Dispersion issues for Holospec spectrometers at JET

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Motivation

- Kaiser Optical Holospec spectrometers at JET
  - KS5D, KS5E, KS7D, KS7C, . . .
- Short focal-length leads to non-constant dispersion across the image plane (CCD camera)
- Difficulties in determining the dispersion
- Difficulties in analysis within CXSFIT
- Inconsistency between KS5C (Czerny-Turner system) and KS5D measured C VI T_i and v_T

Outline

- The grating equation for Holospec instruments
- Validity of 2^{nd} order polynomial approximation, in principle
- Fitting of Sm lamp calibration data to derive the wavelength calibration and dispersion
- Issues with pulse data: Be, C positions
- Discussion

Theory

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Exploiting a transmission grating spectrometer

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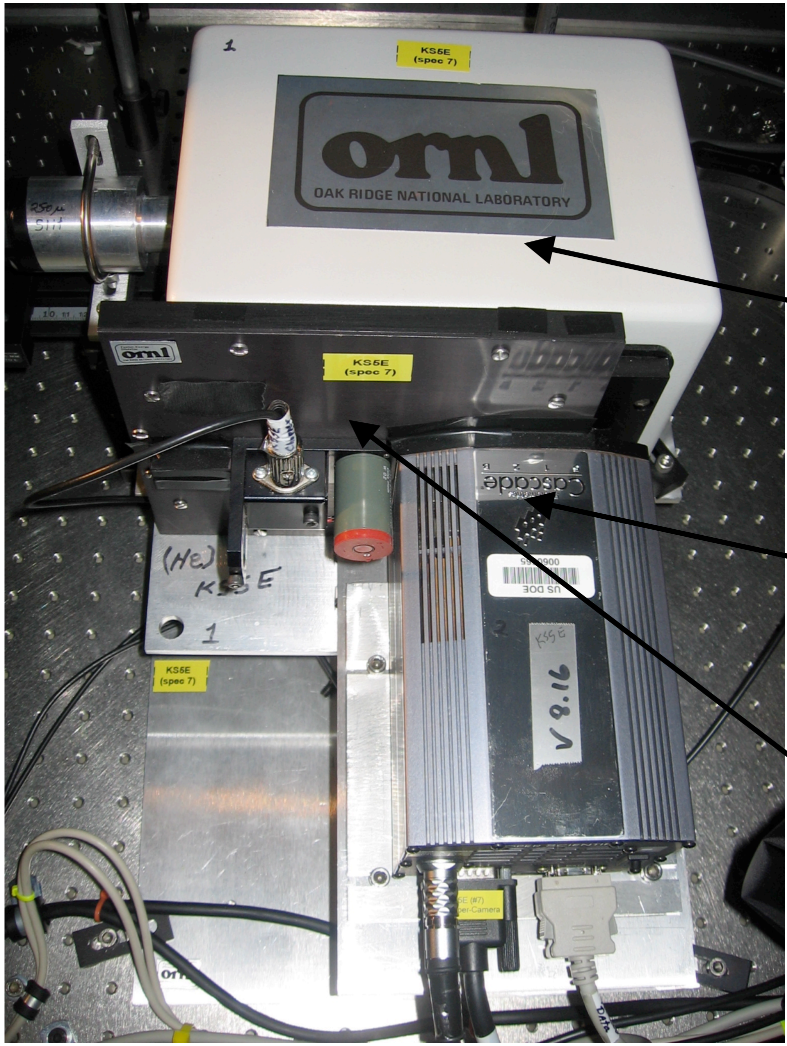
The availability of compact transmission grating spectrometers now allows an attractive and economical alternative to the more familiar Czerny–Turner configuration for many high-temperature plasma applications. Higher throughput is obtained with short focal length refractive optics and stigmatic imaging. Many more spectra can be obtained with a single spectrometer since smaller, more densely packed optical input fibers can be used. Multiple input slits, along with a bandpass filter, can be used to maximize the number of spectra per detector, providing further economy. Curved slits can correct for the strong image curvature of the short focal length optics. Presented here are the governing grating equations for both standard and high-dispersion transmission gratings, defining dispersion, image curvature, and desired slit curvature, that can be used in the design of improved plasma diagnostics. © *2004 American Institute of Physics*. [DOI: 10.1063/1.1787601]

