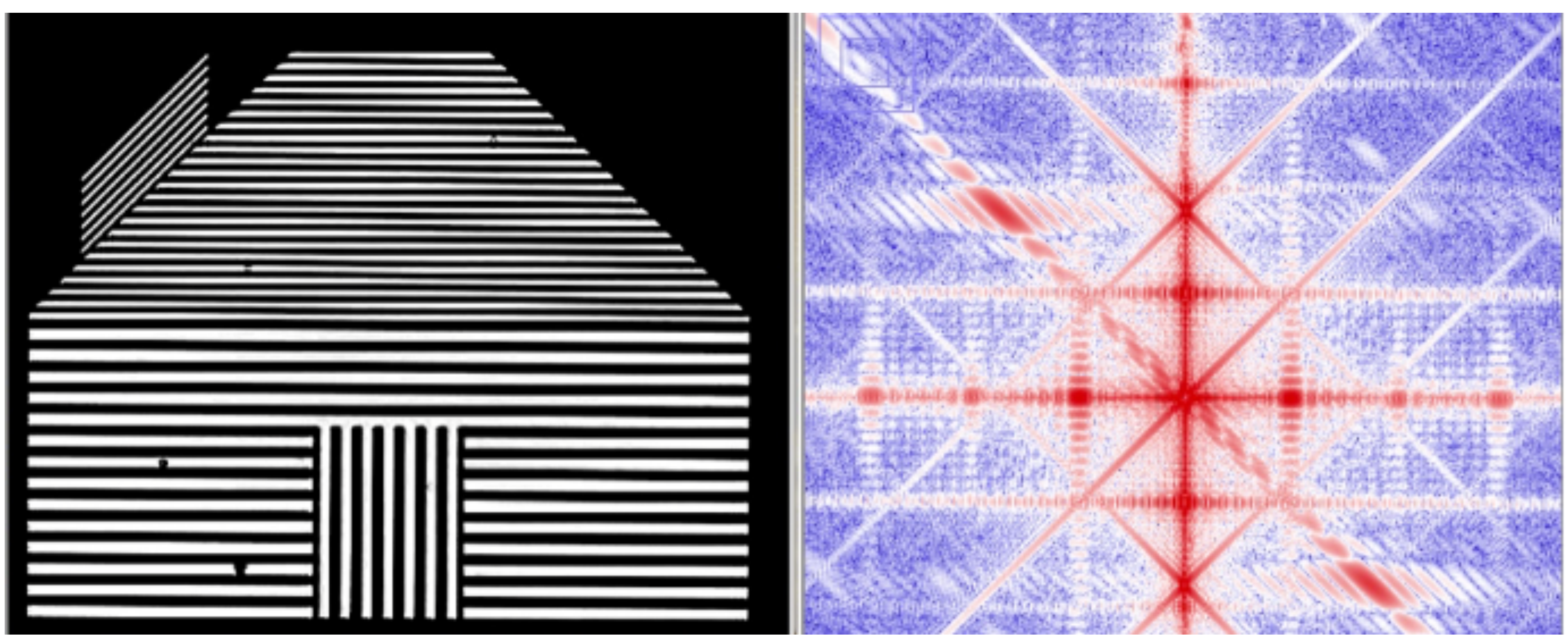
CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

ILP1: Optical Fourier transform

Mikhail Korobko



- I took over the experiment in 2016
- Some modifications every season to improve experience: completely re-wrote the description, updated optics several times, added more simulations
- Average duration: 1.5-2 days + simulations,
but severe drop in duration in the last year (why?)

