

Example Notebook: Read and Display the Young M-star Survey Data Products

We have packaged all the data products with the young M-star survey into fits files with multiple extensions. Below is a description of the file format and example code to access the data products.

```
In [ ]: # Import packages
from astropy.io import fits
import numpy as np
import matplotlib.pyplot as plt
```

HDUList Information

PREPROCESSED_FRAMES: Consists of the sky-subtracted raw coronagraphic frames acquired in our Lp angular differential imaging (ADI) observations.

PARALLACTIC_ANGLE: Parallax angles for the individual frames acquired in the ADI sequence. The indexing order of the parallactic angles matches the indexing order of the preprocessed frames.

PSF_FRAME: Unsaturated unocculted PSF frame for the target.

101X1_SUPER_RDI: Super-RDI reductions with MSE metric ordered reference library for frame size of 101 x 101 pixels with a 1 FWHM central numerical mask. There are 30 reduced images. The first 10 reduced images were obtained with a library size of 1000 frames with (1, 5, 10, 20, 50, 100, 200, 300, 400, 500) PCs. The next 10 reduced images were obtained with a library size of 1750 frames with the same set of PCs. The last 10 reduced images were obtained with a library size of 3000 frames with the same set of PCs.

201X2_SUPER_RDI: Super-RDI reductions with MSE metric ordered reference library for frame size of 201 x 201 pixels with a 2 FWHM central numerical mask. There are 30 reduced images. The first 10 reduced images were obtained with a library size of 1000 frames with (1, 5, 10, 20, 50, 100, 200, 300, 400, 500) PCs. The next 10 reduced images were obtained with a library size of 1750 frames with the same set of PCs. The last 10 reduced images were obtained with a library size of 3000 frames with the same set of PCs.

551X5_SUPER_RDI: Super-RDI reductions with MSE metric ordered reference library for frame size of 551 x 551 pixels with a 5 FWHM central numerical mask. There are 10 reduced images. They were obtained with a library size of 1750 frames with (1, 5, 10, 20, 50, 100, 200, 300, 400, 500) PCs.

OPTIMAL_CONTRAST_CURVE: Final ADI+RDI combined 5 σ contrast curve for each target. Consists of distance from star center in arcseconds and 5 σ contrast as ratio of companion and stellar flux. Discussed in Section 5 of Sanghi+2024.

```
In [ ]: # Provide your path
hdlist = fits.open('/Users/asanghi/Downloads/data/super-rdi-mstar-survey-data-products/L0_Peg_20160615.fits')
print(hdulist.info());
```

Filename: /Users/asanghi/Downloads/data/super-rdi-mstar-survey-data-products/L0_Peg_20160615.fits

No.	Name	Ver	Type	Cards	Dimensions	Format
0	PREPROCESSED_FRAMES	1	PrimaryHDU	19	(587, 587, 37)	float32
1	PARALLACTIC_ANGLE	1	BinTableHDU	11	37R x 1C	[E]
2	PSF_FRAME	1	ImageHDU	22	(65, 65)	float32
3	101X1_SUPER_RDI	1	ImageHDU	9	(101, 101, 30)	float64
4	201X2_SUPER_RDI	1	ImageHDU	9	(201, 201, 30)	float64
5	551X5_SUPER_RDI	1	ImageHDU	9	(551, 551, 10)	float64
6	OPTIMAL_CONTRAST_CURVE	1	BinTableHDU	13	992R x 2C	[E, E]

