High Resolution Echelle Reduction

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A Brief History of Spectroscopy

Photographic Spectra: 1880s to ~1980

- analog (not digital)
- not linear
- limited by the size of the photographic plate
- large wavelength coverage with low resolution
- high resolution with small wavelength coverage
- measurements are made by hand and eye

CCD Echelle Spectra: 1984 to present

- digital
- linear
- limited by size of the CCD
- large wavelength coverage with high resolution
- measurements are made by computer code

Photographic Spectra: 1923

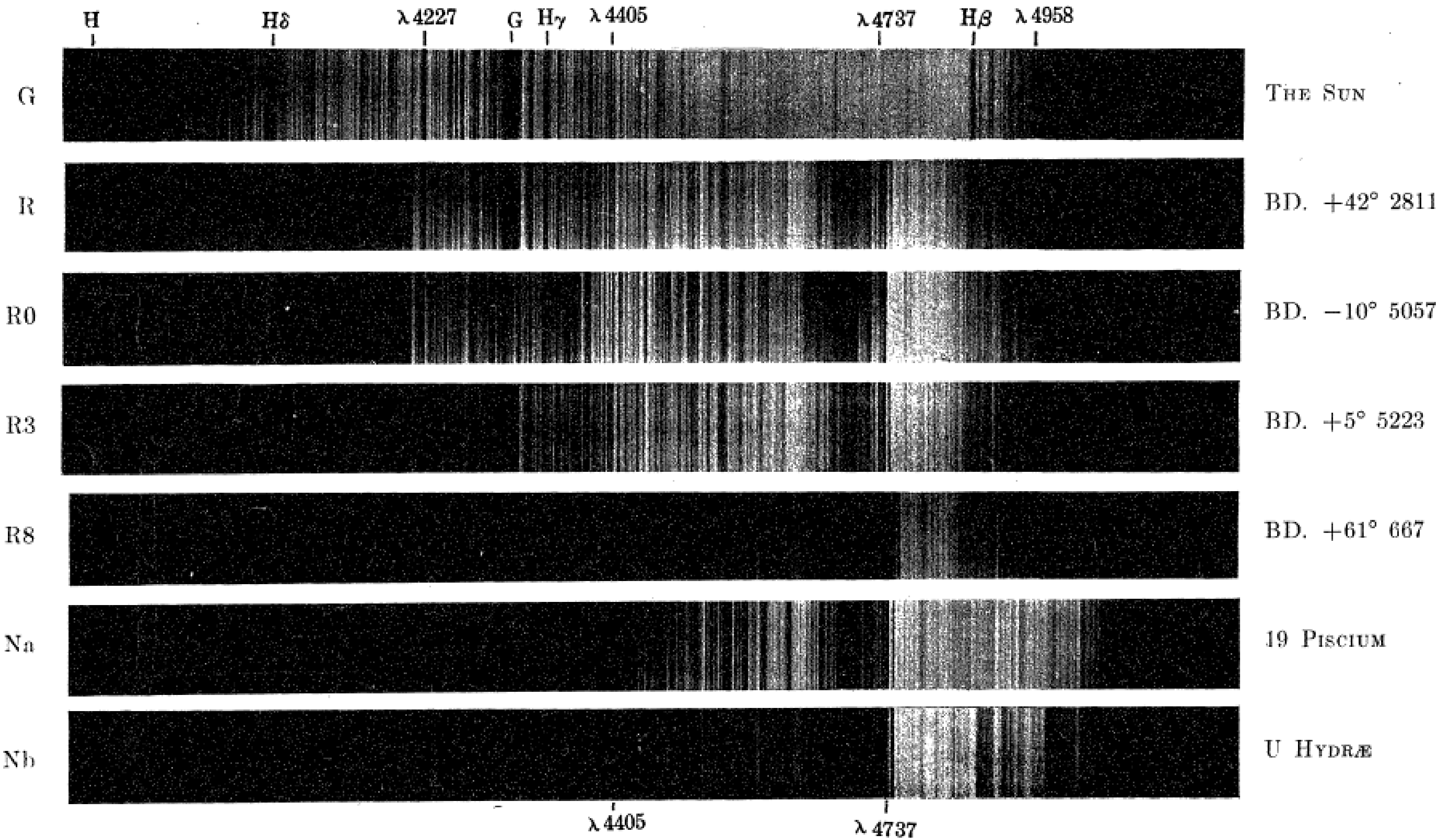
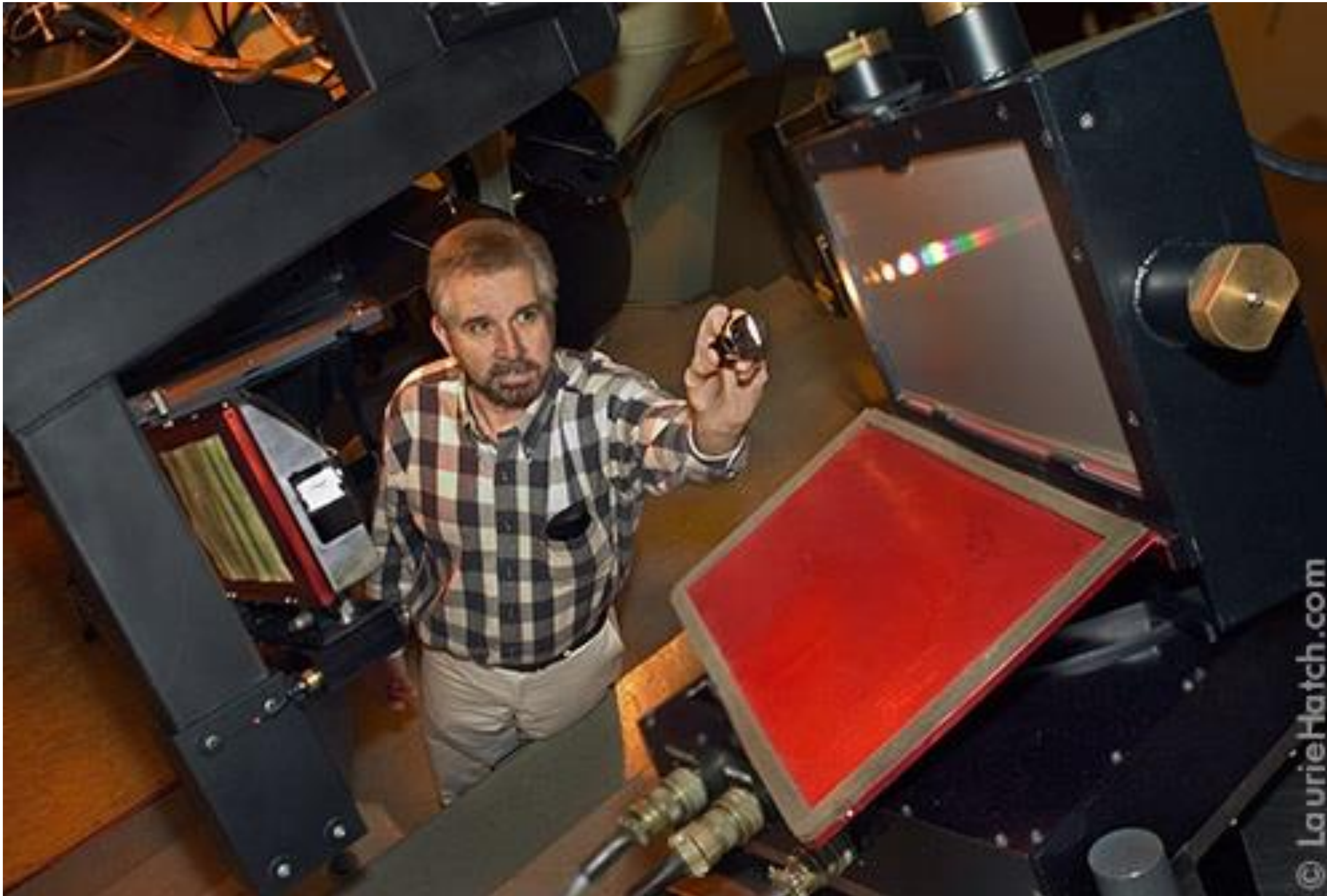
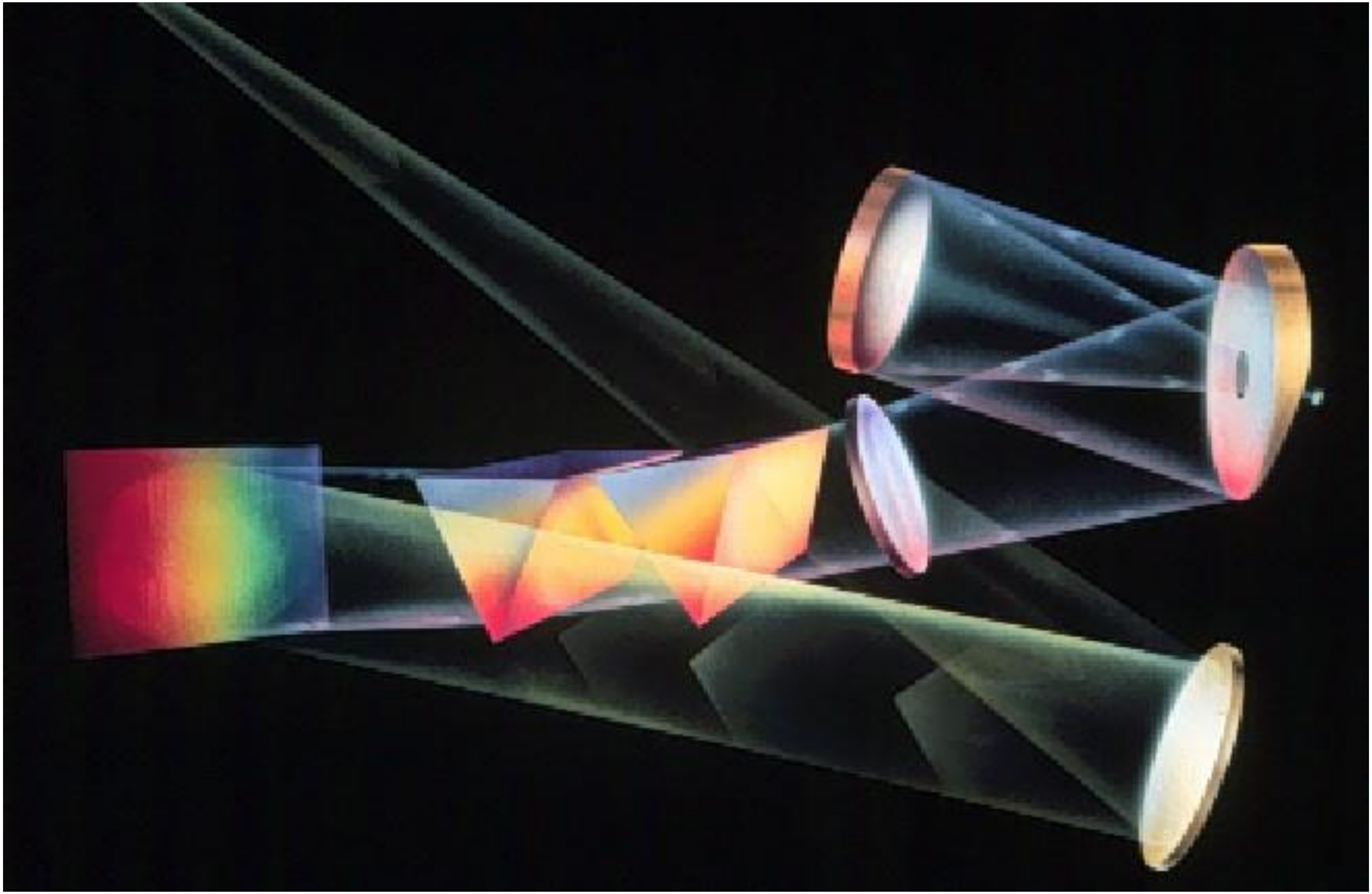


