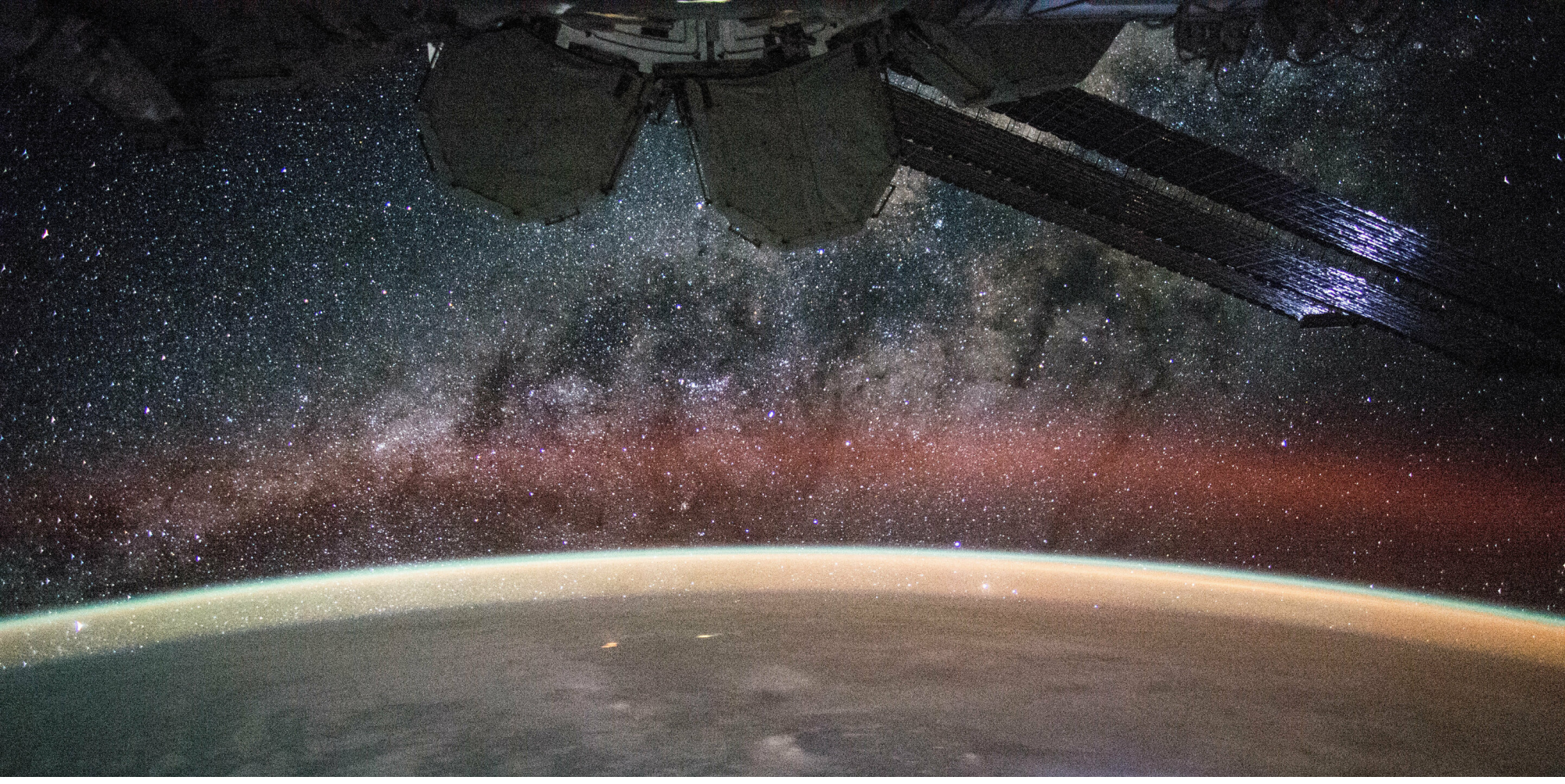


Data Processing Chain for Heterodyne Spectrometer

Matthias Gehnen, Moritz Hefner, Bas Kruisselbrink, Johannes Plett, Felix Rauh

Aachen, June 14, 2019

CAMMP | RWTH AACHEN UNIVERSITY

The Spatial Heterodyne Spectrometer

- Instrument developed at Institute of Energy and Climate Research: Stratosphere (IEK-7)
- Used for studying earth atmosphere by nano-satellite
- Prototype deployed on Chinese communication satellite

3D-printed model without solar panels of AtmoCube-1 [Deiml, 2018]

Research Goals

Measure oxygen emissions in Mesosphere/Lower Thermosphere

↓

Derive temperature information for detecting gravity waves

↓

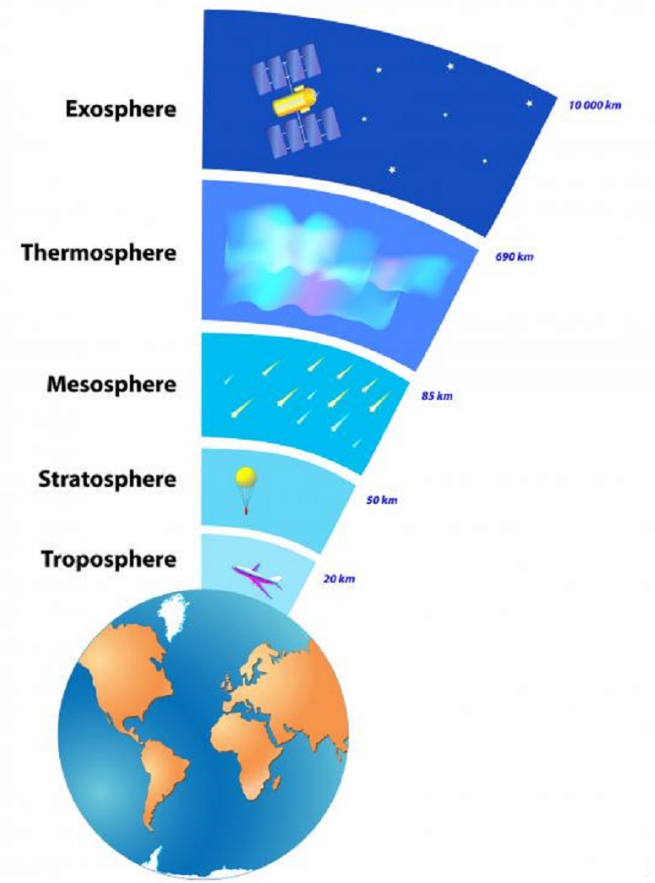
Improve global circulation models

↓

Extend information for climate predictions and weather forecasts to higher altitudes

↓

Quantify climate change, atmospheric coupling processes and space weather effects



Source: wisegeek.com

Overview

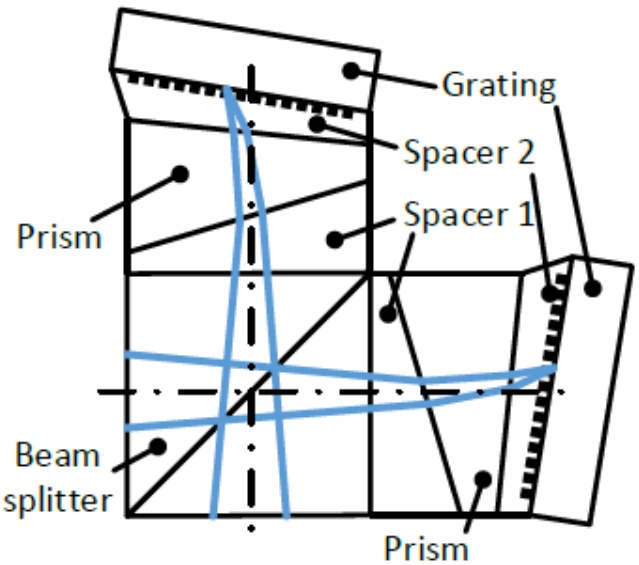
Used Data

- Synthetic
- Real measurements
  - Laser light on earth
  - In the orbit

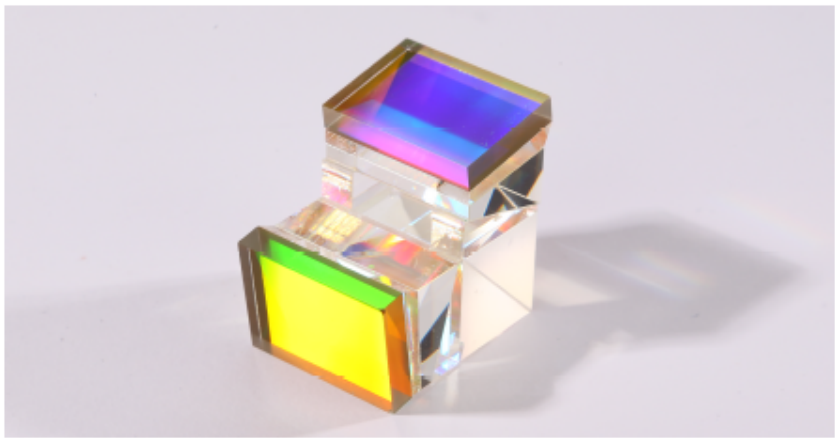
Considered Image Effects

- Saturation (exceeded sensor sensitivity)
- Tilted vertical lines
- Lower intensities towards edges (vignetting)

Schematic of Spatial Heterodyne Spectrometer



(a) Schematic of the SHS.