None
None

Preprocessed Frames with Header

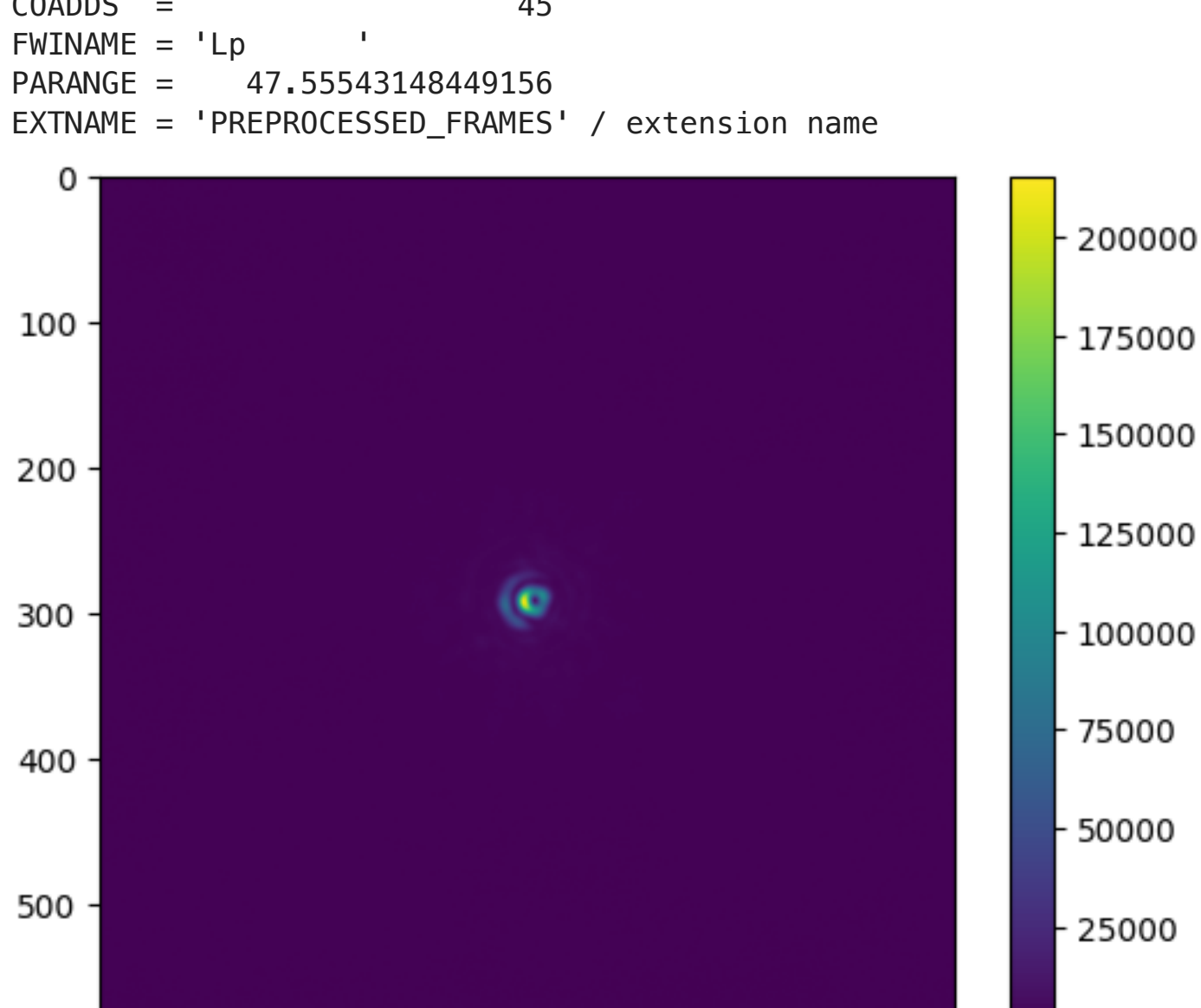
Relevant header information for the preprocessed frames are described below.

