Interferometry measurements at ALBA

Laura Torino

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Cerdanyola del Vallès, Spain
Diagnostic Expert of European Light Sources

Transverse Beam Size

Problem

Electron machine $\Rightarrow$ Beam size $\simeq$ tens of μm or smaller

$\Updownarrow$

Diffraction limited using visible radiation

$\Downarrow$

$$d = \frac{\lambda}{2n \sin\theta} \simeq 100\mu\text{m}$$

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Pinhole

Use X-Rays

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Choosing the correct energy and magnification diffraction limit is bypassed

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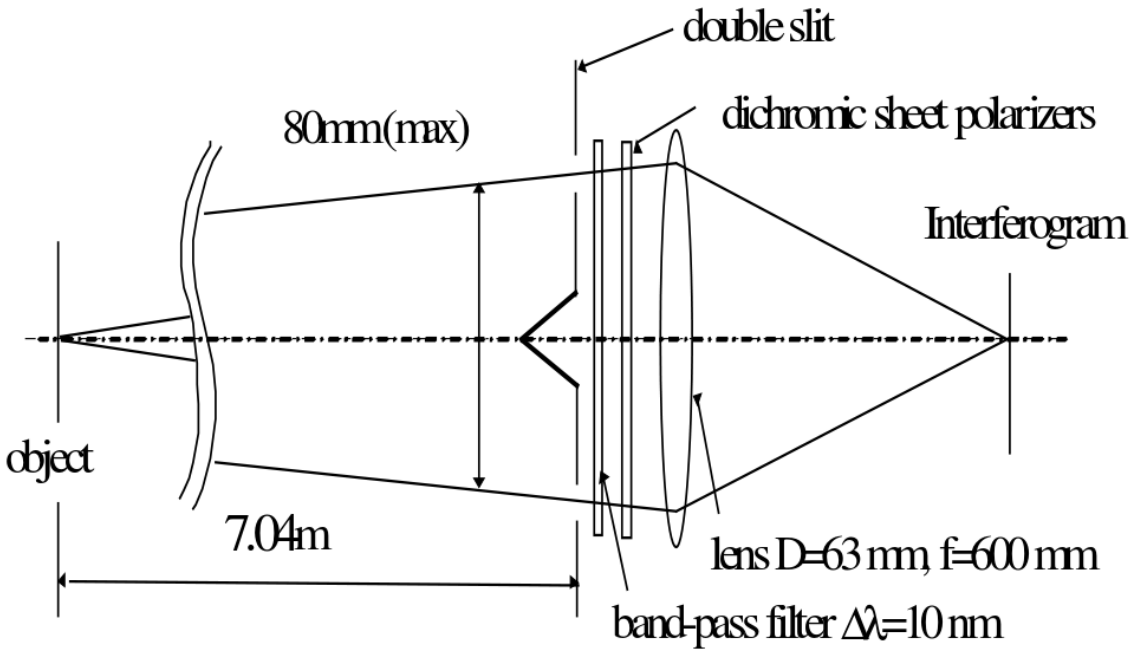
Interferometry

Use Visible radiation

$\Downarrow$

Measuring the degree of spatial coherence of the produced radiation

MITSUHASHI THEORY



$$I = I_0 \left\{ \mathrm{sinc} \left(\frac{2\pi a x}{\lambda f} \right) \right\}^2 \times \left\{ 1 + V \cos \left(\frac{2\pi D x}{\lambda f} \right) \right\}$$

$$\sigma = \frac{\lambda L}{\pi D} \sqrt{\frac{1}{2} \ln \frac{1}{V}}$$

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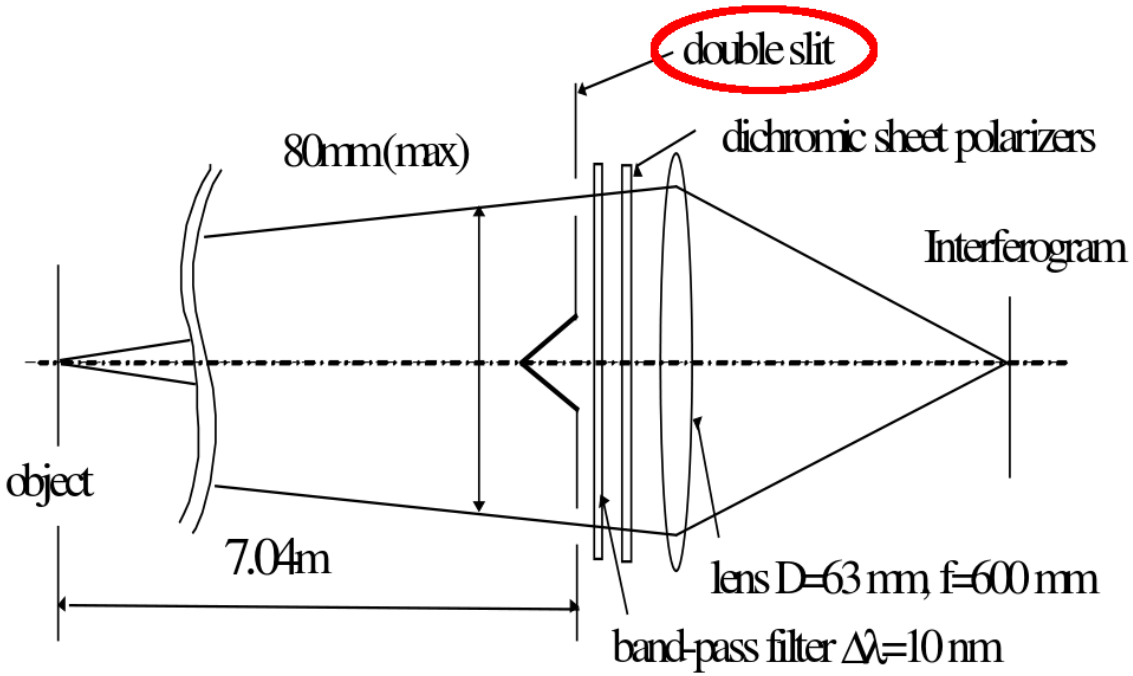

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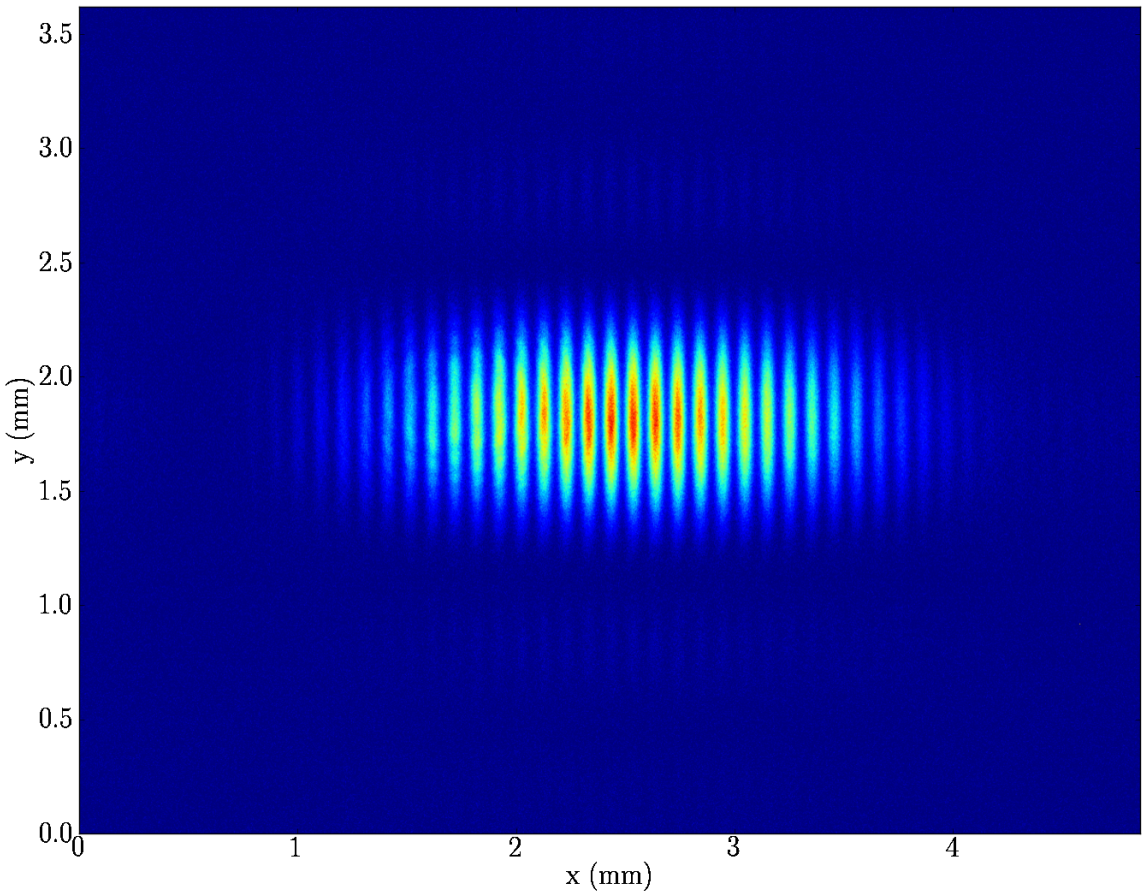
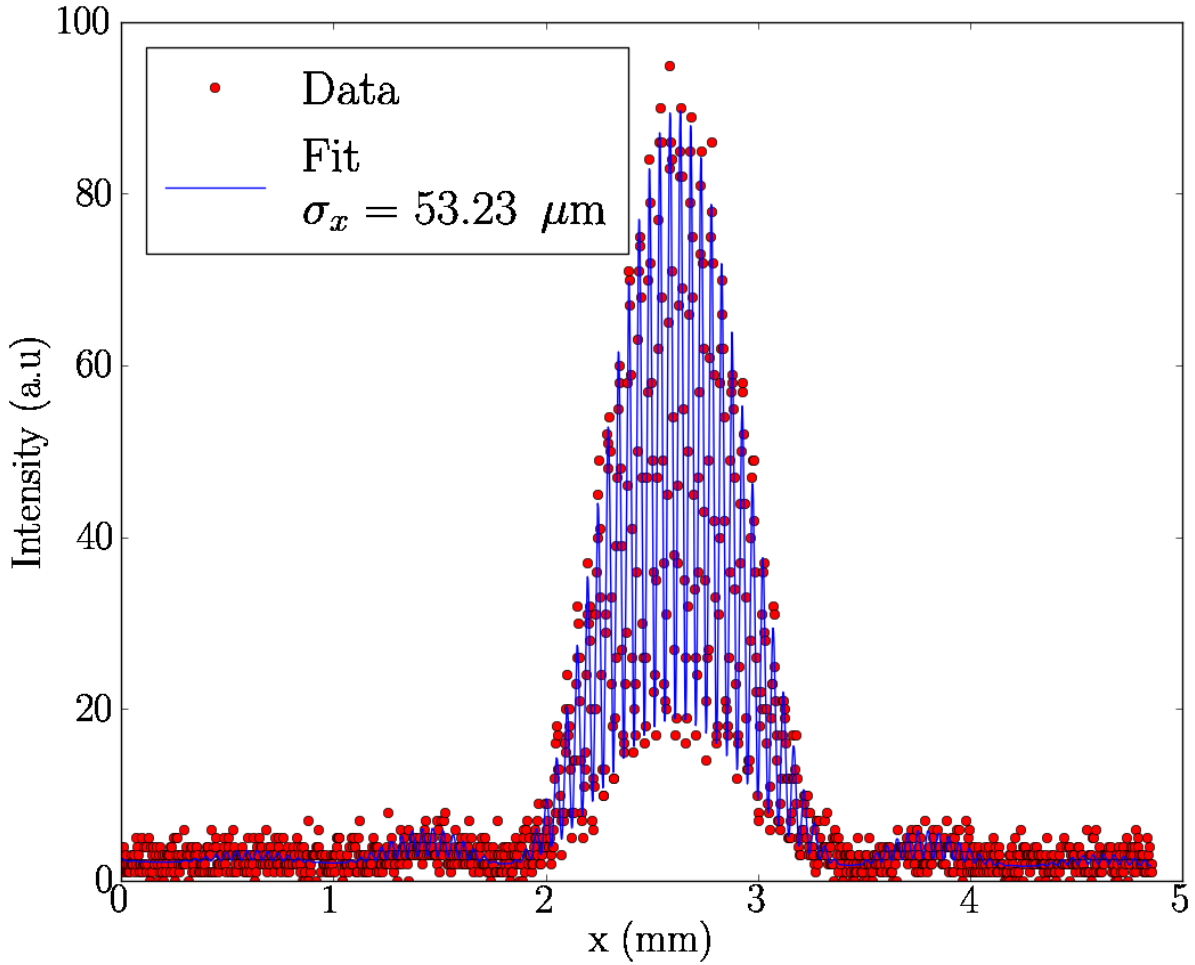
Double Slit Interferogram



