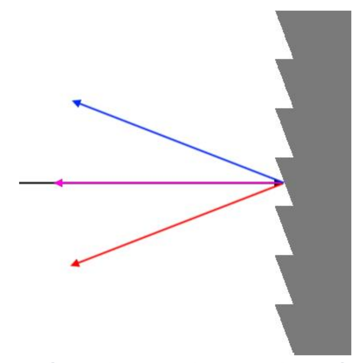
Measuring Period Error of Gratings for Astronomical Use

Jared Termini[1], Casey T. DeRoo[1]
[1]University of Iowa

Data Taking Process

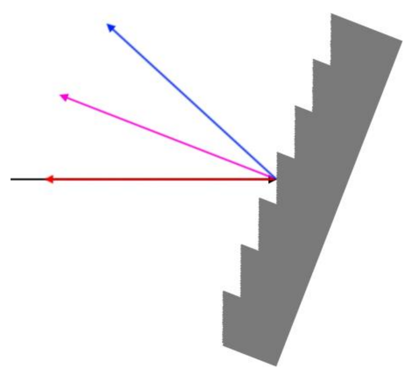
How did I make my measurements?

Instead of moving the interferometer to view each order, we turned the grating so that different orders were reflected back to the interferometer.

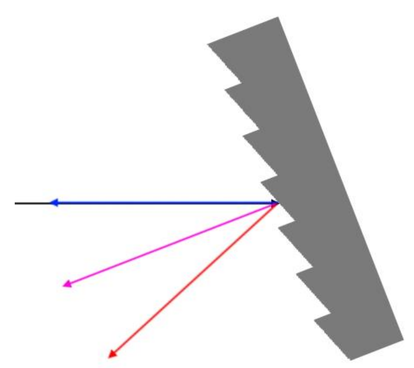


The black arrow is the incident light, the purple arrow is the 0th order, the red arrow is the +1st order, and the blue arrow is the -1st order

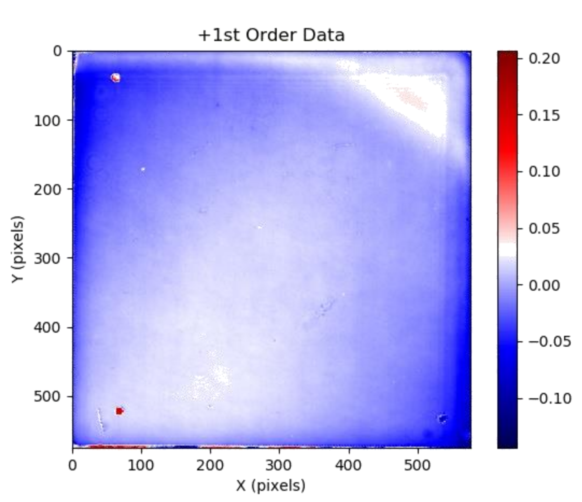
Grating orientation for observing the 0th order