RA: Right Ascension of target in degrees.
DEC: Declination of target in degrees.
NUMSCI: Number of science frames in the sequence.
COADDS: Number of coadds per frame.
ITIME: Integration time per coadd in seconds.
TOTTIME: Total on-source integration time in seconds = NUMSCI x ITIME x COADDS.
FWINAME: Name of photometric filter used.
PARANGE: Range of parallactic rotation achieved in the sequence in degrees.

```
In [ ]: preprocessed_frames = hduList[0].data
display(hdulist[0].header)
```

```
# Display the first frame of the sequence
plt.imshow(preprocessed_frames[0])
plt.colorbar();
```

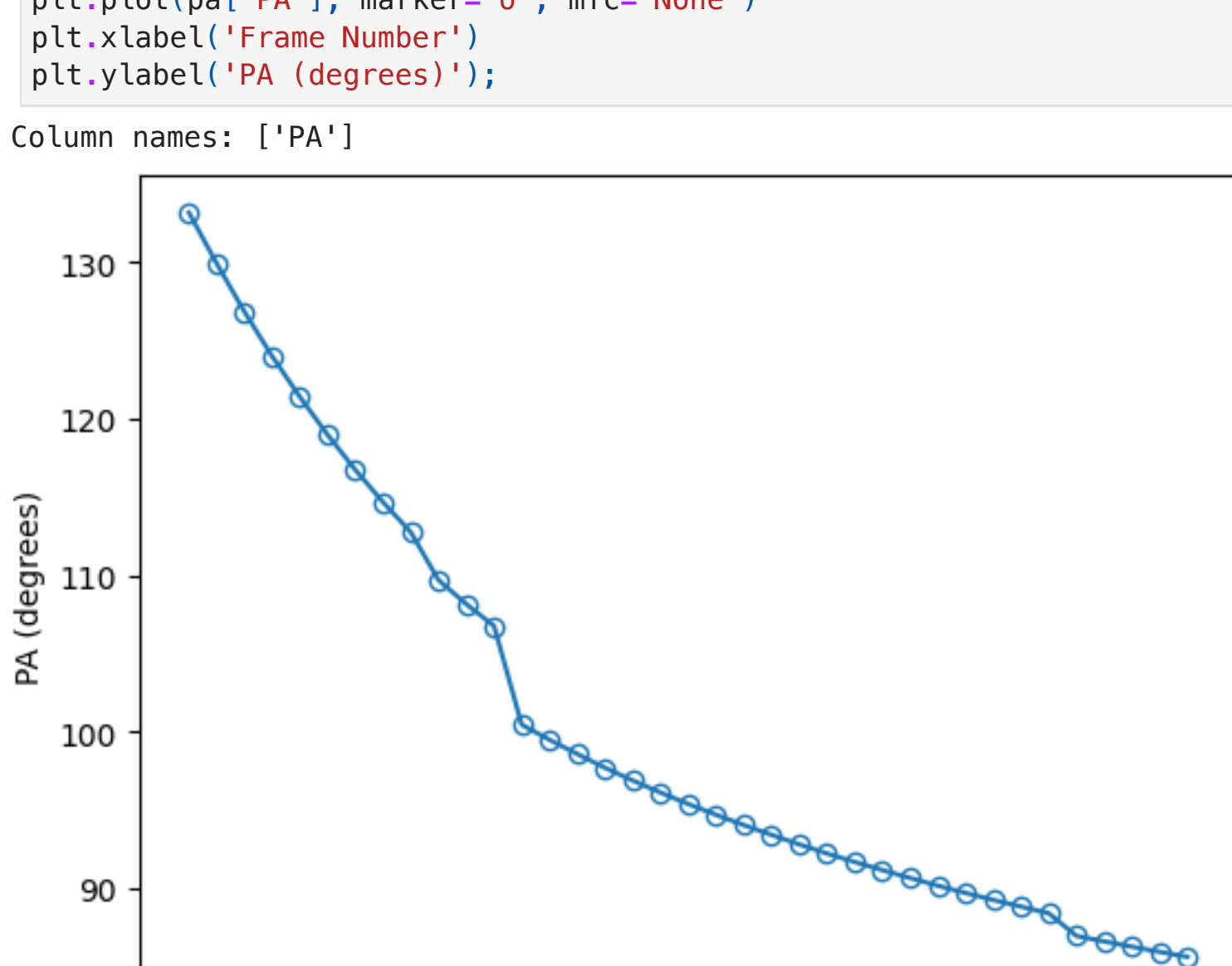
```
SIMPLE = T / conforms to FITS standard
BITPIX = -32 / array data type
NAXIS = 3 / number of array dimensions
NAXIS1 = 587
NAXIS2 = 587
NAXIS3 = 37
EXTEND = T
OBJECT = '21310171+232007'
DATE-OBS = '2016-06-15'
OBSERVER = 'Henderson'
RA = 322.76601
DEC = 23.33188
NUMSCI = 37
ITIME = 1.0
TOTTIME = 1665.0
COADDS = 45
FWINAME = 'Lp'
PARANGE = 47.55543148449156
EXTNAME = 'PREPROCESSED_FRAMES' / extension name
```



