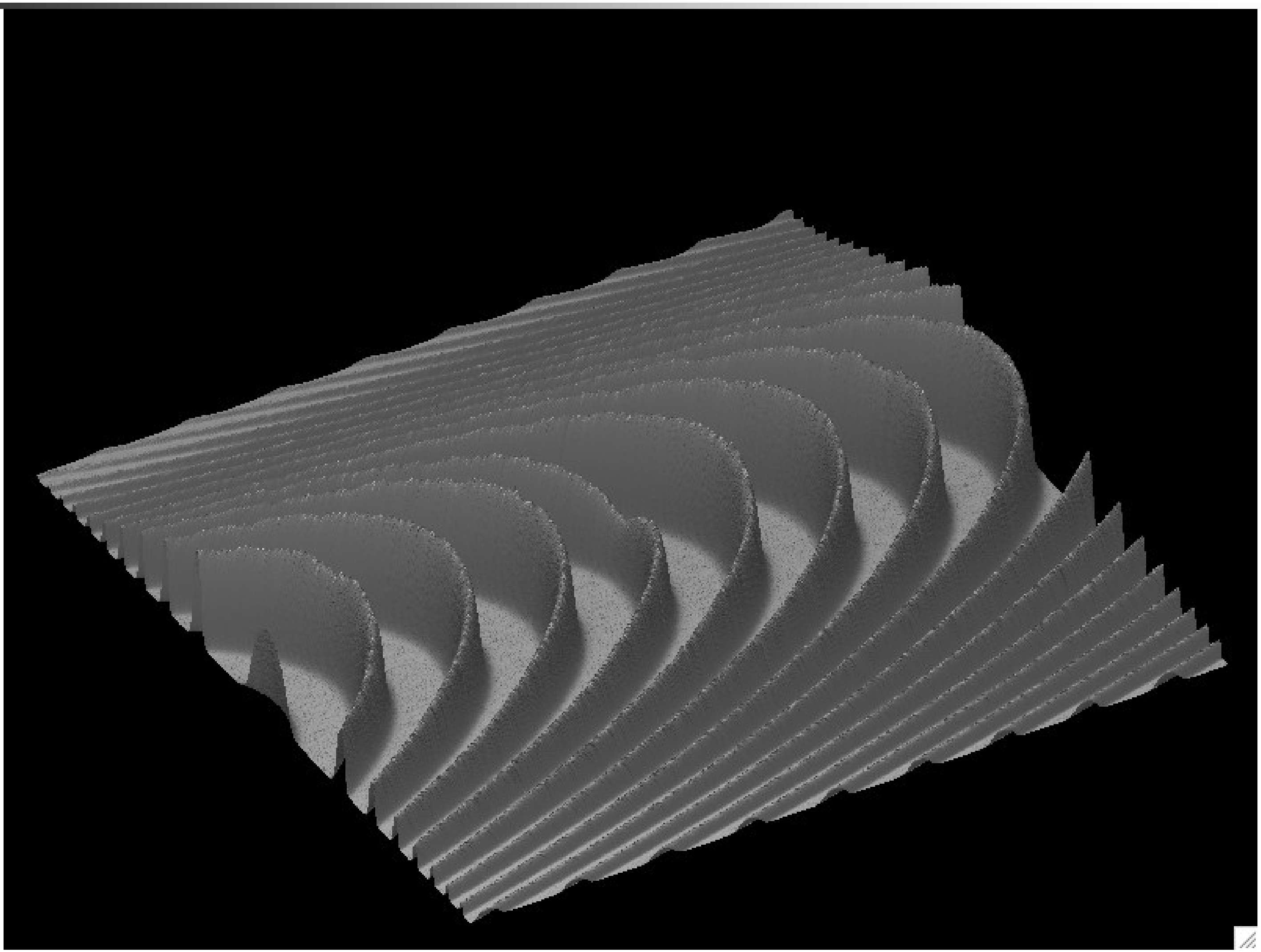
Observational Astronomy

SPECTROSCOPIC

data reduction

Piskunov & Valenti 2002, A&A 385, 1095

Worse-case scenario…



In addition we have calibration data:

- *Bias*
- *Flat field*
- *Dark current*
- *Order tracing*
- *Wavelength map (comparison spectrum)*
- *Blaze calibration*

Spectroscopic reduction in a nutshell

The intensity is given by:

$$I_x = \frac{s-b-d\cdot t}{f-b}\cdot g; \quad \lambda_x = F(x, x_{ThAr}, \lambda_{ThAr})$$

s – signal in science exposure

b – bias level

f – flat field signal

g – gain (e^-/ADU)

d – dark current signal per unit time

t – exposure time

The problem is the errors:

$$\frac{\delta I}{I} = \frac{\sqrt{\delta_s^2 + \delta_b^2 + \delta_{rd}^2 + \delta_d^2}}{s - b - d \cdot t} + \frac{\sqrt{\delta_f^2 + \delta_b^2 + \delta_{rd}^2}}{f - b} =$$

$$= \frac{\sqrt{s + b + \delta_{rd}^2 + d \cdot t}}{s - b - d \cdot t} + \frac{\sqrt{f + b + \delta_{rd}^2}}{f - b};$$

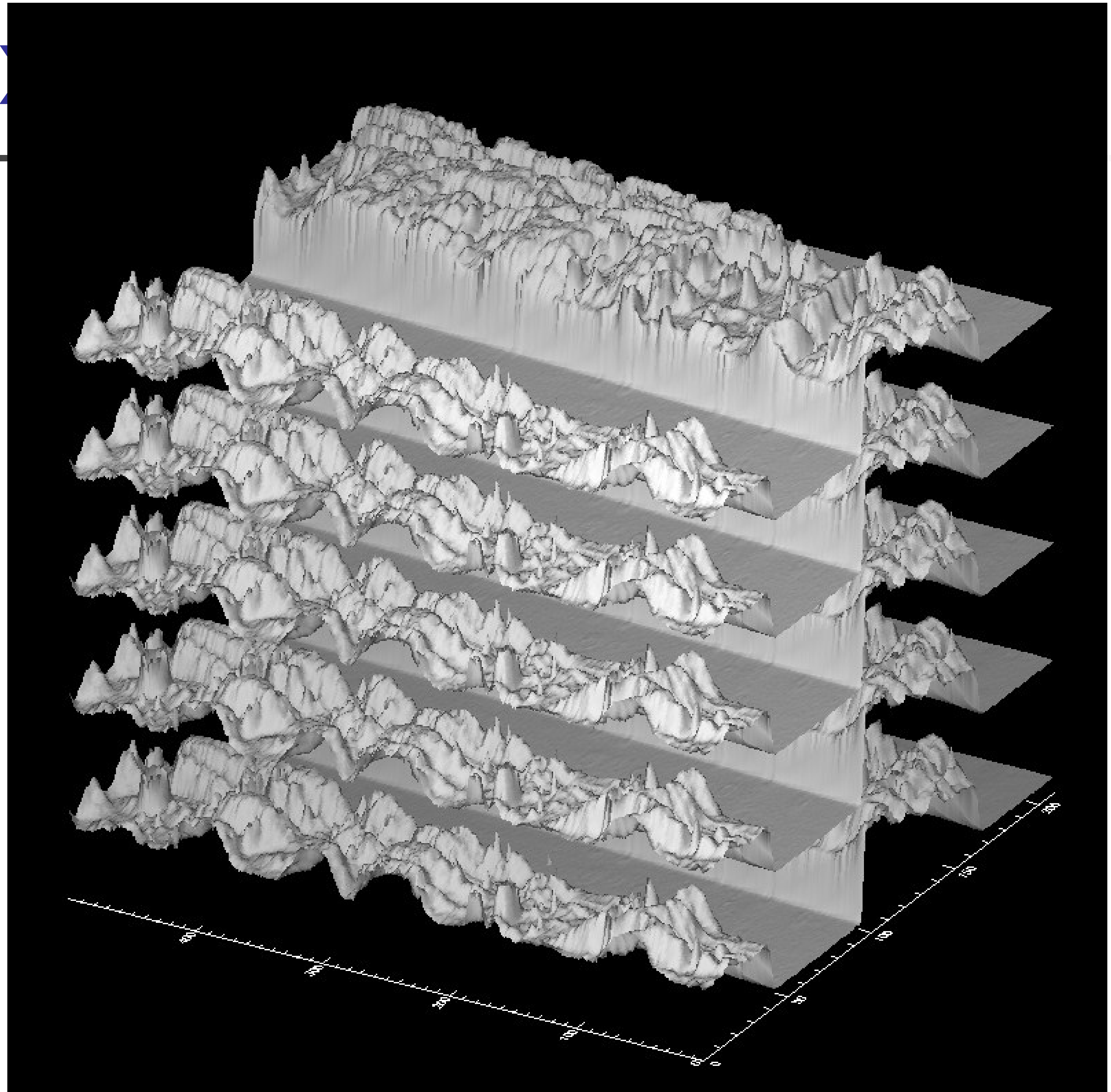
$$\frac{S}{N} = \frac{(s - b - d \cdot t) \cdot (f - b)}{(f - b) \cdot \sqrt{s + b + \delta_{rd}^2 + d \cdot t} + (s - b - d \cdot t) \cdot \sqrt{f + b + \delta_{rd}^2}}.$$

