

# The NIRISS Grism Overlap Tool

This document describes the tool for evaluating the possible overlap of spectra between sources in the NIRISS WFSS and SOSS modes. This is useful if one has one or more specific sources in a particular observation for which it is important to avoid spectral overlap as much as possible. The tool allows the user to examine the scene at different orientations and see which orient ranges produce overlap of the spectra and which do not. It needed these limits can then be used as constraints in the APT file for the program.

The tool is written in standard Python and requires a set of data files that describe the point source response of the instrument in normal imaging and in WFSS/SOSS dispersed images. These files are available separately from the code.

## Obtaining the Code and the Reference Files

The code for the tool is stored on github at the link

[https://github.com/KevinVolkSTScI/grism\\_overlap](https://github.com/KevinVolkSTScI/grism_overlap)

which should be publicly available to all users. The reference files needed for the code are stored on Box at

<https://stsci.app.box.com/folder/140705149002?s=ih166mw8ded6w0qeiw7znc7xuth7n531>

which also should be available to anyone for downloading the files.

The contents of the github repository are the set of codes

<code>fits_image_display.py</code>	the code that handles the FITS image display
<code>general_utilities.py</code>	various utility routines
<code>grism_overlap_tool.py</code>	the main program
<code>mpfit.py</code>	a non-linear fitting routine
<code>mpfitexpr.py</code>	a wrapper for the <code>mpfit.py</code>
<code>scene_image.py</code>	the code for creation of the scene image
<code>soos_scene.py</code>	the code for making the SOSS scene images
<code>wfss_scene.py</code>	the code for making the WFSS scene images

plus two example files for use with the code

`stars_bd30d1753_gaiadr3_allfilters.txt`  
`stars_wdfield_combined_allfilters.list`

plus the readme file and the license file. The two files `mpfit.py` and `mpfitexpr.py` were taken from <https://github.com/segasai/astrolibpy/blob/master/mpfit/mpfit.py> and were written by Sergey Koposov and Mark Rivers from the IDL code by Craig Markwardt. This code is used because it is more robust than the numpy/scipy equivalents. The contents of the Box folder are

f090w\_gr150c\_psfimage.fits  
f090w\_gr150r\_psfimage.fits  
f115w\_gr150c\_psfimage.fits  
f115w\_gr150r\_psfimage.fits  
f140m\_gr150c\_psfimage.fits  
f140m\_gr150r\_psfimage.fits  
f150w\_gr150c\_psfimage.fits  
f150w\_gr150r\_psfimage.fits  
f158m\_gr150c\_psfimage.fits  
f158m\_gr150r\_psfimage.fits  
f200w\_gr150c\_psfimage.fits  
f200w\_gr150r\_psfimage.fits  
gr700xd\_psfimage.fits  
niriss\_NIS\_x1024\_y1024\_f090w\_predicted\_0\_0p00\_0p00.fits  
niriss\_NIS\_x1024\_y1024\_f115w\_predicted\_0\_0p00\_0p00.fits  
niriss\_NIS\_x1024\_y1024\_f140m\_predicted\_0\_0p00\_0p00.fits  
niriss\_NIS\_x1024\_y1024\_f150w\_predicted\_0\_0p00\_0p00.fits  
niriss\_NIS\_x1024\_y1024\_f158m\_predicted\_0\_0p00\_0p00.fits  
niriss\_NIS\_x1024\_y1024\_f200w\_predicted\_0\_0p00\_0p00.fits  
occulting\_spots\_mask.fits  
wfss\_overlap.docx  
wfss\_overlap.pdf  
wfss\_overlap.pptx

The files in the Box folder are first the WFSS and SOSS “point spread function” (PSF) FITS files (f090w\_gr150c\_psfimage.fits, for example), then the imaging PSF fits files (for example, niriss\_NIS\_x1024\_y1024\_f090w\_predicted\_0\_0p00\_0p00.fits), a mask file for the occulting spots in the NIRISS field of view, and documentation files.

## Code Requirements

The code is written in python. It mostly uses standard Python packages (os, math, sys, tkinter, matplotlib, numpy, and scipy) and it uses the astropy package for the FITS file input/output. The astropy package can be installed with the command “pip install astropy” or, if one is using conda, by “conda install astropy”. The astropy documentation is found at <https://docs.astropy.org/en/stable/index.html>. The other “non-standard” package require is the pysiaf package, which is used to map from sky positions to NIRISS detector pixel positions. The pysiaf package is found at <https://github.com/spacetelescope/pysiaf>. The documentation for the package is found at <https://pysiaf.readthedocs.io/en/latest/>. Installation instructions are found in the “Read the Docs” pages. Note that the current version of pysiaf cannot be installed using “pip”, if one uses the command “pip install pysiaf” one gets an obsolete version.

The program is intended to be run from the command line and hence is not arranged as a package. If one is running the code from some directory other than where the source files are located, the directory where the code is stored should be in ones \$PYTHONPATH variable.

The code is known to work in Python versions later than 3.7 on either a MacOS system or a Linux system. No testing has been carried out on a Microsoft Windows system.

## Code Algorithm

The code carries out a sequence of steps to produce either a simulated direct image or a simulated dispersed NIRISS WFSS image for a given sky pointing and orientation. The general steps used are as follows:

- (1) An oversized scene image is created from a star list and an extended source list, or possibly read in from a FITS file. The scene image is made at infinite angular resolution, meaning that each star occupies a single pixel and any extended sources that are defined follow perfect Sersic profiles at the NIRISS pixel resolution. This image is made assuming that the pixels are square and have a uniform angular size projected on the sky of  $0.0656''$ , this being the pre-launch estimated ideal NIRISS pixel size. An optional uniform sky background can be added to the scene image. Details of how the image is generated are given below. The scene image is assumed to be in units of ADU/s equivalent to the JWST pipeline “rate” images. As it is on a uniform pixel grid, the image corresponds to a resampled image from the pipeline. The units of the image are unimportant for the purpose of the code. The scene image is specific to one of the NIRISS WFSS blocking filters. Note that the current scene image in one of the short wavelength filters is also used for the SOSS mode.
- (2) For any desired sky orientation, the standard scene image is rotated with the `scipy.ndimage.rotate` function. The rotation angle is measured counter-clockwise from the y axis of the scene image, which is assumed to follow a line of constant right ascension on the sky with the +y direction being north. Note that one could run into issues with this if the scene is right at the north or south poles on the sky. The pixels are assumed to be in a tangent plane projection centred at some specific sky coordinates ( $\alpha_0$ ,  $\delta_0$ ). The rotation is always about the specified coordinates.
- (3) The rotated scene image is then convolved with a PSF image suitable to the configuration requested. The PSF images are normalized to a total signal of 1. The output image is then displayed for inspection. The image display code allows the user to carry out a limited sub-set of the Image Reduction and Analysis Facility (IRAF) display and `imexam` functions.

The fidelity of the output image depends on several factors. One issue with the code is that the `scipy.ndimage.rotate` function does not work as well as the IRAF routine. The code appears to be intended for extended object image rotation and not for astronomical image rotation. The rotation call is known to produce low-level artefacts in the output image including negative values where the input image has only positive values. The code masks negative values to zero in the rotated images, but other low-level noise is introduced in the rotation that cannot be removed.

The main limitation of the code is that the dispersed images show exactly the same spectral properties at all positions within the field of view, whereas the ground testing of the NIRISS grisms shows that there is some variation in detail in the curvature of the spectral orders

at different positions. This is a result of the convolution, and there is no way to correct for this. The expectation is that changes in the order curvature are small enough that the tool gives a reasonable estimate of the angles to avoid even if the details are not entirely correct.

Finally, the code assumes that the detector area for NIRISS is centred in the pick-off mirror (POM) field of view and that the detector edges are aligned with the POM edges. It is known that the actual situation is somewhat different than this, with the centre of the imaging area being offset from the centre of the POM and with a small rotation of the imaging area with respect to the POM edges. These simplifications make the calculations much easier to carry out, and should have only a small effect on the fidelity of the results.

## Required Inputs for the Code

The code requires either a pre-computed scene image of a particular type or source information that can be used to create the scene image. The normal expectation is that one needs to provide source lists and have the code produce the scene image. The following discusses that situation. The use of a scene image as input is described on page 10 below.

The inputs to the code are assumed to be the same as what is used with the “Multi-Instrument Ramp Generator” code (Mirage) produced at Space Telescope Science Institute. That code can be found at <https://github.com/spacetelescope/mirage>. The code here is limited in the scene generation compared to the Mirage code (e.g. moving objects cannot be simulated) because the NIRISS WFSS mode does not need a number of the capabilities of the Mirage code. The normal inputs to the code are discussed in the next three sub-sections.

### A Stellar Source List

The primary input is assumed to be a stellar source list with sky positions and simulated NIRISS magnitudes. The magnitudes can be input either as AB magnitudes or as the A0V-based magnitudes (“Vega magnitudes” in the Hubble Space Telescope parlance, although there are some differences for the JWST magnitude system compared to what is used for HST). The file needs to have the specific structure shown in Figure 1 below otherwise the code cannot read it. First there may be one or more header lines with the ‘#’ symbol at the start of the line. The only use of these lines is that the code looks for the string “abmag” or the string “vegamag”. Then there is a column heading line, and after that the data values for the stars.

The columns must be in the format shown. The first column must be an index number. This is not used, but needs to be present. The second and third column must be the stellar position in decimal degrees, right ascension and declination. Following that the NIRISS magnitude values for the imaging filters need to be given. The column heading line must also be in the format shown for the magnitude columns, since the column name is matched to the filter of interest in the calculations.

The file is a Mirage stellar list input file, not the Mirage output point source list file. The latter type of file does not have the correct format for input to the grism overlap code.

Files suitable for the input to this code or to Mirage generally require transforming observed magnitudes to estimated NIRISS imaging magnitudes. This can be done with the code at [https://github.com/spacetelescope/jwst\\_magnitude\\_conversion](https://github.com/spacetelescope/jwst_magnitude_conversion) which takes as input photometry in two of a number of possible filters and attempts to transform these values to the

NIRISS filter magnitudes based on the results of some forward modelling of the count rates for various filters. The output from that code needs to be converted into the format that Mirage requires to use with Mirage or with the present code.