(b) Assembled SHS for the precursor mission.

Source: [Deiml, 2018]

Output: Interferogram which then can be transformed to spectrum by FFT

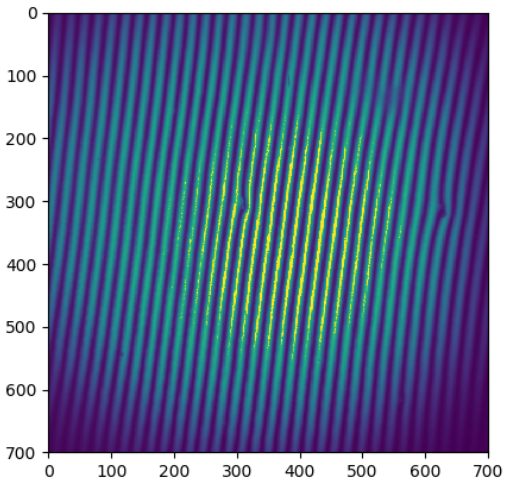
Relation Between Detected Intensities and Incoming Radiation

Relation between $I_g(x)$ and $(\sigma, L(\sigma))$

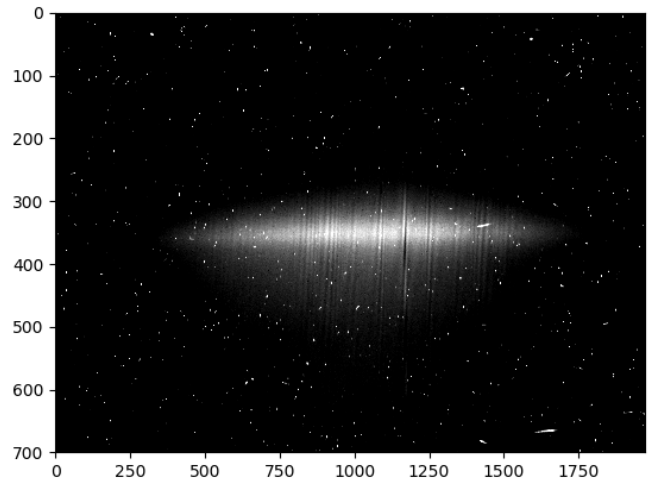
$$I_g(x) = \int_0^\infty 0.5 \cdot L(\sigma) \cdot (1 + \cos(8\pi \tan(\theta_L)\, x\, (\sigma - \sigma_L)))d\sigma$$

- $I_g(x)$ is the intensity of the interference in x
- σ is the wavenumber and $L(\sigma)$ the intensity
- Littrow angle θ_L and Littrow wavenumber σ_L

Laser- and Orbit Data



Laser Data



Orbit Data

Emergent Questions

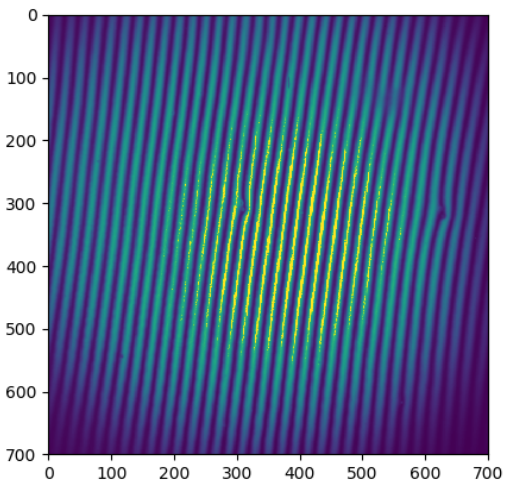
- Why do we have laser data?
- What should we see?

Errors in Laser Data

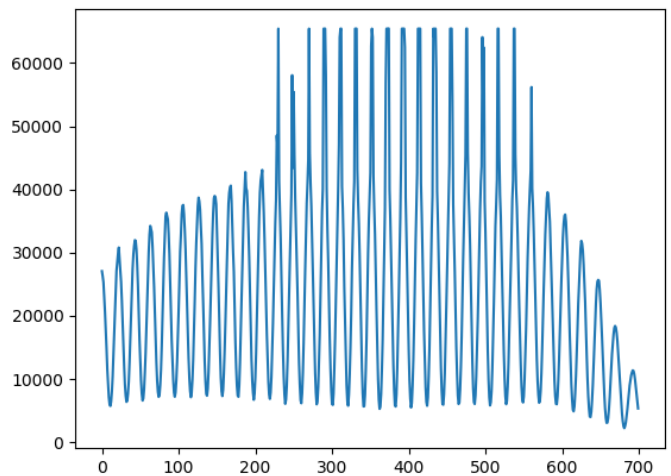
Visible Errors

Decrease of intensity towards edges (vignette)

exceeded sensitivity



Laser Data



One Row of Laser Data

Generating Synthetic Data

- Simulating the detection image of a laser pointer
- Including errors due to tilting and flattening towards the edges

$$I_g(x, \sigma) = 0.5L(\sigma)\,(1 + \cos(8\pi\ \tan\theta_L\ x\ (\sigma - \sigma_L)))$$

Generating Synthetic Data

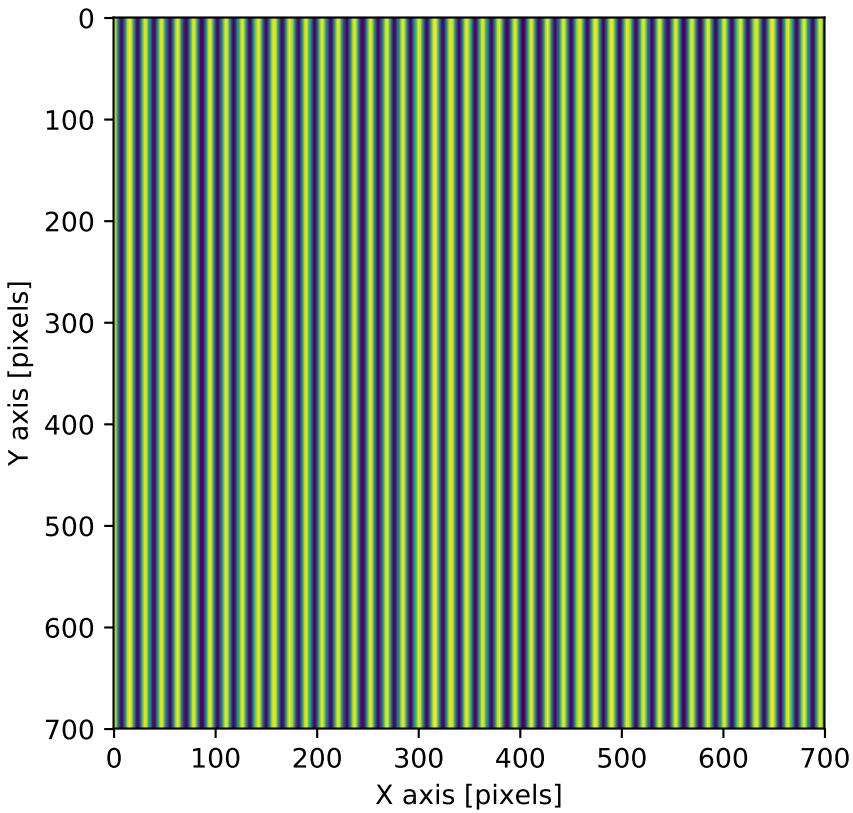
- Simulating the detection image of a laser pointer
- Including errors due to tilting and flattening towards the edges

$$I_g(x, y, \sigma) = f(x, y) \cdot 0.5L(\sigma)\,(1 + \cos(8\pi\,\tan\theta_L\,x\,(\sigma - \sigma_L) + 2\sigma\varphi y))$$

