

Measuring EUV doppler shifts and line widths with the *MOSES* slitless spectrograph

Charles C. Kankelborg and J. Lewis Fox
Physics Department
Montana State University
kankel@solar.physics.montana.edu

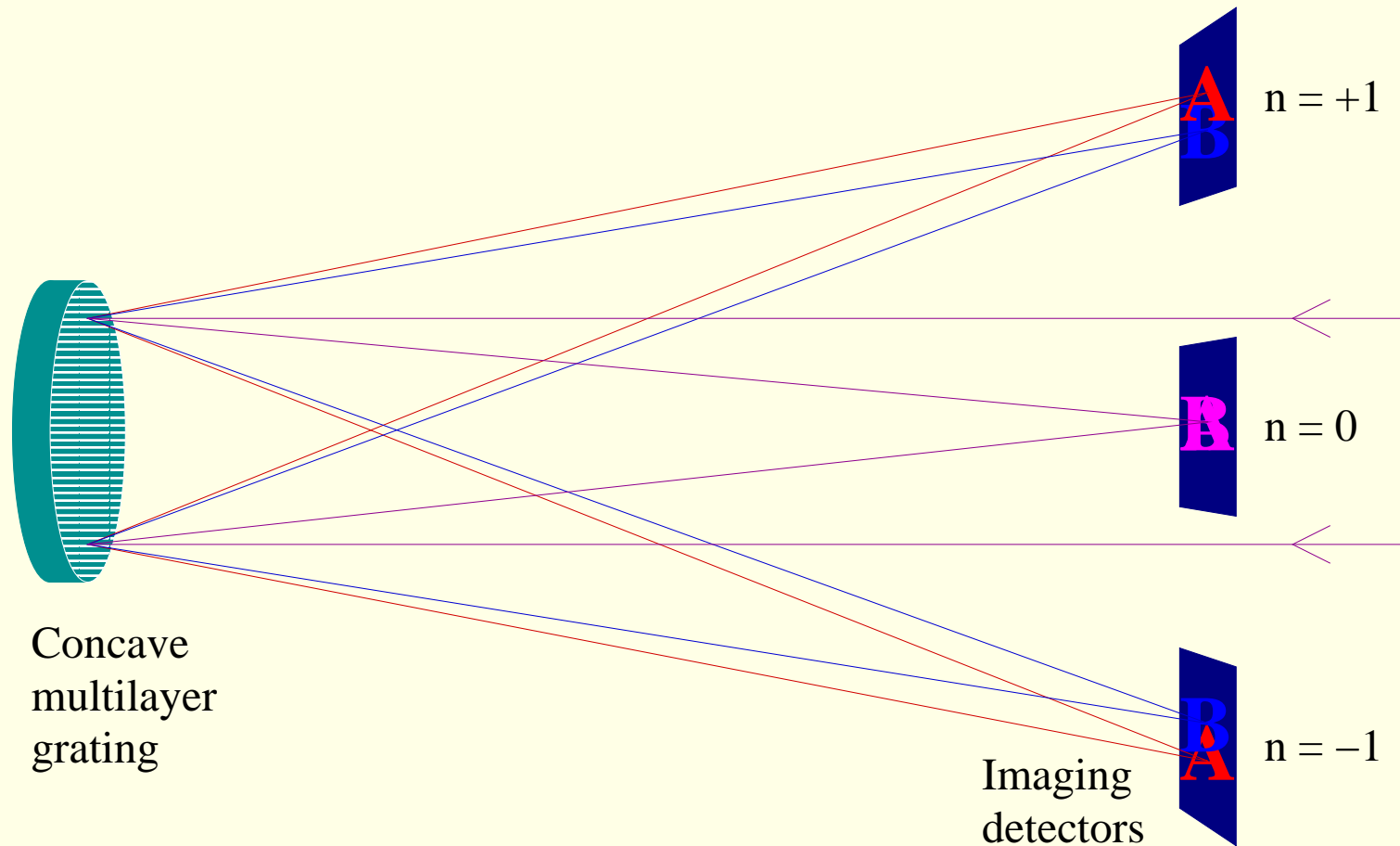
2003 June 16

Abstract

The *Multi-Order Solar EUV Spectrograph (MOSES)* is a sounding rocket instrument designed to observe the solar transition region and corona at 304Å. The *MOSES* optical system is a multilayer coated objective grating, imaging at three spectral orders. We demonstrate fast fourier reconstruction of doppler shift and line width maps from simulated *MOSES* data.