## An Extended Source (Galaxies) List

The extended source input file is similar in structure to the stellar source input file, with the addition of the Sersic profile parameters. The format needs to match the example shown in Figure 2 below. The Sersic profile parameters are the radius in arc-seconds, an ellipticity value between 0 and 1, a position angle in degrees east of north as is normal for astronomical images, and the Sersic profile index. The Sersic parameters must follow the source position and be followed by the magnitude values.

```

# vegamag
#
index x_or_RA y_or_Dec niriss_f090w_magnitude niriss_f115w_magnitude niriss_f140m_magnitude niriss_f150w_magnitude
1 254.70867200 34.30200600 16.0200 15.4582 14.9153 14.7331 14.5520 14.3798 14.3813 14.2330 14.2330
2 254.69595100 34.31485000 15.1334 14.8861 14.6145 14.5504 14.4827 14.4184 14.4009 14.3150 14.3150
3 254.72084300 34.30072000 15.5535 15.2622 14.9415 14.8620 14.7785 14.7029 14.6884 14.5230 14.5230
4 254.71705900 34.33200400 17.3785 16.9199 16.4419 16.2978 16.1510 16.0180 16.0147 15.9354 15.9300
5 254.73648200 34.31427600 15.1511 14.9318 14.6918 14.6369 14.5787 14.5210 14.5021 14.2300 14.2300
6 254.69510000 34.29679100 16.5861 16.2148 15.8111 15.7012 15.5872 15.4870 15.4785 15.3910 15.3910
7 254.72960600 34.33614400 15.2586 14.9321 14.5734 14.4808 14.3840 14.2983 14.2865 14.2451 14.2420
8 254.71334800 34.34232700 15.1923 14.6568 14.1287 13.9557 13.7828 13.6201 13.6204 13.5280 13.5280
9 254.70637500 34.28561800 17.7482 17.0863 16.4930 16.2779 16.0688 15.8656 15.8735 15.9150 15.9150
10 254.67560400 34.30772200 17.6322 17.1087 16.5876 16.4190 16.2500 16.0918 16.0915 15.9916 15.9850
11 254.67912600 34.29634300 16.7942 16.3168 15.8256 15.6742 15.5208 15.3805 15.3781 15.2180 15.2180
12 254.75398900 34.31233900 15.8827 15.3874 14.8841 14.7259 14.5663 14.4190 14.4174 14.4410 14.4410
13 254.67624000 34.29785300 16.0986 16.8619 16.4353 16.3690 16.2516 17.1599 17.9845 18.5739 18.6350
14 254.68191500 34.34041600 16.1452 16.1689 16.1657 16.1674 16.1683 16.1754 16.1762 16.1834 16.1820
15 254.66827400 34.30777600 18.8700 17.5770 16.6350 16.2648 15.9294 15.7238 15.8552 15.7542 15.7530
16 254.73925200 34.28159700 13.9459 13.6529 13.3302 13.2501 13.1660 13.0899 13.0755 13.0350 13.0350
17 254.73732000 34.35220000 17.7188 17.1640 16.6250 16.4452 16.2663 16.0966 16.0978 15.9886 15.9810
18 254.69452000 34.35532800 16.7443 16.1985 15.6646 15.4879 15.3118 15.1454 15.1461 15.0850 15.0850
19 254.74194300 34.35150100 17.3328 16.7195 16.1499 15.9503 15.7542 15.5649 15.5693 15.6190 15.6190
20 254.68704700 34.35386200 16.9461 16.5097 16.0488 15.9133 15.7747 15.6504 15.6460 15.7450 15.7450
21 254.66790800 34.28879000 16.4508 16.6073 16.6797 16.6961 16.7107 16.7786 16.8264 16.8642 16.8660
22 254.72929300 34.35861400 17.0937 16.5262 15.9802 15.7959 15.6131 15.4389 15.4408 15.1990 15.1990
23 254.65906600 34.30375500 15.2091 14.7475 14.2674 14.1221 13.9742 13.8401 13.8369 13.7520 13.7520
24 254.66925000 34.28601500 13.5291 13.0023 12.4793 12.3094 12.1393 11.9799 11.9797 11.7820 11.7820
25 254.66336100 34.33960300 17.6912 17.0310 16.4385 16.2240 16.0153 15.8125 15.8204 15.6858 15.6760
26 254.68710300 34.35860800 17.0860 16.6105 16.1205 15.9698 15.8170 15.6775 15.6750 15.5902 15.5840
27 254.65435300 34.32441400 15.4057 14.8834 14.3632 14.1951 14.0264 13.8688 13.8684 13.7440 13.7440
28 254.69790000 34.36256700 15.9743 15.6181 15.2290 15.1250 15.0169 14.9218 14.9121 15.1290 15.1290
stars_wdfield_combined_allfilters.list Top L1 (Fundamental)
Mark set

```

Figure 1: An example of a Mirage star list file in an emacs editor window. The Figure shows the start of the file where the magnitude system is defined by the “vegamag” keyword. This is followed by the column heading line and the data values.

Normal usage of the code is assumed to be having a stellar source list and making the extended source list optional. In the code as long as at least one file is specified it will function. Note that if both files are specified, they must be in the same directory.

## Additional Input Values



Two additional parameters are needed for the code. One of these is the point assumed for the telescope in the simulated images. The other is a background count rate per pixel in units of ADU/s.

When a scene image is made the pixel positions associated with each star position are calculated using the pysiaf functions. The NIS\_CEN aperture, which is the normal full frame imaging aperture, is used in these calculations. The position specified for the imaging corresponds to the reference point of the NIS\_CEN aperture, located at pixel (1024.5, 1024.5) using a 1-based pixel numbering system. This is therefore offset by 1 from the normal Python indexing. The pixel centre is located at an integer number in the pixel position calculations. Thus, the central position is at the corner of pixels (1024, 1024), (1025, 1024), (1024, 1025), and (1025, 1025).

The conversion from sky position to pixels relative to the centre of the image in pysiaf includes a distortion model for the NIRISS detector, the same for all filters. This model currently is derived from ray-tracing simulations. Hence the distortion is allowed for in the source positions but not in the extended source images used to make the scene image. As the distortion for NIRISS is expected to be small, this should not affect the simulations significantly.

```

#
#
# abmag
# catalogue for the Mirage code. created from GOODS-S catalogue
# Magnitudes are converted from input flux densities.
# Seed value: 865615346 Filter: all
index x_or_RA y_or_Dec radius ellipticity pos_angle sersic_index niriss_f090w_magnitude niriss_f115w_magnitude niriss_f160w_magnitude
2269840 82.83648832 -68.79505663 0.02000 0.030 37.75 2.81 24.2337 24.2637 23.9537 23.8537 23.7
2269841 82.78216734 -68.79469569 0.10215 0.980 187.26 0.48 25.0126 25.0726 25.0326 24.8426 24.6
2269842 82.83425328 -68.81517219 0.16759 0.360 114.09 2.75 24.7272 24.7472 24.4272 24.3672 24.3
2269843 82.71984218 -68.75658472 0.07000 0.090 226.98 0.84 25.7753 25.8153 25.7053 25.5153 25.3
2269844 82.77332582 -68.75074178 0.13000 0.050 90.98 0.34 25.6850 25.7450 25.7250 25.5550 25.4
2269845 82.87675414 -68.75950489 0.21556 0.540 139.43 0.55 25.2326 25.2926 25.2826 25.1226 24.9
2269846 82.77932922 -68.78353995 0.48360 0.907 244.32 0.91 23.5763 23.4663 23.3463 23.3263 23.2
2269847 82.83121469 -68.77942527 0.24230 0.711 45.66 1.02 24.3606 24.3206 24.1106 23.8706 23.6
2269848 82.73609607 -68.76861291 0.75738 0.497 258.31 2.73 22.5315 21.8115 21.2015 21.1315 21.0
2269849 82.74035733 -68.79050944 0.26373 0.540 318.33 0.20 25.7297 25.7497 25.4397 25.3497 25.2
2269850 82.78289749 -68.75756050 0.13000 0.050 120.55 0.34 26.4683 25.7983 24.9483 24.8483 24.7
2269851 82.80352923 -68.76780212 0.26000 0.280 187.61 1.67 26.0480 26.0880 25.9780 25.7780 25.5
2269852 82.72080851 -68.77446474 1.07000 0.270 112.05 1.61 25.8223 25.7323 25.7823 25.8023 25.8
2269853 82.79441016 -68.75473396 0.24000 0.290 -3.98 3.40 25.6898 25.4698 25.3698 25.3498 25.3
2269854 82.84065001 -68.74677745 0.25786 0.431 -29.65 1.03 23.0512 22.7812 22.7512 22.7012 22.6
2269855 82.80681404 -68.78731847 0.02000 0.050 42.34 5.30 26.6393 26.6093 26.5493 26.5893 26.6
2269856 82.72907504 -68.77192320 0.07000 0.040 42.23 8.00 26.7039 26.6939 26.6939 26.6639 26.6
2269857 82.82412580 -68.78817484 0.31148 0.371 -68.54 1.51 24.6114 24.4814 24.2614 23.9514 23.6
2269858 82.75976628 -68.74943989 0.11569 0.644 234.94 1.19 24.2488 24.3188 24.3388 24.3288 24.3
2269859 82.79288500 -68.78336153 0.24000 0.060 23.20 0.46 26.4349 26.4949 26.4649 26.3049 26.1
2269860 82.85067802 -68.75290971 1.26462 0.395 334.55 3.07 25.0528 24.3328 23.8528 23.8028 23.7
2269861 82.87300696 -68.80004759 0.03000 0.070 297.05 0.20 27.1948 27.0548 26.7748 26.8648 26.9
2269862 82.76124385 -68.77511415 0.29000 0.050 178.53 0.24 25.6612 25.6812 25.6712 25.6512 25.6
2269863 82.78192938 -68.76324280 0.19998 0.361 194.81 1.11 23.9693 23.5193 23.3093 23.1993 23.0
2269864 82.71522151 -68.78065098 0.30000 0.730 91.97 2.67 26.3230 26.3130 26.0730 26.2130 26.3

```

Figure 2: An example of the extended source input file seen in an emacs window. The structure is very similar to that of the stellar input file except that there are additional columns for the Sersic profile parameters. The columns need to be in the order shown above. The Sersic radii are in arc-seconds and the orientation angle is in degrees east of north on the sky.

## Creation of the Scene Image

The scene image used in the code is an overside image that can cover the NIRISS pick-off mirror for any arbitrary orientation. The POM area as projected on the sky is assumed to be 2322 pixels square with the ideal pixel size of 0.0656". The diagonal distance from corner to corner in the POM is then 3283 pixels, and the radius from the POM centre to the corners projected on the sky is 107.68". The actual scene image size used is about 29% oversized, being 4231×4231 pixels. The nominal size of the scene on the sky is 4.62589' square. When assembling the source lists for the code to use one should search a radius of at least 3.271'. The scene image needs to be somewhat larger than what the POM area requires because when the SOSS mode is used the centre of rotation will normally be offset 931 pixels in x and 175 pixels in y from the centre of the full image to the SOSS acquisition position. One then needs extra sky area in the scene image to allow rotations around the SOSS acquisition point if requested.

