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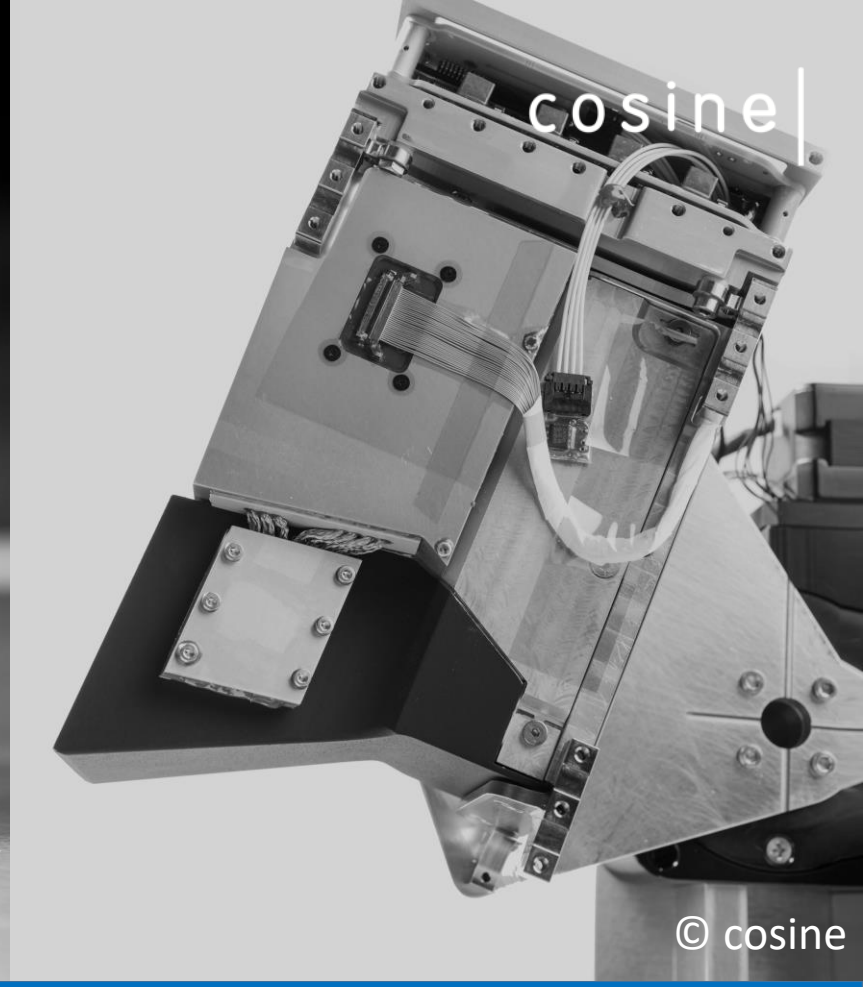
# Silicon Pore Optics for the Athena X-ray observatory

Marco Beijersbergen, cosine






## high energy optics

astronomy | material analysis | health

## inspection systems

energy | agrifood | health | semicon | environment

## remote sensing

space | HAPS | UAV | aircraft

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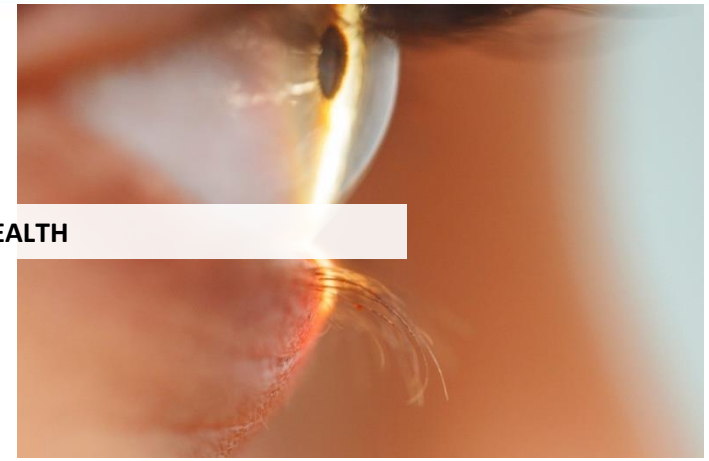
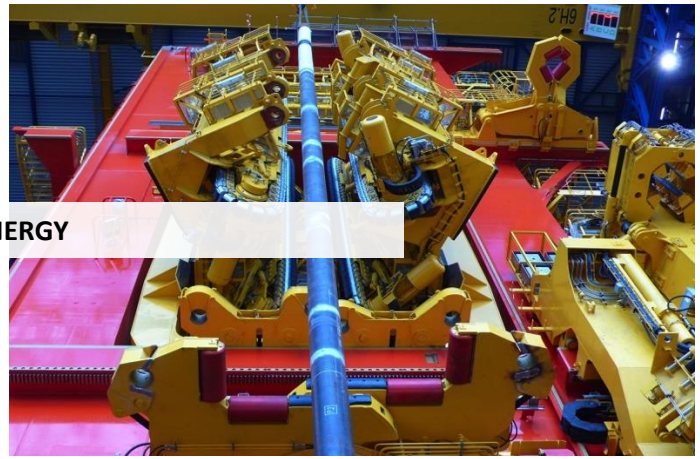
INDUSTRY