Plate O. Stellar Spectra of Classes G, R and N

Steve Vogt: Hamilton echelle spectrometer

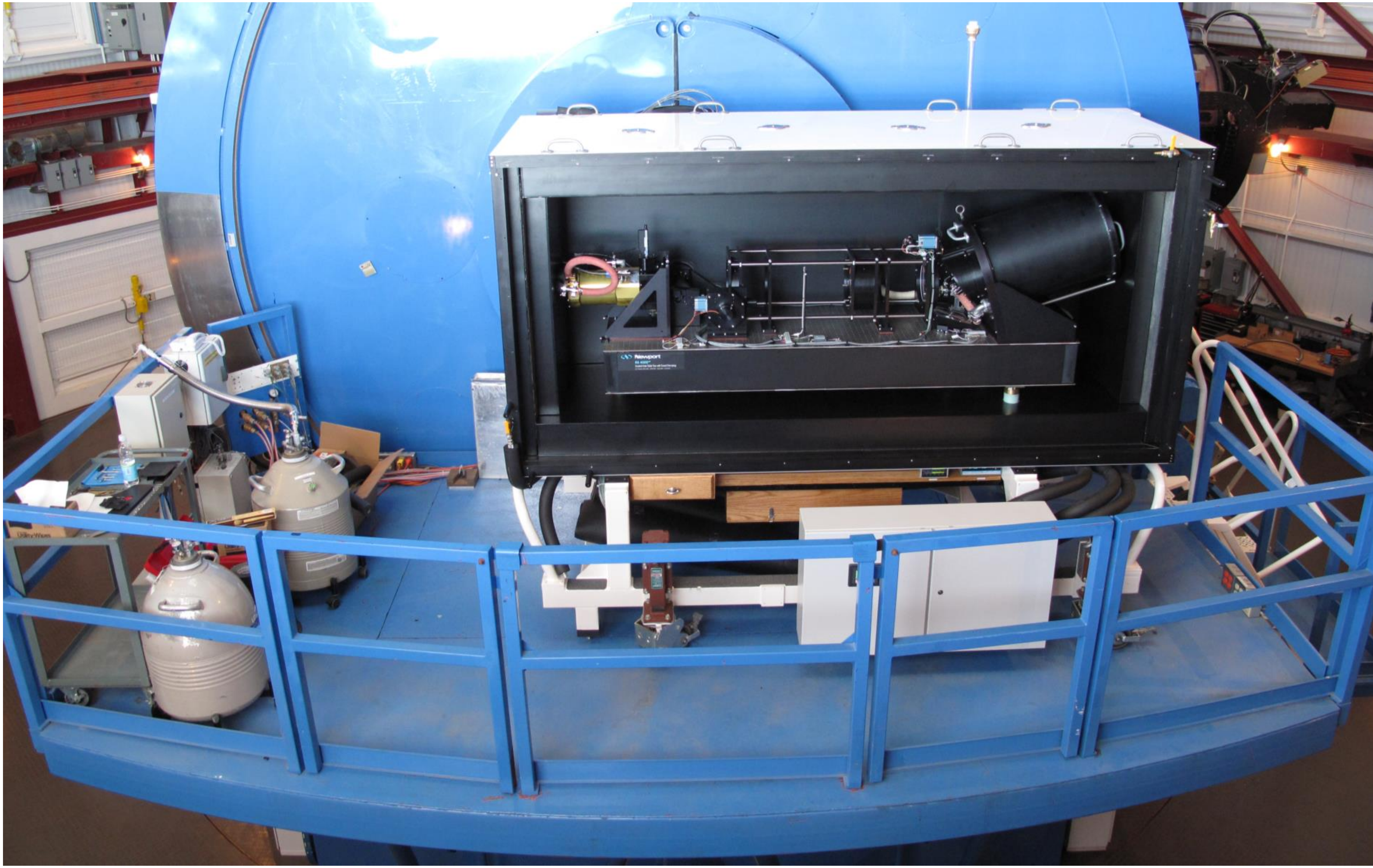


Lick Hamilton Echelle

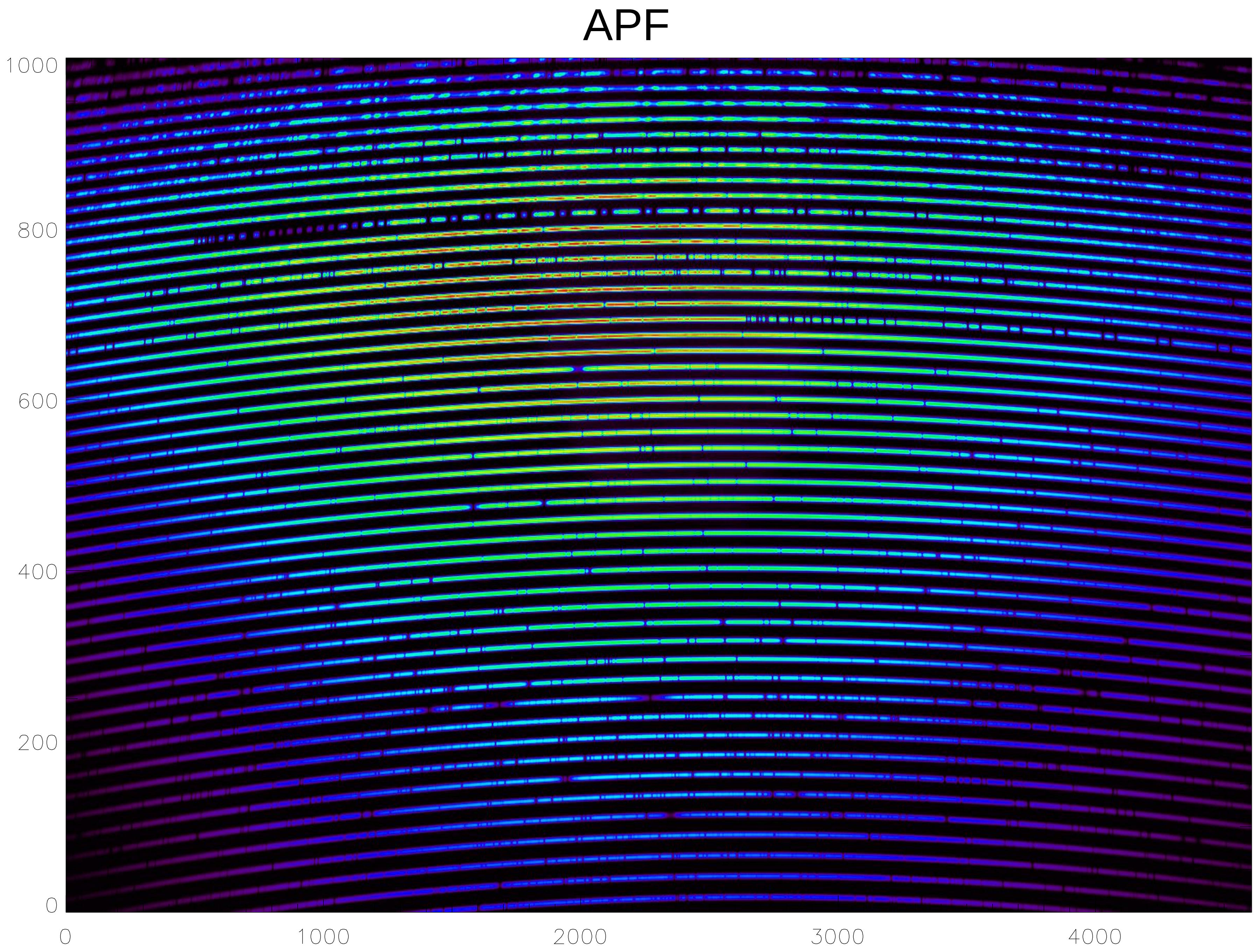



FSC

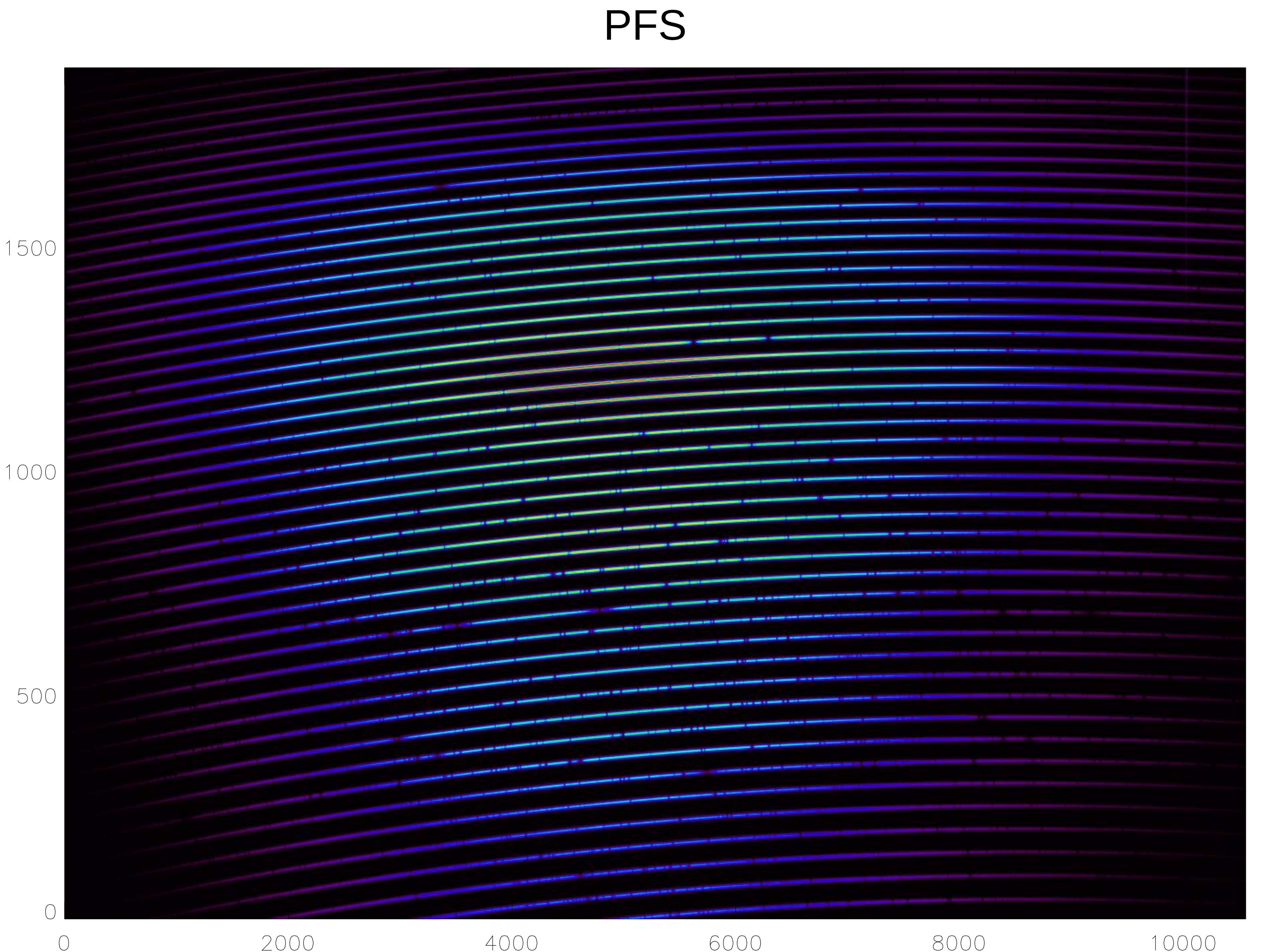
PFS On the Nasmyth Platform



Side insulation panel is removed to show instrument interior

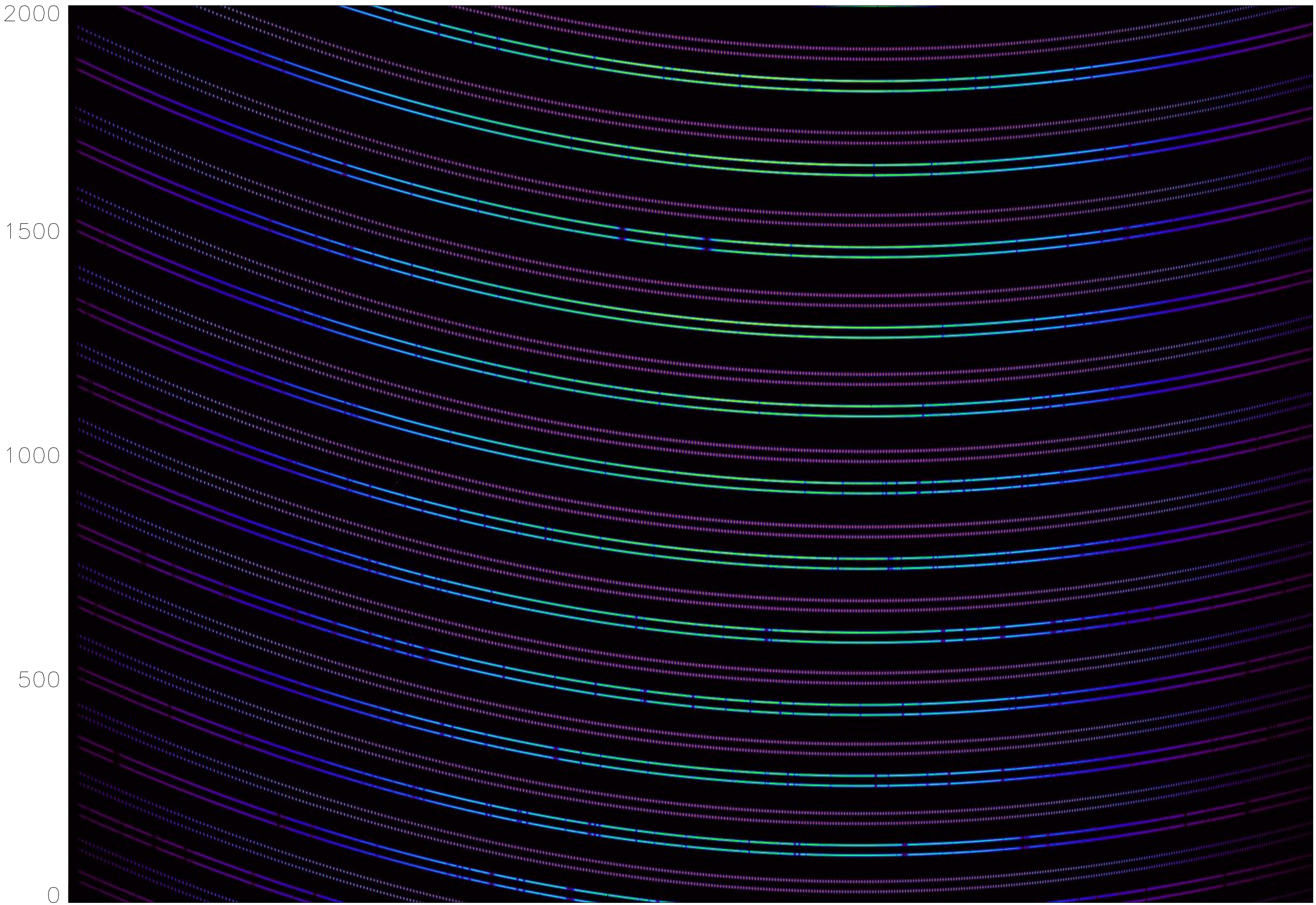


APF
1000
800
600
400
200
0
0
1000
2000
3000
4000



PFS
0
500
1000
1500
0
2000
4000
6000
8000
10000

ESPRESSO RED CCD



BIAS

The amplifiers on CCD generate a non-zero base-line
This must be removed
There are two ways to do this

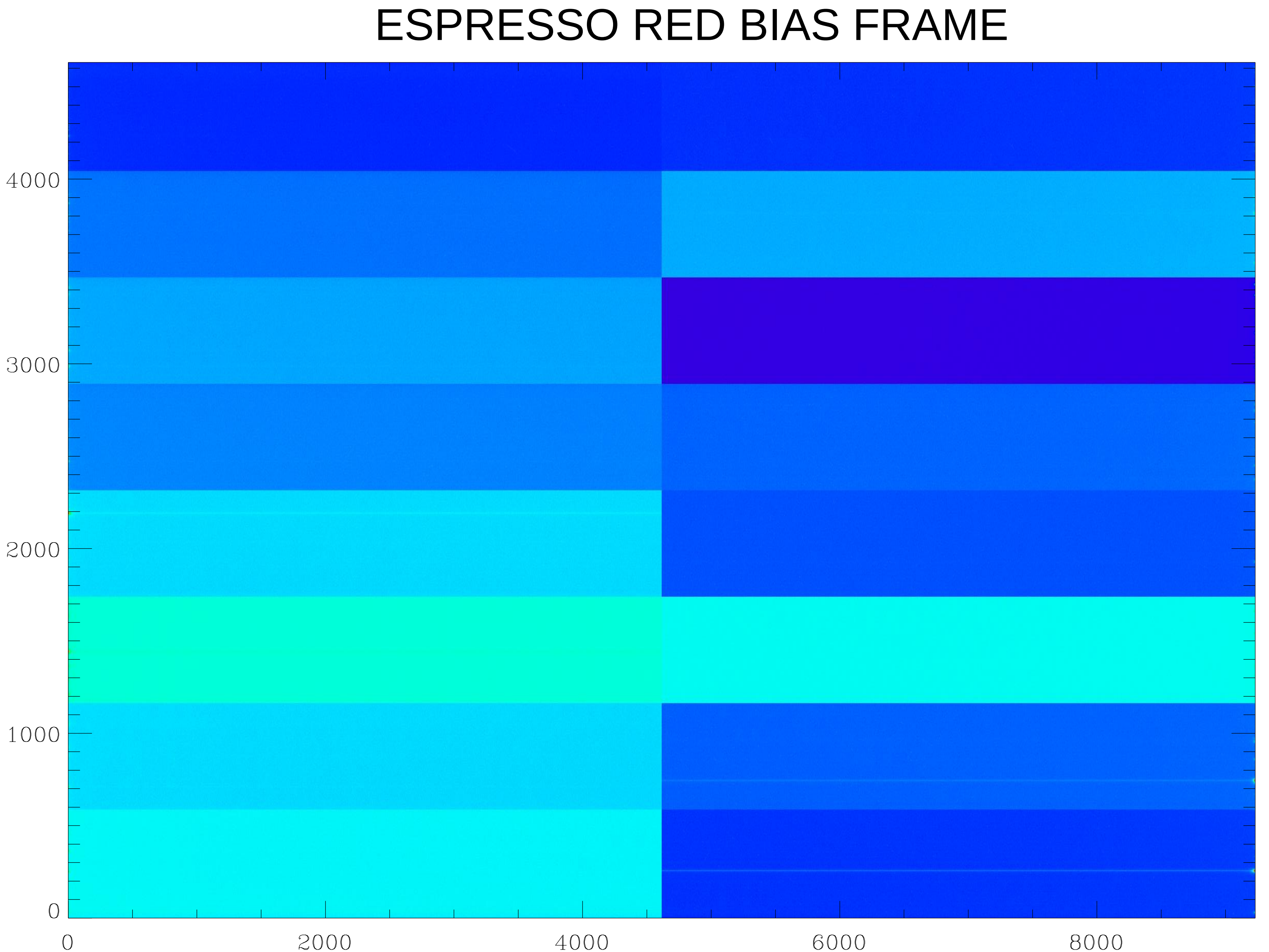
1) Take multiple Bias frames (0 second exposures)
2) Use the over-scan region on the CCD

Subtract the Bias from each observation

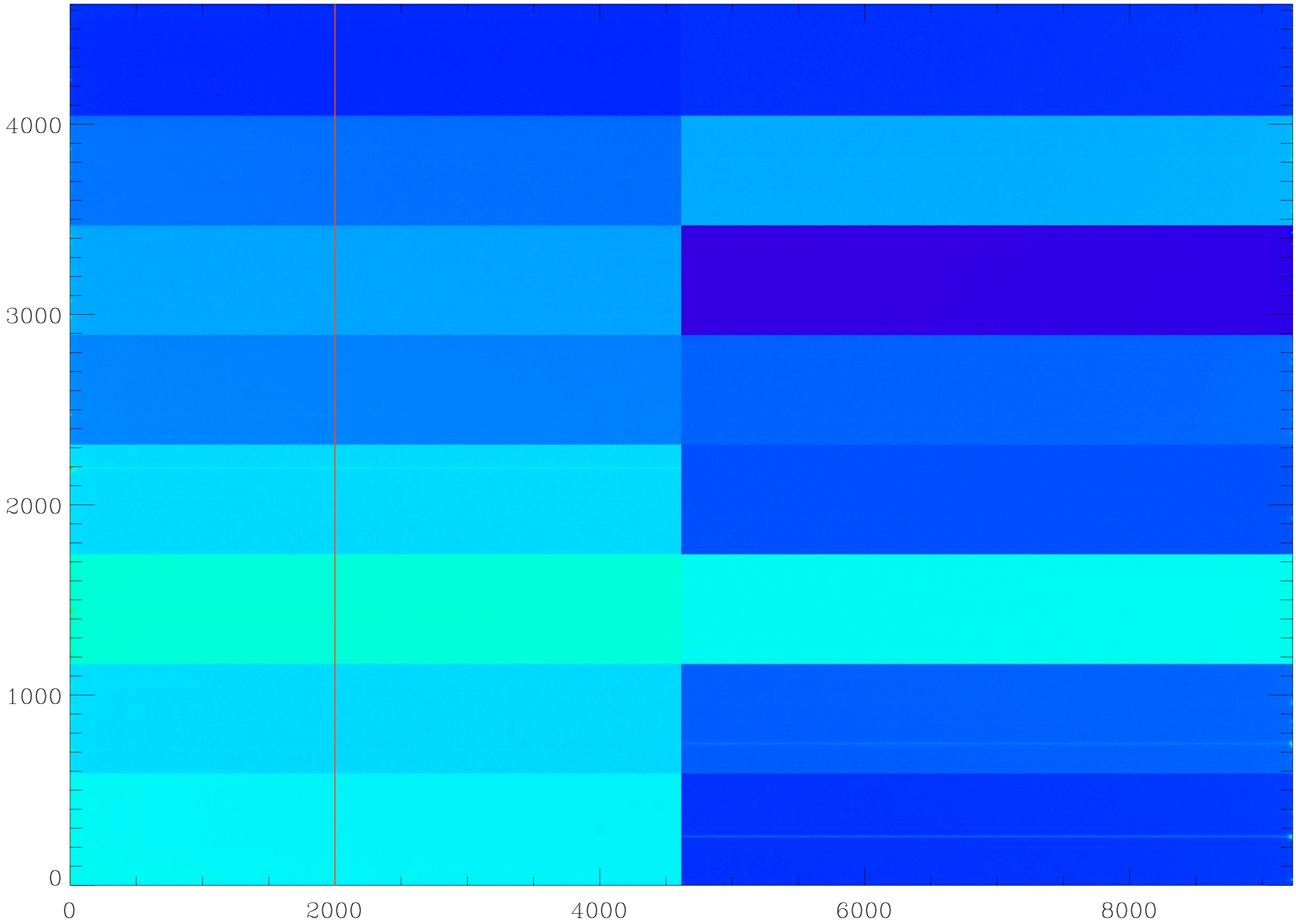
1) For Bias from Bias frames, once per night
2) For over-scan CCD, each frame

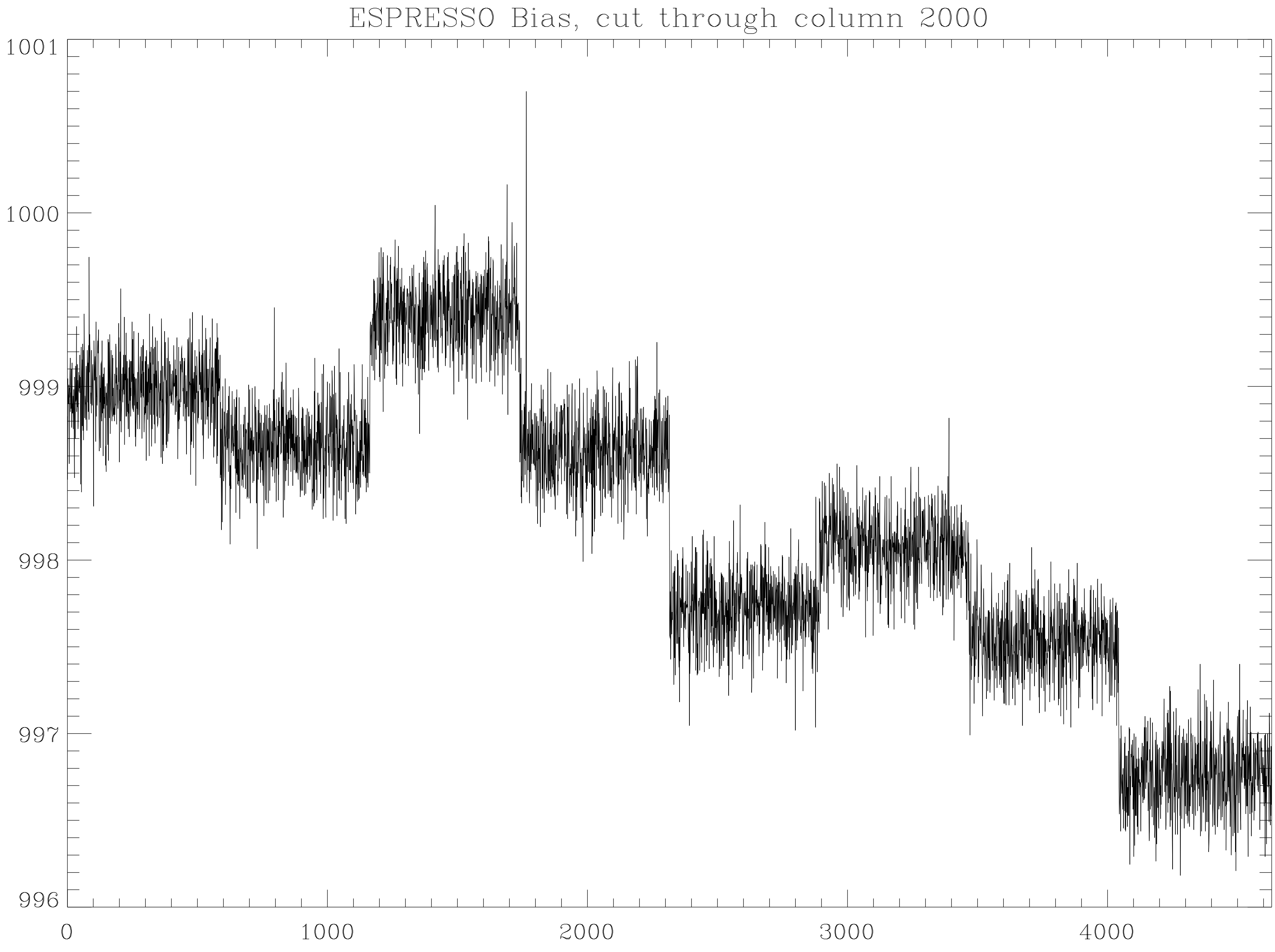
Write a little code to read in the FITS file
Rotate the frames such that :

