Echelle data reduction with FIEStool

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Overview

- Description of FIES
- Echelle data and nuisances
- Extracting and calibrating data
- FIEStool example

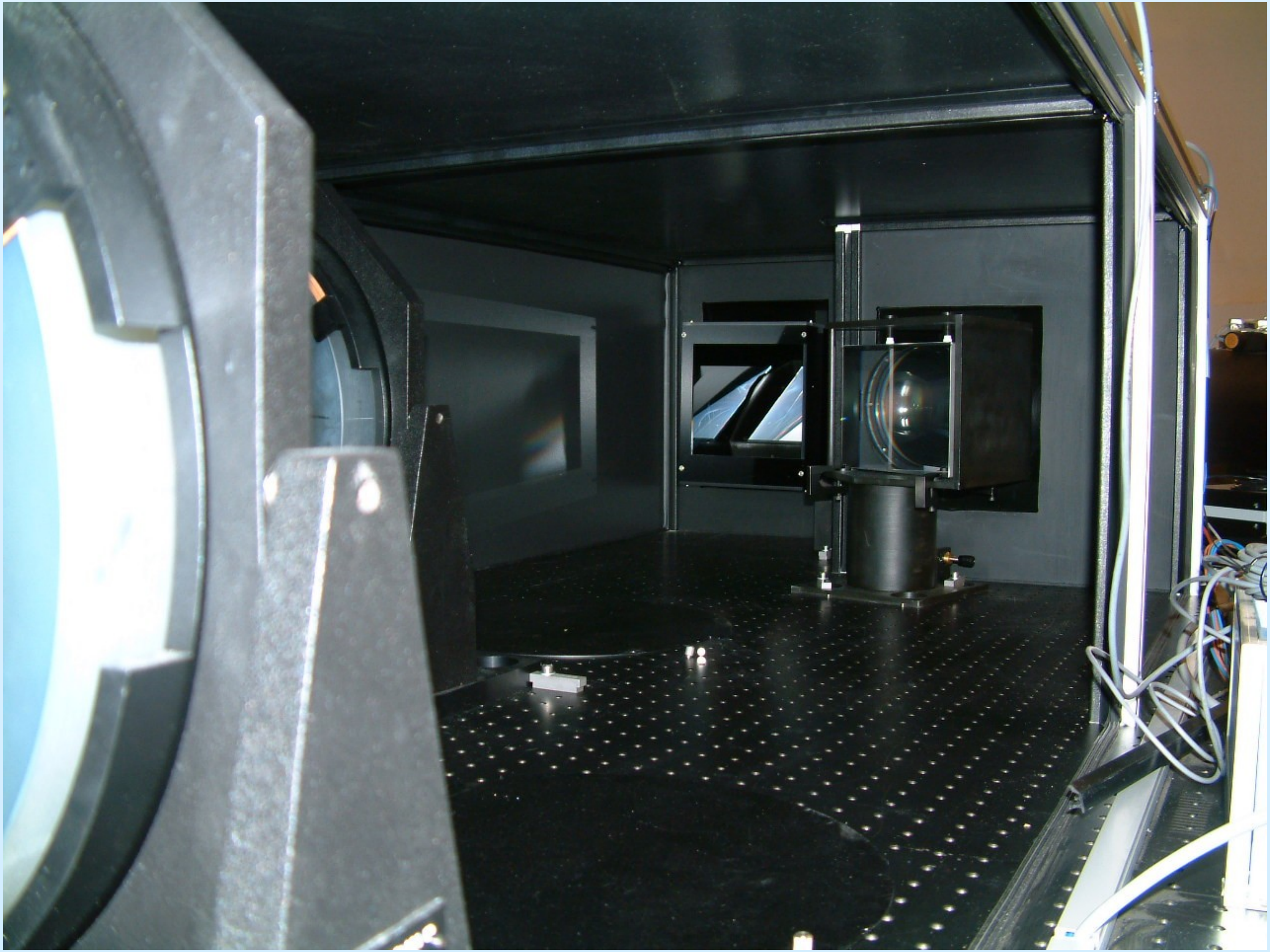
FIES - Characteristics

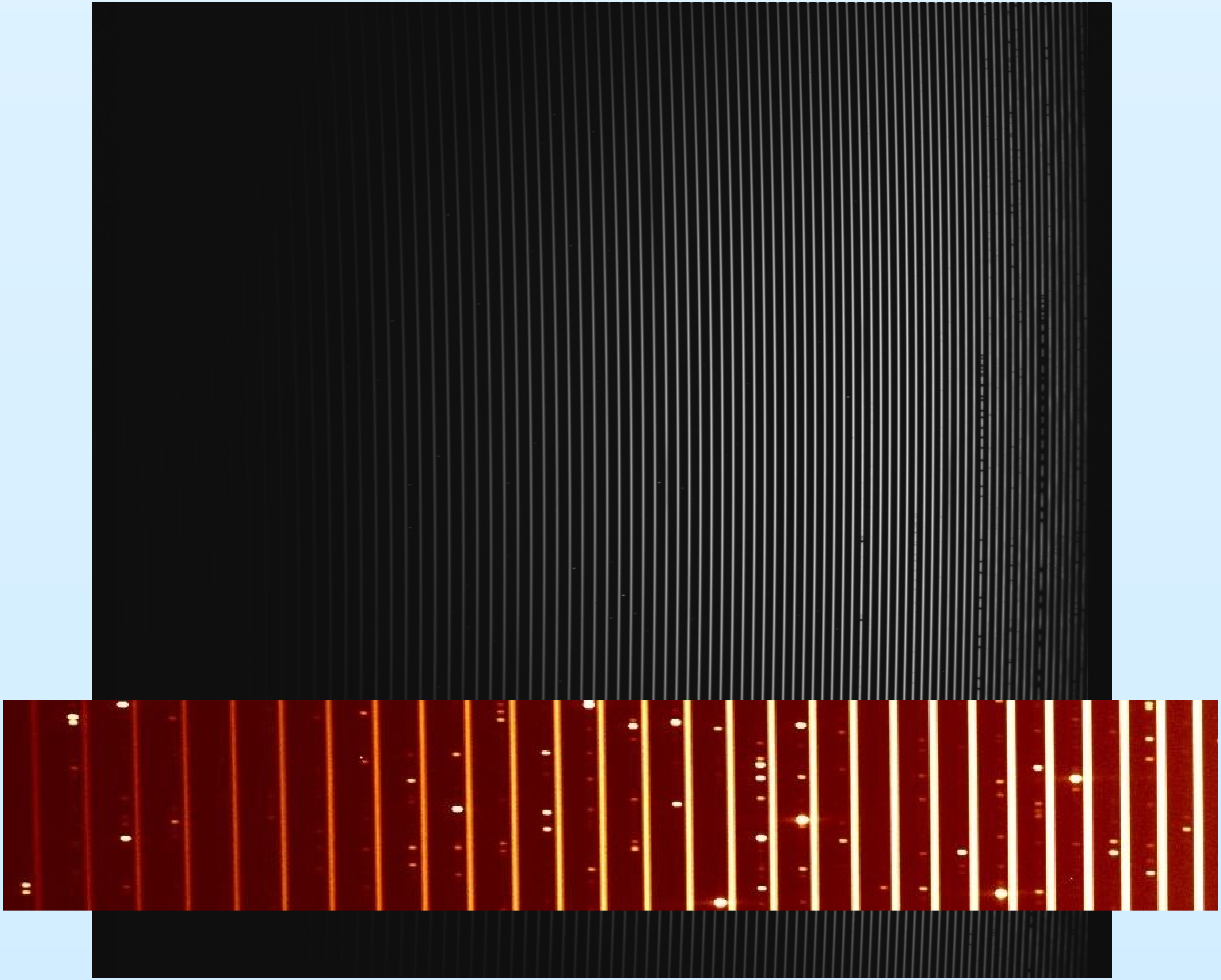
- High-resolution fiber-fed echelle cross-dispersed spectrograph