Double Slit Interferogram



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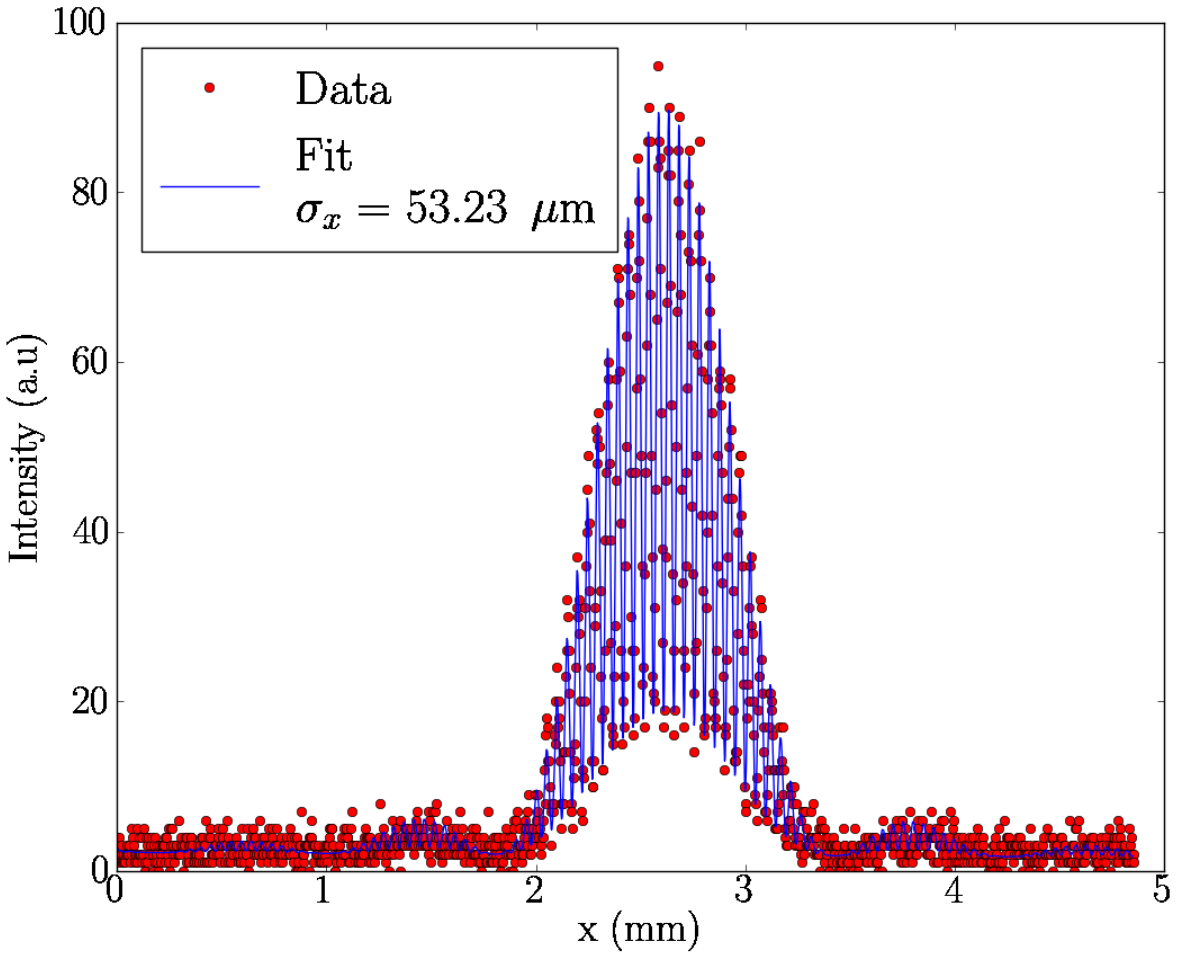


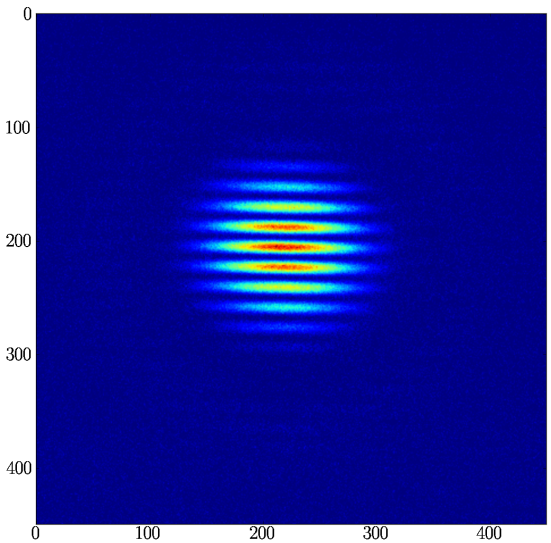
✓ OK horizontal measurements
× No good results for vertical measurements

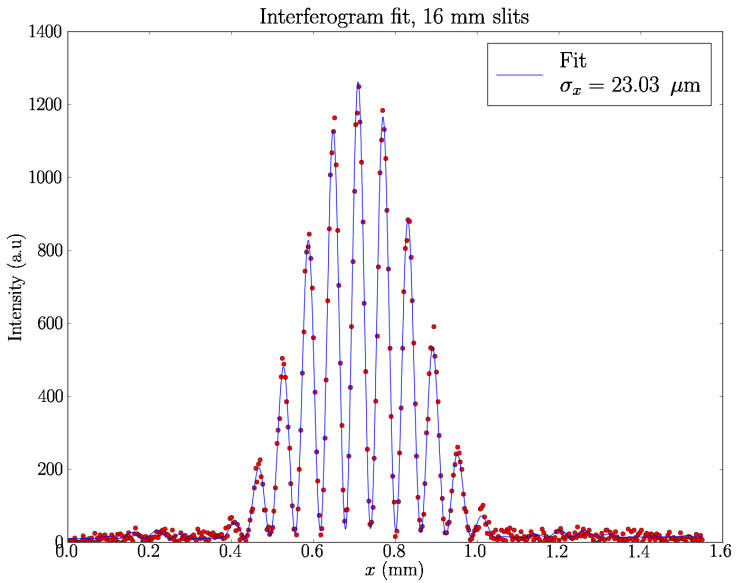
⇕

Not easy to align and fit

Double Pinholes

Using double pinholes instead of slits
diameter = 3 mm





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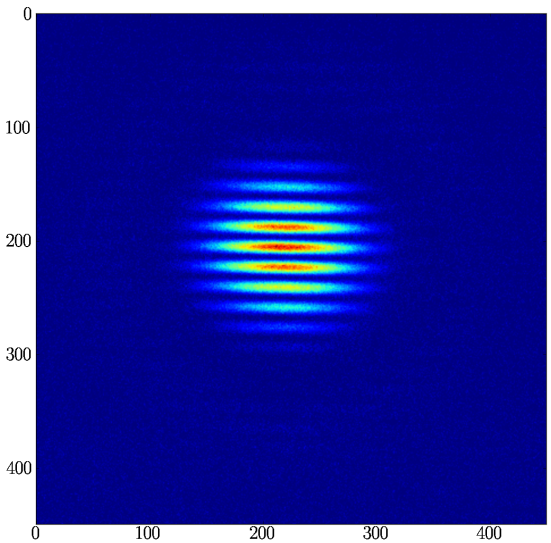

