Princeton Instruments

TECHNICAL NOTE

Better Imaging with a Schmidt-Czerny-Turner Spectrograph

Abstract
For years, images have been measured using Czerny-Turner (CT) design dispersive spectrographs. Optical aberrations inherent in the CT design give images that are blurred and have poor spatial resolution. The aberrations grow larger towards the edges of the focal plane, causing some researchers to abandon these regions of their sensors. A new dispersive spectrograph using a Schmidt-Czerny-Turner (SCT) design greatly reduces optical aberrations, giving sharp images with excellent spatial resolution across the entire focal plane and enabling researchers to use the entire CCD sensor to take images.

The Czerny-Turner Spectrograph
For decades, scientists have measured images and spectra using Czerny-Turner (CT) spectrographs. The imaging applications of this spectrograph include looking at multiple optical fibers, combustion processes, plasmas, and living cells. A schematic diagram of a CT spectrograph is seen in Figure 1.

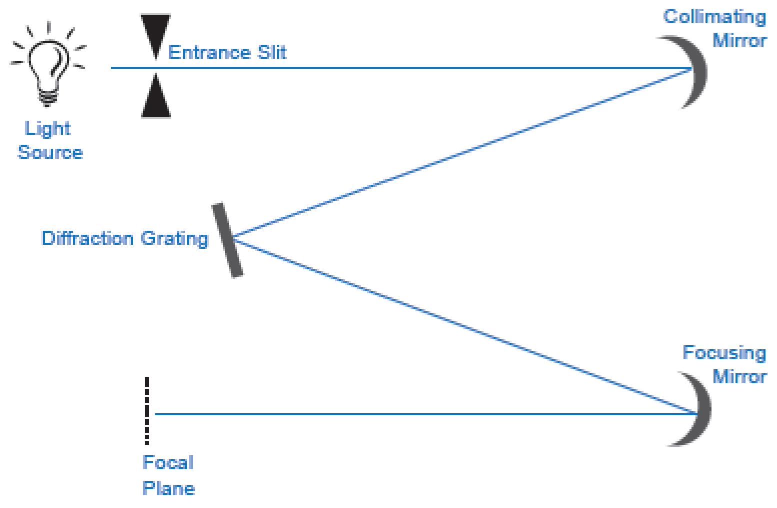

Figure 1.
A schematic diagram of the traditional Czerny-Turner spectrograph (not to scale).

In a CT spectrograph, light passes through an entrance slit, reflects off a collimating mirror, is dispersed by a diffraction grating, and is then brought to a focus by a focusing mirror at the focal plane.

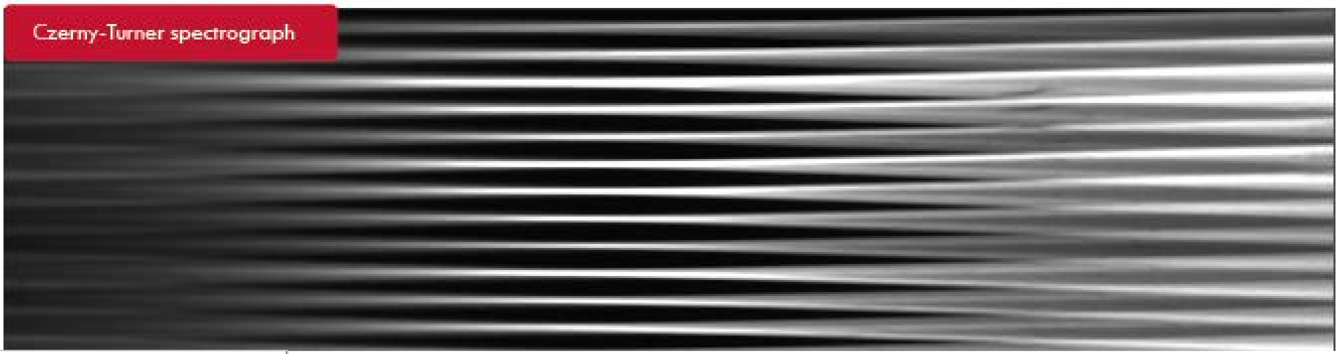

Figure 2.