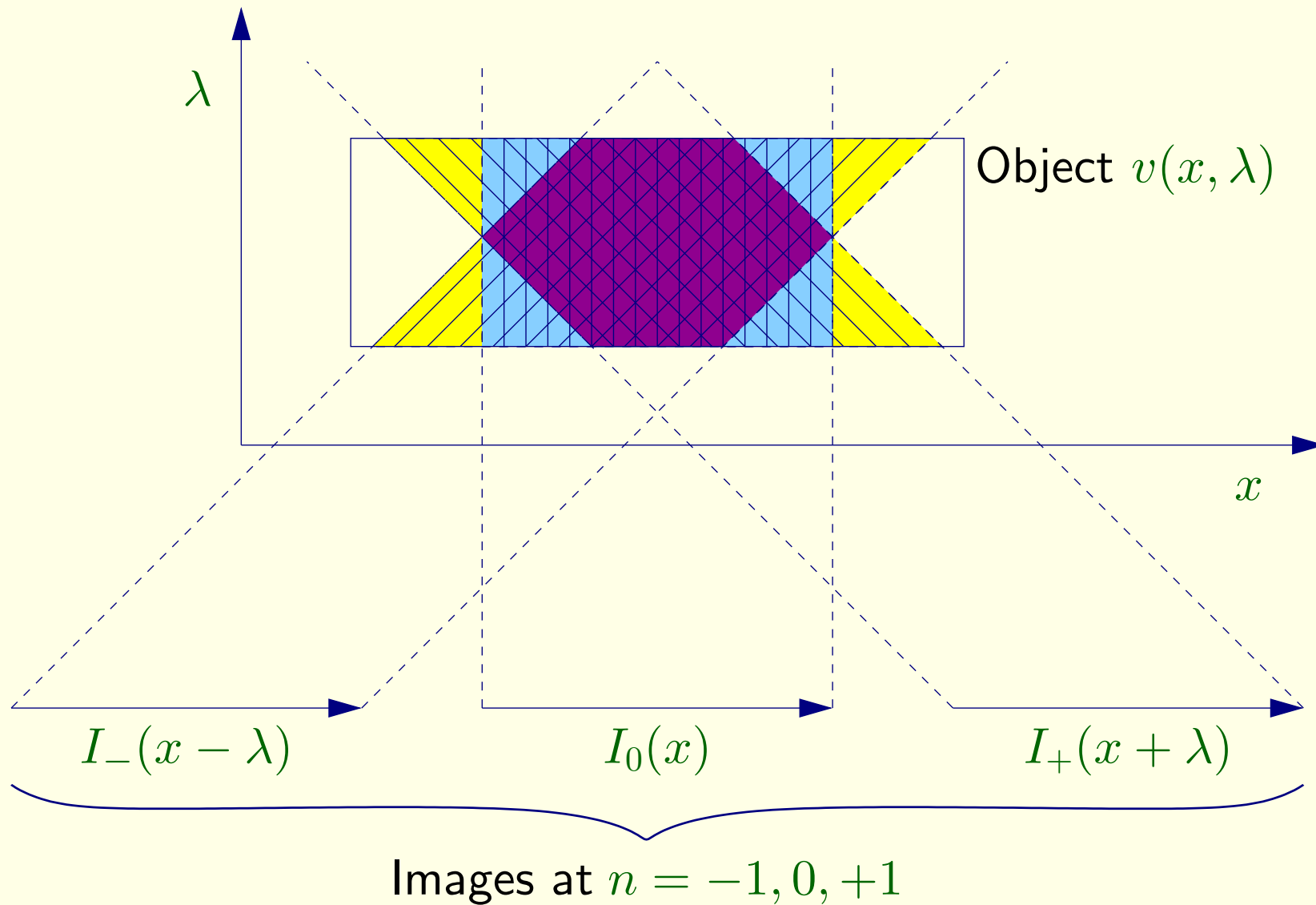
MOSES is sponsored by NASA grant NAG5-10997.

The *MOSES* Concept



Images at 3 orders, $I_+(x + \lambda)$, $I_0(x)$, $I_-(x - \lambda)$, combine simultaneous spectral and spatial information for a large field of view.

Projection through (x, λ) space



Backprojection Algorithm

1. Create a blank image $F(u, v)$ that will hold the FFT of the reconstructed image $I(x, \lambda)$.
2. FFT each of the three projections I_+, I_-, I_0 , and use these to fill in the appropriate slices of $F(u, v)$. We also use the projection along x , $I_\infty(\lambda) = \int_{-\infty}^{\infty} I(x, \lambda) dx$.¹
3. Apply the inverse transform to obtain an initial guess $I(x, \lambda)$.

Problem: negative counts in the backprojected image.

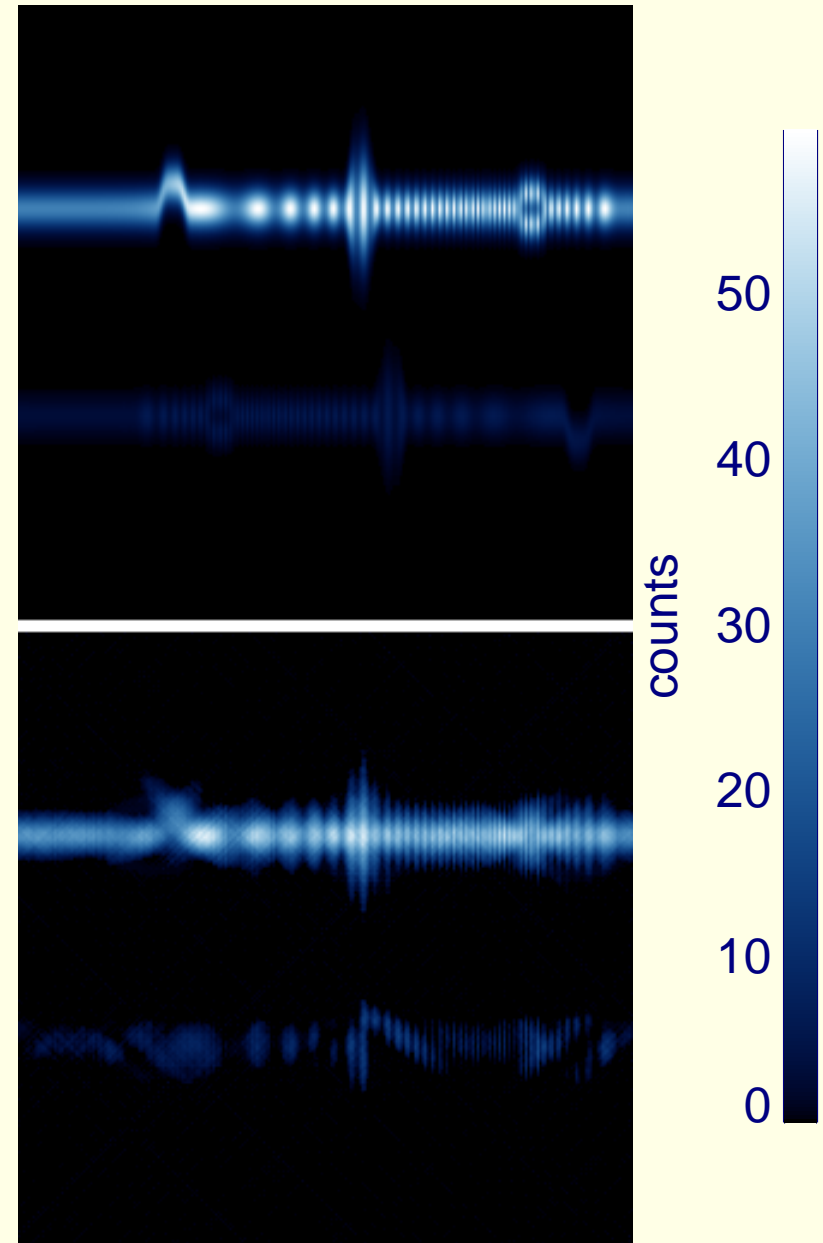
¹ I_∞ can be described by just a few parameters. For example, we can infer the line center position by cross-correlating I_+ and I_0