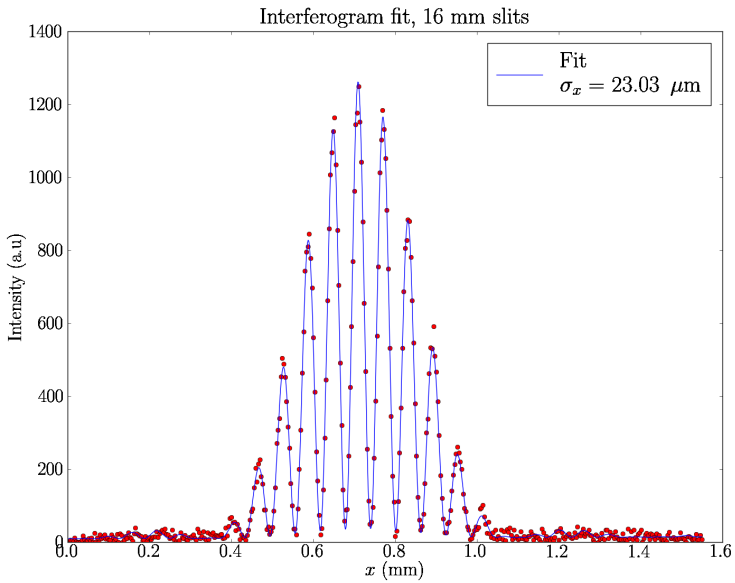

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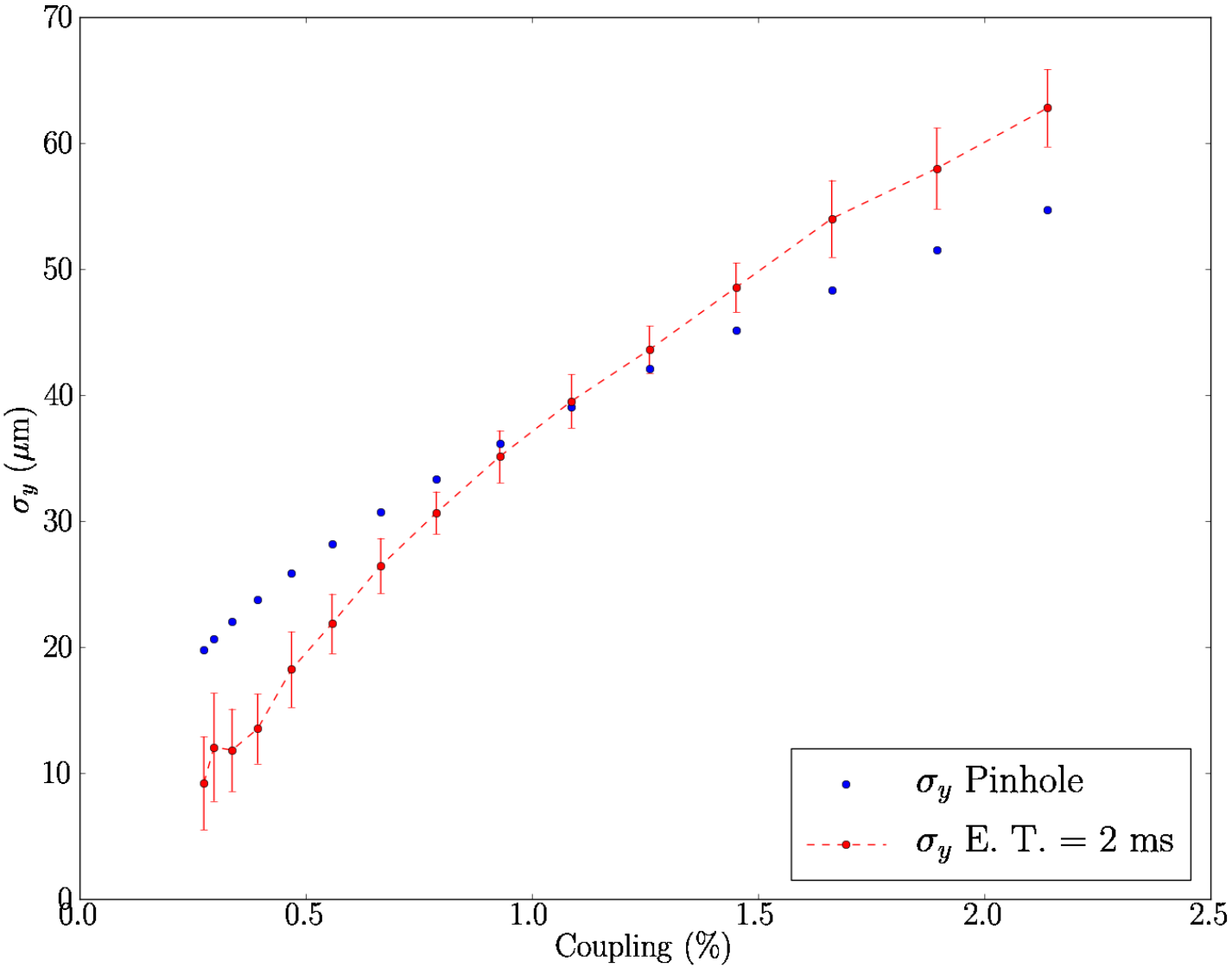
Coupling Scan

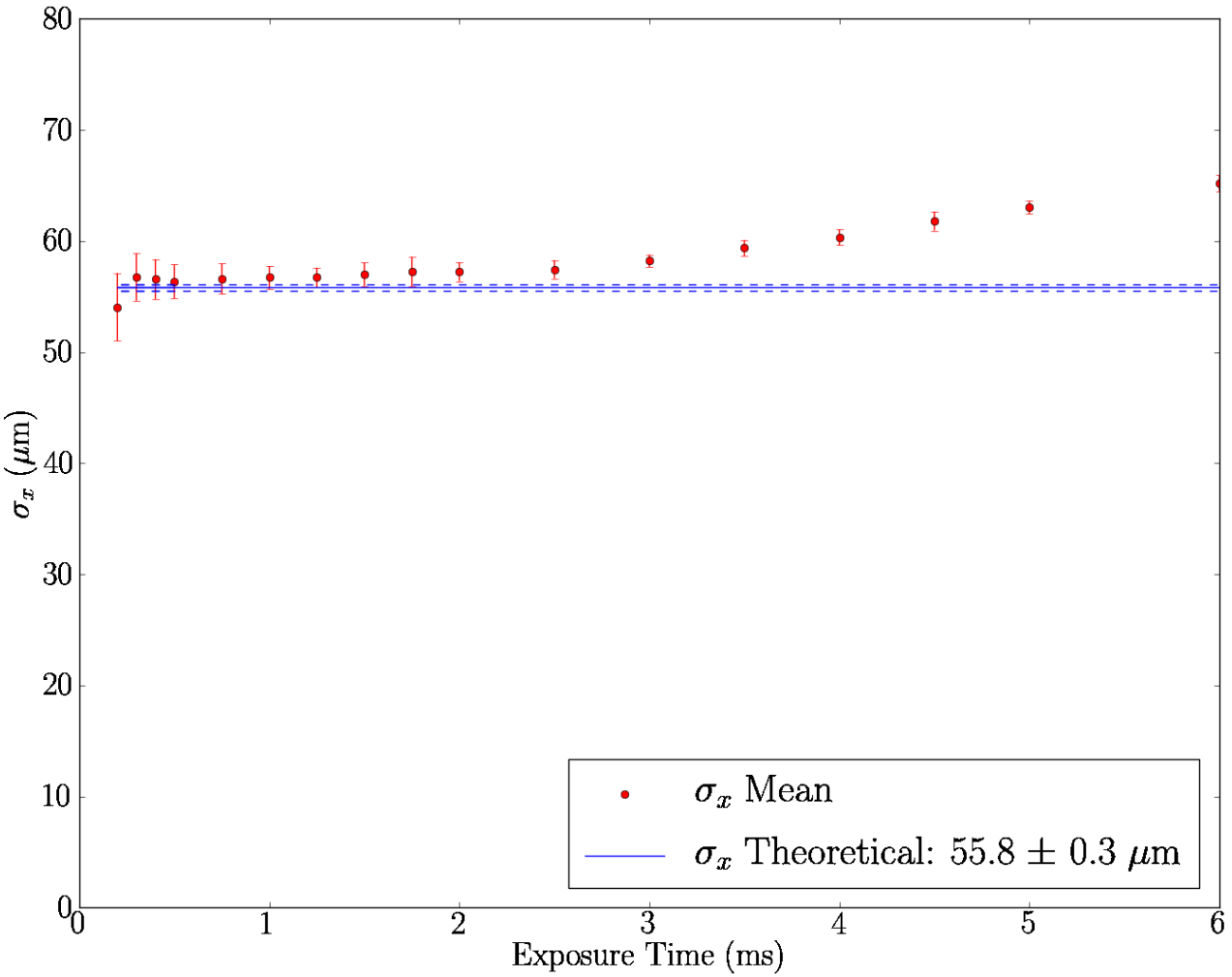


Issues

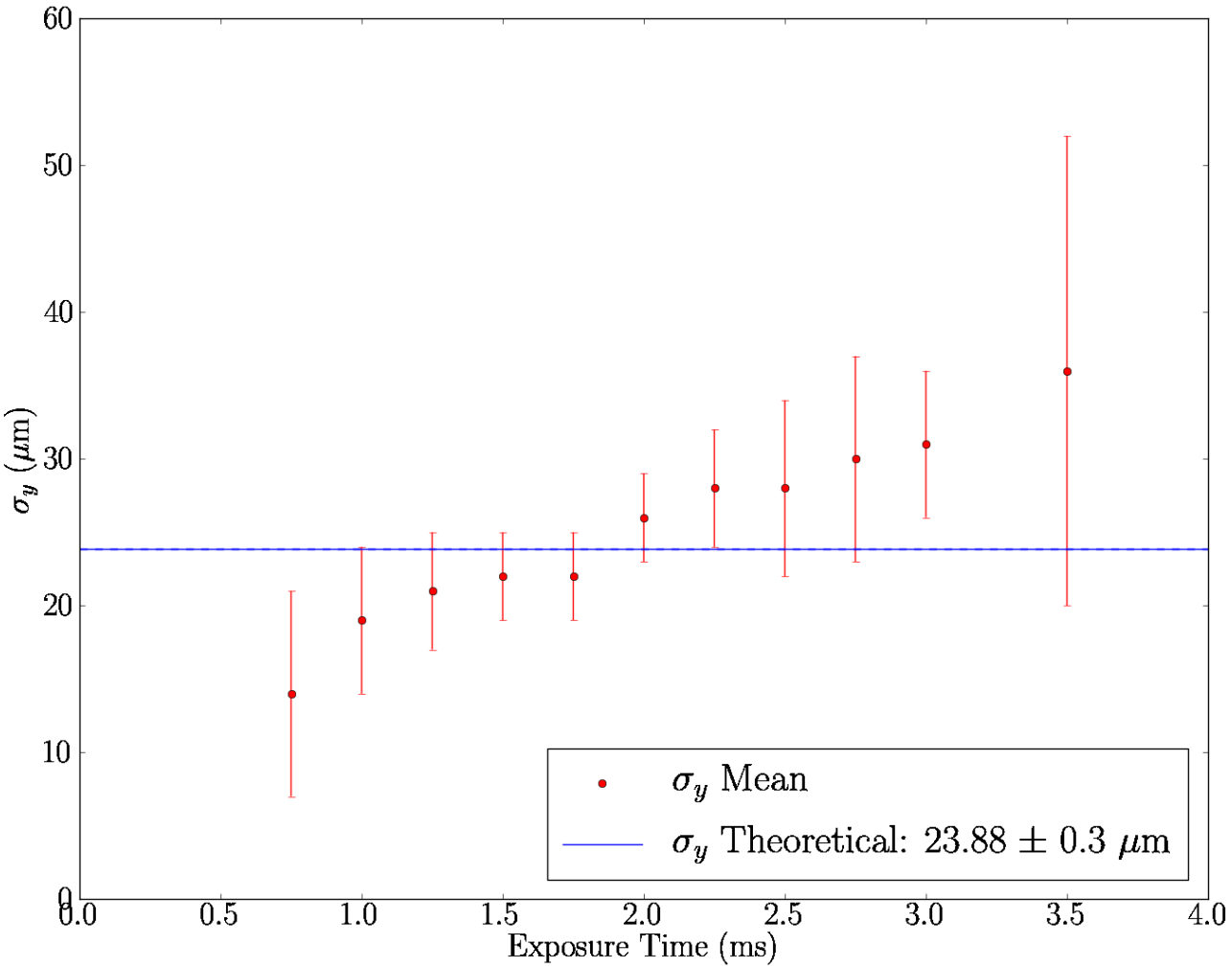
Once we learned how to align...
Additional issues come:

- Beam size measurements are sensitive to the CCD exposure time
  - Linearity of the CCD
  - Mechanical vibration or air turbulence influence
- Some applications require more light
  - Further image processing to match images

