UNIVERSITÀ DEGLI STUDI DI PADOVA

XUV spectroscopy for space (SOLAR-C EUVST) and laboratory applications

CNR IFN Istituto di Fotonica e Nanotecnologie

Gabriele Zeni - 37th Cycle

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Dr. Luca Poletto
Dr. Fabio Frassetto

Admission to thesis evaluation - 13/09/2023

Summary

- XUV spectroscopy for Space application: **SOLAR-C/EUVST**
- XUV spectroscopy for Laboratory application: **XUV bendable grating**
- XUV spectroscopy for Laboratory application: **COSP**

XUV spectroscopy for Space application: **SOLAR-C/EUVST**

SOLAR-C_EUVST

Extreme UltraViolet High-Throughput Spectroscopic Telescope

JAXA M-class mission

International participation

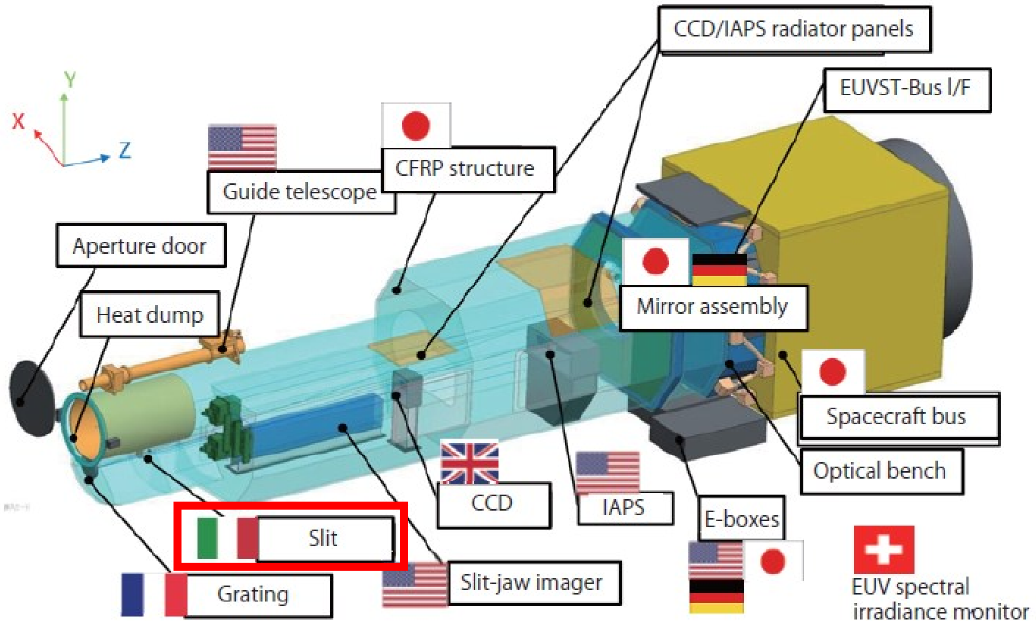
Purpose: to understand

- Formation of solar atmosphere and solar wind
- Instabilities of the solar atmosphere

The Italian contribution

INAF (Istituto Nazionale di Astrofisica) is responsible for the realization of the Slit Assembly

CNR-IFN will perform the calibration of the Slit Assembly



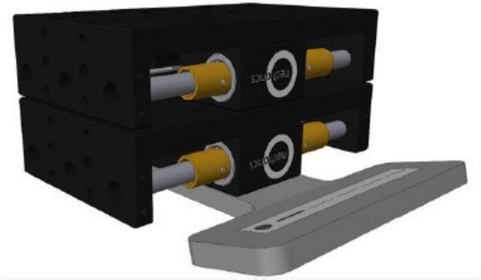
The Slit Assembly

Slit Assembly

Limit the light entering the imaging spectrograph

Reflect light onto the Slit-Jaw Imager

- 4 scientific slits
- 1 calibration slit
- 1 pinhole
- 1 circular aperture
- stop position



Positioner: two linear translators (piezo-actuator)

Redundancy and efficiency

Slit Assembly coating analysis

with Lorenzo Cocola, Luca Poletto

Preliminary theoretical analysis of the Slit Assembly coating

High solar input on thin substrate → Coating to reduce heat absorption

Coating requirements:

- High reflectivity, especially in 280 nm band
- Not exceed 600 nm thickness

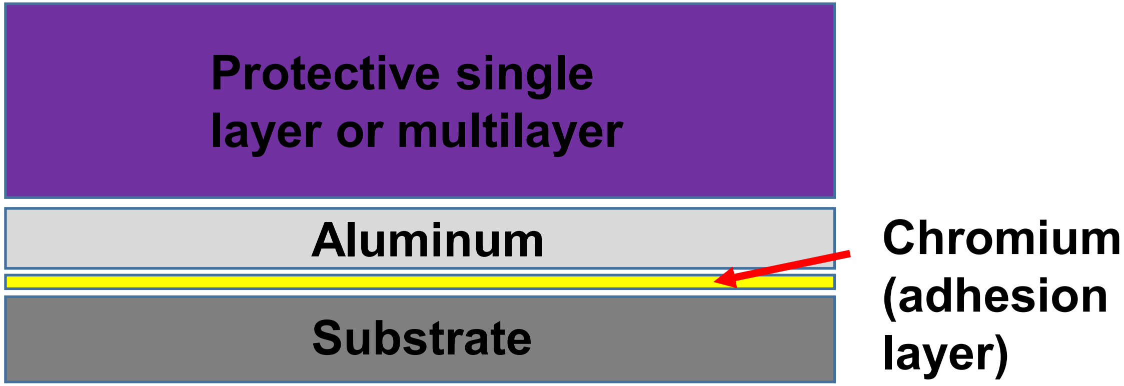
Coating	N7419	N7420	N7421	N7422	P3157	P3158
Solar absorbance α	0.254	0.322	0.396	0.175	0.560	0.603
Solar flux absorption by PM (W)	22.22	28.20	34.68	15.33	48.96	52.76
Reflected Solar flux (W)	65.27	59.29	52.82	72.16	38.53	34.73
Solar flux input on slit (W)	4.64	4.22	3.75	5.13	2.74	2.47

Slit Assembly coating analysis

Metal-based coating

Gold ✗
Silver ✗
Aluminum ✓

Needs protective layer → Protected Al coating
- Single-layer protected Al coating
- Multilayer protected Al coating



Slit Assembly coating analysis

Single-layer protected Al coating

- Simple (single layer of SiO_2 or MgF_2)
- Not so efficient

Multilayer protected Al coating

- Complex (fully dielectric multilayer)
- Very efficient

Theoretical analysis of several coating structures:

- **SiO_2/Al and MgF_2/Al single layer**
- **[MgF_2/SiO_2]^3/Al; [Al_2O_3/SiO_2]^3/Al; [TiO_2/SiO_2]^3/Al and SiO_2/[ZrO_2/SiO_2]^3/Al multilayer**

Slit Assembly coating analysis

A genetic algorithm is prepared to optimize the thickness of each single layer
Another algorithm calculates the absorbed heat

N7422 Primary Mirror Coating		
Slit coating	Absorbed Heat (250-1700 nm)	Reflected Heat
Bare Al (reference)	0.357 W	4.213 W
Al + single layer [SiO_2 or MgF_2]	0.467 W	4.103 W
[Al_2O_3/SiO_2]/Al, 6 layers	0.386 W	4.184 W
[ZrO_2/SiO_2]/Al, 7 layers	0.363 W	4.207 W