A white light source imaged on the focal plane of a CT spectrograph through a bundle of 14 optical fibers (100 micron optical fibers, 1200 g/mm grating, first order, and back-illuminated CCD).

The optical aberration called field astigmatism occurs when lenses and mirrors are used to focus light off axis, which is the case for the CT spectrograph. Field astigmatism causes vertical and horizontal distortion of images as seen in Figure 2.

In the center of Figure 2, note how the optical channels are thin, straight, and spatially well resolved. However, towards the left and right edges of the focal plane, the channels are broadened, distorted, and overlap because of field astigmatism, giving what is sometimes called the “bow tie” effect. At the very edges of the sensor, the spatial resolution is poor so there is significant crosstalk between the channels (i.e., photons from different optical fibers strike the same pixels on the CCD). The optical aberration called coma occurs when mirrors are used to image a source off axis. The distortion causes a “tail” to appear on images, similar to that on a comet.

The net effect of the optical aberrations present in a CT spectrograph is seen in Figure 3.

Note in Figure 3 that the optical fibers are well imaged in the center of the focal plane, but that along the top, bottom, left, and right edges of the sensor the images are distorted due to optical aberrations. This is why some researchers avoid using the edges of their CCD sensors. The net effect of these optical aberrations is a degradation of image crispness and a loss of spatial resolution. This makes it more difficult, for example, to follow a particle during a combustion process or visualize a fluorescing organelle inside a cell.

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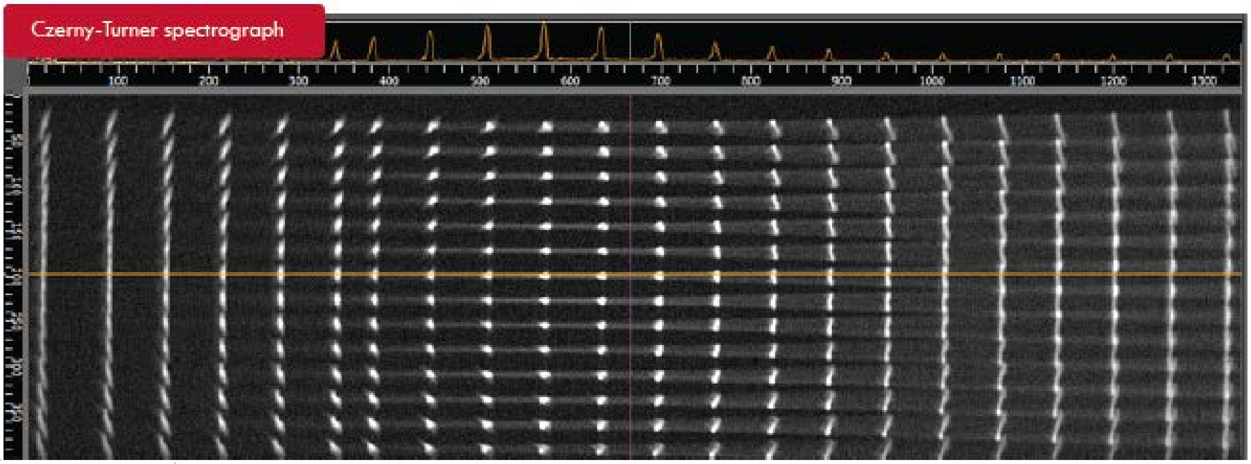

Figure 3.

An image of a stack of 14 optical fibers stepped across a focal plane as measured by a Czerny-Turner spectrograph. Note the smearing of the image at the top, bottom, left, and right of the sensor caused by optical aberrations. (100 micron diameter core fibers, 435 nm source, 1200 g/mm grating, back-illuminated CCD, zero order.)

The Schmidt-Czerny-Turner Spectrograph

The new Schmidt-Czerny-Turner (SCT) spectrograph from Princeton Instruments, the IsoPlane® SCT 320, has a unique design that eliminates field astigmatism and reduces coma. The IsoPlane is shown below in Figure 4.

Figure 4.

