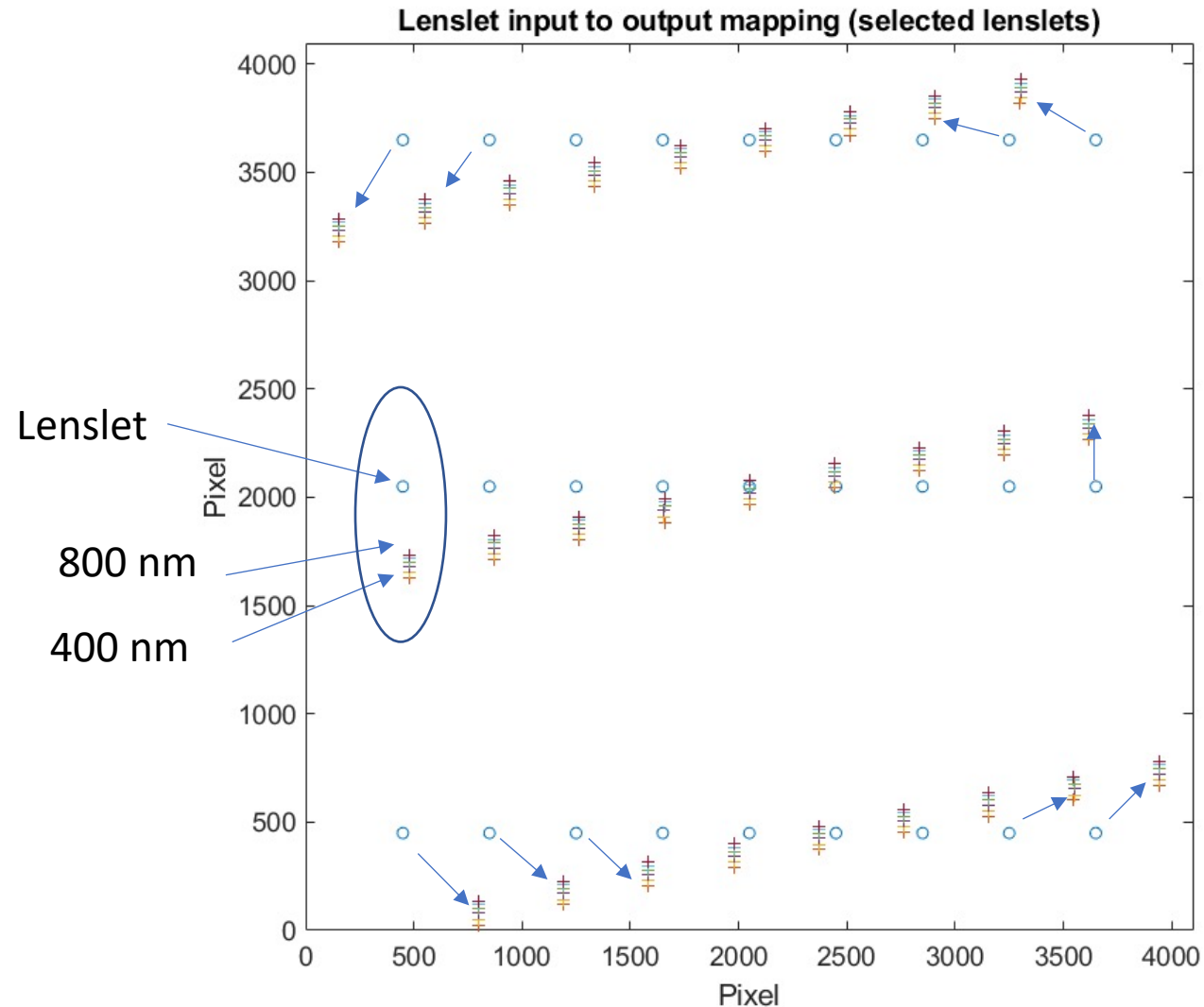
# RST Spectrum of Sigma Drac (starshade removed)