Generating Synthetic Data

- Simulating the detection image of a laser pointer
- Including errors due to tilting and flattening towards the edges

$$I_g(x, y, \sigma) = f(x, y) \cdot 0.5L(\sigma)\,(1 + \cos(8\pi\,\tan\theta_L\,x\,(\sigma - \sigma_L) + 2\sigma\varphi y))$$

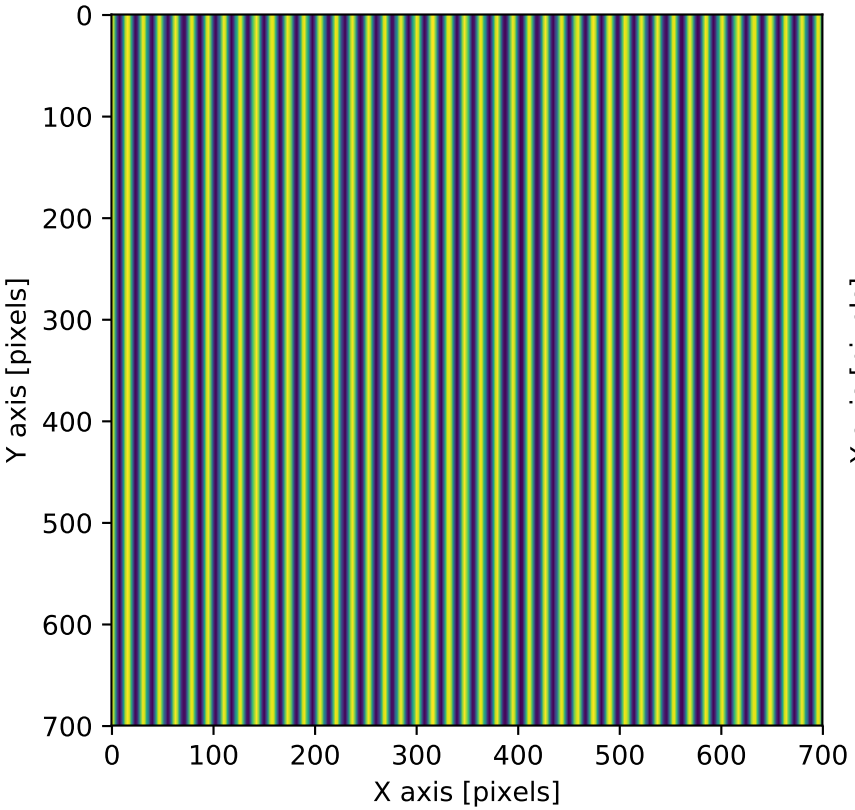


Without effects

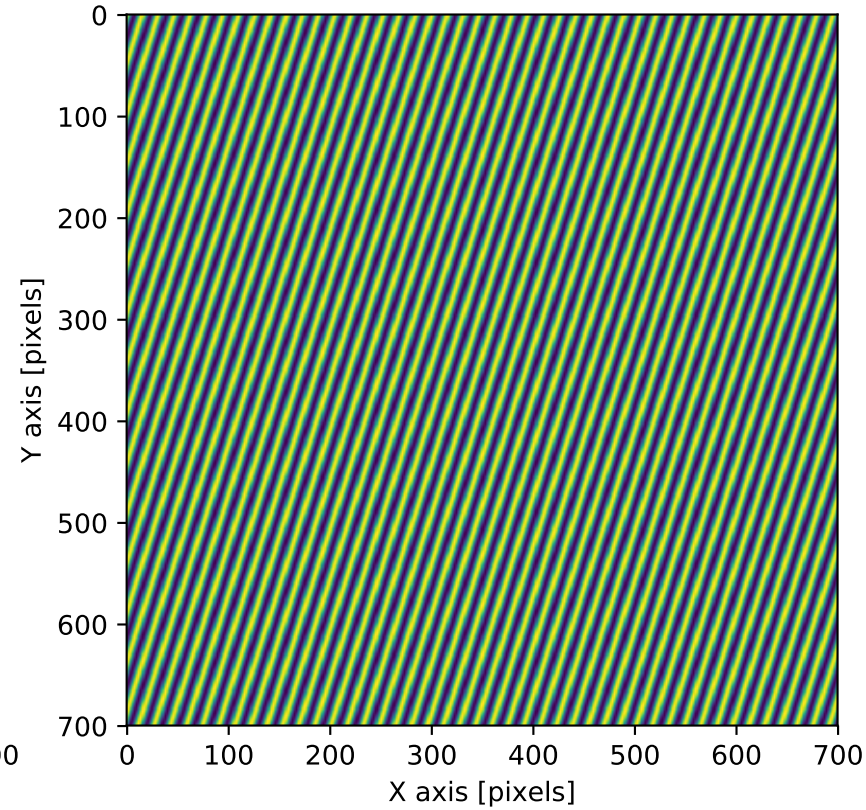
Generating Synthetic Data

- Simulating the detection image of a laser pointer
- Including errors due to tilting and flattening towards the edges

$$I_g(x, y, \sigma) = f(x, y) \cdot 0.5L(\sigma)\,(1 + \cos(8\pi\,\tan\theta_L\,x\,(\sigma - \sigma_L) + 2\sigma\varphi y))$$