Parallactic Angles for Preprocessed Frames

```
In [ ]: pa = hduList[1].data
print("Column names:", pa.names)
plt.plot(pa['PA'], marker='o', mfc='None')
plt.xlabel('Frame Number')
plt.ylabel('PA (degrees)');
```

Column names: ['PA']



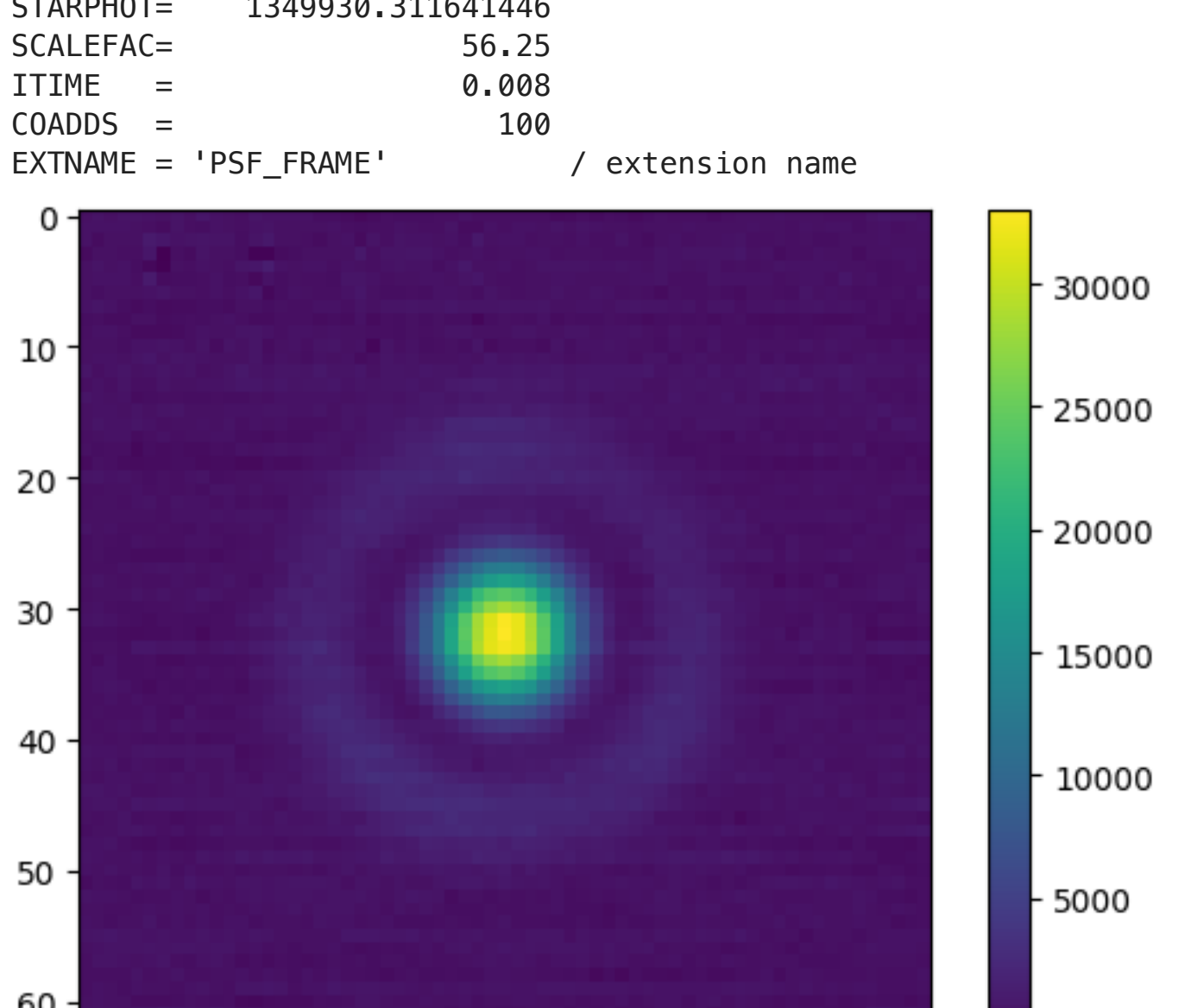
Unsaturated PSF Frame with Header

Relevant header information for the PSF frame is described below.

COADDS: Number of coadds for the PSF frame.
ITIME: Integration time per coadd in seconds.
STARPHOT: Total flux of the star (in counts) estimated by performing aperture photometry of the PSF frame.
SCALEFAC: Scale factor that accounts for the difference in integration time between a single science frame and the PSF frame. Computed as (ITIME_sci x COADDS_sci) / (ITIME_psf x COADDS_psf)
Note: STARPHOT x SCALEFAC is thus the total flux of the star (in counts) that is used to scale contrast when computing contrast curves.

```
In [ ]: psf_frame = hduList[2].data
display(hdulist[2].header)
plt.imshow(psf_frame)
plt.colorbar();
```