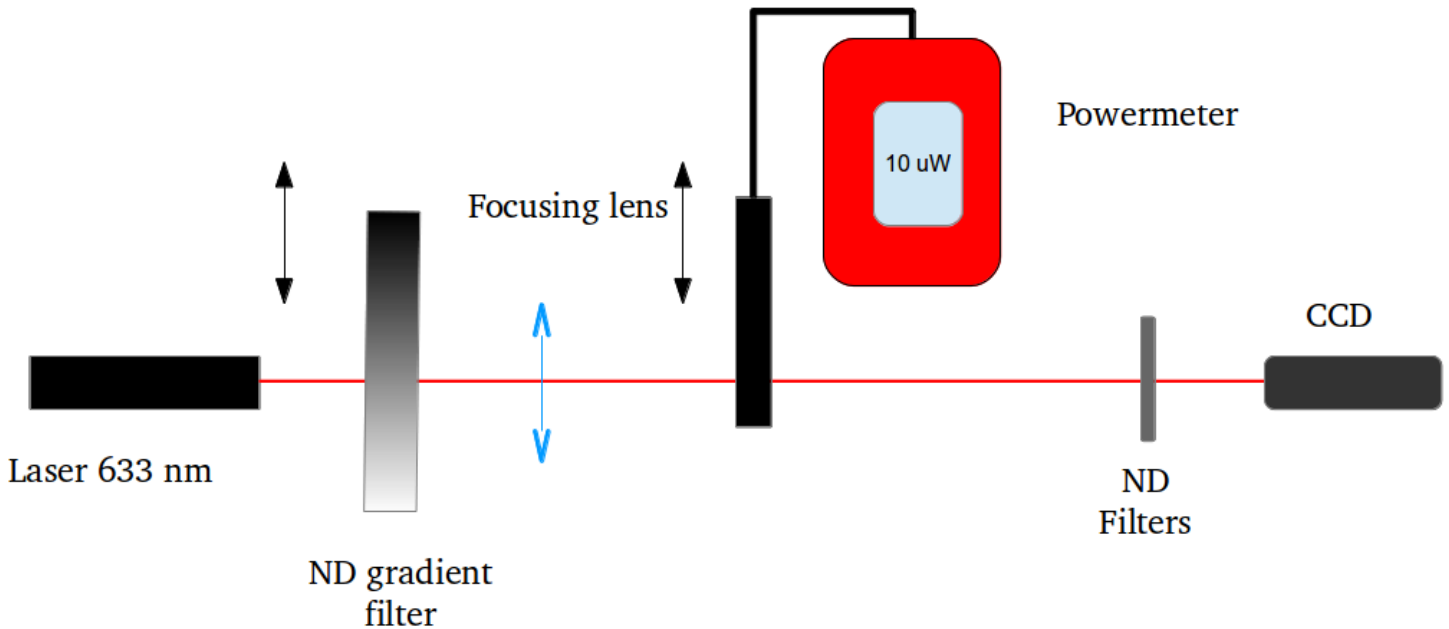
CCD Exposure Time Scan Horizontal



CCD Exposure Time Scan Vertical



CCD Linearity



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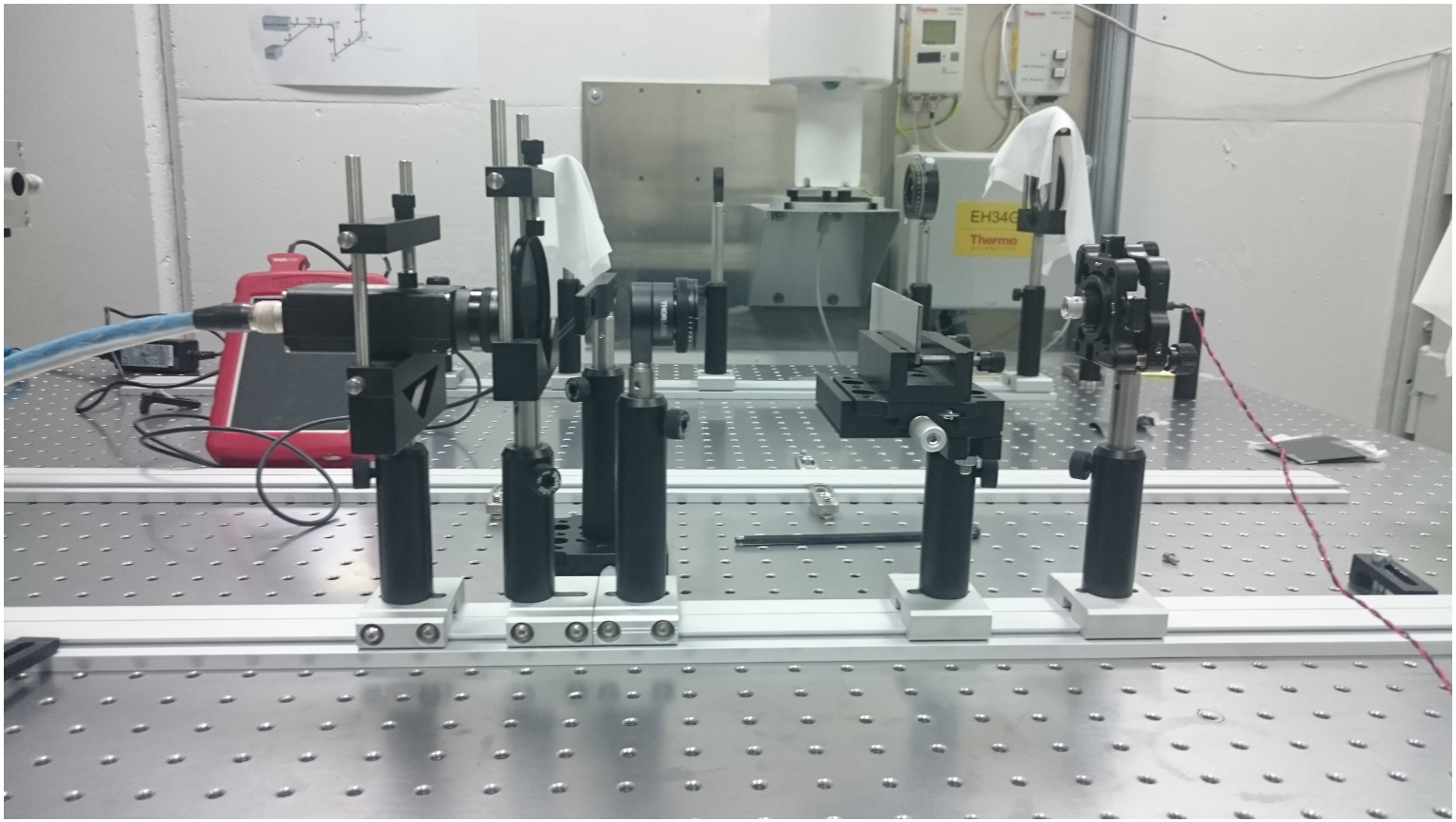
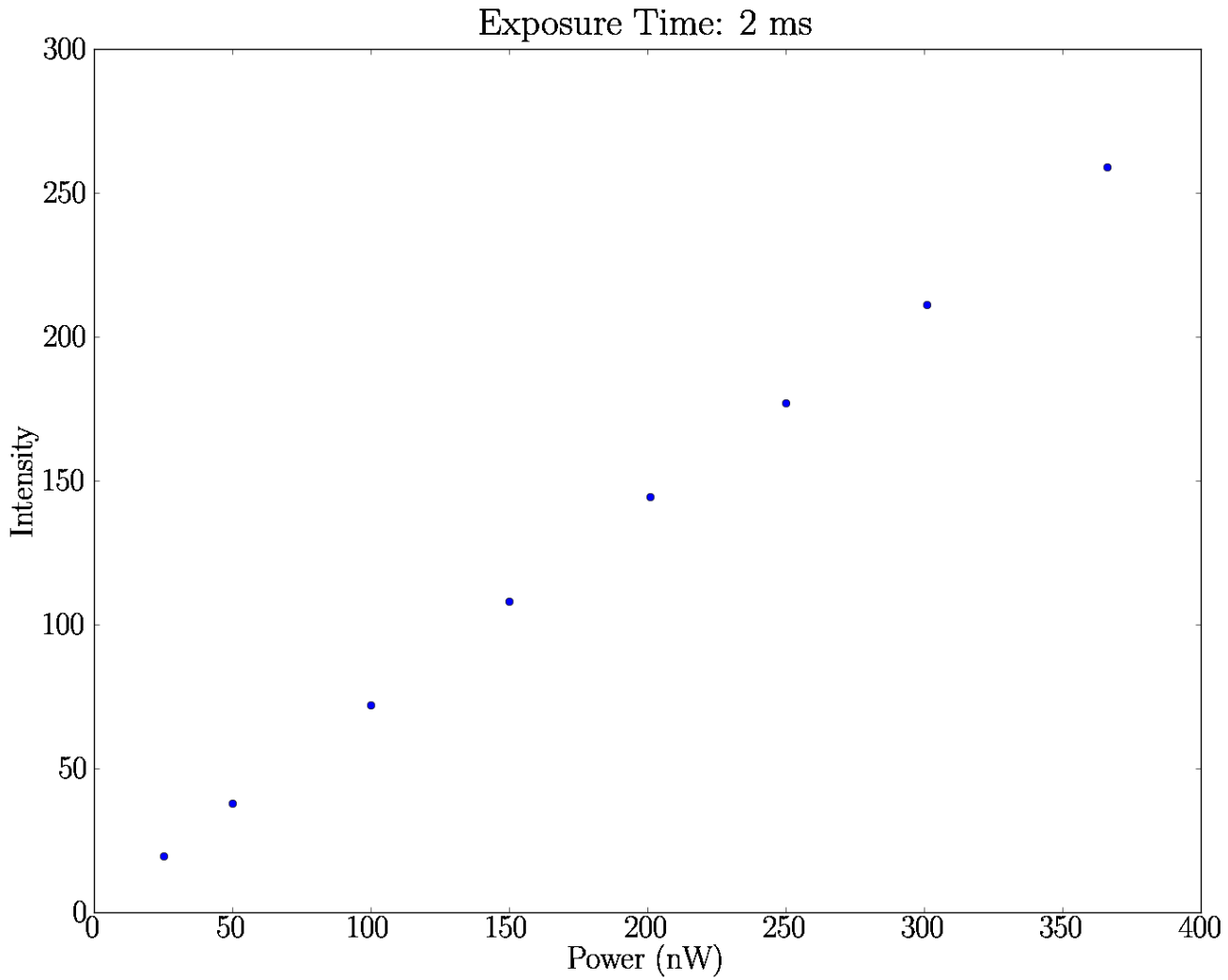
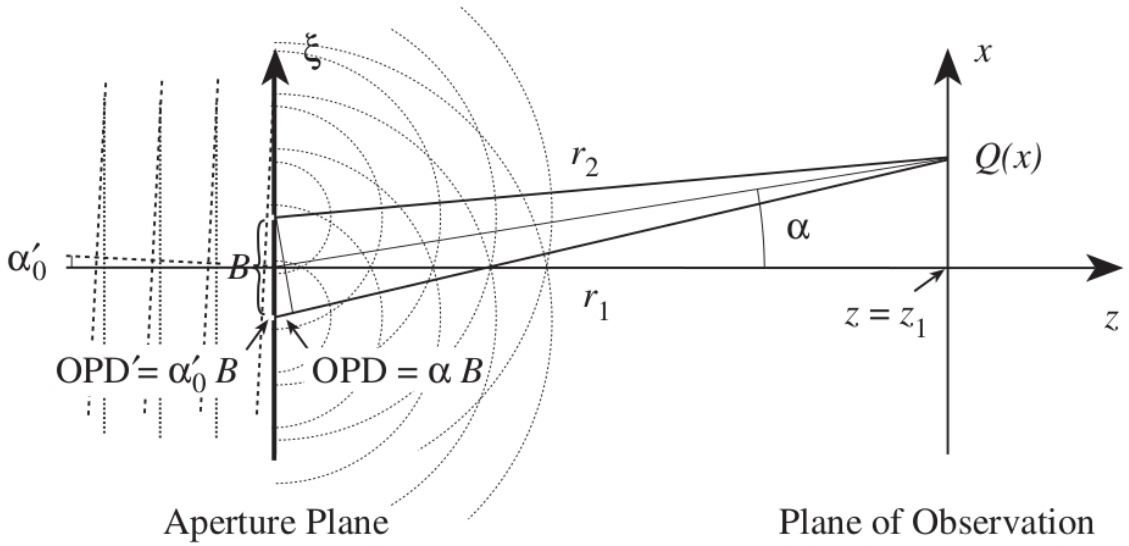


CCD Linearity



VIBRATIONS / AIR TURBULENCE

Mechanical vibrations and air turbulences have the effect of varying the width of the interference fringes magnifying the effective beam size



Introduction to Spatial Interferometry, Andrea Glindeman, ESO Garching

$$I \propto I_0 \left\{ 1 + \cos\left(\frac{2\pi}{\lambda} \alpha B \right) \right\}$$