HEALTH

SAFETY & SECURITY



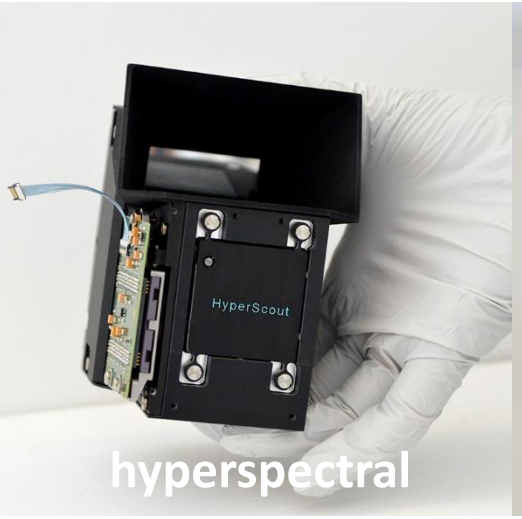
ENERGY

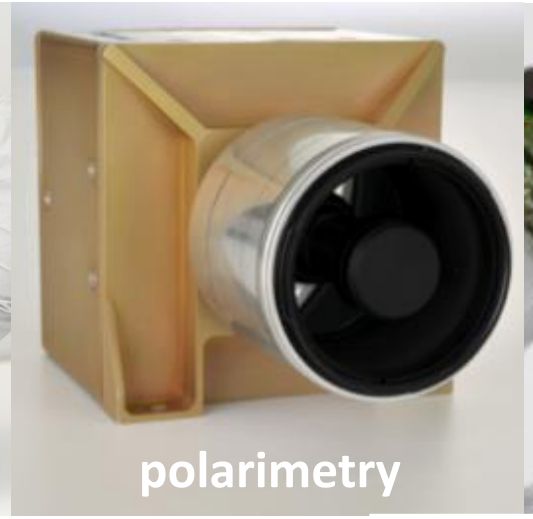
AGRI & FOOD

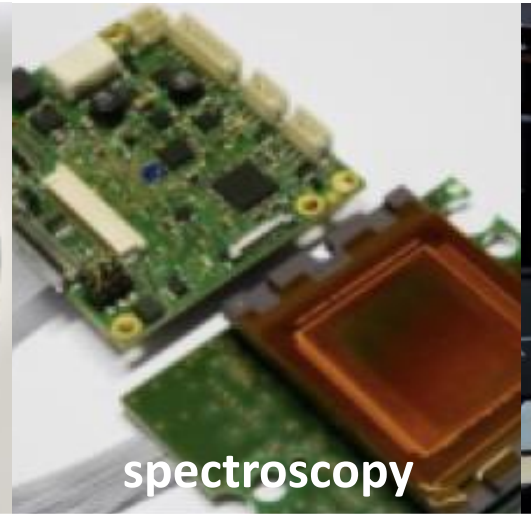
ENVIRONMENT

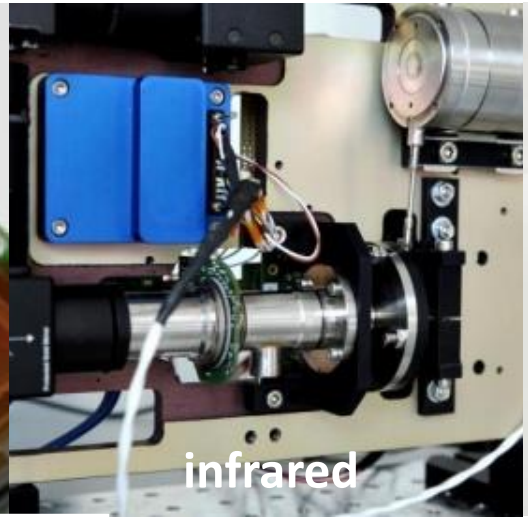
Bringing the measurement system to the sample

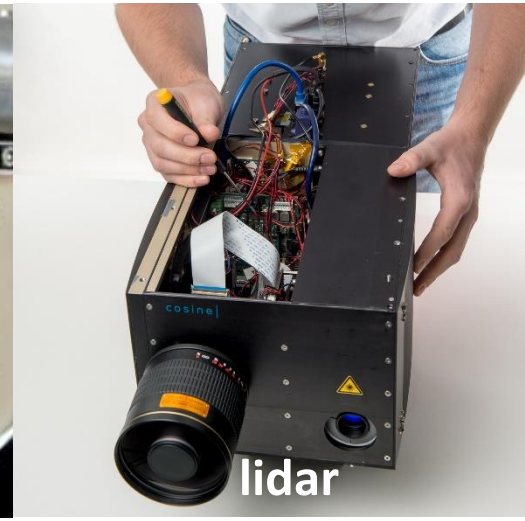
# small instruments for operational use

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sats | smallsats | aircraft | uav | drones | field | towers | vehicles

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# HyperScout

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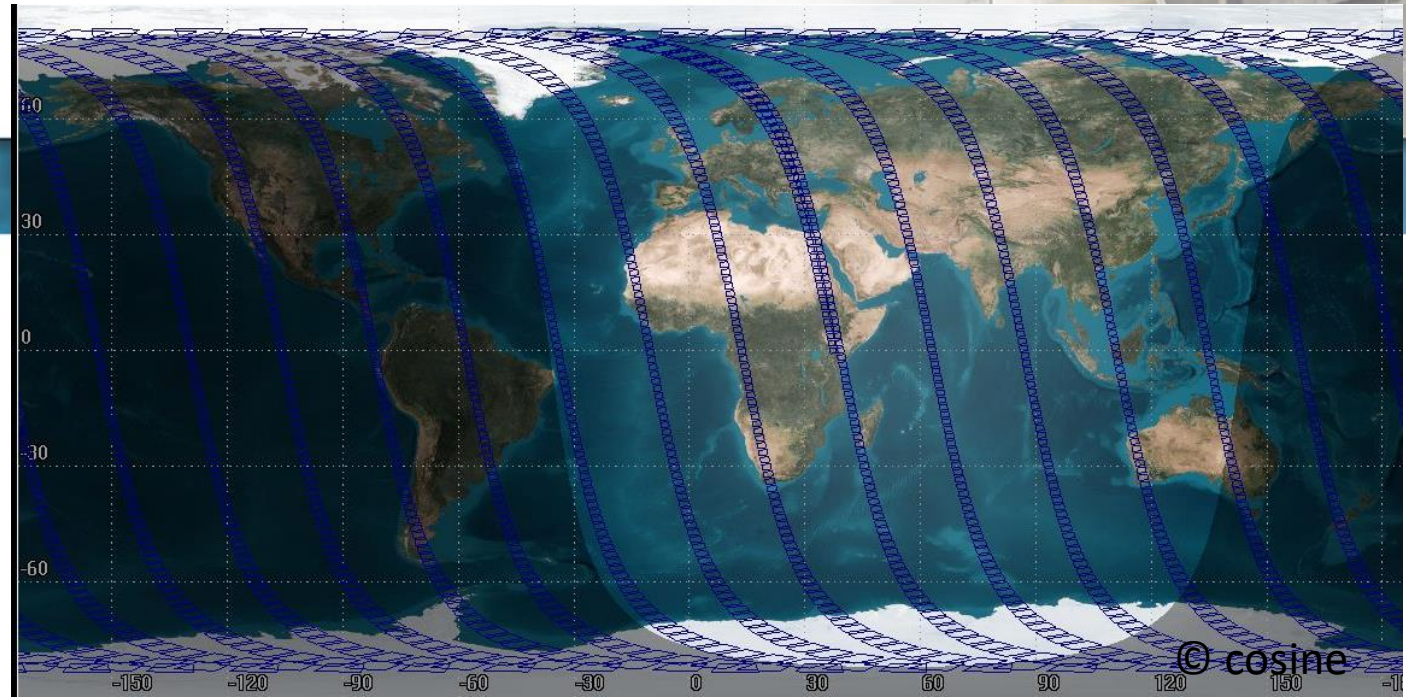
cosine measurement systems