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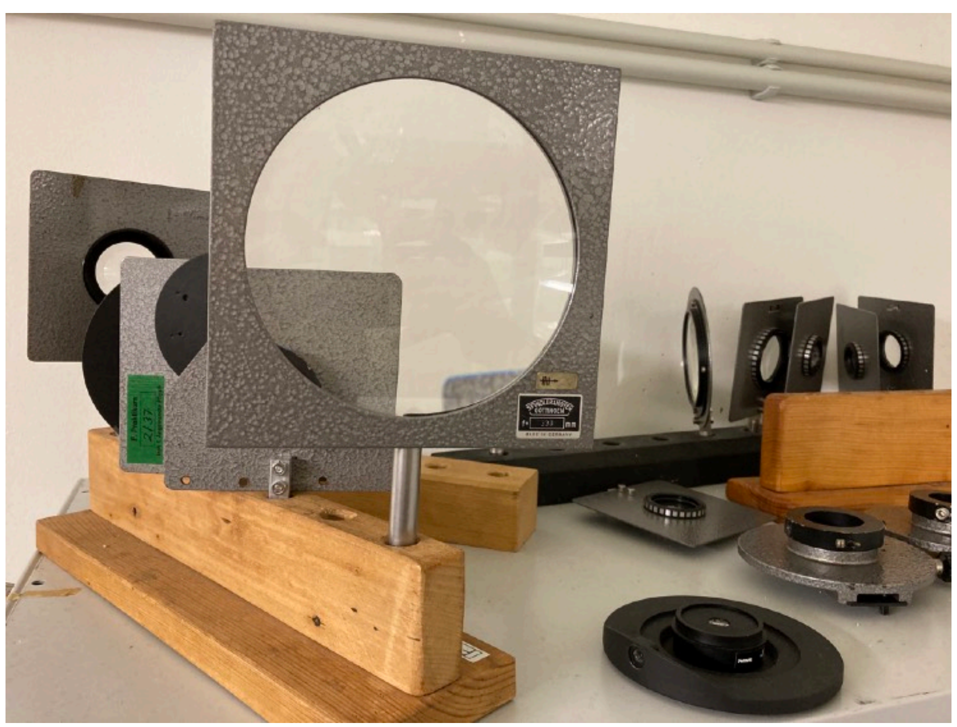
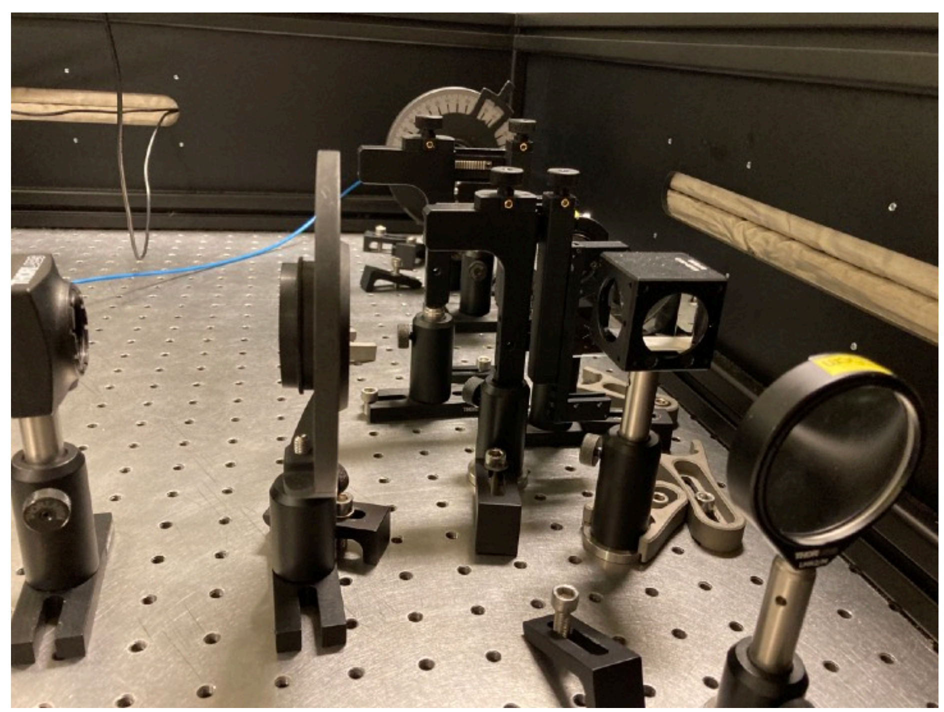
This season:

- Completely new components: new alignment, new masks, +1 CCD, etc
- New exercises: more quantitive analysis, more simulation
- New description: from 1 page of exercises to 9 pages

