FINAL PRESENTATIONS – 2024 / INTERNSHIP PROGRAM

Name, Surname: Vojtěch Votruba

Internship on Beam Propagation Through an Axicon for Plasma Experiments, IN_00

Mentor: Jiří Šišma
Department: Department of Radiation Physics and Electron Acceleration

ABOUT ME

- 21 years old, living in Prague
- 3rd year bachelor's student
- Physics, Charles University

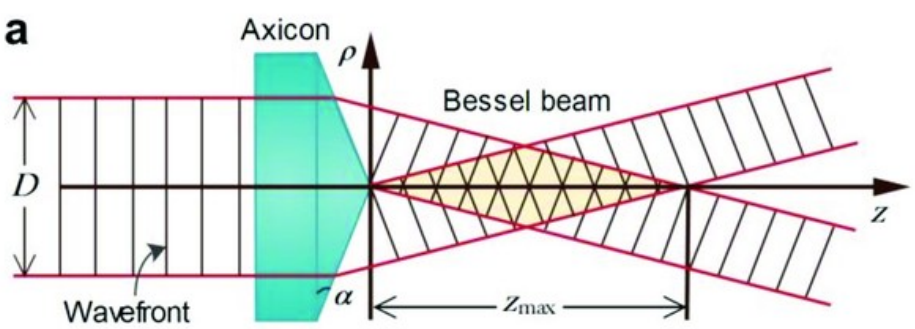
CHARLES UNIVERSITY

HOW DID I LEARN ABOUT ELI, WHY DID I APPLY?

- Career Counselling section, Faculty website
- Internships are great!
- Different experience – experimental science, simulations
- Large institution (biggest research project in Czech history – according to Wikipedia :))

WHAT WAS MY INTERNSHIP TOPIC ABOUT?

- Motivated by an upcoming experiment
- Electron acceleration
- Axicons generate Bessel beams
- **The interaction of a nozzle and a Bessel beam**
- Two parts
  - Computational
  - Experimental



C. S., Suchand Sandeep & Khairyanto, Ahmad & Aung, Tin & Vadakke Matham, Murukeshan. (2023). Bessel Beams in Ophthalmology: A Review. Micromachines. 14. 1672. 10.3390/mi14091672.

WHAT WAS MY INTERNSHIP TOPIC ABOUT?

Computations

- Simulating wave propagation

- Refraction and diffraction
- Main issue: significant memory (and time) costs ~10-100 GB
- Method of choice: WPM (faster than BPM), Language: python

WHAT WAS MY INTERNSHIP TOPIC ABOUT?

WPM

S. Schmidt, T. Tiess, S. Schröter, R. Hambach, M. Jäger, H. Bartelt, A. Tünnermann, and H. Gross, "Wave-optical modeling beyond the thin-element-approximation," Opt. Express 24, 30188-30200 (2016).

- Original WPM:

$$E(x,y,z+\Delta z) = \frac{1}{2\pi}\int \tilde{E}(k_x,k_y,z)\, e^{ik_z(k_x,k_y,x,y)\Delta z}\, e^{i(k_x x+k_y y)}\, dk_x\, dk_y \quad , \quad (2a)$$

$$k_z(k_x,k_y,x,y) = \sqrt{k_0^2 n^2\left(x,y,z+\tfrac{\Delta z}{2}\right) - k_x^2 - k_y^2} \quad , \quad (2b)$$

$$\tilde{E}(k_x,k_y,z) = \mathcal{F}_{x,y}\{E(x,y,z)\} = \frac{1}{2\pi}\int E(x,y,z)\, e^{-i(k_x x+k_y y)}\, dx\, dy \quad .$$

- Improved WPM for an inhomogeneous medium:

$$I_m^z(x,y) = \begin{cases} 1 & n_z(x,y) = n_m \ , \\ 0 & n_z(x,y) \neq n_m \ , \end{cases}$$

$$E(x,y,z+\Delta z) = \sum_m I_m^z(x,y)\mathcal{F}^{-1}\left\{e^{ik_z^m(k_x,k_y)\Delta z}\mathcal{F}\{E(x,y,z)\}\right\} \quad , \quad (4)$$

$$k_z^m(k_x,k_y) = \sqrt{k_0^2 n_m^2 - k_x^2 - k_y^2} + \kappa(k_x,k_y) \quad .$$

WHAT WAS MY INTERNSHIP TOPIC ABOUT?