To make the scene image the pixel position of each star in the input list is calculated with respect to the defined image centre. If this pixel position is within the image area, the source brightness is calculated from the source magnitude in ADU/s units, and the value is added to the pixel. Each star is placed on a single pixel, whatever one is closest to the calculated position. For the extended sources, if any, the Sersic profile is calculated for a stamp image that is 301×301 pixels with the source position taken to be the centre of the middle pixel (150, 150) in the Python 0-based counting. This is done with the `astropy.modelling.models.Sersic2D` routine. The normalized stamp image is scaled to the total signal calculated from the source magnitude. The edges of the stamp image are then calculated by matching the centre pixel of the stamp image to the pixel position of the source and taking that part of the stamp image that is within the scene image area. Note that if the centre position of the extended source is outside the scene image area then the Sersic profile is not calculated and the source is not included. Hence a large galaxy whose centre is off the scene image would not be included even if it would be large enough to show up on the image. With the padding of the scene image beyond the POM area, a galaxy would have to be larger than about 10" in (total) radius to be excluded from the image and still be able to affect the POM area.

When making the scene image a uniform background is added to each pixel at the option of the user. The scene image is made in the standard orientation with north up and east at left.

## Use of the Tool

The code is invoked by starting the `grism_overlap_tool.py` code on the command line. One either invokes the code via 'python `grism_overlap_tool.py`' or runs the code as an executable file. This causes the creation of a parameter window as shown in Figure 3. The Figure shows the appearance of the window in a MacOS system; the appearance is slightly different on a Linux system.

The tool has a message area at the top. Below that is an area for setting the parameters of the simulation. Just below the message area are radio buttons for the WFSS blocking filter and for the grism selection (the filter does not affect the GR700XD case). Below that, entry fields are provided for the required inputs that the code needs to make a scene image. The first of these is the entry field for the sky background value. The next two entry fields are for the names of the stellar source list and the extended source list. These two files are assumed to be in the same

directory, which is given in the “File Path” entry field. The code also needs to know the path to the imaging and WFSS PSF FITS images, which needs to be specified in the “WFSS PSF Path” entry field. When the code is started, the directory where the code is run is inserted into both the file path and PSF path fields. Finally, there is an entry field where one can specify the sky position  $\alpha$  and  $\delta$  in decimal degrees.

For selecting the stellar and extended source list files and for setting the path values there are buttons at right. If selected these bring up the normal tkinter file query window from which one can select a file name. When this is done for the “File Path” or “WFSS PSF Path” items the resulting file name is split into the directory path and the file name itself, and the directory path is inserted in the “File Path” field. One can also enter the file name and directory path values into the fields directly. For the two path entry fields the “Select Directory” button also brings up the standard file selection window. If one then selects any file in the target directory the directory path is extracted and put into the entry field. The file name itself is ignored in that case. Figure 4 shows the appearance of the tool with the fields filled in sufficiently to generate a scene image.

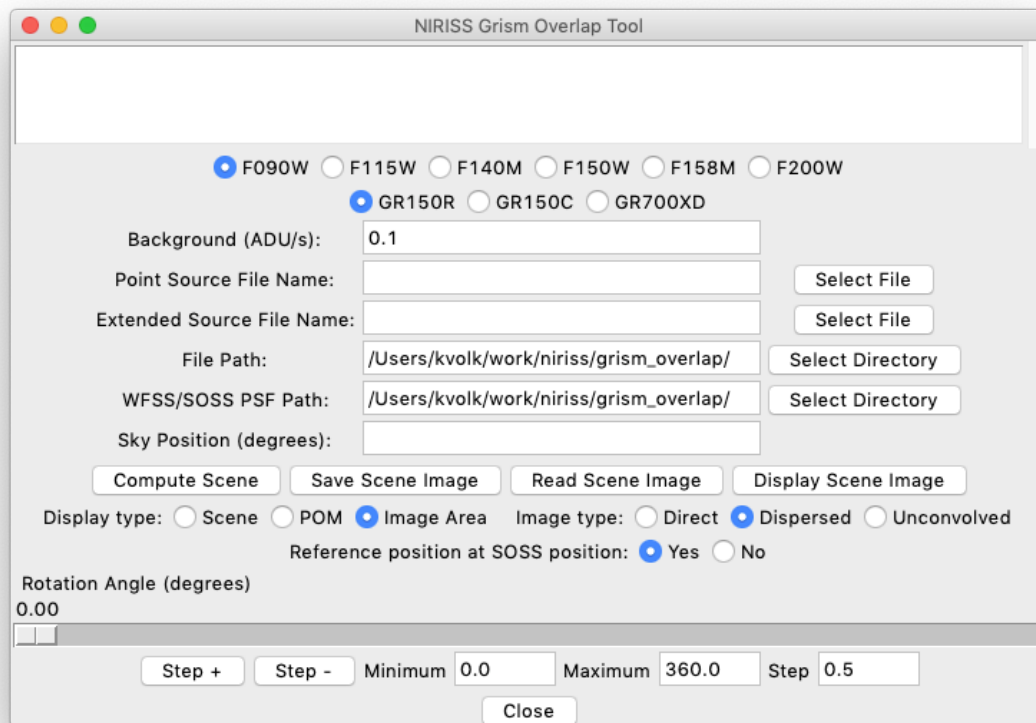


Figure 3: The initial appearance of the grism overlap tool main window.

The next step that is required is to use the “Compute Scene” button to generate a scene image. In general, one needs one scene image per blocking filter, since the relative brightnesses of the sources in the field will vary over the six NIRISS filters. Figure 5 shows the appearance of the window after the scene image has been generated. There are a couple of lines in the message area noting that the scene image has been made. If there was an error, an error message would be shown in the message area.



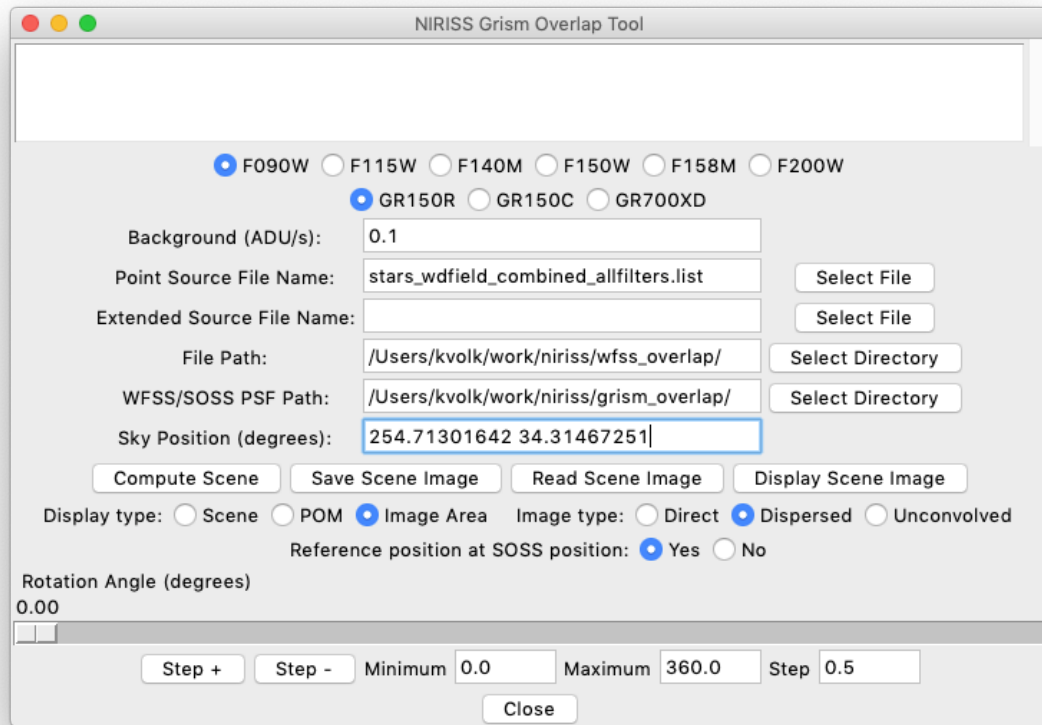


Figure 4: The appearance of the grism overlap tool when the parameters for the scene generation have been specified.

The file `stars_wdfield_combined_allfilters.list` is the same file as was shown in Figure 1. The field is an area surrounding the photometry standard WD 1657+343, using the GAIA DR3 initial release to get the star positions and estimated NIRISS magnitudes. The sky position entered is the position of the white dwarf star in the GAIA catalogue. Thus, when the scene image is made the target star will be at the reference position in the image. One can leave the “Sky Position” entry field blank when making a scene image. If so, then the average position from the stars in the point source list is used as the reference position. Generally, it is better to specify the reference position explicitly before creating a scene image, since the position specified is the centre of rotation for the images. If the star field is sparse, the reference position may not be close to the catalogue centre point.

The scene image may take some time to run if there are many sources, especially for extended sources where the calculation time per object is larger. If calculation of a scene image is time consuming, the image can be stored as a FITS file using the “Save Scene Image” button, and such an image can be read back in with the “Read Scene Image” button. In such an instance, the scene image is read in directly and the scene image computation is not needed.

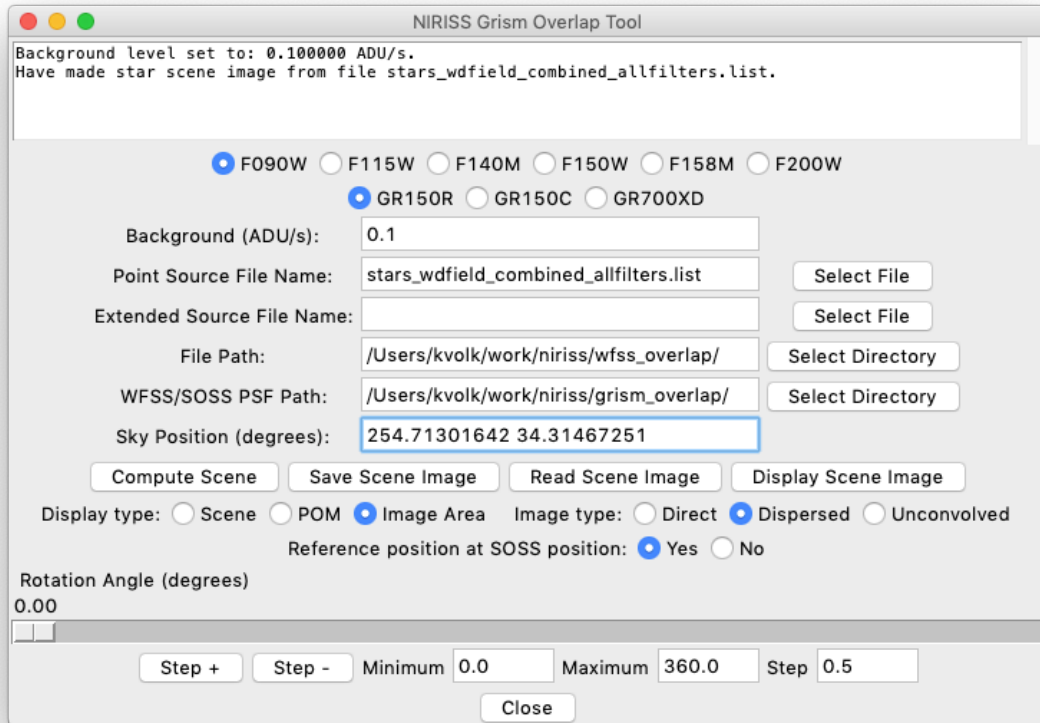


Figure 5: The appearance of the main window after the “Compute Scene” button has been activated.