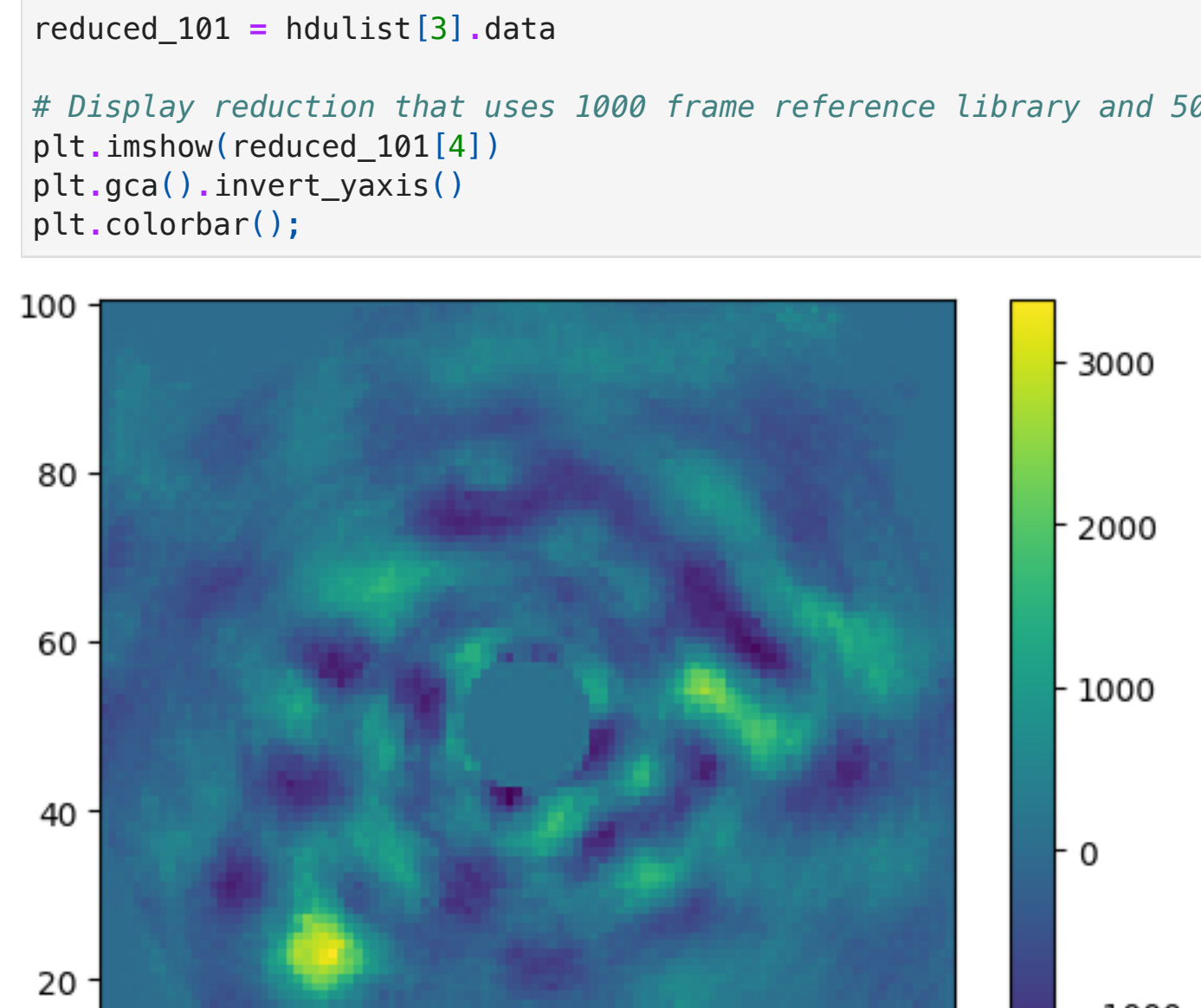
```
XTENSION= 'IMAGE' / Image extension
BITPIX = -32 / array data type
NAXIS = 2 / number of array dimensions
NAXIS1 = 65
NAXIS2 = 65
PCOUNT = 0 / number of parameters
GCOUNT = 1 / number of groups
OBJECT = '21310171+232007'
DATE-OBS = '2016-06-15'
OBSERVER = 'Henderson'
RA = 322.76596
DEC = 23.33176
NUMSCI = 34
PSFITIME= 0.008
HIERARCH PSFCOADDS = 100
FWINAME = 'Lp'
PARANGE = 47.55543148449156
STARPHOT= 1349930.311641446
SCALEFAC= 56.25
ITIME = 0.008
COADDS = 100
EXTNAME = 'PSF_FRAME' / extension name
```