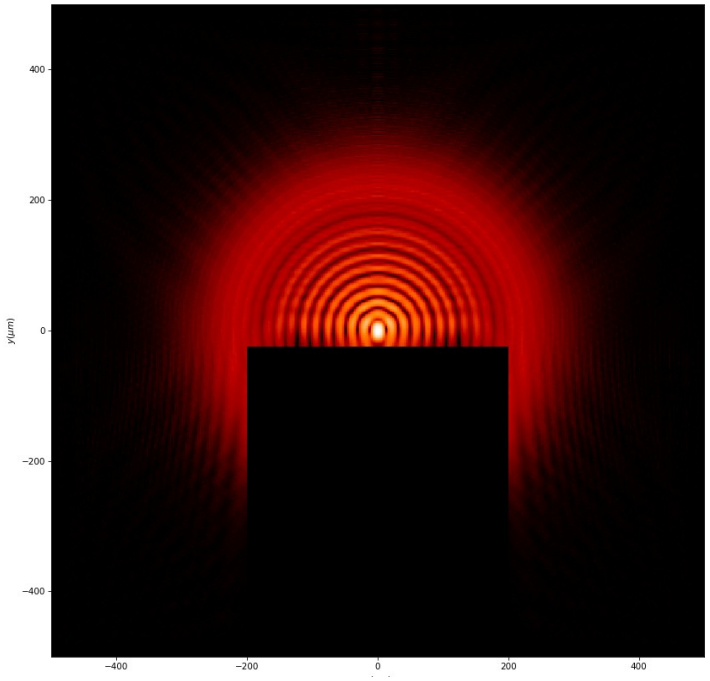
Technical things

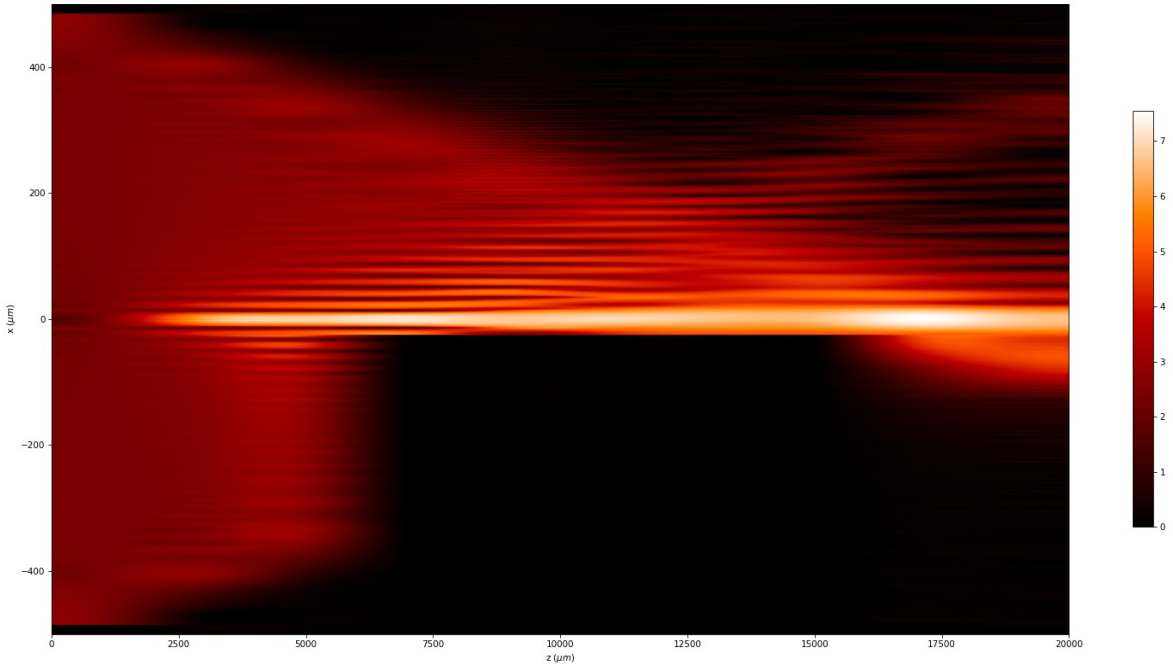
- Main library: diffractio.py
  - L.M. Sanchez Brea, “Diffractio, python module for diffraction and interference optics”, https://pypi.org/project/diffractio/ (2019)
- Core functionalities were unoptimized

  → rewrote WPM, some classes, created custom object for the nozzle
- Cut the memory usage at least 2x
- Significant speedup using different numerical libraries (pyFFTW, numexpr)
- Room for improvement?