Short focal length spectrometers



- Design pioneered by R.E. Bell at PPPL
  - Multiple curved entrance slits
  - 20 channels/instrument
- Spectrometer
  - Kaiser Optical Holospec f/1.8
  - Transmission gratings for high throughput
- CCD camera
  - Roper Cascade 512B
  - Roper PhotonMax 512
  - Fast framing (5 or 10 ms)
- Rotary chopper
  - Scitech Instruments 300
  - Prevents image smearing during read-out
- PC driven

Holospec Grating Equation

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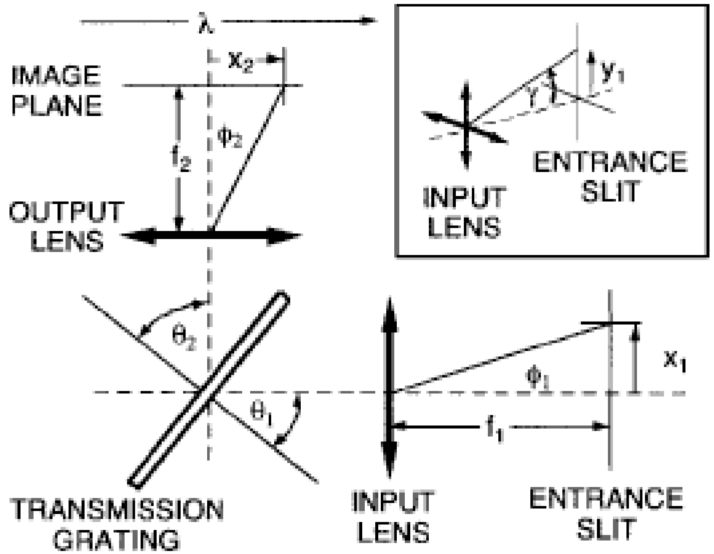


FIG. 1. Schematic of transmission grating spectrometer.

$\lambda = \lambda_0 \cos \gamma[\sin(\theta_1 + \phi_1) + \sin(\theta_2 + \phi_2)]/$ [s

$\lambda = \lambda_0 \cos \gamma[\sin(\theta_1 + \phi_1) + \sin(\theta_2 + \tan^{-1}($x

$$\lambda = A_t[B_t + \sin(C + \tan^{-1}(x_2/D))]$$

$\partial\lambda/\partial x_2 = (\lambda_0 / f_2) \cos \gamma \cos(\theta_2 + \tan^{-1}(x_2/f_2$

$$\partial\lambda/\partial x_2 = (A_t / D) \cos(C + \tan^{-1}(x_2/D)) \cos^2 (\tan^{-1}(x_2/D))$$

Holospec grating equation (cont.)

$\lambda = A_t[B_t + \sin(C + \tan^{-1}(x_2/D))]$

$\partial\lambda/\partial x_2 = (A_t/D) \cos(C + \tan^{-1}(x_2/D)) \cos^2(\tan^{-1}(x_2/D))$

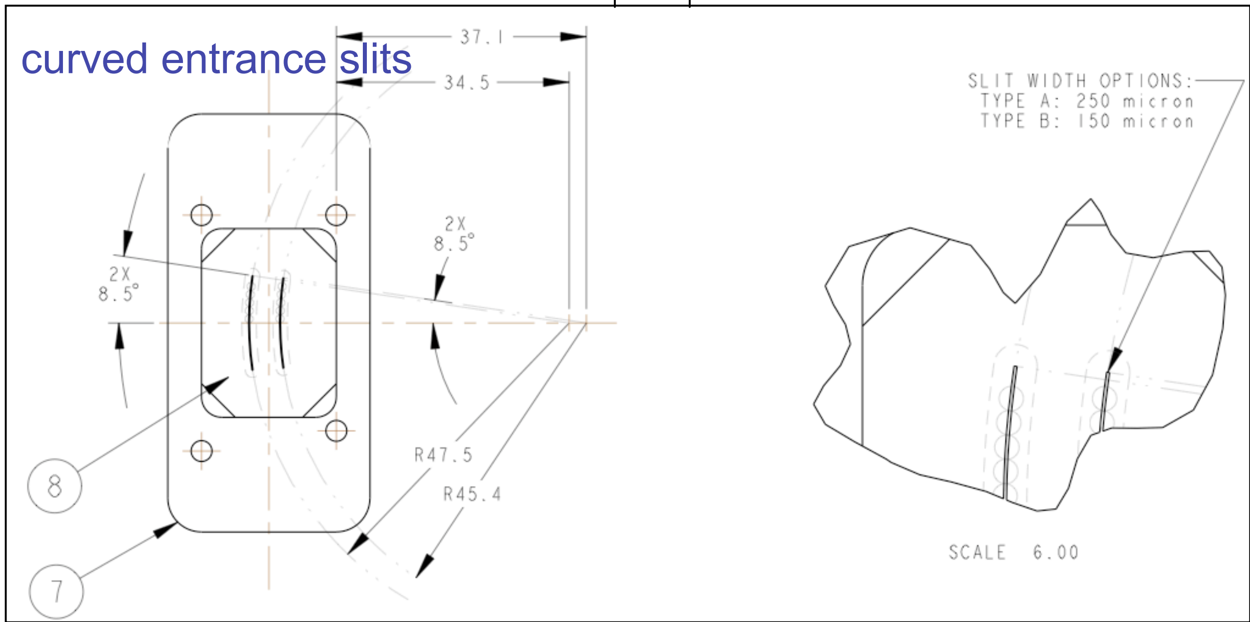
$A_t = \lambda_0 \cos\gamma / [\sin\theta_1 + \sin\theta_2]$ $= (5290\ \text{Å}) \cos\gamma / [\sin 40^\circ + \sin 50^\circ]$ $\sim 3751 \pm 5$ Å