1) Wavelength increases from left to right
2) Wavelength of the orders increase from bottom to top

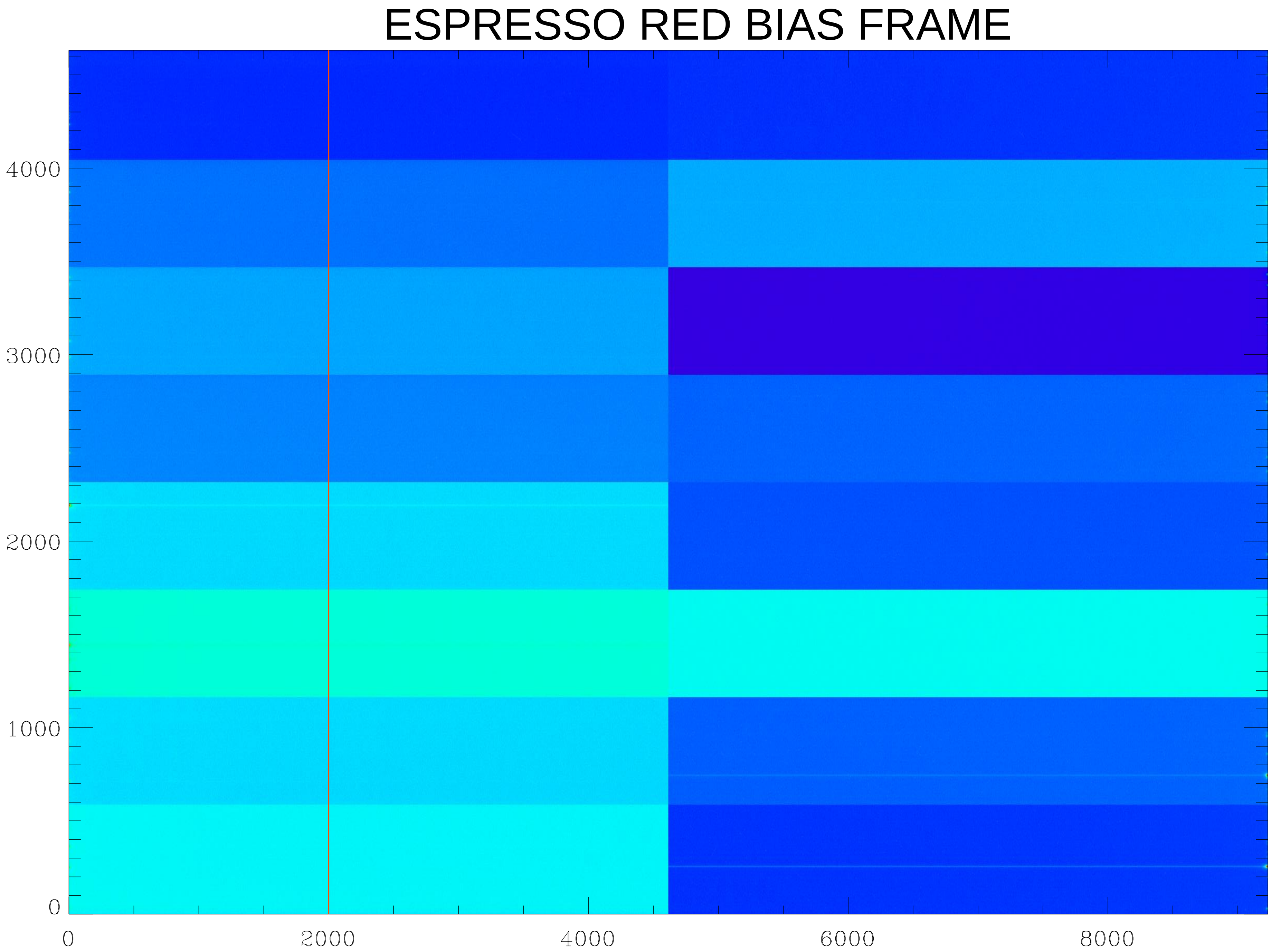

ESPRESSO RED BIAS FRAME
0
1000
2000
3000
4000
0
2000
4000
6000
8000

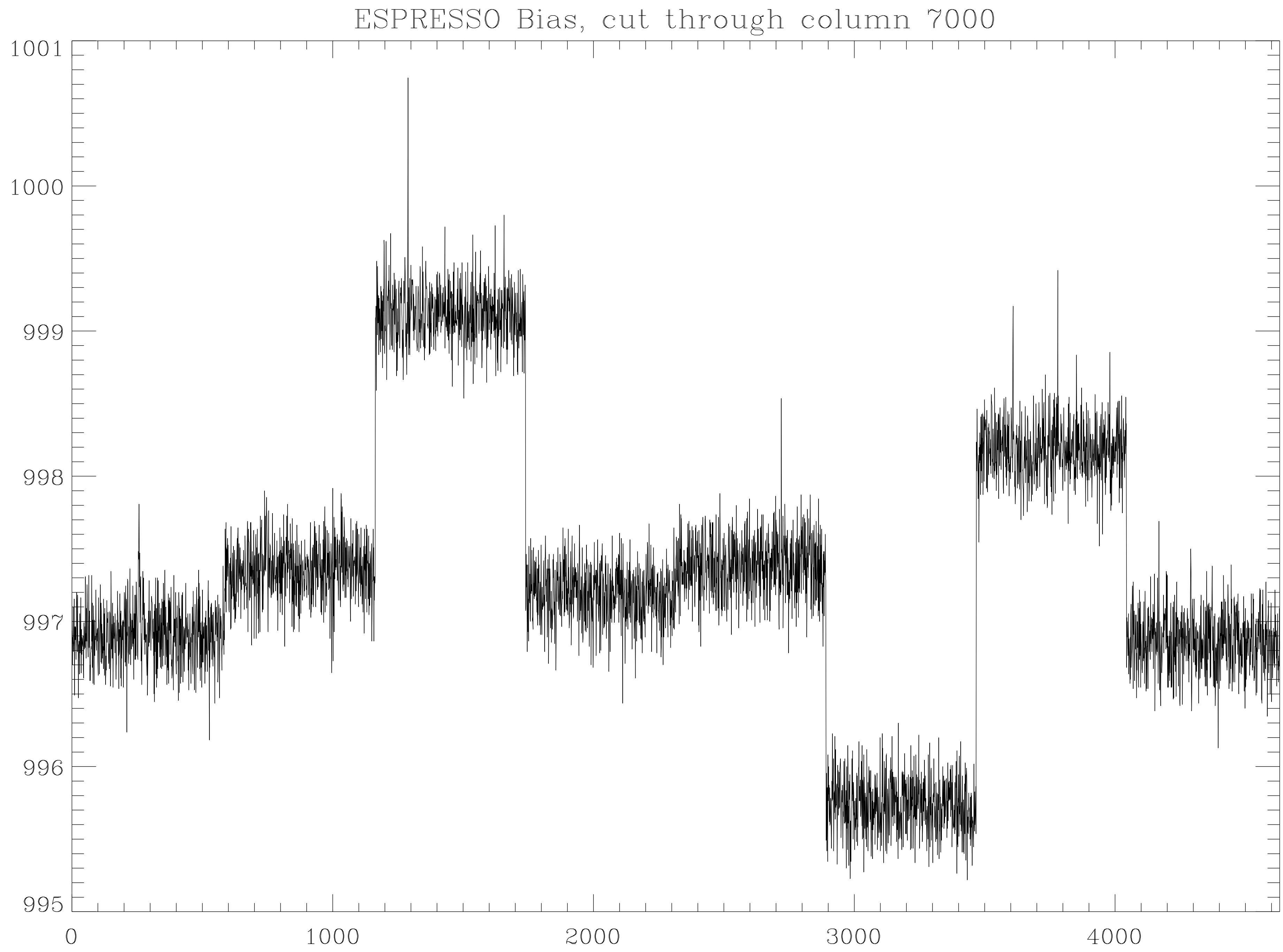
ESPRESSO RED BIAS FRAME



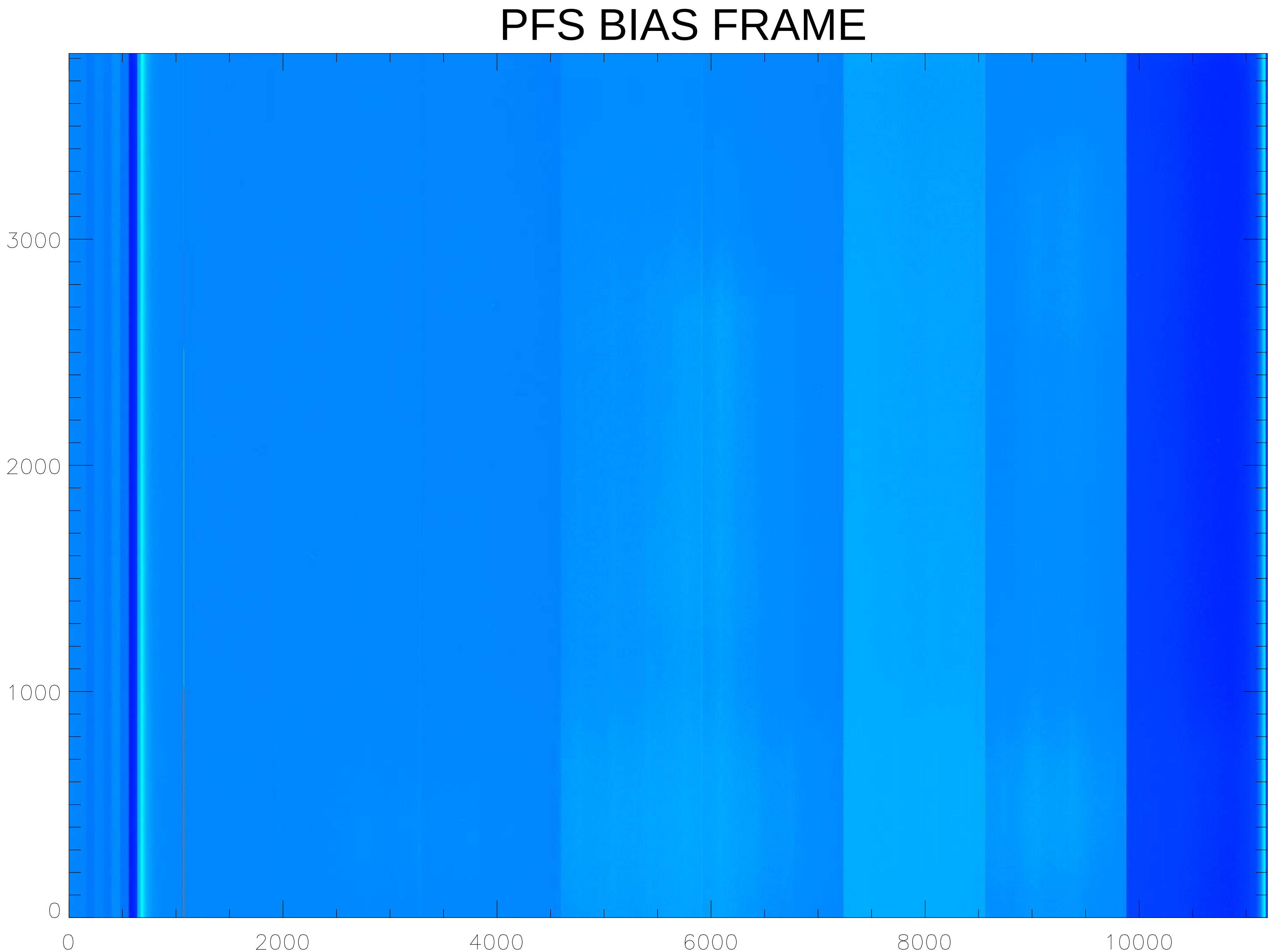


ESPRESSO Bias, cut through column 2000
1001
1000
999
998
997
996
0
1000
2000
3000
4000

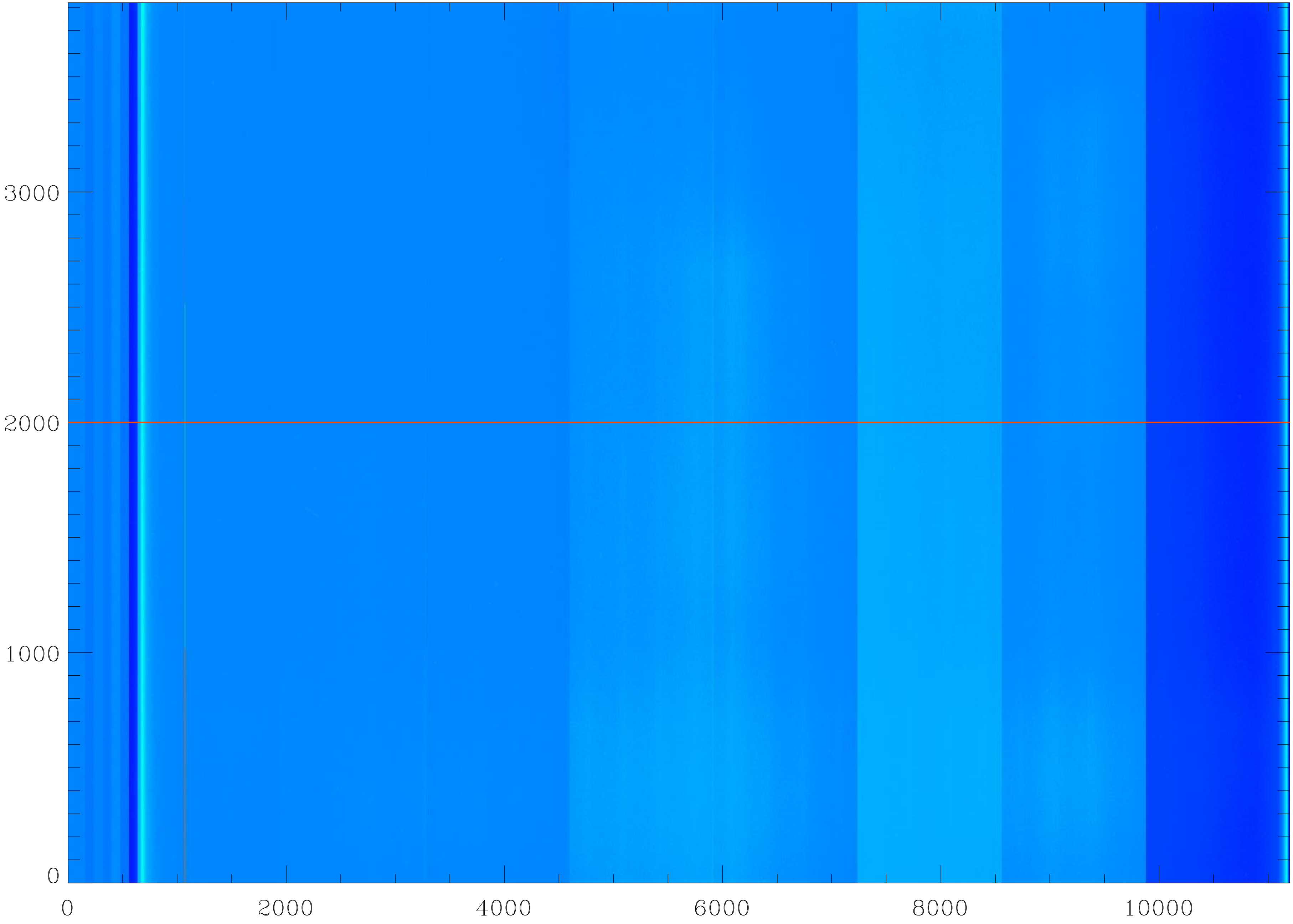

ESPRESSO RED BIAS FRAME
0
1000
2000
3000
4000
0
2000
4000
6000
8000

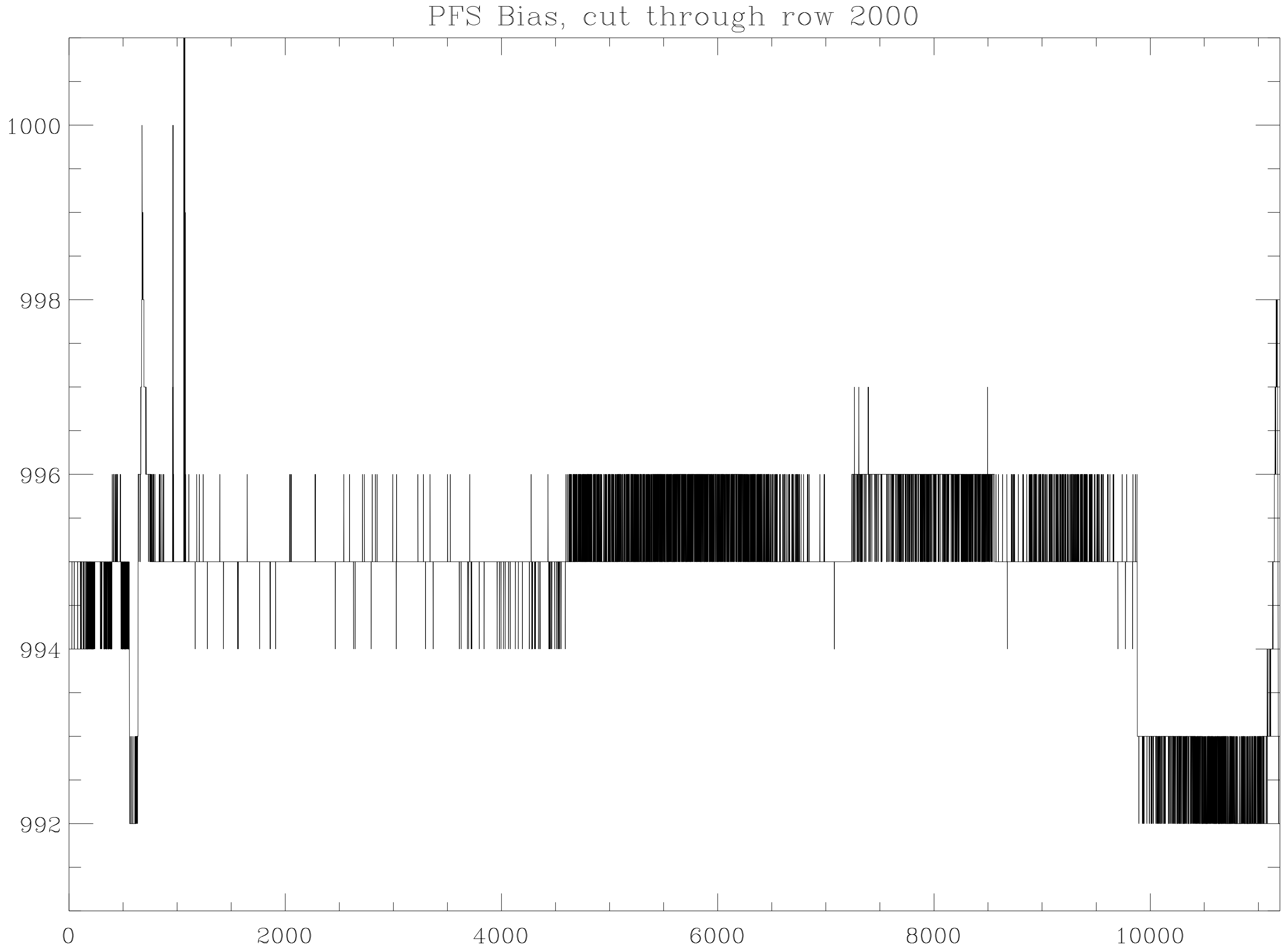


ESPRESSO Bias, cut through column 7000
1001
1000
999
998
997
996
995
0
1000
2000
3000
4000