Non-negativity (iterative approach)

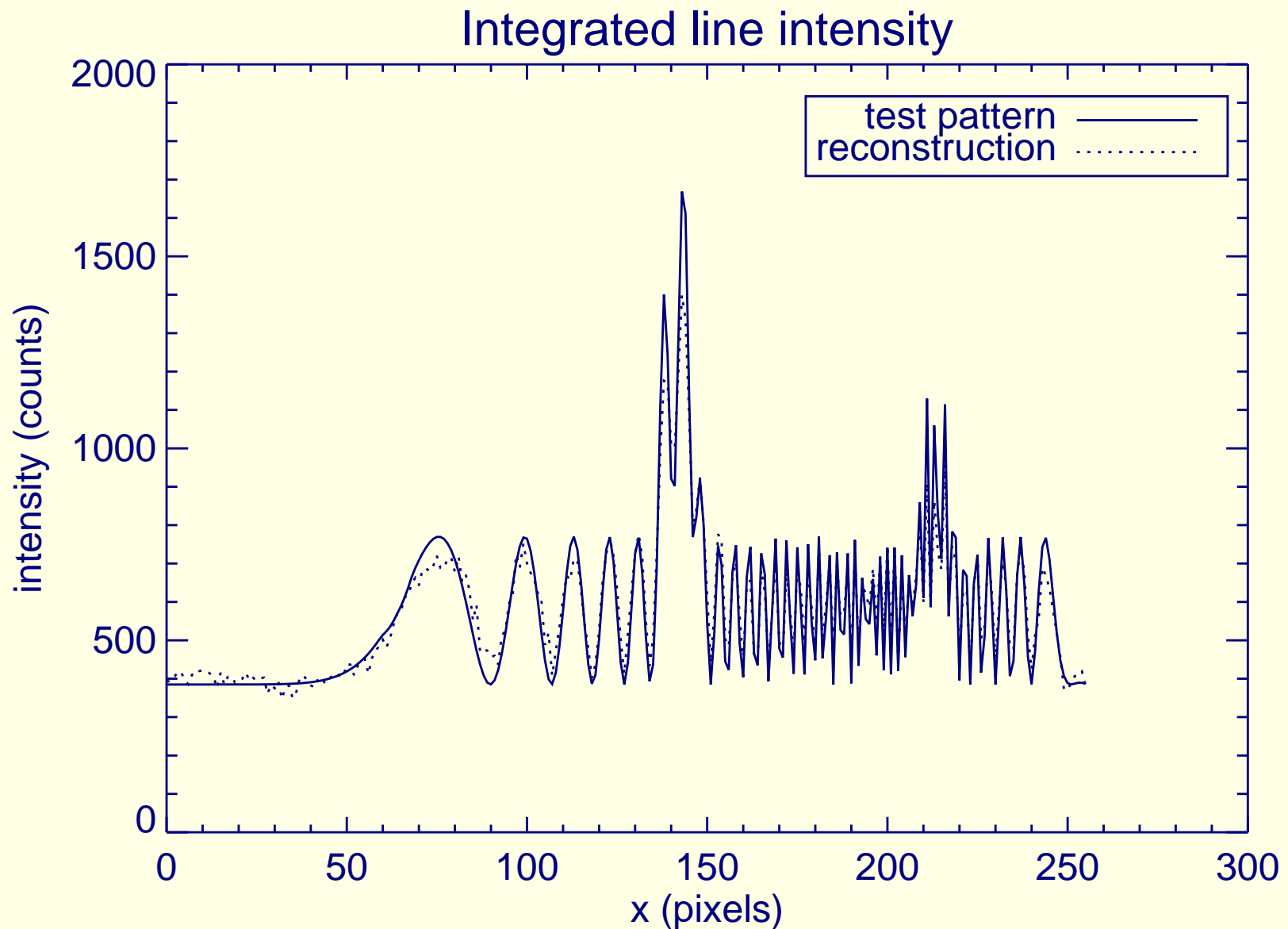
1. Zero all negative elements of the backprojection.
2. Fourier transform the result, use it to fill the wedges of $F(u, v)$ that are not constrained by the data.
3. Inverse Fourier transform to obtain an improved backprojection.
4. Repeat until the sum of the negative counts in the backprojection is small compared to the total uncertainty in image counts.
5. Zero all negative pixels in the backprojection.