$B_t = \sin(\theta_1 + \phi_1)$ $= \sin(40^\circ + \phi_1)$ $\sim 0.64 \pm 0.02$

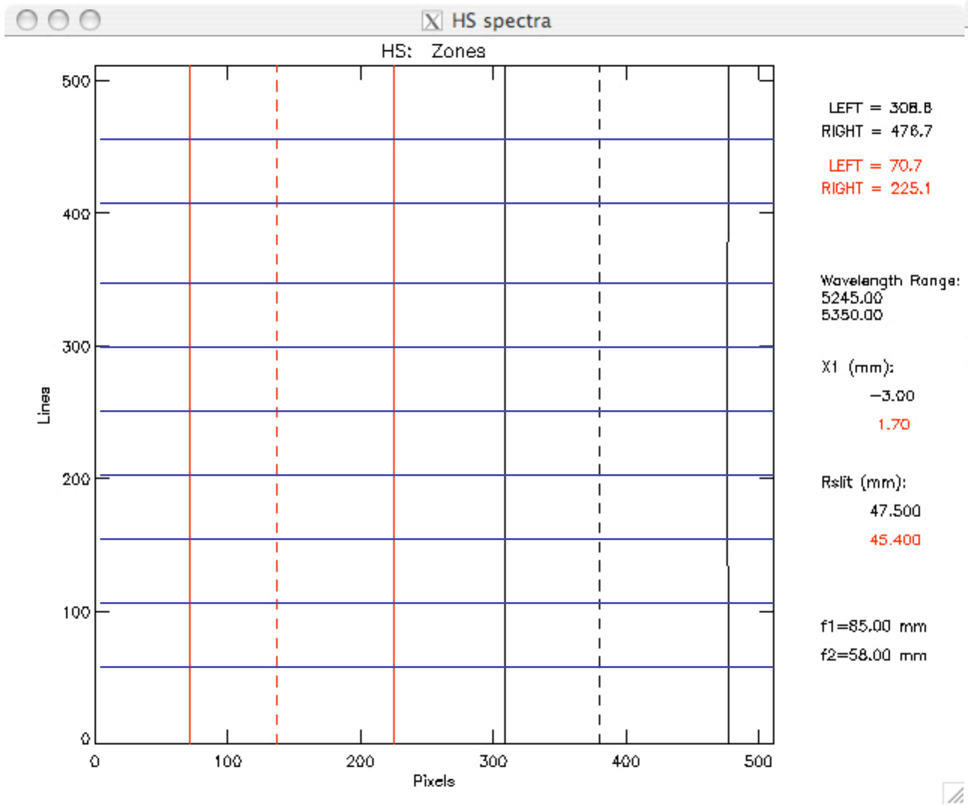
$C = \theta_2$ $= 50^\circ$