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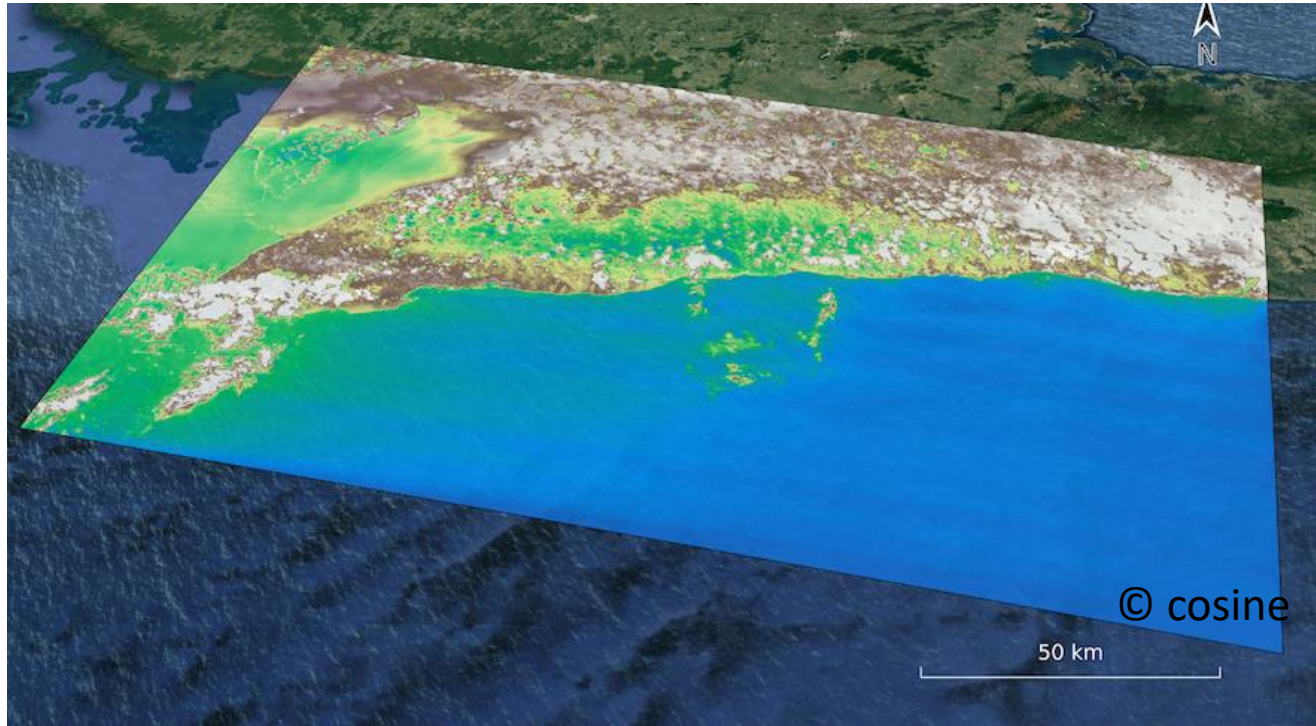


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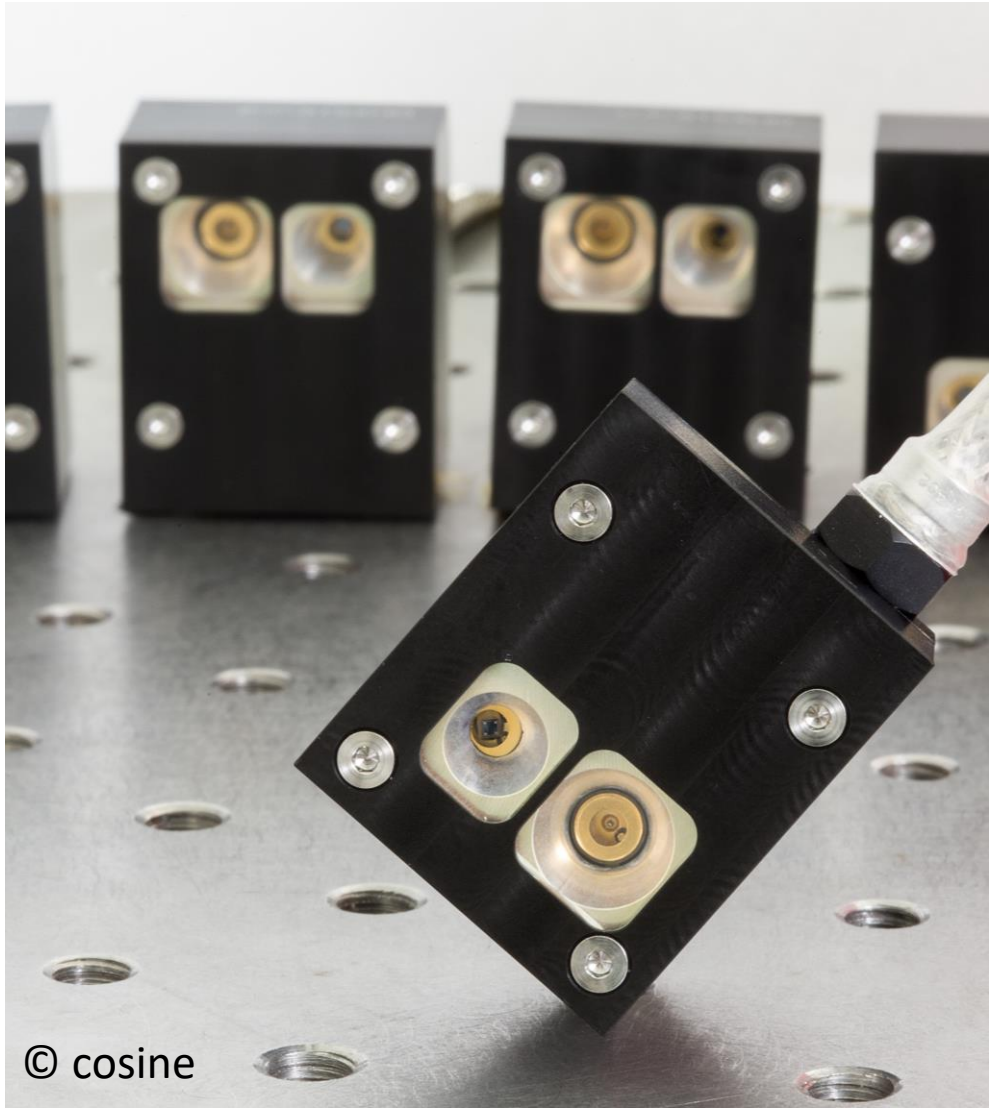
# NightPod