Super-RDI Reduced Frames

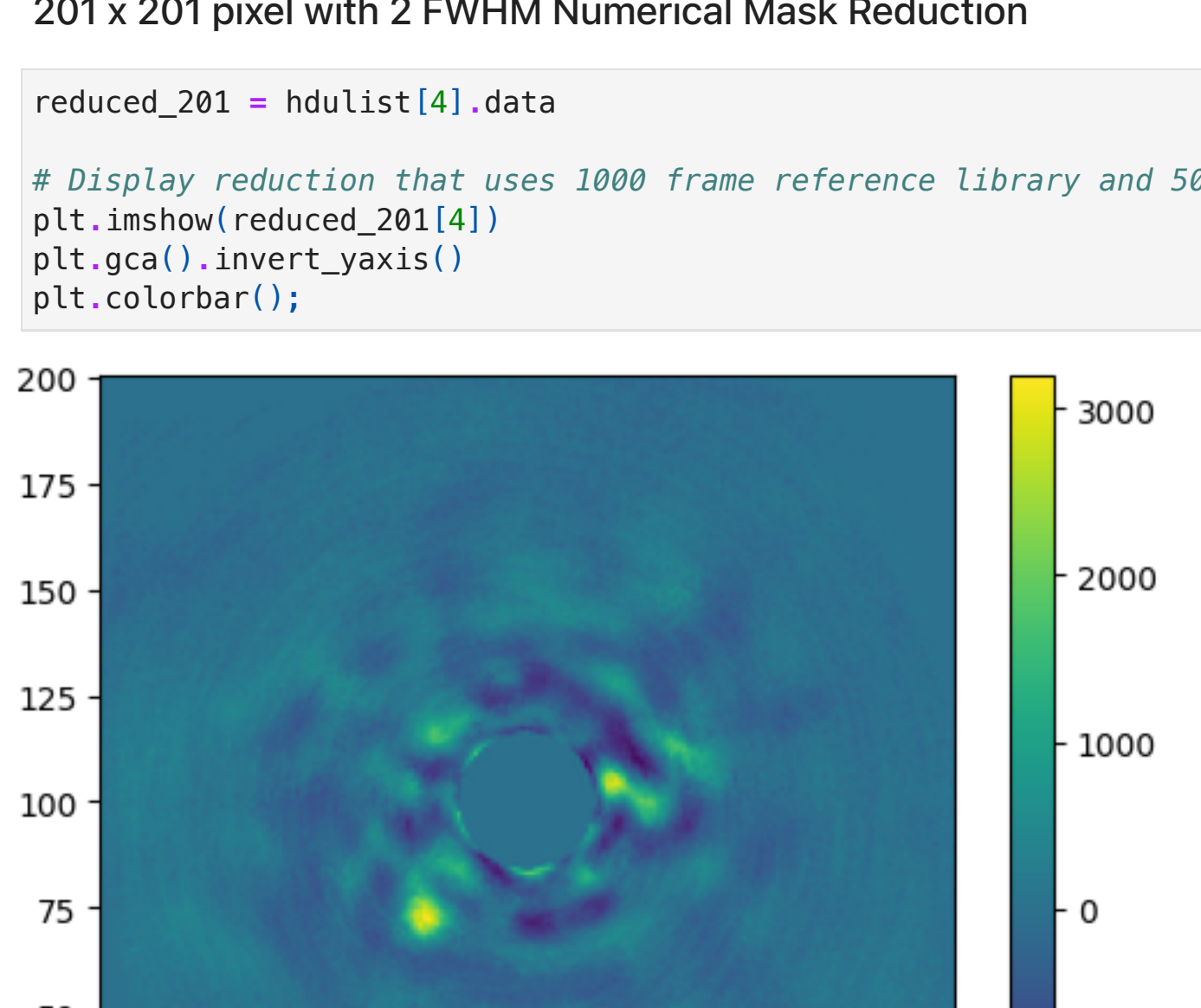
101 x 101 pixel with 1 FWHM Numerical Mask Reduction

```
In [ ]: reduced_101 = hduList[3].data
# Display reduction that uses 1000 frame reference library and 50 PCs
plt.imshow(reduced_101[4])
plt.gca().invert_yaxis()
plt.colorbar();
```