2016 → 2023





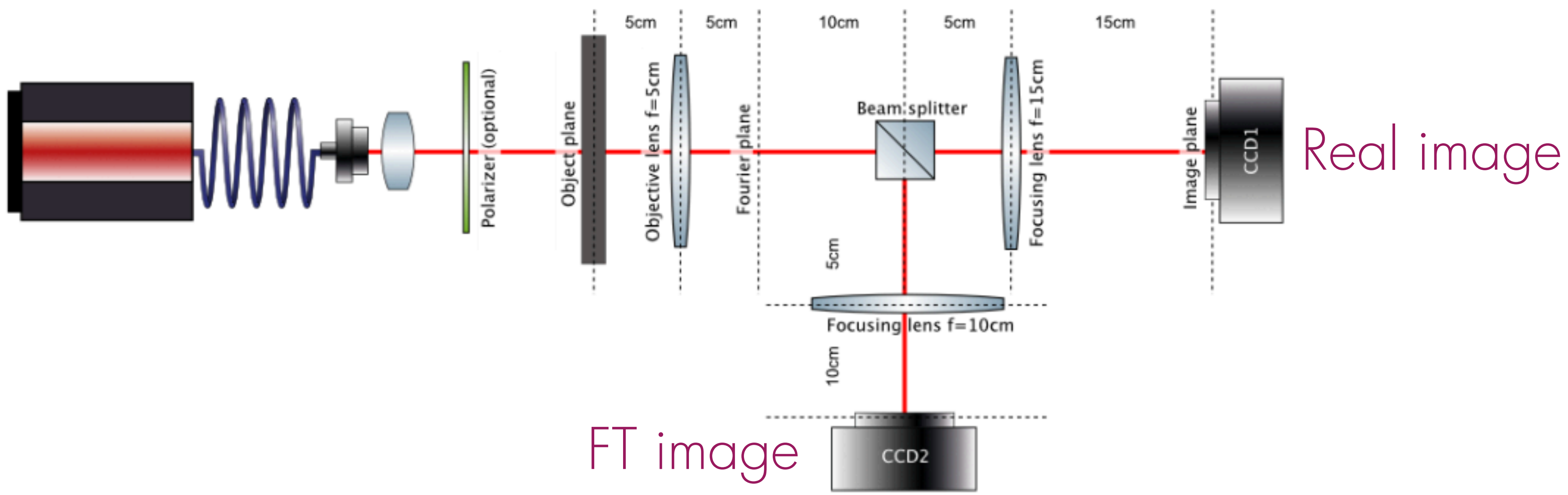
Main goal: understanding of FT and its origin in diffraction on a physical level

1. Detailed introduction (since no previous knowledge is required)
2. Day 1: optical alignment, first test, understanding the experimental setup
3. Day 2: completing the experimental setup, main experiments
4. Day 3: finishing & re-taking the data if needed, computer simulations
5. Not in presence: data analysis & protocol

Main goal: understanding of FT and its origin in diffraction on a physical level

Several steps:

1. Introduction: fundamental properties of FT and diffraction
2. Experiment 1: Far field diffraction, Fourier limitation, qualitative measurements of wavelength, grid period, lens magnification
3. Experiment 2: FT with various objects, comparison to far field, filtering
4. Simulation 1: Computer simulation of Experiment 2 and their comparison
5. Simulation 2: Computer simulation of FT properties on self-generated images



Data analysis

- CCD pixel size → image size & distances
- Diffraction on a grid allows to calibrate measurements
- Pixel size, statistical errors → data analysis
- Difference between analog and digital FT, observing errors due to optics misalignment, dust, astigmatism, etc.