Without effects

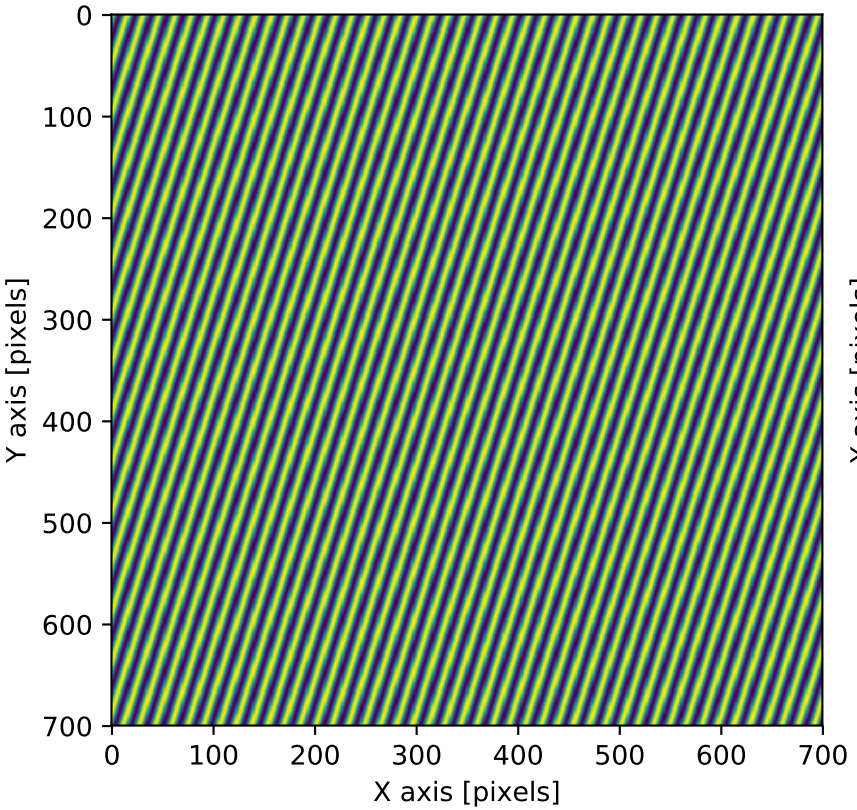


Tilted

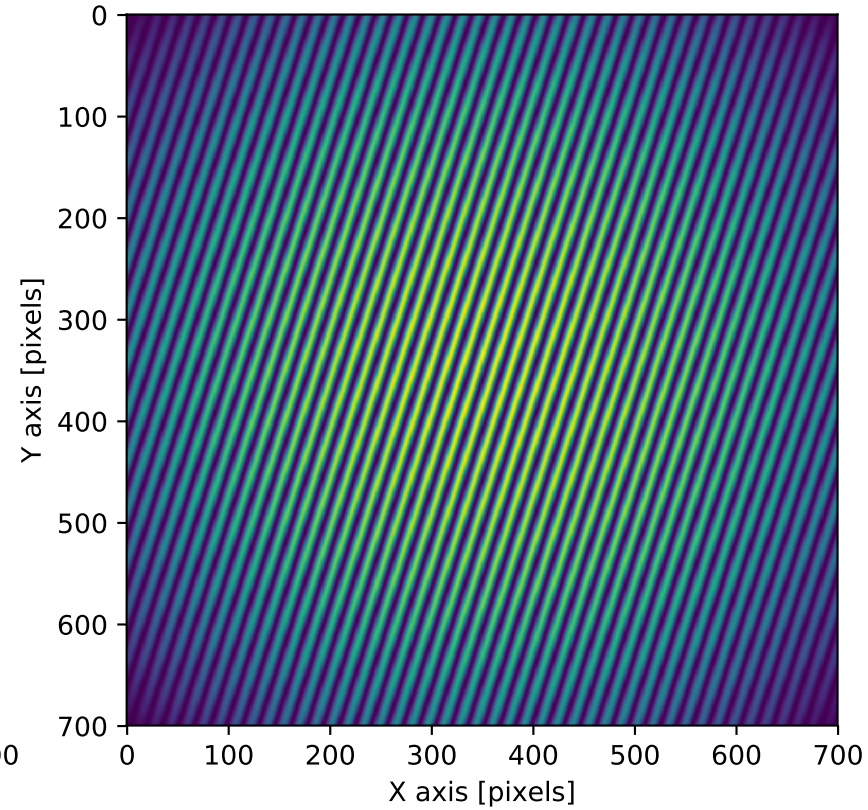
Generating Synthetic Data

- Simulating the detection image of a laser pointer
- Including errors due to tilting and flattening towards the edges

$$I_g(x, y, \sigma) = f(x, y) \cdot 0.5L(\sigma)\,(1 + \cos(8\pi\,\tan\theta_L\,x\,(\sigma - \sigma_L) + 2\sigma\varphi y))$$

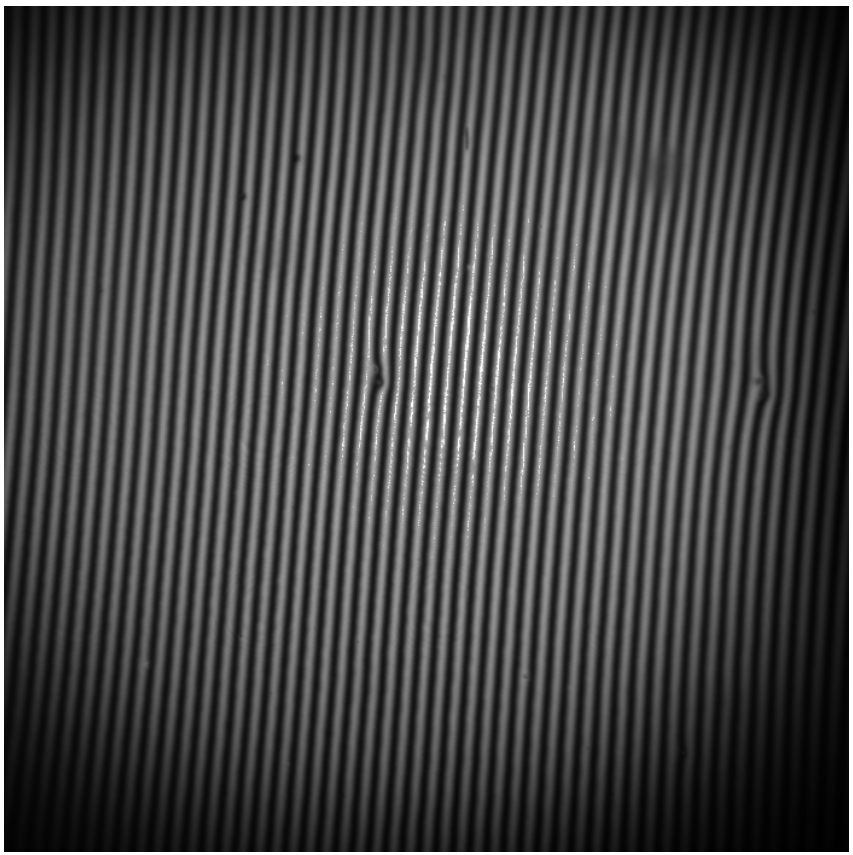


Tilted



Tilted and flattened

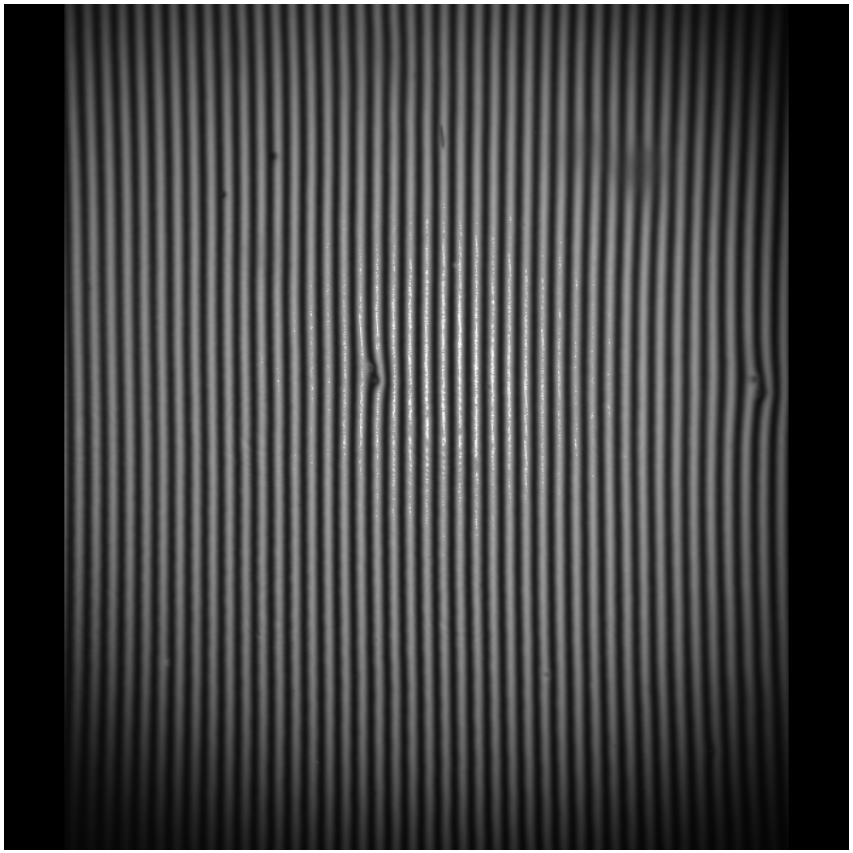
Correction of Tilted Images



Data from the laser

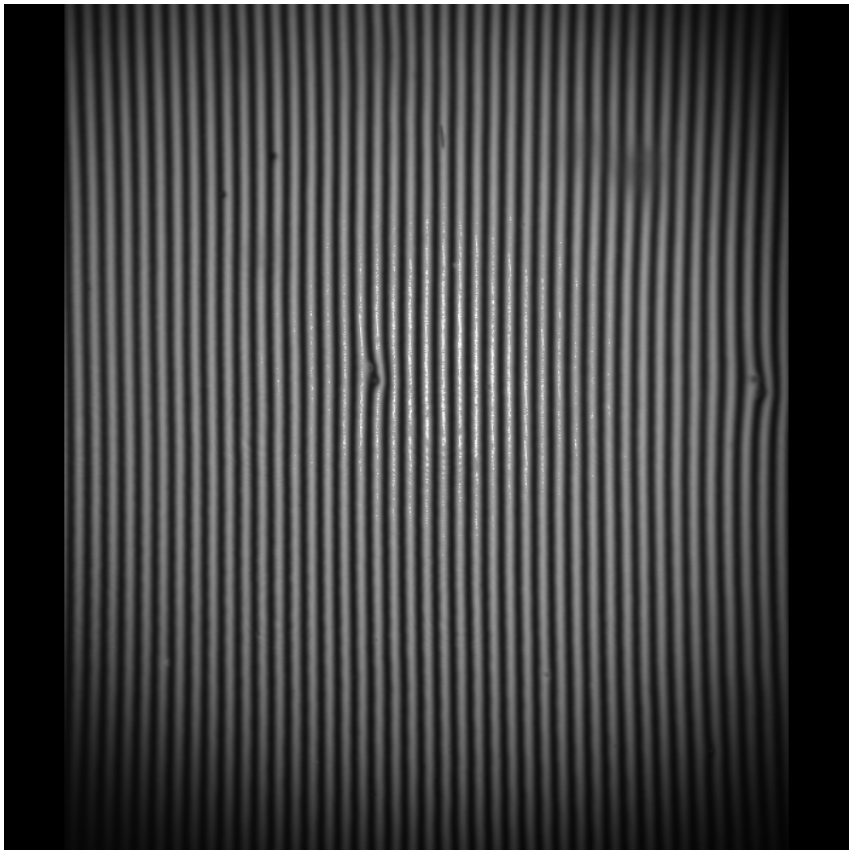
- Spectrum is tilted
- Problem: how much is it tilted?
- Idea: find line with maximum intensity
- Angle of this line represents the tilt
- Tilt back by this value