With this capability, one can also read in a scene image created from other observations if desired. However, in such a case the scene image needs to conform to the assumed structure of the scene image. The properties of concern are as follows:

- the image needs to be stored in FITS extension zero;
- the image needs to be real numbers, dimension 4231×4231 pixels with pixel size 0.0656” square;
- within the scene image, the POM area is 2322×2322 pixels, the Python sub-array indexing being [955:3277, 955:3277];
- within the POM area the “output” image area has 2048×2048 pixels, the Python sub-array indexing being [1092:3140, 1092:3140];
- no negative numbers should appear in the image;
- the image should be deconvolved with the imaging PSF of the telescope/instrument.

The deconvolution of the image by the PSF is required so that the PSF properties of the instrument (e.g. diffraction spikes) are removed as much as possible from the scene image. If this is not done, such features will be imprinted on the simulations.

In the code the scene image is assumed to be in units of ADU/s in the current NIRISS blocking filter. If a scene from another instrument is used as input, the units can be arbitrary as long as the values are positive. The code generally is expecting numbers of magnitude roughly

from 0 to 3000 ADU/s. Values much smaller or larger than this range may cause issues in some of the plots, but would not affect the calculations.

## Displaying the Scene Image

Once a scene image has been created, or read in, the tool is ready to show images. One has controls in the lower part of the main window for the scene that is displayed. The filter and the grism are selected by the radio buttons at the top of the window. The rotation angle and the type of image to display are controlled by the options in the lower part of the window. One has three choices for the part of the scene image to display and three choices for the type of image to display. The type of image to be displayed can be either the scene image without convolving with any PSF file, the scene image convolved with the imaging PSF for the selected filter, or the scene image convolved with the WFSS PSF for the selected filter/grism combination. The first of these options, the “Unconvolved” radio button, is intended just to allow the user to verify the scene image if needed. This would not be very useful in the case of a scene with only stars present, but might be useful if there are extended sources in the field.

An example of one of the WFSS PSF files is shown in Figure 6. The image here is for the F090W/GR150C combination. The image is the result of measurements made during ground testing of NIRISS. One is able to identify orders from +7 to -3 in the image, although the higher orders are very faint. There are also a couple of faint optical ghost features seen in the image, which are thought to be due to reflections within the grism itself. These are seen just below the main spectrum, offset somewhat to the left. The entire image is normalized to 1 for the convolution, and the image is arranged so that the original undispersed point source position is in the centre of the image, so it correctly simulates the offsets from the direct image position to the spectral positions.

The convolution of the scene image with the SOSS or WFSS PSF image means that the relative positions of the spectral orders from the source position is the same for all sources in the field. What was observed in the ground testing for the WFSS case was that the curvature of the line of the spectral orders varies a little over the field, although the sampling in the ground testing was somewhat sparse. Thus, the real observations will not match the WFSS simulations exactly. The hope is that variations in the trace curvature are small so that the results of the tool will be accurate enough for finding overlap.

In the SOSS case we do not have enough data to determine whether there is a field dependence of the rather complex PSF shape. The brightest part of the observed PSF is order 0 which is off the detector area for a star at the acquisition position. Other stars in the field to the left of the target star on the detector may be in positions such that their order 0 spectrum is on the detector and overlaps with the target source order 1 or order 2 spectra.

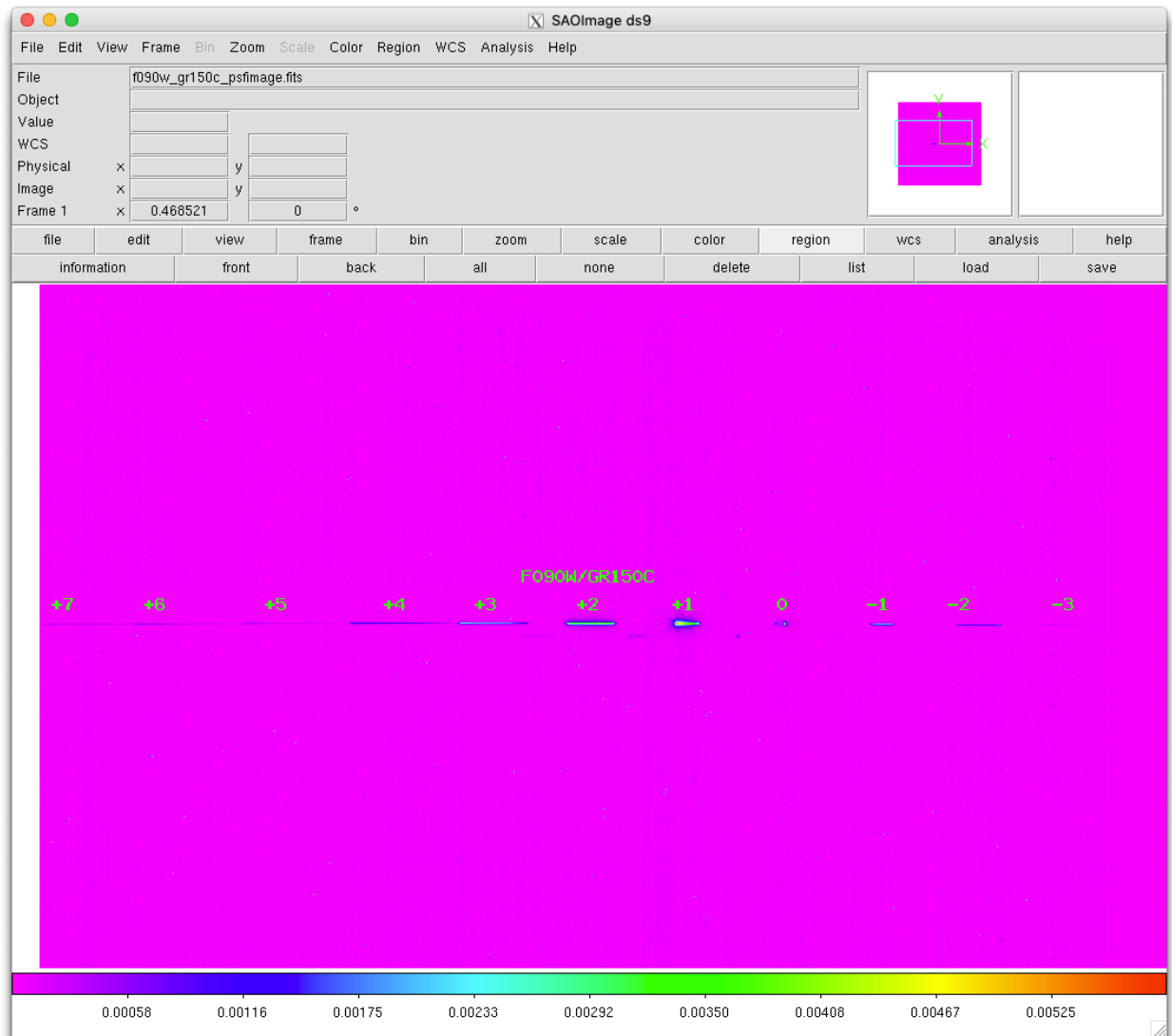


Figure 6: An example of one of the WFSS PSF images, with the spectral orders marked.

Normally one would want to examine the direct image to see the sources at various orientations long with looking at the resulting dispersed images. One has the option of showing only the NIRISS detector area, showing the POM area, or showing the whole scene image. For the latter two cases the outline of the image area is drawn with a white dotted square and the outline of the POM area is shown by a white dashed square on the display if the full image area is shown. If the full POM area is shown then the image area is outlined by the dotted square drawn on the image. For the dispersed image case the scene area outside the POM is set to zero when the full area is displayed, whereas for the direct image case all the sources over the scene area are shown.

When the “Display Scene” button is pressed the first time an image display window is created. All the images are displayed in this window. ***One should not close the image display window.*** If one does this, the code will not make a new window and one will have to restart the tool to get the display window again. The initial appearance of the image display window is shown in Figure 8 below. When an image is initially displayed the full image range is

determined and these values are placed in the “Display Minimum” and “Display Maximum” entry fields. Also, an IRAF-style “zscale” function is applied to the image to get the minimum and maximum values for a zscale display and these are put into the “Zscale Minimum” and “Zscale Maximum” fields.

Figure 7 shows what the scene image looks like for the NIRISS image area. Since the PSF is small compared to the entire area one usually cannot see the stars very well in the default linear display of the whole image range. One usually needs to use the “log” or “sqrt” radio buttons to see stars in the field. For direct images the “zscale” option will normally show the stars in the field so one can determine how many stars are present, but it is not too useful for comparison with the dispersed images because it normally shows the entire PSF to the faint wings.