WHAT WAS MY INTERNSHIP TOPIC ABOUT?

Initial attempts (nice, but wrong)

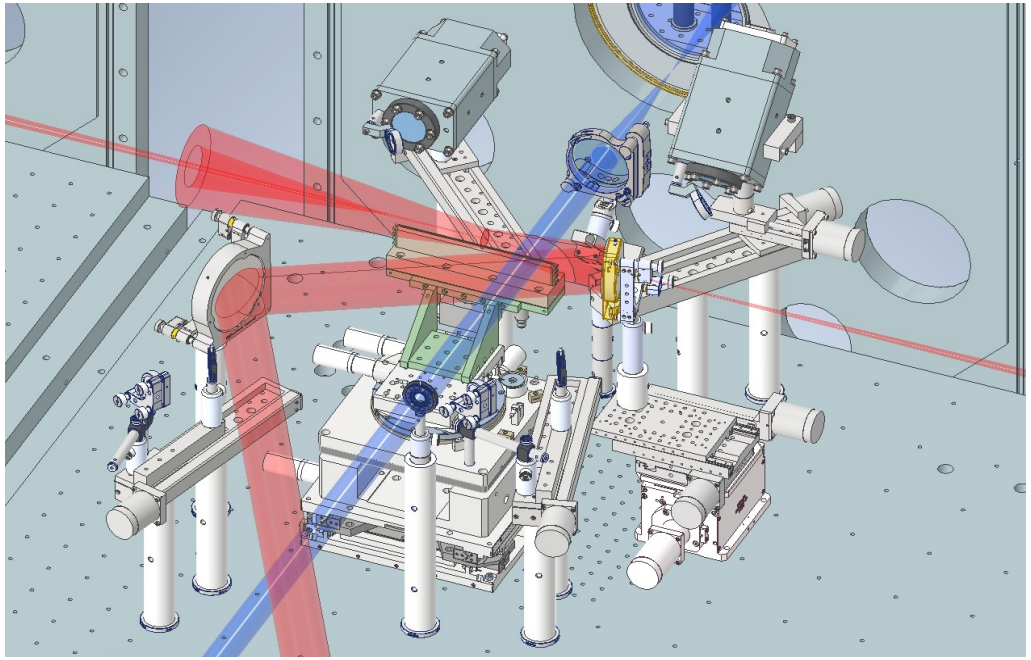




WHAT WAS MY INTERNSHIP TOPIC ABOUT?

Measurement

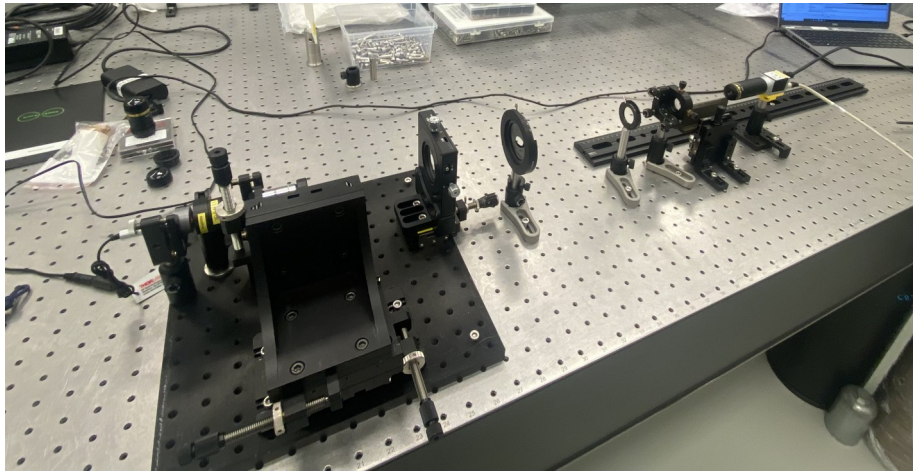
- Conducted in E5
- Rough estimate of the actual experiment



WHAT WAS MY INTERNSHIP TOPIC ABOUT?