Credits: ESA

# Hayabusa 2 - MASCOT



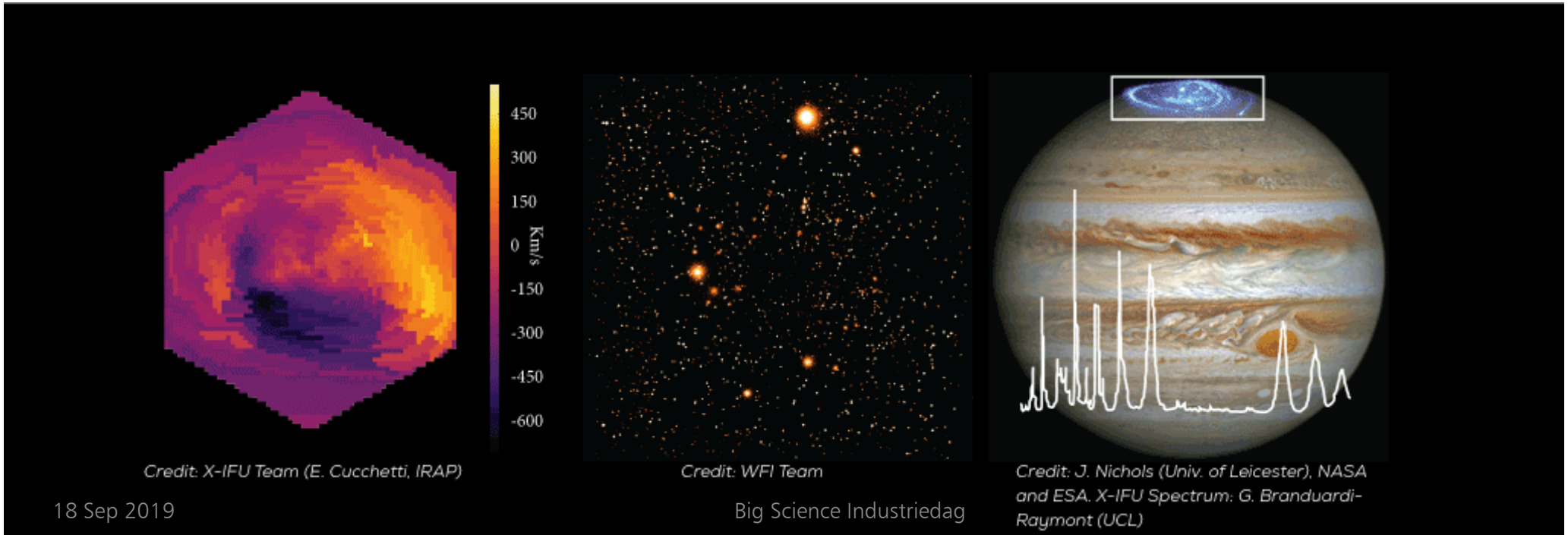
# The Athena X-ray observatory

**The Hot and Energetic Universe**

- selected by ESA in its Cosmic Vision program
- Second L-class mission
- Launch 2031

# Key scientific objectives

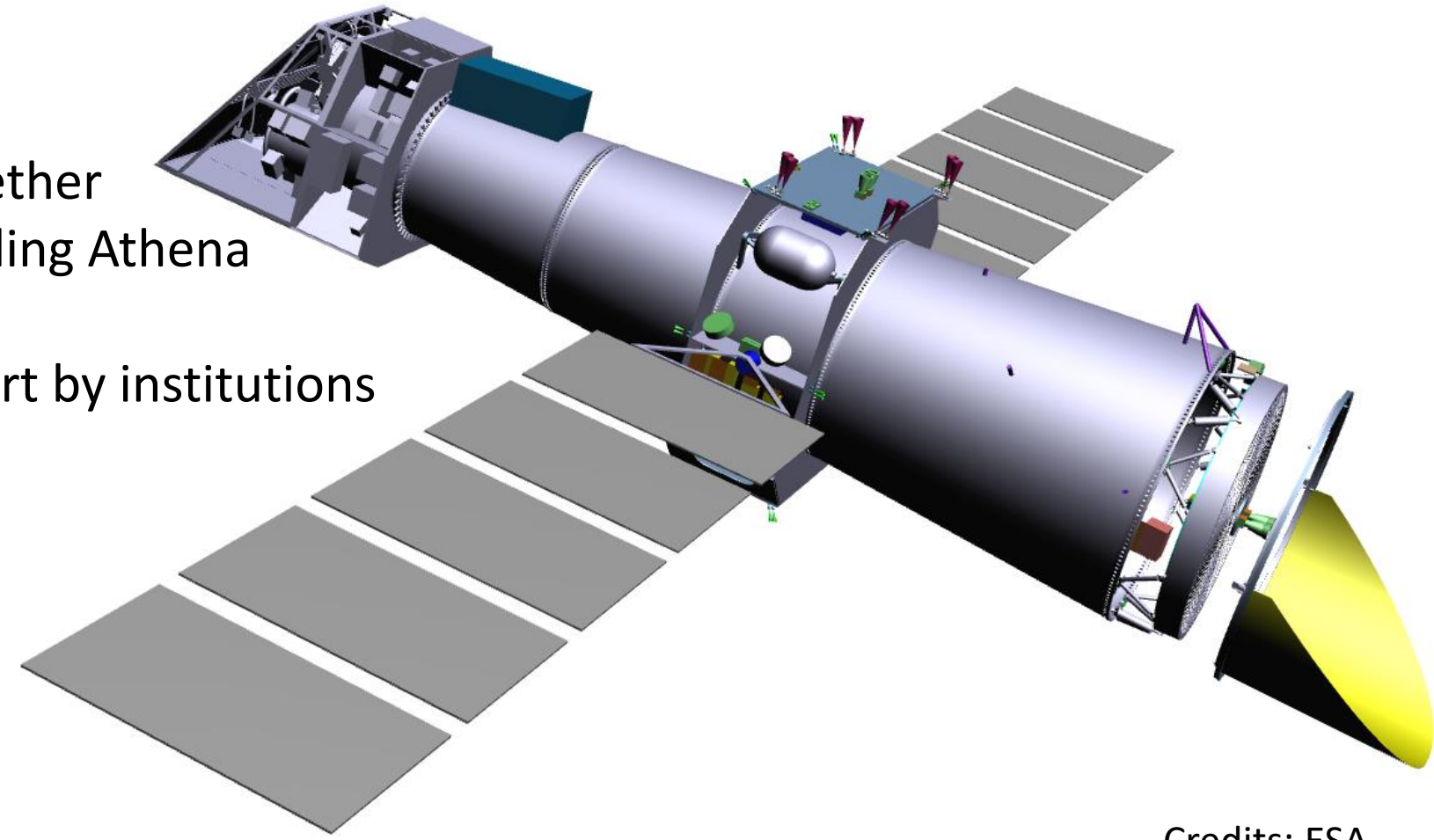
- Determine how and when large-scale **hot gas structures** formed in the Universe and track their evolution from the formation epoch to the present day.
- Perform a complete census of **black hole growth** in the Universe, determine the physical processes responsible for that growth and its influence on larger scales, and trace these and other energetic and transient phenomena to the earliest cosmic epochs.
- Provide a unique contribution to astrophysics in the 2030s by exploring **high energy phenomena** in all astrophysical contexts, including those yet to be discovered.