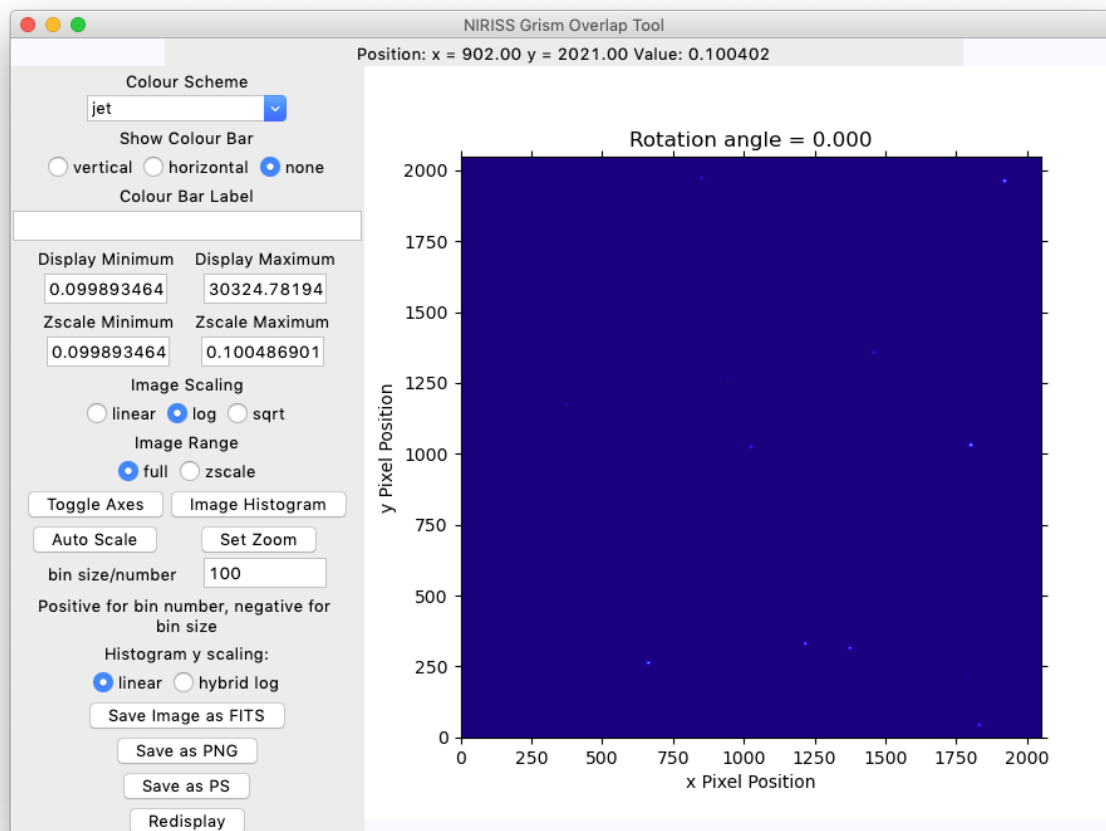


Figure 7: The scene image as displayed with logarithmic scaling.

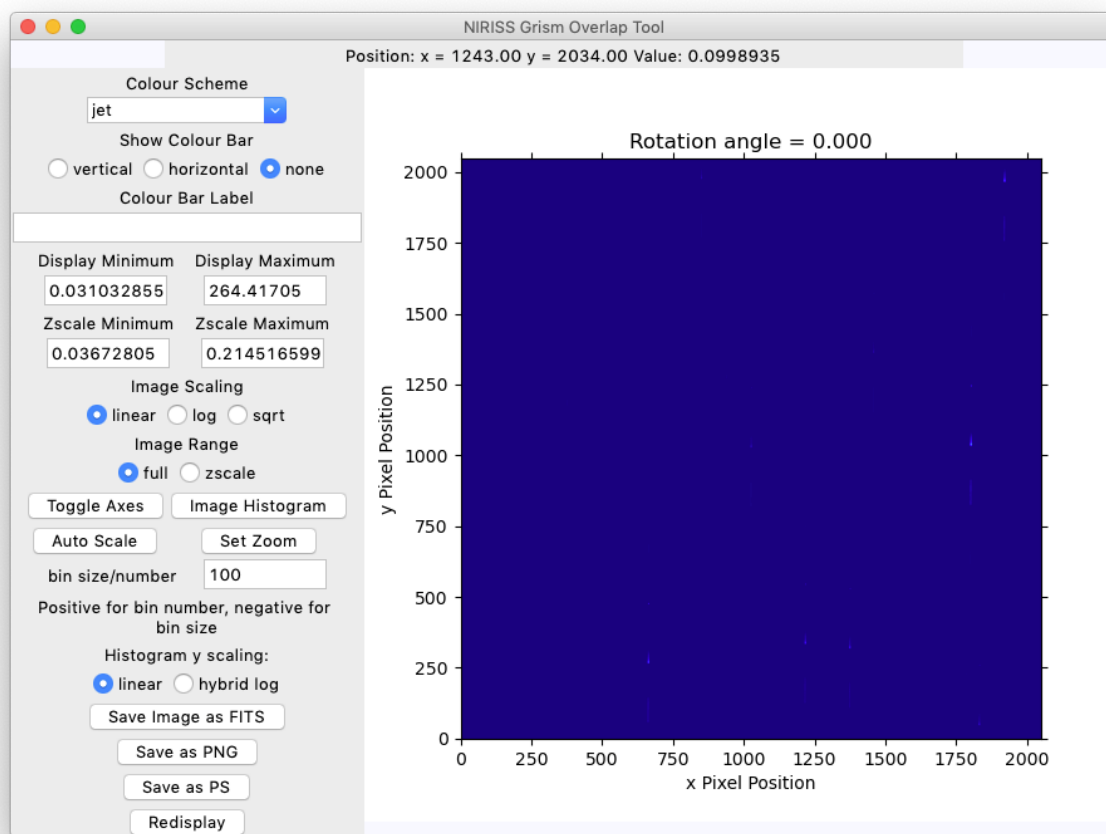


Figure 8: The initial appearance of the image display window with the default options, as seen on a MacOS system. The appearance will be slightly different on a Linux machine. The image is displayed at right and the controls for the image display are at right.

As seen in the above Figure 8, often when the default display parameters are used the image does not show much detail. The default is a linear display over the entire image range. There are a number of controls at left in the window that can be used to see more details in the image. One can use the “log” or “sqrt” radio buttons to change the mapping of the pixels in the displayed image. The “sqrt” function takes the square-root of the absolute value of the pixels and for the negative pixels multiplies by  $-1$  to make a new image which is then displayed. The “log” radio button directs the code to apply an IRAF-like logarithmic transformation to the image. In this case, the image is normalized to the range from 1 to 1000 linearly from the minimum to the maximum values, then the base 10 logarithm is applied to give values in the range from 0 to 3. This new image is then displayed. Figure 9 shows the appearance of the window with this option selected. This shows the spectra of the objects in the field.

In the tool one can also change the “Display Maximum” or “Display Minimum” values in the entry fields, and use the “Redisplay” button at the bottom left to redisplay the image using the new parameters. This is only possible if the full image range option is selected, as the code calculates the zscale parameters and uses them directly, so any changes the user may attempt to make the entry values are ignored. If one changes the display range, the original values can be



restored using the “Auto Scale” button. Figure 10 and Figure 11 show the display of this same image in the “sqrt” and “log” options, respectively, for the full image range. It is often useful to change the display maximum value to something lower than the full image range and redisplaying the image to allow one to see the low level signals in the image, since these are of the most interest for the evaluation of spectral overlap.

In many cases for the direct images a better view of the stars is obtained by selecting the “log” or “sqrt” options for the image scaling and then changing the display maximum in the entry field to a smaller value, say 1% of the maximum. If this is done and the “Redisplay” button is pressed one will have the image redisplayed with the new range. This helps to see fainter stars in the field that are more than 5 magnitudes fainter than whichever star (or galaxy, in some cases) is setting the upper limit of the display range.

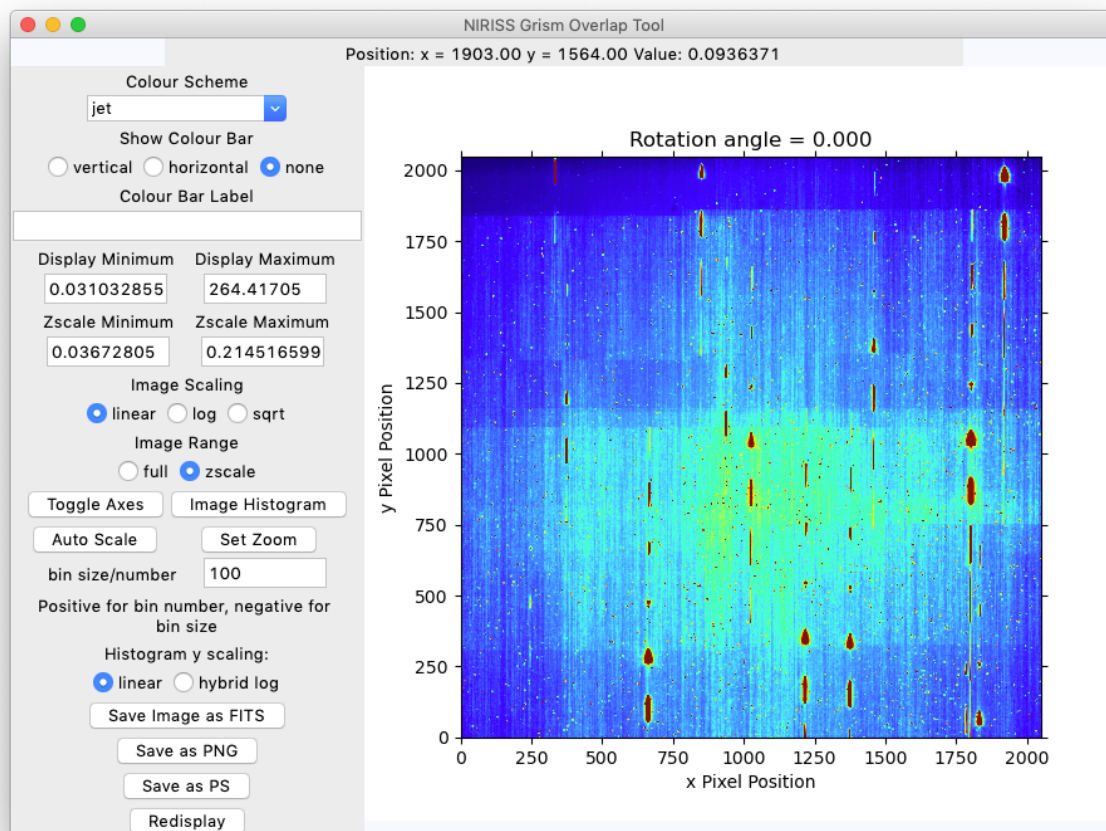


Figure 9: The image displayed using the “zscale” option to show the low level structure.

Once an image has been displayed when the cursor is on the image the pixel position and the image value at the cursor are written to the text field at the top of the window. The signal value shown is always the value in the original image and not in any transformed image that might be displayed. There are instances where the cursor event is out of range of the plot but still gets sent to the routine that writes out the position. In such cases an error message may appear in the terminal window, which is benign.