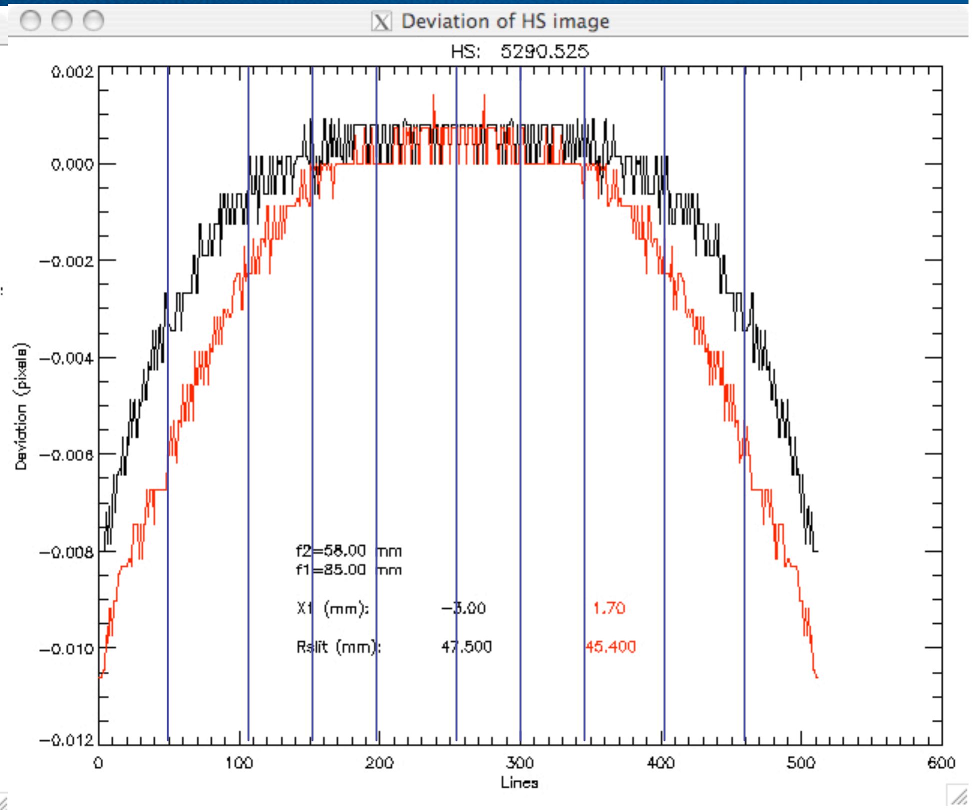
$D = f_2$ $= 58$ mm

nominal values for KS5D



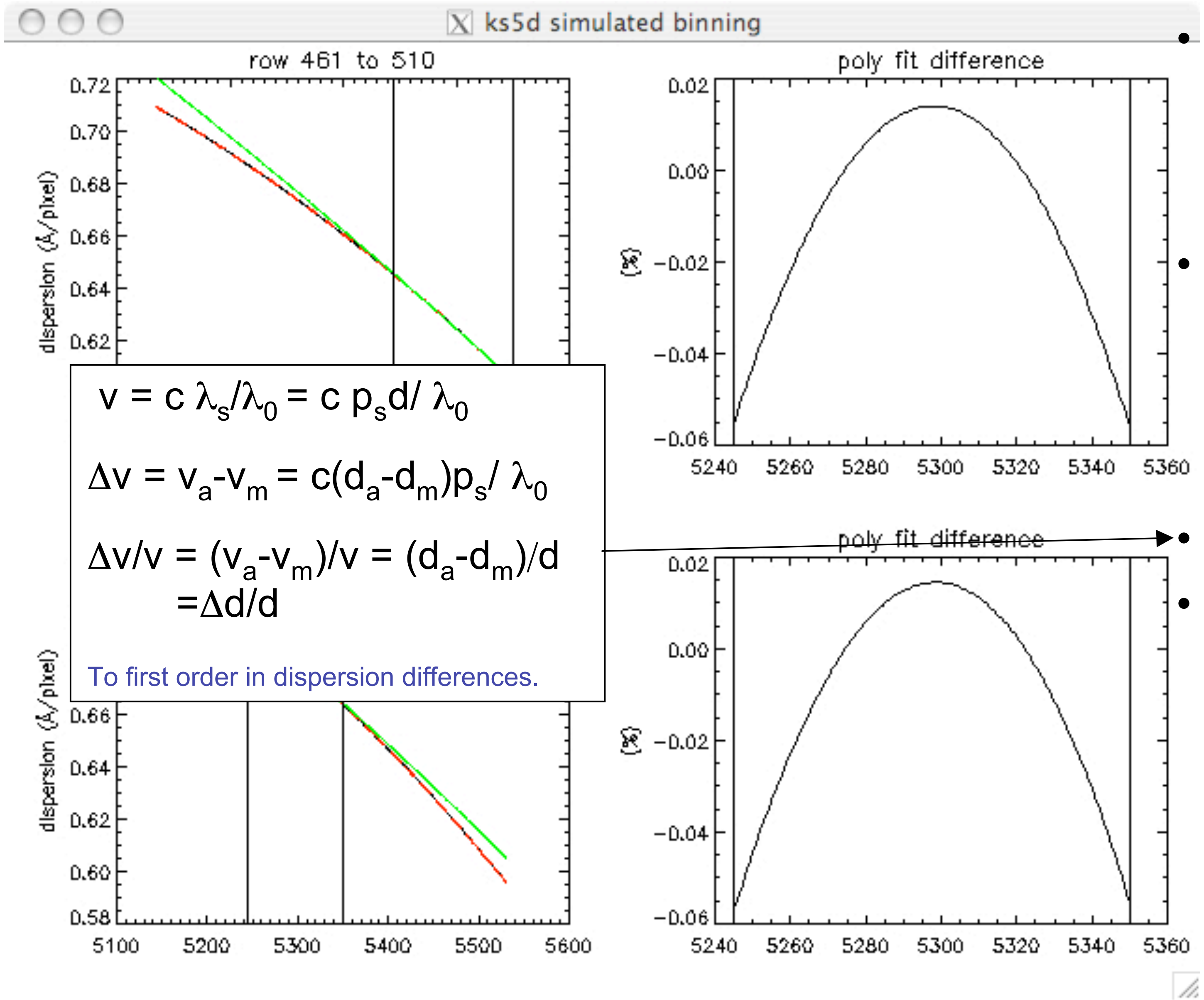
Binning into “tracks”