# Habex IFS Modeling

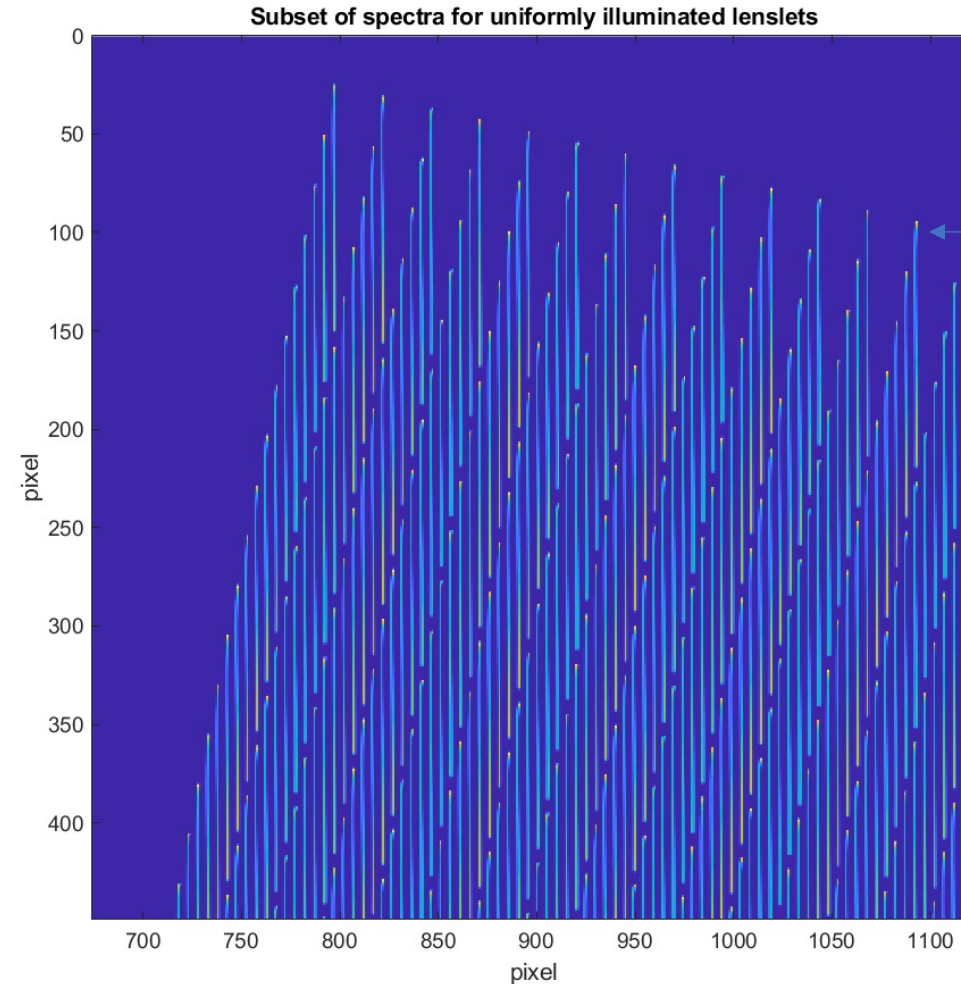
- Lenslets are assumed to be 300 x 300 microns wide on a square grid with 100% collecting efficiency inside each square.
- There are 165x165 lenslets, but only the central 129x129 are used here.
- 300 um corresponds to 11.6 mas.
- Lenslet focal length is 3000 microns.
- Detector grid is 12 microns.
- Lenslets assumed to form diffraction limited image with intensity equal to the sum of the energy incident on the lenslet at each wavelength. PSF assumes circular lenslet aperture with 300 um diameter.
  - This ignores any variable phase and variable illumination over the lenslet aperture.
- Models 1 nm bandwidth steps over 400-1000 nm bandpass
- Ray trace through the back-end prisms and lenses maps the focal plane position of the center of each lenslet image at each wavelength.

IFS maps: image plane projected onto detector array assuming 12 um pixel pitch.





# IFS image for uniformly illuminated lenslets and uniform spectrum



The curly part is 400 nm.  
The prisms were designed for best performance over 450-1000 nm.