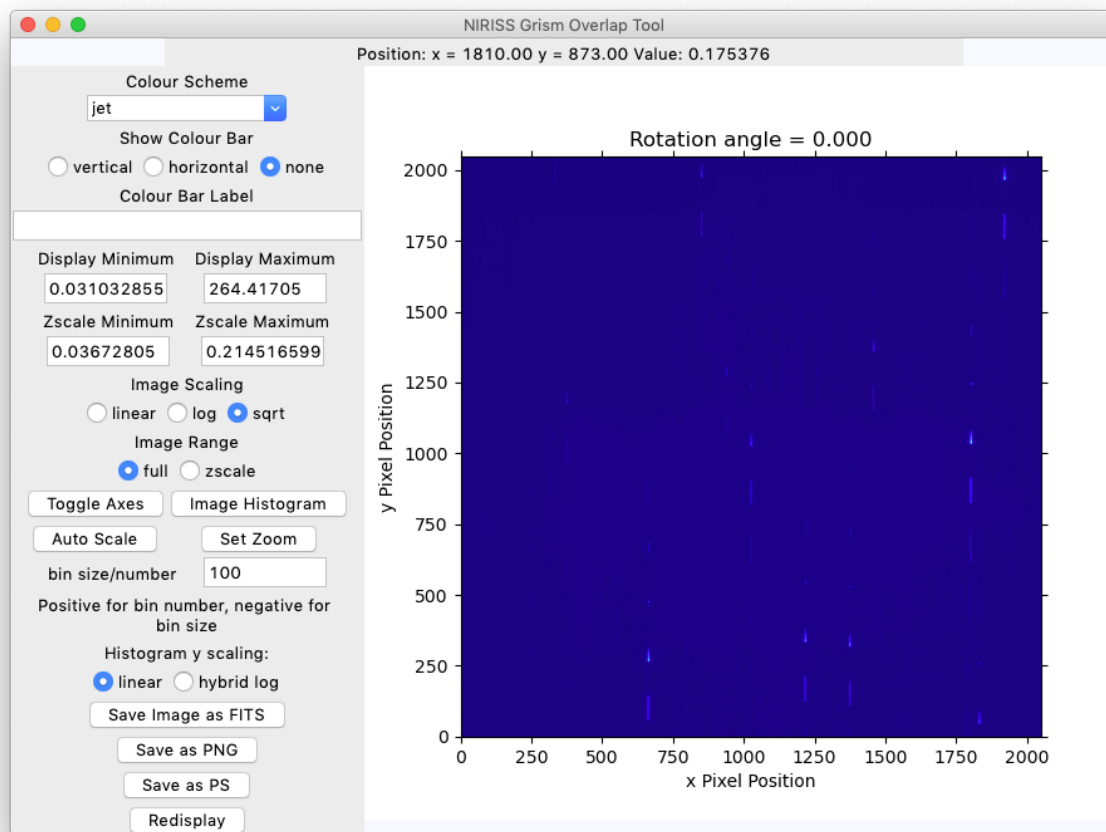


Figure 10: Display of the dispersed image with the “sqrt” option selected.

There is the option of adding a colour bar to the plot area if the “vertical” or “horizontal” radio buttons are selected. When a selection is made any text in the “Colour Bar Label” entry box is used to label the colour bar. If one changes the text in the label window one needs to change the radio button selection to make it take effect.

Another function at left is the “Toggle Axes” button. It toggles the display of the x and y axes in the plot.

The tool has an image histogram option. The display minimum/maximum entry fields set the range of the histogram. The “bin size/number” entry field sets the number of bins in the histogram if the value is positive and larger than 10. The value is truncated to an integer if it is a floating point value. If the value in the entry field is negative the absolute value is taken and this value is then used as the step size in the histogram. A new window is created to show the histogram plot. One is able to save the histogram plot to a file in either postscript or PNG form. The control of the histogram plot is somewhat limited since there is no way to change the y axis range or use anything but linear scaling on both axes, but it does give a quick look at the distribution of values in the image. Each time a histogram is requested a new window is created.

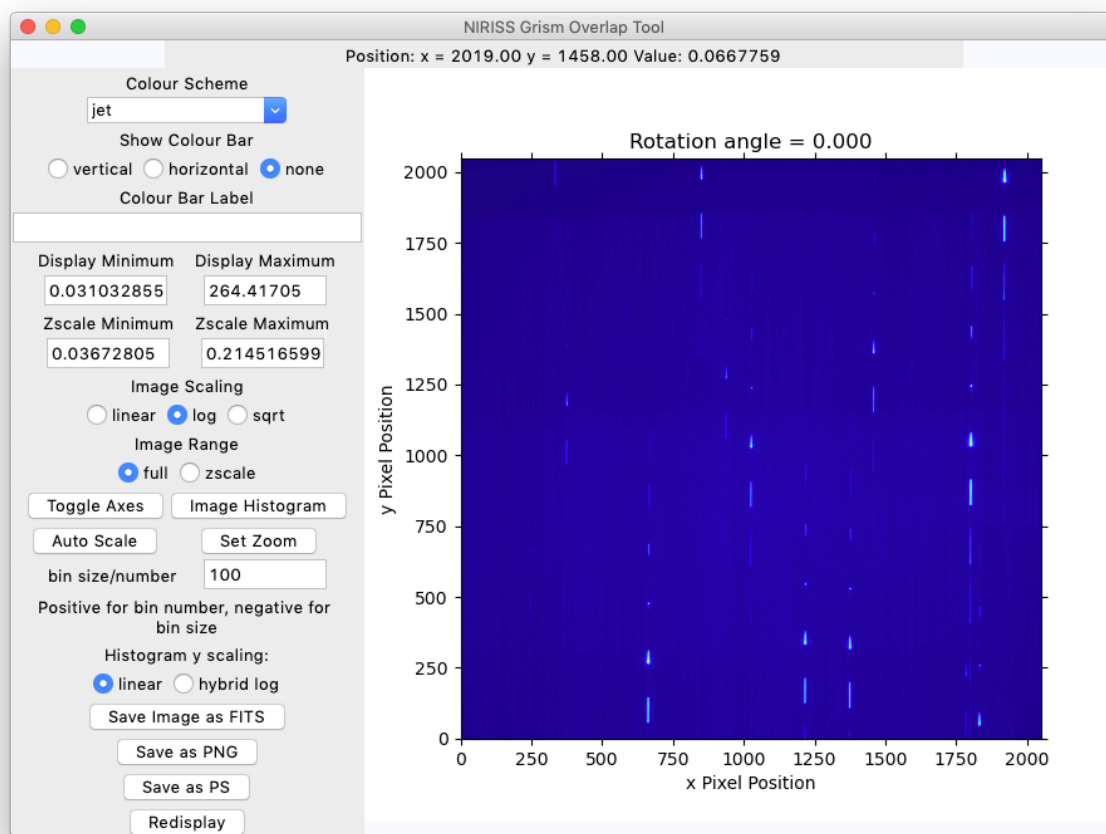


Figure 11: Displaying the dispersed image with the “log” option selected.

## Use of the “Zoom” Function

The default in the image display is to show the full image. There is an option to display a sub-image rather than the full image. The “Set Zoom” button brings up an entry window where the user can enter an integer zoom value, 1 or larger. If a zoom value is entered, the size of the input image is divided by the zoom factor (rounded to an even integer) and a sub-image with this dimension is extracted around the image reference position. The reference position is originally placed at the centre of the image, but if one clicks with the mouse anywhere in the image display the pixel position thus selected becomes the reference point for zooming. When a zoom value is entered, the image is redisplayed. The various settings at right including the image range are not affected by extracting a sub-image to display.

The zoom values that are allowed range from 1 to a maximum value that produces a sub-image of size 64 pixels. One needs to set the zoom back to 1 to get the full image display if the value is set.

Each time a new image configuration is displayed by the tool, the zoom value is set to 1.

## Key Commands

In the image display window one can use key commands “j” and “k” to get image profiles in the x and y directions respectively. These are similar to the IRAF imexam key commands. The code takes the cursor position where the key is pressed, and extracts a pixel area 20 pixels in the x direction and 5 pixels in the y direction for the j key, or 20 pixels in the y direction and 5 pixels in the x direction for the k key. The extracted region is averaged over the short dimension and plotted as a vector. Thus when one is looking at a dispersed image with the spectra along the y axis one can get a cross-cut profile with the j key, and for the case of spectra along the x axis one can get a cross-cut profile with the k key. Along with the plot of the data values, the code carries out a non-linear least squares fitting of the data with a Gaussian profile plus a constant baseline. The best fit function is overplotted along with the data values, and the parameters are shown on the plot. When such a plot is done, the plot window needs to be closed before any further input can be entered into the main window or in the image display window.

The “r” and “c” key commands for plotting the row or column at the current cursor position are also provided.

## Rotating The Scene Image

The main purpose of the tool is to allow the user to change the position angle and see how this affects the output image. For changing the angle, one has the option of using the slider in the main window to set the rotation angle, measured in degrees east of north in the usual way, to any value from 0° to 360° with a resolution of 0.01°. Alternatively, one can use the “Step+” and “Step-” buttons to change the current rotation angle by whatever step amount is given in the “Step” entry field. The range of allowed angles for the step function is read from the “Minimum” and “Maximum” entry fields. If one just clicks on the slider with the cursor, it moves 0.01° either up or down depending on the side of the slider where the cursor is located.

The image rotation is done using the `script.ndimage.rotate` function as noted previously. The entire image is rotated about the centre position, so if a source is placed on the centre position, then its spectrum or image PSF remains fixed as the rotations are done. Each time a rotation is done the image display is updated. The rotation calculations are not fast enough to allow the tool to have a “movie mode”.

## Use of the GR700XD Option

The GR700XD option works in a similar way to what is done for the GR150R and GR150C grisms. However, there are two “modes” selected by the “Reference Position at SOSS position” radio button. If this value is “no” then the scene image is rotated about the centre in the usual manner, as required, and then the output image is directly convolved with the GR700XD PSF function. That is equivalent to placing the GR700XD grism in the beam after a regular imaging observation without doing an acquisition for the SOSS mode.

***It is important to note that the current scene image in one of the blocking filters is used for the SOSS simulations, rather than an image as would be seen with no blocking filter.*** The detailed relative brightness values for the sources are not correct. As the goal is to visualize the overlap this is a secondary concern, especially considering that the PSF image is made with a

“wrong” source spectrum in any case as noted above. Estimates of the overlap as a function of rotation for the preparation of JWST observing proposals in SOSS mode can be made from the Universite de Montreal SOSS contamination tool which can be found at the ‘SOSS Simulators and Tools’ page [http://jwst.astro.umontreal.ca/?page\\_id=401](http://jwst.astro.umontreal.ca/?page_id=401) or the equivalent tool on the STScI ExoCTK page <https://exoctk.stsci.edu/>.

Figure 12 shows the scene image from Figure 7 with the display maximum reduced by a factor of 100 to show all the stars in the field clearly. The primary target WD 1657+343 is the source near the centre of the image. Figure 13 shows the result of selecting the GR700XD grism for this field with the reference position at the image centre not at the SOSS acquisition position, so it is what is expect if the GR700XD grism is simply inserted into the scene in Figure 12.