- The CCD is vertically binned into tracks, corresponding to fibers viewing different radial NBI volumes.
- Curved entrance slits ensure that spectral lines have minimal deviation (horizontally) within a track.

Simulated KS5D dispersion



$v = c\,\lambda_s/\lambda_0 = c\,p_s d/\lambda_0$

$\Delta v = v_a - v_m = c(d_a - d_m)p_s/\lambda_0$

$\Delta v/v = (v_a - v_m)/v = (d_a - d_m)/d$
$= \Delta d/d$

To first order in dispersion differences.

- Calculated λ(p) and d(p) binned over actual KS5D track definitions.
- 2^{nd} order polynomial fit to λ(p) over the range of KS5D filter bandpass.
- $\Delta v/v = \Delta d/d < 0.1\%$
- It is valid for CXSFIT to linearly approximate d(p) within passband.

Calibration sensitivity

Sensitivity to Dispersion:

$v = c\,\lambda_s/\lambda_0 = c\,p_s d/\,\lambda_0$

$\Delta v = v_a - v_m = c(d_a-d_m)p_s/\,\lambda_0$

$\Delta v/v = (v_a-v_m)/v = (d_a-d_m)/d$
$=\Delta d/d$

1% error in dispersion implies 1% error in measured velocity.

Sensitivity to wavelength "offset":

$v = c\,\lambda_s/\lambda_0 = c\,(\lambda-\lambda_0)/\,\lambda_0$

$\Delta v = v_a - v_m = c[(\lambda_a-\lambda_0)-(\lambda_m-\lambda_0)]/\,\lambda_0$
$=c\,(\lambda_a-\lambda_m)\,/\,\lambda_0$

$\Delta v/v = (v_a-v_m)/v = (\lambda_a-\lambda_m)\,/\,(\lambda_m-\lambda_0)$
$= [(\varepsilon_a+\lambda_s+\lambda_0)-(\varepsilon_m+\lambda_s+\lambda_0)]\,/[\,(\varepsilon_m+\lambda_s+\lambda_0)-\lambda_0]$
$= (\varepsilon_a-\varepsilon_m)\,/(\varepsilon_m+\lambda_s)$
$= \varepsilon_m\,/(\varepsilon_m+\lambda_s)$

$\Delta v/v = [\varepsilon_m/\lambda_0]/[v/c+\varepsilon_m/\lambda_0]$

If v_T~300 km/s then v/c~0.001,
1% error in wavelength offset implies ~100% error in measured velocity
0.1% error in wavelength offset implies ~50% error in measured velocity.
0.01% error in wavelength offset implies ~10% error in measured velocity.