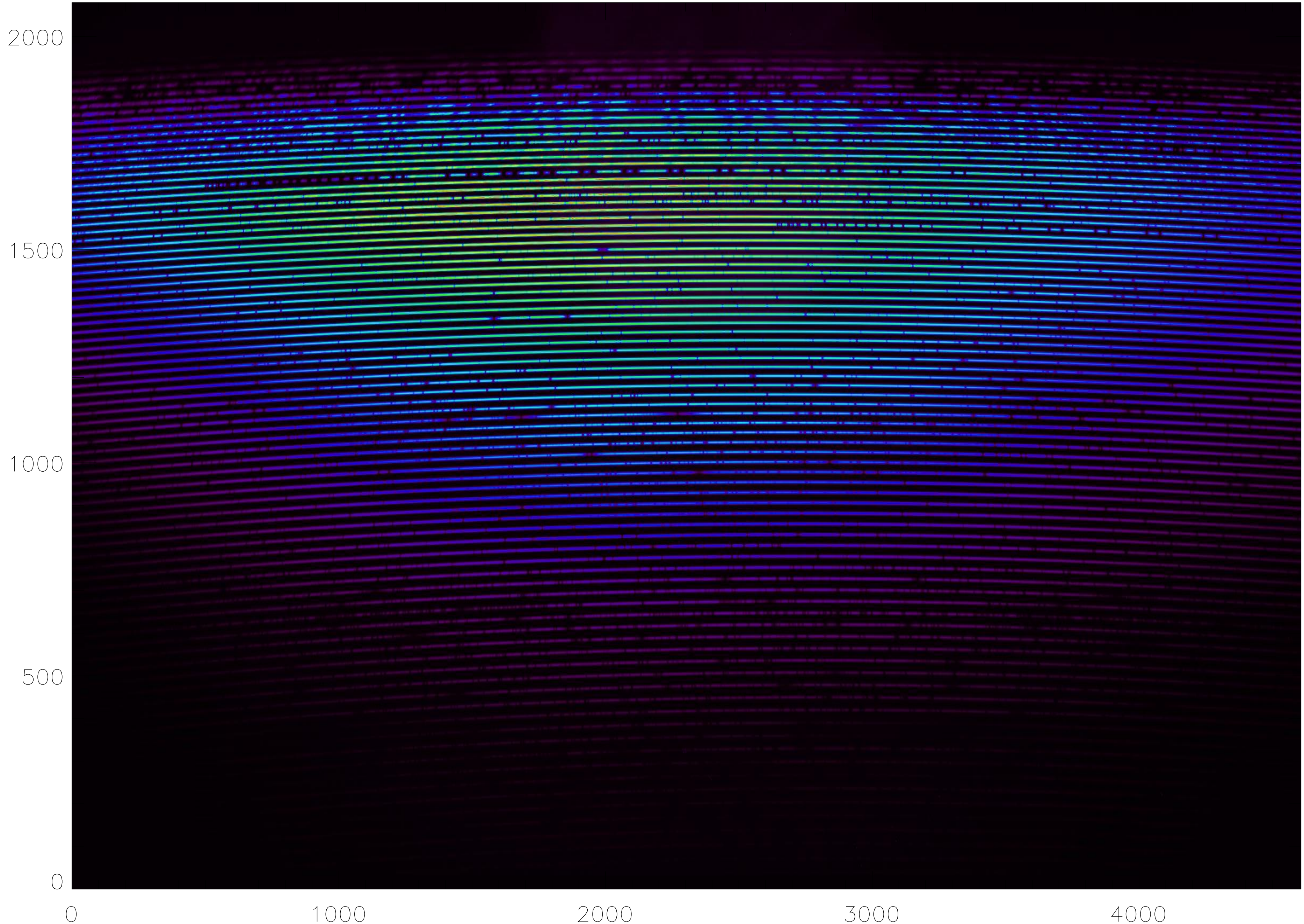

PFS BIAS FRAME
0
1000
2000
3000
0
2000
4000
6000
8000
10000

PFS BIAS FRAME

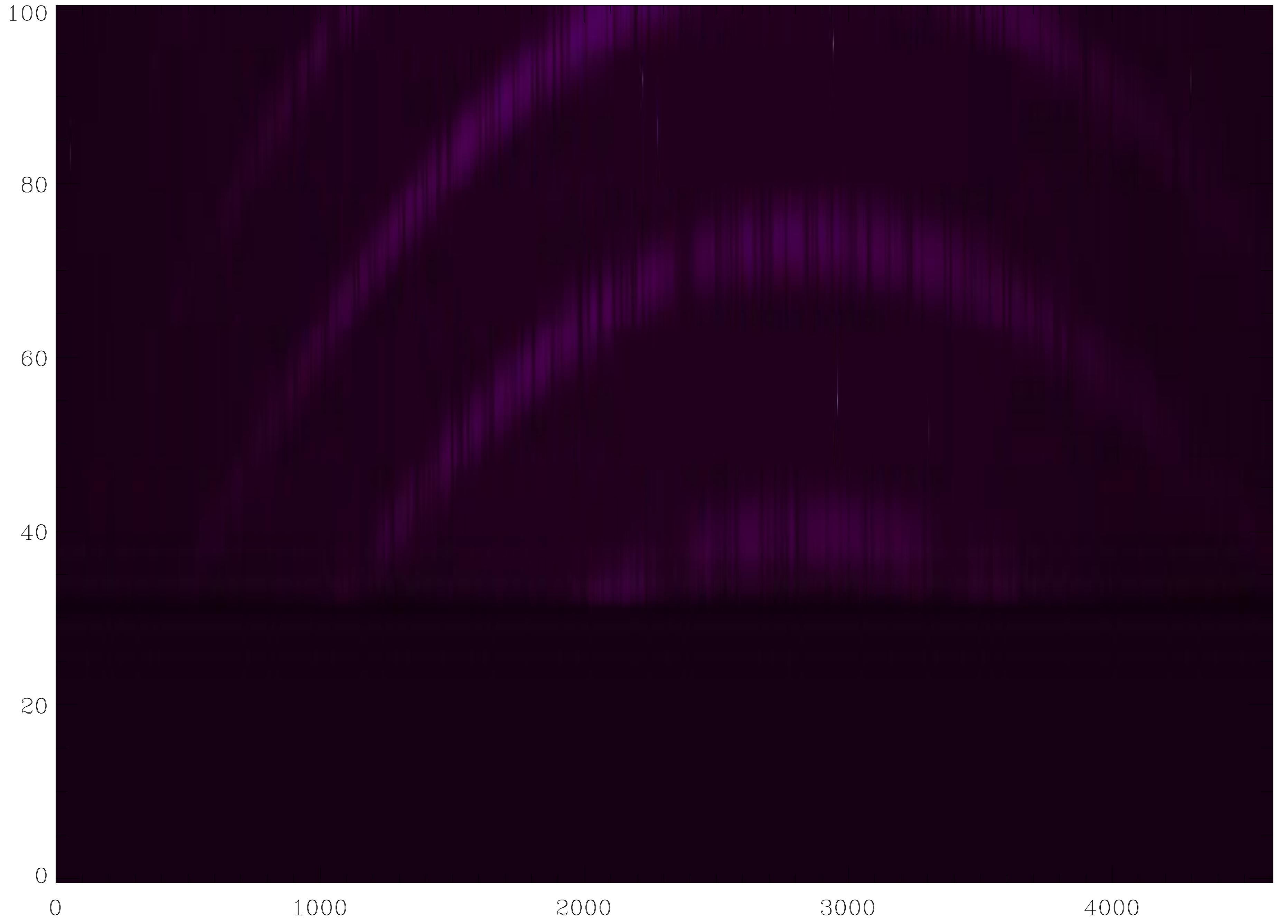


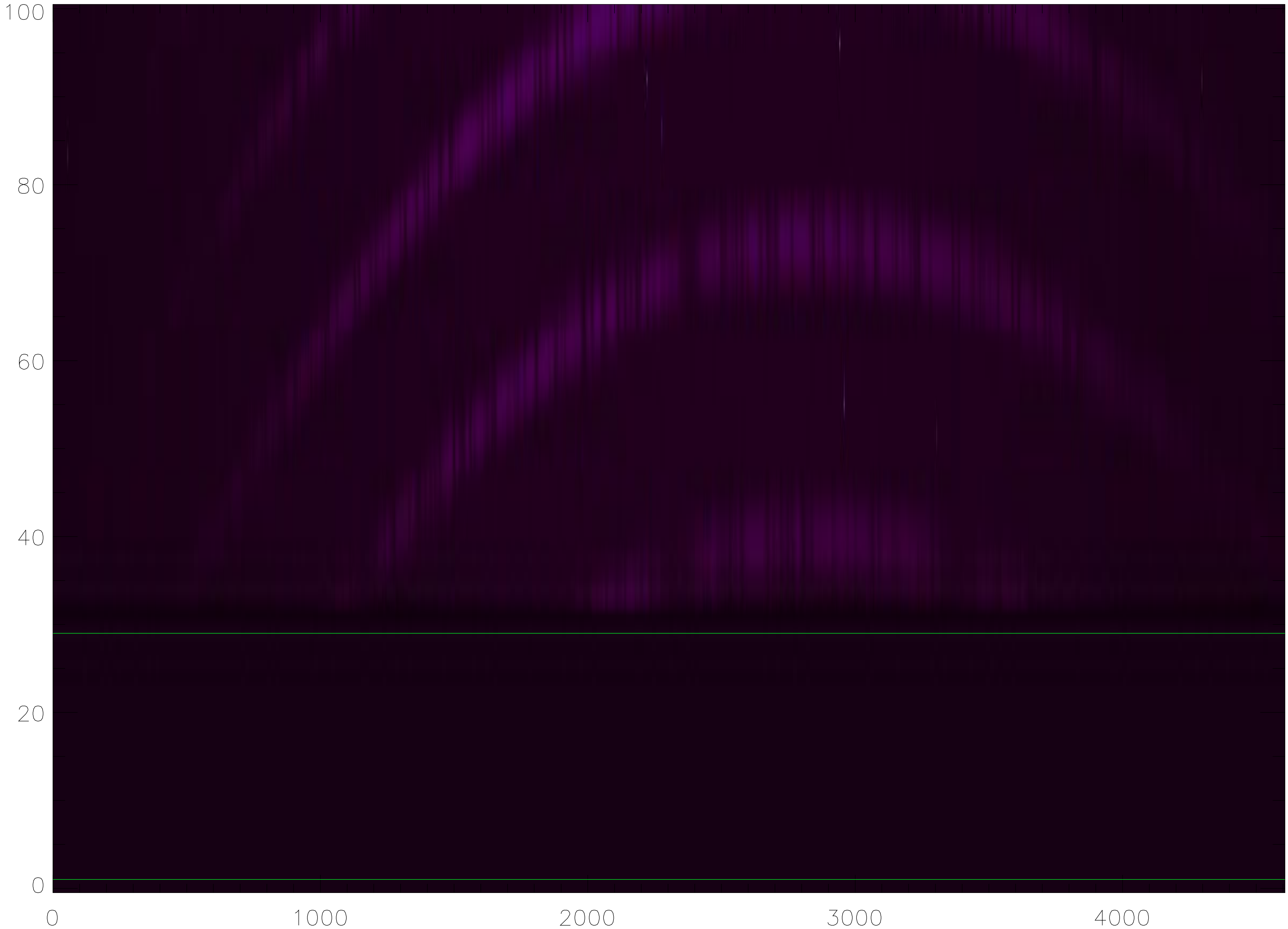

PFS Bias, cut through row 2000
1000
998
996
994
992
0
2000
4000
6000
8000
10000

APF: Bias determination without Bias Frames

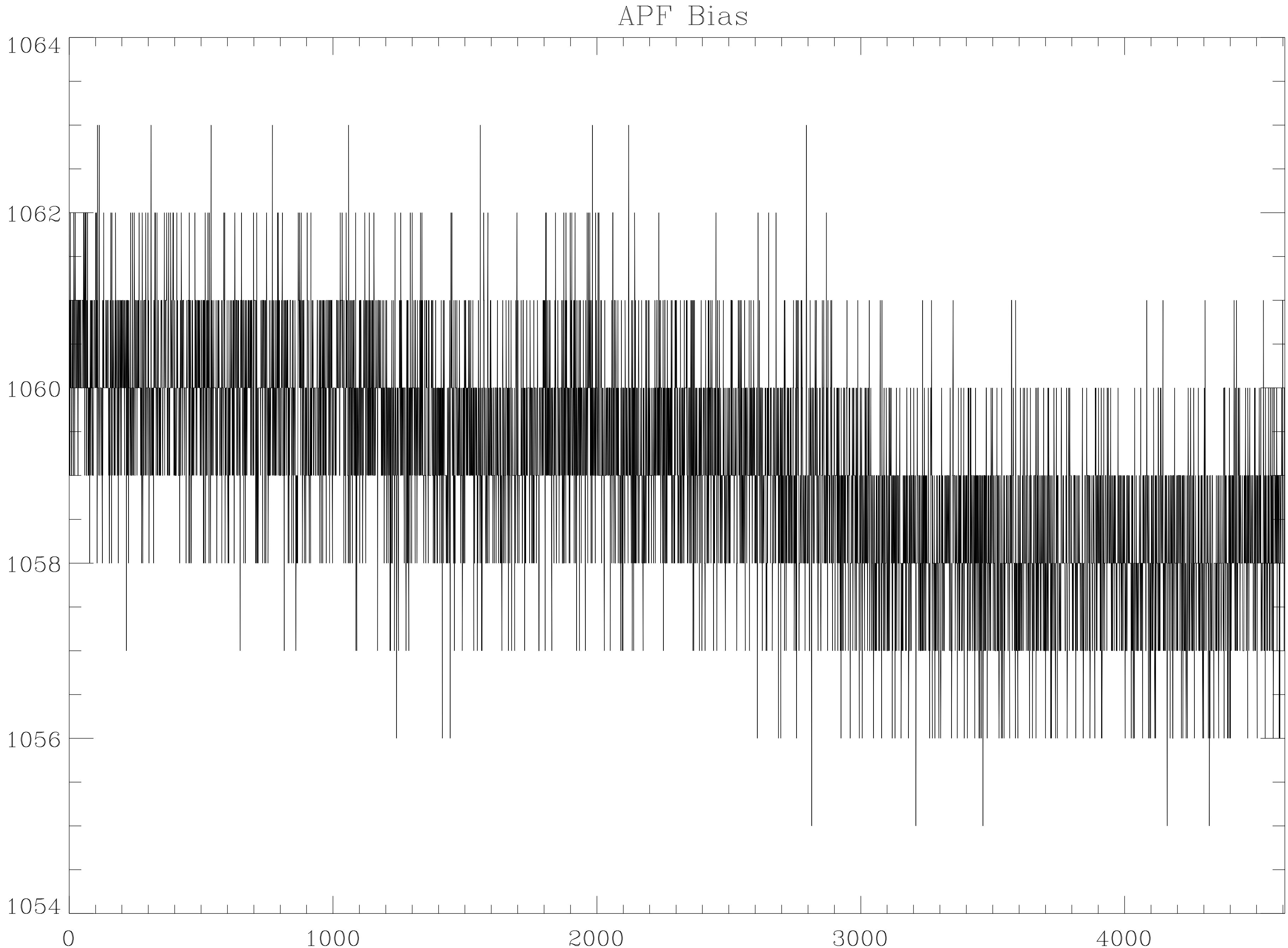


APF: Find the Over-Scan region





100
80
60
40
20
0
0
1000
2000
3000
4000

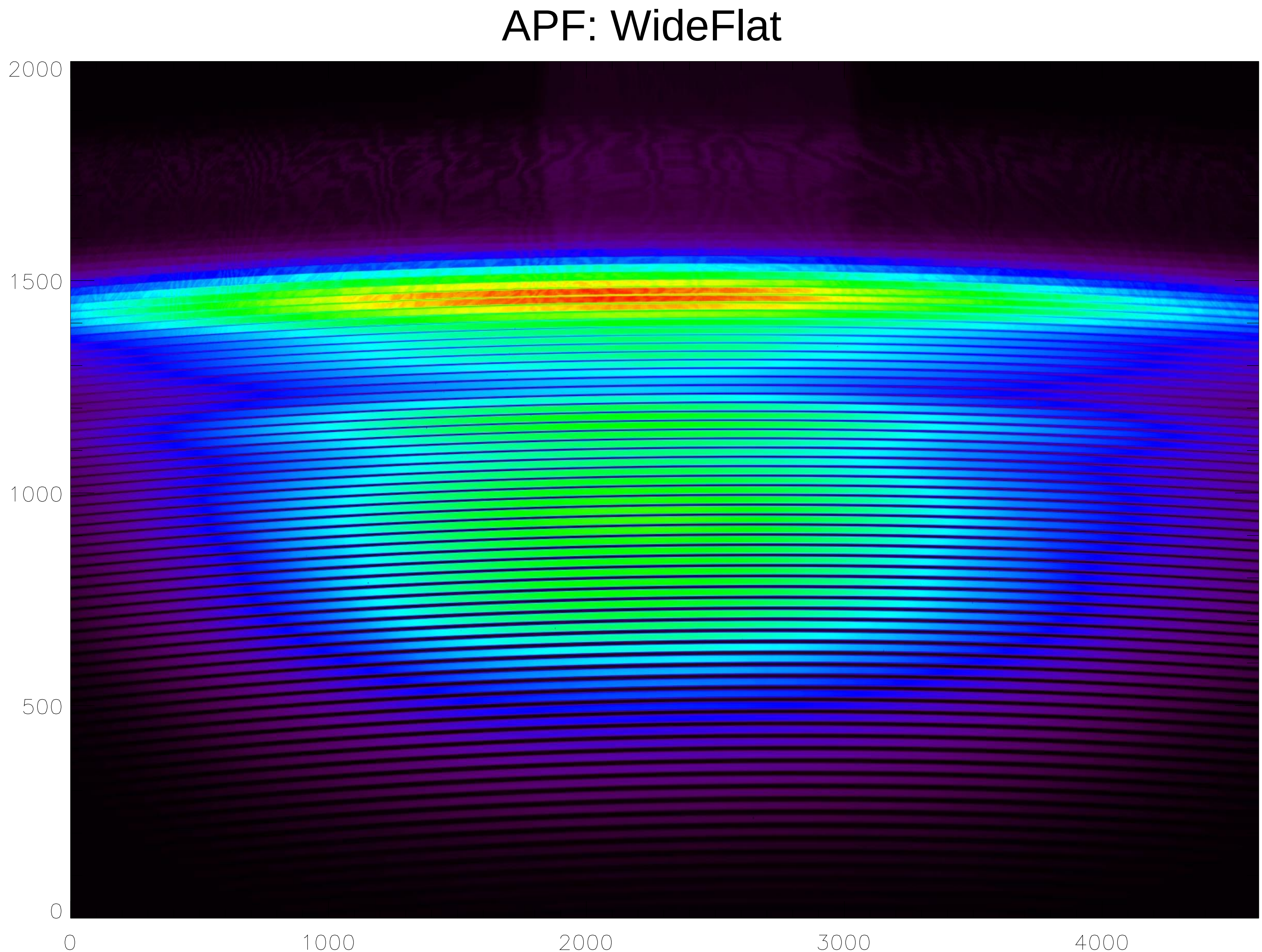


APF Bias
1064
1062
1060
1058
1056
1054
0
1000
2000