Pincushion Effect



Pattern after reverse tilt

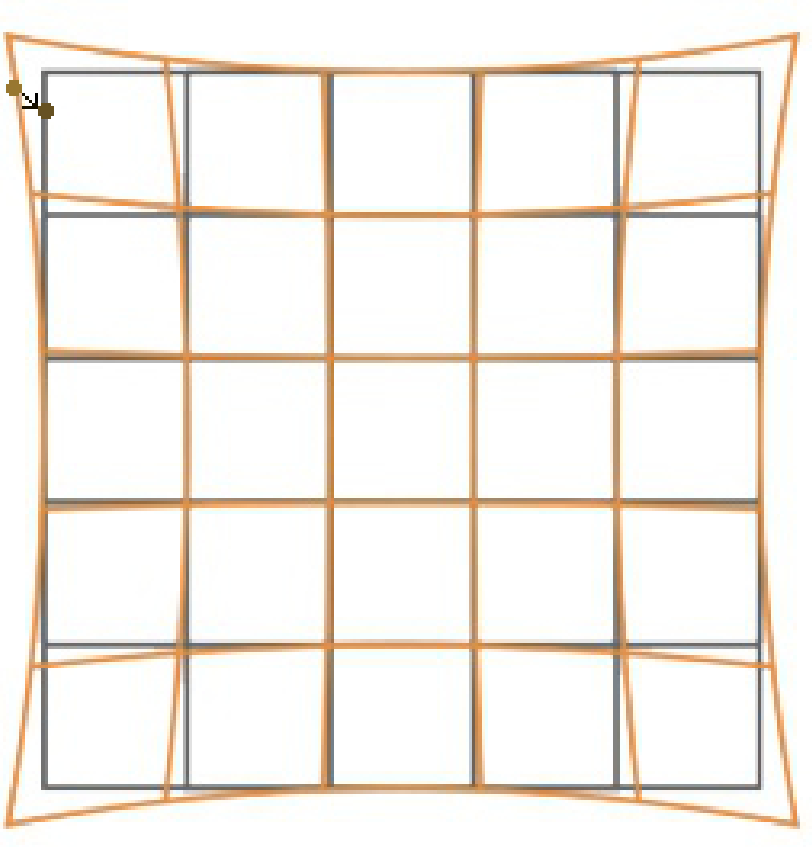
Pincushion Effect



Pattern after reverse tilt

- Remaining problem: Pincushion distortion
- Image magnification increases with distance from optical axis
- Physical reasons: quadratic distortion
- Get level of distortion analogously to tilt: search for parabola

Pincushion Effect

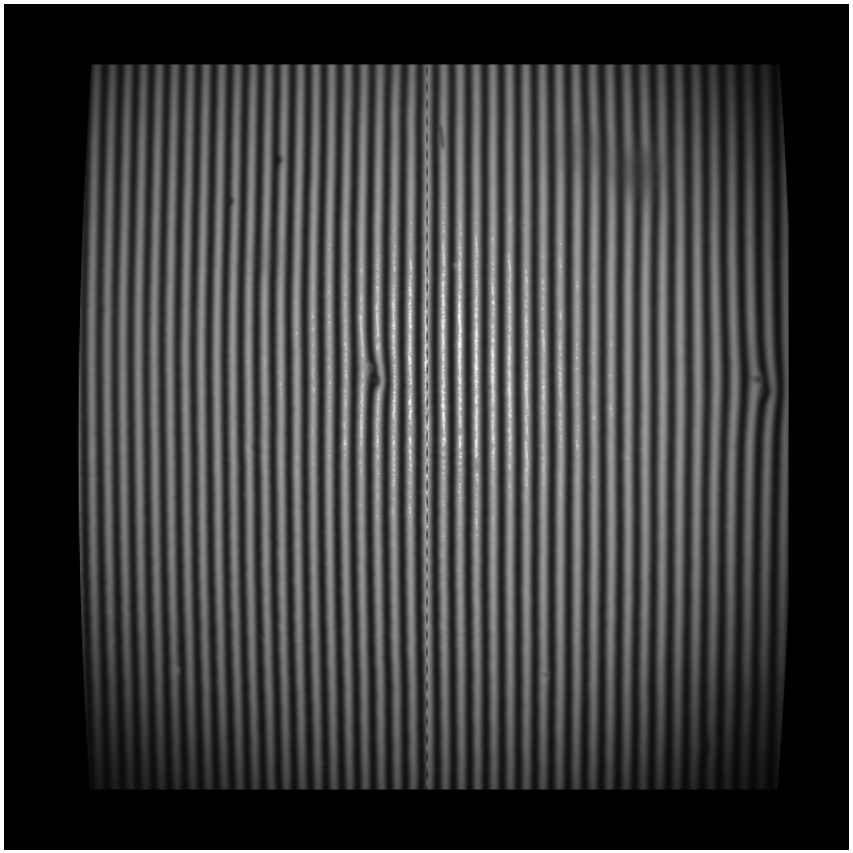


Orange: the picture as measured,
gray: picture without pincushion

picture from http://www.fotokurs-bremen.de

- Calculate the origin of every pixel with the quadratic functions
- Move the pixels to the correct places

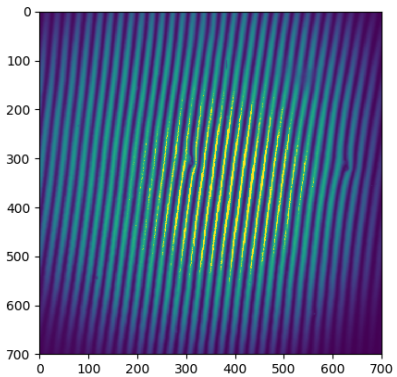
Pincushion Effect



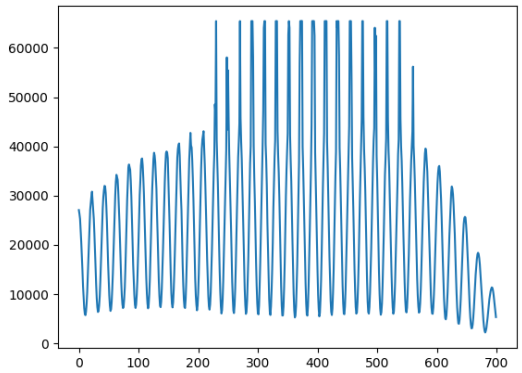
Result after both filters

- We get a vertical, straight pattern to work with.