# Revolutionary mission

Community and ESA working together
to create new technologies, enabling Athena

Optics development is a joint effort by institutions
and industry, led by ESA



Credits: ESA

# Silicon Pore Optics development team

cosine measurement systems

stacking and mirror module production

micronit MICROFLUIDICS

plate production

e2v

plate production

DTU

plate coating

SRON

FEM, engineering
env testing

Osservatorio Astronomico di Brera

simulation

Media Lario

MM integration

PTB

x-ray metrology

MPE

x-ray metrology

ZEISS

mandrels

siltronic perfect silicon solutions

wafers

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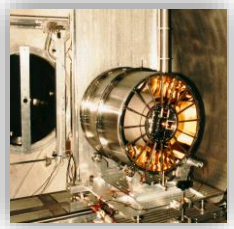
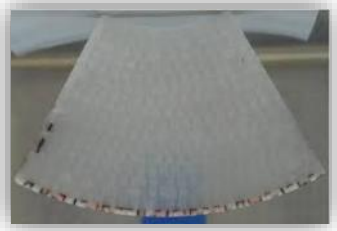
- X-ray tracer of mirror module
- Science Analysis System



**XMM Science Simulator**

1999

- Optical metrology
- X-ray measurements
- Used on MIXS-C of BepiColombo



**MPO development**

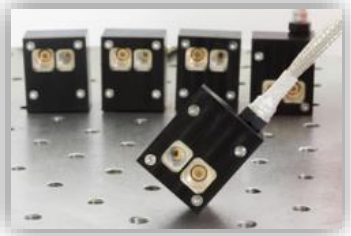
2005

- 3D cameras for ISS
- Built avionics & cameras
- Used by Thomas Reiter and Paolo Nespoli

**3D cameras**

2006

- Optical proximity sensor
- On Mascot lander of DLR inside Hayabusa-2



**GNC sensor asteroid lander**

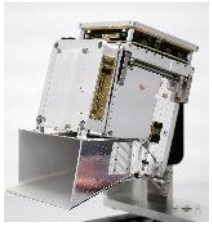
2014

- Hyperspectral imaging for cubesats (GomX-4B sat)
- Built FM including optics and embedded electronics

**Hyperscout 1**

2015

- Hyperspectral imaging including thermal and artificial intelligence



**Hyperscout 2**

2018

1999 2002 2005 2006 2009 2014 2015 2018

**SPO invention**

2002

- Gen1 robot
- First SPO stack
- Proof of principle
- Co-inventor of patent

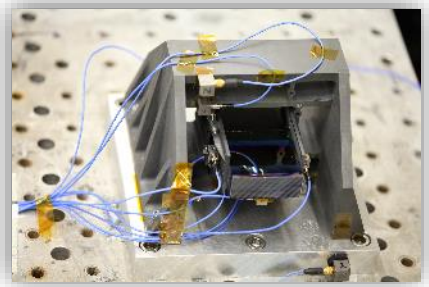
**Stacking robot**

2006

- First SPO f=50 m mirror module
- X-ray metrology
- First Cesic petal

**SPO ruggedisation**

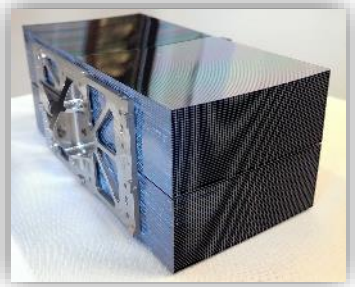
2009



- Gen3 robot f=50 m
- Mirror module assembly
- Vibration testing
- X-ray metrology

**Transition to ATHENA**

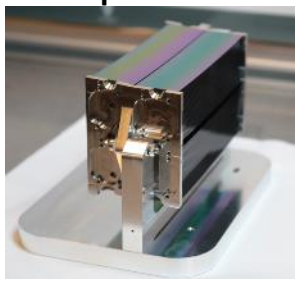
2015



- Gen5 stacking robot f=20 m
- Mirror module assembly
- Environmental testing
- X-ray metrology

