X-ray Optical Systems

Ladislav Pína

FAKULTA JADERNÁ A FYZIKÁLNĚ INŽENÝRSKÁ ČVUT V PRAZE

Generation of X-ray Radiation

- Change of velocity vector of charged particle – continuum spectrum - Brehmstrahlung
- Change of state of quantum system – quantum transitions - line spectrum

Typical Sources of X-ray Radiation

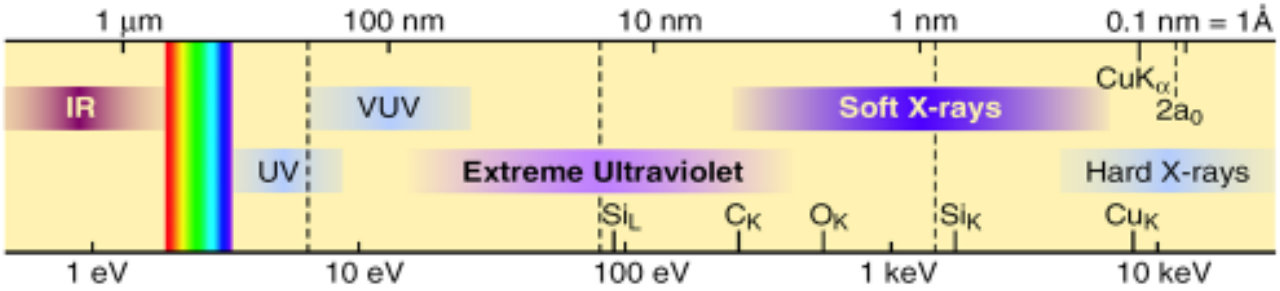
- X-ray Tube (electron beam interacting with a solid target)
- Synchrotron
- Free Electron Laser
- Hot Plasmas (Laser plasma, Tokamak, Z-pinch, Plasma focus, Stellar objects – LPP and DPP)

Applications of X-ray Radiation

From MeV to eV

- **Industry – NDT, material research**
- **Medicine – radiography, tomography, therapy**
- **X-ray diffraction - crystalography, genetics, pharmaceutical industry**
- **Diagnostics of hot plasmas – spectroscopy, imaging**
- **EUV lithography – nanopatterning, semiconductor industry**
- **Astrophysics – stars, black holes, gamma bursts**

Electromagnetic radiation spectrum (IR, VIS, UV, EUV, SXR, XR, HXR)



D. T. Attwood *Soft X-rays and Extreme Ultraviolet Radiation: Principles and Applications* (Cambridge University Press, Cambridge, 1999)

13.5 nm – 92 eV EUV Lithography

6.2 nm – 200 eV BEUV Lithography

283 - 531 eV (2.34 – 4.39 nm) Water Window Microscopy

200 - 2000 eV (6.22 – 0.62 nm) Soft X-ray Spectroscopy

X-Ray Optics

Reflective optics

Capillaries, polycapillaries, parabolic, elliptic and foil mirrors, paraboloidal and ellipsoidal mirrors. K-B system, Wolter system