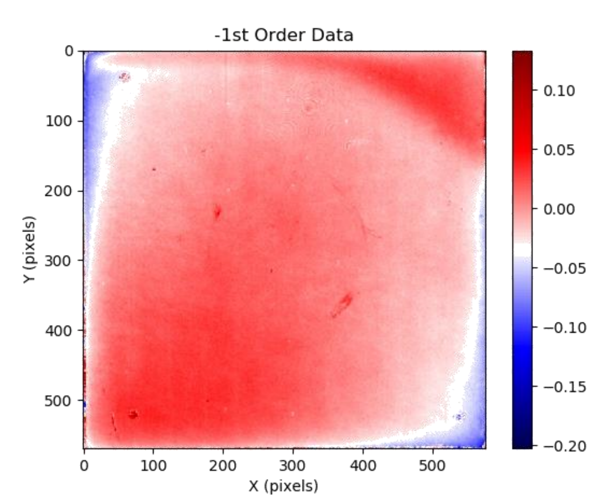


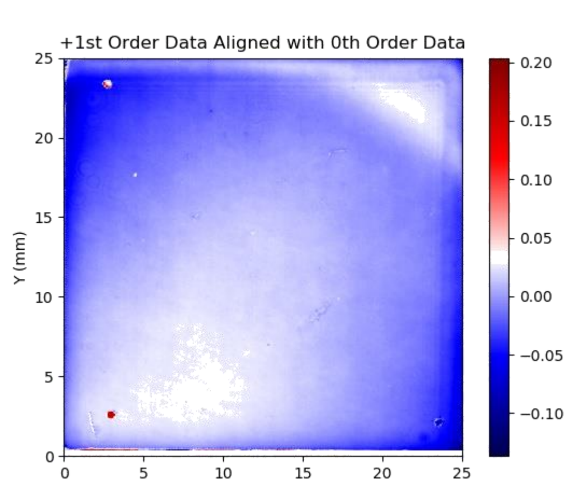
Grating orientation for observing the +1st order

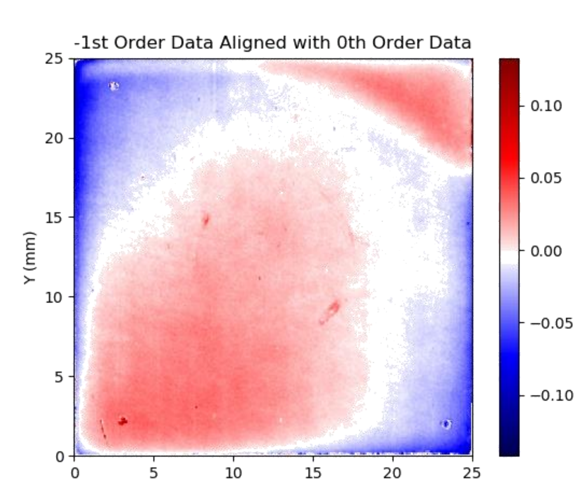


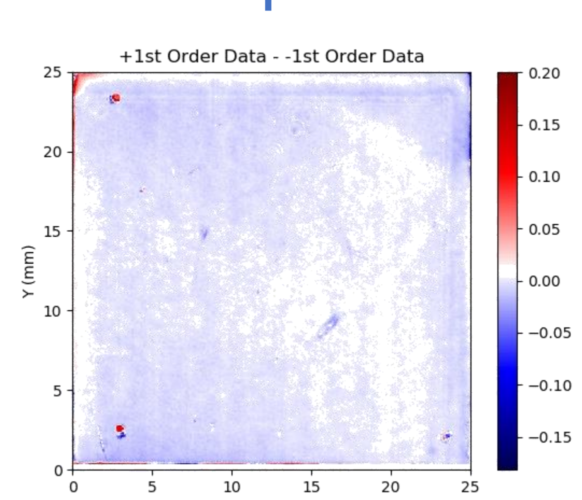
Grating orientation for observing the -1st order