If f is close to b, the S/N is determined by the S/N of the flat field!!!

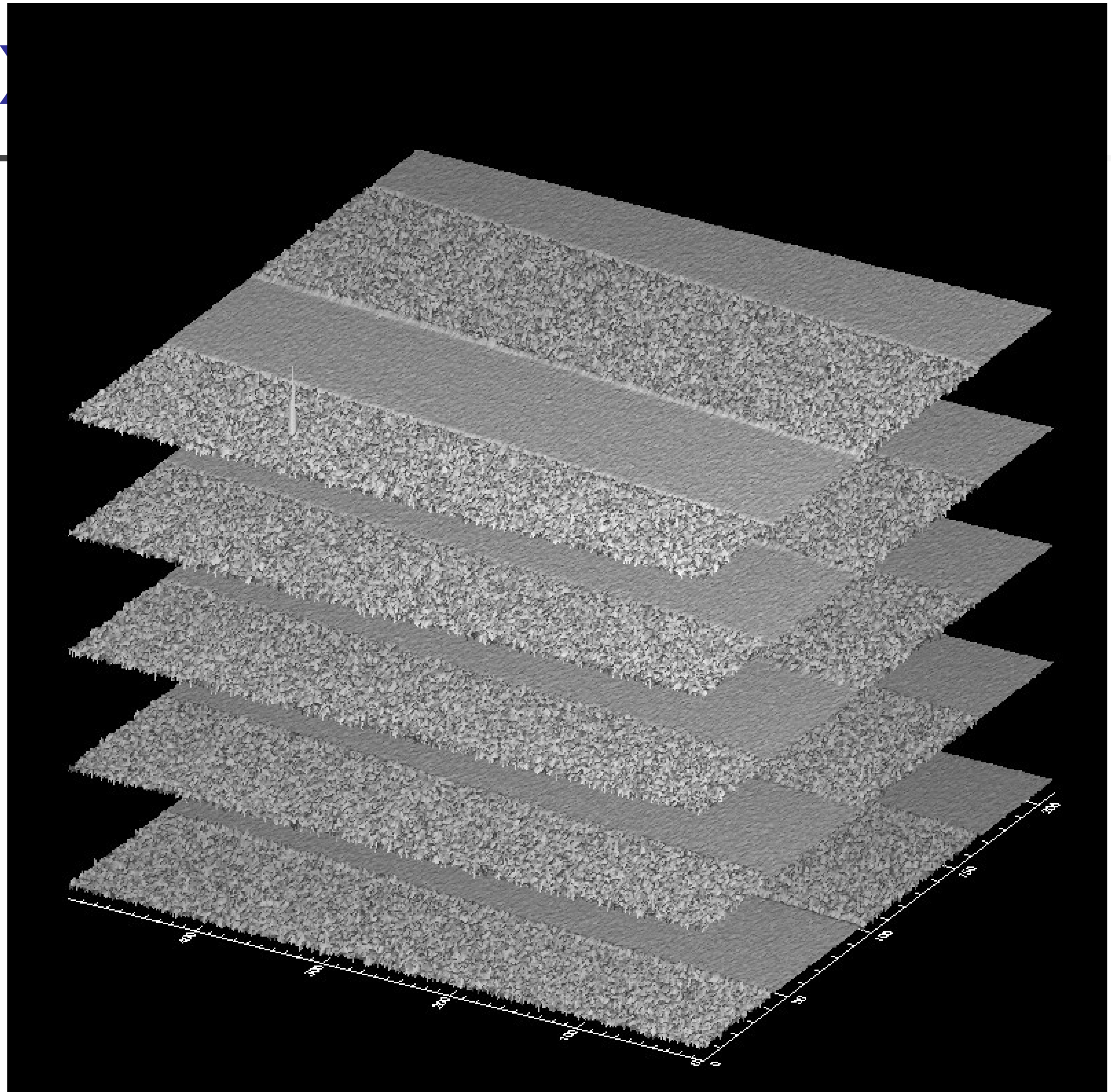
One step at a time: making master bias and master flat/dark

- The goal is to replace the actual calibration data with a model which is free of random noise but carries all the necessary calibration signatures.
- Master S/N must be much larger than the S/N in science frames!!! Add together signal in many frames
- Main issue: getting rid of random errors, e.g. cosmic ray hits
- Method: filtering within a frame or across a stack of frames
- Cross-check between groups of calibration frames