No monochromatisation, but hard energy cut-off

Refractive optics

Multiple Lenses

Microfabricated Kinoform structures

Difractive optics

Crystals

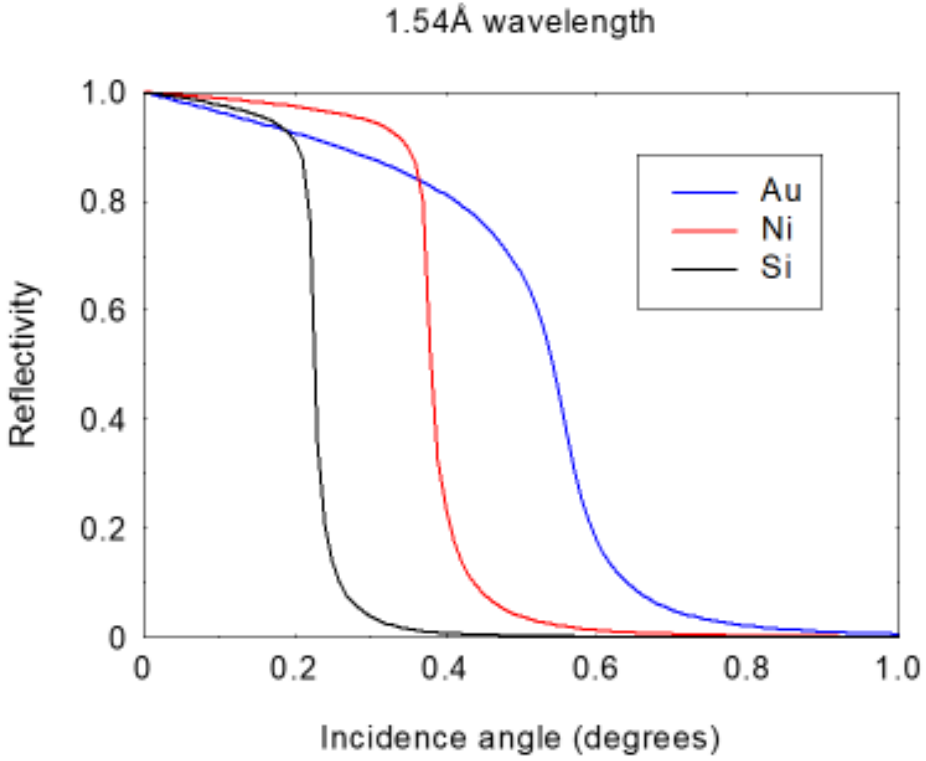
Multilayered structures

Fresnel lenses

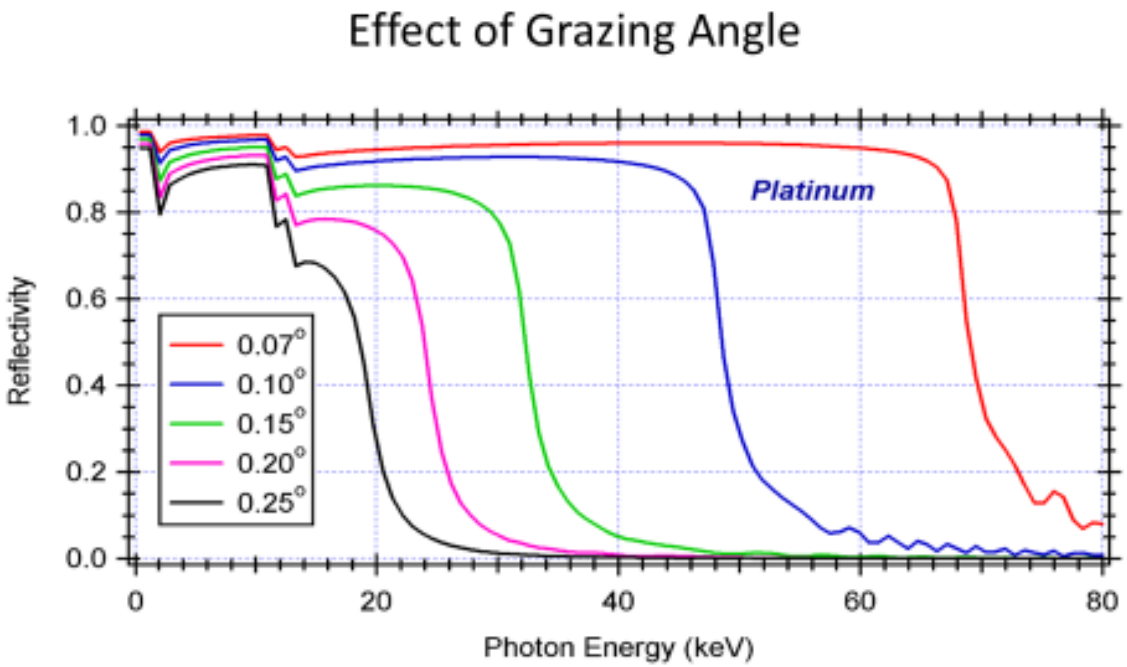
Grazing Incidence Optics

- Total external reflection
  - Capillaries, polycapillaries
  - Parabolic, elliptic and foil mirrors, paraboloidal and ellipsoidal mirrors
  - Kirkpatrick-Baez optic
  - Wolter optic
  - No monochromatisation, but hard energy cut-off