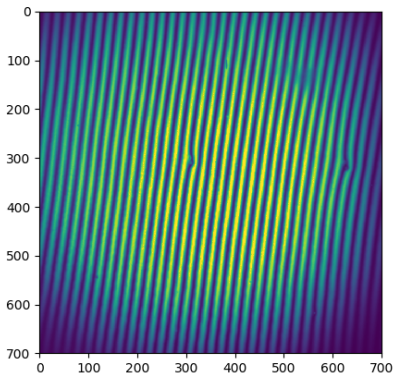
Saturation



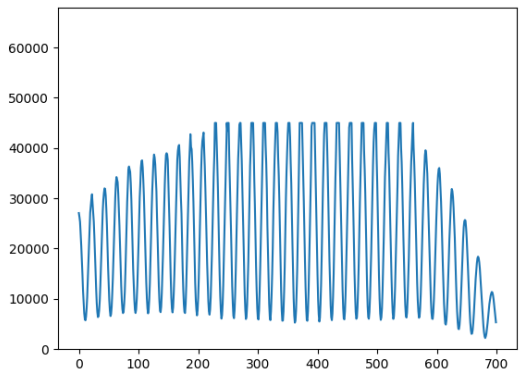
Raw Image



Intensities with Saturation



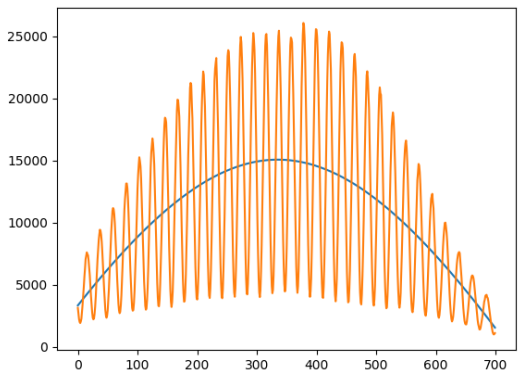
Mitigated Saturation



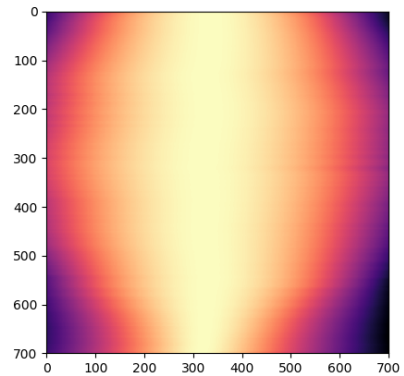
Peaks cut off

Sensitivity Function

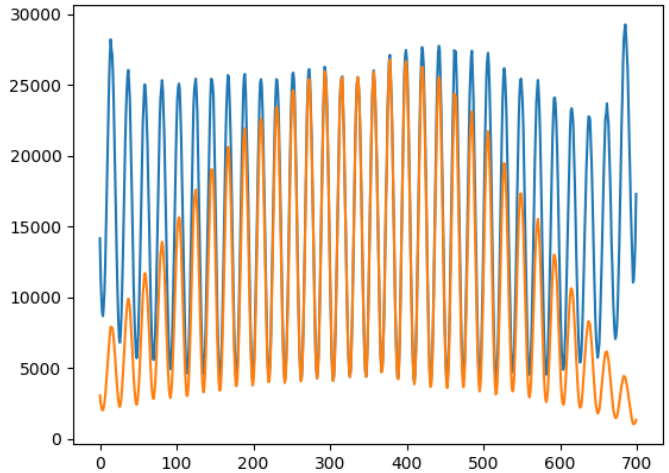
- Counter the vignetting by modeling the flattening as a curve
- Parabolic function: $f(x) = ax^2 + bx + c$
- Hyperbolic function: $g(x) = a\sqrt{1 + \frac{(x+b)^2}{c^2}} + d$
- Sensitivityfunction: $s_p(x) \sim \frac{1}{f(x)}$ and $s_h(x) \sim \frac{1}{g(x)}$



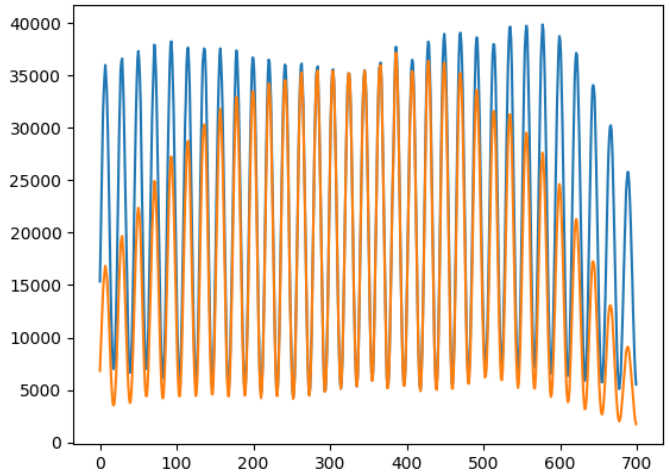
Curvefitting of one row



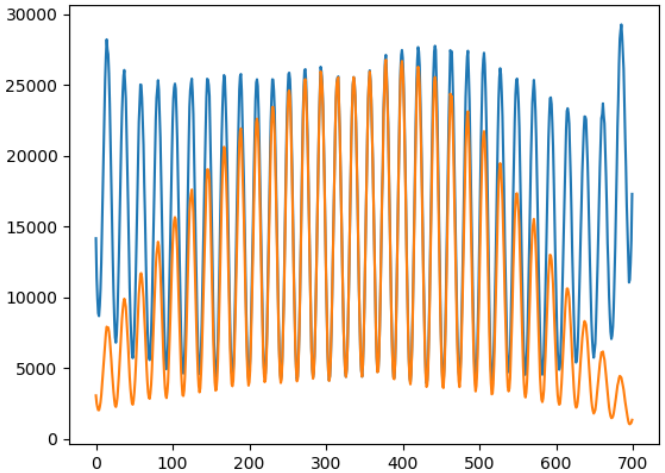
Sensitivity functions per row of one interferogram