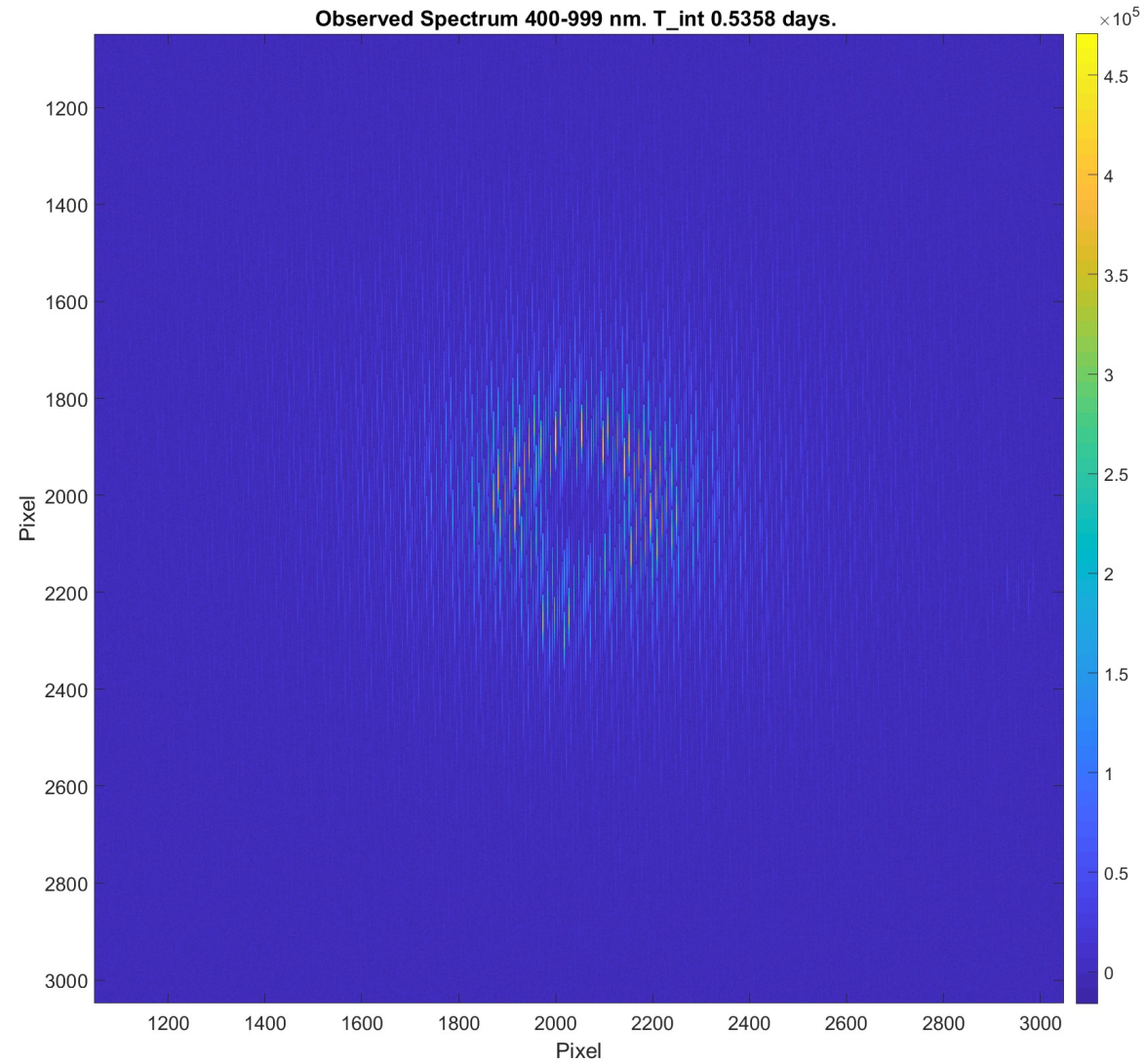
# Mapping spectra to an image

- We provide input-to-output maps that will allow reconstruction of an image data cube (RA, Dec, wavelength).
- Arrays `xcenpix` and `ycenpix` are 16641 x 600 arrays.
  - The 600 columns are wavelengths increasing from 400 to 999 nm.
  - The 16641 rows are the x and y positions in the image plane for the *i*'th lenslet. 16641 = 129x129 lenslets.
- Vectors `xcenpixO` and `ycenpixO` are the positions of the 16641 lenslets.
- Once the spectrum is measured, a data cube can be constructed by mapping the `xcenpix` and `ycenpix` positions to `xcenpixO` and `ycenpixO`.