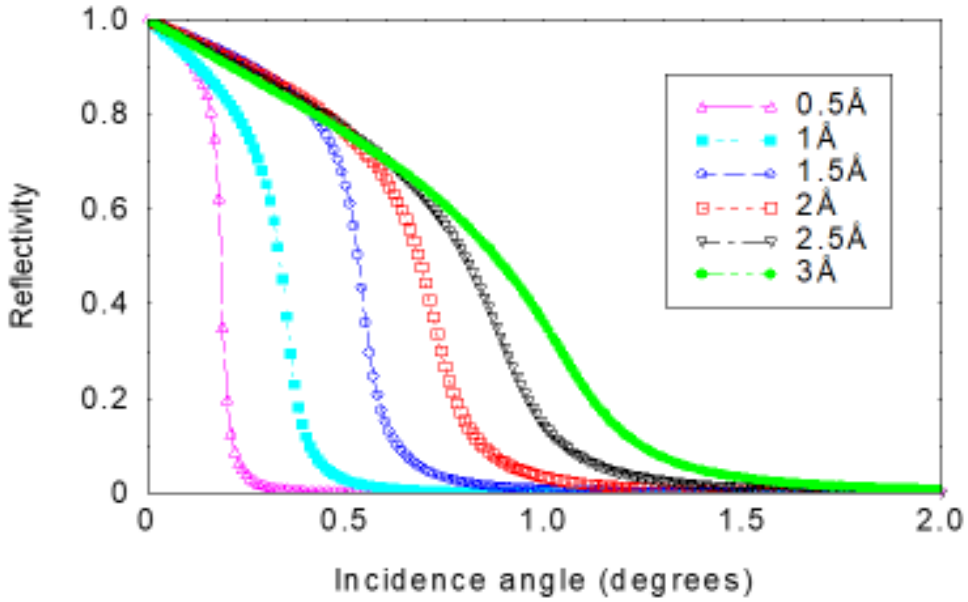
Grazing-incidence reflectivity for Au, Ni and Si