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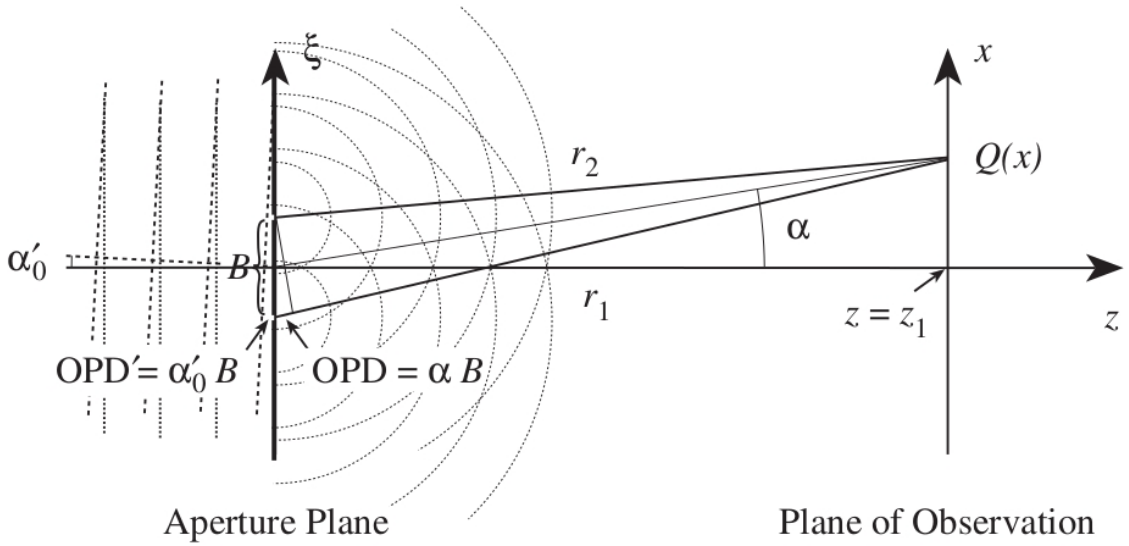

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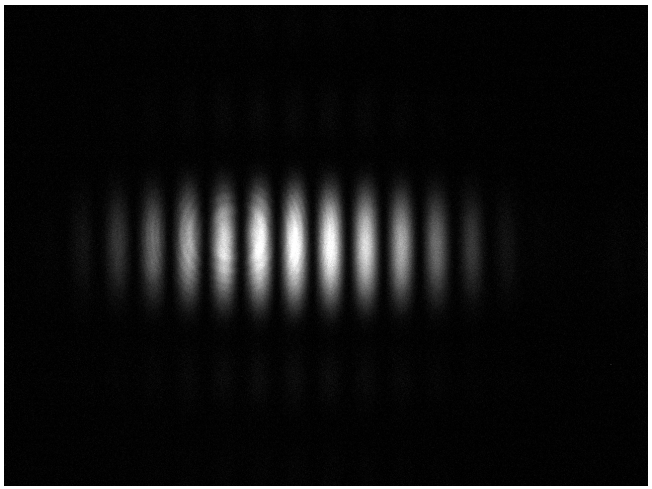
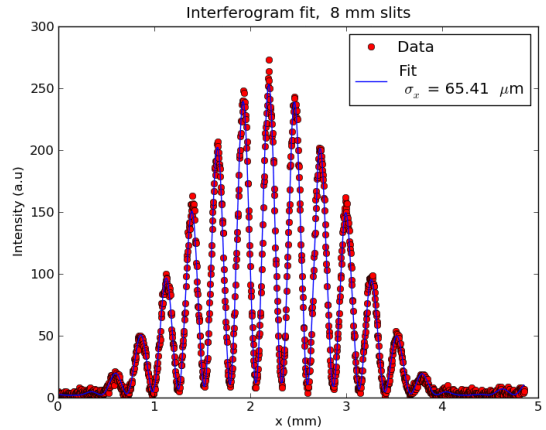
$$I \propto I_0 \left\{ 1 + \cos\left(\frac{2\pi}{\lambda} \alpha B \right) \right\} \qquad I \propto I_0 \left\{ 1 + \cos\left(\frac{2\pi}{\lambda} (\alpha + \alpha'_0) B \right) \right\}$$

VIBRATIONS / AIR TURBULENCE 2

Proper displacement of the interferogram position over the CCD sensor ⇒ Accumulating the images for long time generate a fictitious blow of the beam size





Possible solution: match low exposure time images

Matching Algorithm

Problem:

At low exposure time the images are very noisy $\Rightarrow$ Simply matching the maximum might not be enough

Solution:

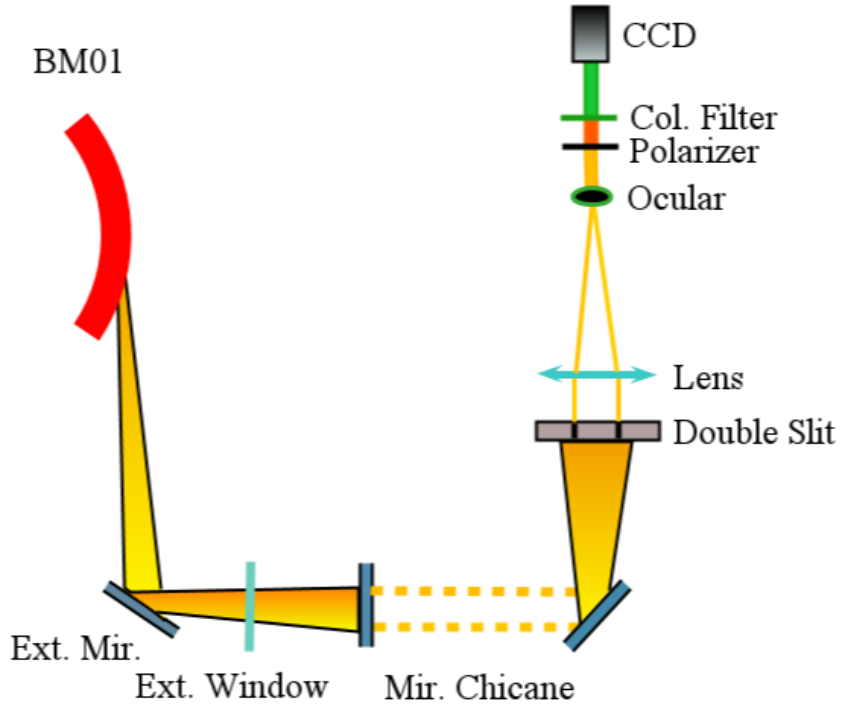
A bit of image processing:

- Chose a Reference and an Image
- Apply a low pass filter
- Normalize
- Compute the correlations: $(\text{Reference} \otimes \text{Image})^2$
- Find the maximum of the correlations matrix
- Displace the Image of the given amount
- Sum the shifted images