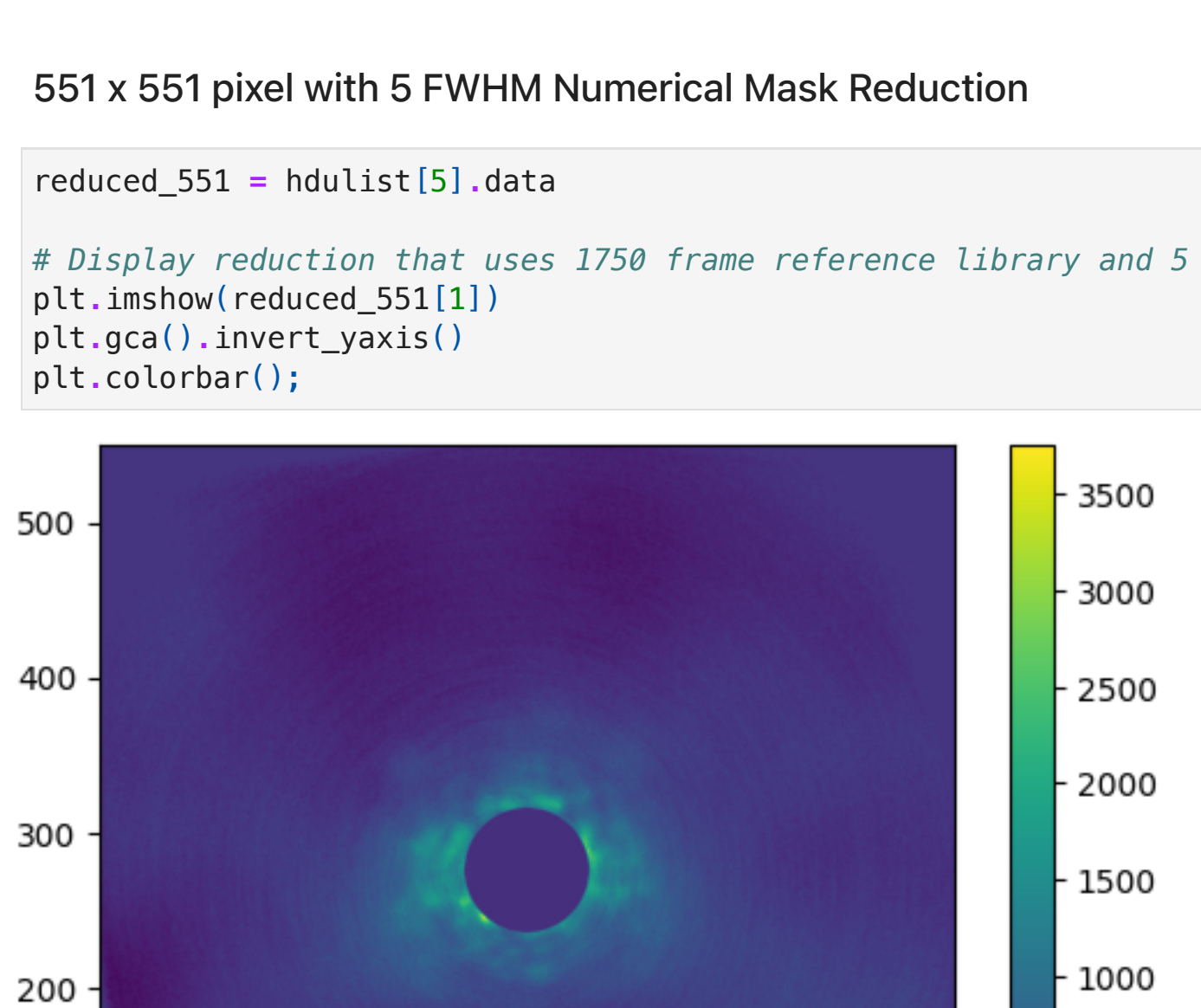
201 x 201 pixel with 2 FWHM Numerical Mask Reduction

```
In [ ]: reduced_201 = hduList[4].data
# Display reduction that uses 1000 frame reference library and 50 PCs
plt.imshow(reduced_201[4])
plt.gca().invert_yaxis()
plt.colorbar();
```



551 x 551 pixel with 5 FWHM Numerical Mask Reduction

```
In [ ]: reduced_551 = hduList[5].data
# Display reduction that uses 1750 frame reference library and 5 PCs
plt.imshow(reduced_551[1])
plt.gca().invert_yaxis()
plt.colorbar();
```



ADI+RDI Optimal Contrast Curve

```
In [ ]: cc_object = hduList[6].data
print("Column names:", cc_object.names)
```

```
# Access data from specific columns
dist = cc_object['DIST_ARCSEC']
contrast = cc_object['CONTRAST']
```

```
# Convert to Delta Magnitude units of contrast
plt.plot(dist, -2.5*np.log10(contrast))
plt.gca().invert_yaxis()
plt.xlabel('Distance (arcsec)')
plt.ylabel('Delta mag');
```

Column names: ['DIST_ARCSEC', 'CONTRAST']