Slit Assembly coating analysis

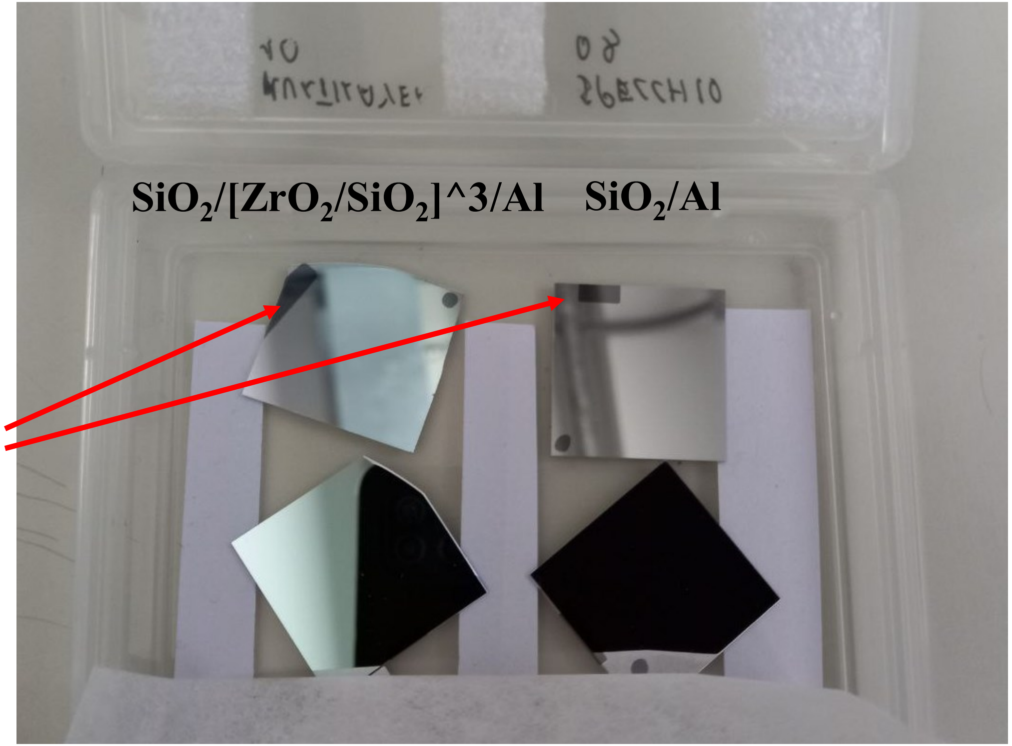
Label	Structure	Total thickness
$[ZrO_2/SiO_2]$ / Al, 7 layers	SiO2 (40 nm)	523 nm
	ZrO2 (74 nm)	
	SiO2 (82 nm)	
	ZrO2 (25 nm)	
	SiO2 (32 nm)	
	ZrO2 (90 nm)	
	SiO2 (80 nm)	
	Al (90 nm)	
	Cr (10 nm) – adhesion layer	

Label	Structure	Total thickness
SiO_2/Al, single layer	SiO2 (257 nm)	357 nm
	Al (90 nm)	
	Cr (10 nm) – adhesion layer	

Slit Assembly coating analysis

Measurements of the optical properties and thickness of the coating samples

Clamped area
Bare substrate
used for
thickness
measurements

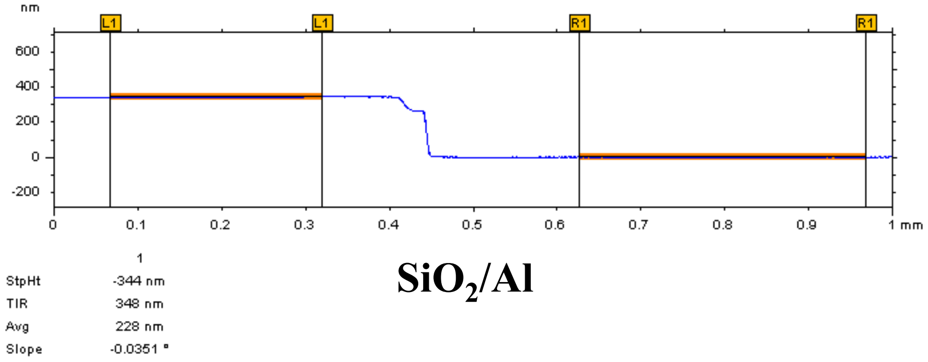


Measurements campaign:

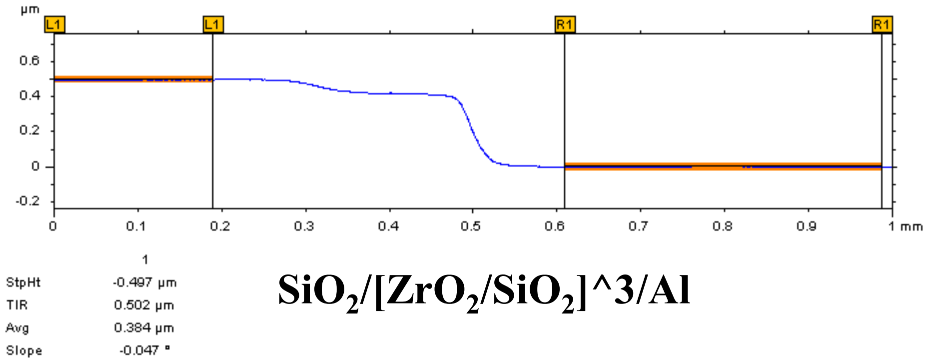
- Profilometric analysis
- Reflectance analysis

Reflectometer
Spectrophotometer
FTIR spectrometer

Slit Assembly coating analysis



SiO_2/Al

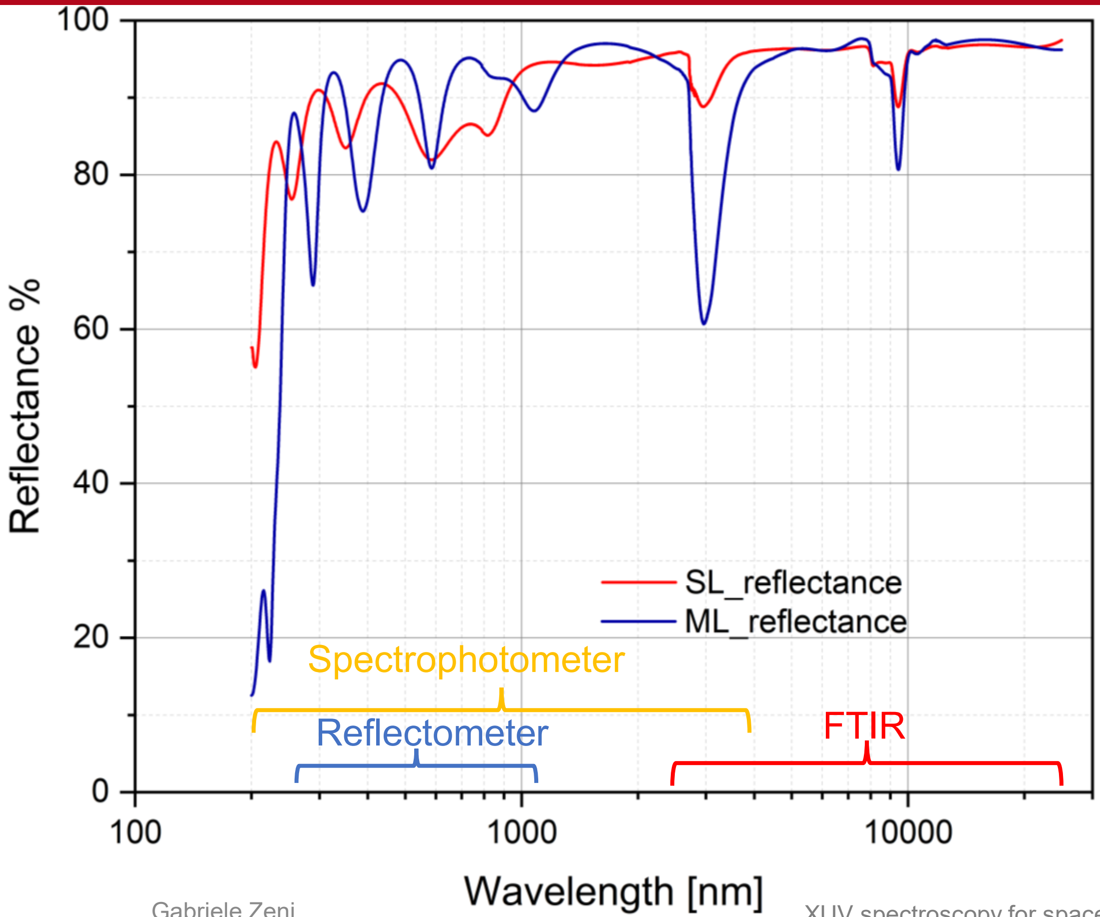


$SiO_2/[ZrO_2/SiO_2]$^3/Al

	Theoretical thickness	Measured thickness	Error
Single layer	357 nm	344 nm	3.8%
Multilayer	523 nm	497 nm	5.2%