Ex



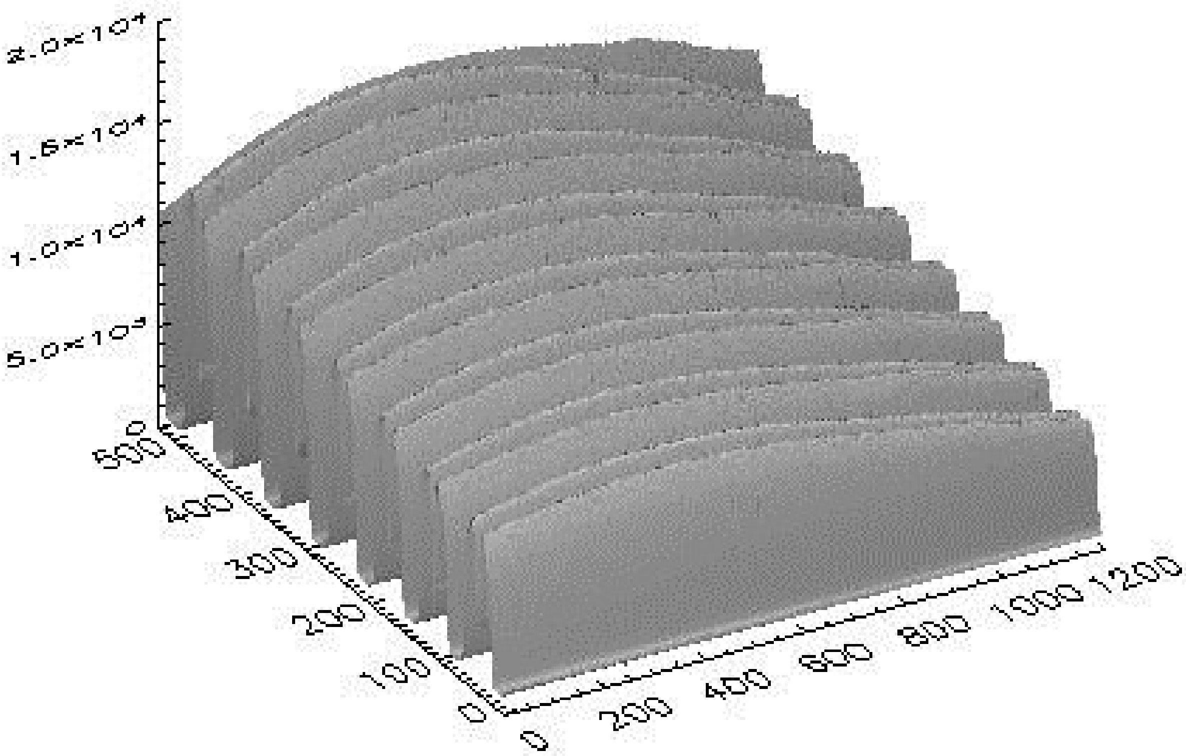
Ex



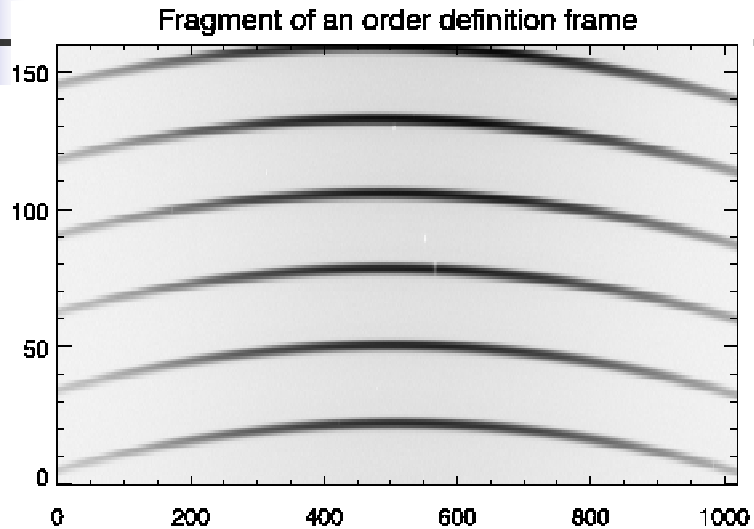
6 times larger vertical scale

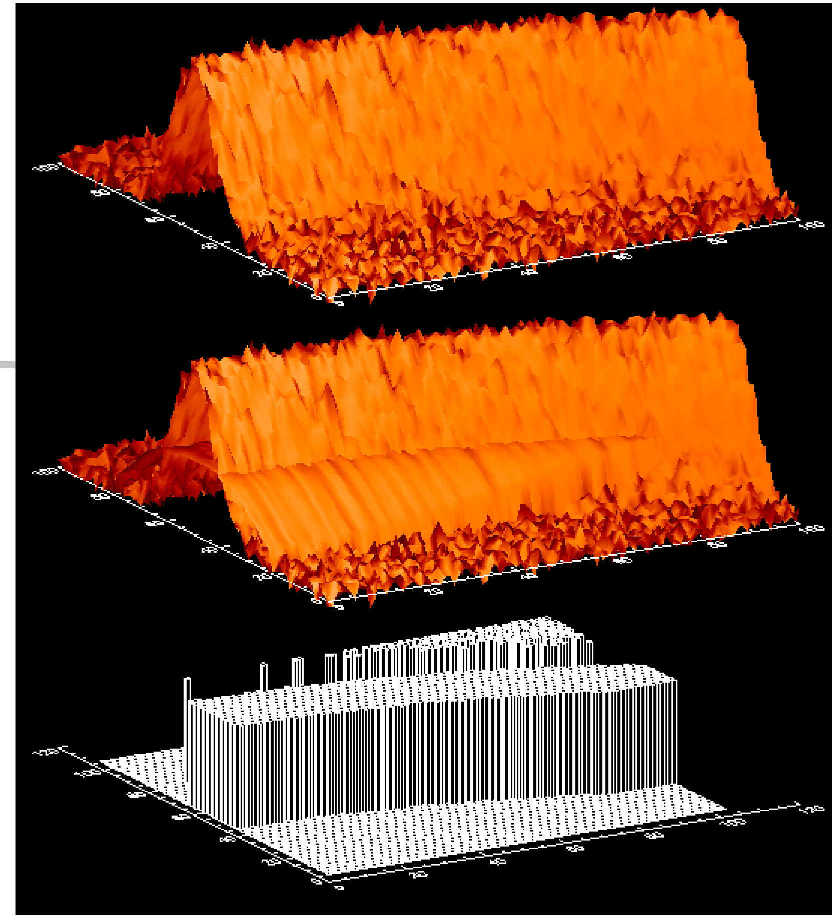
Flat field

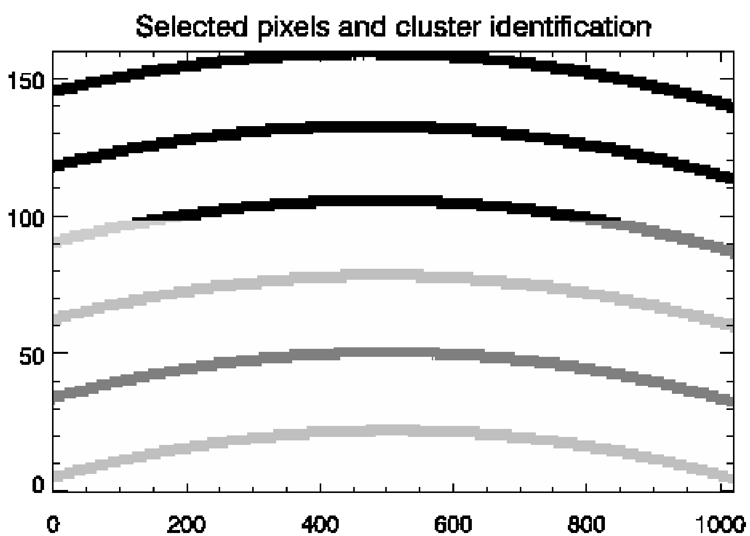
Fragment of a master flat field



Order tracing

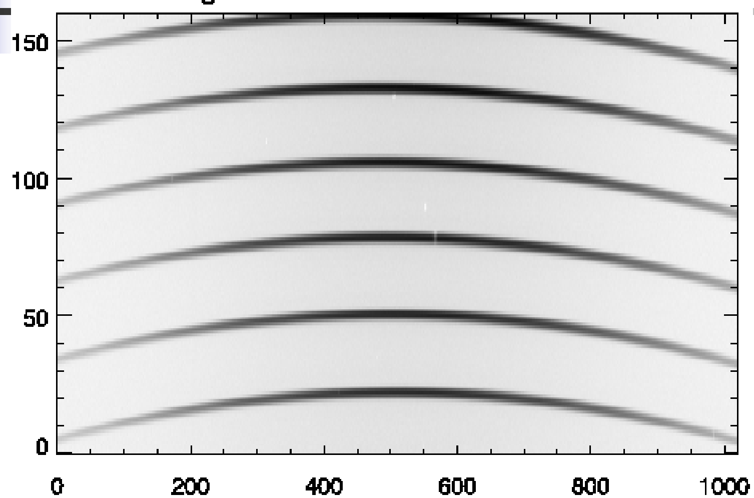




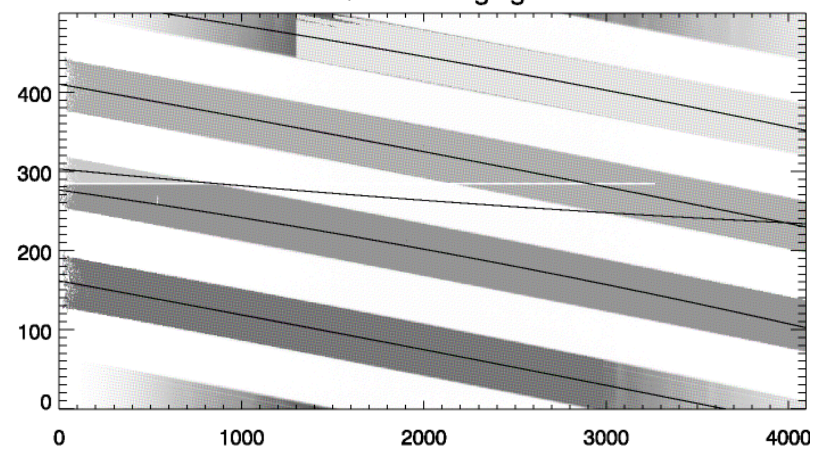


Order tracing (2)

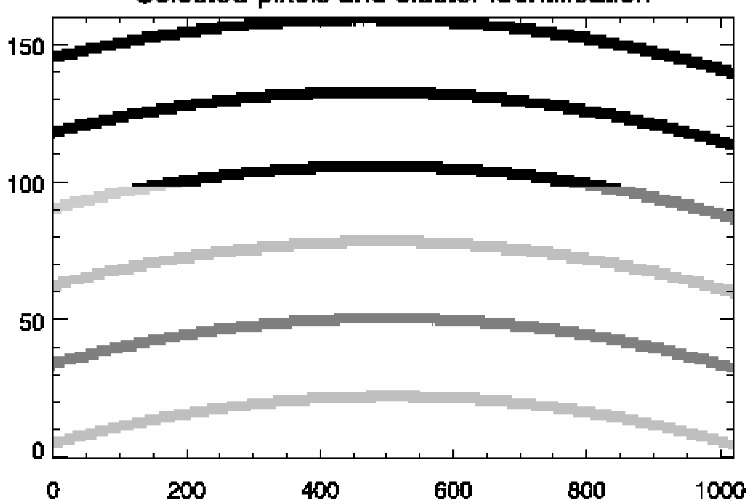
Fragment of an order definition frame



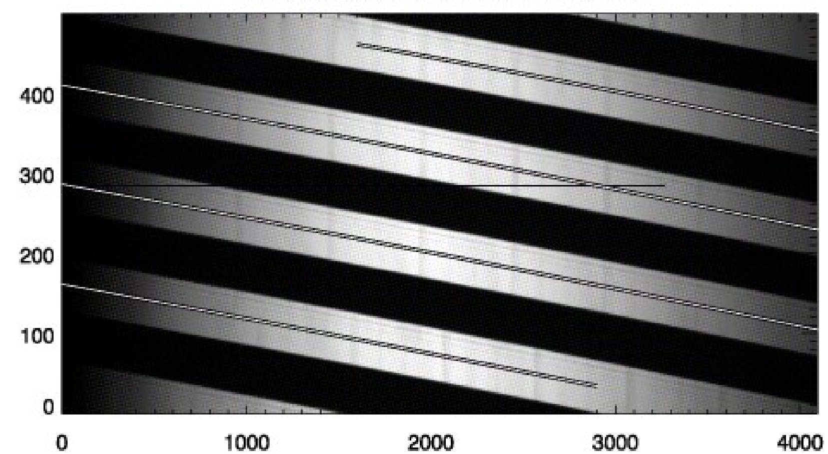
Cluster merging



Selected pixels and cluster identification

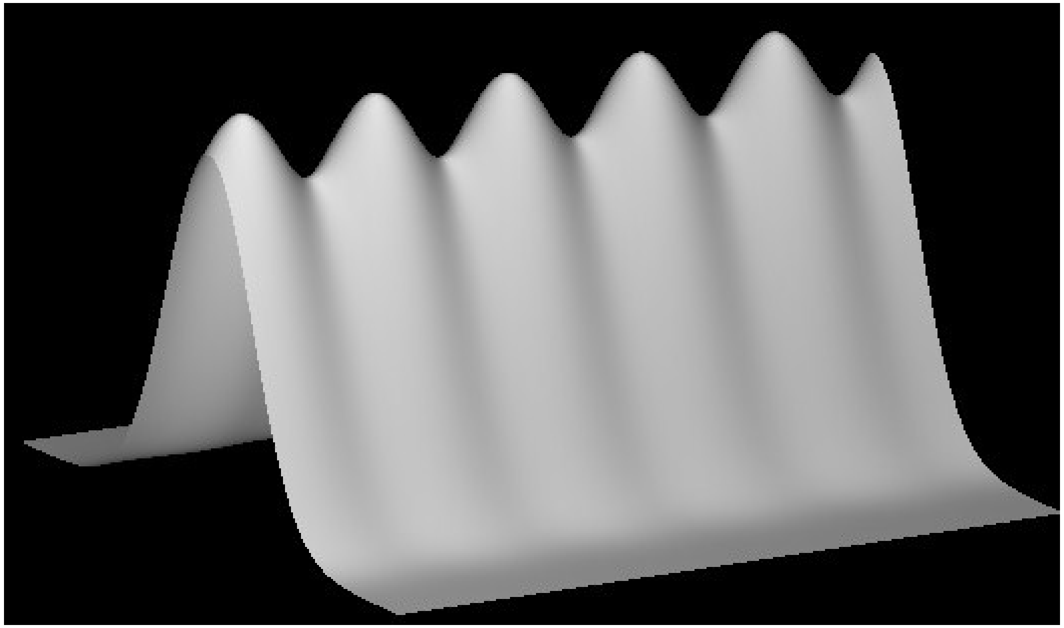


Final definition of order locations



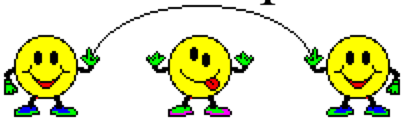
Conceptual Algorithm

Any point in the focal plane can (in principle) be represented by a product of the *sPectrum* and the *sLit illumination function* $f(x,y) = P(x) \cdot L(y - y_c)$



$$\overbrace{(\sin x + a)}^{P(x)} \cdot \overbrace{e^{-\left(\frac{y}{b}\right)^2}}^{L(y)}$$

looks like a real spectral order



Now the Real Thing…

- CCD pixel with coordinates x and y is given by:

$$f(x,y) = P(x) \cdot \int_y \Pi(y' - y_c) \cdot L(y')dy'$$

- In practice we reconstruct the slit function L on some discrete grid with resolution ≥ than CCD pixels. Thus we can write:

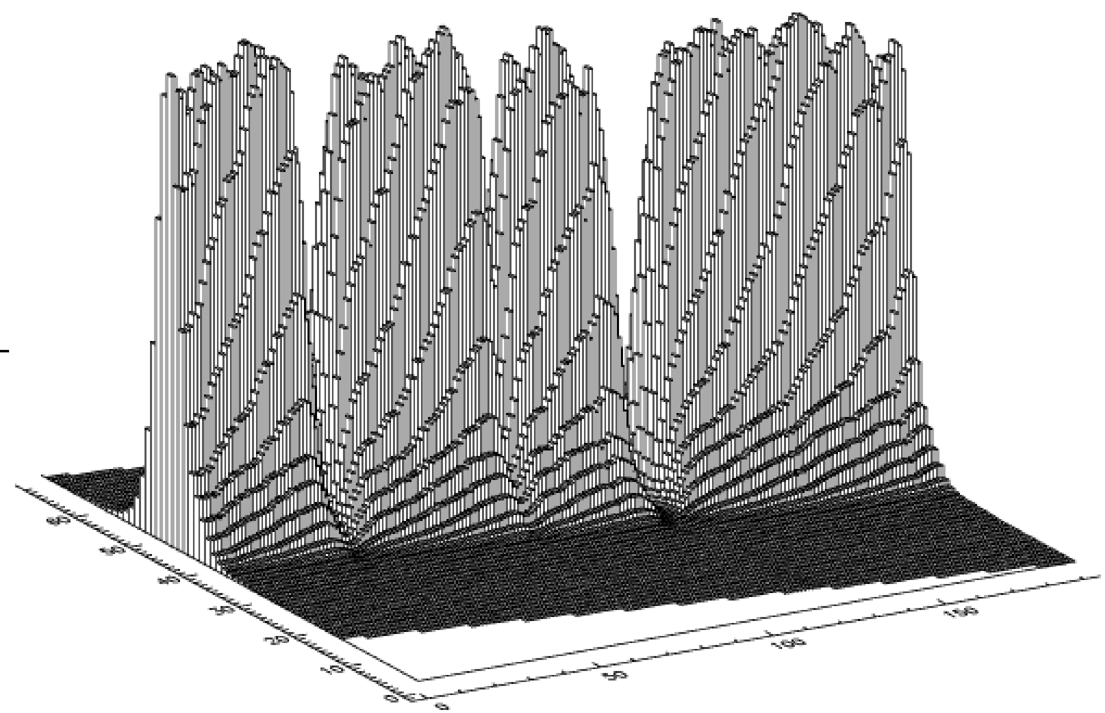
$$f(x,y) \approx P(x) \cdot \sum_j \omega_{x,y}^j L_j$$

Slit function decomposition

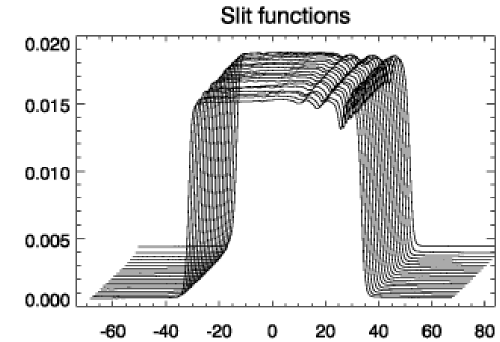
- Ideal model: Image on CCD is a sequence of monochromatic images of the entrance slit sampled with CCD pixels

$$S_{xy} = Sp_x \times Sf_y$$

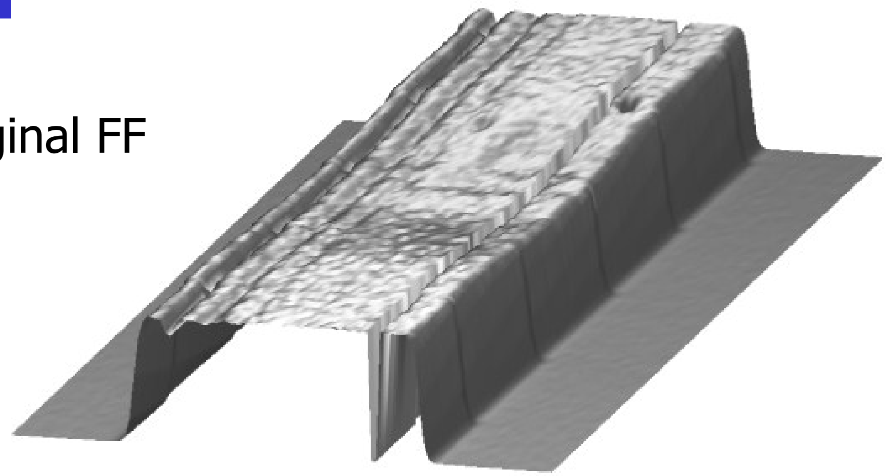
$$S_{xy} = \sum_{i \in y} \omega_{i,x,y} Sp_x Sf_{i+}$$



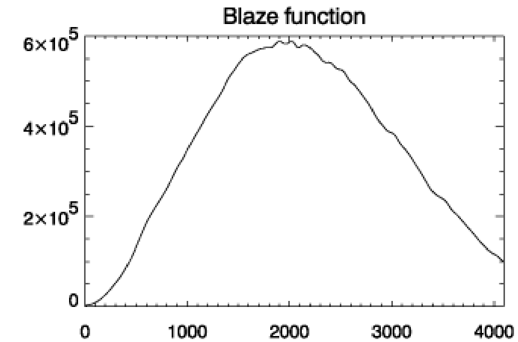
Normalizing flat field

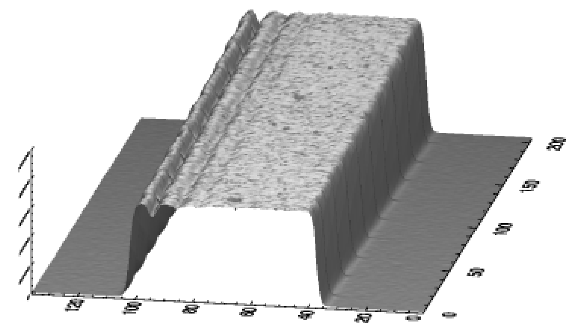


Original FF

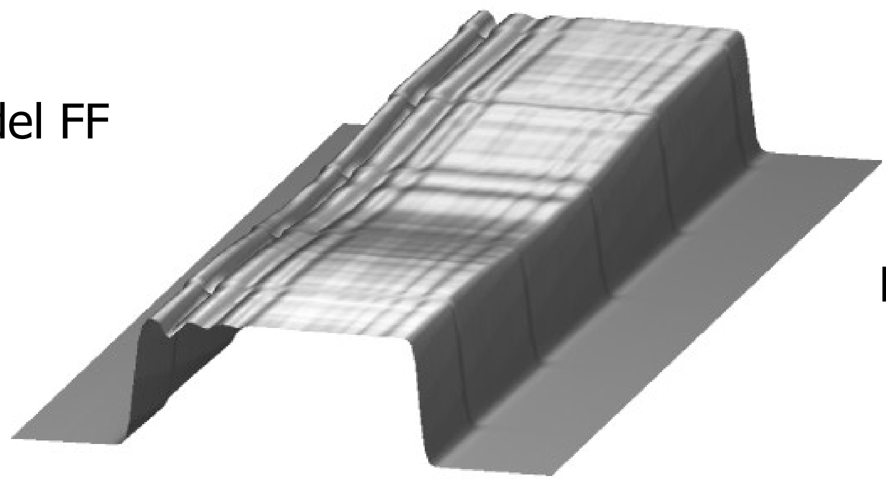


“Spectrum”