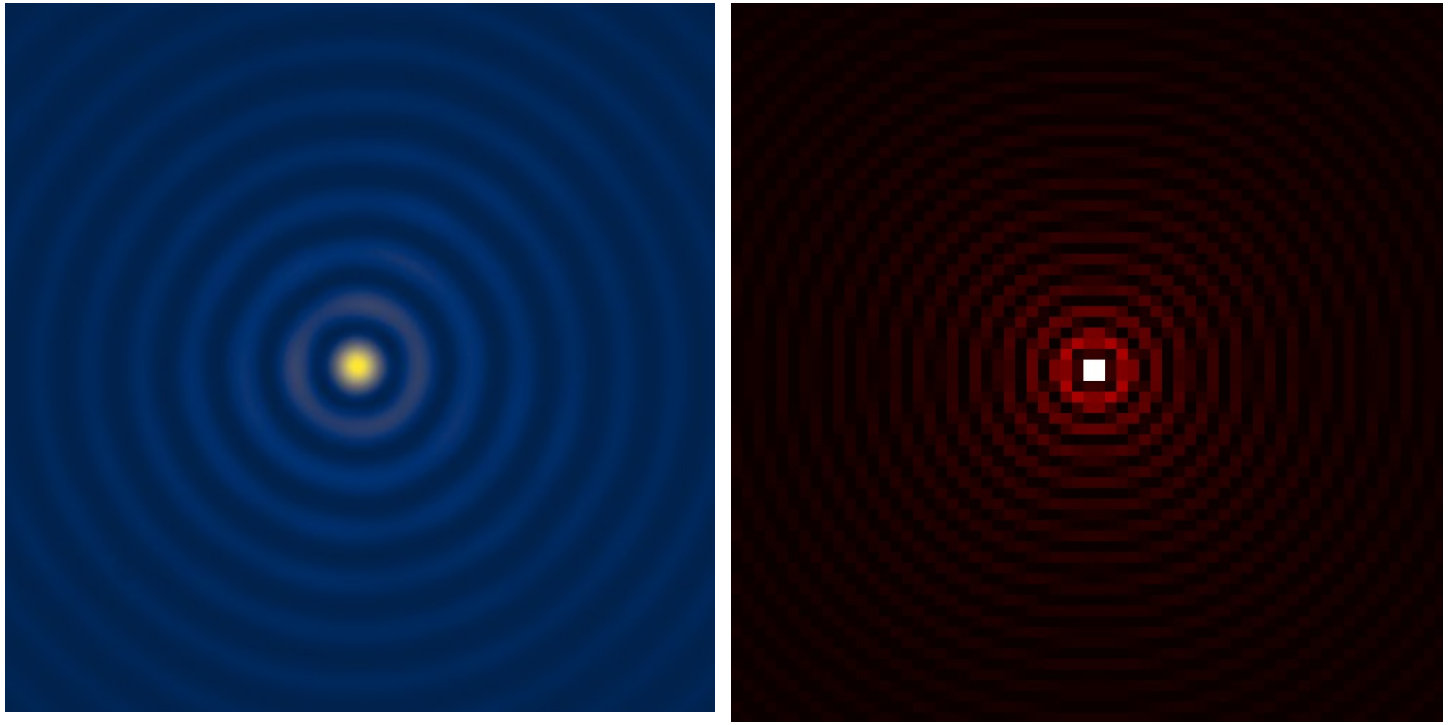
Setup

- Axicon, 170 dg, 1 inch diameter
- Laser – Thorlabs CPS635
- 10x Edmund objective, 36279-UC
- 2.3 OD intensity filter
- Keplerian telescope