- Max resolution of R ~ 68000
- Large wavelength range (3700 - 7400 Å)

- Available on standby-basis

- Fiber feed to own building and enclosure
  - ⇒ Stable temperature
  - ⇒ No mechanical vibrations





Observing modes of FIES

- Low-resolution fiber (R ~ 25 000)
- Medium-resolution fiber (R ~ 47 000)
- High-resolution fiber (R ~ 68 000)

- High-resolution fiber + ThAr
- Medium-resolution fiber + ThAr

The challenge of reducing cross-dispersed echelle spectra

Convert the *intensity*

of *stellar light*

at *pixel(x,y)*

into

Intensity of stellar light at wavelength λ

The challenge of reducing cross-dispersed echelle spectra

Convert the *intensity*

of *stellar light*

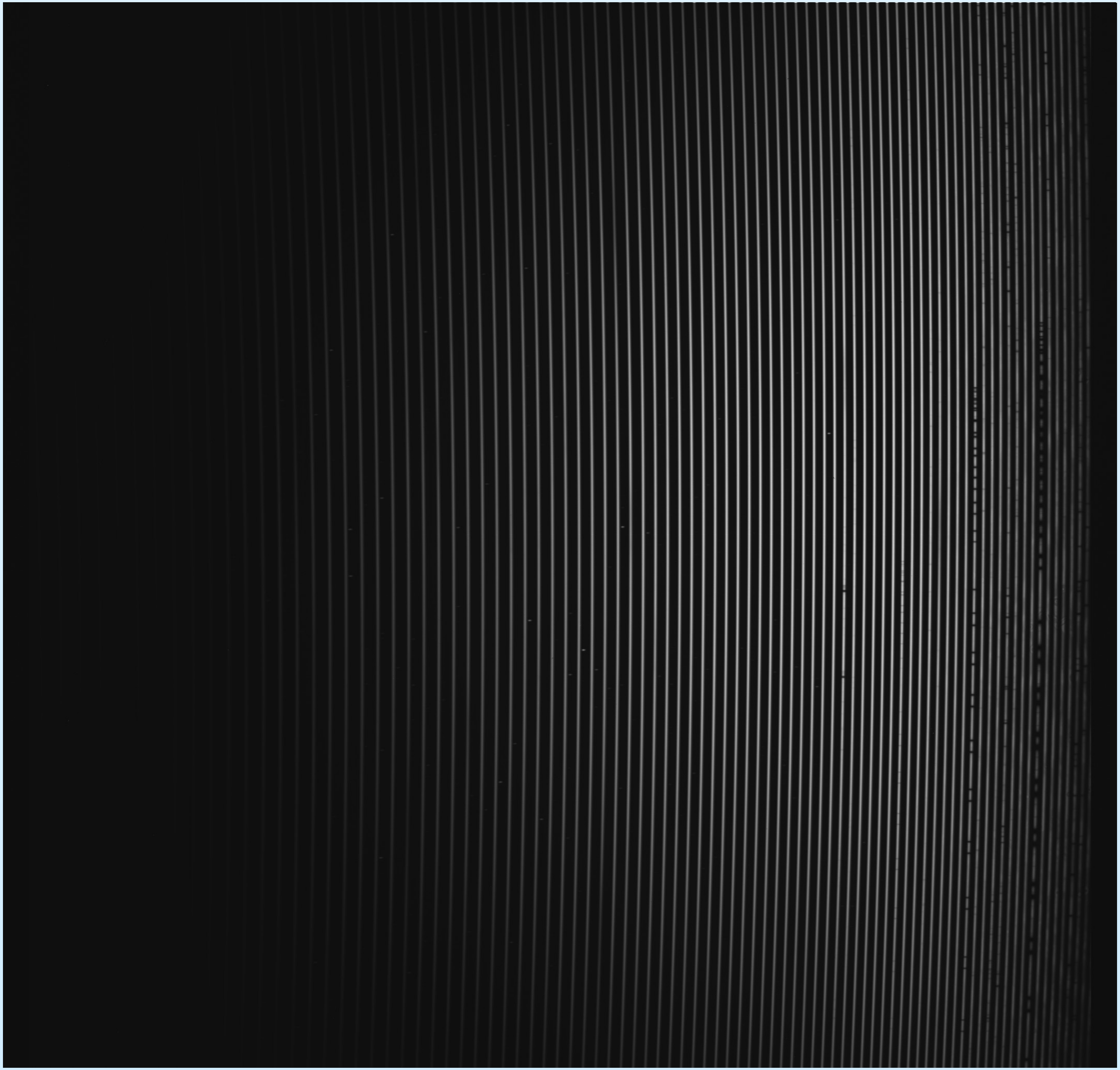
FIES has a fixed layout (no moving parts)

at *pixel(x,y)*

The reduction problem remains the same

into

Intensity of stellar light at wavelength λ



Extracting data from a CCD

CCD is semiconductor, with associated problems
Data will be affected by :

- Bias
- Dark current
- Readout noise

Need to understand sources of noise before we can assign proper weights to the individual pixels