3000
4000

FLAT FIELDING

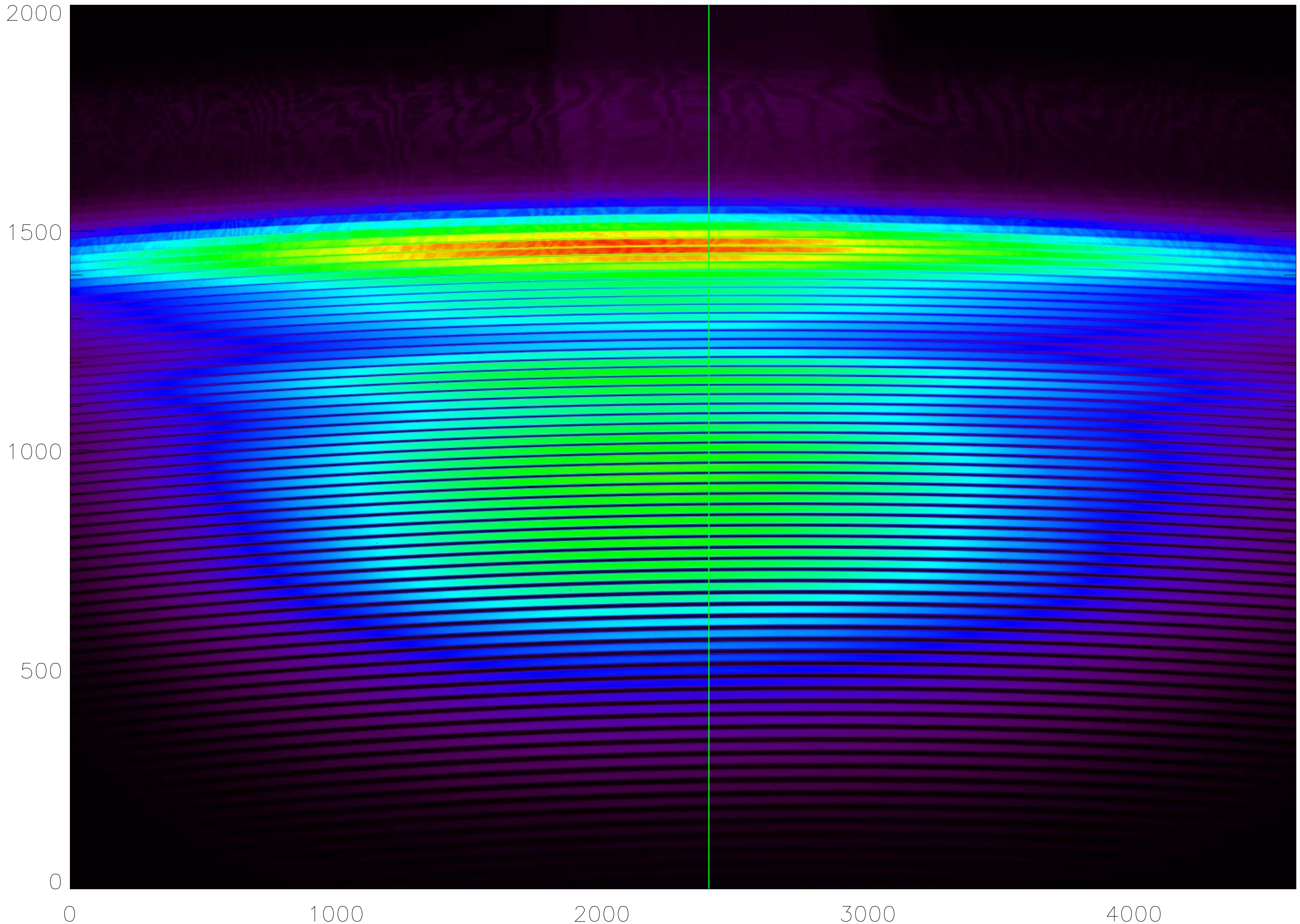
Each pixel has a unique and slightly different quantum efficiency
These variations must be removed

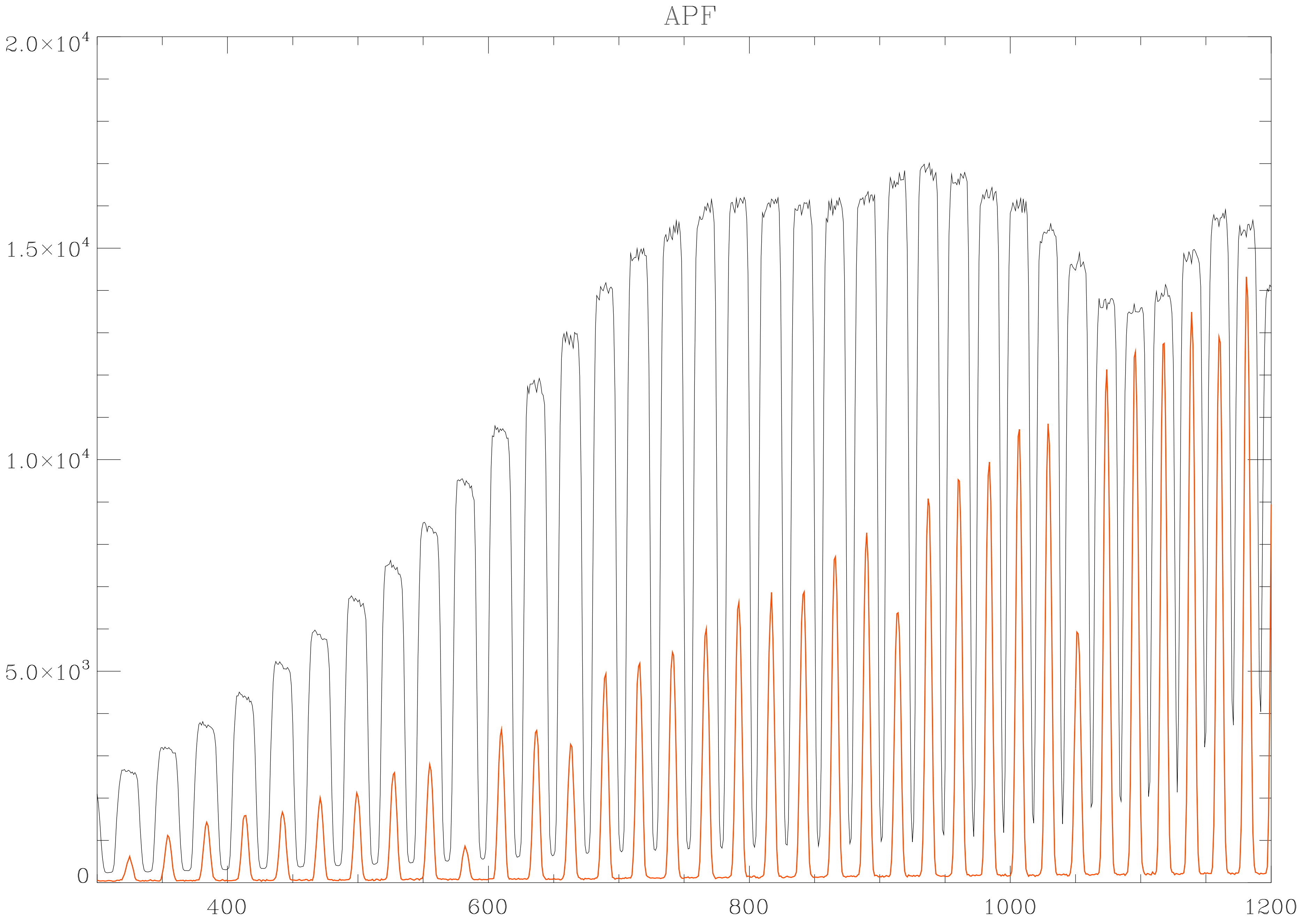
1) Multiple exposures of a white-light lamp
2) Remove cosmic rays (cleaning)
3) If possible use a longer slit for the flat field exposures
4) Note: this is not possible for fiber fed spectrometers
5) Retain the original blaze function



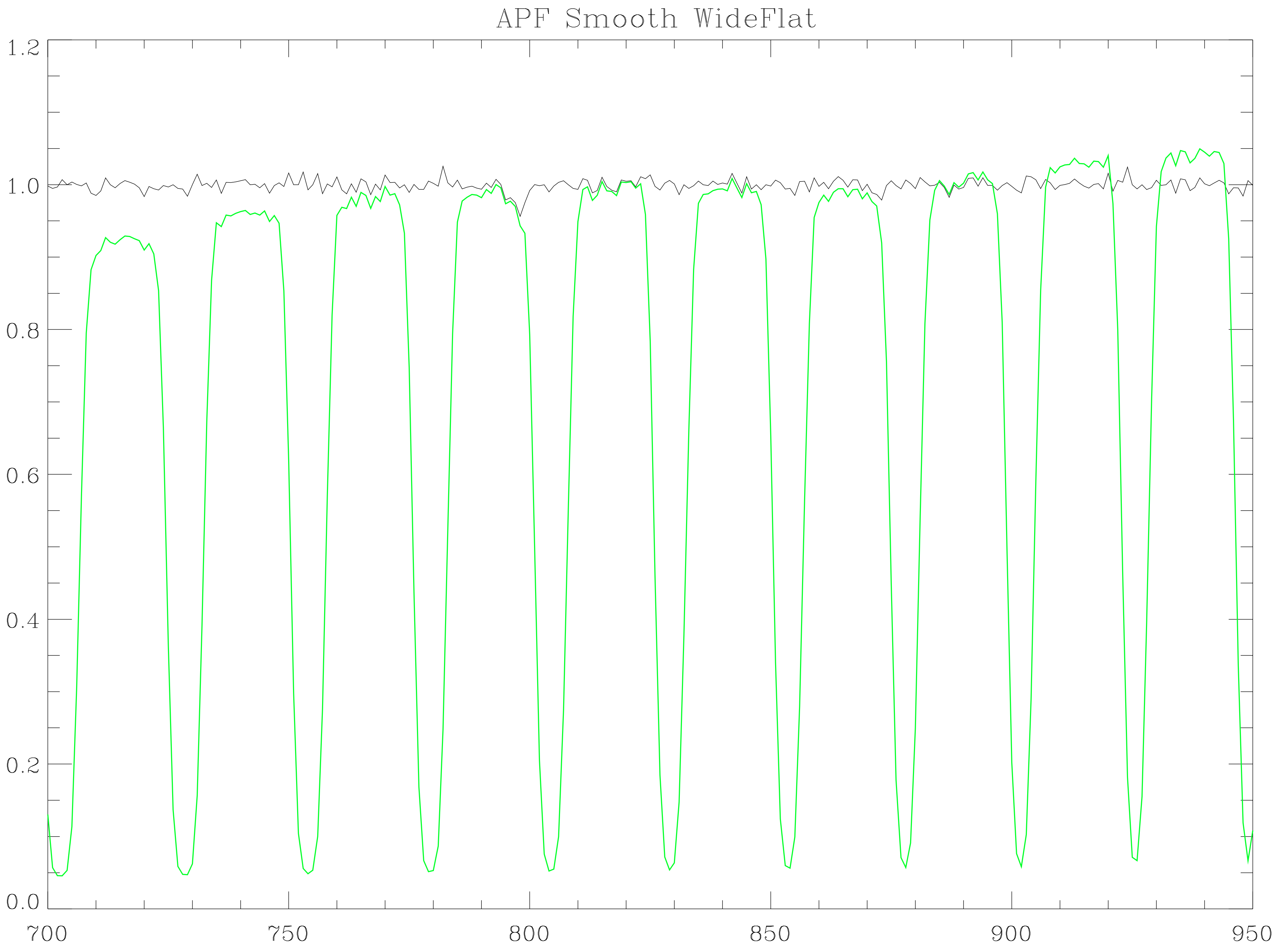
APF: WideFlat
2000
1500
1000
500
0
0
1000
2000
3000
4000