Reconstruction of an artificial test pattern

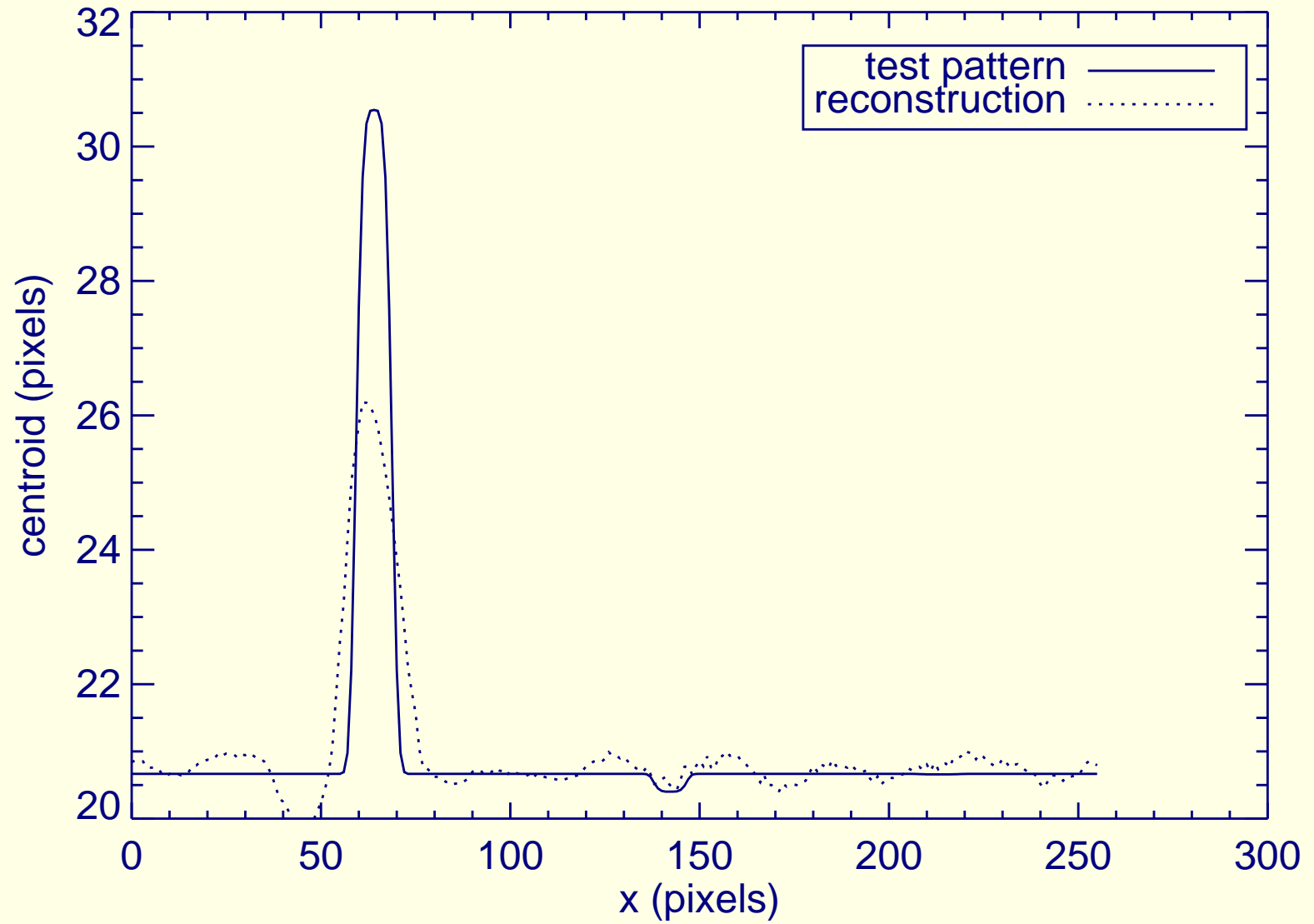
A hypothetical spectrum $I(x, \lambda)$ (top) was projected to form images at three orders (not shown). Backprojection (bottom) from noised images recovers the strong line. Plots below show initial and reconstructed characteristics of the strong spectral line.