The Princeton Instruments IsoPlane SCT 320 Schmidt-Czerny-Turner spectrograph shown with a PIXIS 400 CCD camera.

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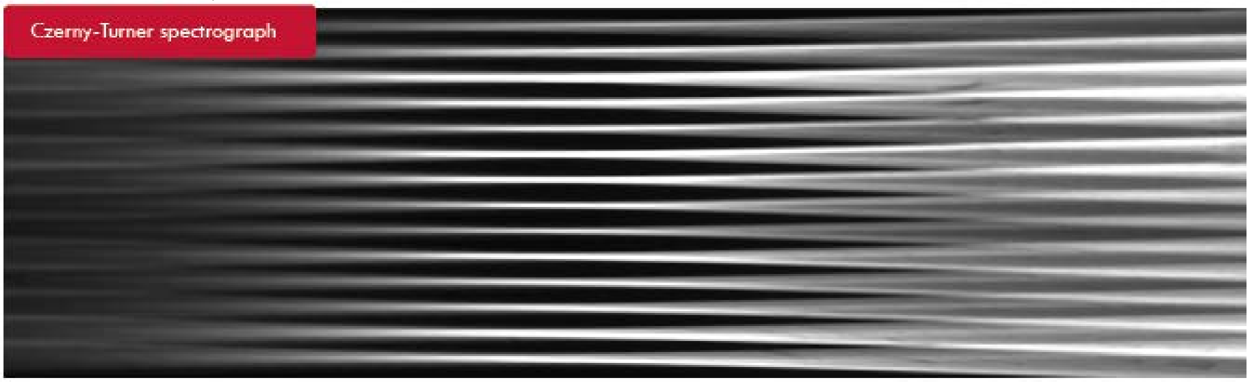
The IsoPlane has a 320 mm focal length and a three position on axis grating turret. Camera focus is optimized using a micrometer attached to the focusing mirror. By calculating the magnitudes of the optical aberrations present in the Czerny-Turner design a spectrograph can be built to compensate for them, which lead to the development of the IsoPlane. The IsoPlane has zero astigmatism at all wavelengths across the entire focal plane and has greatly reduced levels of coma, giving images that are sharp and well focused as seen in Figure 5.



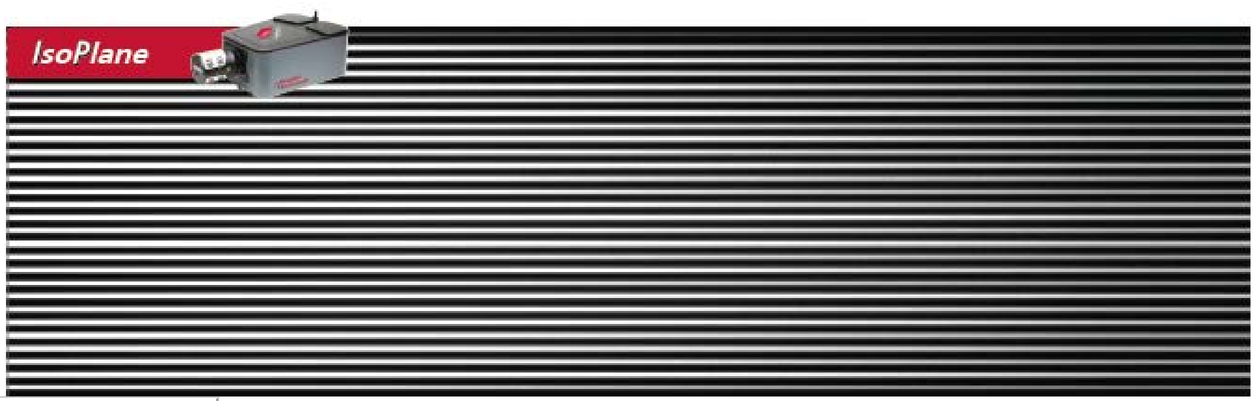


Figure 5.
Top: Same image as Figure 2. Bottom: A white light source imaged on the focal plane of an SCT spectrograph through a bundle of 28 optical fibers (200 micron optical fibers, 1200 g/mm grating, first order, and back-illuminated CCD).