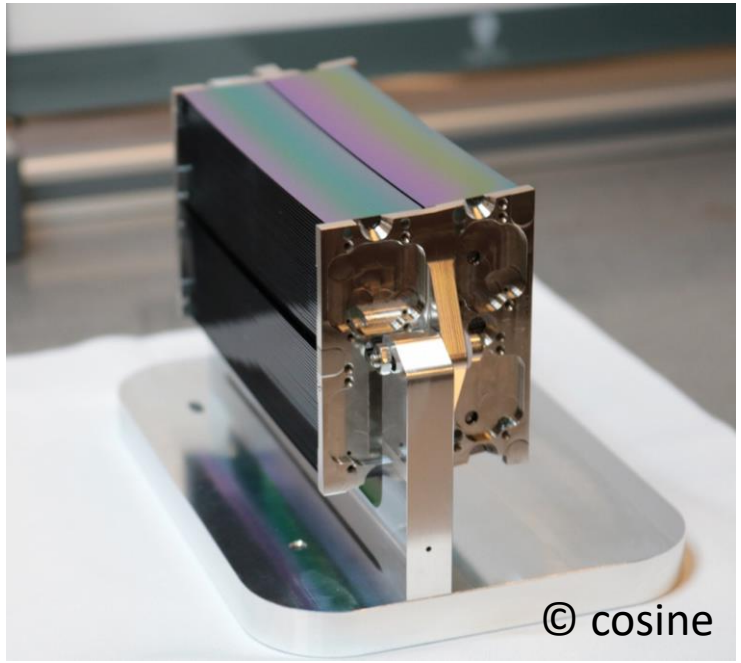
**Preparation for mass production**

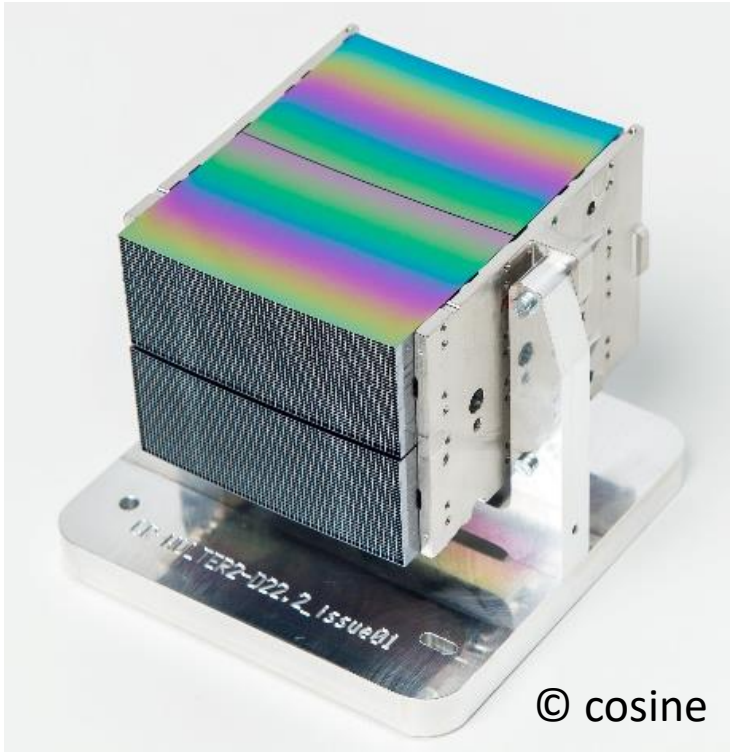
2018

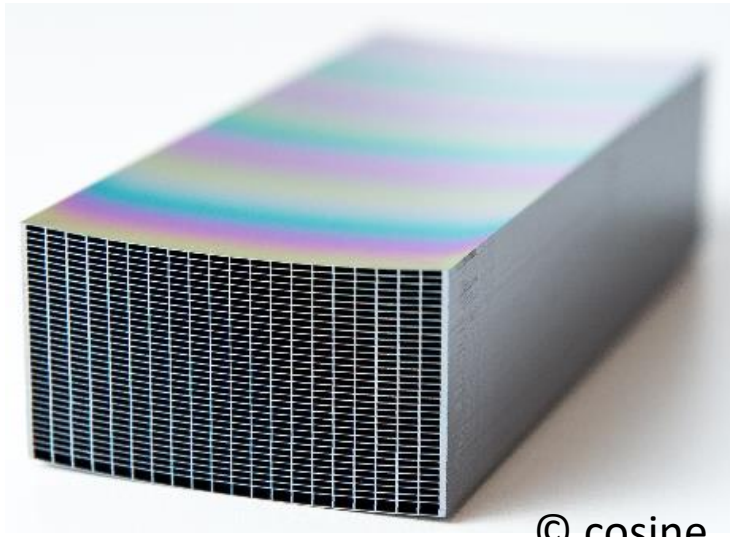


- Gen6 stacking robot f=12 m
- 3 radii
- Plate mass production and coating

# SPO invented to realise largest x-ray telescope to date

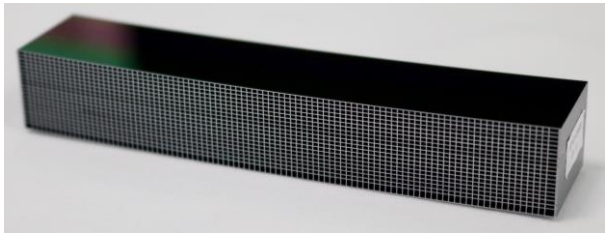
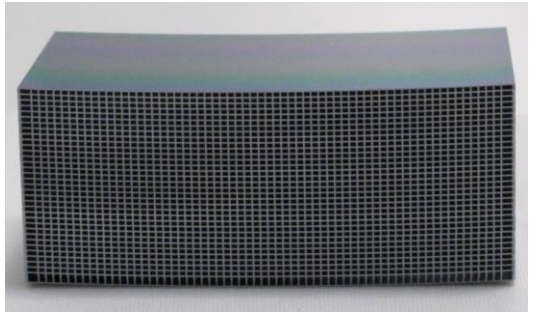


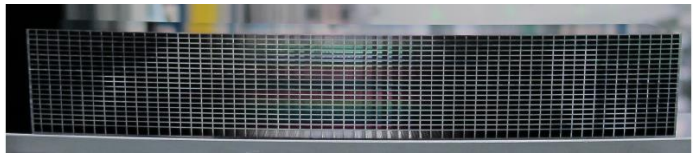
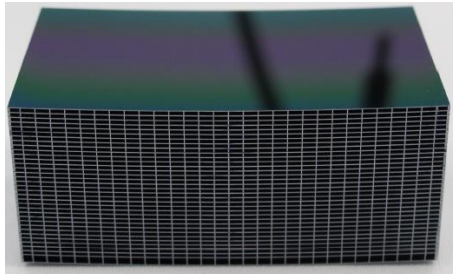



# Stacks with different shapes, open area, coating ...

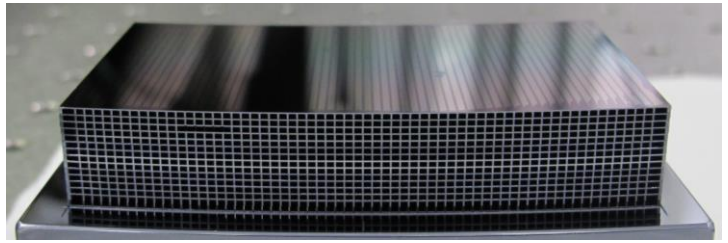
- Radii spanning Athena's optic (1500, 737, 240 mm)


- Increased open area (wider rib spacing)