APF: WideFlat



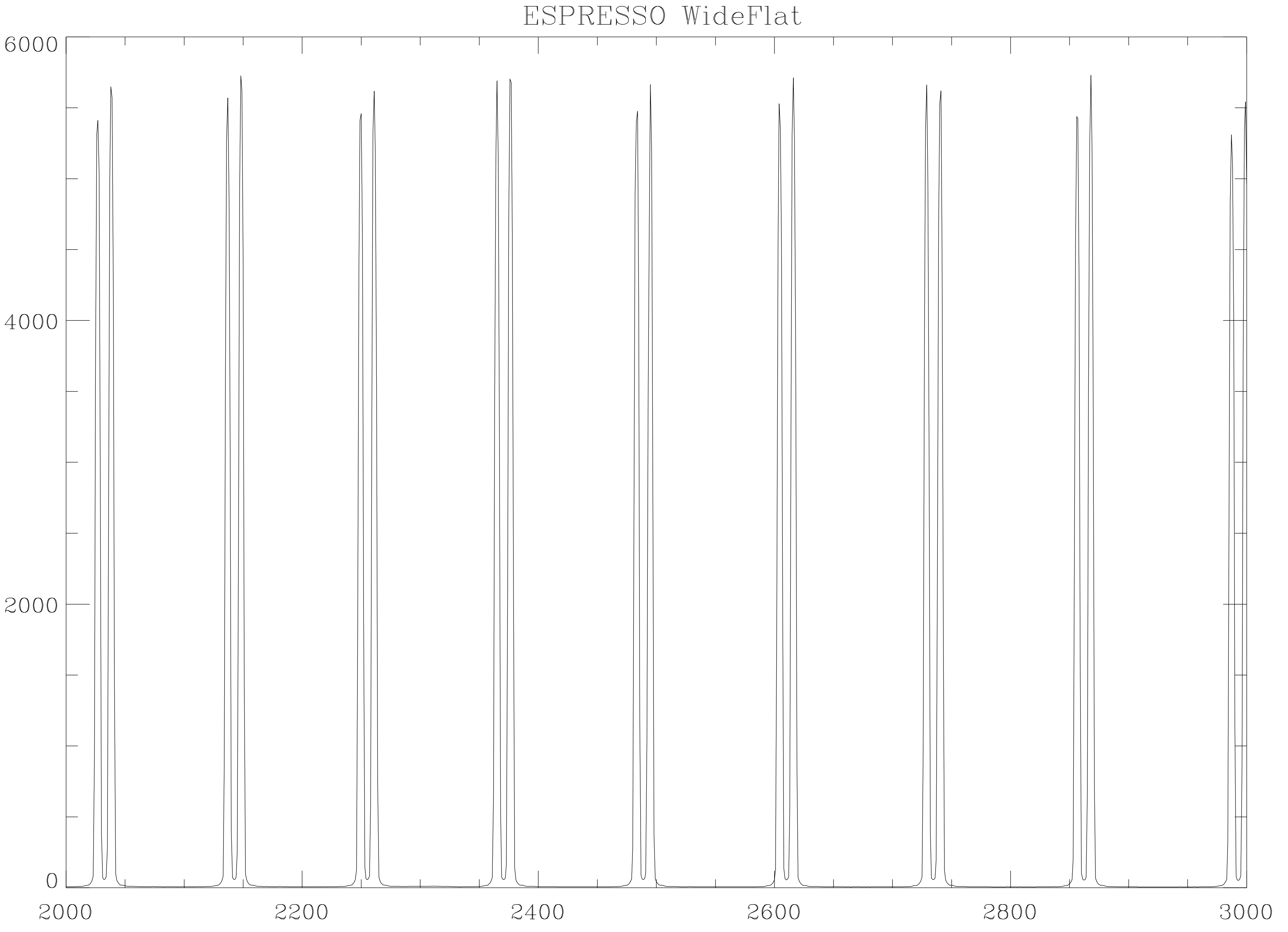


APF
2.0×10^4
1.5×10^4
1.0×10^4
5.0×10^3
0
400
600
800
1000
1200

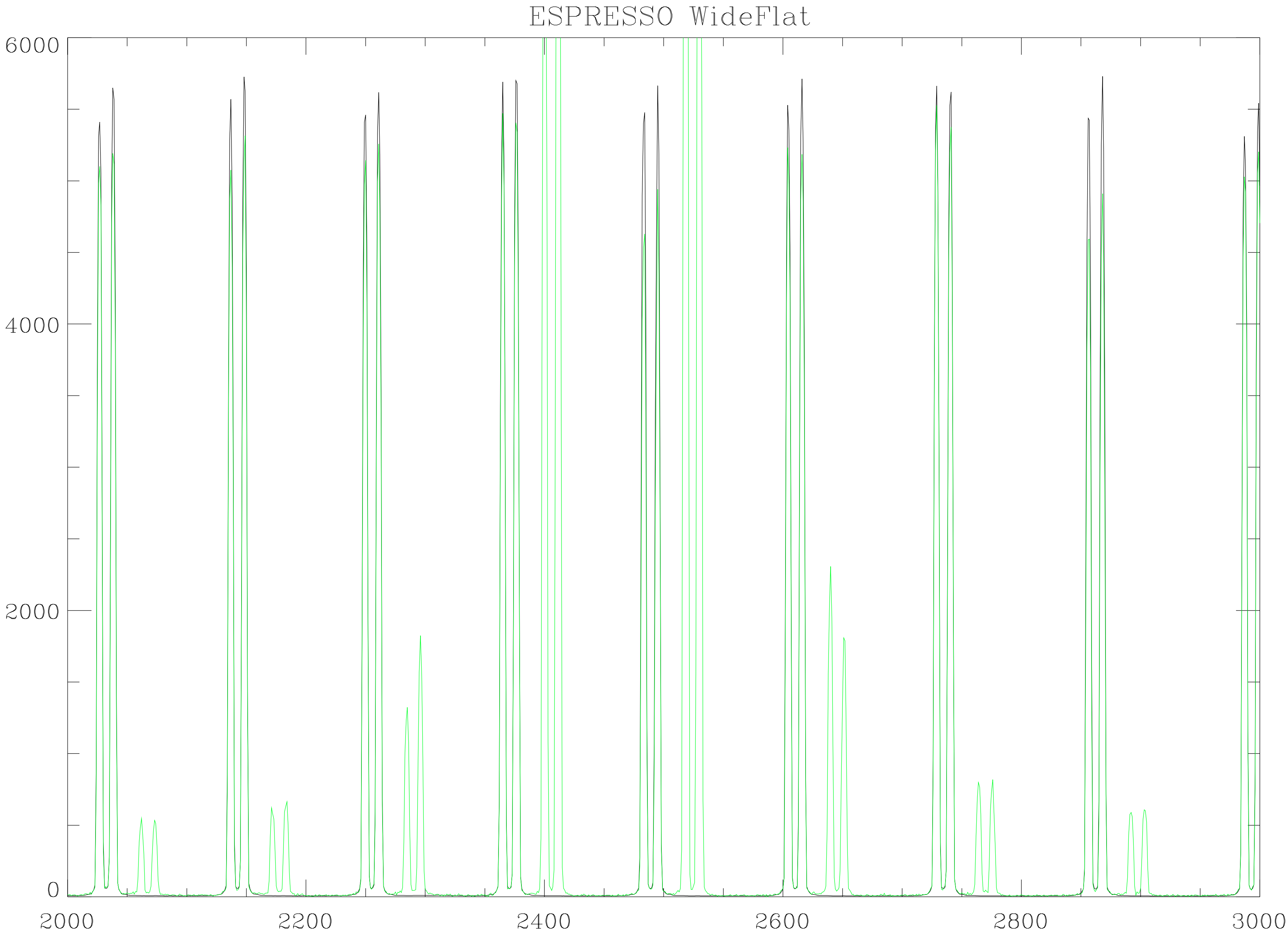


APF Smooth WideFlat
1.2
1.0
0.8
0.6
0.4
0.2
0.0
700
750
800
850
900
950

ESPRESSO Red CCD WideFlat



ESPRESSO Red CCD WideFlat

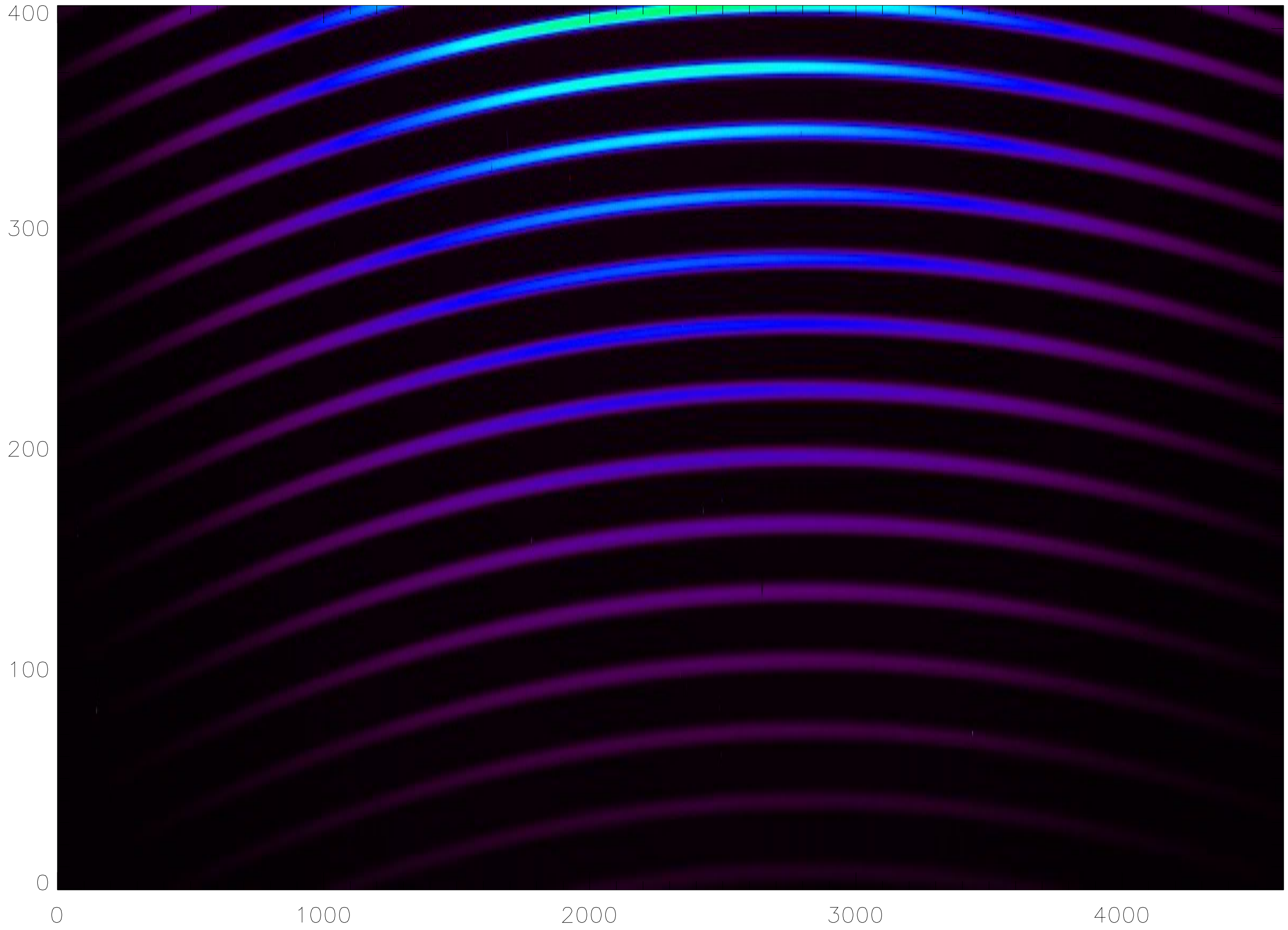


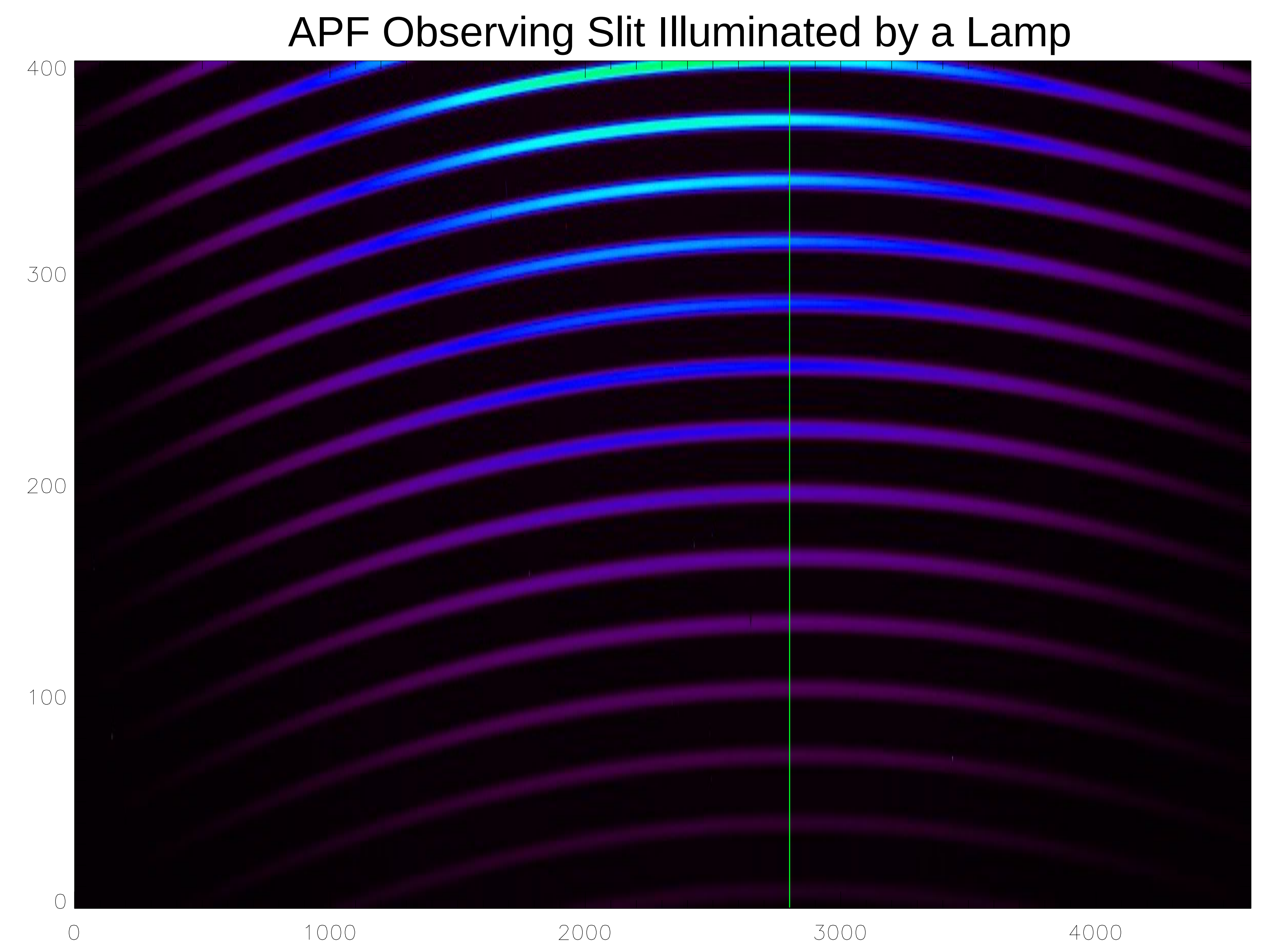
Order Location

We need to define the location of each order

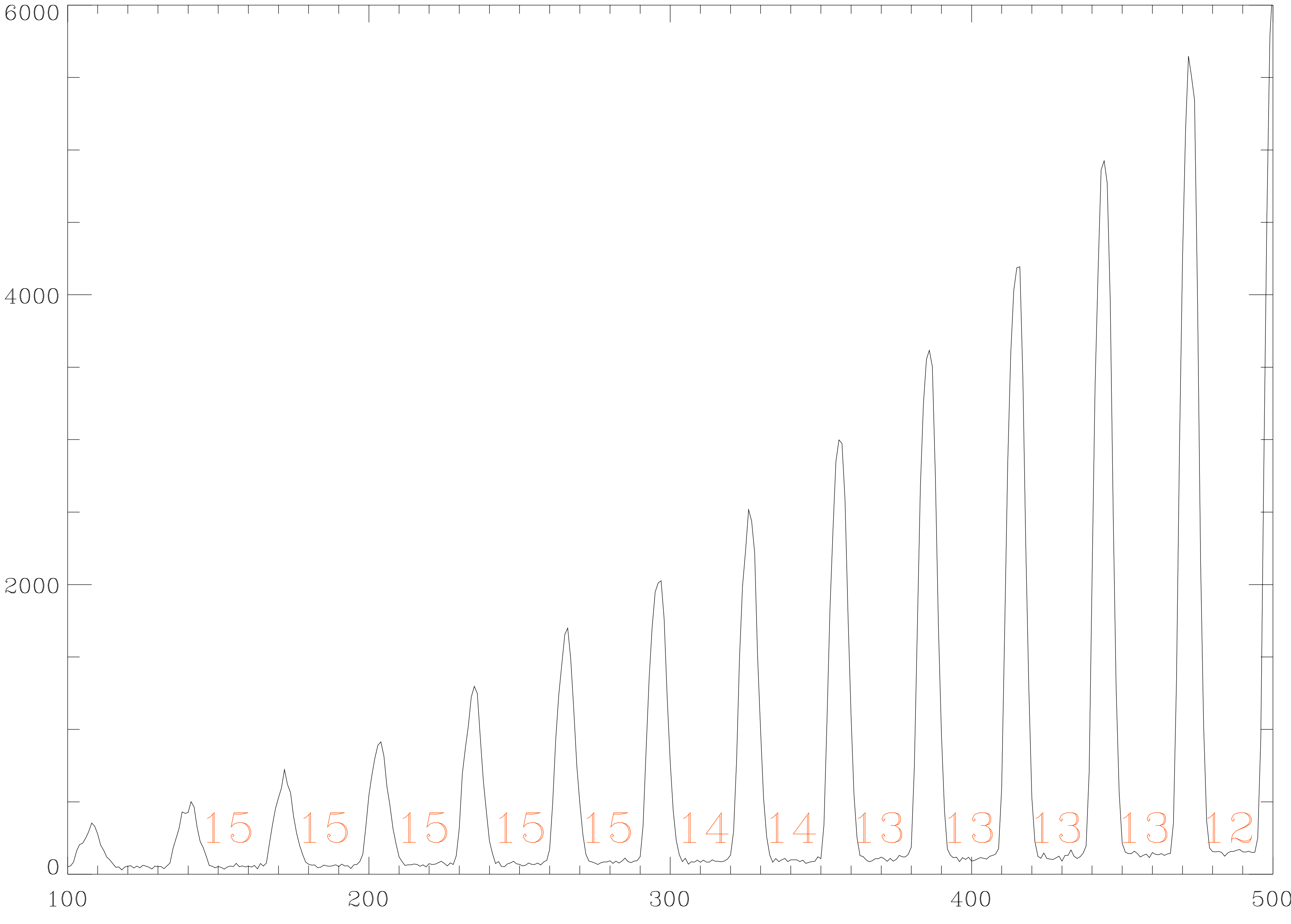
1) Start with a “narrow flat” (lamp that fills the slit)
2) Take a cut through a column near the center
3) Hardwire the widths of the troffs
4) Locate the orders along the blaze
5) For each order, trace out the location of the troffs