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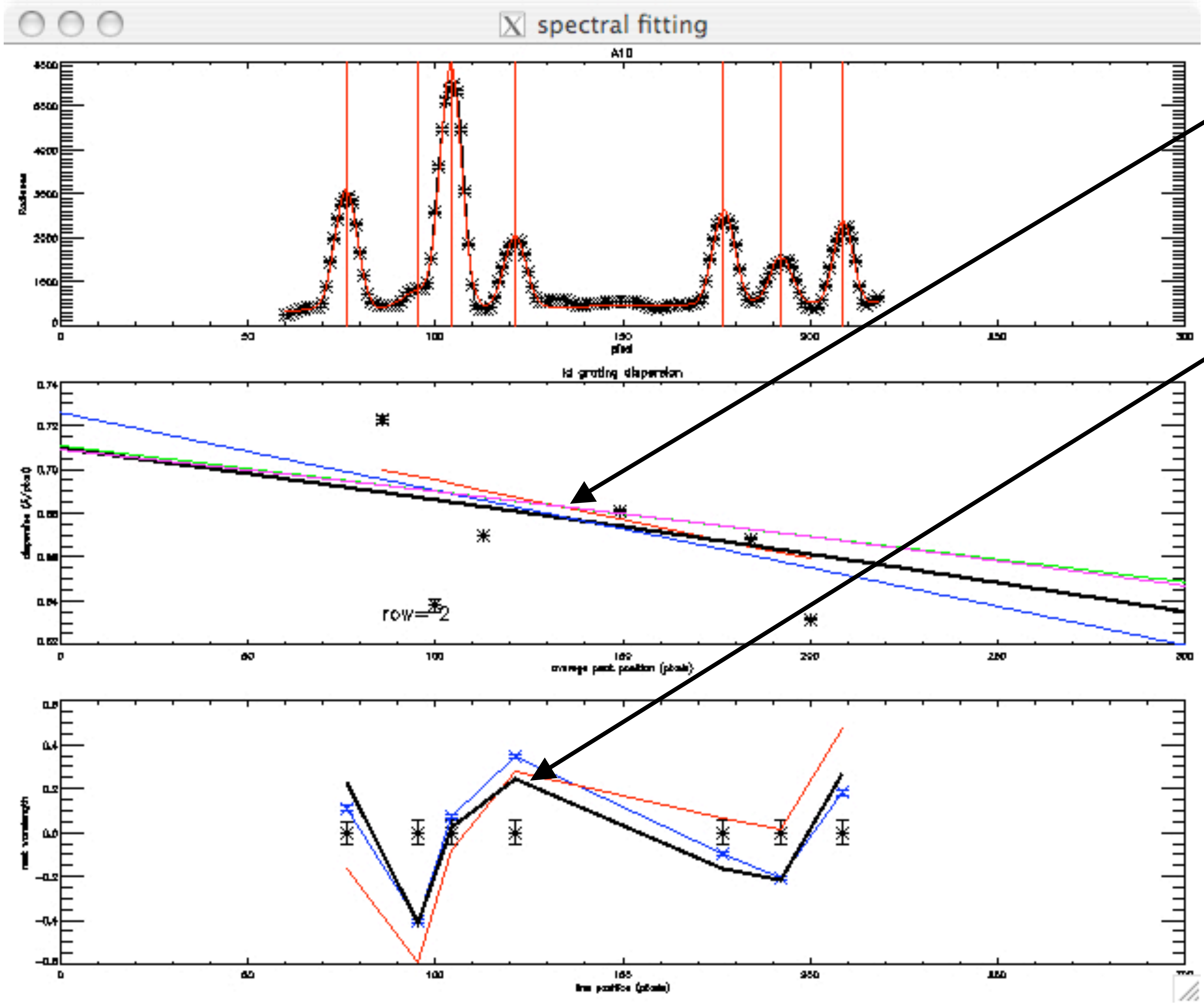
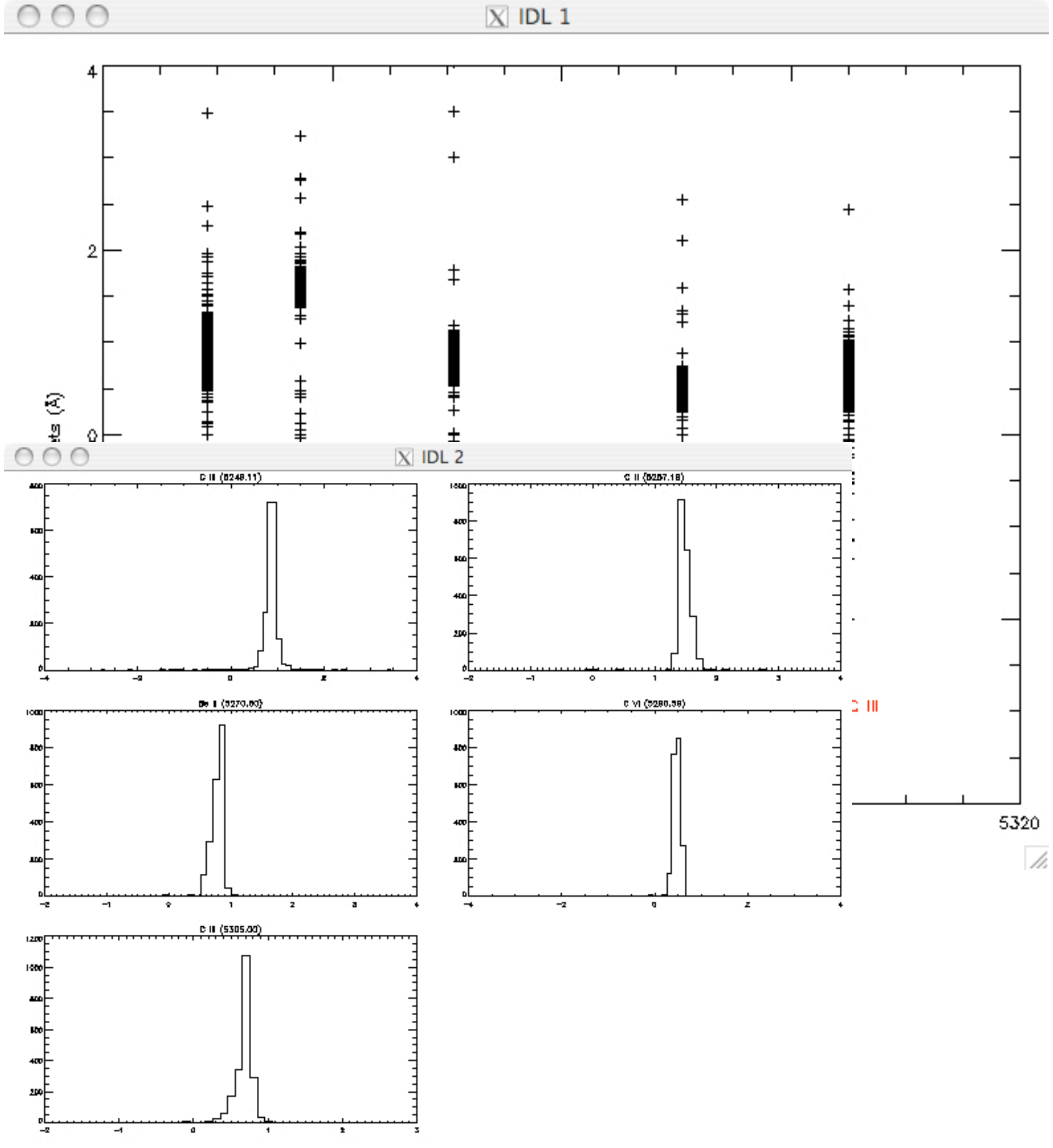
Sm calibration data



- ~1% error in dispersion
  - ~1% error in meas. velocity
- ~0.2 to 0.5 Å offset error
  - ~0.01% error in λ offset
  - ~10% error in meas. velocity
  - Finding line centers to this accuracy implies ~1/4 pixel resolution for KS5D

Pulse data (73916)



- Applying calibration from Sm lamp to JET data shows substantial offsets
  - Non-stationary passive, edge lines?
  - Limit to instrument resolution?
  - Poor calibration?
- Correctible within CXSFIT

Discussion

- How should dispersion for these instruments be determined?
  - Fit to Sm calibration data (good enough?)
  - incorporate “pulse” data, C, Be, etc.?
  - Use “first principles” function or 2nd-order polynomial?