Many thanks to Josep Nicolás

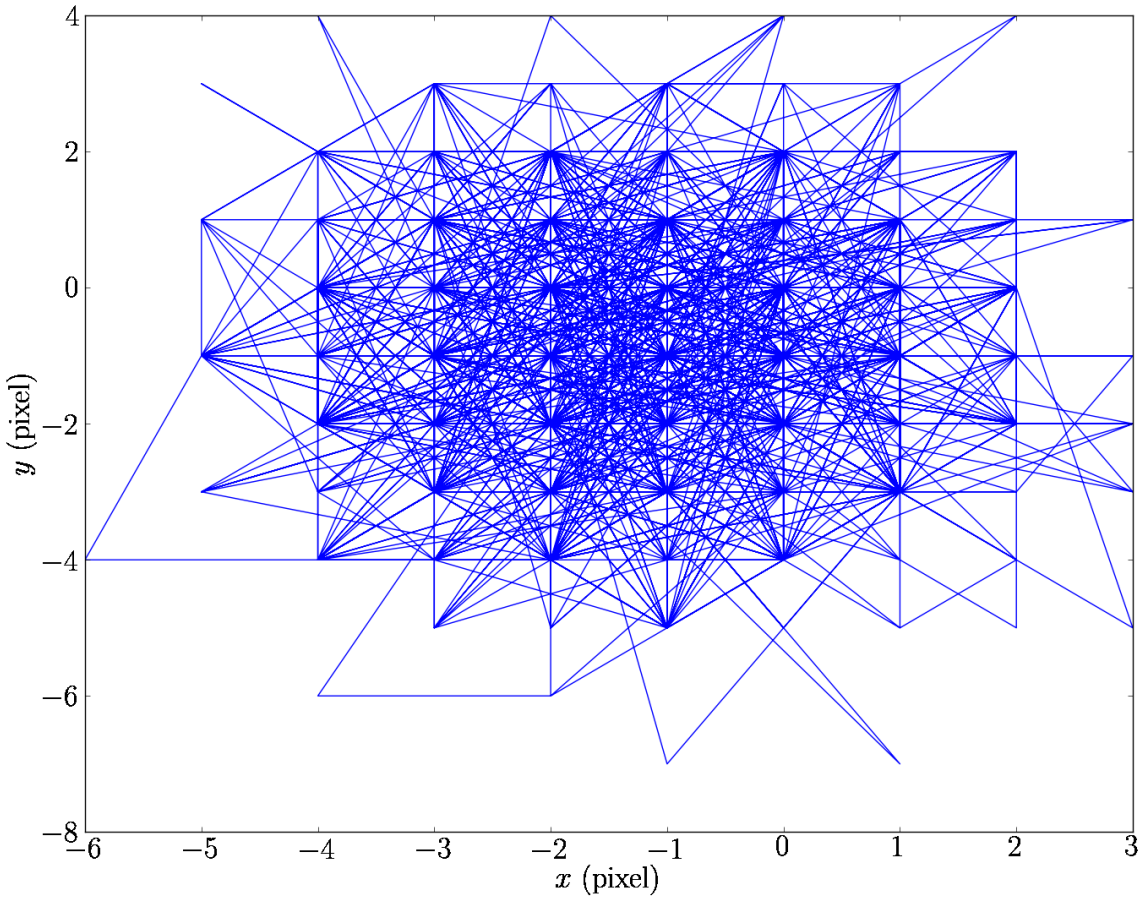
Image Acquisition

- Frame Rate = 100 Hz
- Exposure time = 100 μs
- Acquisition Time = 30 s

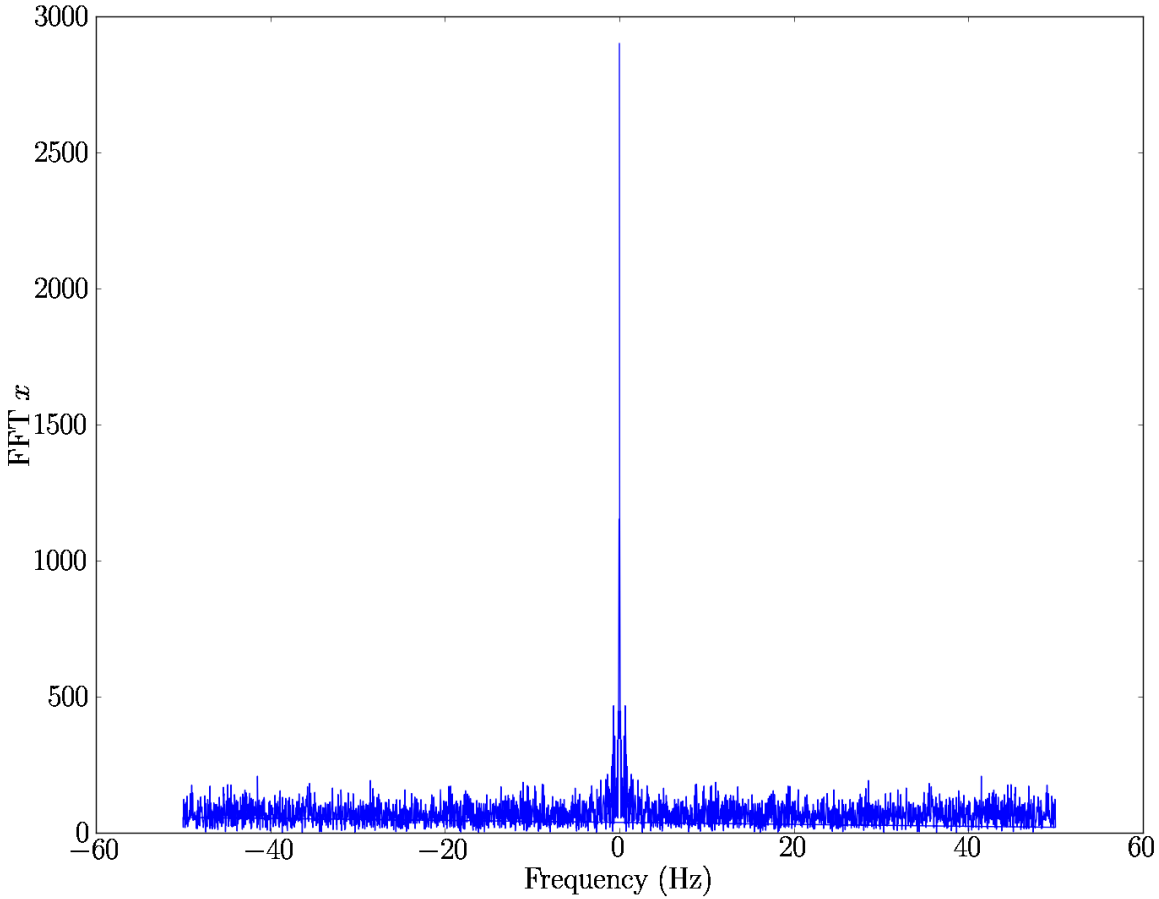


3000 Images to be matched
Effective Exposure Time = 300 ms

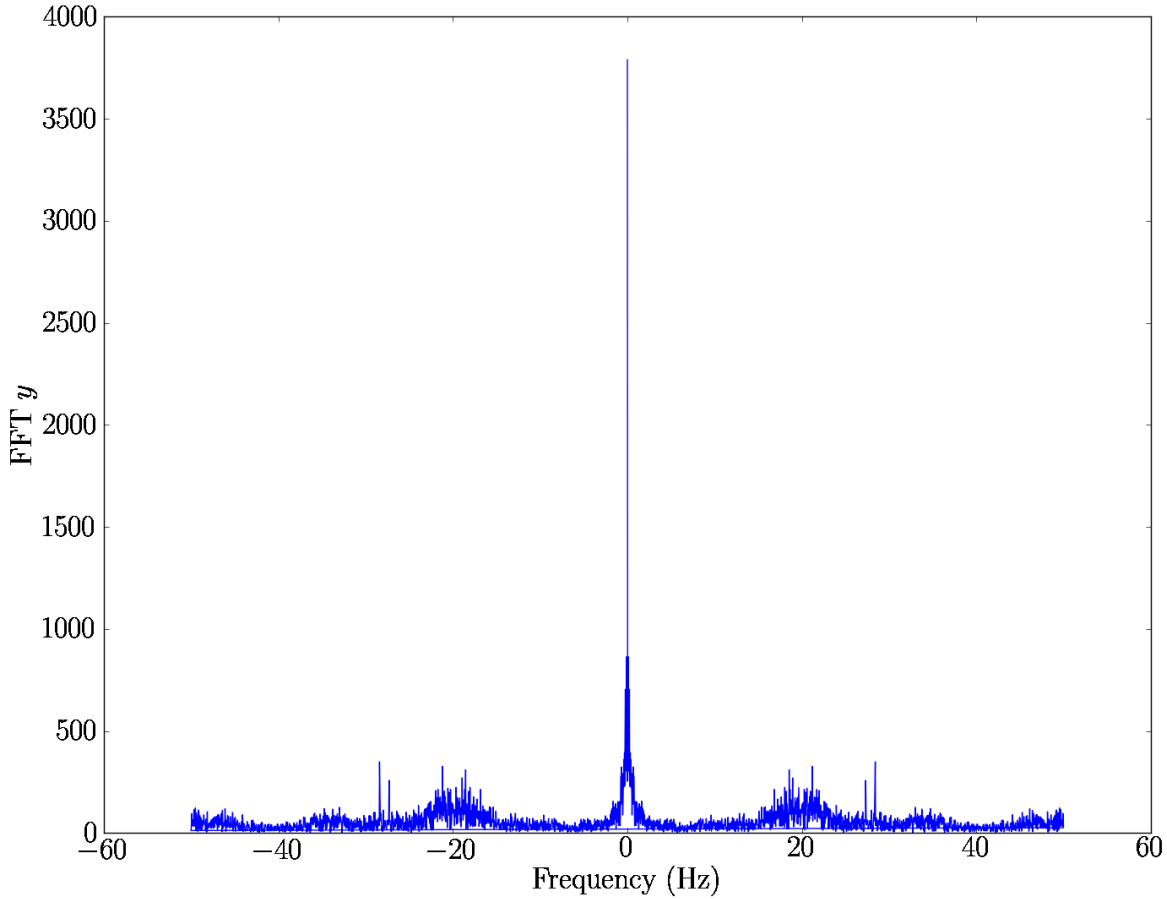
DISPLACEMENTS



Horizontal Vibrations



Vertical Vibrations



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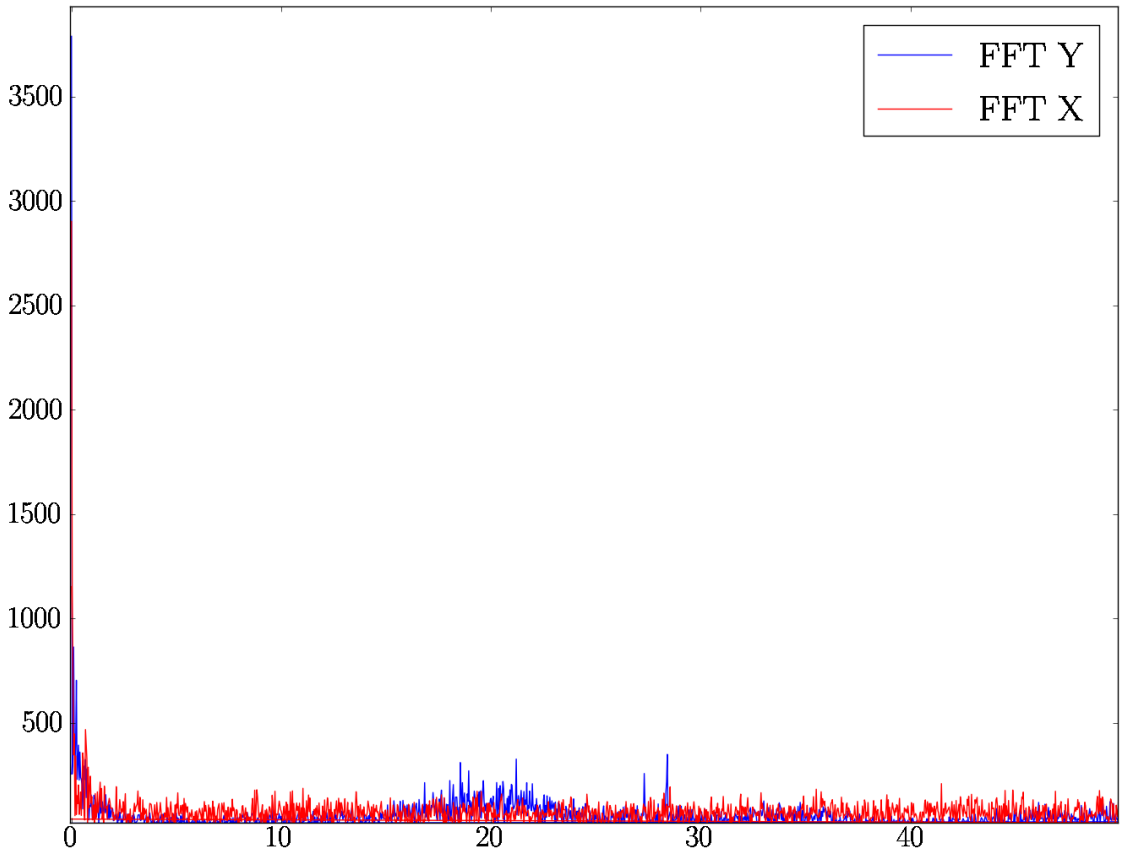

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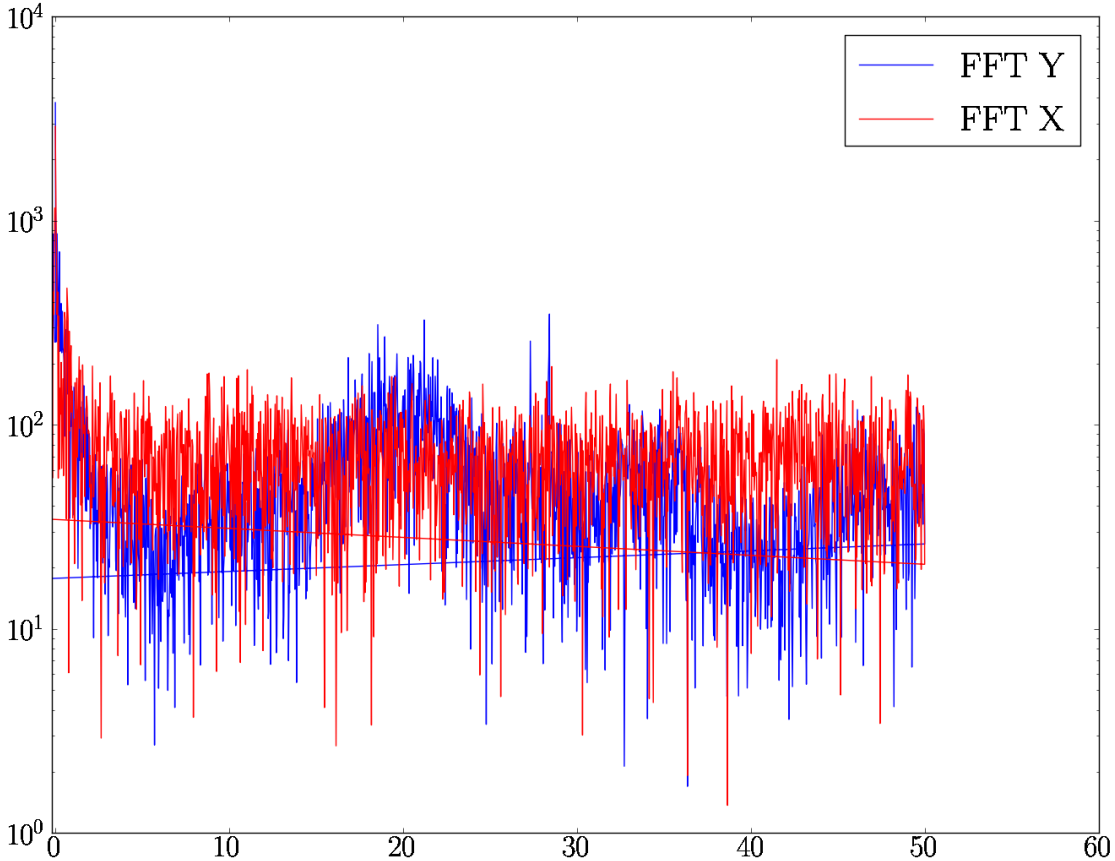
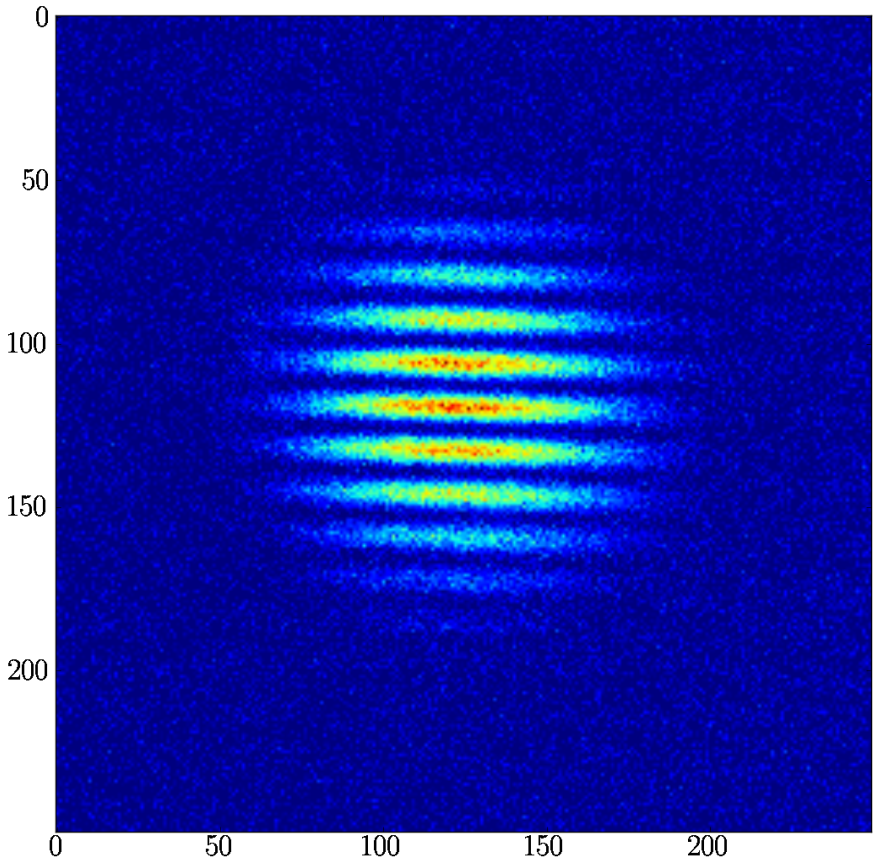