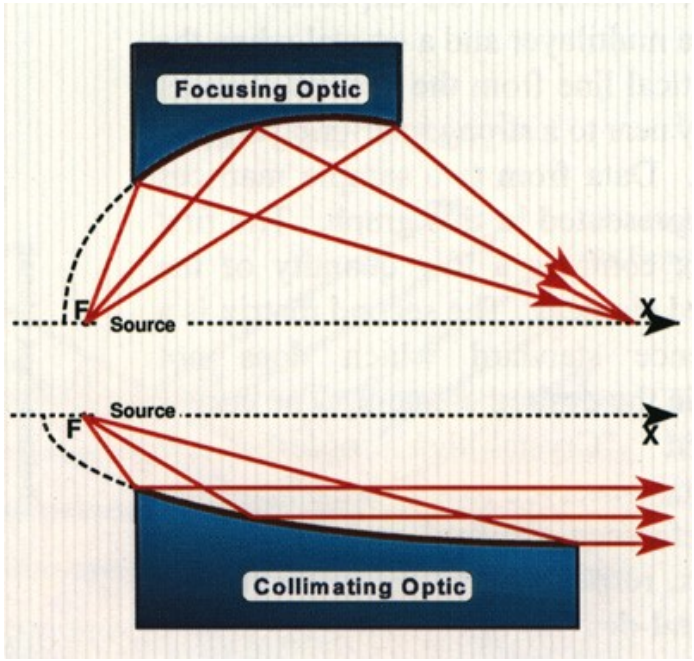


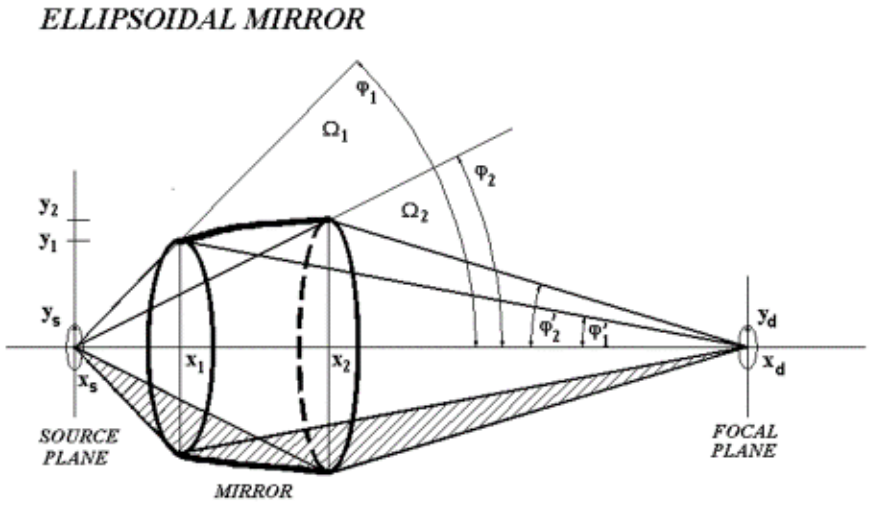
Absorption reduces reflectivity near the critical angle

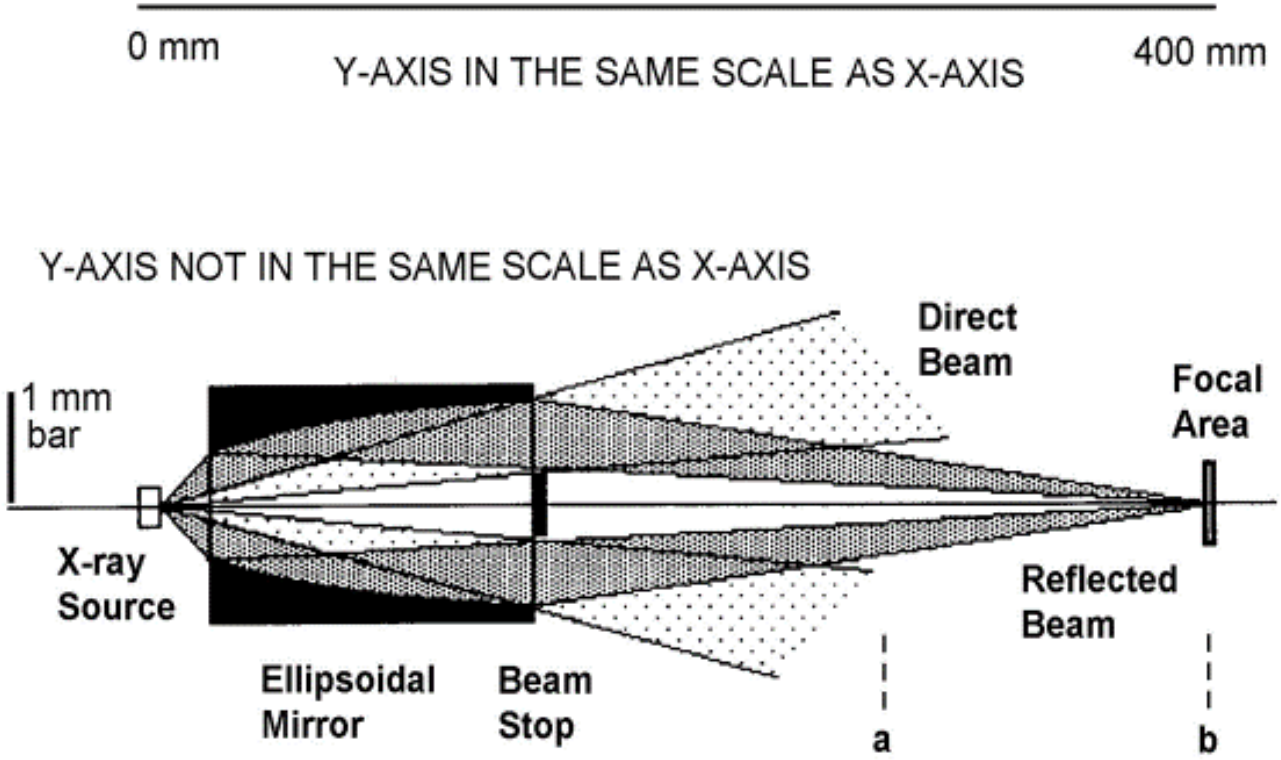

Effect of Grazing Angle
Platinum
0.07°
0.10°
0.15°
0.20°
0.25°
Reflectivity
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
Photon Energy (keV)