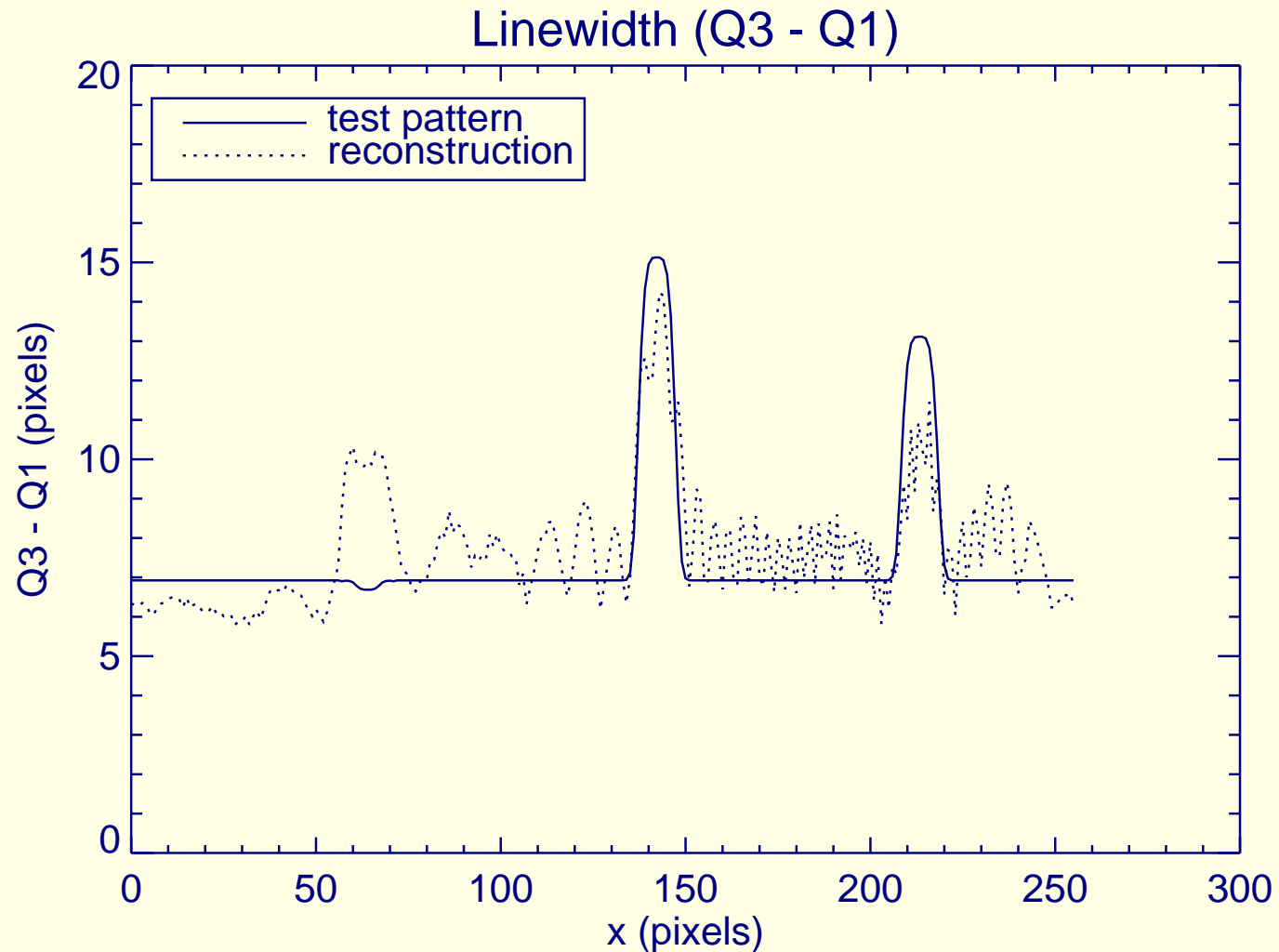


Intensity, line center and line width



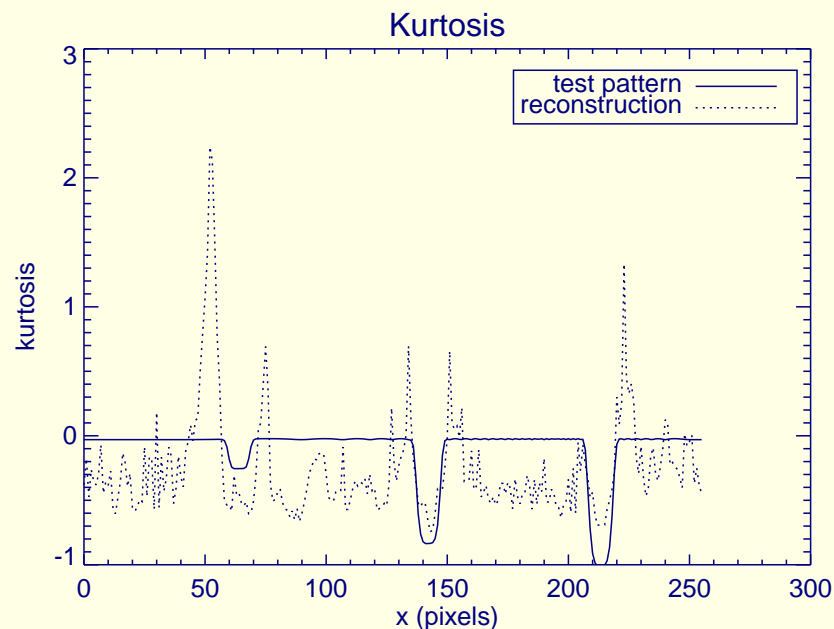
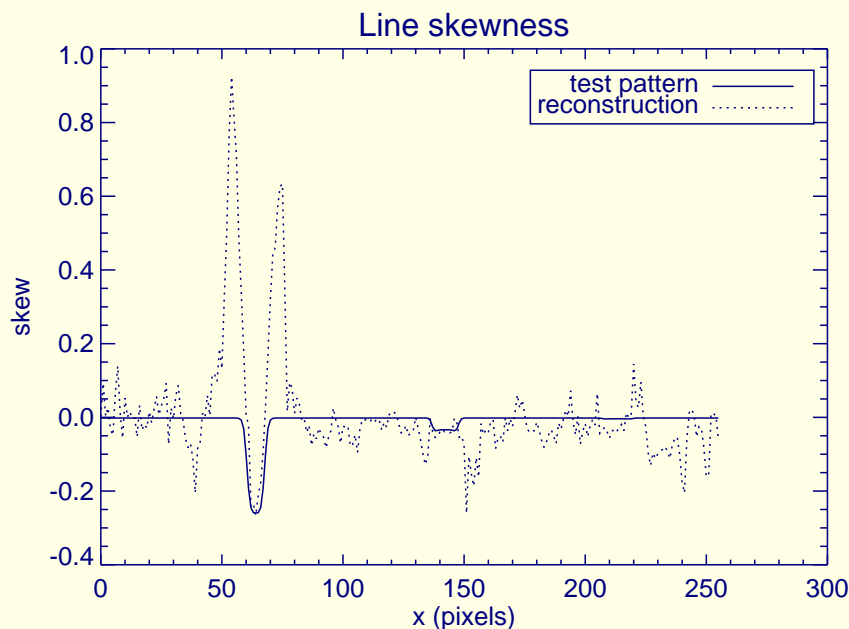
Line Centroid





Here we use the difference between the first and third quartiles of the spectrum, which has lower noise than the second moment.