Raw Image



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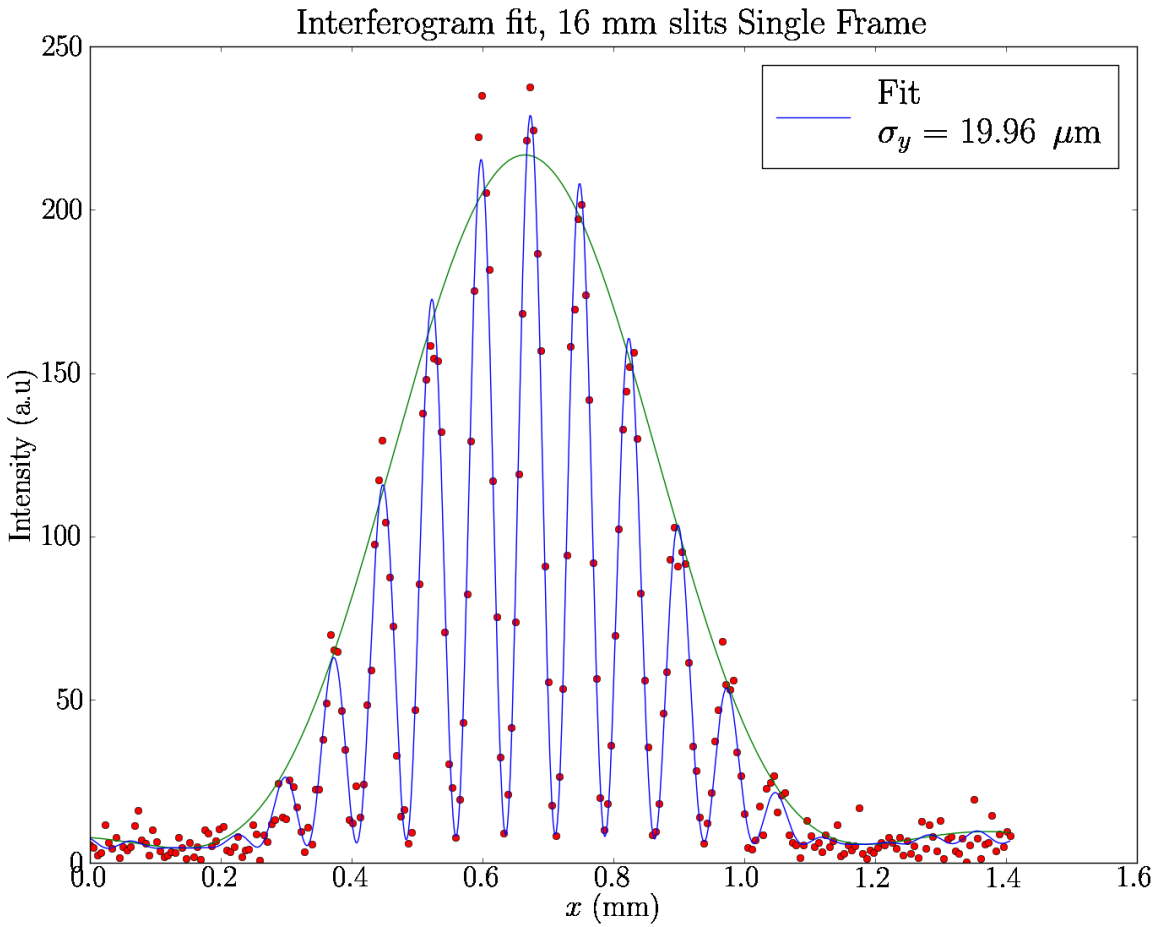
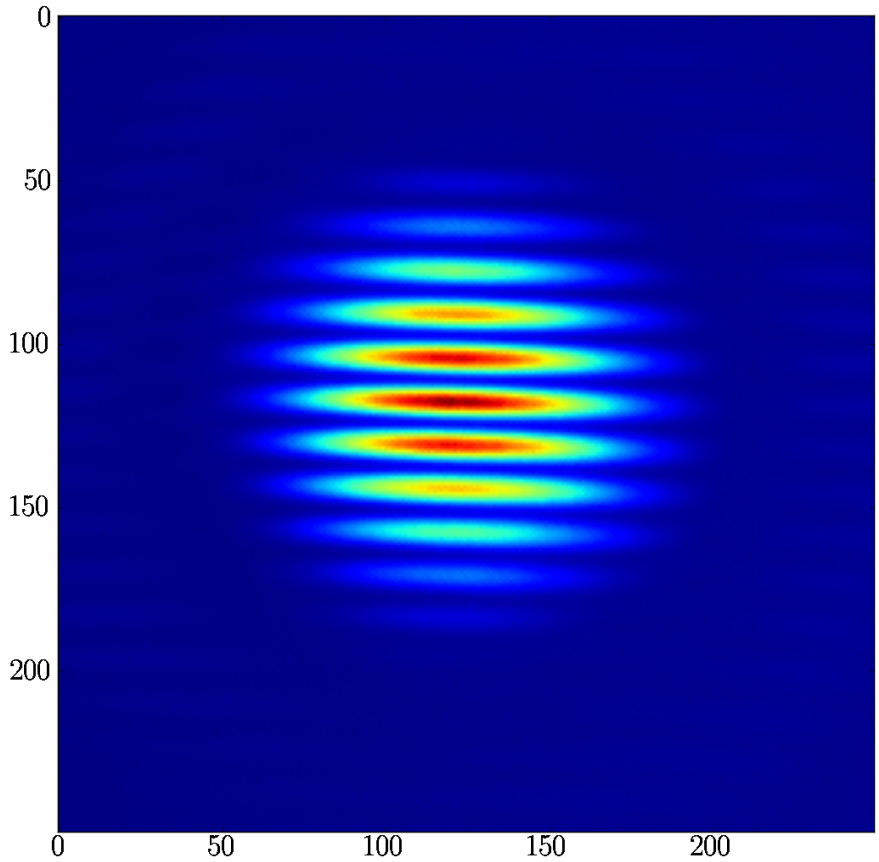

Interferogram fit, 16 mm slits Single Frame
Fit
$\sigma_y = 19.96\ \mu$m
Intensity (a.u)
x (mm)
0
50
100
150
200
250
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

Simple Superposition



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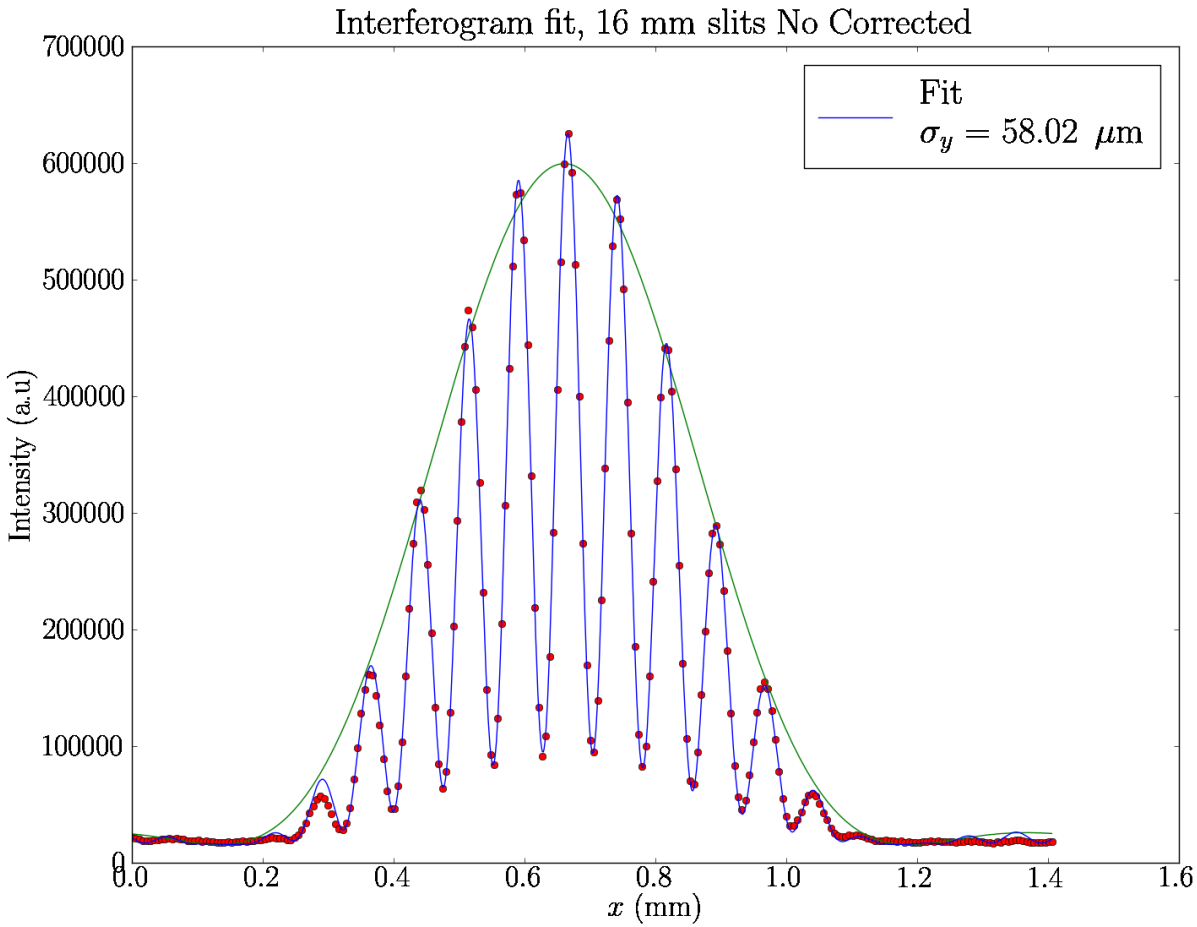
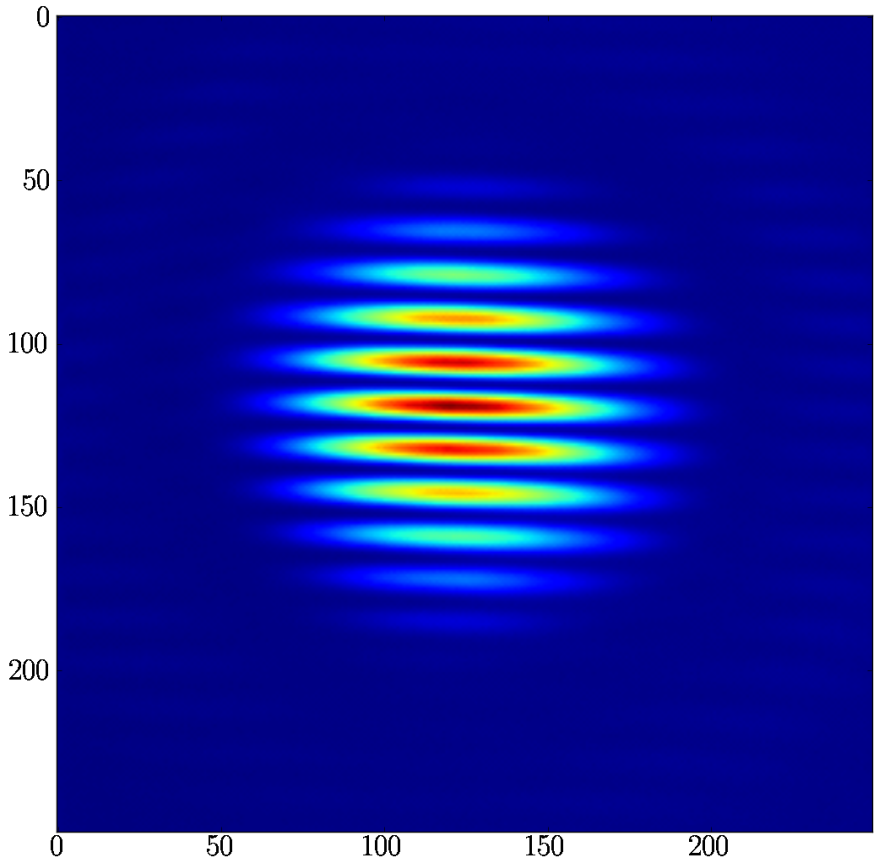