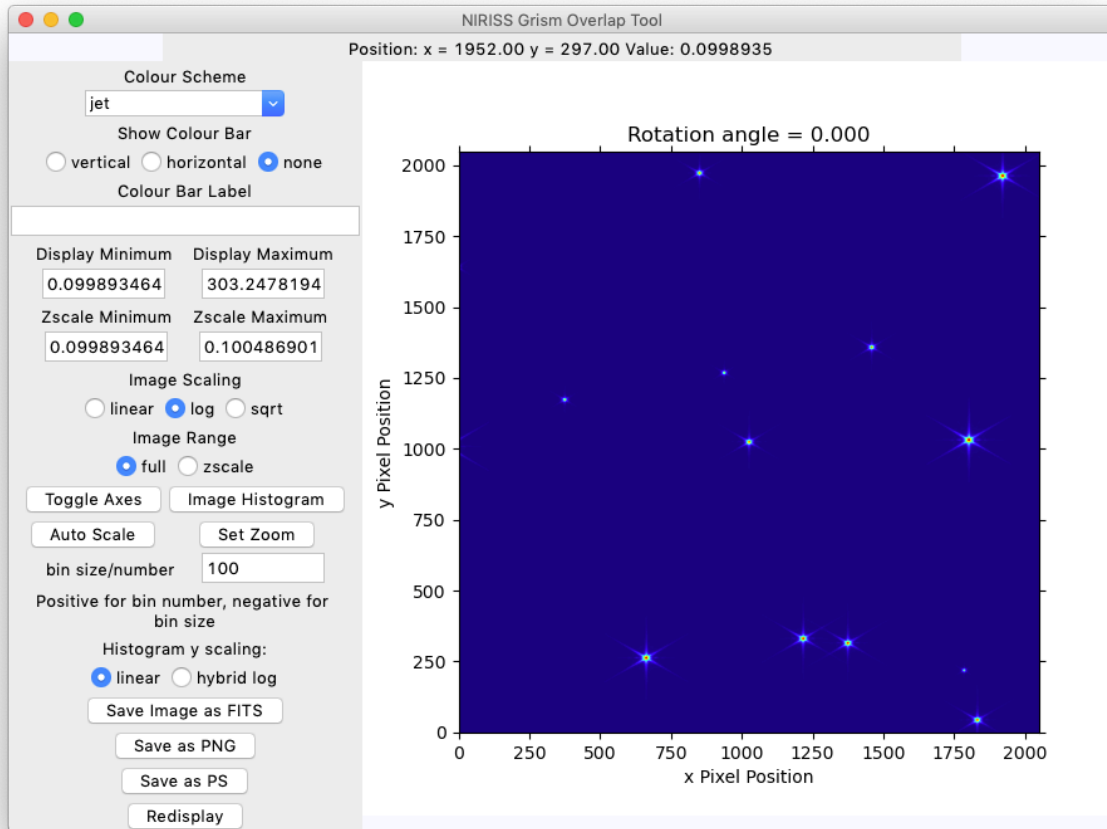


Figure 12: The scene image from Figure 7 with a restricted range to show the stars better.

In Figure 13 the brightest traces in the field are generally for the zero orders. The zero order spectrum of the four star in the centre/lower left part of the direct image are seen in the upper right area of the dispersed image. There is a large offset from the direct image positions to the spectral positions, and hence the lower part of the dispersed image has no spectra in it because any stars that would nominally produce spectra in this area are below the edge of the POM. The brightest order 1 trace in the upper part of the dispersed image is from the bright star in the right centre part of the direct image, with the pair of stars seen in the lower centre area and the star further to the left producing the other brighter spectral traces in the centre left part of



Figure 13. The background structure is due to variations in which orders are contribute to the signal in different parts of the image. The brightest area in the upper right is for pixels that can receive light from orders 0, 1 and 2, while the area to the left is where only light for orders 1 and 2 reaches the pixels.

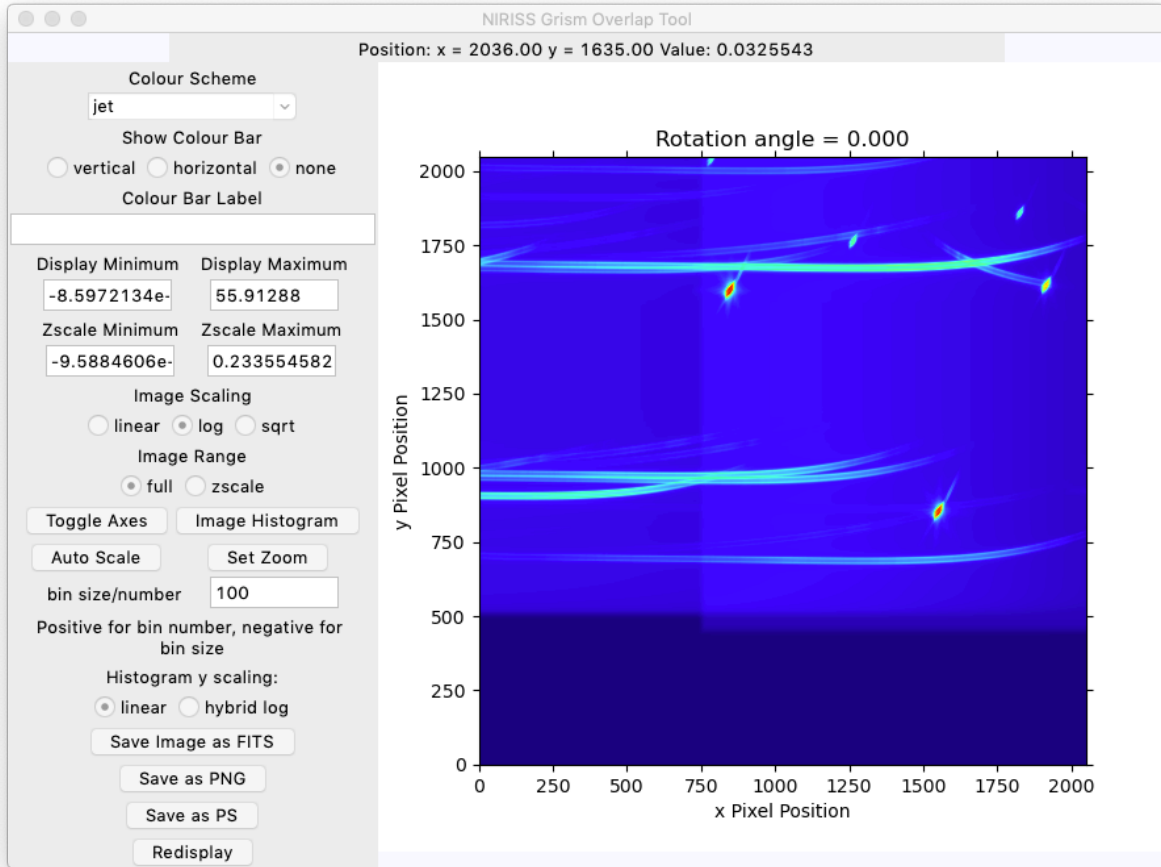


Figure 13: The result of selecting the GR700XD grism for the WD 1657+343 scene, with no rotation and with no offset of the field.

Although the occulting spots produce variations in the background for the WFSS case, in the SOSS case the spectral shift of the grism takes the occulting spots far off above the detector and so no effect is seen.

Using the stars file for BD+60°1753 gives an example of a more normal SOSS mode target, as the star is much brighter than other stars in the field. Figure 14 shows the scene image with the maximum value of the display reduced by a factor of 100 and logarithmic scaling to show the fainter stars in the field. Figure 15 shows the predicted dispersed image if the GR700XD grism is inserted without any offset of the field. Then in Figure 16 one sees the dispersed image in the case where the offset to the SOSS acquisition position is included. This would be the normal SOSS output for a full frame exposure. In the latter Figure one sees the standard star spectrum in the normal position. In Figure 15 the spectrum of the standard is off the field of view and one sees instead a spectrum of the fainter star that is to the right of the



standard star in Figure 14. The bright blob in the upper right is the zero order spectrum for the standard star.

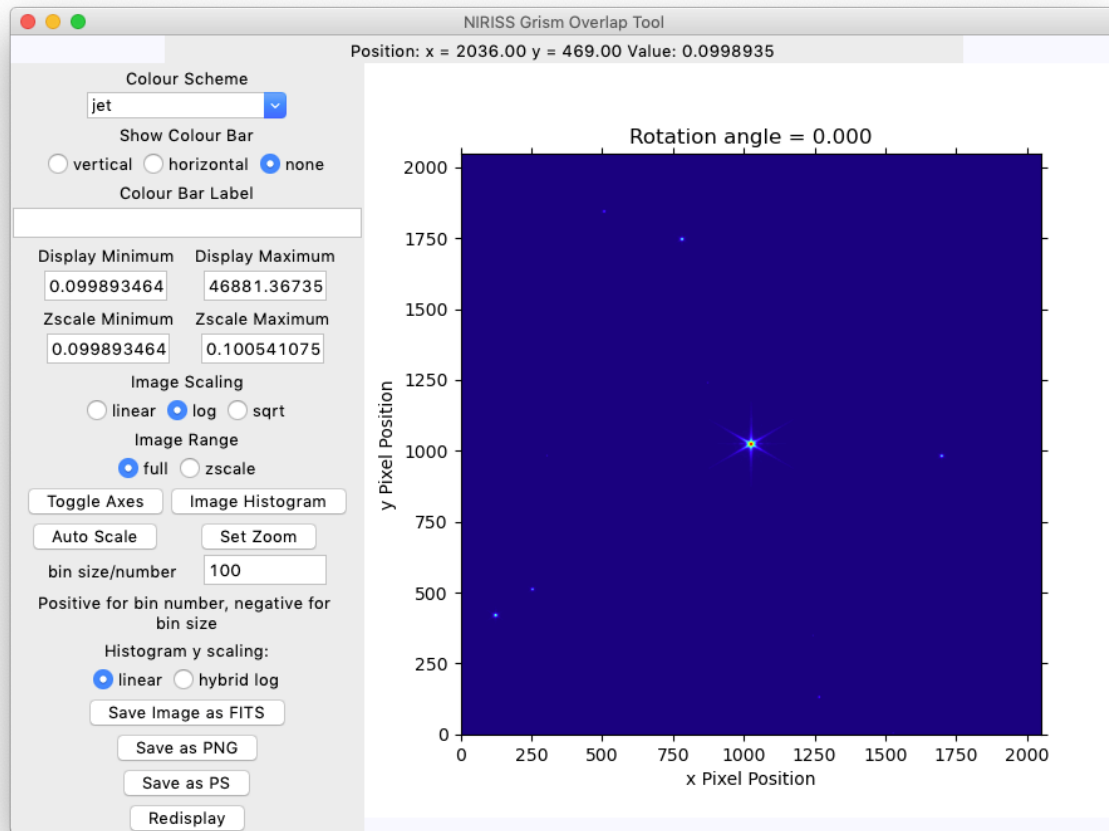


Figure 14: A display of the scene image for the file stars\_bd30d1753\_gaiadr3\_allfilters.txt, the field of the photometric standard BD+30°1753 based on the GAIA eDR4 catalogue.