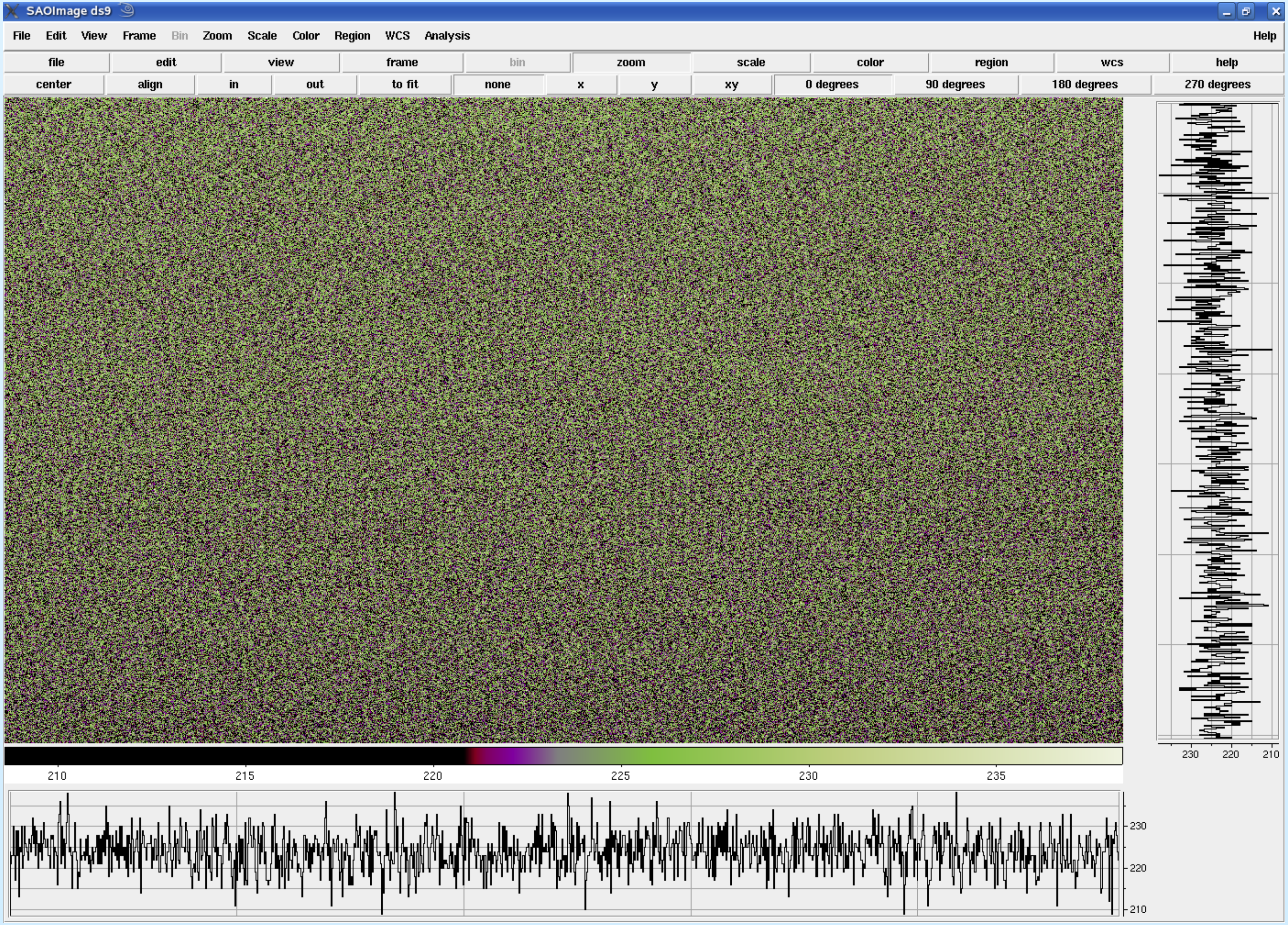
Bias

Before we even start to look at the data, the amplifier introduces a background level (bias)

Bias may be show structure, and can be different across the CCD

The bias can be measured accurately by averaging a number of bias frames

Best 'average' is obtained by rejecting deviant pixels


SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
file edit view frame bin zoom scale color region wcs help
center align in out to fit none x y xy 0 degrees 90 degrees 180 degrees 270 degrees
210 215 220 225 230 235
230 220 210

Other noise sources

Dark current

While waiting for the integration to complete, some electrons *spontaneously* move across the band gap of the semiconductor, generating 'false' electrons

Readout noise

Readout noise is generated by the amplifier. It is a measure of the uncertainty with which the amplifier measures the voltage of each individual pixel.

Other noise sources

Photon noise

comes from the uncertainty in measuring
an intensity with a limited number of photons

Is has Poisson statistics (shot noise)

Photon noise can be estimated as the square root of the measured number of photons

number of electrons = number of counts * gain

Combining noise

By combining the different sources of noise, one can calculate the variance of each individual pixel of the CCD

$$\sigma^2 = \sigma^2_{RO} + \sigma^2_{DC} + \sigma^2_{elec}$$

$$\sigma^2 = \sigma^2_{RO} + N_{DC} + N_{elec} \qquad (N_{elec} = G\, N_{phot})$$

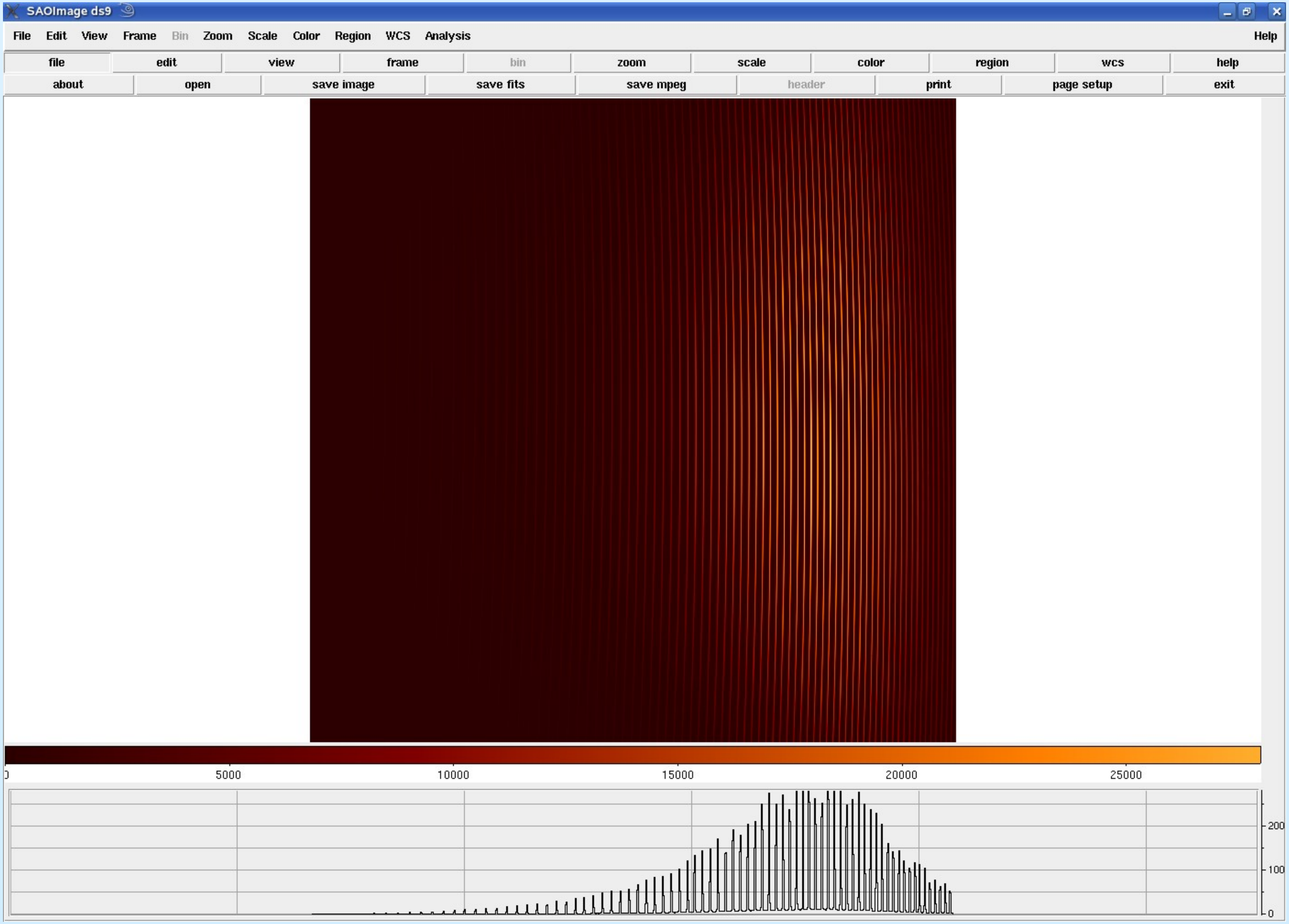
For most spectroscopy applications, the dominant source of noise is the photon noise