Variation of reflectivity with X-ray wavelength (Au)

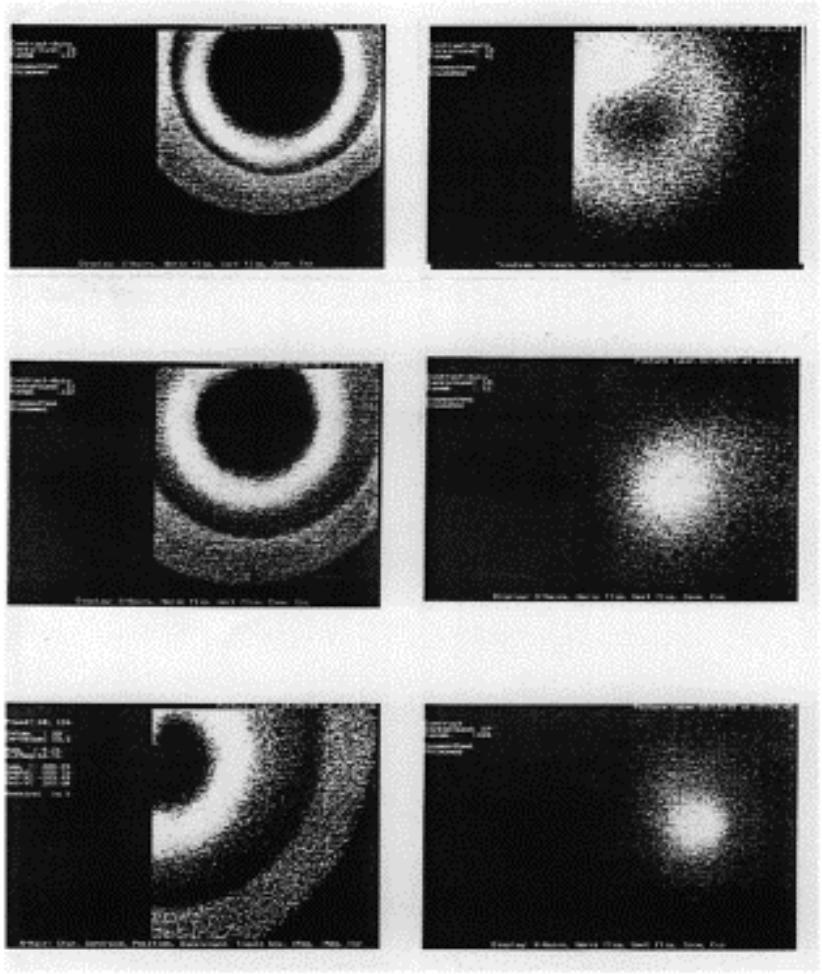



Focusing Optic
F
Source
X
Source
F
X
Collimating Optic

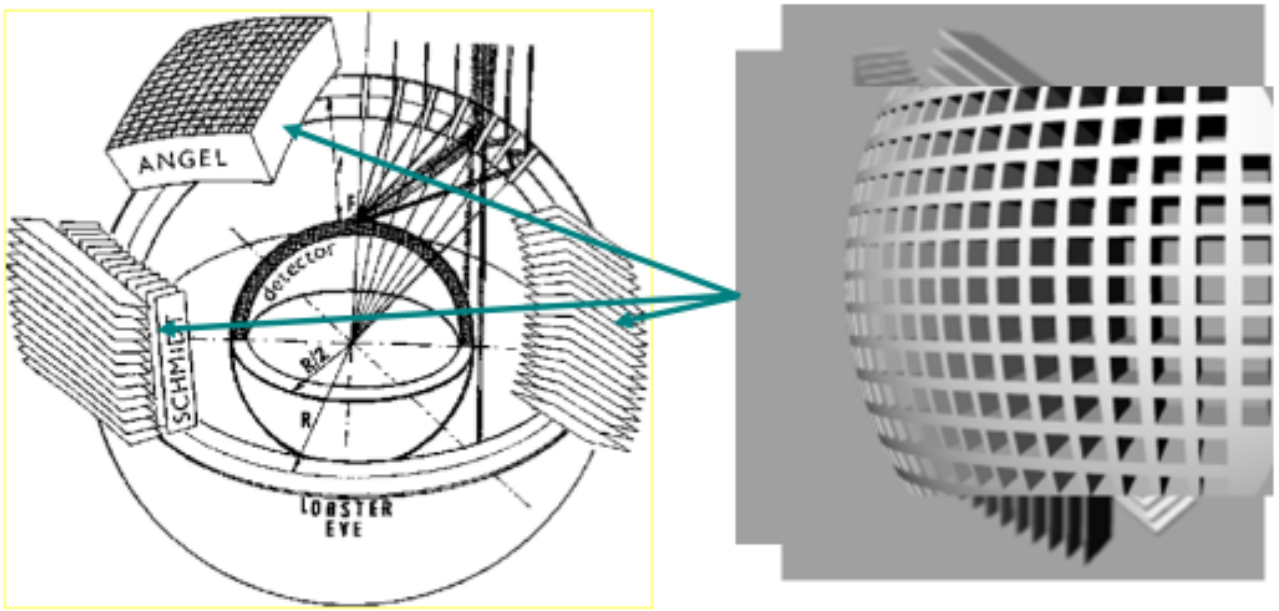

ELLIPSOIDAL MIRROR
φ1
Ω1
φ2
Ω2
y2
y1
ys
xs
x1
x2
φ'2
φ'1
yd
xd
SOURCE PLANE
MIRROR
FOCAL PLANE


0 mm
Y-AXIS IN THE SAME SCALE AS X-AXIS
400 mm
Y-AXIS NOT IN THE SAME SCALE AS X-AXIS
1 mm
bar
Direct
Beam
Focal
Area
X-ray
Source