Small deposition error, compatible with the intrinsic precision of the deposition process

Slit Assembly coating analysis



Complete reflectance measurements, from the near UV (200 nm) to the mid IR (25 μm)

Three partially overlapped measured region:

- Reflectometer:
  300 – 1100 nm
- Spectrophotometer:
  200 – 3000 nm
- FTIR spectrometer:
  2500 – 25000 nm

Slit Assembly coating analysis

Absorbed heat, calculated using the measured sample reflectance
In the case of P3157, using also the reflectance measured by MPS

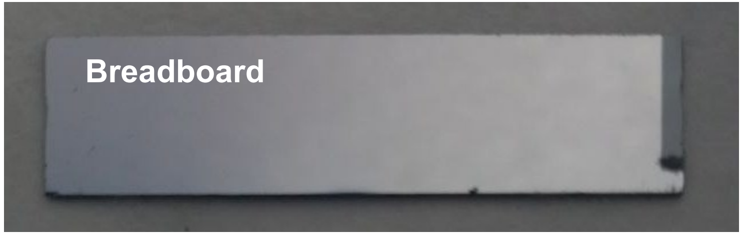
P3157 Primary Mirror Coating

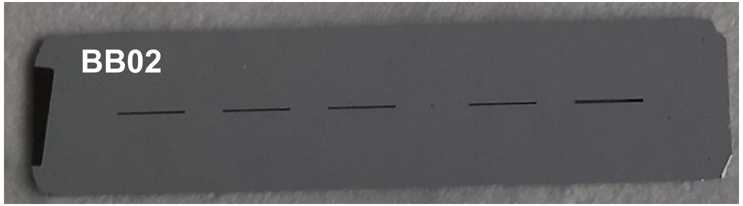
Slit coating	Absorbed Heat (250-2500 nm)
SiO_2/Al	0.2659 W
$[ZrO_2/SiO_2]/Al$, 7 layers	0.2133 W

N7422 Primary Mirror Coating

Slit coating	Absorbed Heat (250-2500 nm)
SiO_2/Al	0.5290 W
$[ZrO_2/SiO_2]/Al$, 7 layers	0.4248 W

Slit Assembly coating analysis





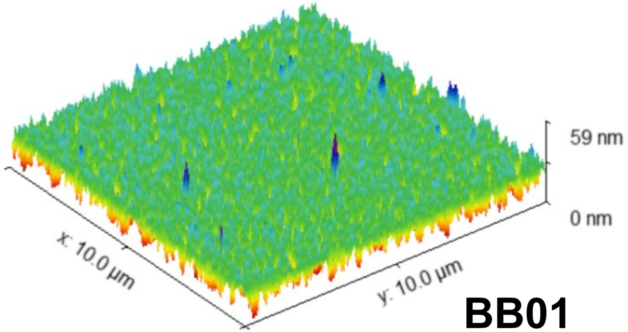
First prototype samples of the Slit Assembly

- Si substrate
- $[SiO_2]/Al$ optical coating

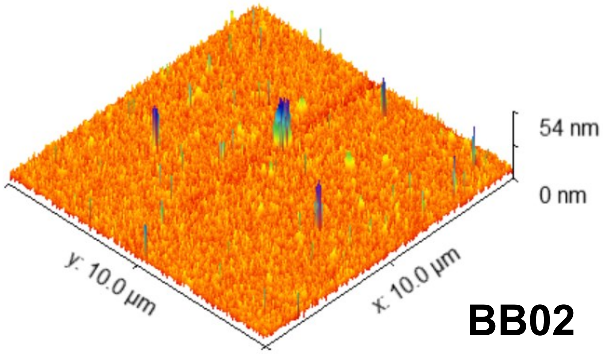
Test:

- Surface roughness
- Surface reflectivity
- Surface planarity

AFM (Atomic Force Microscope) to evaluate the surface roughness



BB01



BB02

Five areas of 10x10 µm for each sample

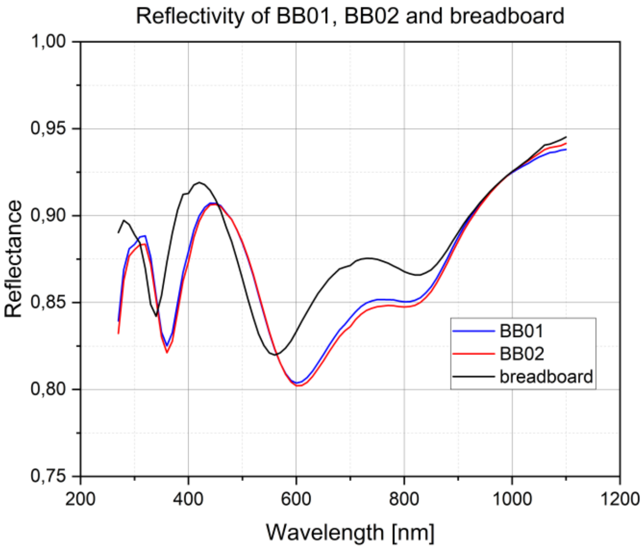
Sample	Roughness RMS
BB 01	1.906 nm
BB 02	1.911 nm
Breadboard	1.621 nm
C1	1.604 nm
C2	1.798 nm

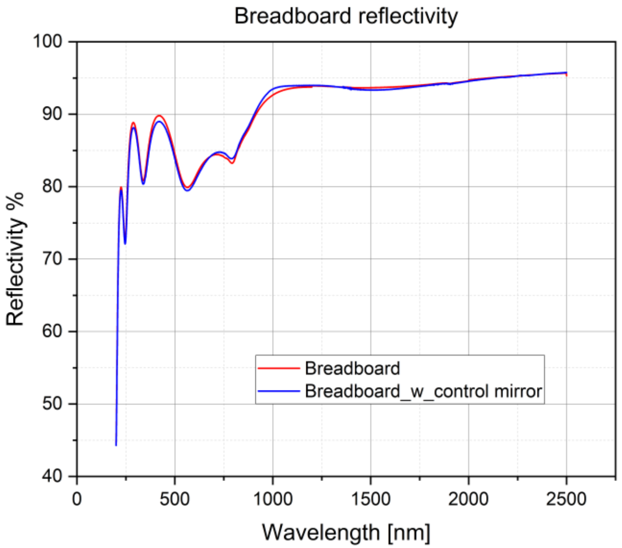
Slightly larger for slit samples, probably due to chemical etching prior to the deposition (under investigation)

Slit Assembly coating analysis

Reflectivity: reflectometer + spectrophotometer
The spectrophotometer allows only the breadboard sample due to beam dimension
Comparable reflectivity (within the instrumental error ±2%)