Other sources of nuisance

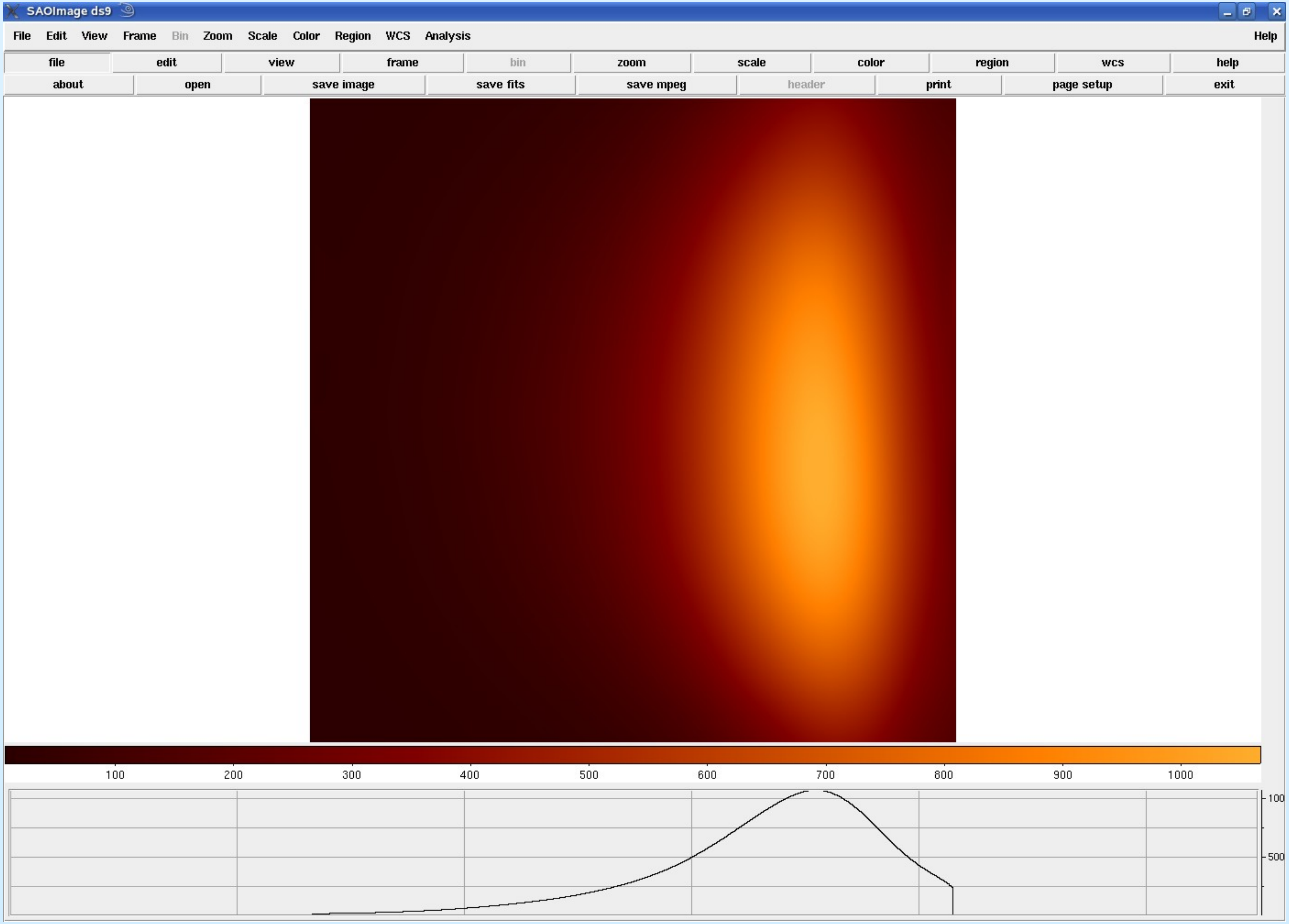
In addition CCD images suffer from

- Scattered light
- Variable pixel sensitivities
- Fringing

Scattered light



Scattered light

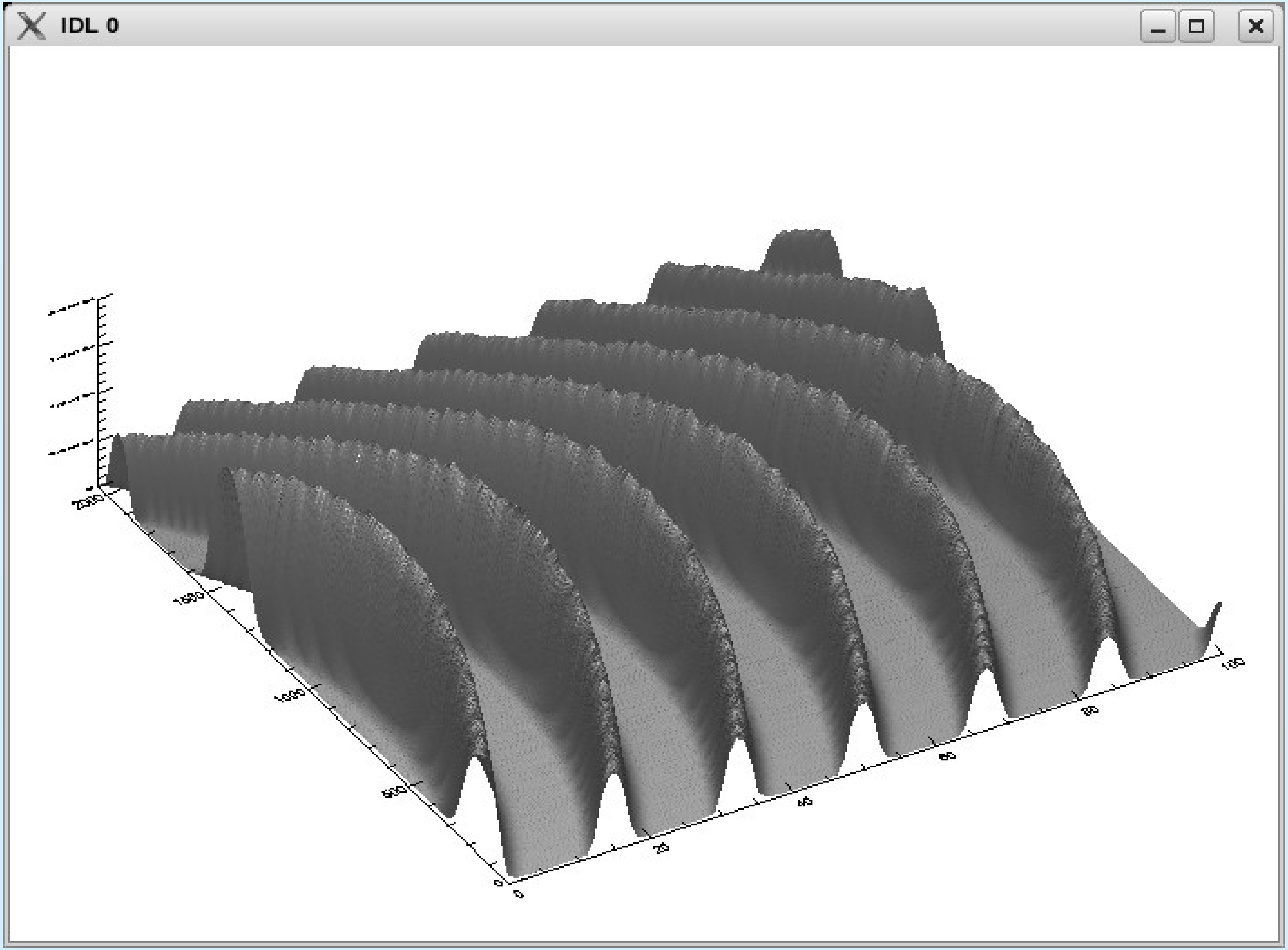


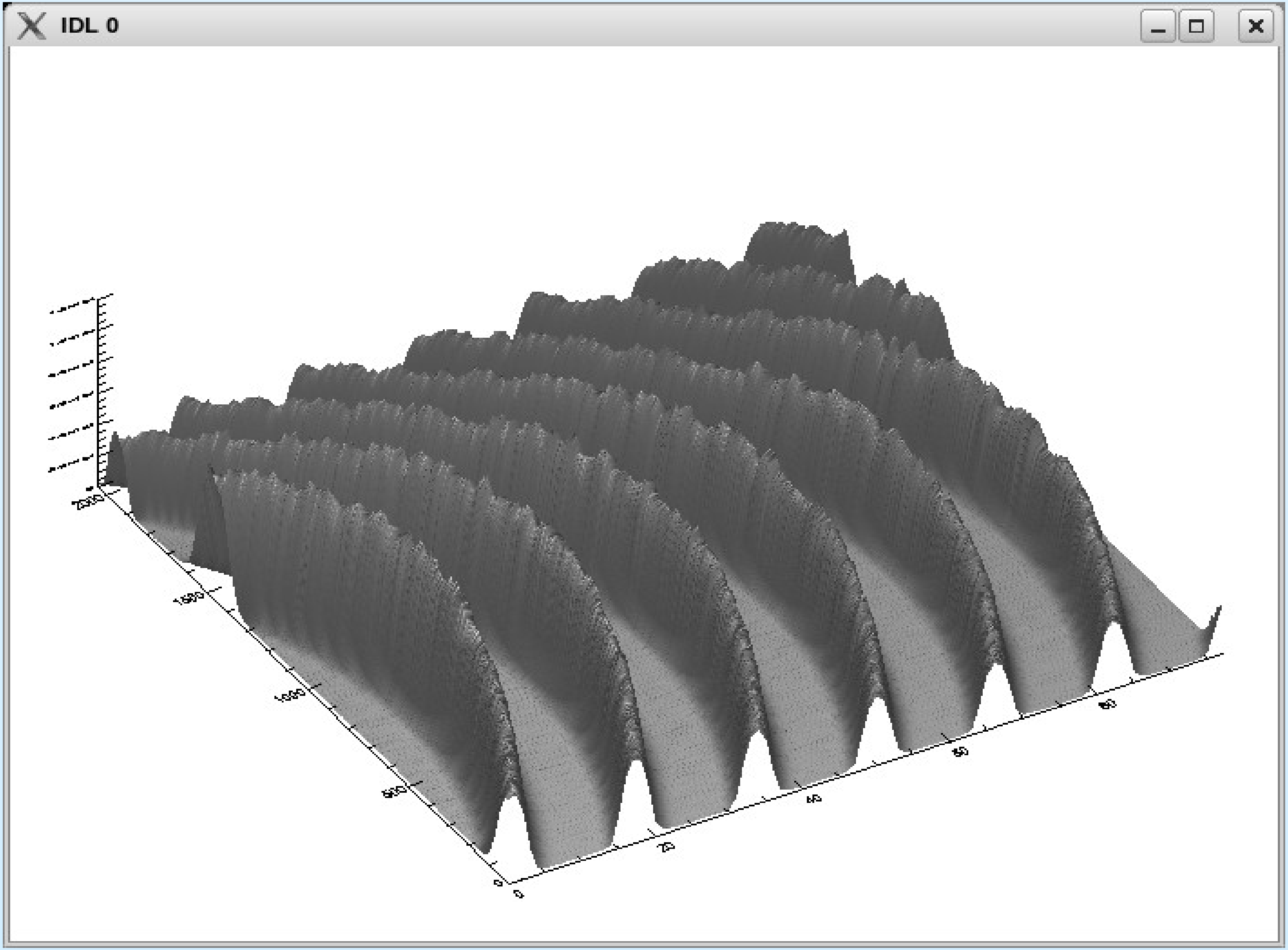
Pixel sensitivities and fringing

Spectra from a hot black body have no features, and can be used to determine the small-scale variations due to variable pixel sensitivities and fringing

(similar to flat-fielding an image)

Also, since flat-field spectra are smooth, they can also be used to *normalize* the instrumental response along the dispersion direction (the blaze shape)


IDL 0


IDL 0

Normalized flat fields

Echelle flat fields do not have a uniform illumination across the whole CCD

- Echelle blaze shape
- Narrow orders

It is therefore undesirable to simply divide an image by a flat, because this will amplify the (low!) signal that is present in the edges of the orders

Normalized flat fields

To accurately translate pixel values in intensities, the observed flat field needs to be processed in two stages :

- Model pixel responses fringing with 2D normalized flat
- Model blaze shape with extracted flat

It is therefore very important to have a very high signal-to-noise in the master flat