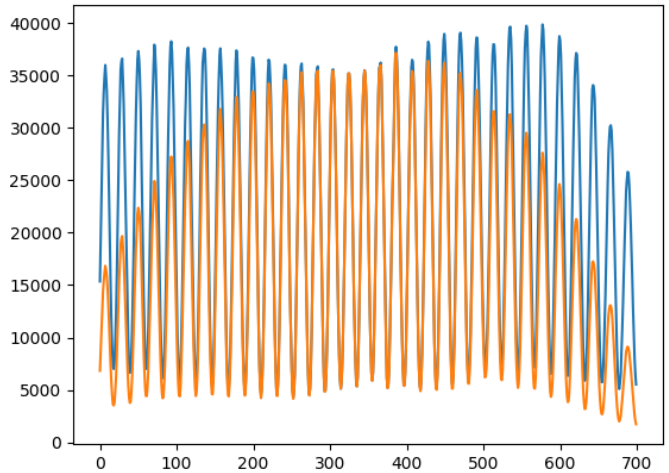
Parabolic Sensitivityfunction



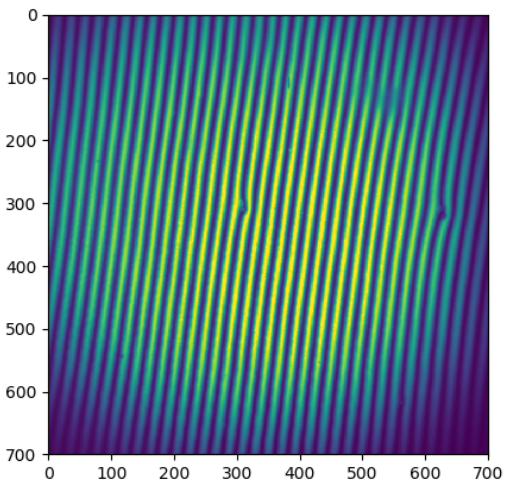
Hyperbolic sensitivity function



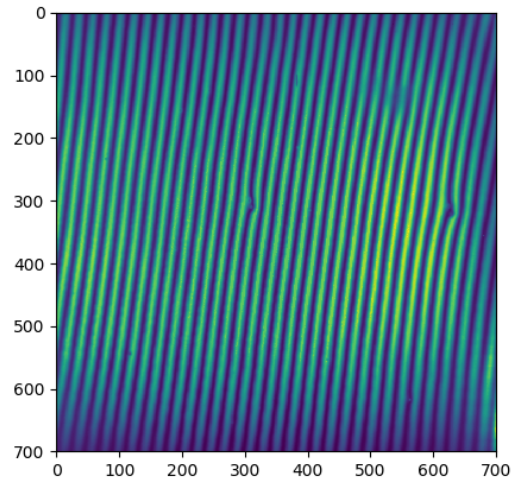
Parabolic Sensitivityfunction



Hyperbolic sensitivity function

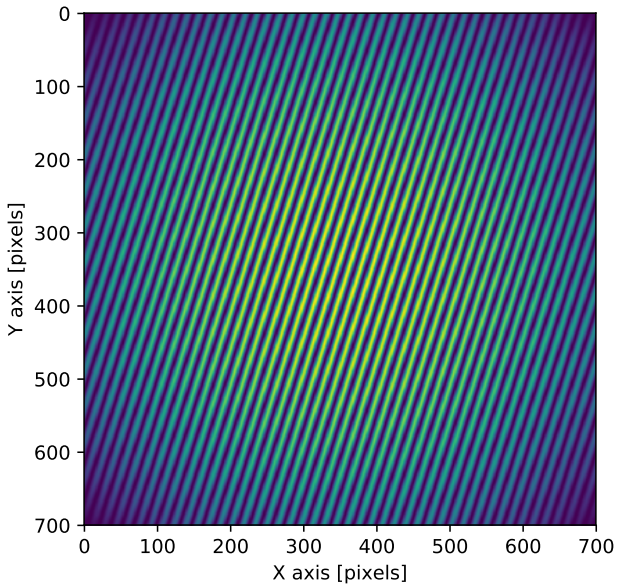


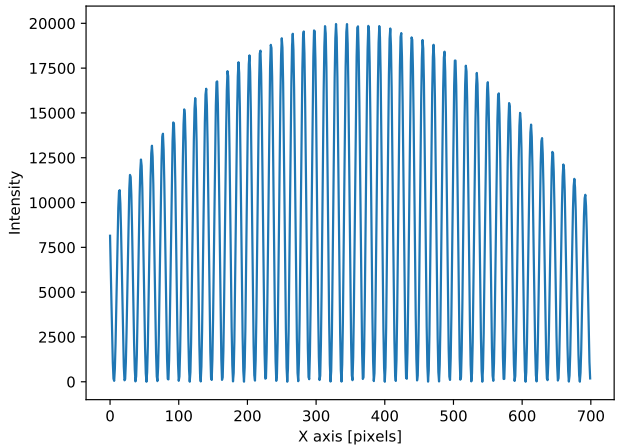
Mitigated saturation



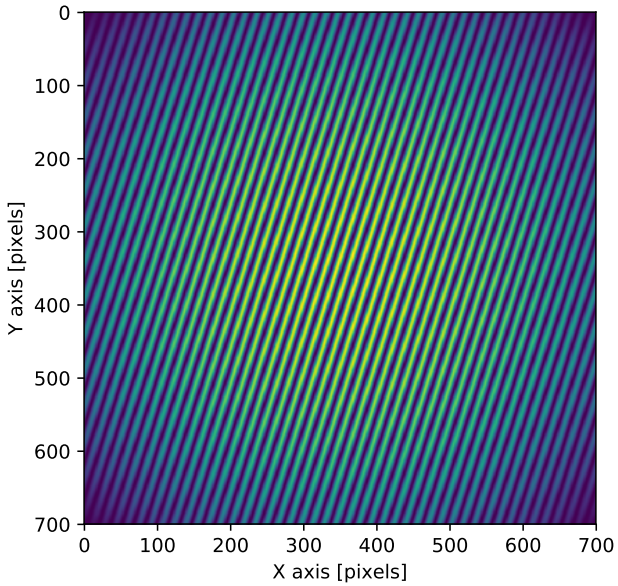
Improved vignetting and saturation

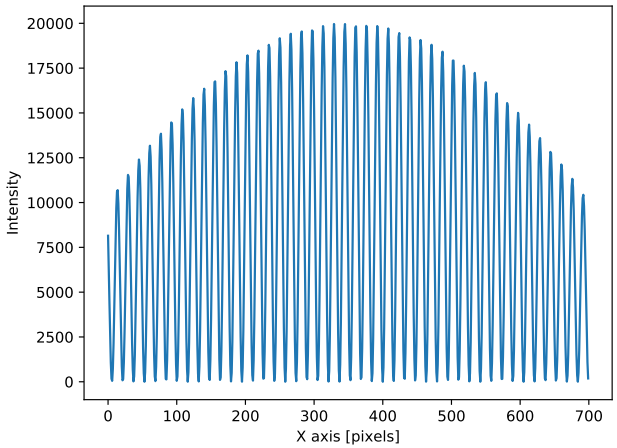
Summary on Synthetic Images

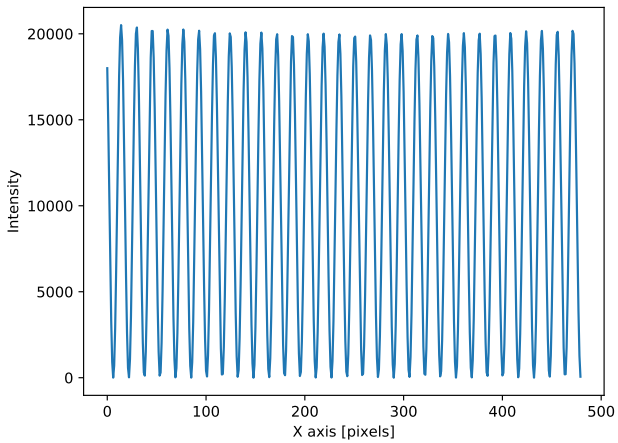


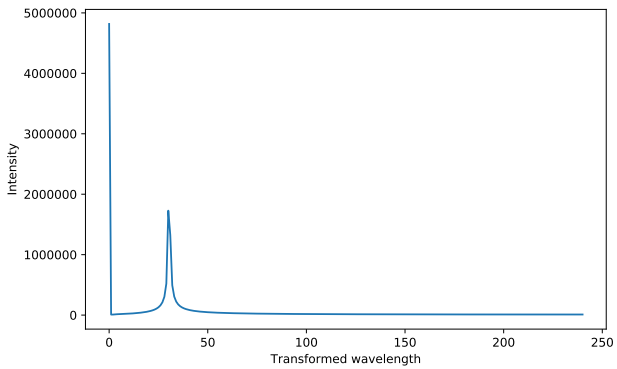


Summary on Synthetic Images

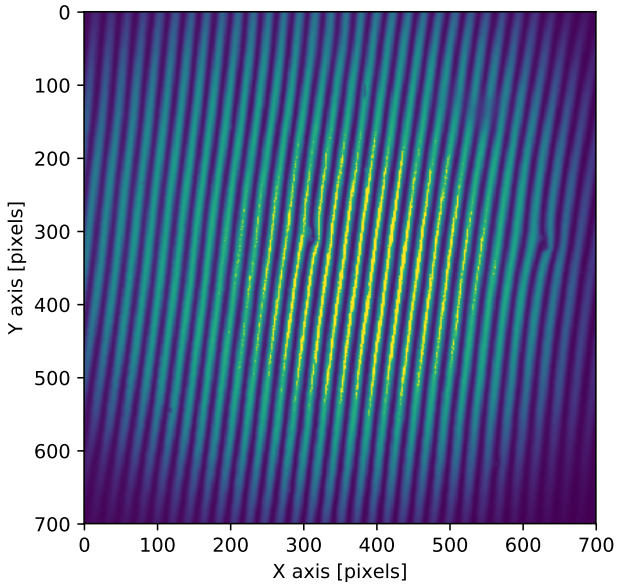


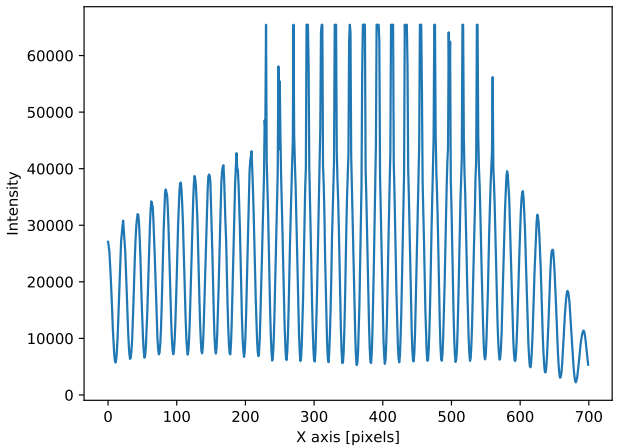




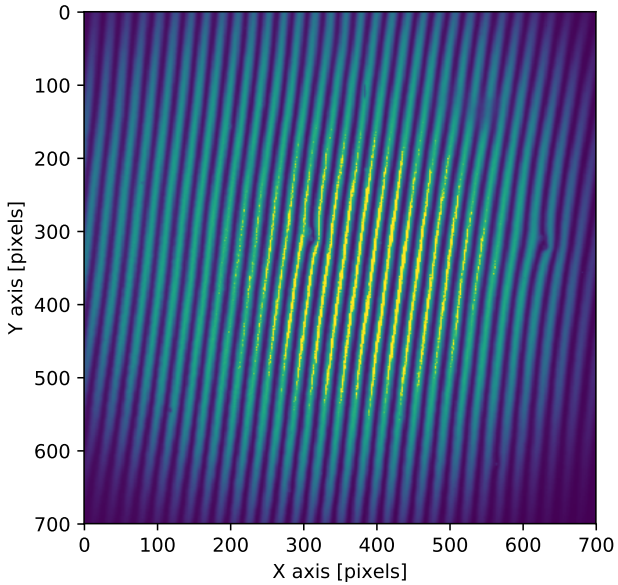