Reflected
Beam
Ellipsoidal
Mirror
Beam
Stop
a
b

X-ray Optical Systems



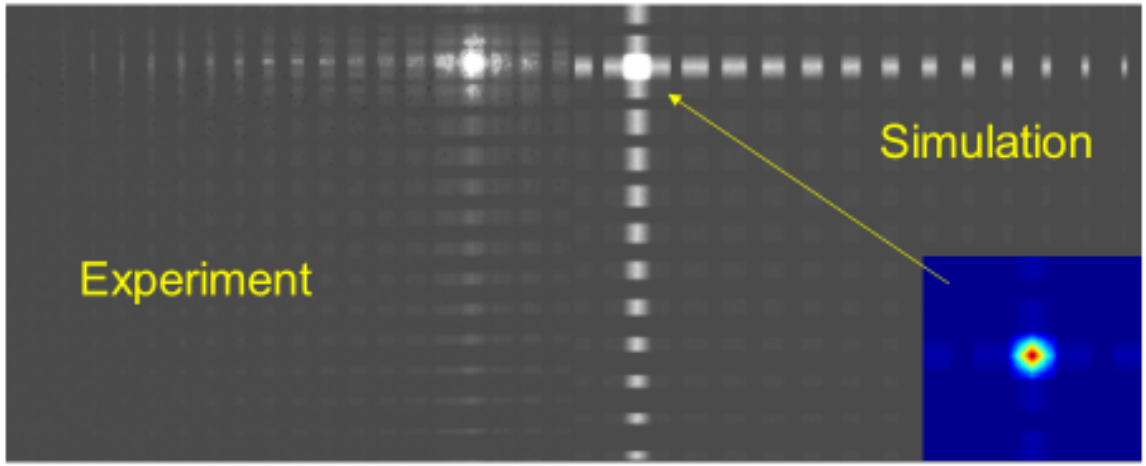
Lobster Eye (MFO) Optic Concept



Multi-Foil X-ray Optics

LE X-ray experiment vs theory

- Point-to-point focusing system
- Source: 20 μm size, 8 keV photons
- Source-detector distance: 1.2 m, 8 keV photons
- Detector: 512x512 pixels, 24x24 μm pixel size
- Gain: ~570 (experiment) vs. ~584 (comp. simulation)