Matched Images



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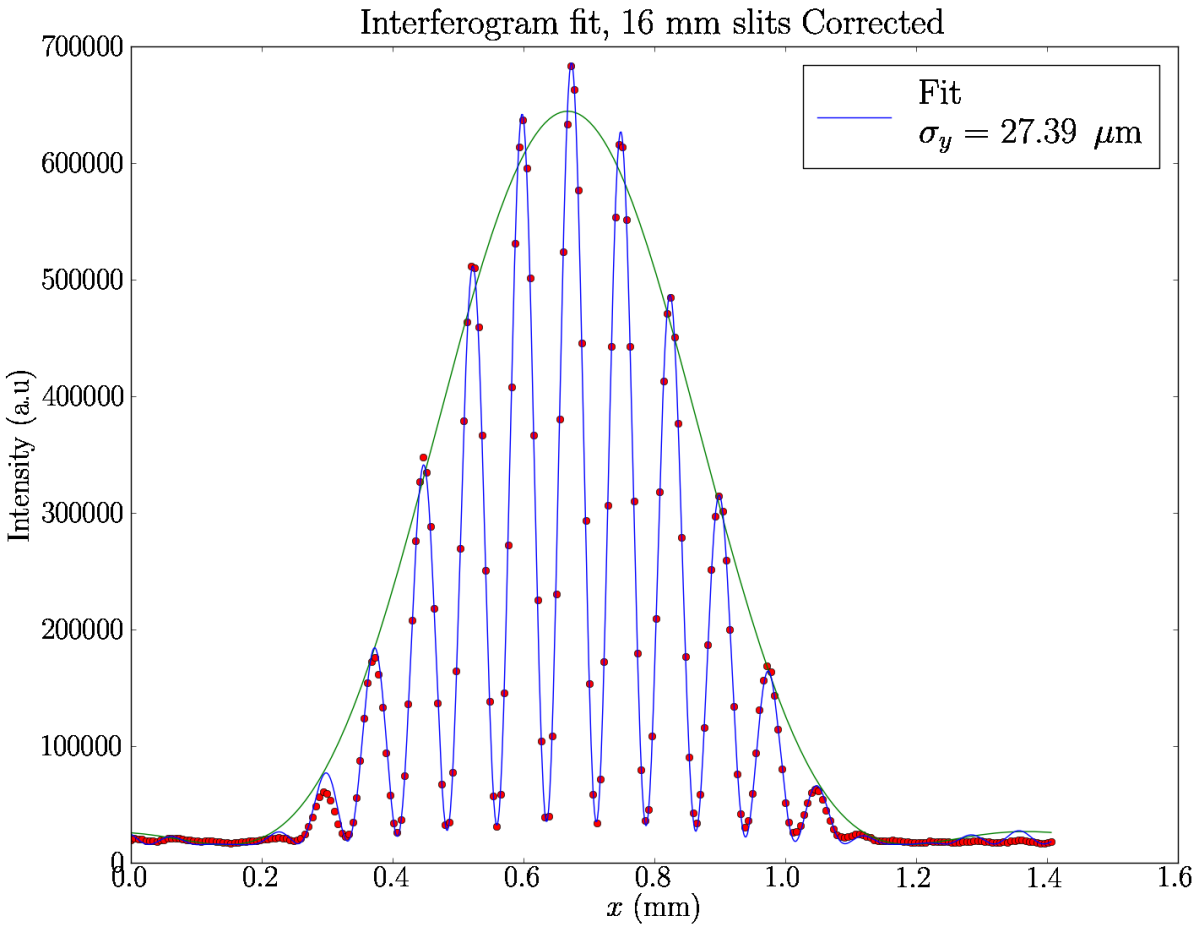
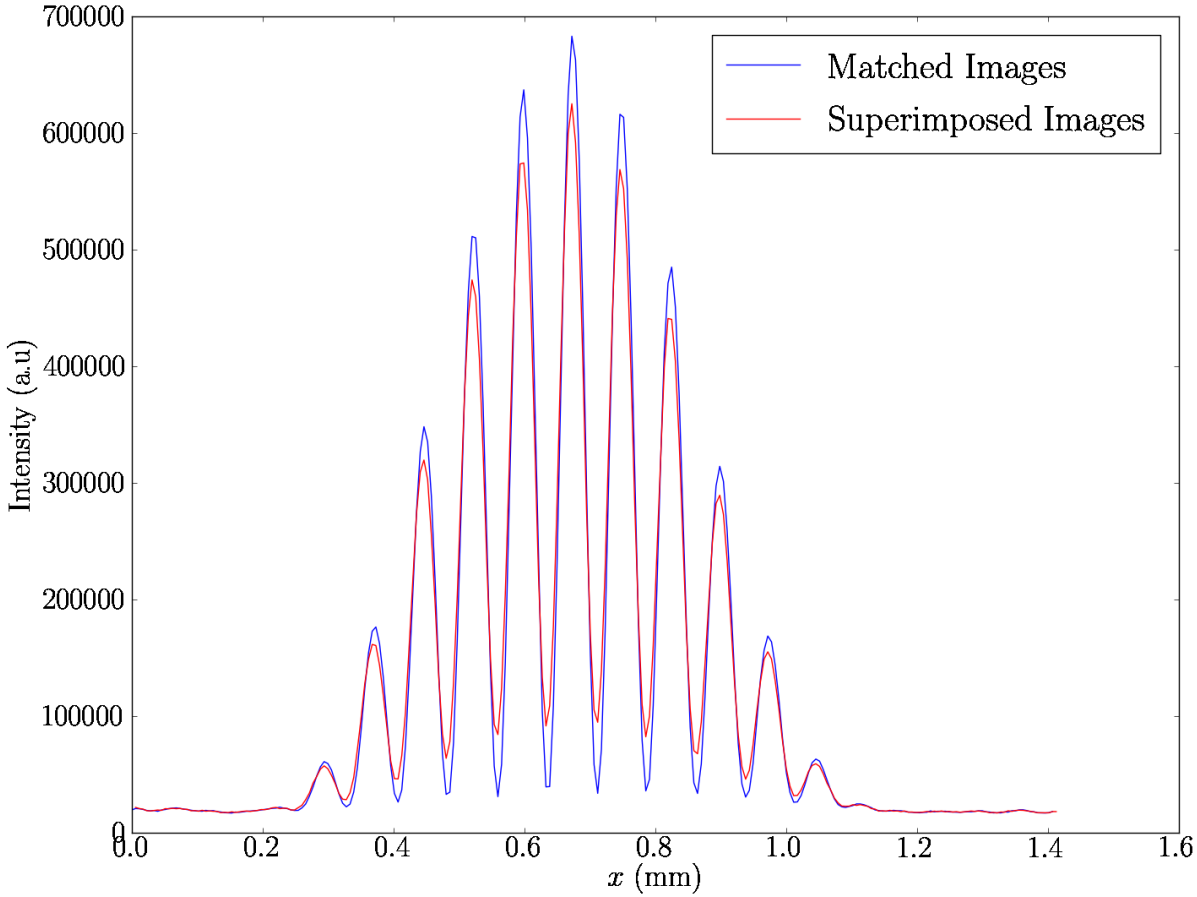


Comparison


Matched Images
Superimposed Images
Intensity (a.u)
x (mm)
0
100000
200000
300000
400000
500000
600000
700000
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

SUMMARY

- Interferometry is not that easy as it looks like
- Use pinholes instead of slits worked better for us
- Theory had to be changed accordingly
- Linearity of the CCD was tested
- Matching algorithm to minimize the effect of air turbulence was developed

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- Use pinholes instead of slits worked better for us
- Theory had to be changed accordingly
- Linearity of the CCD was tested
- Matching algorithm to minimize the effect of air turbulence was developed
- We could have a really cool logo for the ALBA DEELS

Many thanks to T. Mitsuhashi, U. Iriso, J. Nicolás, S. Blanch for the valuable help.

BACKUP SLIDES

THEORY

$$I = I_0 \left\{ \frac{\mathrm{J}_1\left(\frac{2\pi a x}{\lambda f}\right)}{\left(\frac{2\pi a x}{\lambda f}\right)} \right\}^2 \times \left\{ 1 + V \cos\left(\frac{2\pi D x}{\lambda f}\right) \right\}$$

$$\sigma = \frac{\lambda L}{\pi D} \sqrt{\frac{1}{2} \ln \frac{1}{V}}$$

- I_0 Intensity of the interferogram
- J_1 Bessel function of the first kind
- a Half diameter of the pinhole
- f Focal distance between the first lens and the CCD
- λ Radiation wavelength
- V Visibility $\simeq \frac{I_{Max} - I_{min}}{I_{Max} + I_{min}}$
- D Distance between the pinholes centers
- L Distance between the source and the double pinholes system