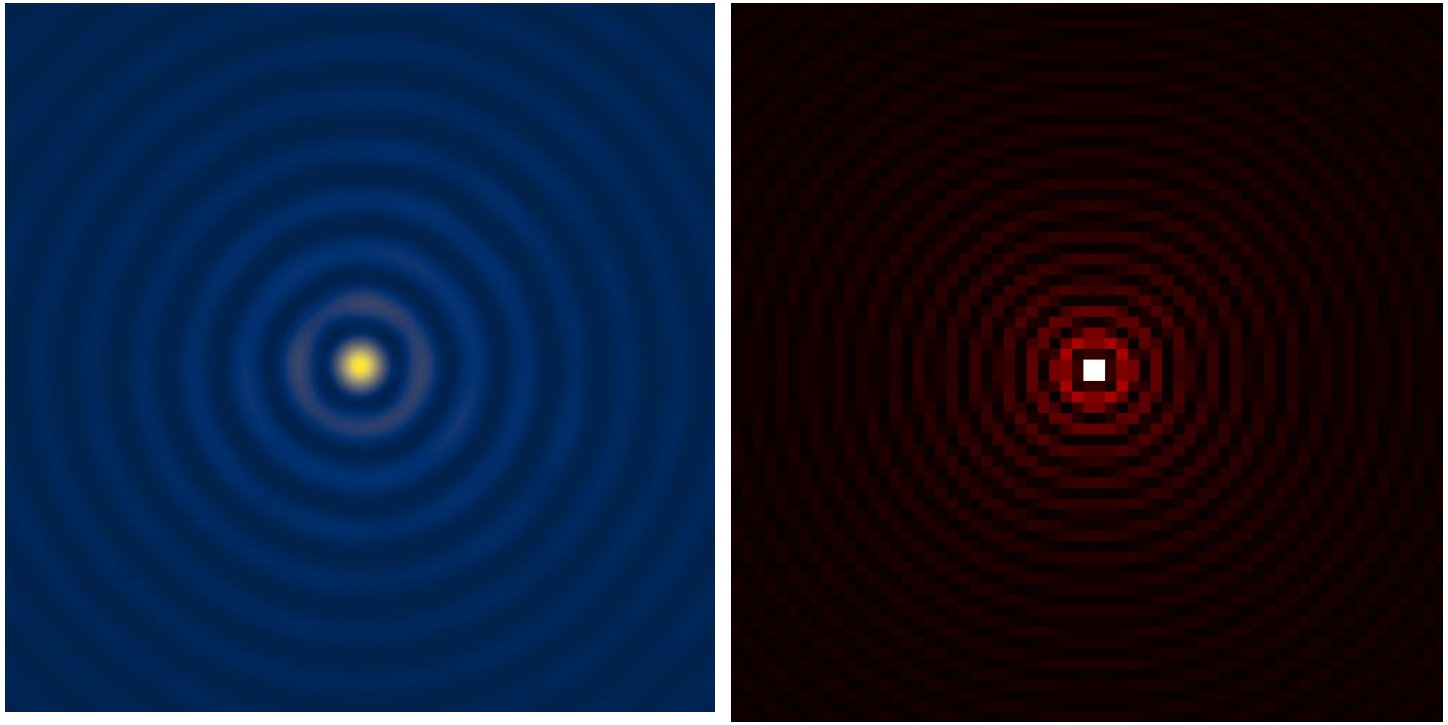
WHAT WAS MY INTERNSHIP TOPIC ABOUT?