Bentham Reflectometer

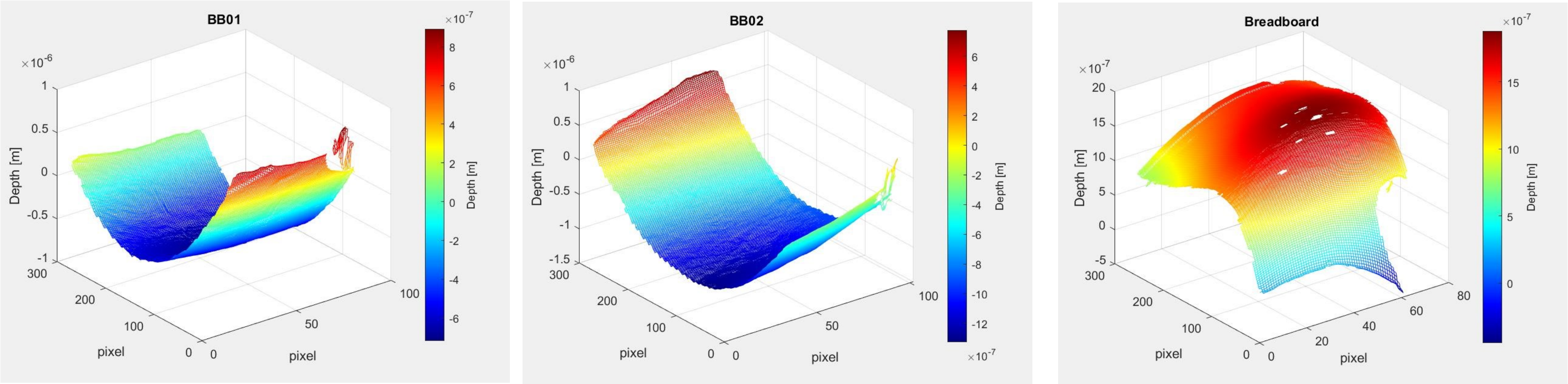




Cary Spectrophotometer

Slit Assembly coating analysis

Zygo Interferometer → Interferogram to evaluate the planarity



Almost cylindrical small curvature on the long size, less than ≈2 μm peak-to-valley

In small 6x6 mm region, equivalent to the FoV, the curvature is <200 nm, well below the requirement

Slit Assembly coating analysis

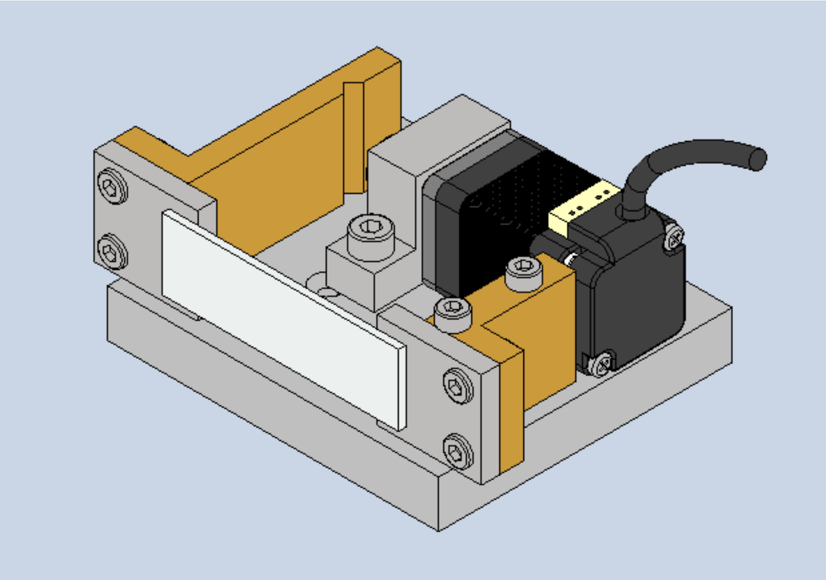
The study has been shared with other EUVST teams and it has been presented at the ICSO 2022 conference and at the SPIE 2024 conference

Zeni G. *et al.*, **Multilayer coating analysis for heat rejection on the Slit Assembly of SOLAR-C EUVST,** Proc. of SPIE Vol. 12777, Conference Paper, Jul 2023

Zeni G. *et al.*, **Reflectivity analysis of a proposed multilayer coating for the Slit Assembly of SOLAR-C EUVST ,** Proc. of SPIE Vol. 13100, Conference Paper, Aug 2024

Next steps:

- Development of a calibration technique to evaluate the impact of the solar flux onto the SA when mounted on its frame



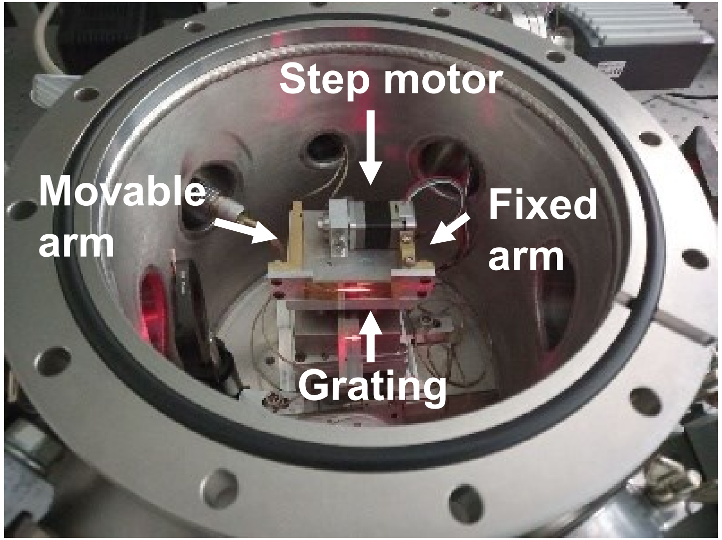
XUV spectroscopy for Laboratory application: **XUV bendable grating**

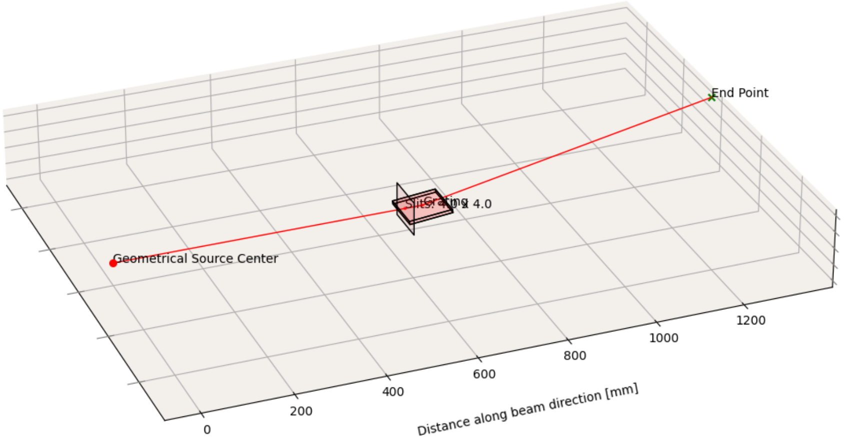
XUV deformable grating

with Fabio Frassetto, Luca Poletto

Focusing test of XUV deformable grating

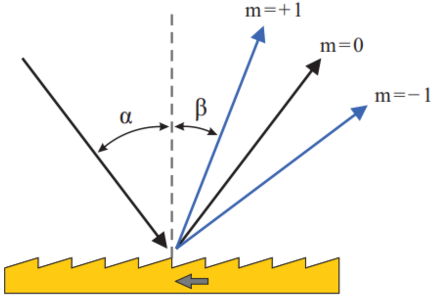
Deformable grating could be used in monochromator, reducing the amount of optical elements

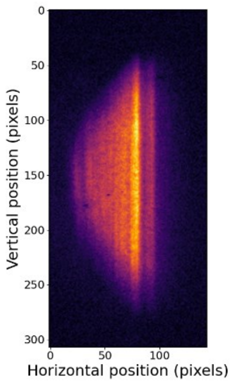




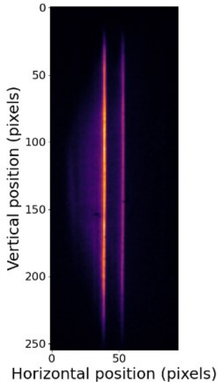
XUV deformable grating

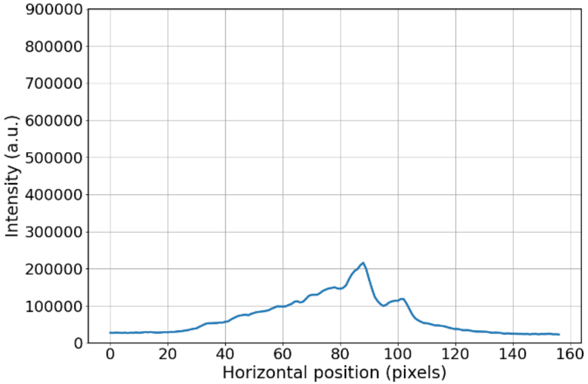
Test with He and Ne, three lines each, both with the blaze arrow of the grating toward the source and toward the camera