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Abstract

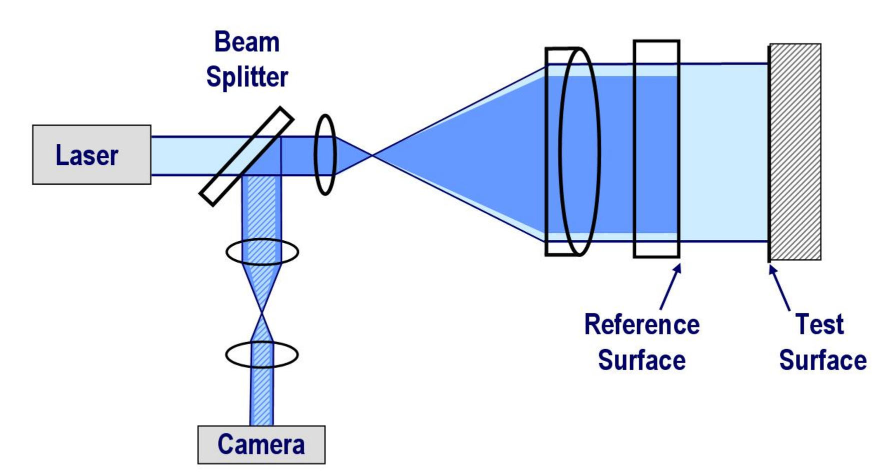
X-ray spectra offer a wealth of information about the physical conditions around black holes, the hot gas surrounding galaxies, and stellar coronae. Getting these spectra, however, requires making precise X-ray gratings. These gratings must have grooves many times smaller than a human hair, and placing them at the sub-nanometer level. This groove placement can be accomplished with electron-beam lithography (EBL), and the gratings can be measured with an interferometer. EBL also opens new doors into how X-ray optics are designed, potentially reducing the number of optical surfaces required. This would decrease the size and mass of the instrument, thus reducing the cost to send it into space, all while increasing the sensitivity of the instrument. By using the 4D Technology Fizeau interferometer at the University of Iowa to assess and quantify errors in the grating pattern, we can gather vital feedback to the EBL patterning process. By repeating this process many times, we will develop a set of EBL patterning parameters that can be used to create accurate patterns. Measuring our grating and quantifying any residual errors in the period of the grating will allow us to evaluate the feasibility of new spectrometer designs and estimate their performance capabilities.

Introduction to Interferometry

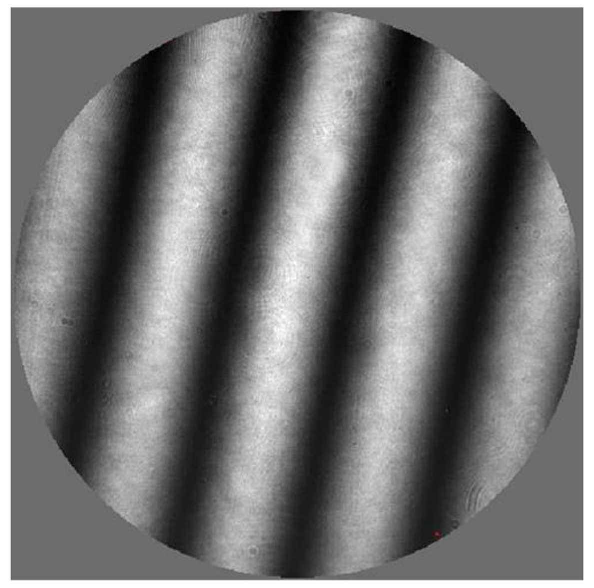
How does a Fizeau interferometer work?

Our interferometer uses a laser with a wavelength of 632.8 nm. When the light hits a surface it reflects back into the interferometer. If the surface is perfectly flat, then the reflected light will be in phase with the incident light. If the surface is not flat, then the reflected light will be out of phase with the incident light because it had to travel slightly longer (low point) or shorter (high point) path.

A beam splitter divides the beam from a 632.8 nm laser in a "reference beam" and a "test beam." The reference beam goes to a high-quality optics with a precisely known surface and is reflected by the optics back to the beam splitter. The test beam goes to the test optic and reflects back to the beam splitter. If the test optic is not perfectly flat, then the returning beam will be out of phase with the reference beam. When the beam splitter reflects the beams to the camera, it recombines the beams. Recombining the beams creates an interference pattern because of constructive and destructive interference between the out of phase beams.