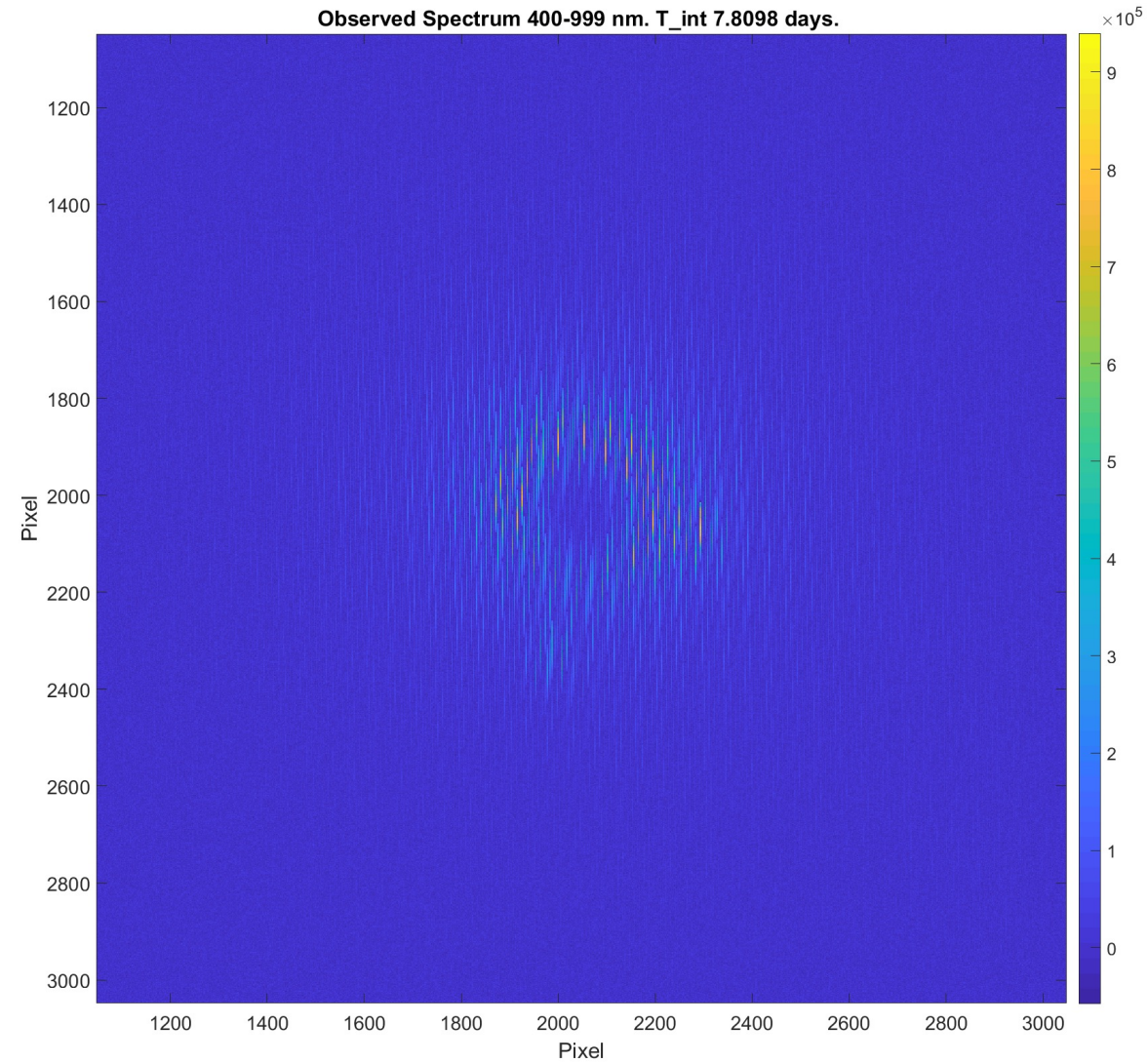
# HabEx Observational Configurations

- **case 1 ;% tau ceti**
- load('C:\Users\shaklan\Documents\MATLAB\starshade\SISTER\config\sister\_R01\_v1\_sez1\_snr3\_0400\_1000\_nm\_r2\_HabEx.mat');
- outn = 'Habex\_tau\_ceti\_scene\_1'
- **case 2 ;% sigma draconis epoch 1**
- load('C:\Users\shaklan\Documents\MATLAB\starshade\SISTER\config\sister\_R05\_v2\_sez2\_snr3\_0400\_1000\_nm\_r2\_HabEx.mat');
- outn = 'Habex\_sigma\_draconis\_scene\_1'
- **case 3 ;% sigma draconis epoch 2**
- load('C:\Users\shaklan\Documents\MATLAB\starshade\SISTER\config\sister\_R06\_v2\_sez2\_snr3\_0400\_1000\_nm\_r2\_HabEx.mat');
- outn = 'Habex\_sigma\_draconis\_scene\_2'
- **case 4; % tau ceti starshade moved**
- load('C:\Users\shaklan\Documents\MATLAB\starshade\SISTER\config\HabEx\_R01\_starshade\_moved.mat');
- outn = 'Habex\_tau\_ceti\_wo\_starshade';
- **case 5; % sigma draconis starshade moved**
- load('C:\Users\shaklan\Documents\MATLAB\starshade\SISTER\config\HabEx\_R05\_starshade\_moved.mat');
- outn = 'Habex\_sigma\_draconis\_wo\_starshade';