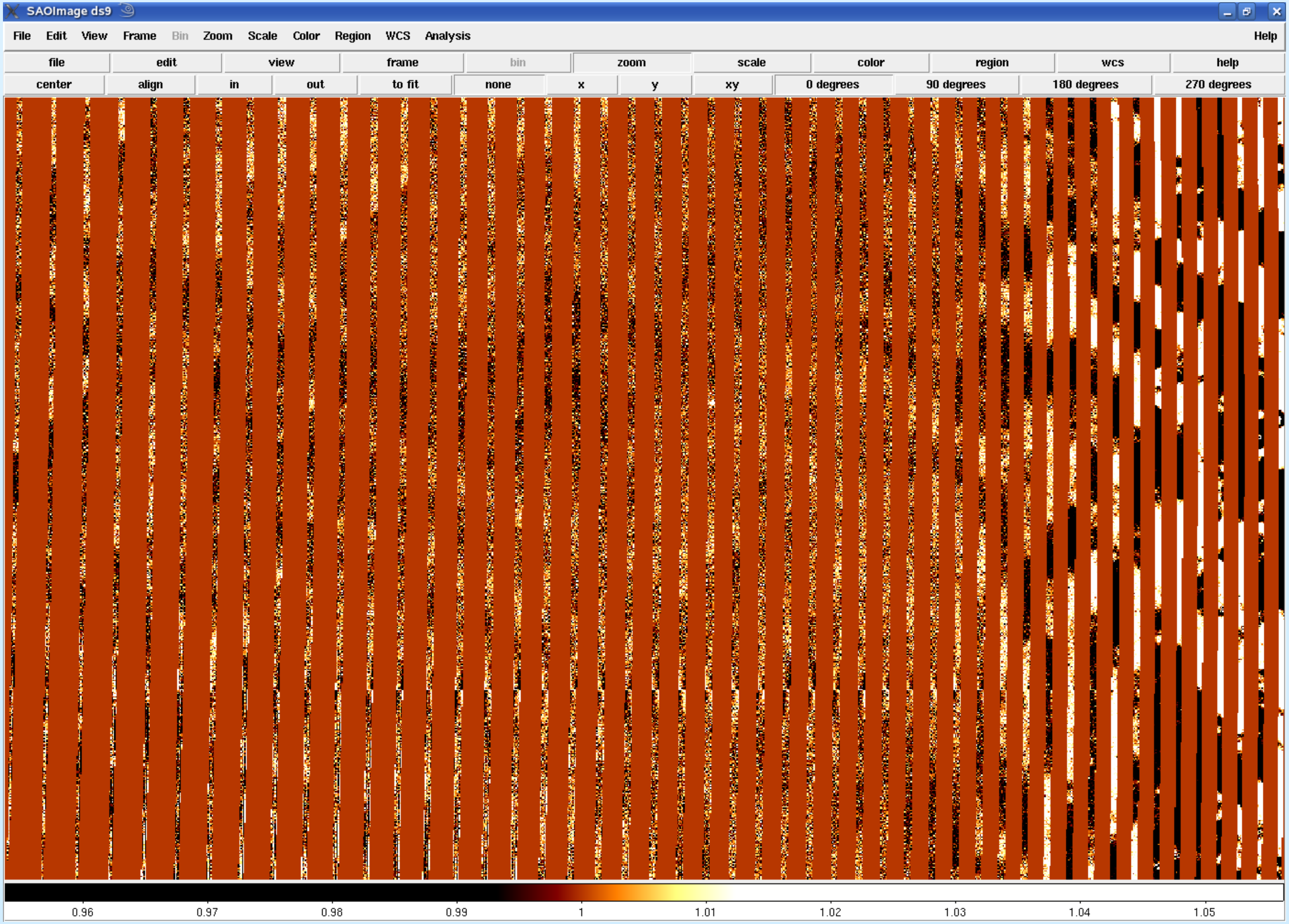
Preparing the normalized flat field

A normalized flat can be calculated as follows :

1) Remove bias and scattered light from master flat
2) Fit cross-order profiles
3) Extract spectra into 1-dimensional orders
4) Fit blaze shape (low-order polynomial)
5) Renormalize flat field, such that only small-scale pixel-to-pixel variations remain
6) Set remaining pixels in normalized flat to 1

7) Save the blaze shape for future reference

Normalized flat field



Reference data

In order to model all these effects, it is important to create a set of well-behaved reference data.

These data can be used to calibrate the observations

Each observing mode needs its own set of reference data

Reference data typically constructed once per night

Reference data

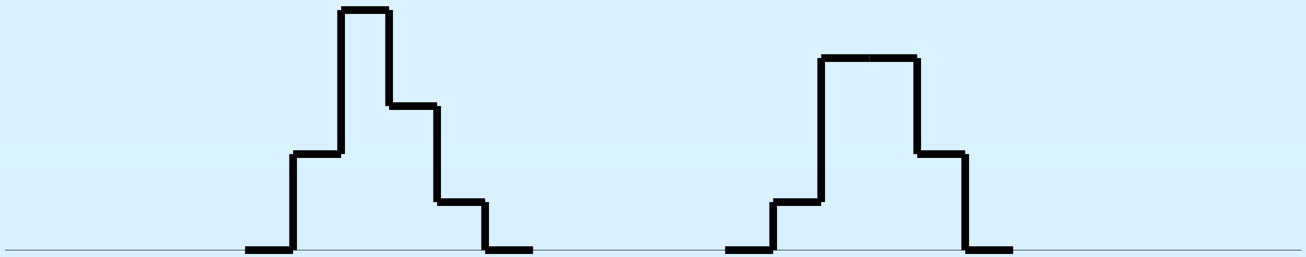
1 - Master bias frame

2 - Master flat field

3 - Order locations

4 - Master normalized flat field

“Optimal extraction”