Fizeau interferometer diagram. Image credit: 4D Technology



Interference pattern. Image credit: 4D Technology

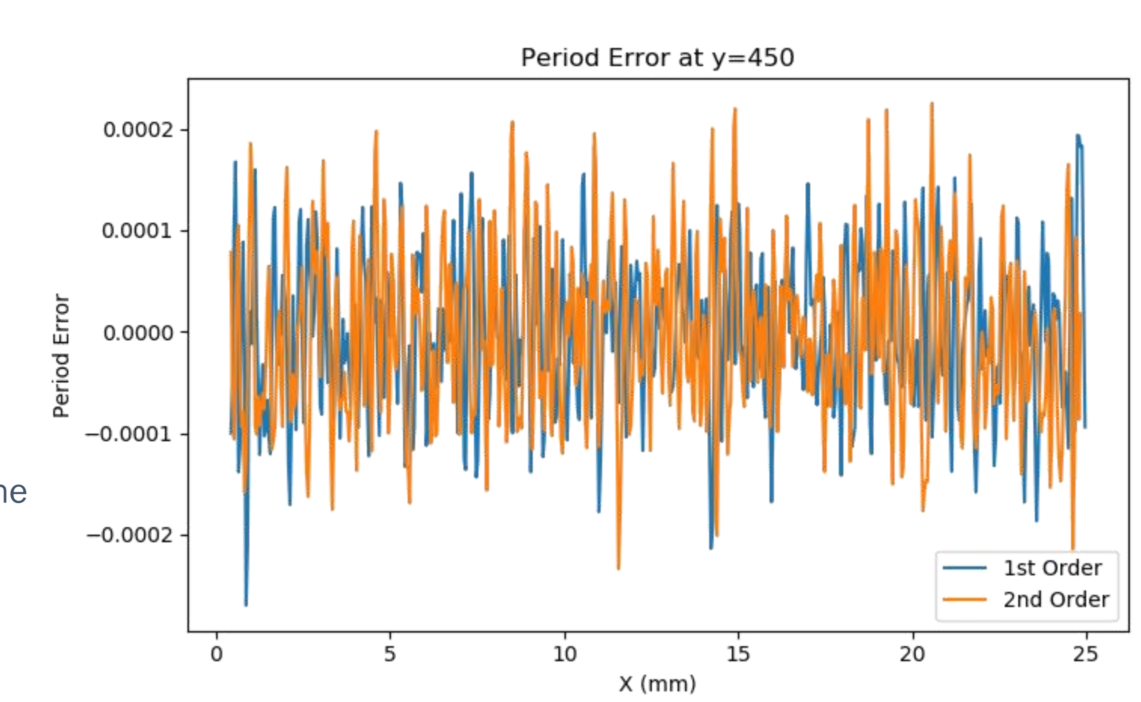
Future Work & Conclusions

Conclusions:

- We used an interferometer to collect measurements of the 0th, ±1st, and ±2nd orders.
- Our results are in line with our expectations of the period error of a commercial grating.

Future Work:

- Improve our analysis process to determine the limiting resolution of the grating.
- Measure electron-beam lithography written gratings.



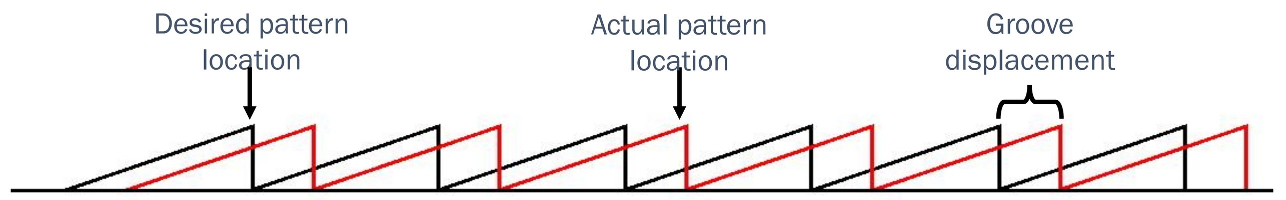
Groove Placement Accuracy

What is groove placement accuracy?

There are three elements of groove placement accuracy: groove displacement, groove period, and groove period error.

What is groove displacement?

The groove displacement is the measurement of how far off each groove is from where it is supposed to be.



Why groove displacement is important?