# Habex IFS image of Tau Ceti

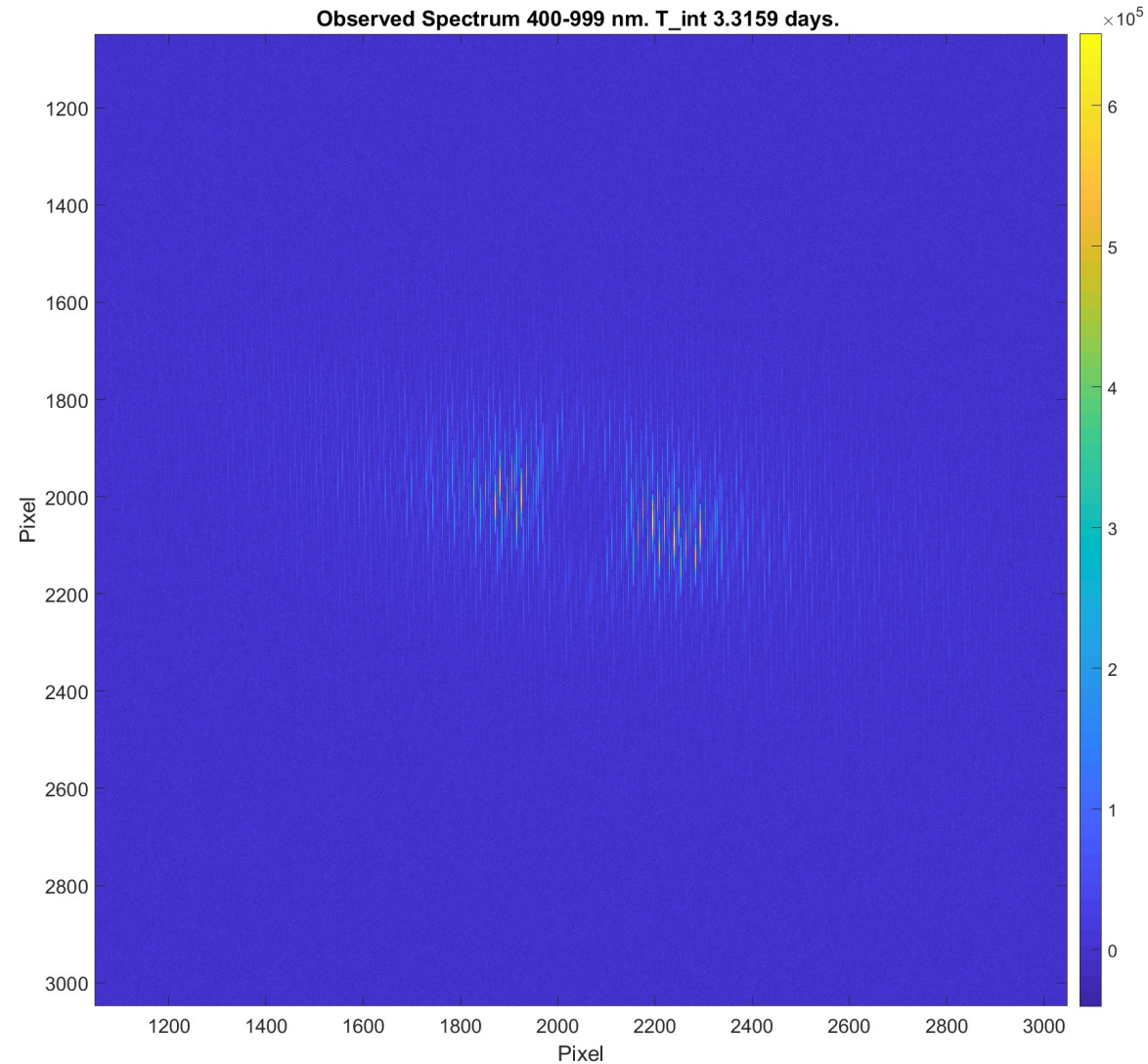


# Habex IFS image of Sigma Draconis, Scene 1



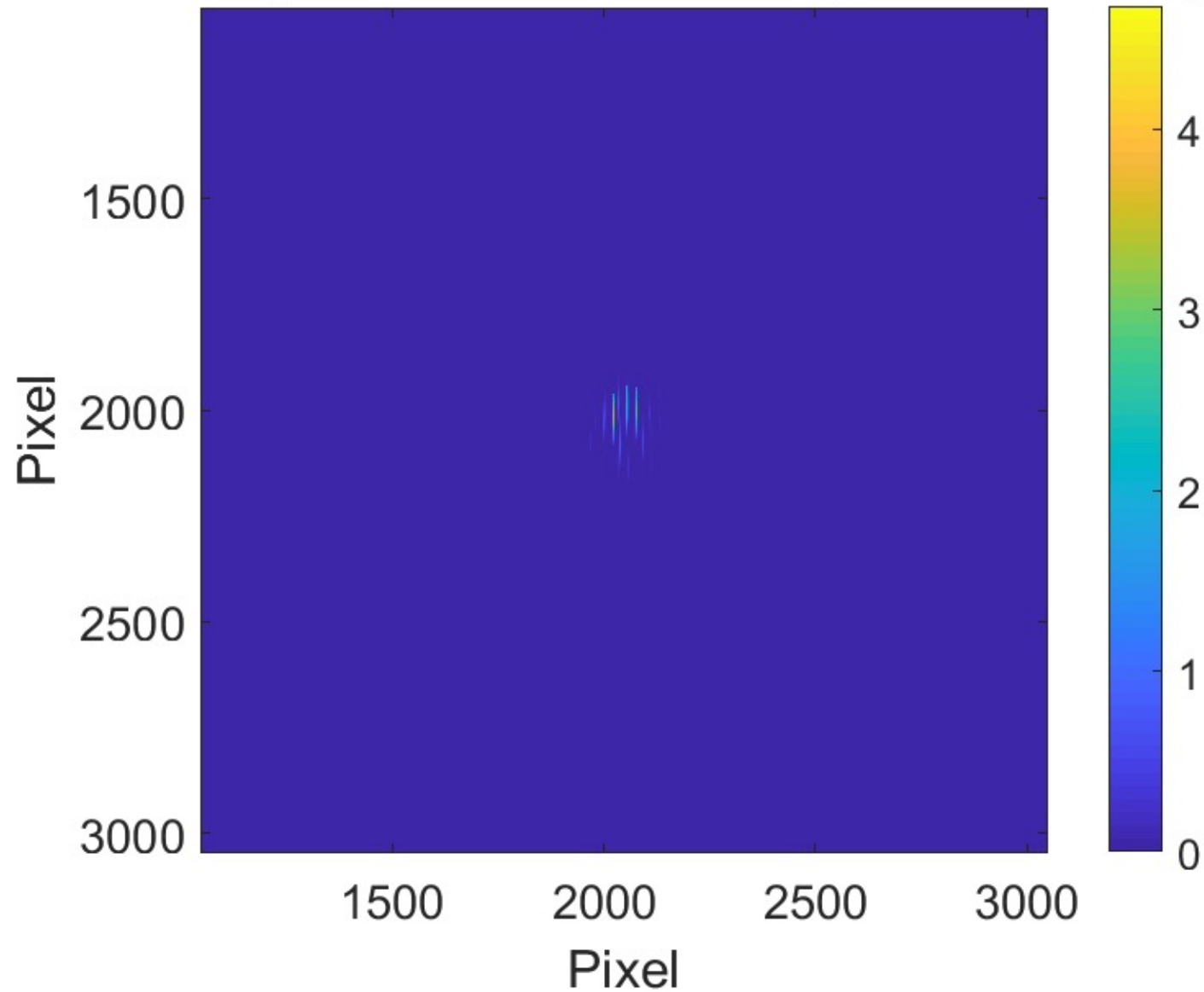


# Habex IFS image of Sigma Draconis, Scene 2



# Habex IFS image of Tau Ceti (starshade removed)

**Observed Spectrum 400-999 nm. T<sub>int</sub> 0.5358 days<sup>13</sup>**



# Habex IFS image of Sigma Draconis (starshade removed)