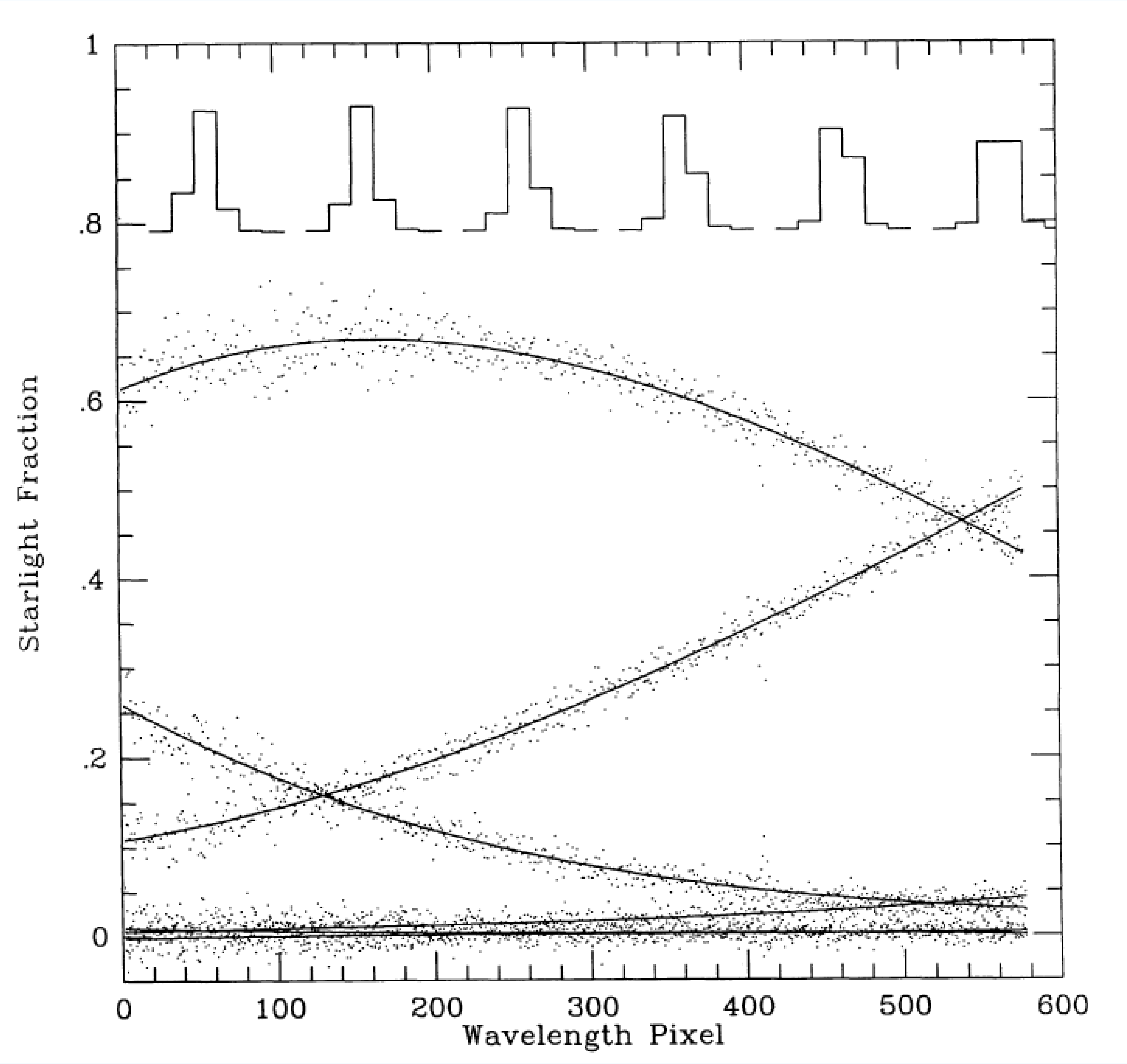


Better than simple sum across the spatial profile

Use weights for the individual pixels based on their fractional contribution to the spatial profile

Works well if spatial profile changes only slowly and smoothly along the spectrum

Will also 'clean' profiles -> reject cosmics



1
.8
.6
.4
.2
0
Starlight Fraction
0
100
200
300
400
500
600
Wavelength Pixel

Reduction of stellar data

We can now (finally) proceed to reduce stellar data

The steps are the following :

1) Subtract master bias
2) Model and subtract scattering
3) Divide by normalized master flat
4) Extract the spectrum
5) Divide by blaze shape

Wavelength calibration

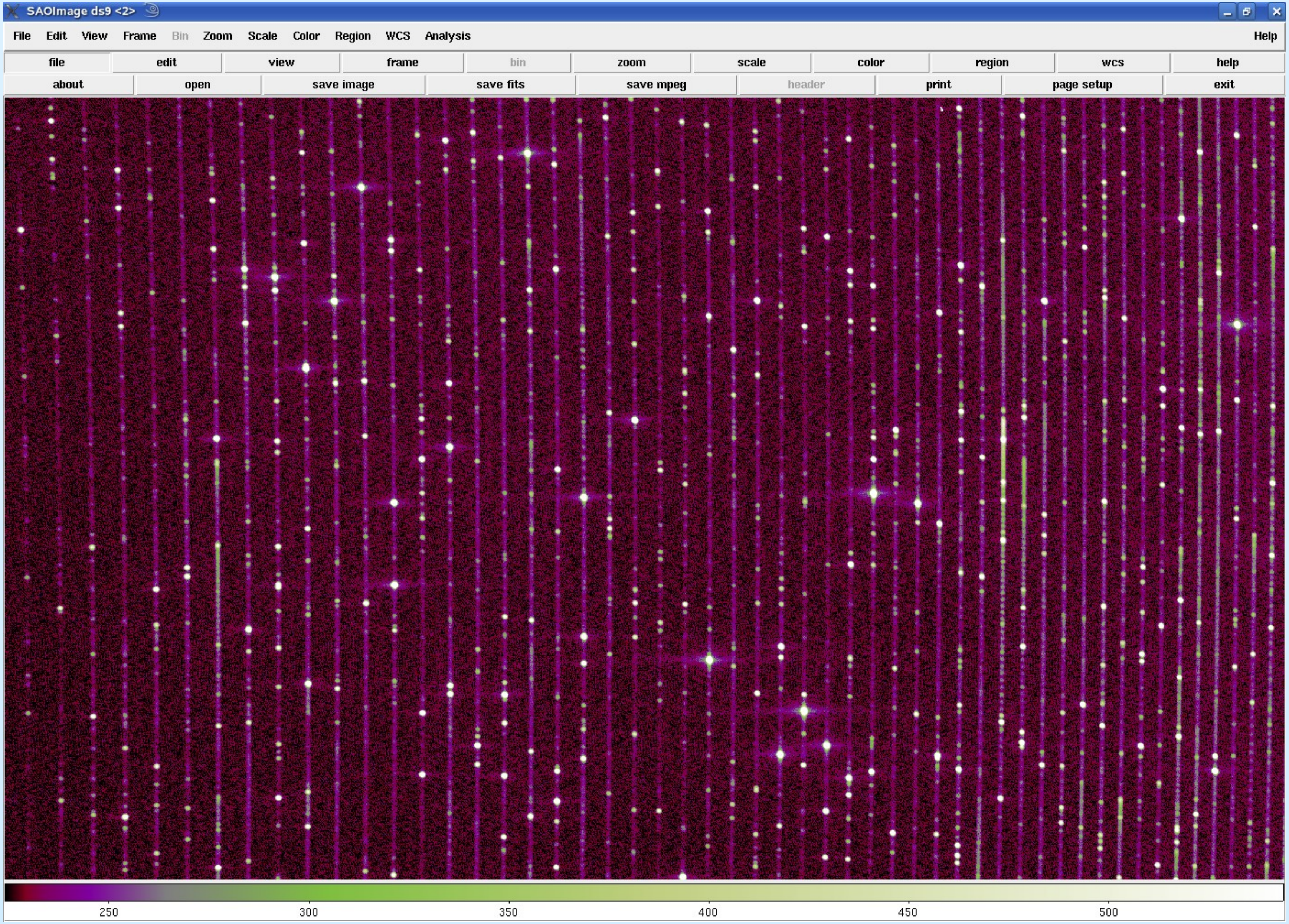
Problem separate from data extraction

Use lamp to create reference frame

Wavelength calibration can be done as often as desired

Use same reduction method as for normal frames

Calibration lamp frame



Wavelength calibration

Determine line positions (pixels) in each order
and compare with lists / atlases

Because dispersion depends linearly on both λ and *n*,
one can calculate a 2-dimensional dispersion relation

Old solution can be used as guess for next solution

Simultaneous ThAr spectra

By observing an object spectrum together with a calibration lamp spectrum, instrumental drifts are eliminated

Reduction is similar as for normal lamp spectra, except that the spectra are shifted (in both x and y!)