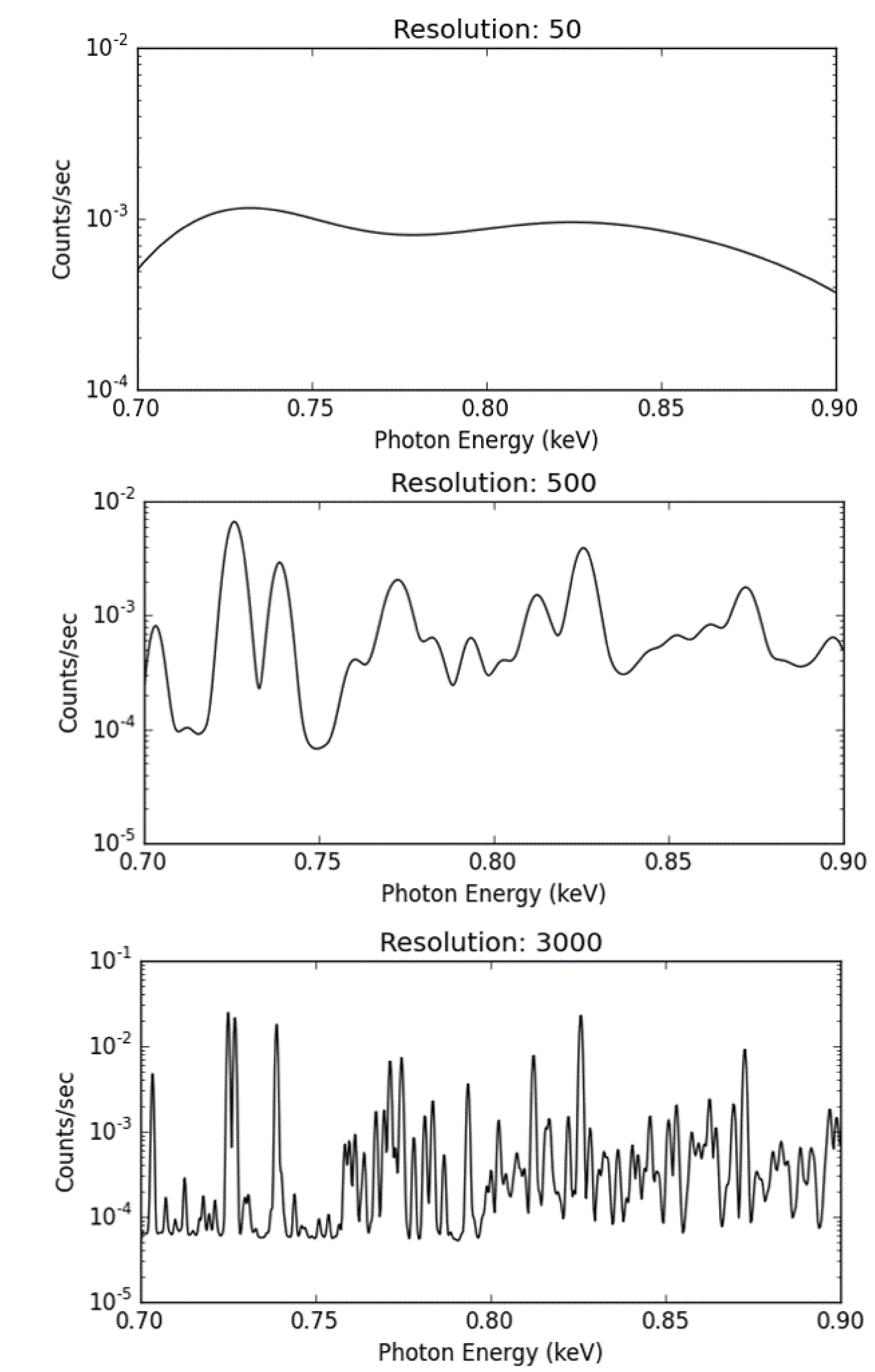
A uniform groove displacement may not be so bad. However, in reality, the groove displacement is non-uniform. The non-uniformity results in a groove density and groove period that change along the length of the grating.

What is the groove period?

The groove period is the mean periodicity of the groove pattern.

Why groove period and period error are important?

The groove period and period error are the most important elements because they determine the resolving power of a spectrometer. Large period errors will broaden the measured spectrum, leading to a lower resolution. The ability to create high resolution spectrometers require a low period error.



Simulated spectrum of the X-ray binary Capella using varying resolutions