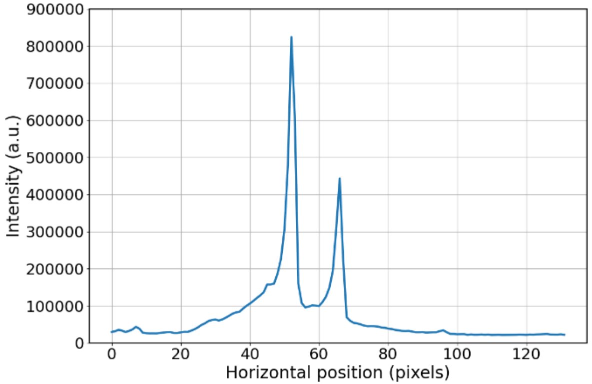




Ne 74.0 nm doublet

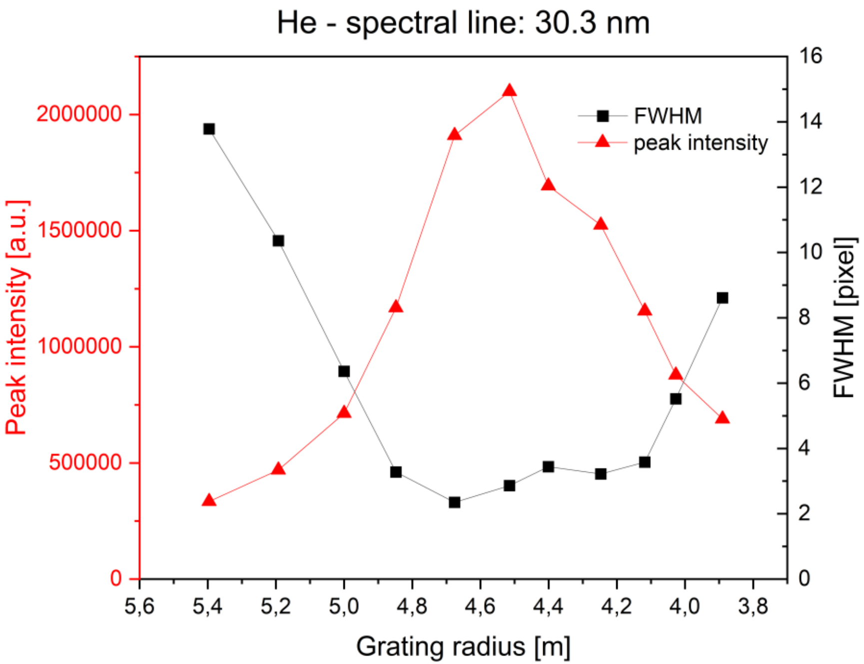






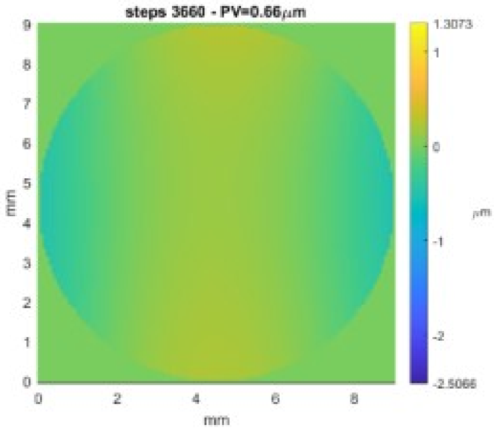
Plot the FWHM and the peak intensity

Obtain the bending radius for the in-focus position

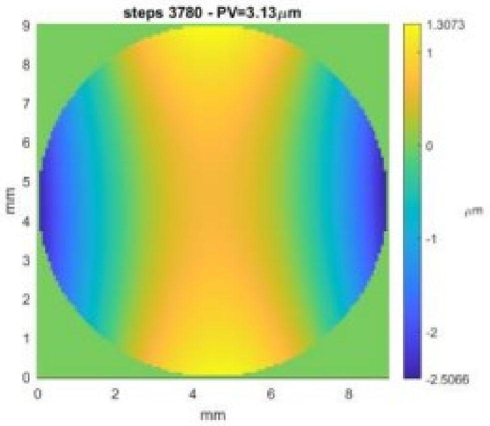


XUV deformable grating

Shack-Hartmann wavefront sensor (WFS) analysis → To analyze the shape of the deformation

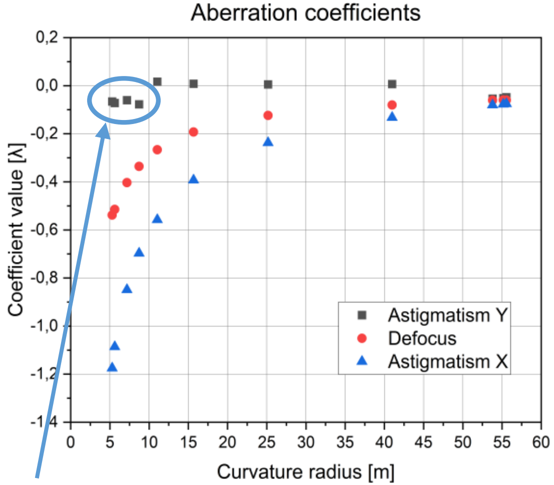


R = 50 m



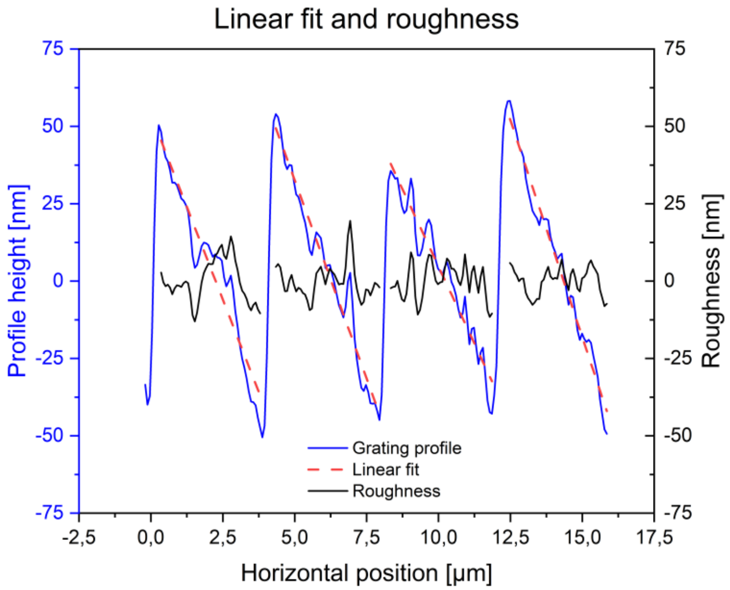
R = 5 m

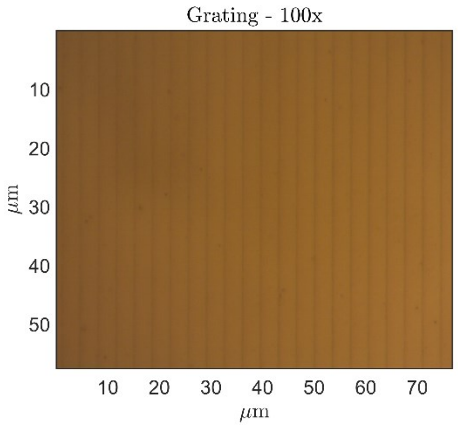
Almost pure cylindrical deformation

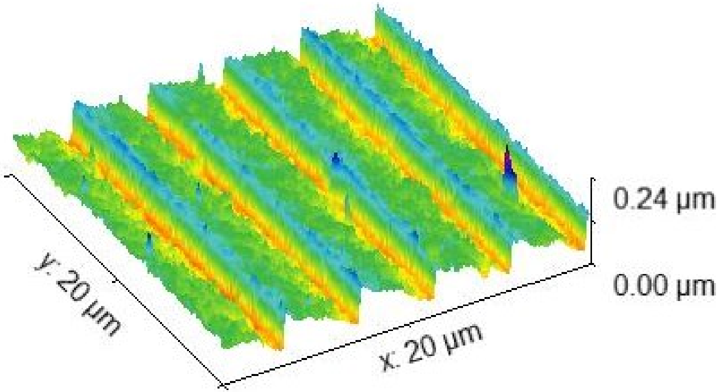


Very little residual sagittal astigmatism: unwanted torsional deformation

Optical microscope surface analysis
AFM surface and roughness analysis







XUV deformable grating

Results:

- Fully working mounting frame
- Complete bending test of the deformable grating
- Complete analysis of the grating surface

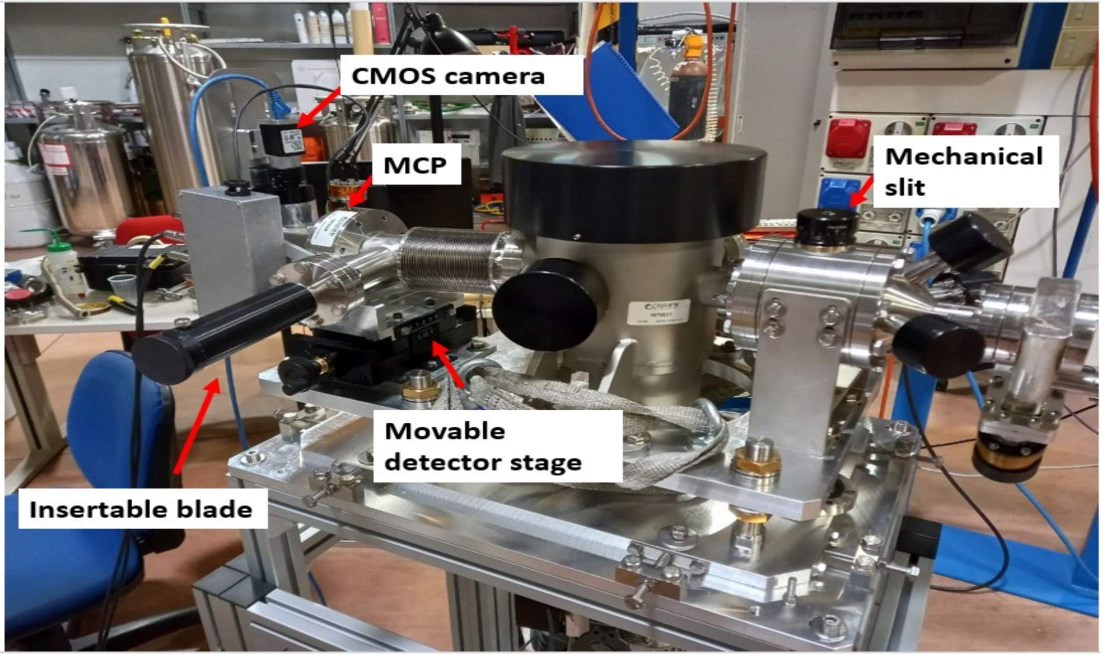
The study has been presented at the SPIE Optics and Optoelectronics Conference in Prague, April 2023 and the AOIM – Adaptive Optics for Industry and Medicine in Padua, March 2024

Zeni G. *et al.*, **Bendable grating for monochromatization in the extreme-ultraviolet,** Proc. of SPIE Vol. 12581, Conference Paper, June 2023

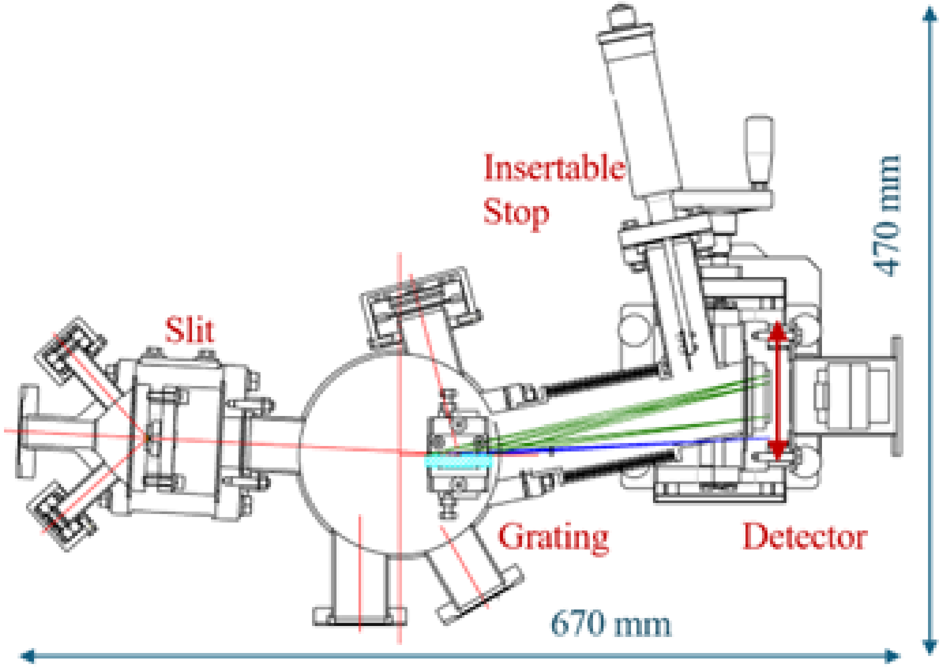
Zeni G. *et al.*, **Monochromatization in the EUV region with a low-cost active grating,** Adaptive Optics for Industry and Medicine XIII

Next steps:

- Possible development of a complete two stage bendable grating instrumentation



XUV spectroscopy for Laboratory application: **COSP**



COmpact **SP**ectrometer – **COSP**

Grating spectrometer for FEL application

Achieve medium resolution in a **wide spectral range**

For:

- Optimizing of the machine parameters
- Monitoring of the harmonics stability

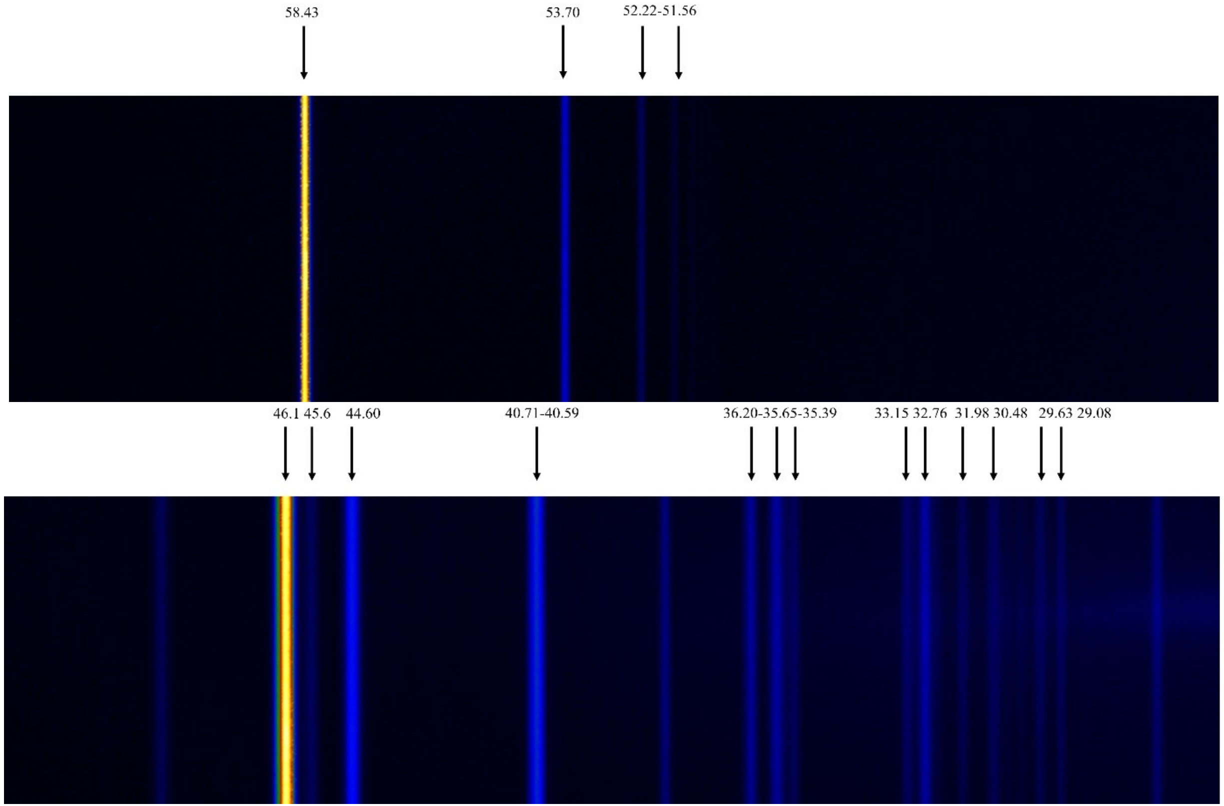
Calibration and commissioning activities