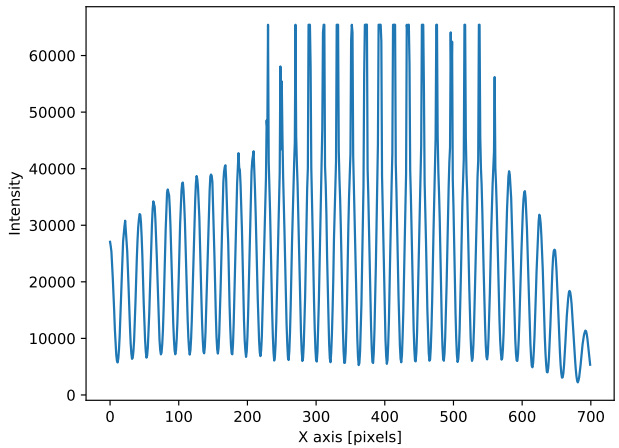
Summary on Real Laser Measurements

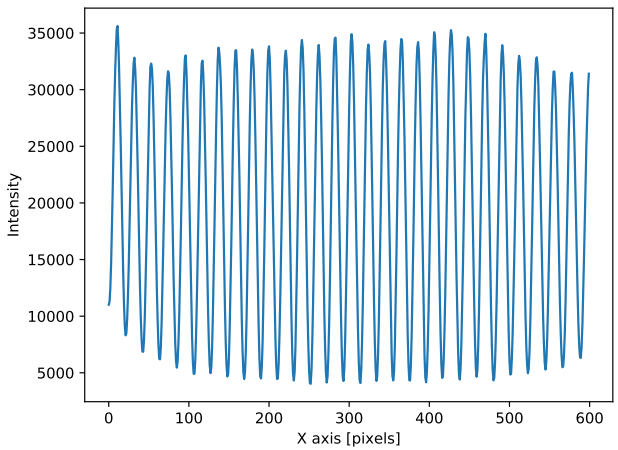


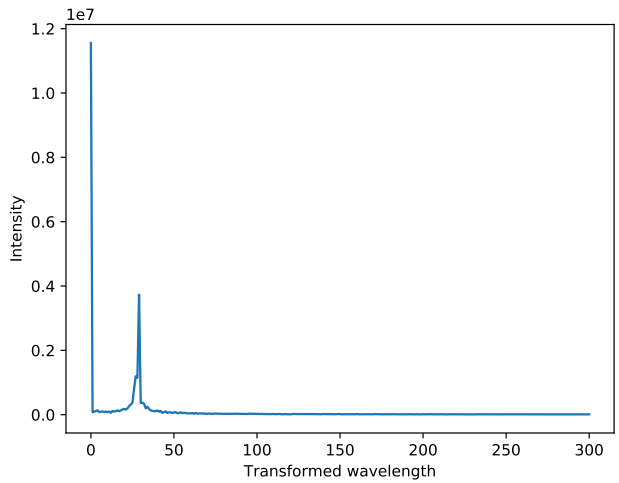


Summary on Real Laser Measurements

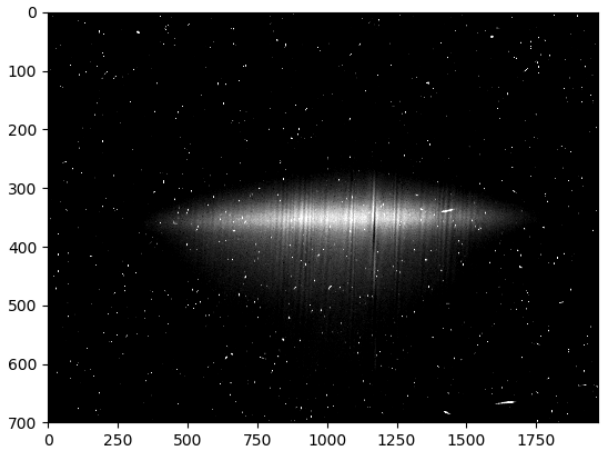


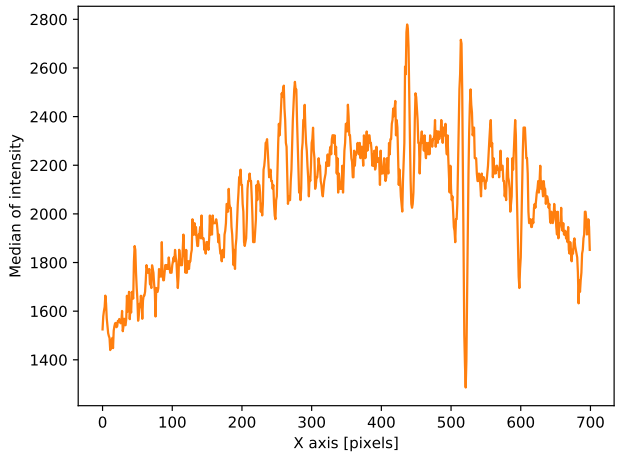




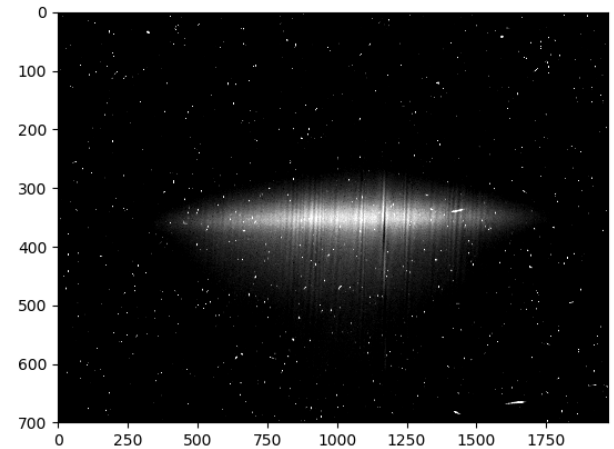


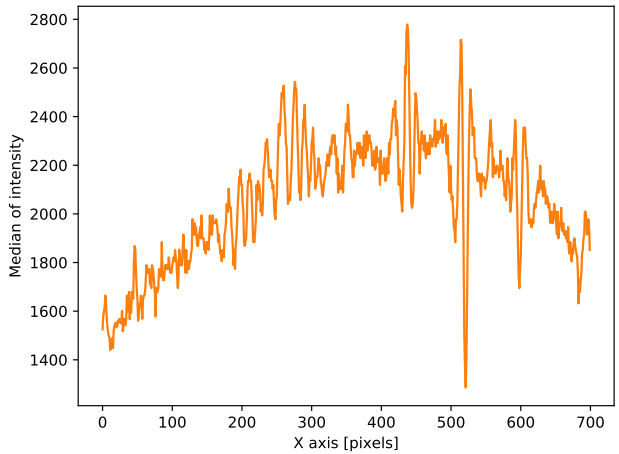
Summary on Orbit Data

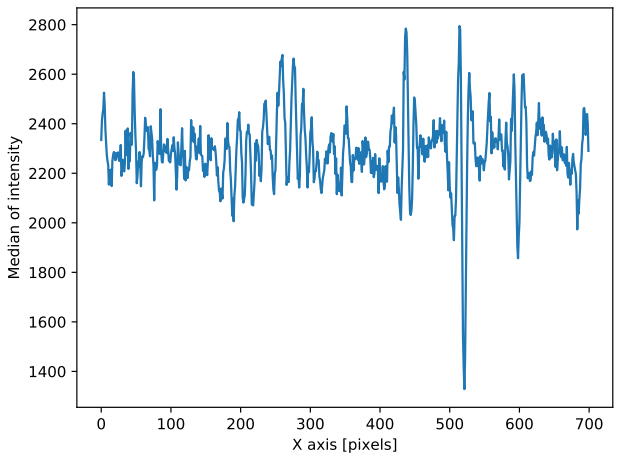


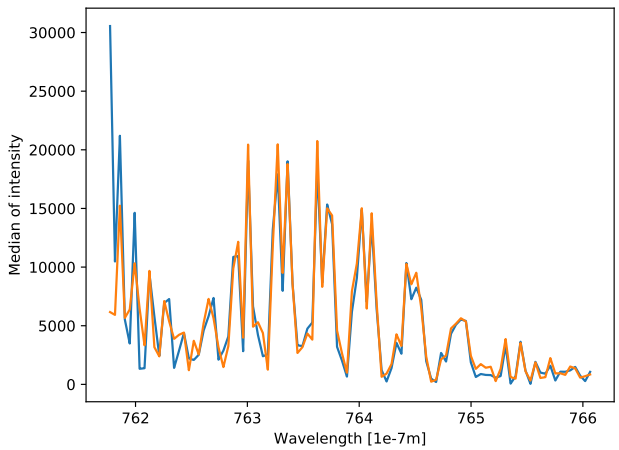


Summary on Orbit Data









Thank you for your attention!

Deiml, M. (2018).
Development of a Small Satellite Remote Sensing Payload for Passive Limb Sounding of the Atmospheric Oxygen Emission.
PhD thesis, Bergische Universität Wuppertal.
http://elpub.bib.uni-wuppertal.de/servlets/DocumentServlet?id=7530.