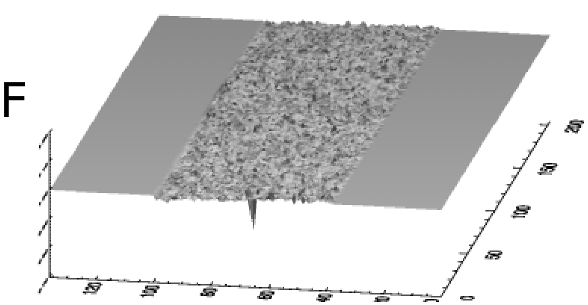




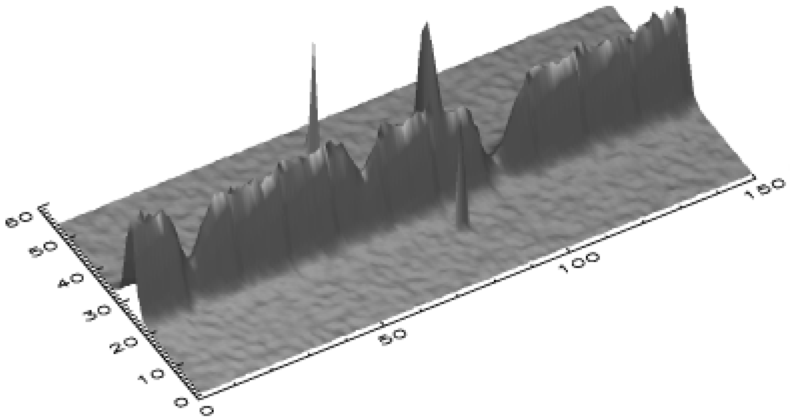
Model FF

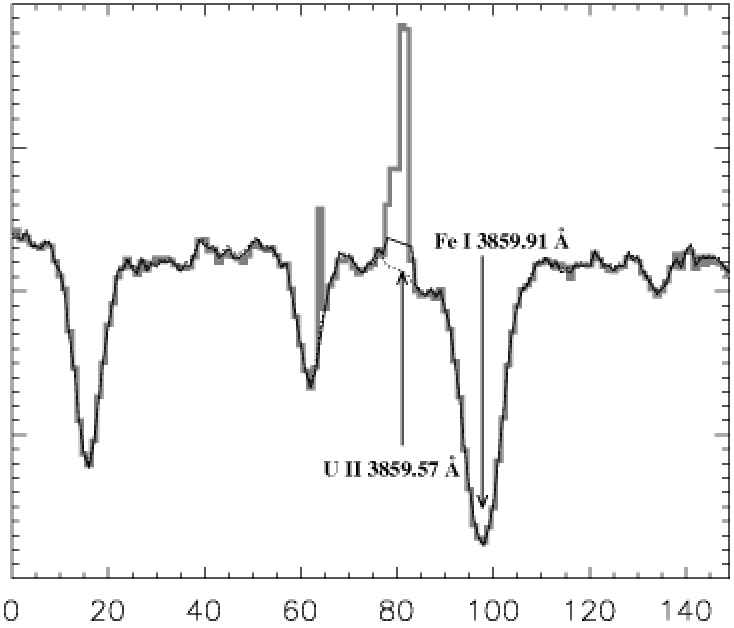


Normalized FF

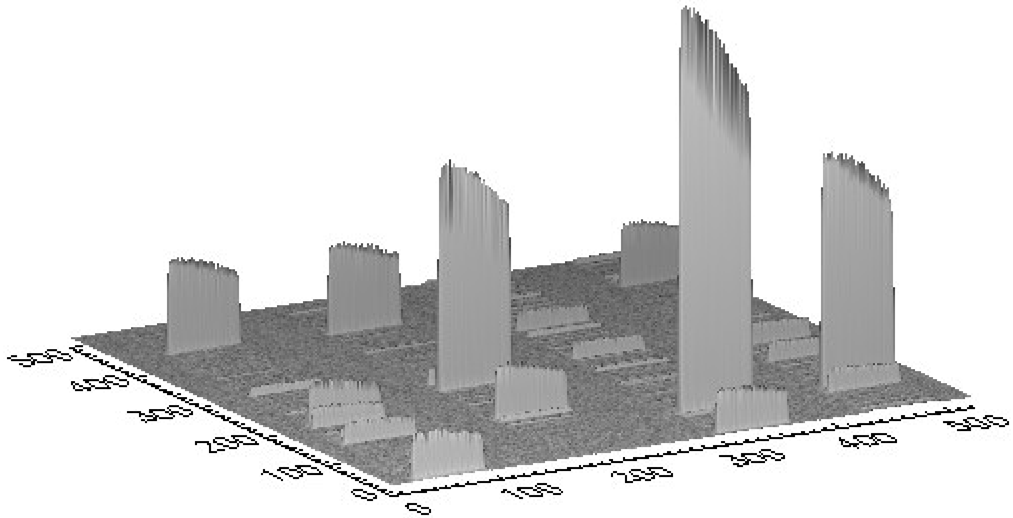


Extracting science spectrum





Wavelength calibration

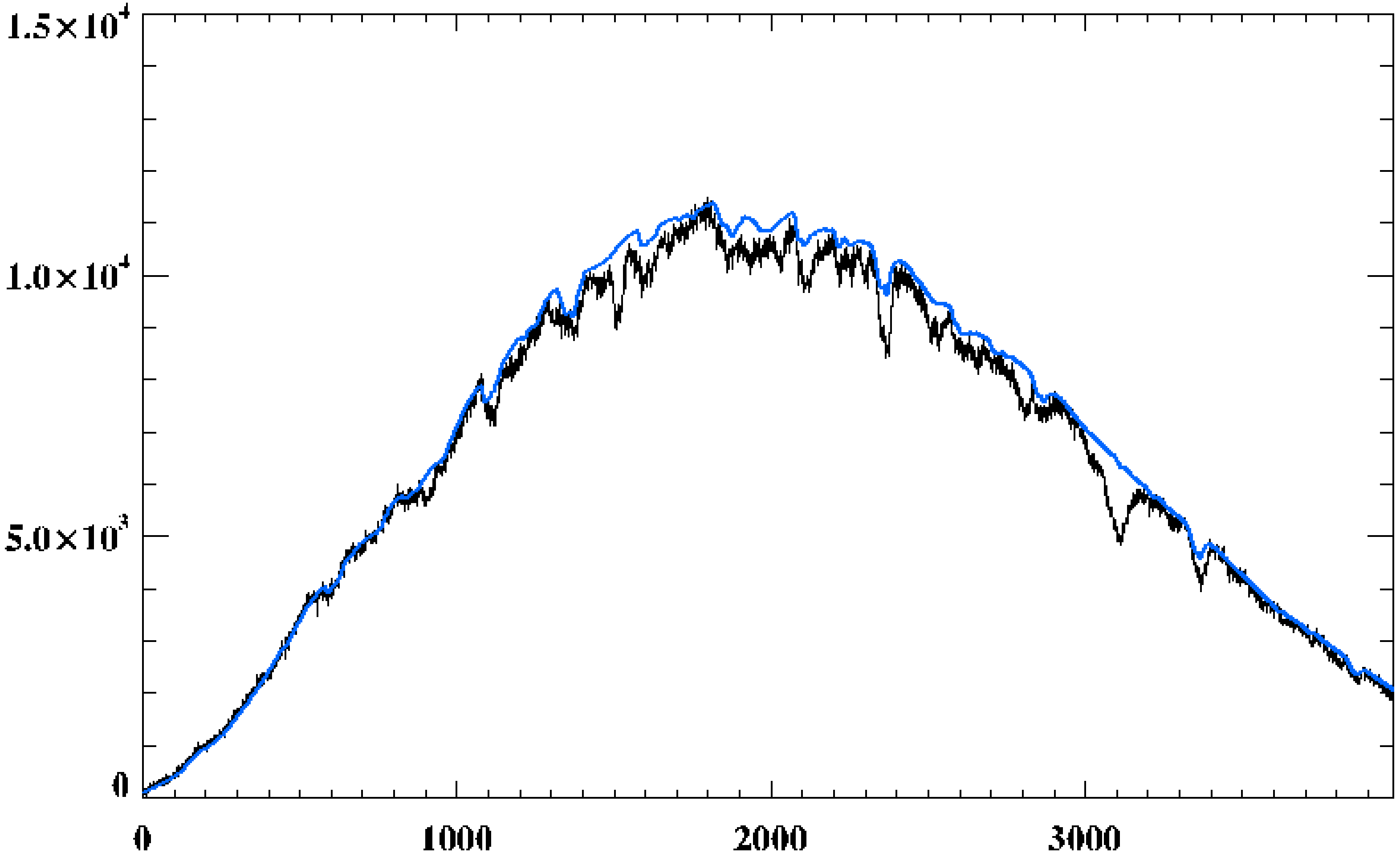


$$\lambda_{x,m} = \sum_{i,j} a_{i,j} m^i x^j$$

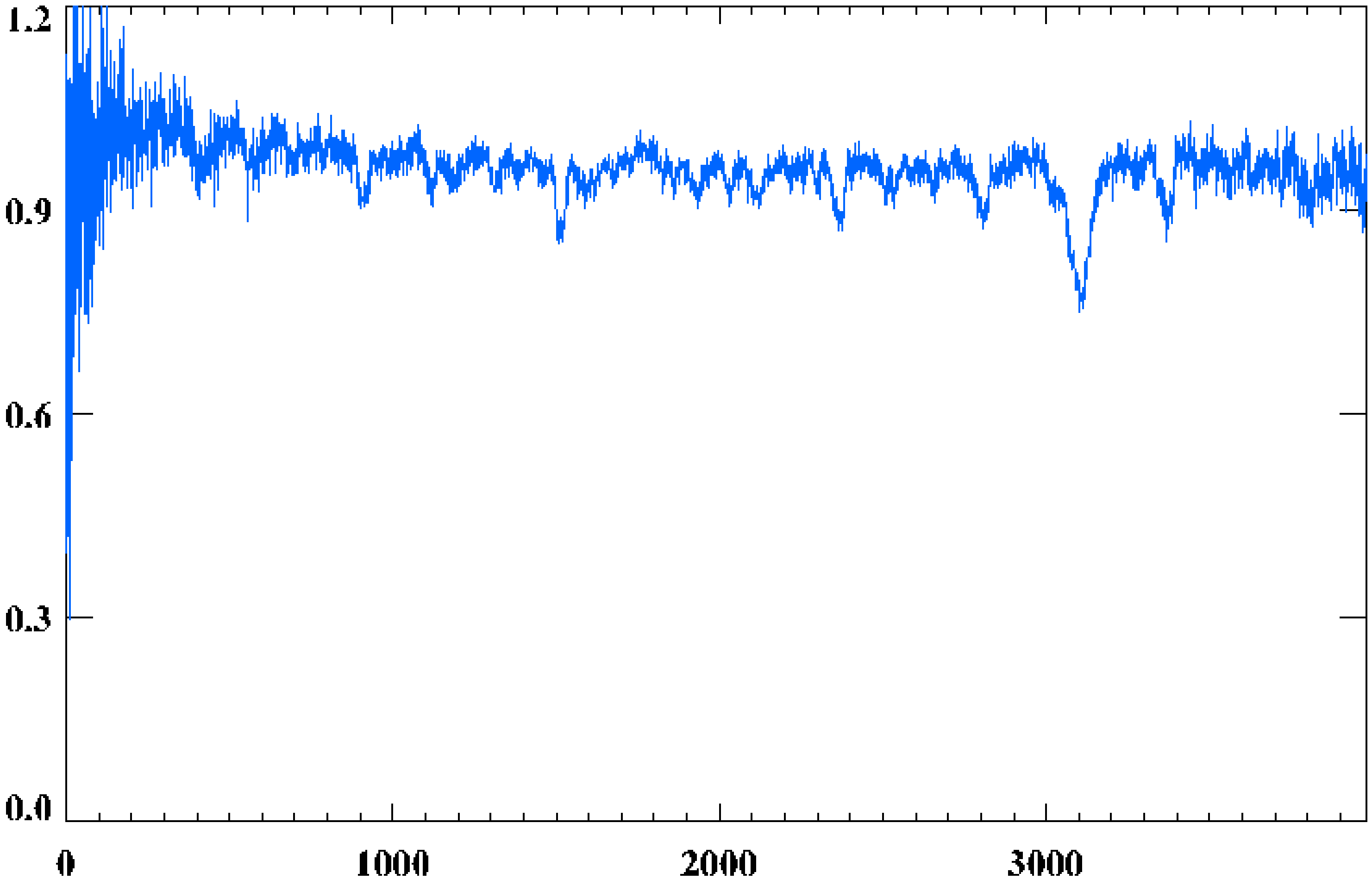