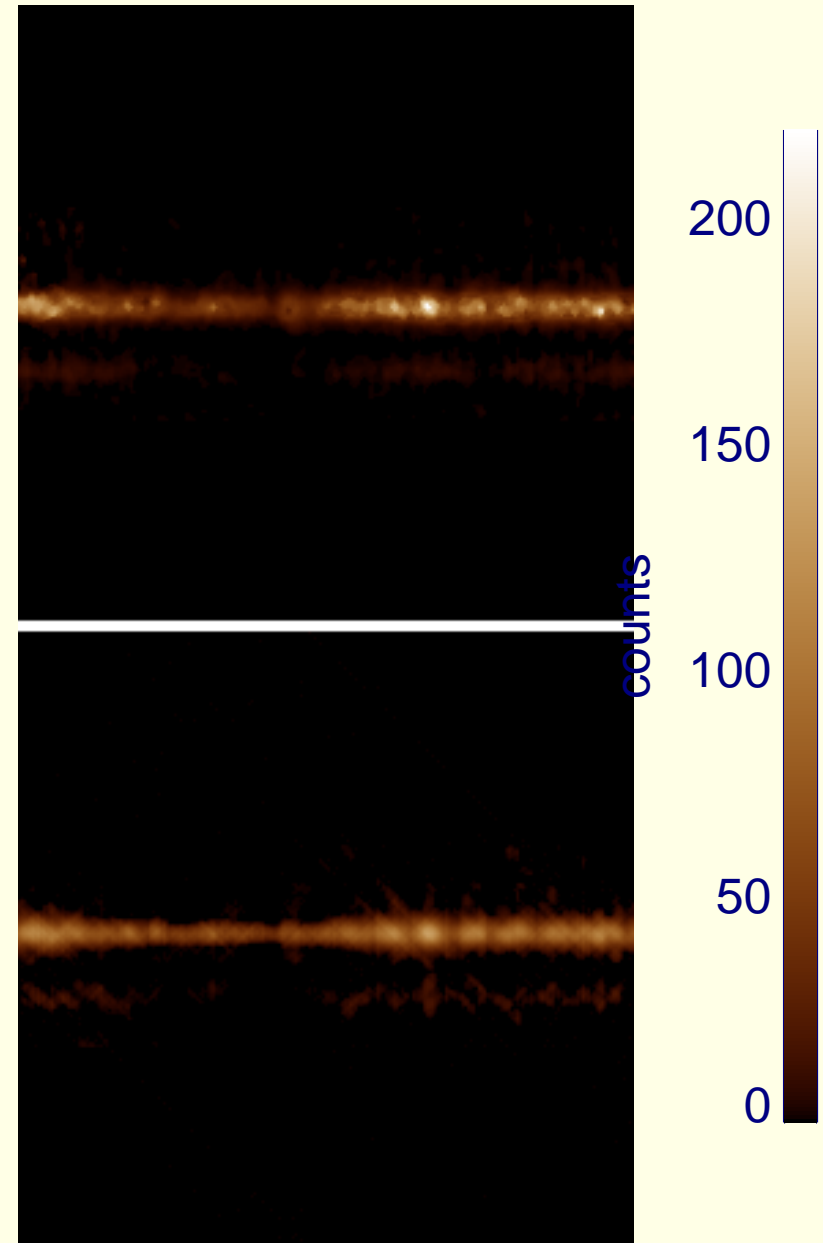
Higher moments



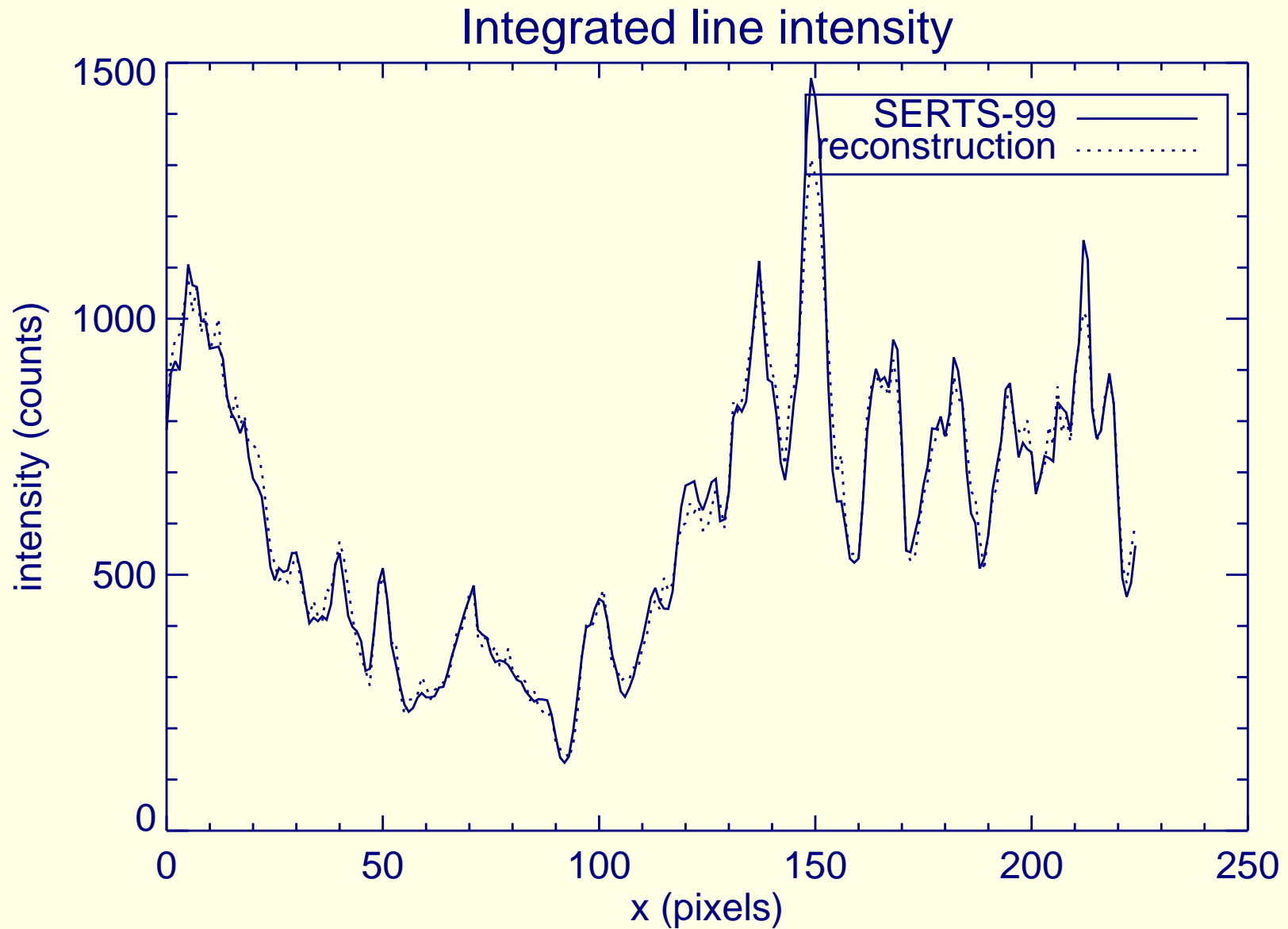
The backprojected spectrum shows large skew and kurtosis exactly where artifacts occur in the lower moments of the line profile. The instrumental nullspace in fact connects the lower and higher moments.