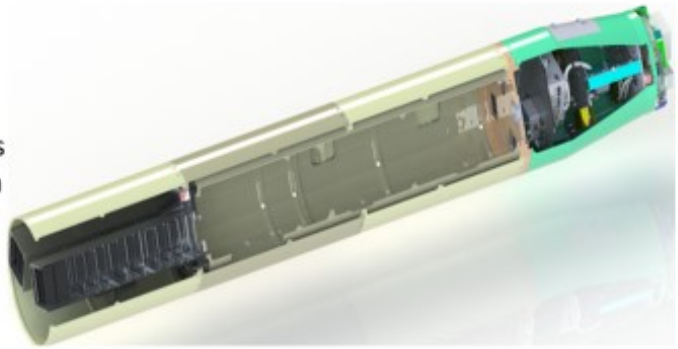


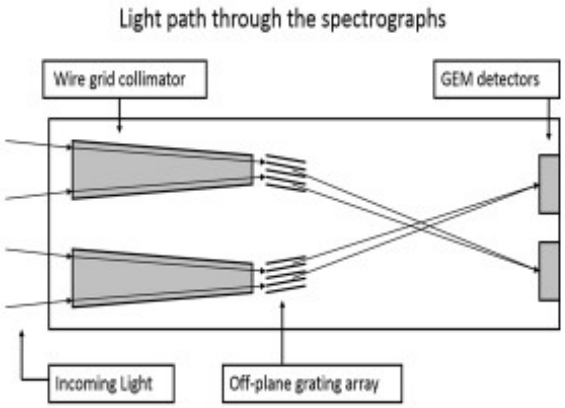
Multifoil optics for astrophysics

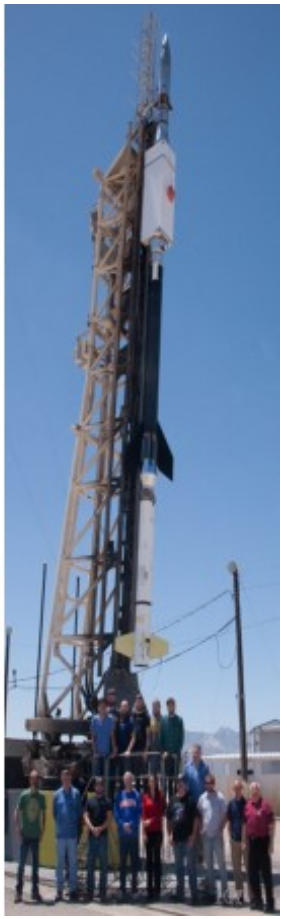
- International projects:
  - Novel X-ray Optics Technologies for ESA X-ray Astrophysics Missions (ESA PECS project, end 6/2011)
  - Applications of Kirkpatrick Baez Imaging Systems in Space – cooperation with Prof. W. Cash at al., *University of Colorado at Boulder* (Ministry of Education, Youth and Sports, end 12/2012)

OGRESS

- Diffuse X-ray spectrometer
- Targeted Cygnus Loop Supernova Remnant
- Launched May 2015







EU project COST MP1203

(LD14032 MSMT 2013-2016)

Advanced X-ray spatial and temporal metrology

Ladislav Pína, Radka Havlíková, Chiara Liberatore,

Alexandr Jančárek, Libor Švéda

Water Recover X-ray Rocket (WRX-R)

- OGRESS had a problem with the GEM detectors accelerating electrons
- First channel, change out the detectors for Hybrid CMOS Detectors
- Second channel is a Lobster Eye instrument from the Czech Technical University
- Water recover
  - Opens ability to launch recoverable rockets from locations such as Kwajalein and Wallops Island
- Southern hemisphere sky target