Results (1.27 cm from centre), scale ~0.08 mm



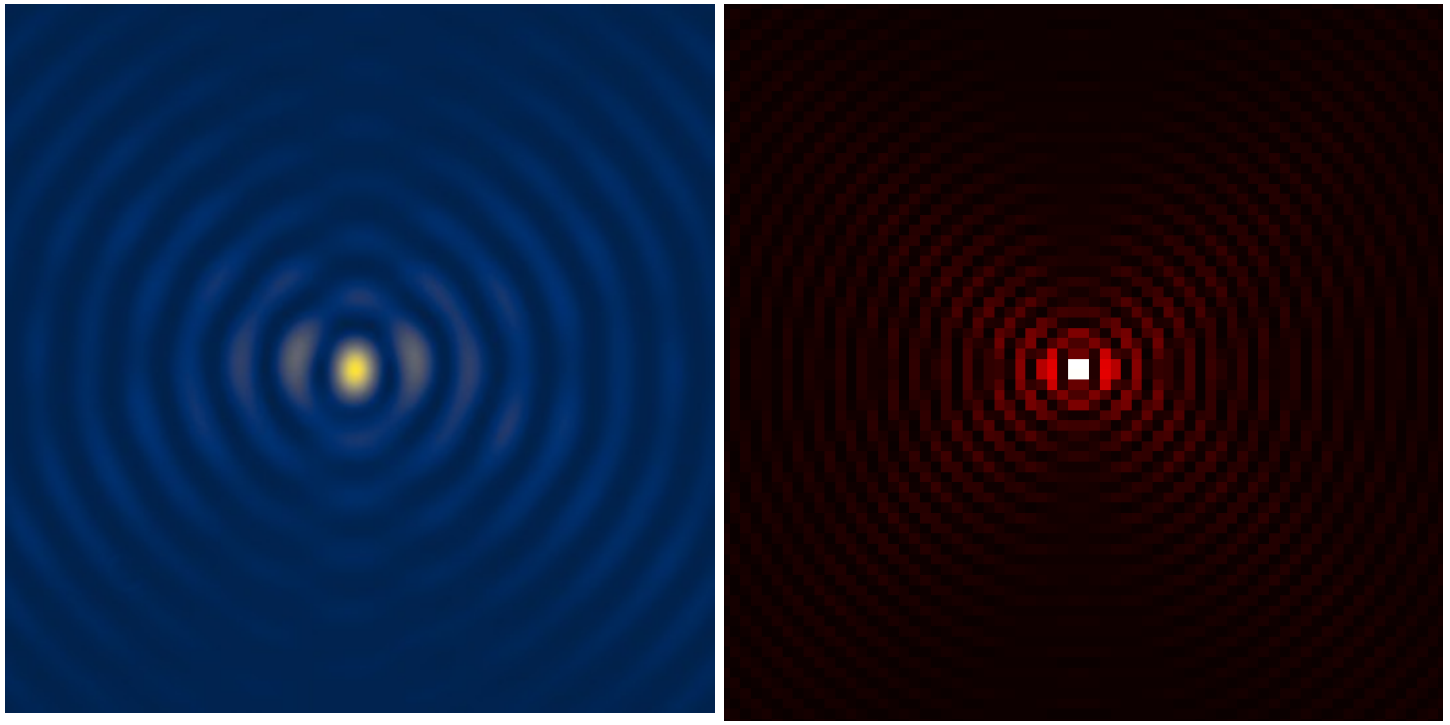
WHAT WAS MY INTERNSHIP TOPIC ABOUT?