Pixel number

Order number

Continuum fit

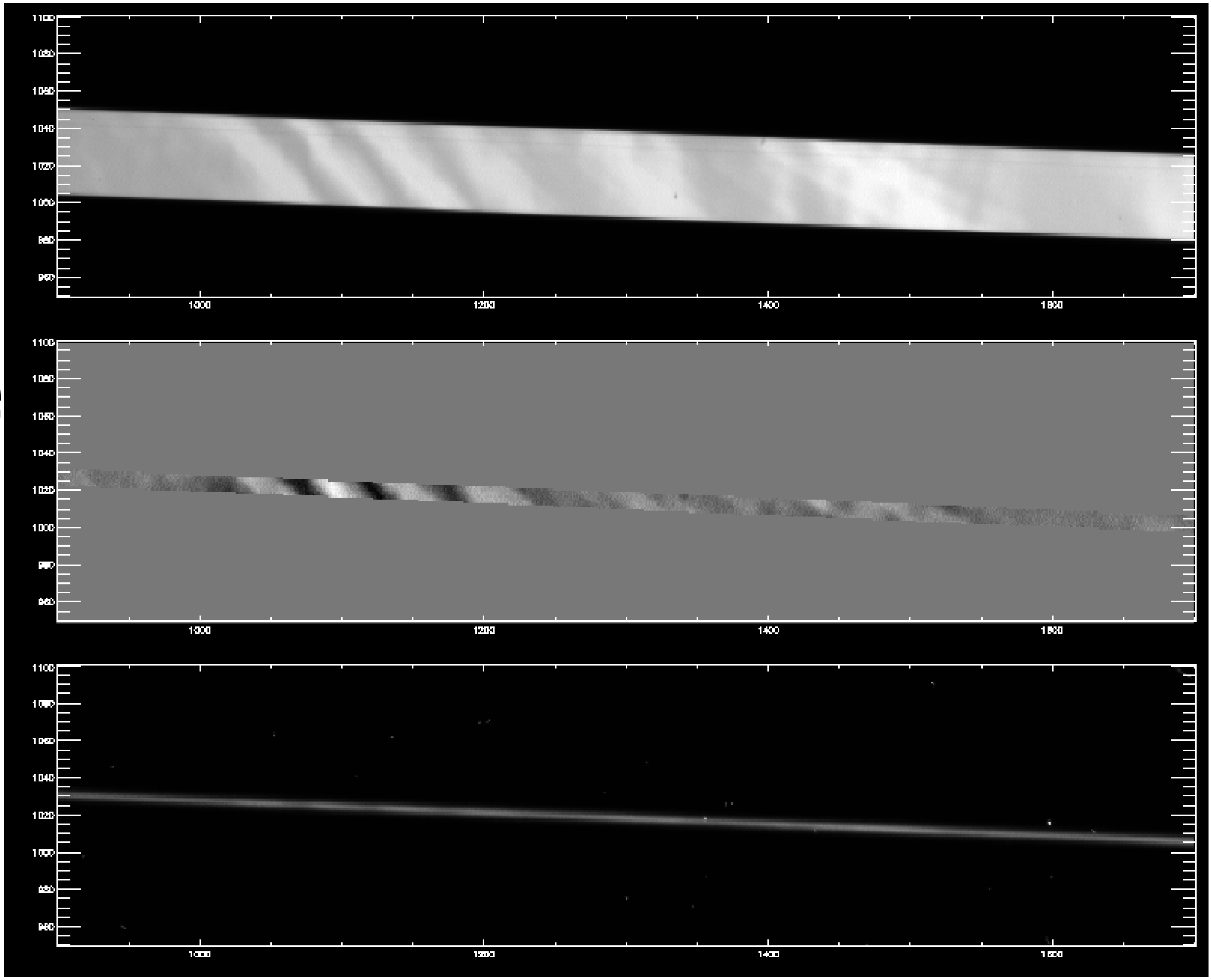


… but it is not perfect

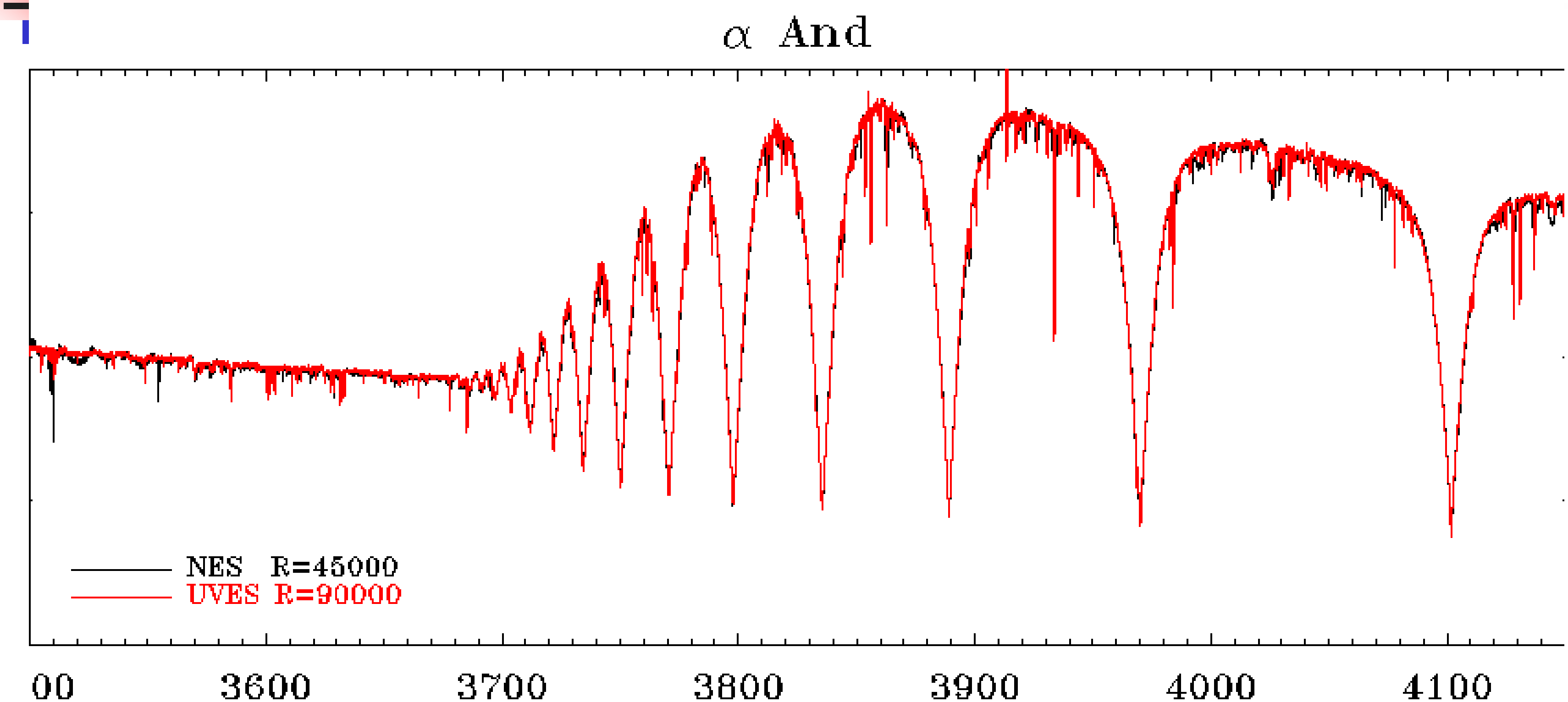


Fringing

Accurate fringing removal requires identical slit illumination by the FF as it is illuminated by the science target



Comparison with other algorithms



UVES POP Library, Bagnulo et al. 2003, Messenger 114, 10

FIES data reduction

- Attend a tutorial on using REDUCE
- Setup your own reduction script to create:
  - Master bias
  - Master flat
  - Normalized flat

  and to extract:
  - ThAr
  - your science spectra + pulsating star spectra
- Create a wavelength solution using *wavecal* and ThAr spectrum
- Fit the continuum using *make_cont*
- Compare spectra in selected wavelength regions