APF Observing Slit Illuminated by a Lamp

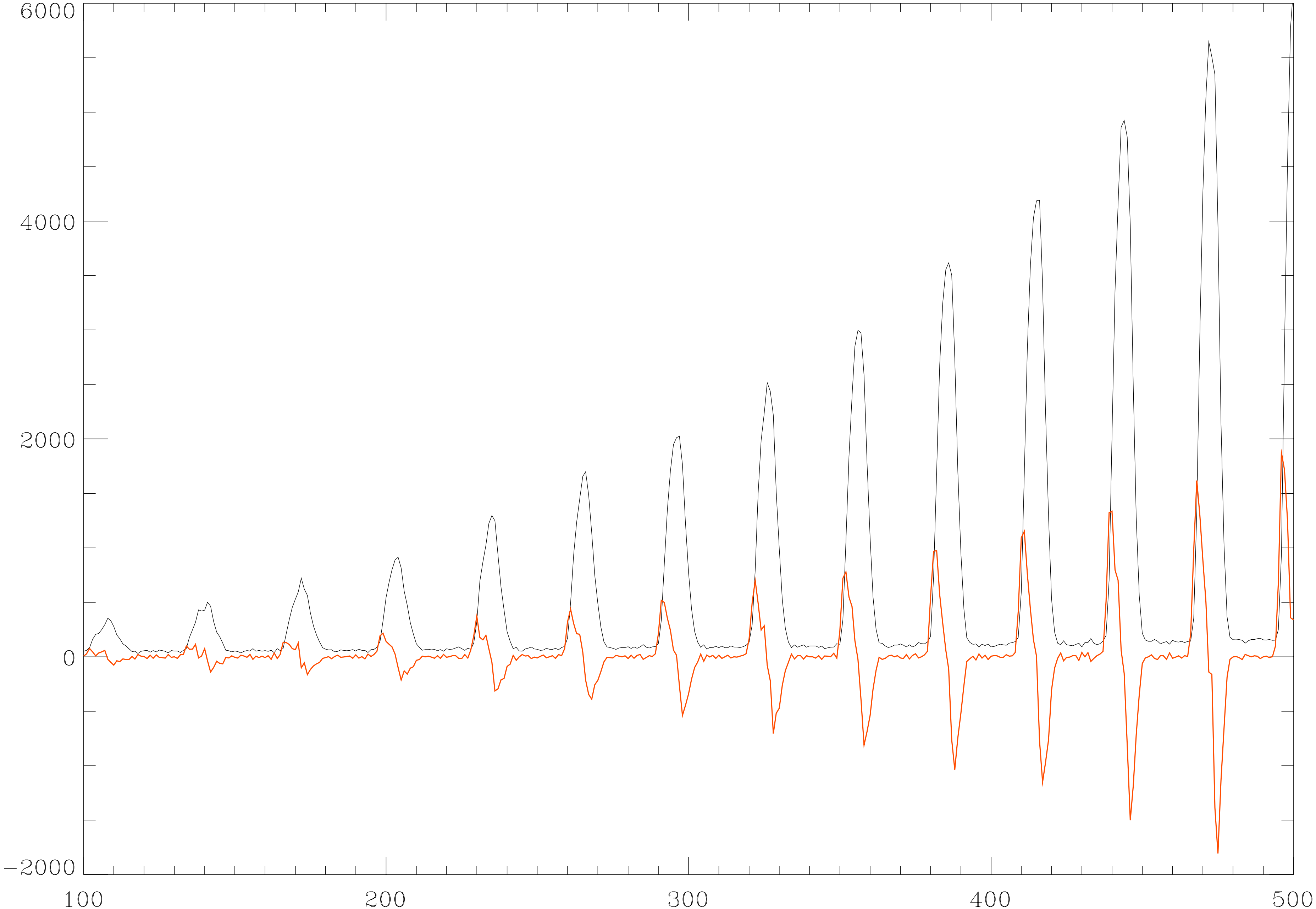



APF Observing Slit Illuminated by a Lamp
400
300
200
100
0
0
1000
2000
3000
4000

APF: eyeball & hardwire the width of the troffs



APF: find approximate location of the orders

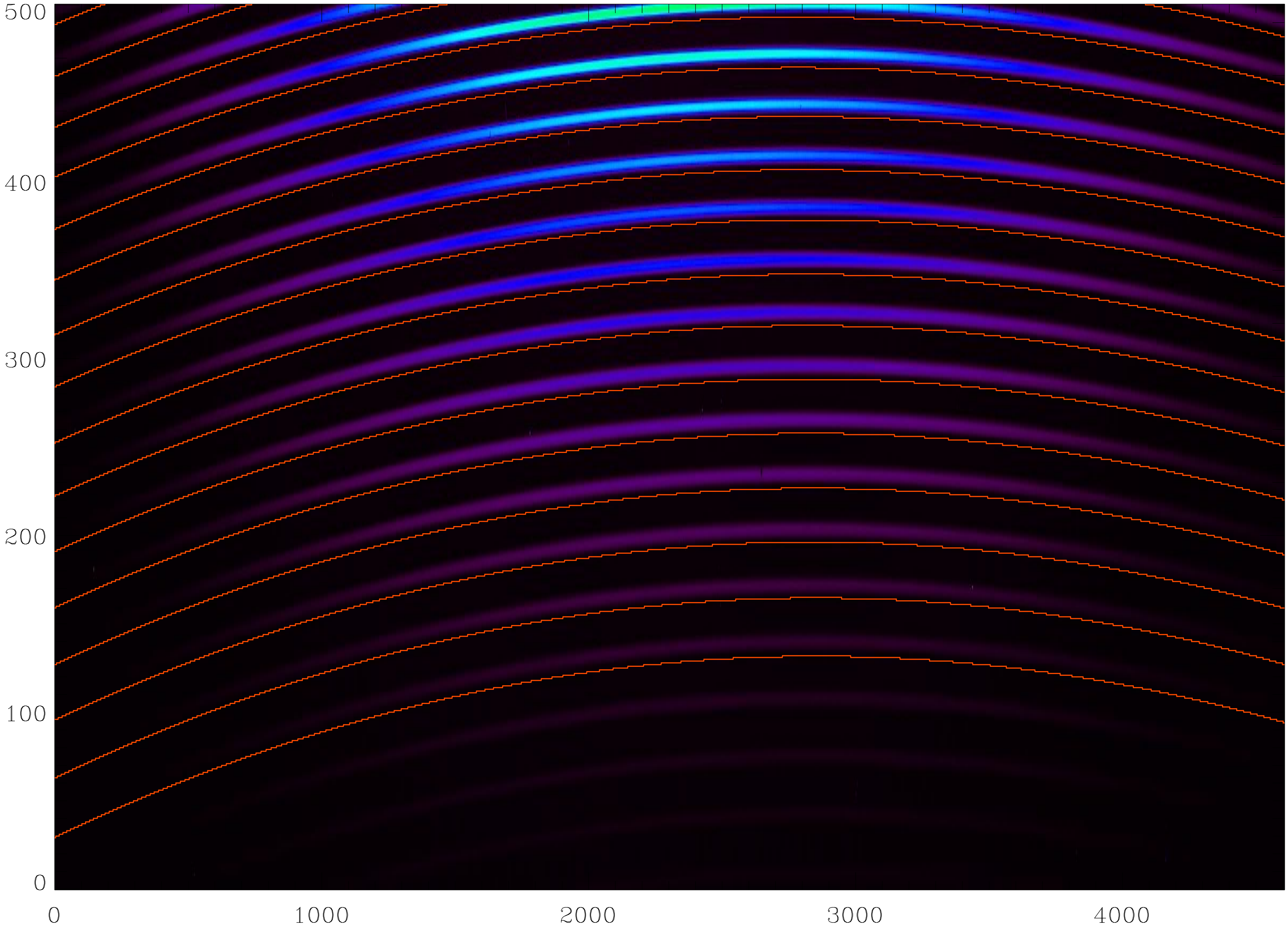


Order Location

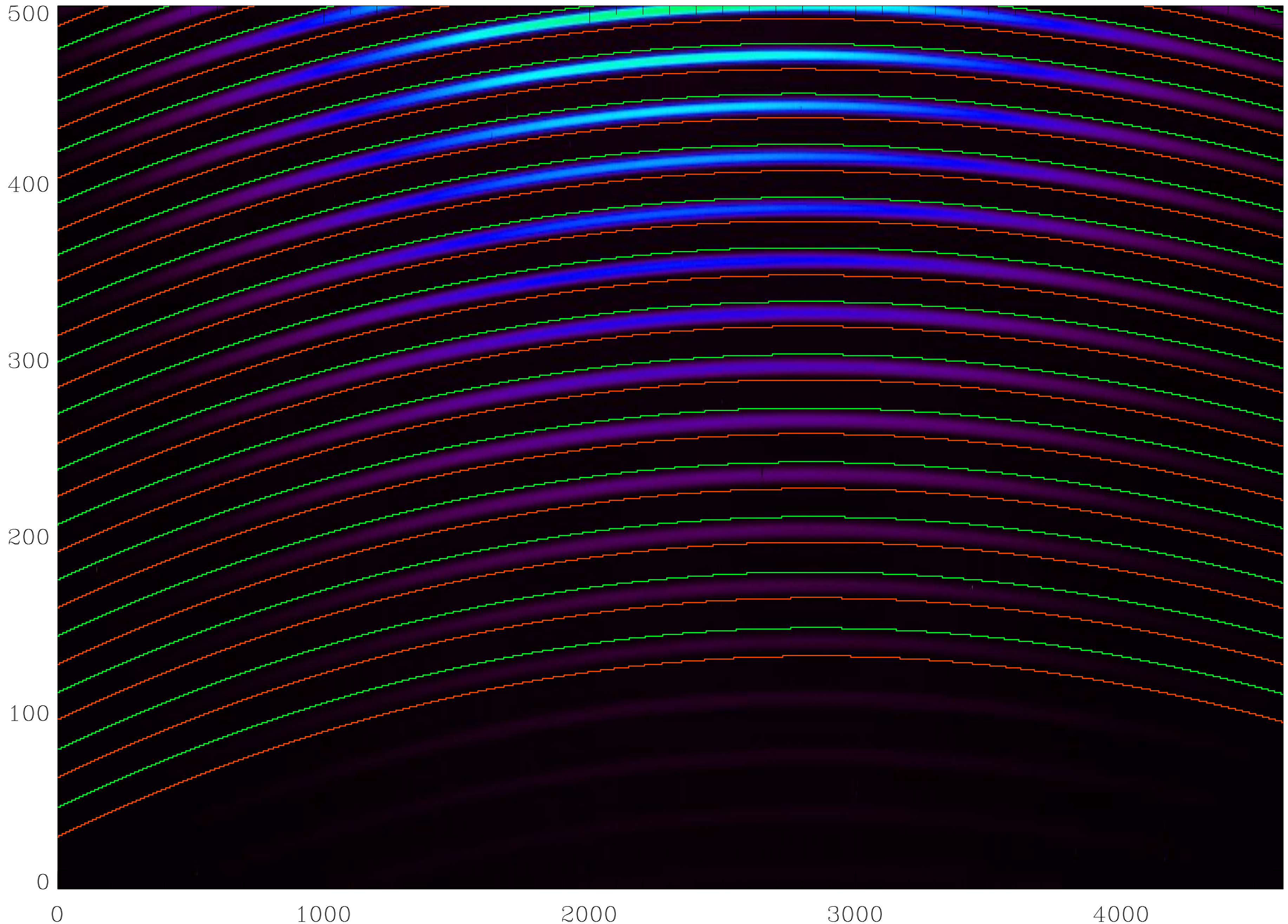
Using the hardwired width of each troff:

1) Build a “boxcar” the width of the troff
2) Move the boxcar, pixel-by-pixel, in the region of the troff
3) Sum the counts in the narrow flat within the boxcar
4) Find the location that minimizes the summed counts
5) This precisely marks the location of the troff
6) Repeat this last step for the column 5 pixels away
7) After completing this for the entire order, fit a cubic

APF: location just below each order



APF: location just below and above each order



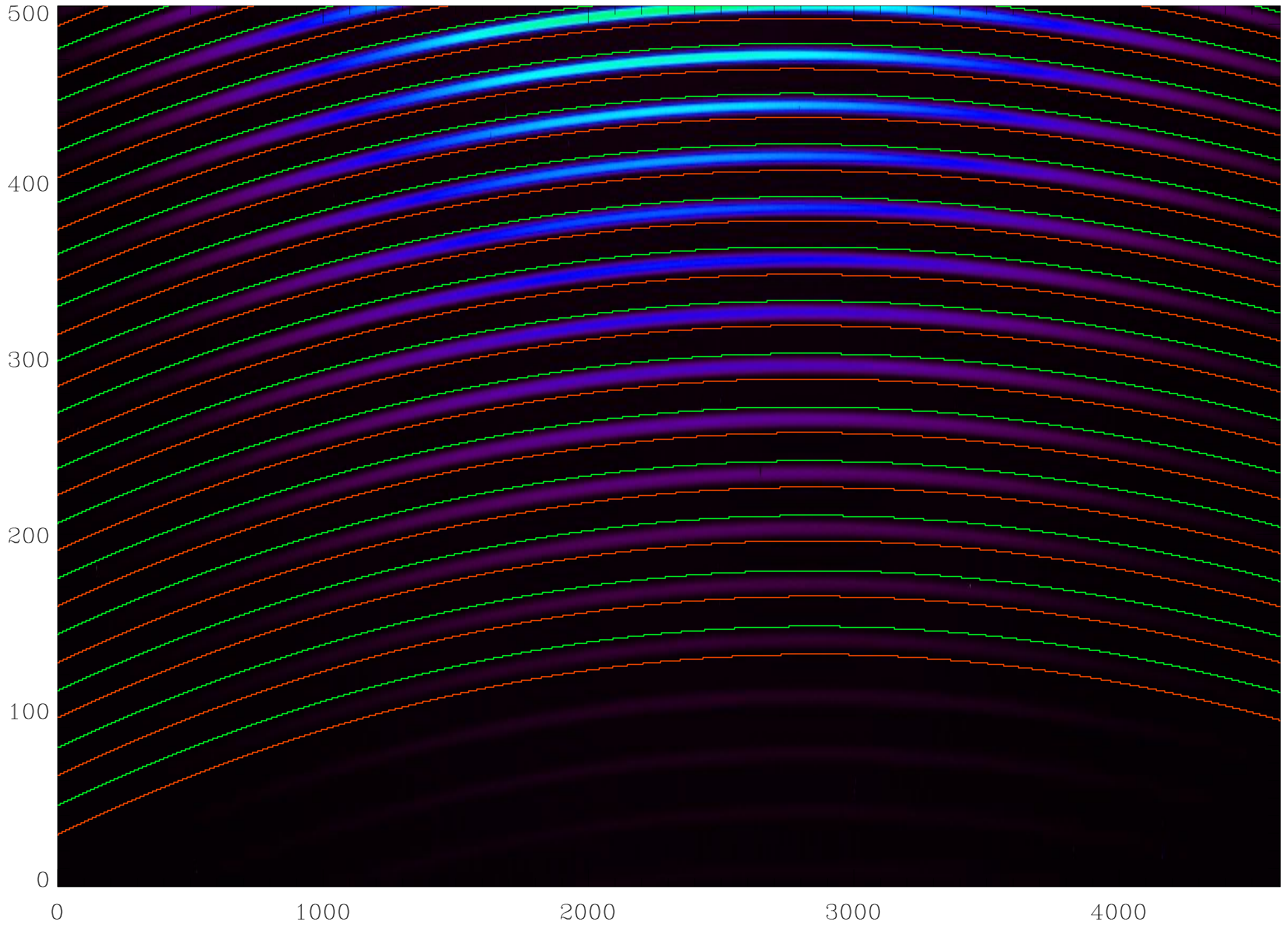
Scattered Light

We need to build a scatted light image

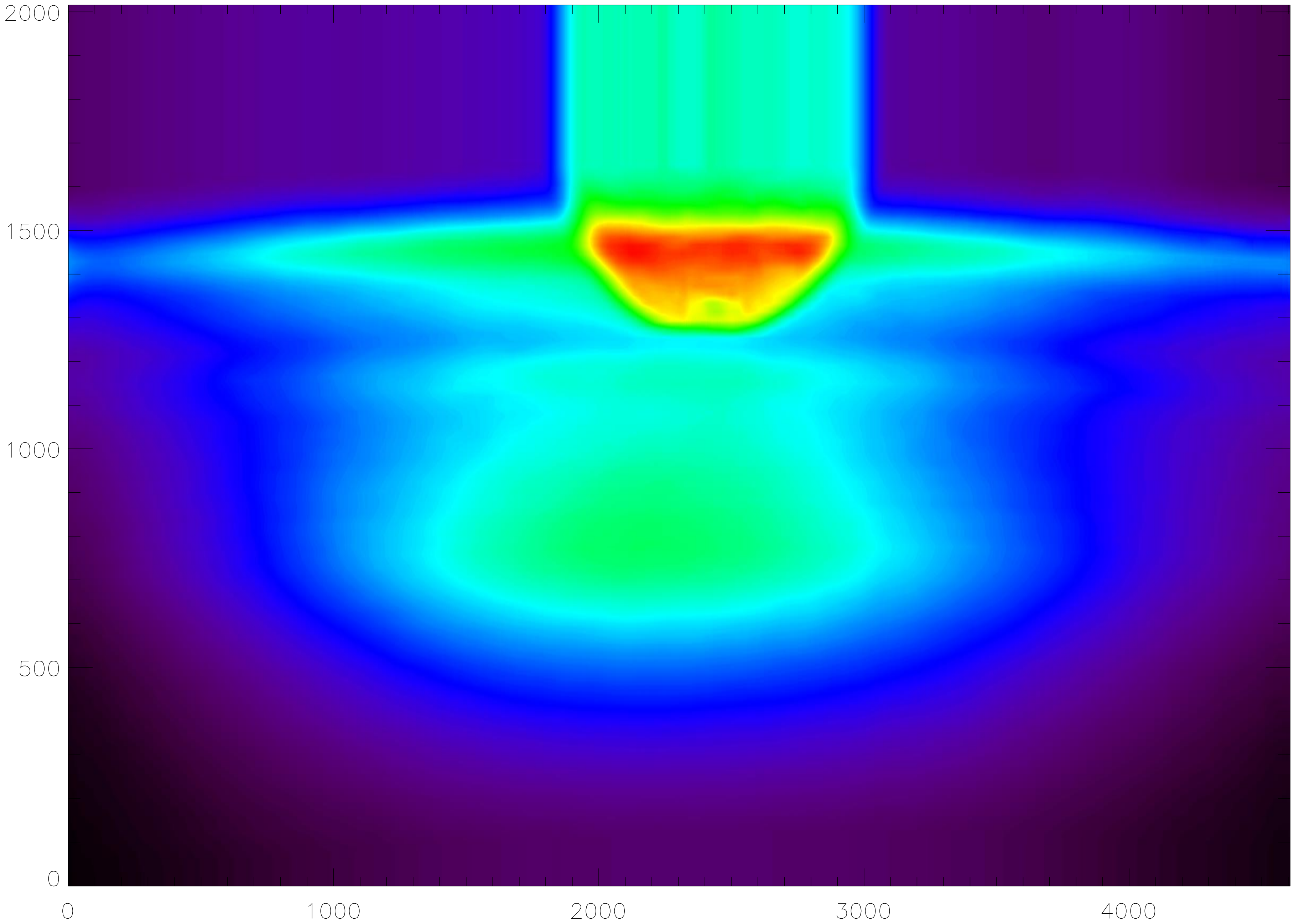
The scattered light can be measured in the troffs

1) Estimate the scattered light in each column of the troff
2) Interpolate the scattered light across each order
3) Build the scattered light image
4) Subtract the scattered light image

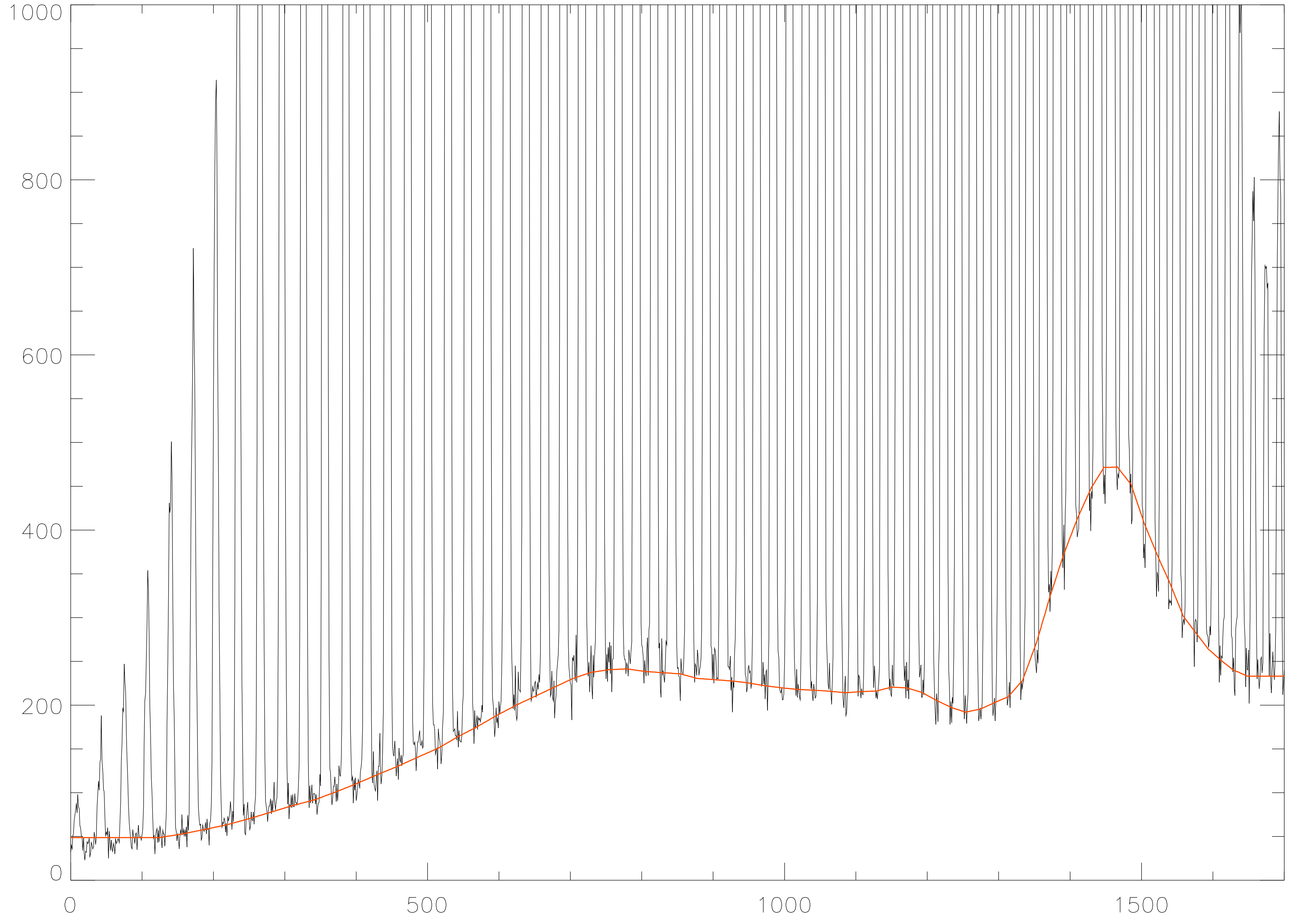
APF: location just below and above each order