Results (0.67 cm from centre), scale ~ 0.08 mm



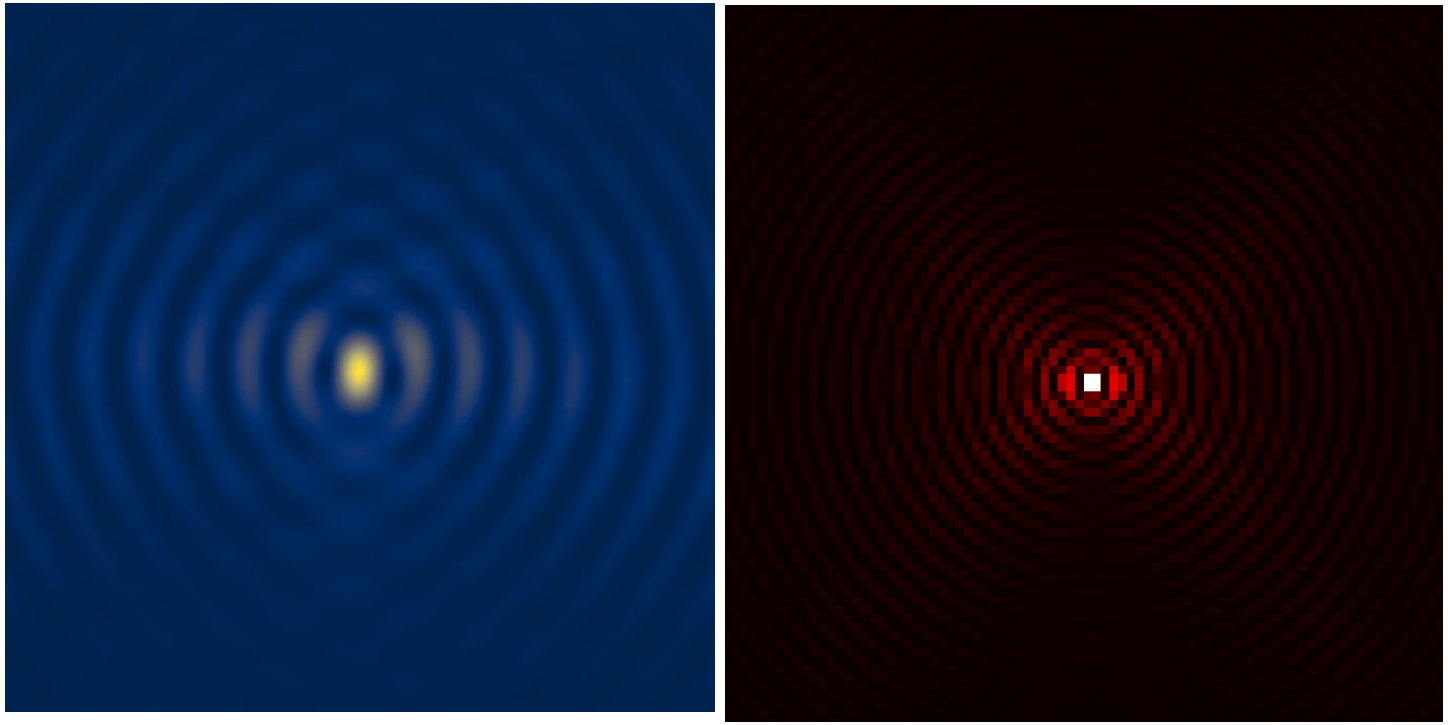
WHAT WAS MY INTERNSHIP TOPIC ABOUT?

Results (0.47 cm from centre), scale ~ 0.08 mm



WHAT WAS MY INTERNSHIP TOPIC ABOUT?

Results (0.27 cm from centre), scale ~ 0.08 mm

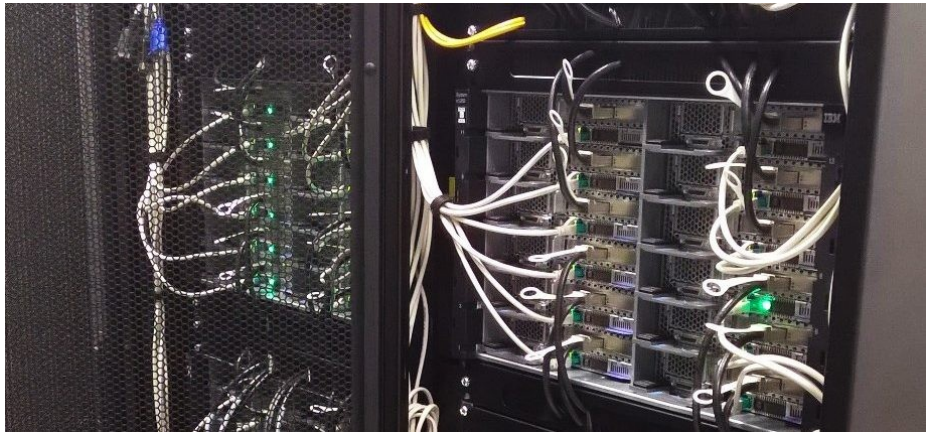


WHAT HAVE I LEARNED, WHAT WAS THE BIGGEST CHALLENGE?

- Electron acceleration
- **Diffraction theory, numerical algorithms for beam propagation**
- **Optimizing memory usage**
- HPC
- Practical lab work

WITH WHOM HAVE I WORKED WITH? HOW WAS THE COOPERATION?

- Jiří Šišma
  - mentor
- Edwin Chacón-Golcher
  - HPC cluster usage
- IT Department
  - HPC cluster access
- Others from the Department
  - Andrea Kollarova, Filip Vitha, lllia Zymak, Alžběta Špádová…



WHAT WERE MY EXPECTATIONS VS. REALITY?

- The internship overall was enjoyable - ✓
- I learned a lot - ✓
- 190 GB would not be enough for a full scale experiment - ✗

Thank you for your attention