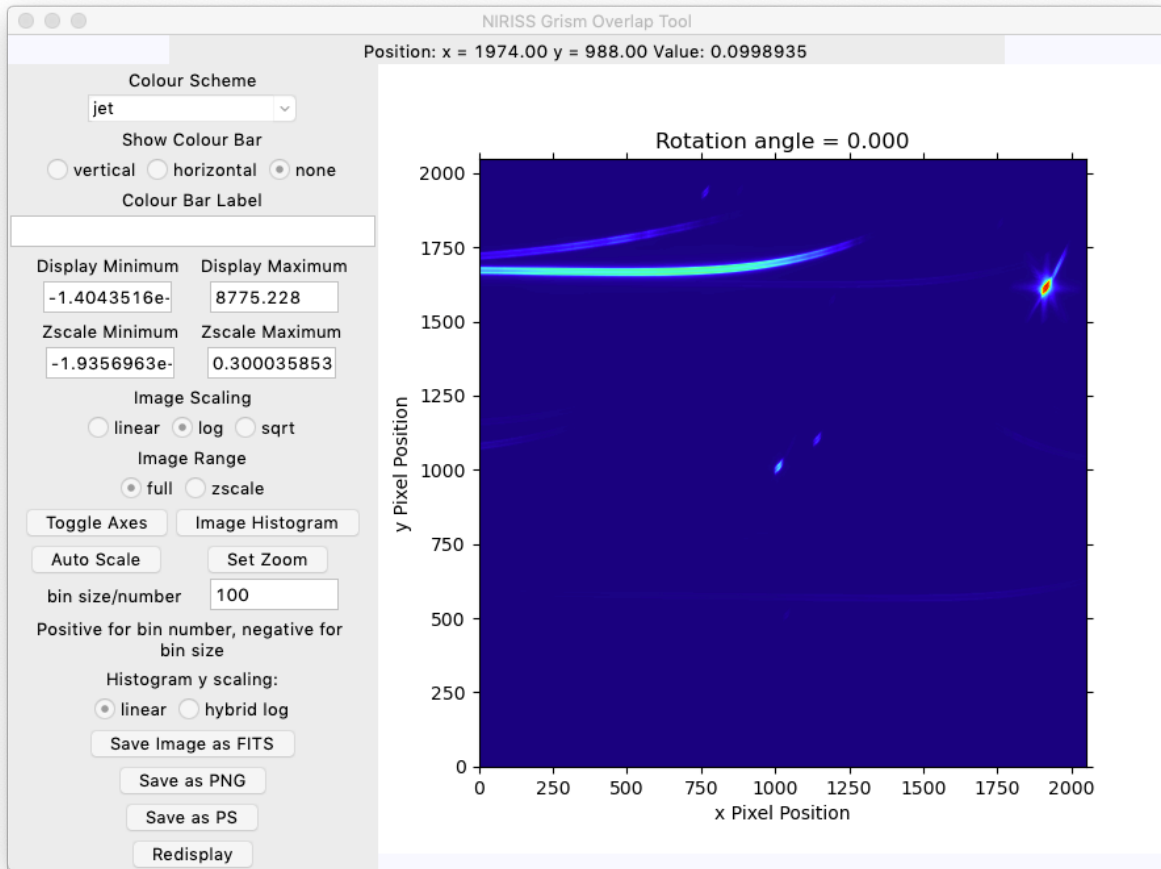


Figure 15: The predicted dispersed image of the scene in Figure 14 with the GR700XD grism in the beam.

The last Figure shows the full scene image with the same display parameters as in Figure 14, but with the reference position set at the SOSS acquisition position and the GR700XD grism selected. Instead of the white boxes that outline the POM area and the image area being centred on the standard star as would be the case if the GR150R or GR150C grism were selected or if the reference position was set at the field centre, the boxes are shifted left and a bit down to place the reference position at pixel [1955, 1199] in the image area, using an IRAF-like notation. That is pixel [3047, 2291] in the full scene image.

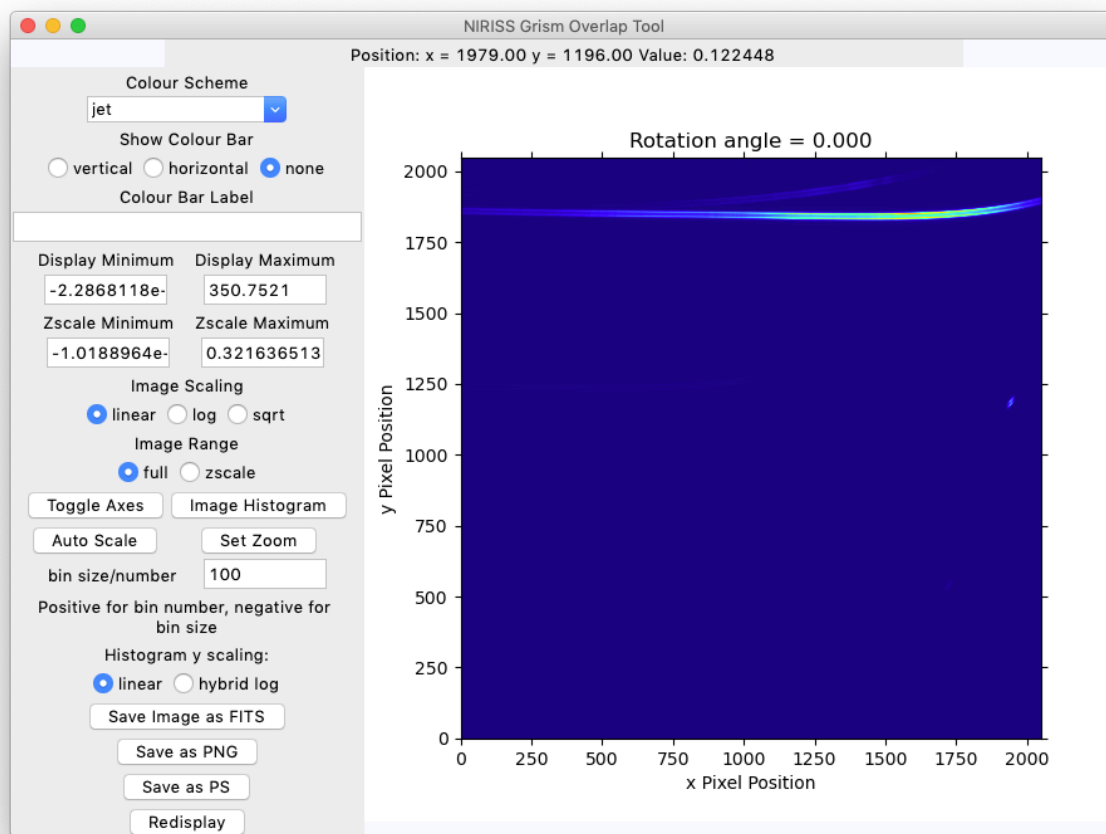


Figure 16: The predicted dispersed image from the scene image in Figure 14 with the offset to the SOSS acquisition position.

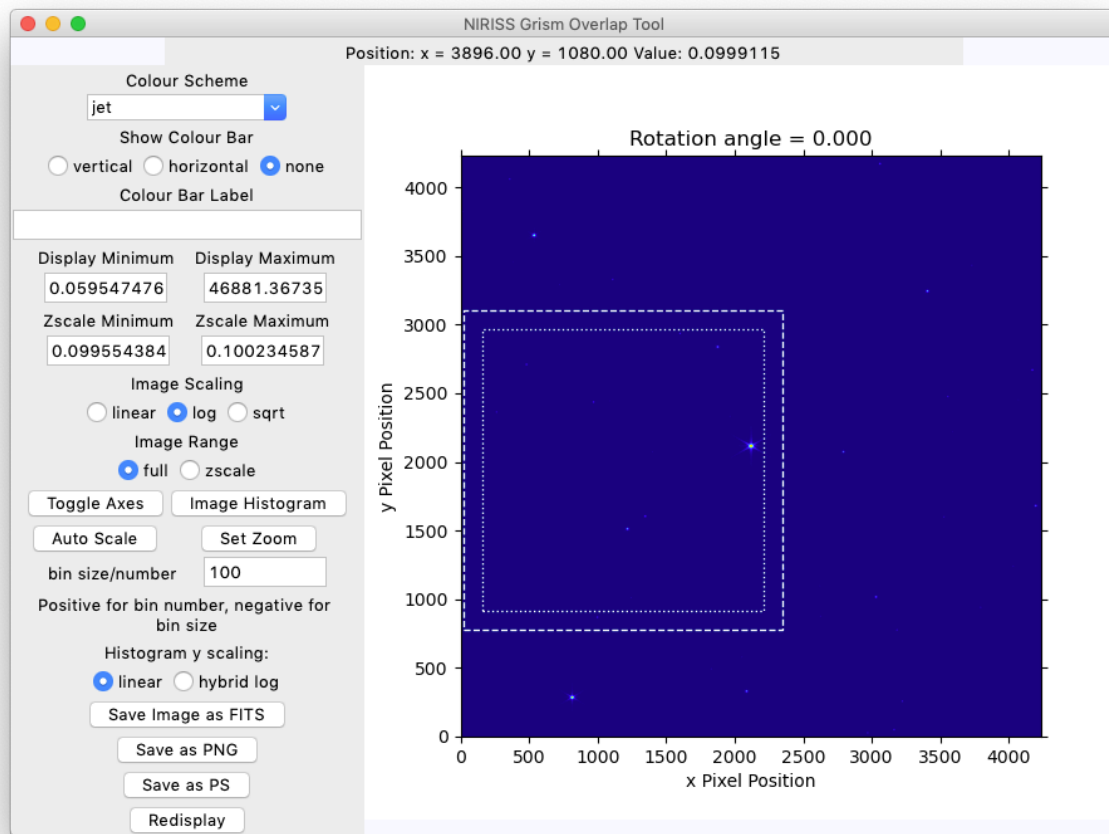


Figure 17: The scene image for the BD+30°1753 with the offset to the SOSS acquisition position included in the display of the POM and imaging areas. If the “Reference position at SOSS position” flag is set to “No” then the white boxes would be centred on the image display since the star is at the centre of the scene image.