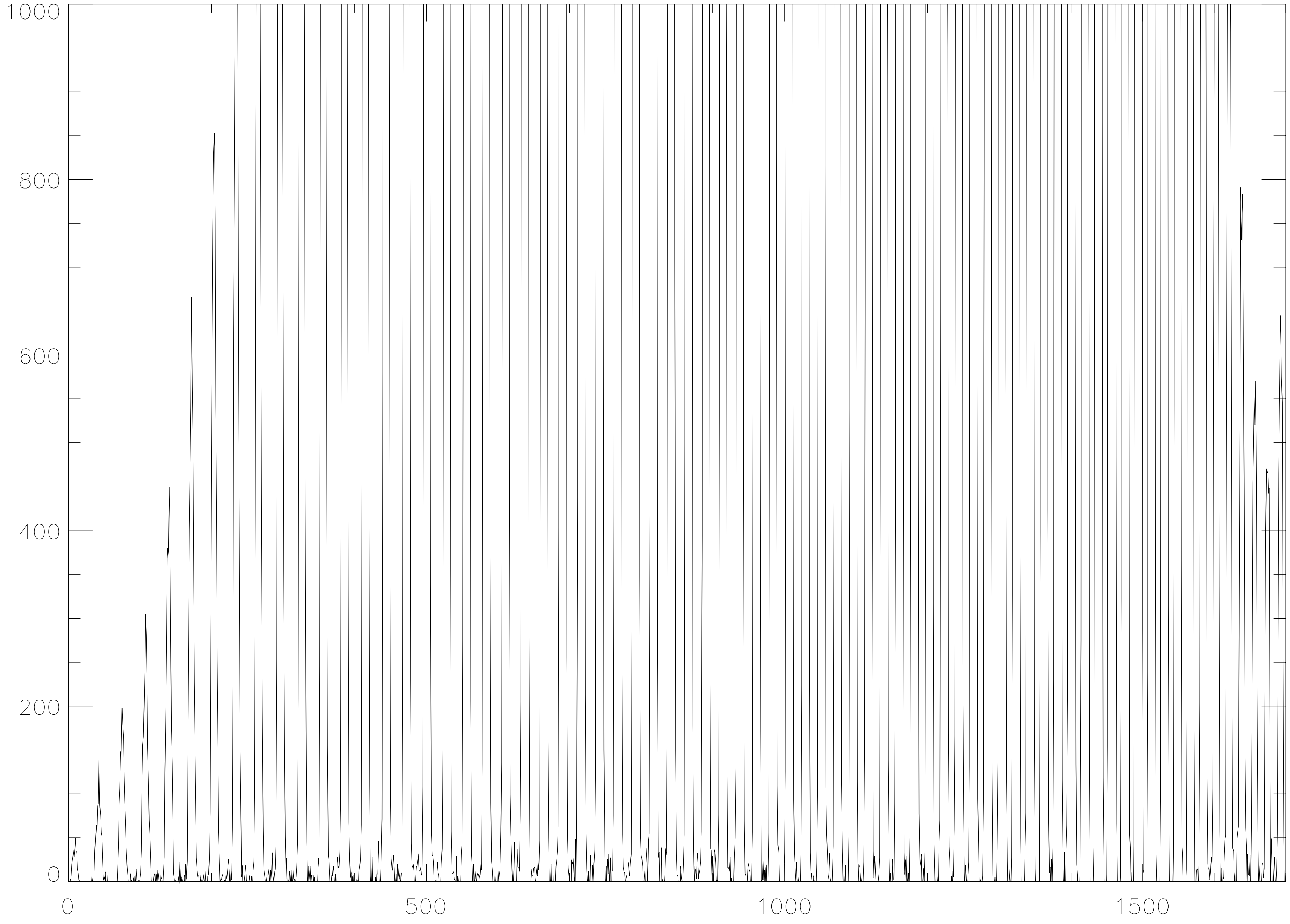
APF: scattered light image



APF: Cut through column 2800



APF: Cut through column 2800 after scattered light subtraction



APPLYING THE WIDEFLAT

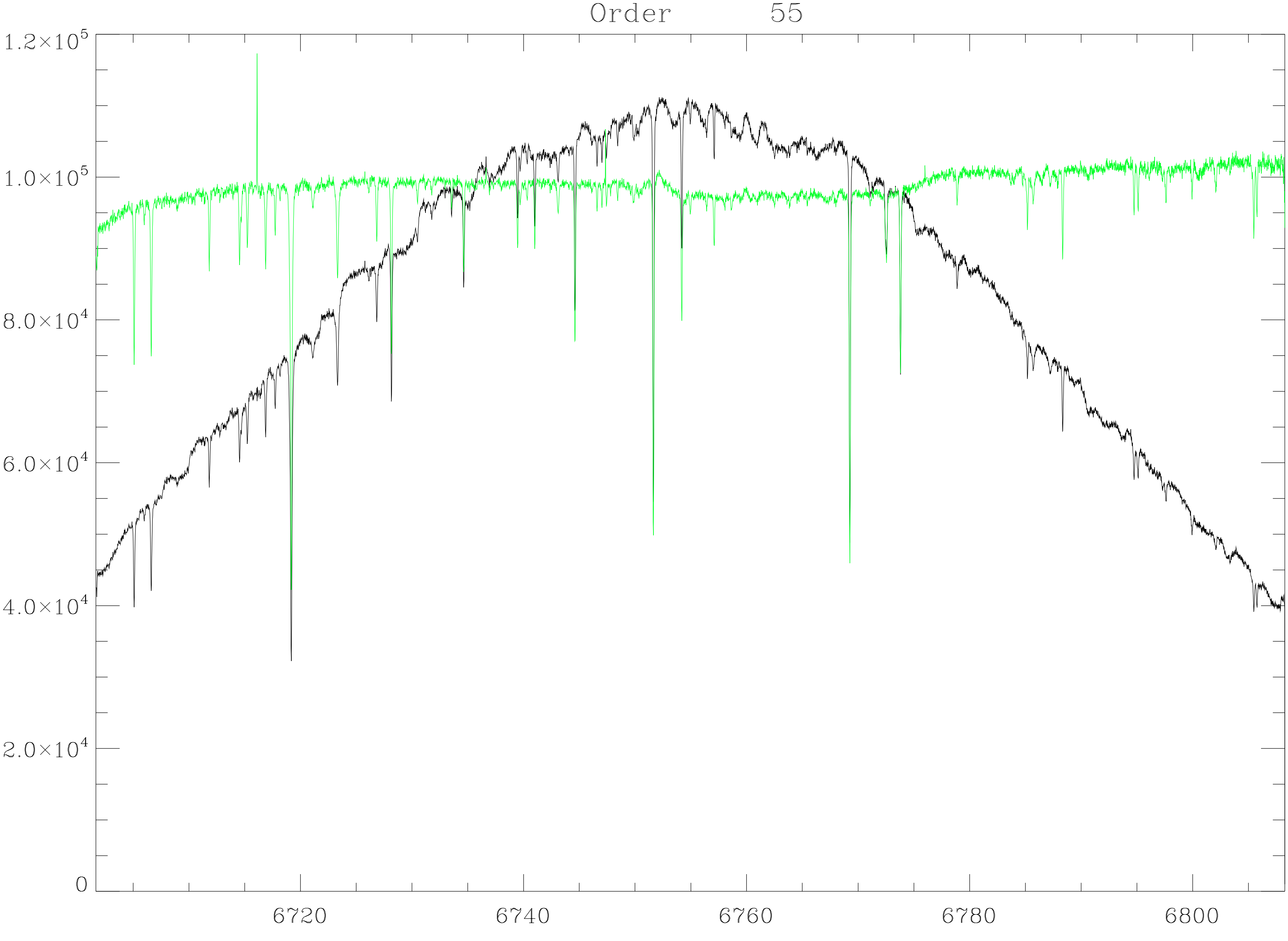
WideFlat from long slit

1) Divide image by the smoothed WideFlat
2) This preserves the Blaze function
3) This can make “fringing” in the red orders worse

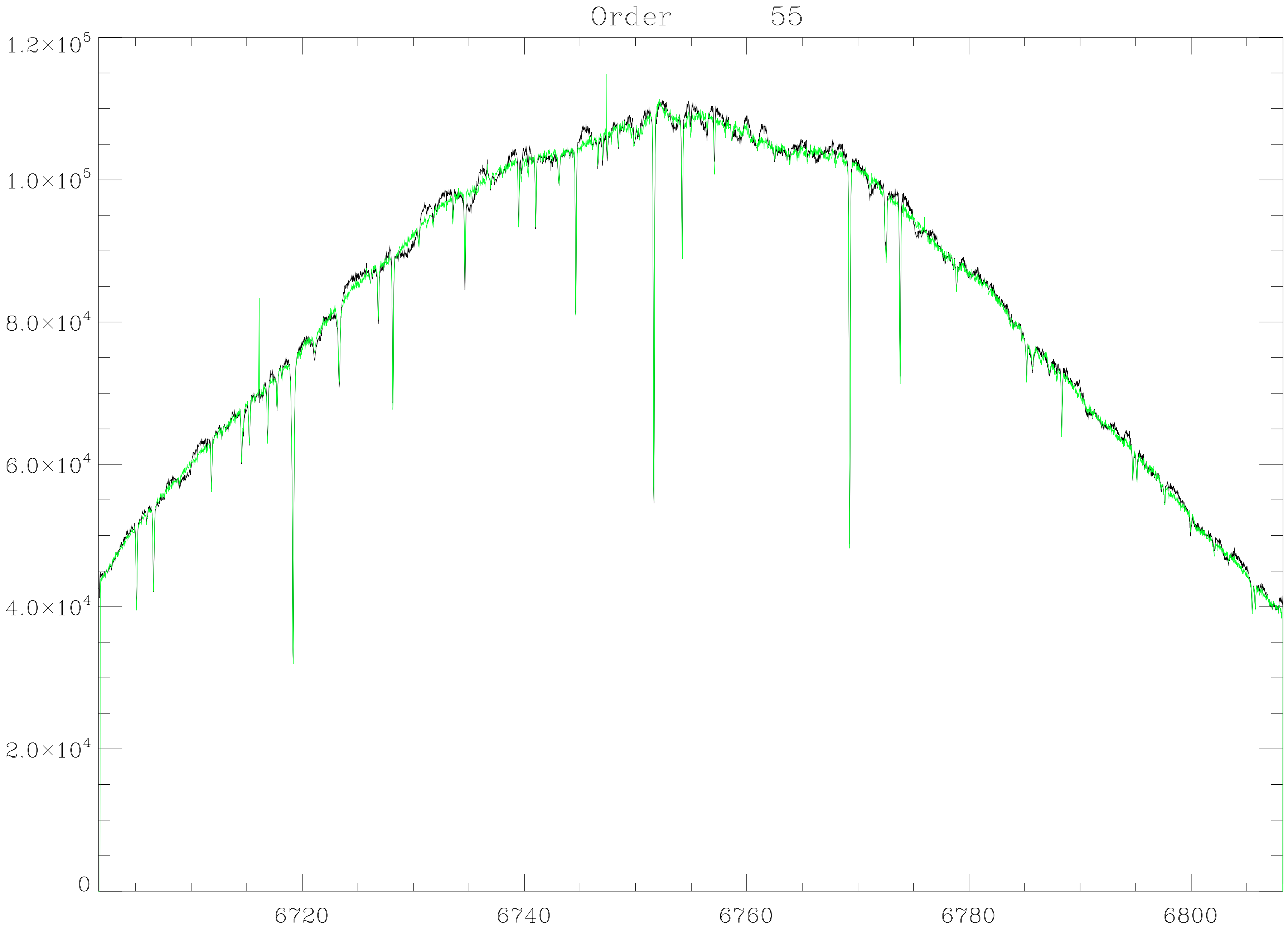
WideFlat from fiber or long slit

1) Force the WideFlat troffs to a be a “large” value
2) Divide the image by the “forced WideFlat”
3) This minimizes “fringing” in the red orders
4) But it removes the Blaze function
5) Blaze function must be restored after mashing the image

APF: reduced image with “smoothed” WideFlat



APF: reduced image with WideFlat

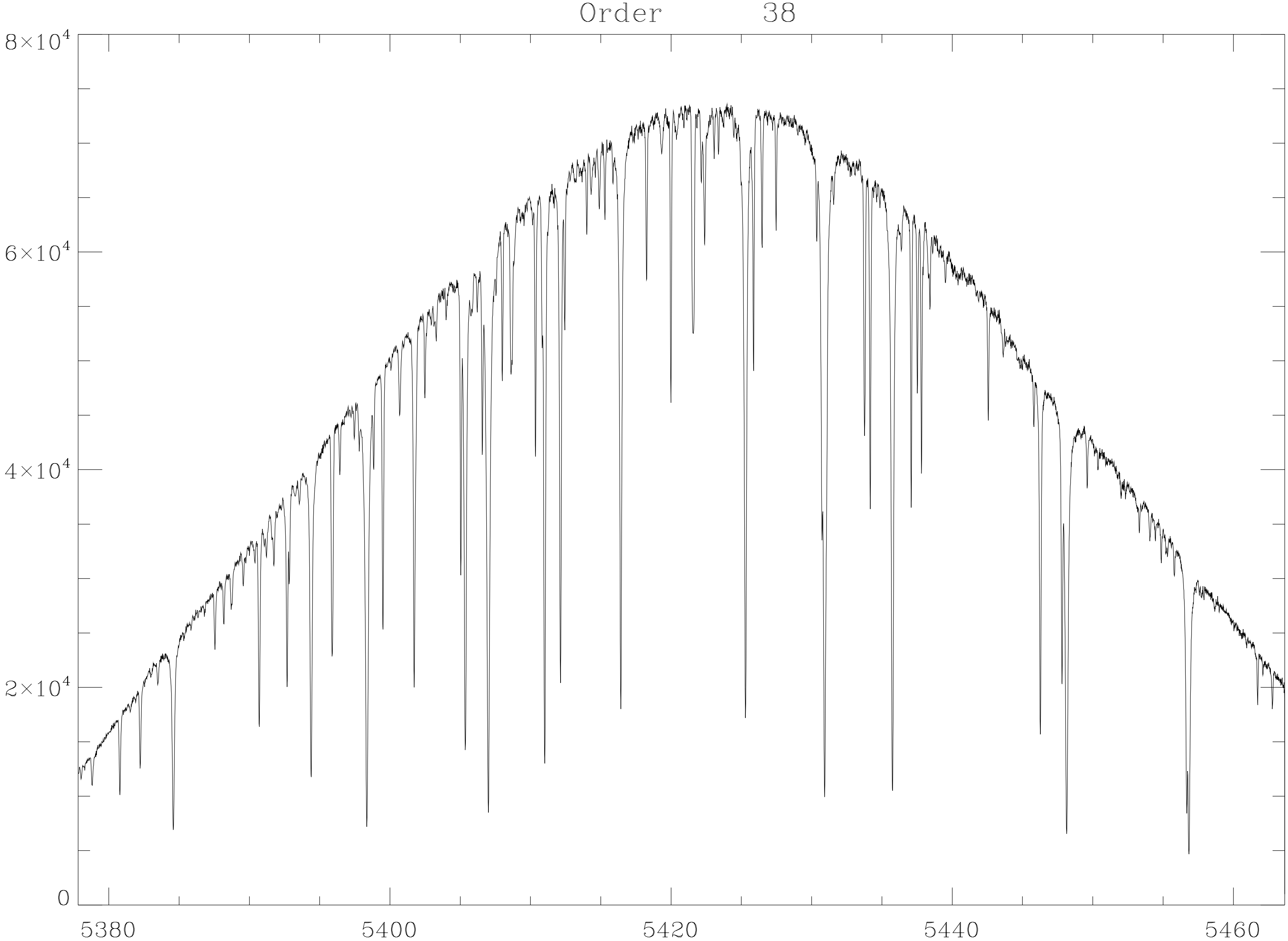


Generating 1D Spectra

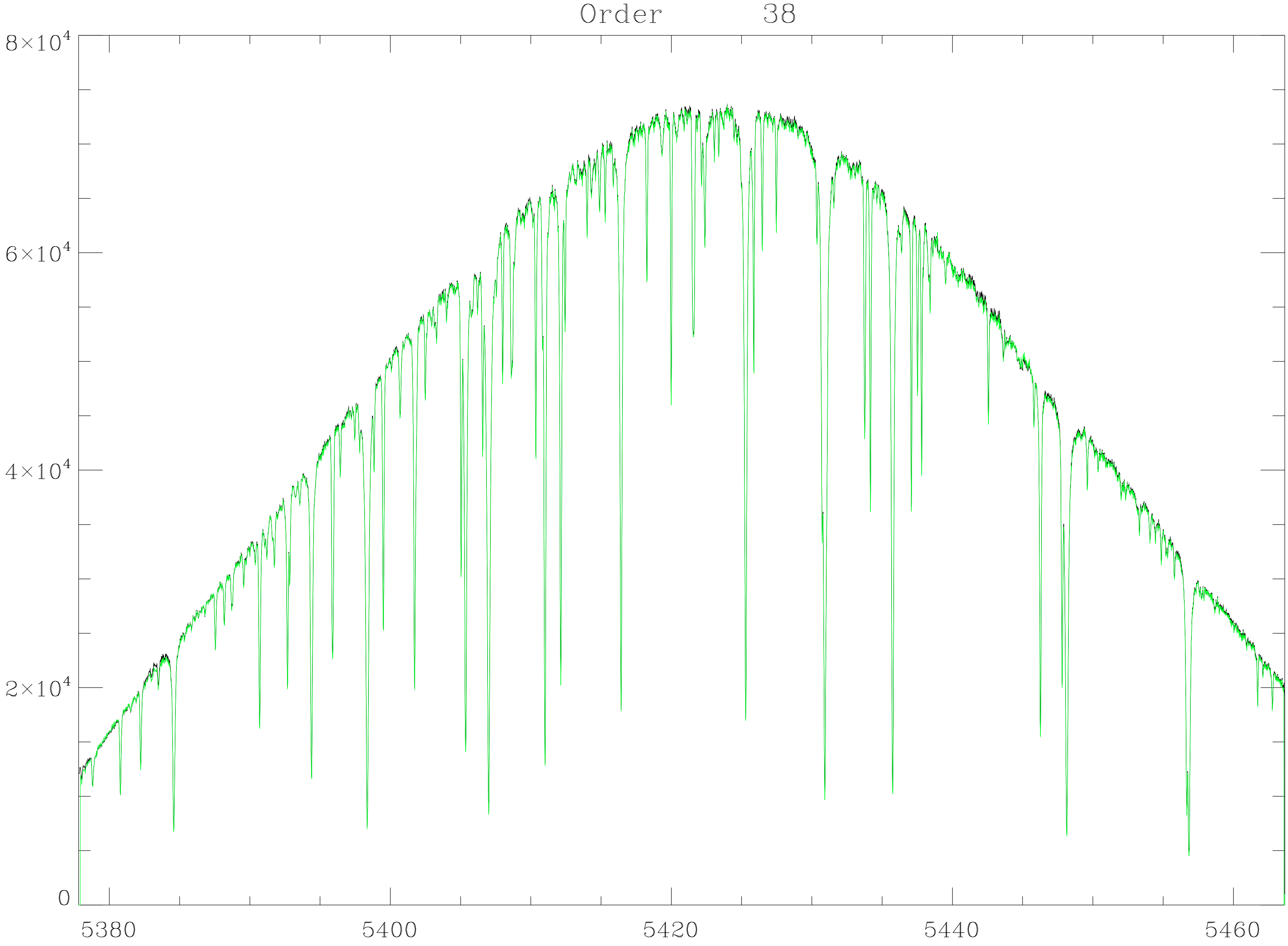
For each order:

1) Step through each column
2) Using the order location, mash the pixels in the column

APF: reduced image with “smoothed” WideFlat



APF: reduced image with WideFlat



RECAP

1) Generate nightly bias image from bias frames
2) or subtract off bias from each image from over-scan region
3) Build nightly WideFlat from WideFlat frames
4) Locate the orders
5) Build the scattered light image
6) Subtract the scattered light image
7) Divide image by the WideFlat
8) Mash the image to generate the final 1D spectra

Not yet discussed:

1) cosmic ray removal
2) night sky removal
3) line tilt

Comments & Suggestions

1) Write “modular” programs for each step
2) Every spectrometer is different
3) Be Flexible
4) Be creative
5) Attack problems with trial & error
6) Bookkeeping is one of the hardest problems
7) Always try the easiest thing first