Hollow cathode lamp

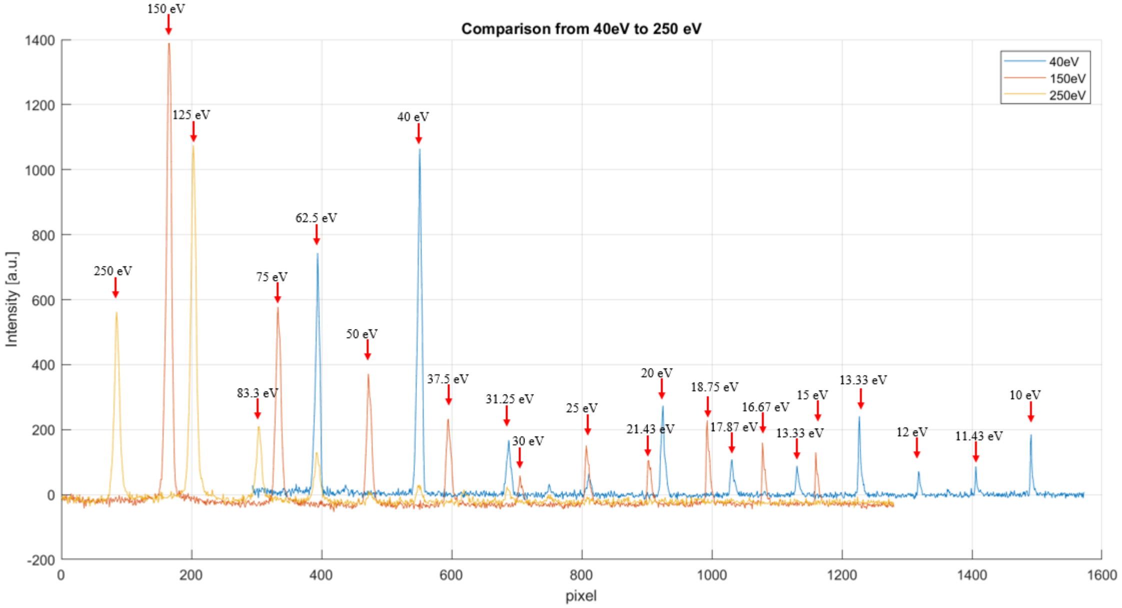
- He I lines
- Ne II lines

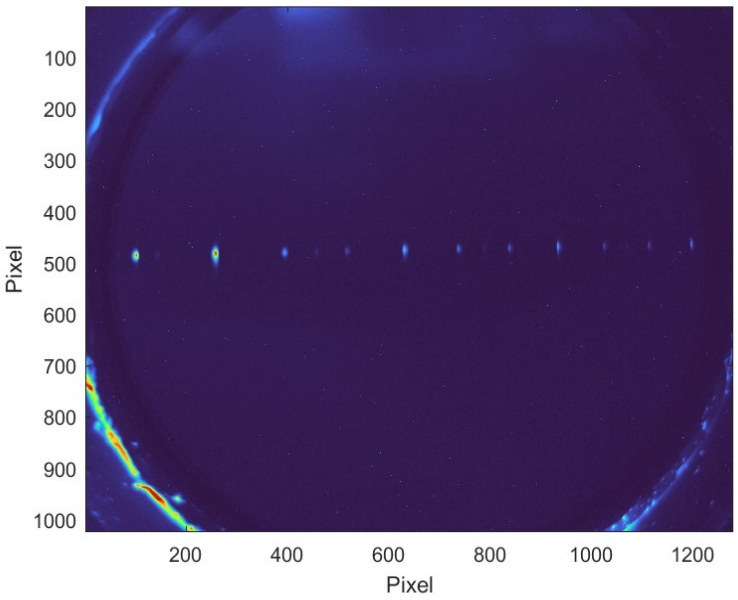
Observation and identification of the spectral lines

Confirm the grating alignment and dispersive capabilities



Test with CiPo – Circular Polarization beamline
Energies from 40 eV to 250 eV (20 nm to 5 nm)



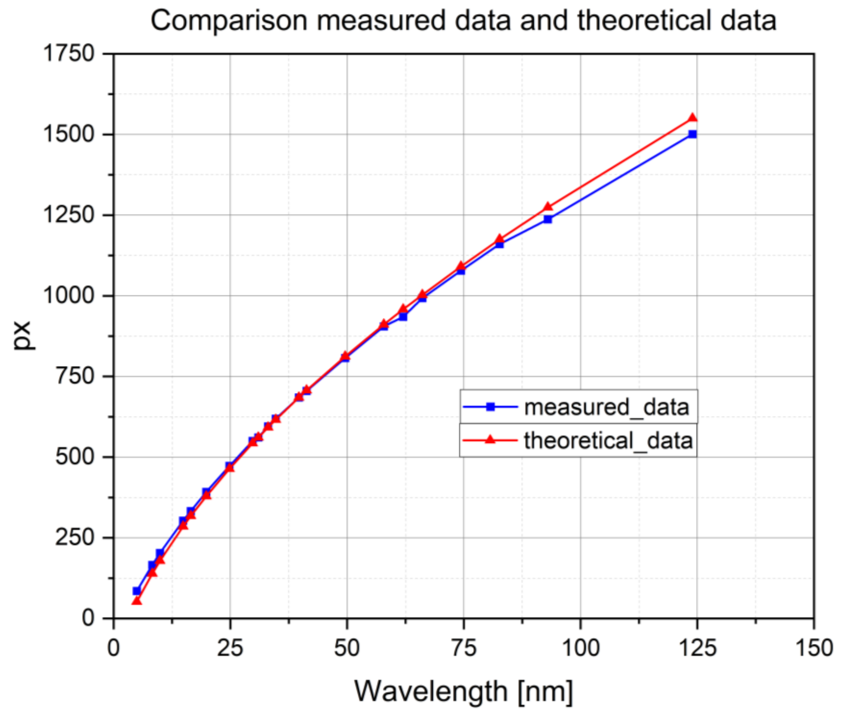


From the position of the signal onto the detector (pixel position)