For each frame, the measured offsets are used to adjust the wavelength scale (no resampling)

FIEStool implementation

FIEStool can perform the calculation of reference data, as well as do the reduction of science frames

The tasks performed by FIEStool are *tuned* to the specific optical layout, properties and observing modes of FIES

User interaction is minimal

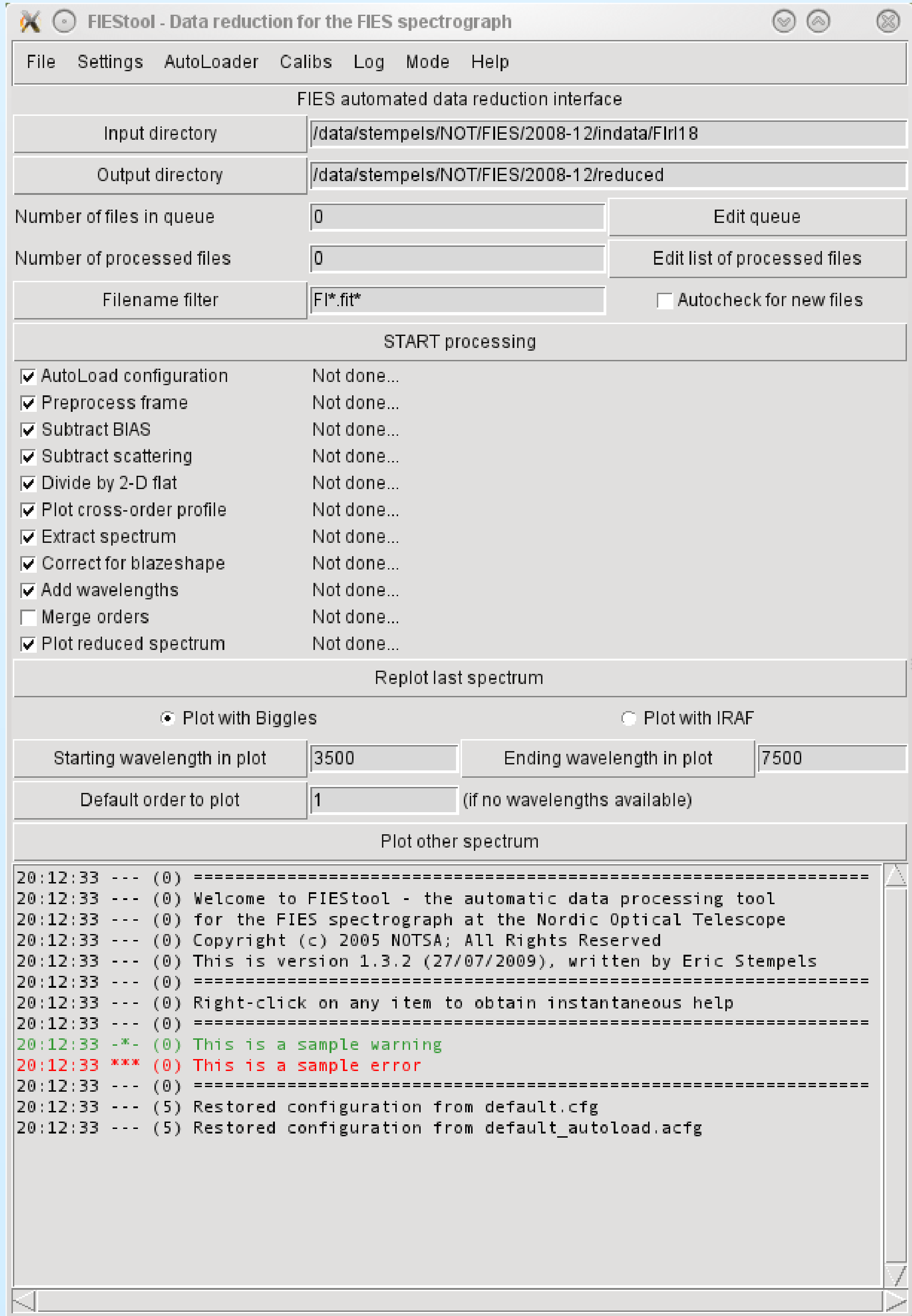
FIEStool implementation

FIEStool can be configured to recognize the chosen reduction mode, and choose the appropriate reference data

Spectra reduced with FIEStool can be used for direct scientific analysis

Remaining issues

- Heliocentric correction (header)
- Order merging
- Continuum normalization
- Data analysis (line strengths, radial velocities, etc)


FIEStool - Data reduction for the FIES spectrograph
File Settings AutoLoader Calibs Log Mode Help
FIES automated data reduction interface
Input directory
/data/stempels/NOT/FIES/2008-12/indata/FIrl18
Output directory
/data/stempels/NOT/FIES/2008-12/reduced
Number of files in queue
0
Edit queue
Number of processed files
0
Edit list of processed files
Filename filter
FI*.fit*
Autocheck for new files
START processing
AutoLoad configuration Not done...
Preprocess frame Not done...
Subtract BIAS Not done...
Subtract scattering Not done...
Divide by 2-D flat Not done...
Plot cross-order profile Not done...
Extract spectrum Not done...
Correct for blazeshape Not done...
Add wavelengths Not done...
Merge orders Not done...
Plot reduced spectrum Not done...
Replot last spectrum
Plot with Biggles
Plot with IRAF
Starting wavelength in plot
3500
Ending wavelength in plot
7500
Default order to plot
1
(if no wavelengths available)
Plot other spectrum
20:12:33 --- (0) ==
20:12:33 --- (0) Welcome to FIEStool - the automatic data processing tool
20:12:33 --- (0) for the FIES spectrograph at the Nordic Optical Telescope
20:12:33 --- (0) Copyright (c) 2005 NOTSA; All Rights Reserved
20:12:33 --- (0) This is version 1.3.2 (27/07/2009), written by Eric Stempels
20:12:33 --- (0) ==
20:12:33 --- (0) Right-click on any item to obtain instantaneous help
20:12:33 --- (0) ==
20:12:33 -*- (0) This is a sample warning
20:12:33 *** (0) This is a sample error
20:12:33 --- (0) ==
20:12:33 --- (5) Restored configuration from default.cfg
20:12:33 --- (5) Restored configuration from default_autoload.acfg