Reconstruction of a *SERTS-99* spectrum

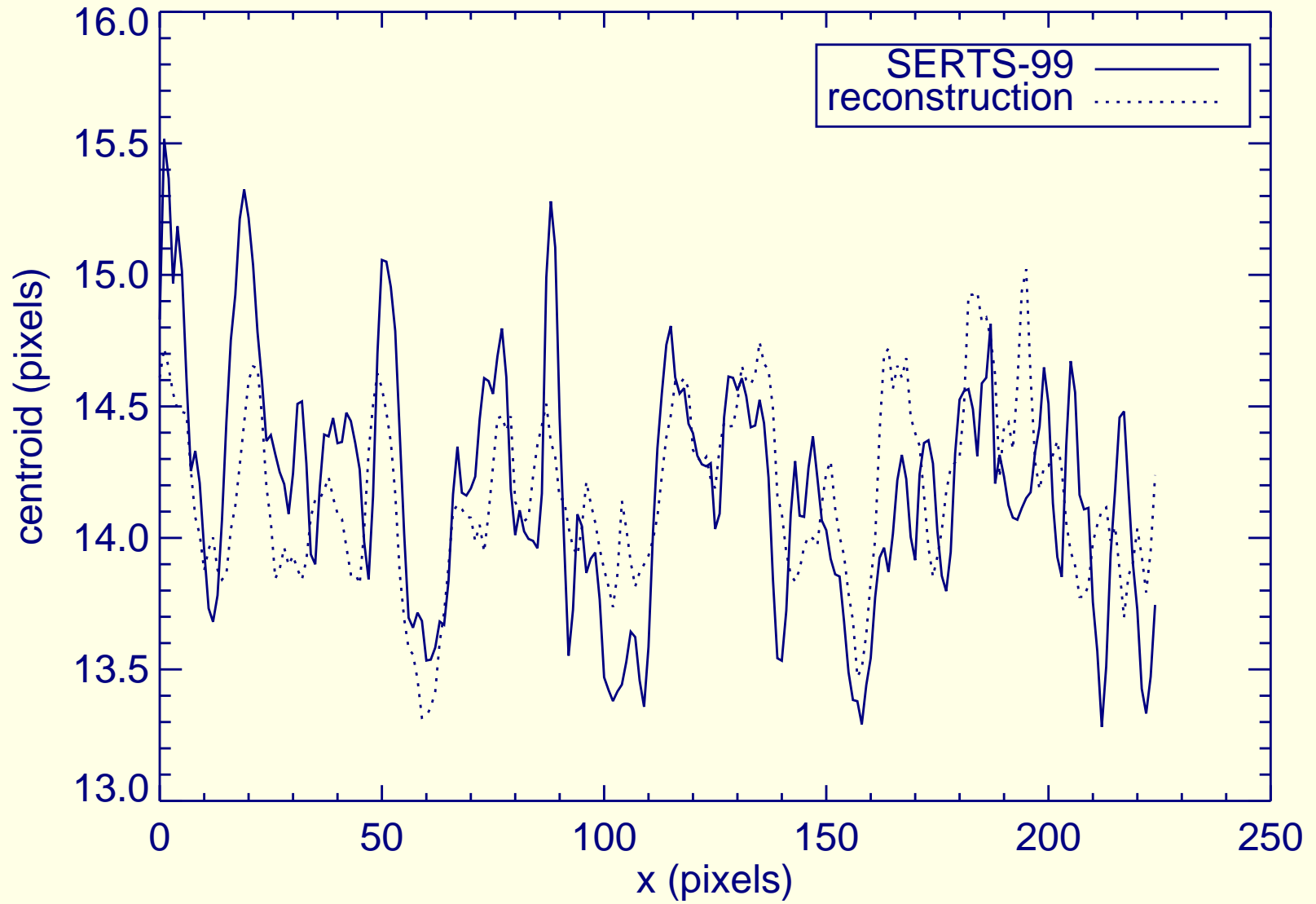
This example uses *SERTS* data (top) from the actual spectral range of the *MOSES* instrument. The lines are He II λ 303.8 Å, and Si XI λ 303.3 Å. Extracted line profile information is below.