- Coated (iridium) to increase reflectivity; roughened to decrease stray light

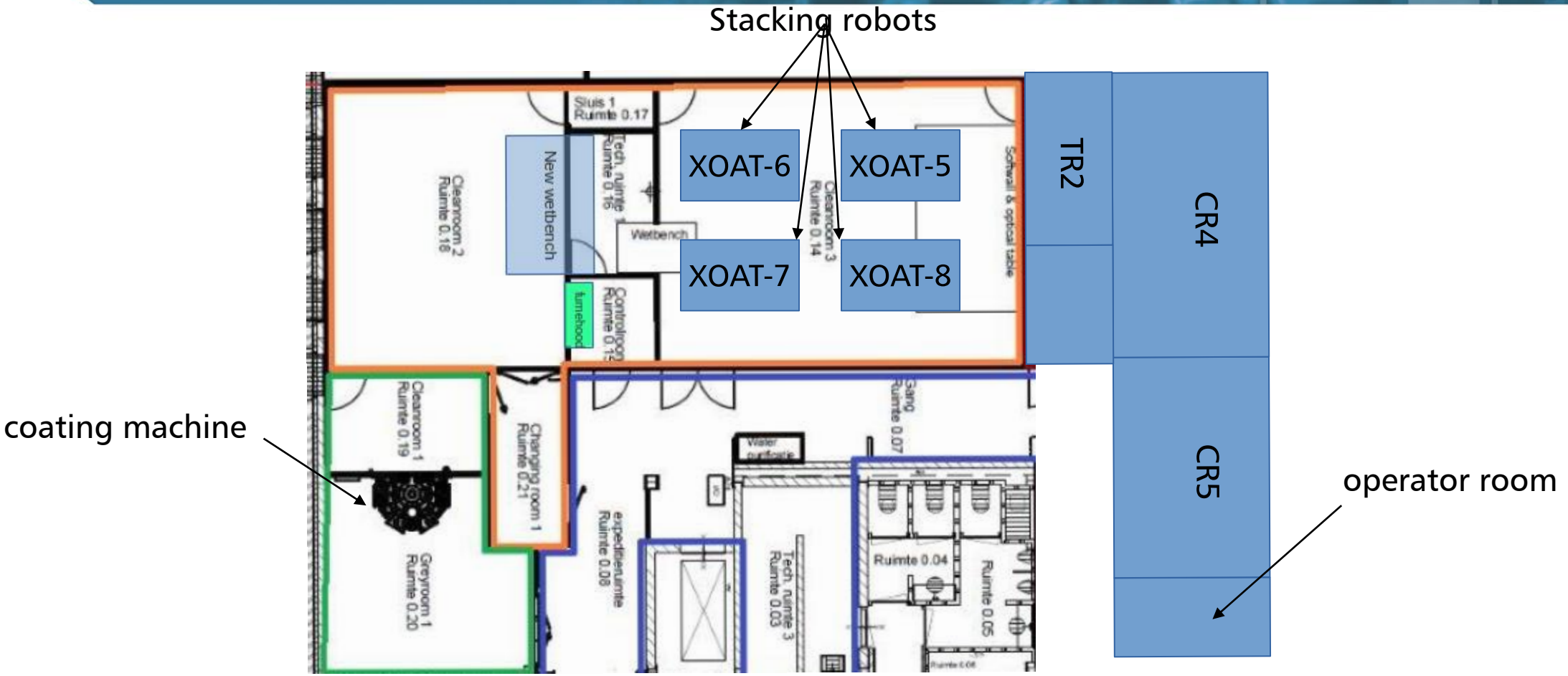



production movie available on request

# Fully automatic production process

- State of the art subsystems
  - FRT
  - Hexapod
  - Robotic arm
  - Metrology
  - Camera systems
- 4 robots in place
- used for ESA, MPE and SRON developments

# SPO facilities for ATHENA



# Synchrotron beam lines

- 12 m beamline operational at Bessy-II/PTB
- Back-up beamline to be implemented at ALBA

# Coating facility

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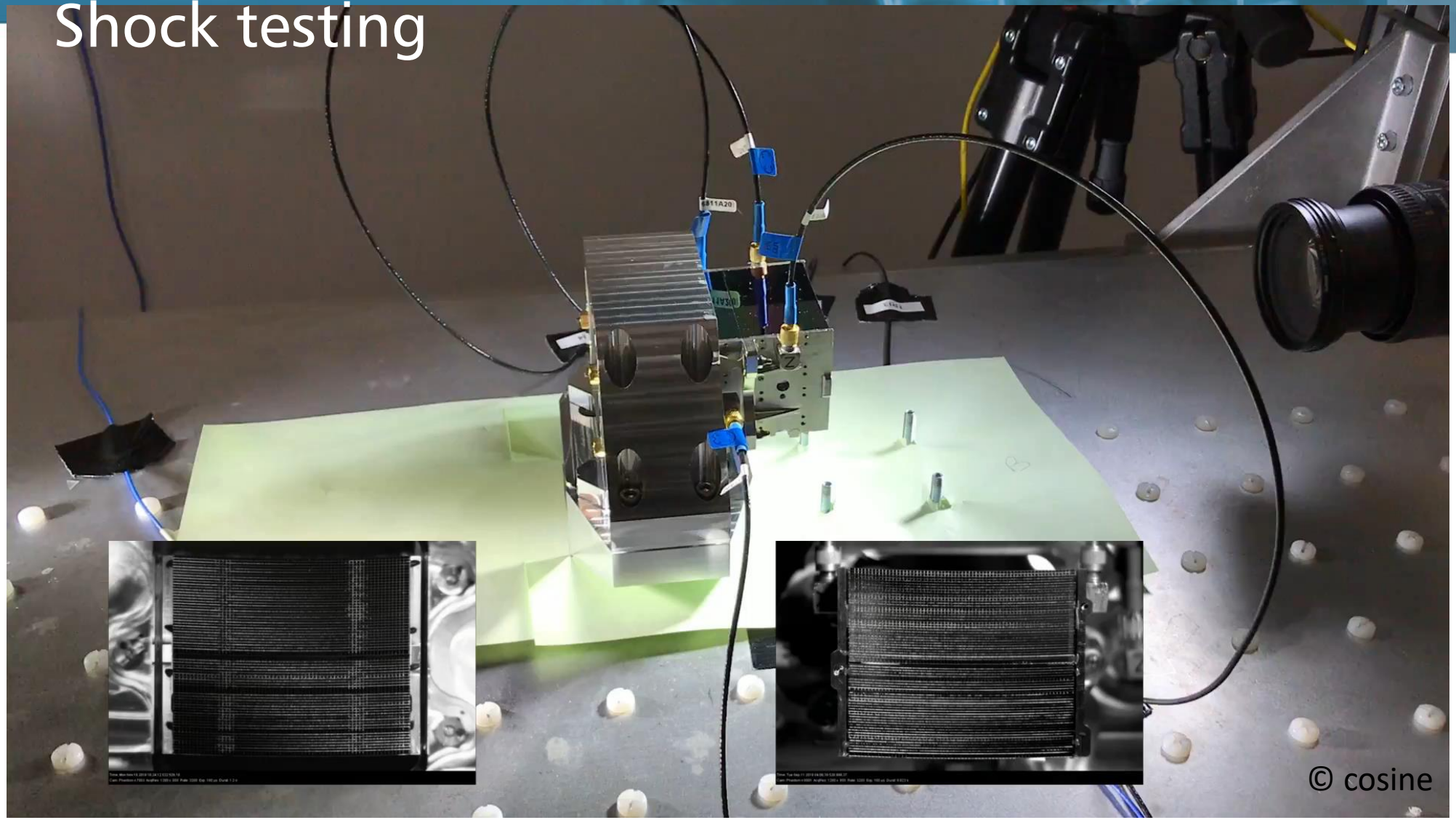
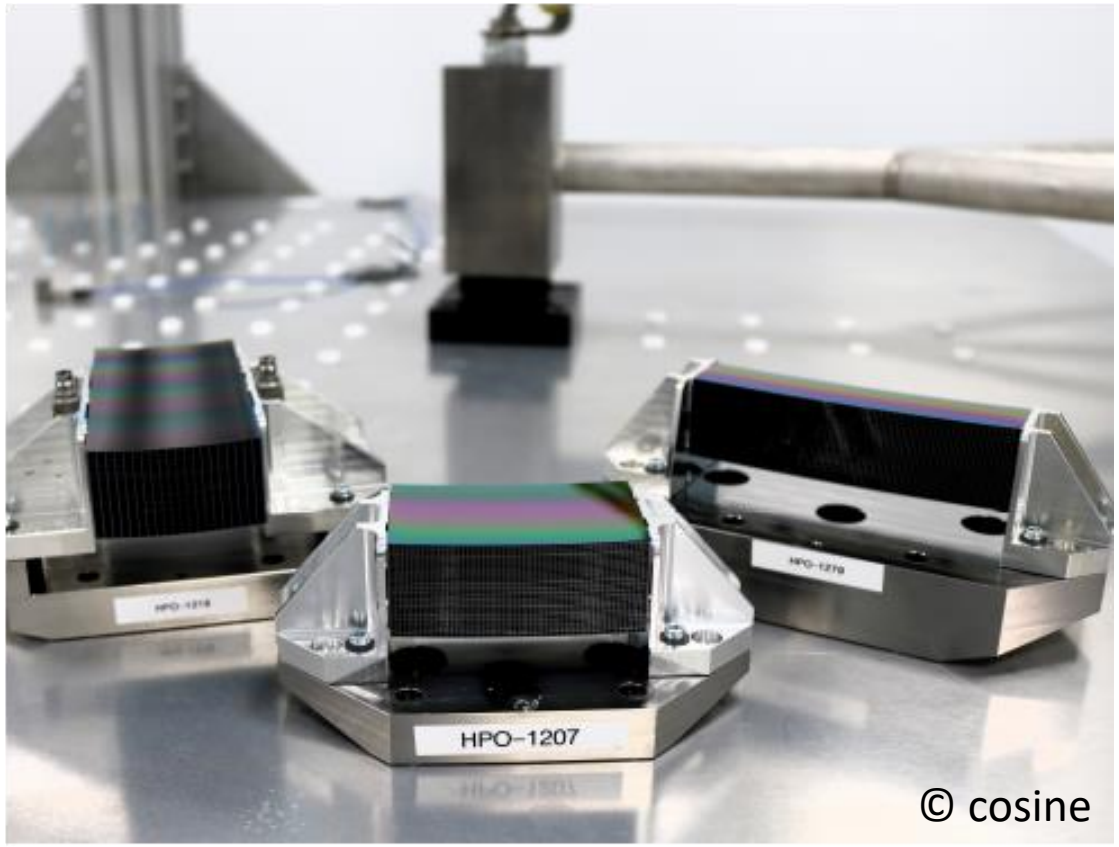
# Shock testing