Improved Imaging with the IsoPlane

The IsoPlane has zero field astigmatism at all wavelengths and at all points across the focal plane. The resulting improved image quality is seen in Figure 5.

The top of Figure 5 is the same image shown in Figure 2. Again, optical aberrations destroy spatial resolution causing the optical channels to overlap and create significant crosstalk, particularly at the focal plane edges. The bottom of Figure 5 shows 28 optical channels measured by the IsoPlane. The image is crisp and clear at all points on the focal plane. There is little crosstalk between the channels thanks to the reduction in optical aberrations. Figure 5 shows that an IsoPlane can easily image 28 channels while a CT spectrograph struggles with 14.

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Another example of the imaging power of the IsoPlane is seen in Figure 6.

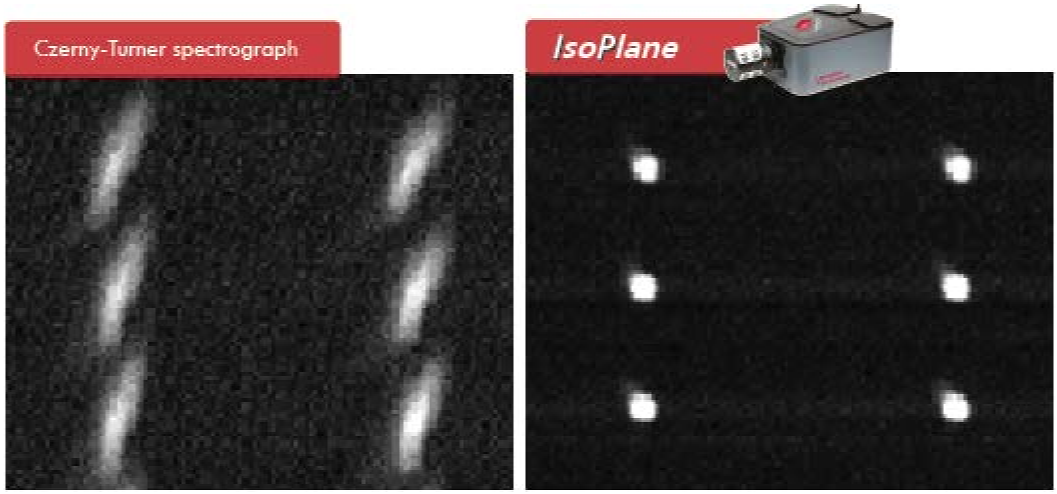
Figure 6.
Top: Same as Figure 3, a stack of optical fibers imaged with a CT spectrograph. Bottom: An image of the same optical fiber bundle seen in Figure 3, as measured with the IsoPlane.

The top of Figure 6 is the same image shown in Figure 3. Again note how blurred the image is, particularly at the focal plane edges. The bottom of Figure 6 is an image of the same optical fiber bundle, obtained with an IsoPlane. Because of the greatly reduced levels of optical aberrations present in the IsoPlane, this image is sharp at the top, bottom, left, and right edges of the focal plane.

A final example of the improved imaging available with an IsoPlane is seen in Figure 7, which shows images of six round optical fibers taken from the upper left hand corner of a CCD.

Figure 7.

Images of six optical fibers taken from the upper left hand corner of a CCD.
Left: Traditional Czerny-Turner.
Right: IsoPlane.



The optical aberrations inherent in the CT design cause the light from the optical fibers to become smeared out, giving an elliptical image at the focal plane. The image obtained with the IsoPlane is sharper and rounder.

Conclusions

Optical problems inherent in Czerny-Turner spectrographs include field astigmatism and coma. These aberrations distort images measured with CT spectrographs, particularly at the edges of the focal plane. The Schmidt-Czerny-Turner, or IsoPlane, spectrograph from Princeton Instruments has a unique optical design that completely eliminates field astigmatism at all wavelengths and at all points across the focal plane, and reduces coma to negligible levels. This means the IsoPlane gives sharp and spatially well resolved images across the entire CCD sensor.

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