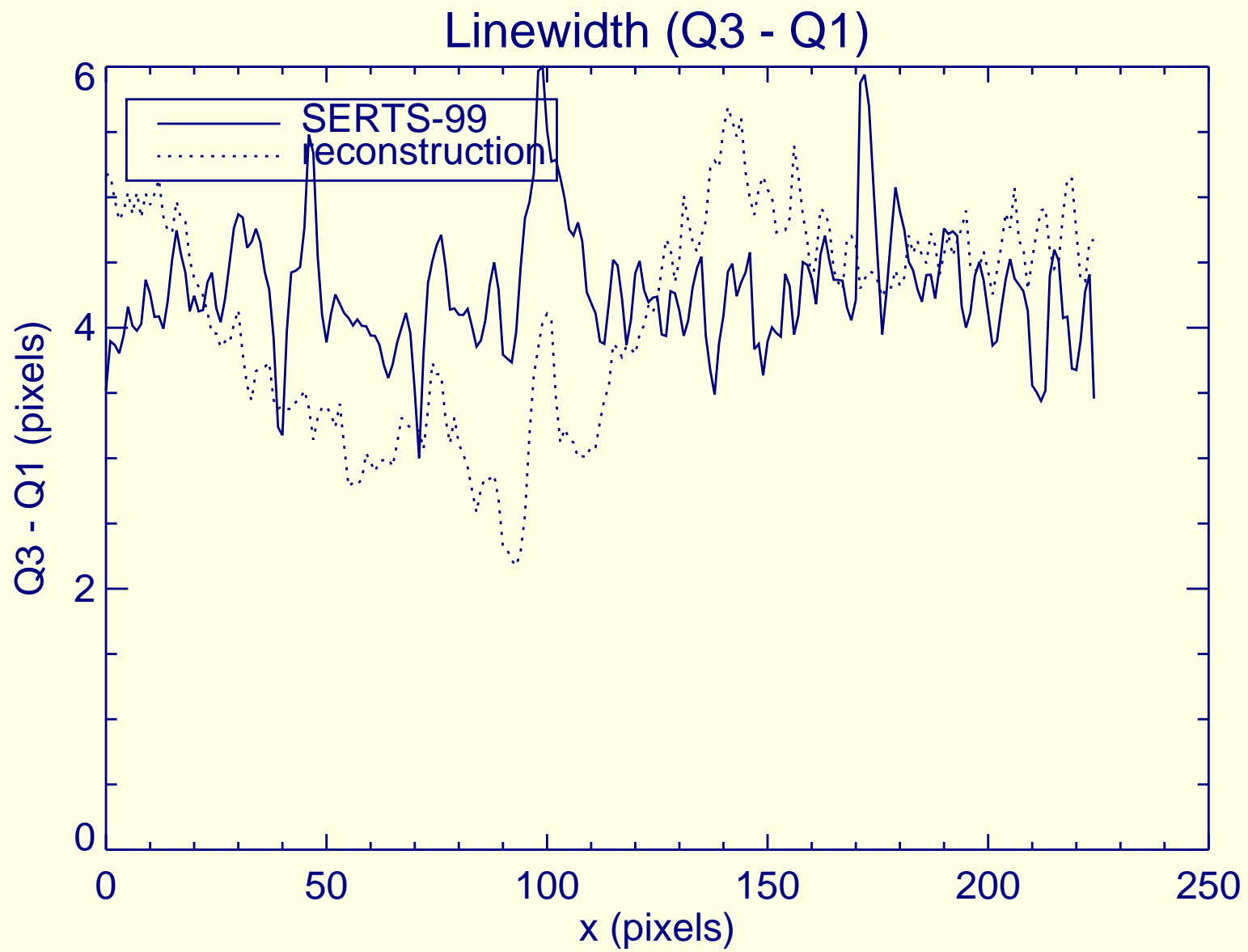


Intensity, line center and line width



Line Centroid





Discussion

The backprojection algorithm recovers doppler shifts with sub-pixel sensitivity. Line width is measured, but with lower sensitivity.

Noise in the images is not amplified by reconstruction (this is a well-known property of tomographic backprojection).

The presence of a second, weaker spectral line acts as a noise source but does not otherwise hamper reconstruction of the strong line. Backprojection fails to recover the weaker line.

Large doppler features bleed spatially and cause artifacts in first and higher moments of the line profile nearby.

Prospects for further work

Several shortcomings of the Fourier backprojection method may be addressed by better algorithms:

- Backprojection fits the data (including the noise) exactly. A better reconstruction would arrive at reduced $\chi^2 \sim 1$.
- Artifacts in doppler shift and line width are often accompanied by skew and kurtosis of the line profile. Since the instrument is insensitive to these higher moments, constraining their amplitude should improve the fidelity of the reconstructed spectrum.

Work is ongoing with several more sophisticated inversion algorithms.