PennState

CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF NUCLEAR SCIENCES AND PHYSICAL ENGINEERING

Department of Physical Electronics

DISSERTATION THESIS

ABSORPTION OF EUV RADIATION IN MATTER AND RELATED PROCESSES

Author: MSc. Chiara Liberatore

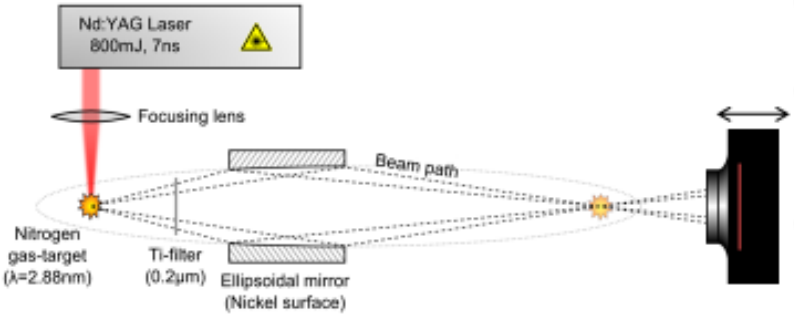
Supervisor: Doc. Ing. Ladislav Pina, DrSc.

Advisor: Prof. Dr. Akira Endo

Prague, 2015

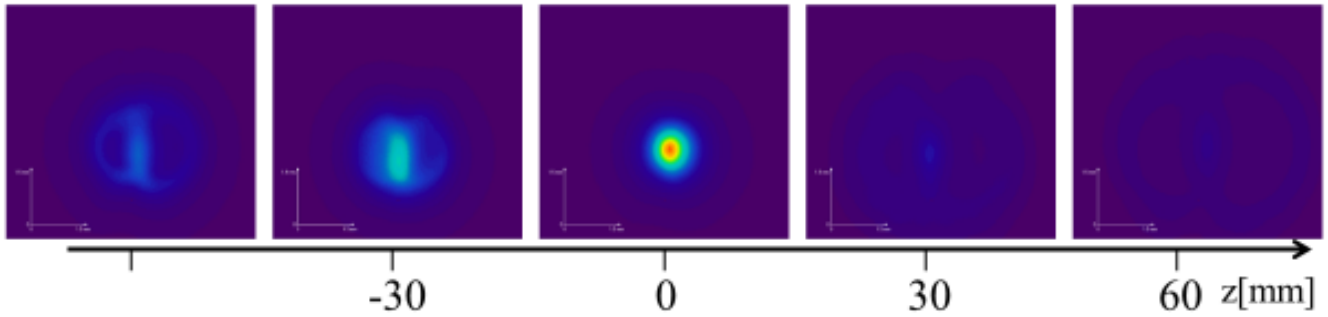
Focusing of soft X-ray radiation

Setup at LLG with ellipsoid



- 200 nm Ti filter
  → T = 72%
- (before: 1200 nm, T=14%
  = 1/5 · 72%)
- phosphor coated CCD
  → exposure level ~ 80%
  in focal plane

Dr. Klaus Mann, LLG Gottingen



Ph.D. Defense

SXR and EUV nanoscale imaging using compact laser plasma sources based on a double stream gas-puff target and Fresnel optics

Alfio Torrisi

Supervisor: ppłk dr hab. inż. P. Wachulak (IOE – MUT, Warsaw)
Co-Supervisor: doc. Ing. L. Pina (FNSPE-CTU, Prague)

Institute of Optoelectronics

Military University of Technology, Warsaw (Poland) - April 10th 2017

Cooperation

- Academy of Sciences of the Czech Rep. (plasma physics, HHG generation, PALS, HiLASE, ELI)
- Institute of Opto-Electronics Warsaw, Poland (LPP sources, X-ray optics, detectors, biophysics, …)
- UTEF CVUT Praha
- ADVACAM Praha
- CEITEC VUT Brno
- VZLU Praha
- TOPTEC Turnov
- CRYTUR Turnov
- RITE Praha
- Others (ESA, NASA, industry, academic institutions in USA, Japan, Ireland, Germany, Italy …)

THANK YOU FOR ATTENTION

Prague