# Shock testing

| Type | HPO number | Required level * | Passed level |
|---|---|---|---|
| Inner radius R = 277 mm | HPO-1218 | 150 g | 971 g |
| | HPO-1234 | | 896 g |
| Middle radius R = 737 mm | HPO-1198 | 200 g | 893 g |
| | HPO-1207 | | 929 g |
| | HPO-1210 | | 977 g |
| | HPO-1215 | | 946 g |
| Outer radius R = 1500 mm | HPO-1117 | 250 g | 827 g |
| | HPO-1082 | | 926 g |
| | HPO-1272 | | 833 g |
| | HPO-1279 | | 848 g |



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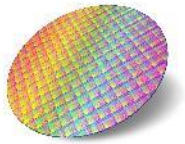
* Requirement for mirror module

# Further developing SPO for other applications






Athena

Arcus II

…

Synchrotrons

Material analysis

Semicon

Medical

Research

Optical bench

XUV optics

Laue lenses

Neutron optics

Space

Non-space

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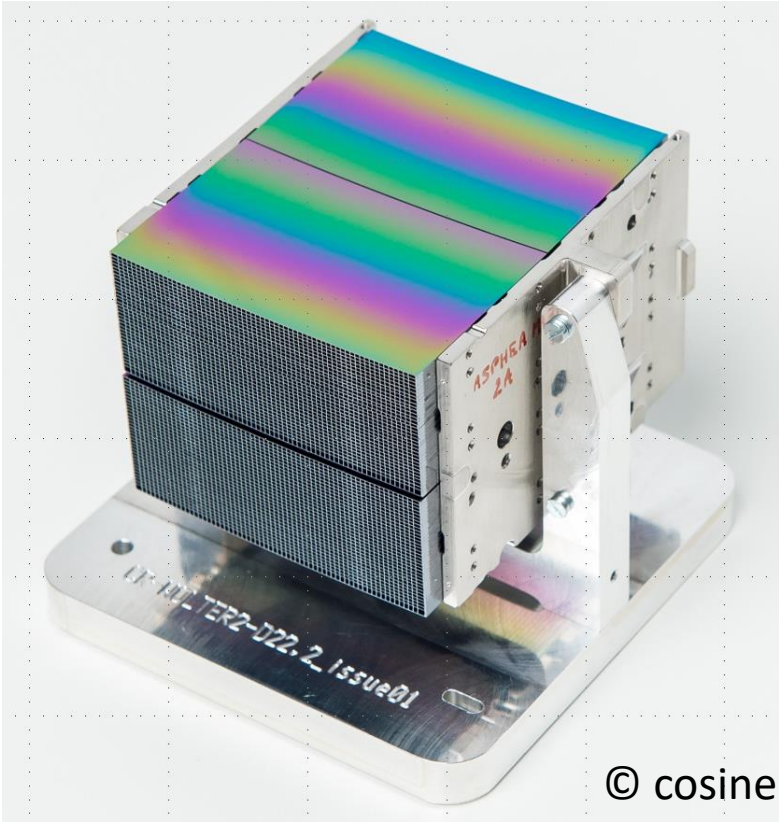
# SPIE 2019 papers on ATHENA Optics

- Development and manufacturing of SPO x-ray mirrors, [11119-13]
- Installation and commissioning of the silicon pore optics coatings facility for the Athena mission, [11119-14]
- Performance and stability of Ir/SiC x-ray mirror coatings for ATHENA, [11119-15]
- Stacking of mirrors for silicon pore optics, [11119-16]
- X-ray testing of silicon pore optics, [11119-17]
- Assembly of confocal silicon pore optic mirror modules, [11119-18]
- Environmental testing of silicon pore optics for Athena, [11119-19]
- Status of the silicon pore optics technology, [11119-20]
- Integration facility for the ATHENA X-Ray Telescope, [11119-21]
- BEaTriX--the Beam Expander Testing X-Ray facility for testing ATHENA's SPO modules: progress in the realization, [11119-22]
- VERT-X: a VERTical X-ray rasterscan facility for calibrations, [11119-23]
- PANTER activities toward testing and calibrating ATHENA optics, [11119-24]
- ATHENA: phase A study status and optics/instrument accommodation, [11119-27]
- A low-energy x-ray reflectometer for characterization of ATHENA mirror coatings [11119-25]
- Thermal simulations for characterization of ATHENA mirror modules with a radiating box in the BEaTriX facility [11119-53]
- BEaTriX--the Beam Expander Testing X-ray facility for testing ATHENA's SPO modules: the collimating mirror [11119-54]



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