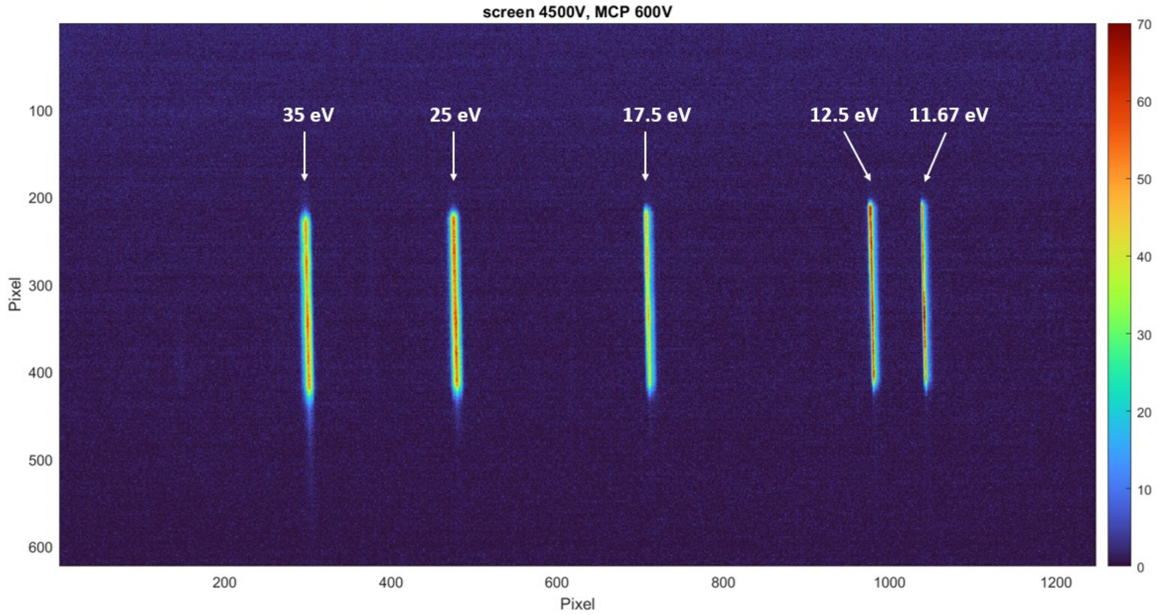
Polynomial fit

$$y = -a + b*\lambda - c*\lambda^2 + d*\lambda^3 - e*\lambda^4 + f*\lambda^5 - offset/0.033$$

If the energy is unknown, the position on the detector gives the signal energy



Test at FERMI LDM – **L**ow **D**ensity **M**atter beamline of the free electron laser
Two harmonics, 7th and 5th (35 and 25 eV) and their second order
Variable MCP and screen voltage to test the linearity of the system



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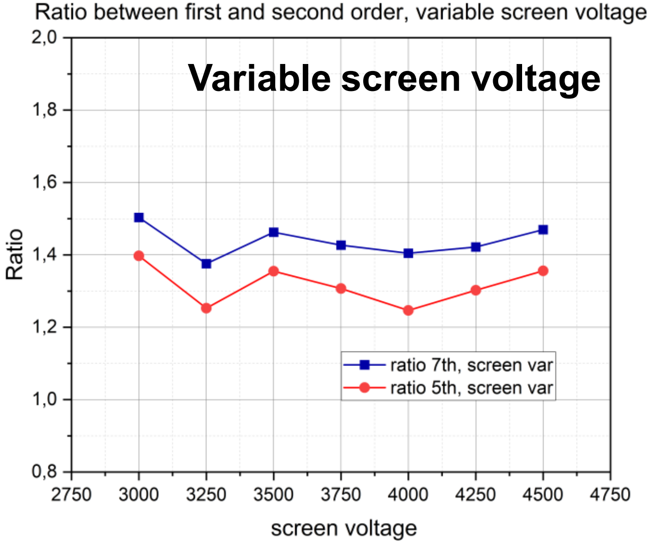
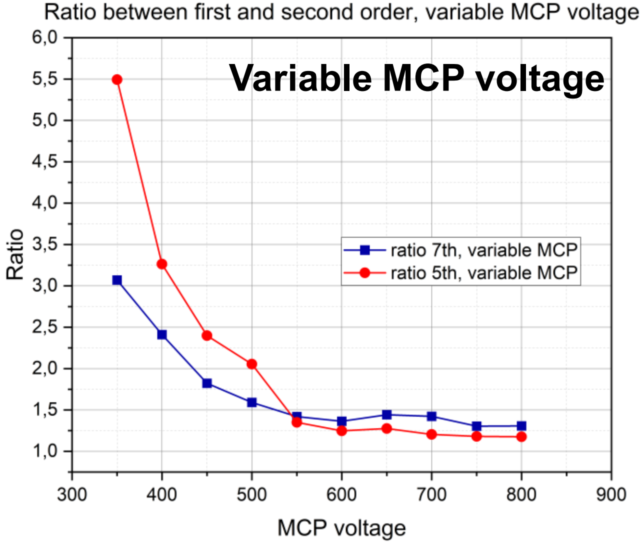
Elettra Sincrotrone Trieste

COSP

Ratio between first and second order at different MCP and screen voltage

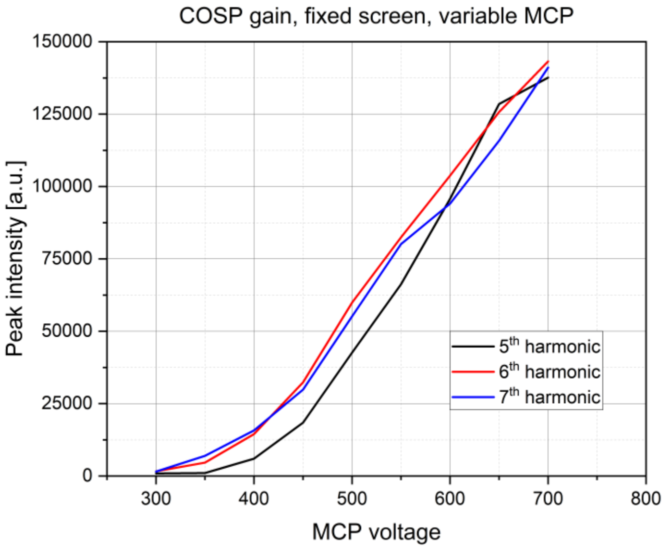
- Screen voltage: no effect on linearity
- MCP voltage: **high level of non-linearity**

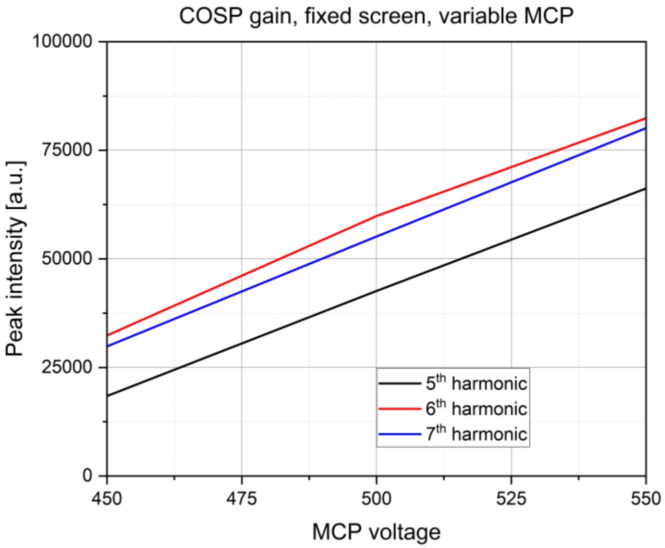




Three harmonics (7th, 6th and 5th) with fixed screen and variable MCP voltage

Region of linear gain: **450-550 V for the MCP**





Results:

- Successful commissioning of the COSP
- First tests of COSP during the preparatory phase of an experiment by prof. Sansone (Freiburg University)

The results have been presented at the SRI 2024 Conference in Hamburg, Aug 2024

Zeni G. *et al.*, **COSP: a dedicated compact wide-band spectrometer for free-electron-laser monitoring,** under submission to Photonics Journal

Thanks for the attention

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Activities for unexpected delays

- Collaboration in research activities at CNR-IFN lab, especially characterization of optical space elements operating in the UV and visible band
- Collaboration in the research activities about deformable grating and satellite instrumentation for the EUV observation
- Study of the reflectivity of mirror coatings in the UV band

Primary Mirror Coating Analysis

with Udo Schuehle, Luca Teriaca

From January 2023 to June 2023: in Max Planck Institute for Solar System Research in Gottingen

Preliminary analysis of the reflectance stability of the PMA coating at variable temperatures

Temperature	Reflectance at 121.6 nm
22° C	37.7 %
60° C	37.8 %
100° C	37.9 %
100° C (after 18 hours)	37.8 %
120° C	38.5 %