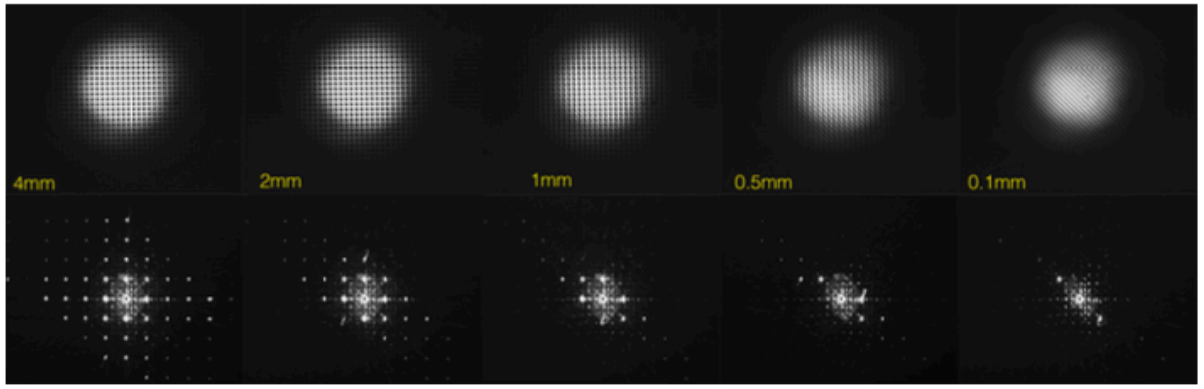


Figure 27: F4 Grating

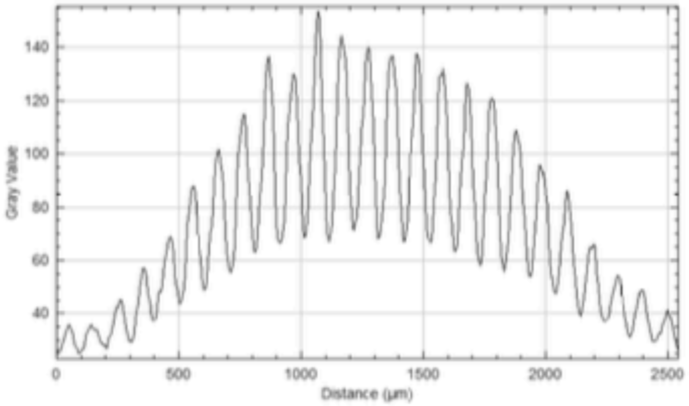


Figure 28: F4 Grating Plot

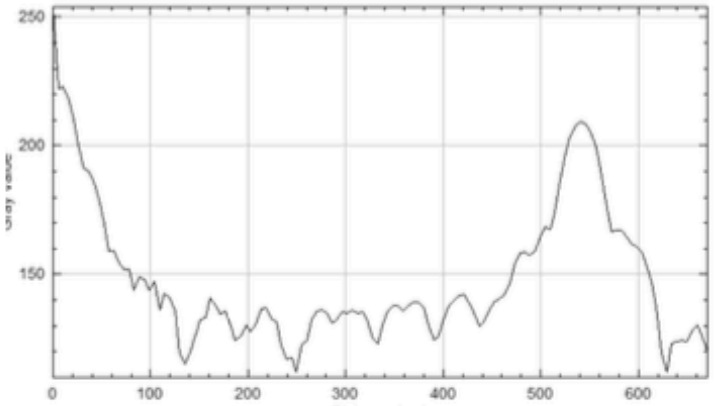
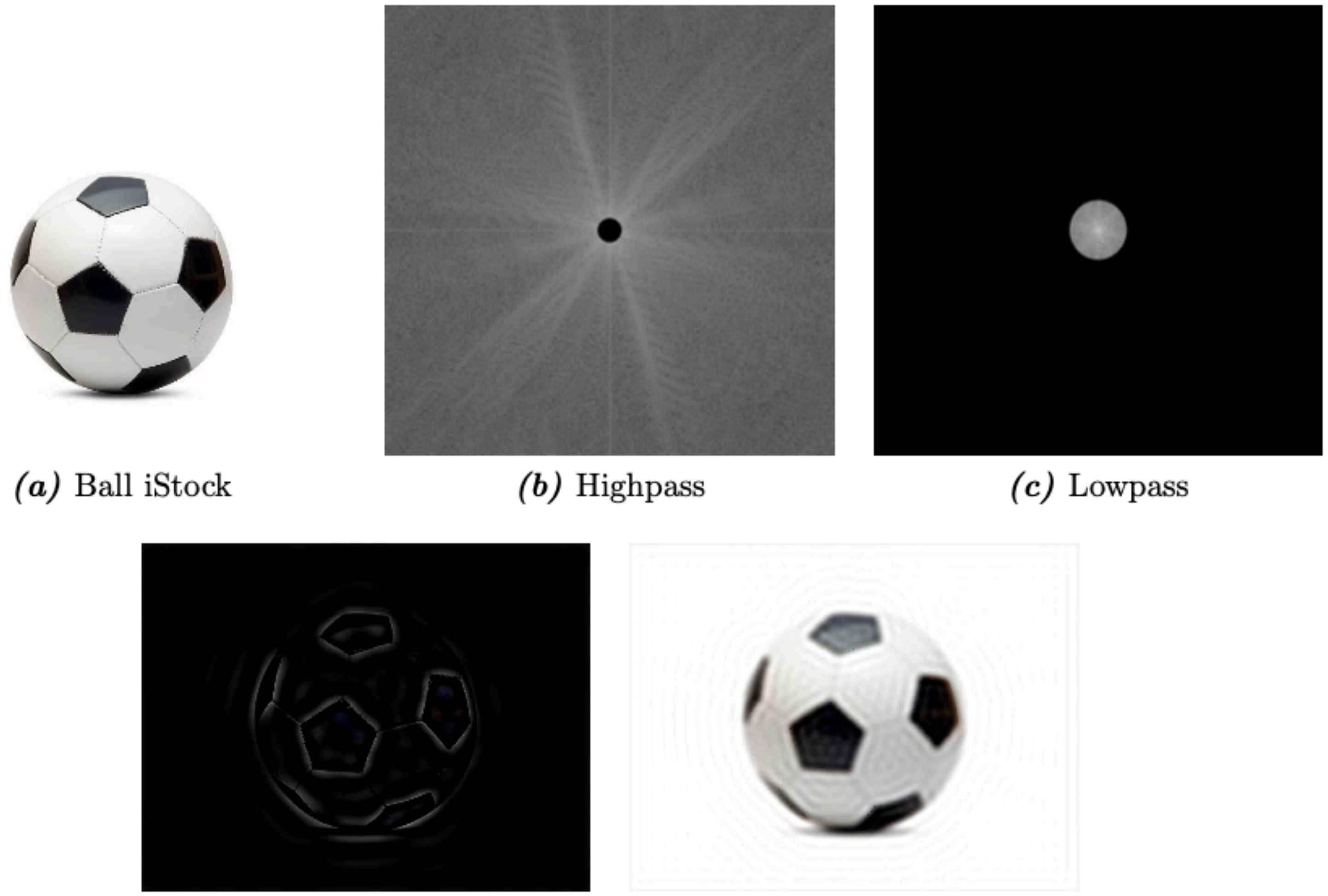


Figure 29: Profile plot of Fourier transform to the first maxima

Practical skills

- Precise optical alignment
- Working with lenses, understanding properties of real lenses
- Working with scientific image processing software: ImageJ



(a) Ball iStock *(b)* Highpass *(c)* Lowpass

(d) ReFFT Highpass *(e)* ReFFT Lowpass

Points of reflection

Scientific context:

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Aim of the experiment:

- The emphasis of the experiment: optical setup and experimenting with different objects; qualitative picture backed up with quantitive data & simulation
- Comparison to state-of-the-art: equipment is most modern. Techniques are old, but that's the point of the experiment

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Experimental setup (The black box)

- Do students have the possibility to assemble the setup? Full
- Can they modify parameter? What is the largest systematic effect? Full
- Do they learn how is the measurable "signal" obtained? Yes

Points of reflection

Data analysis methods

- Data analysis: key aspect
- Challenges: getting good data, understanding FFT
- Self-written code: no (no code at all)

Link to modern research

- Modern application: holography, tomography, computing, signal processing, spectroscopy, metrology, imaging, etc.
- Where these are applied: XFEL, ILP, CEFL...Where are they not?
- Skills: working with optical systems, precise alignment, hypothesis testing
- Difference to state-of-the art: that's a small piece of any state-of-the art system. Here — more direct monitoring

Future

More improvements in progress:

- Implementing feedback from the students
- New quantitive measurements and data analysis on comparing experiment & simulation
- Linking more to quantum uncertainty relation
- Holography experiment