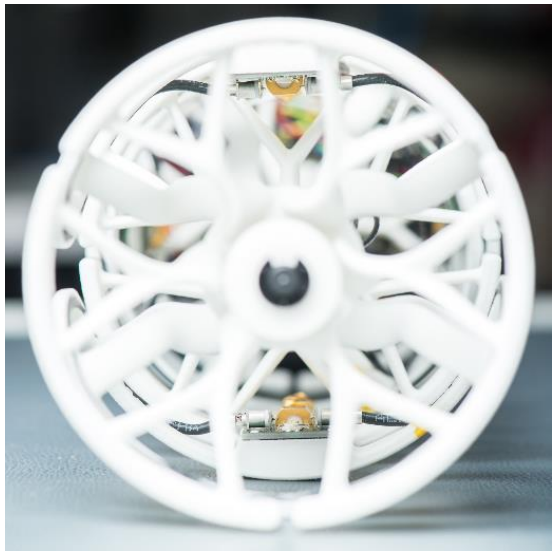
cosine

# The world's best X-ray mirrors for space-based astronomy spin-in from semicon and spin-off to beam lines, material analysis and health care

Max Collon on behalf of the SPO team

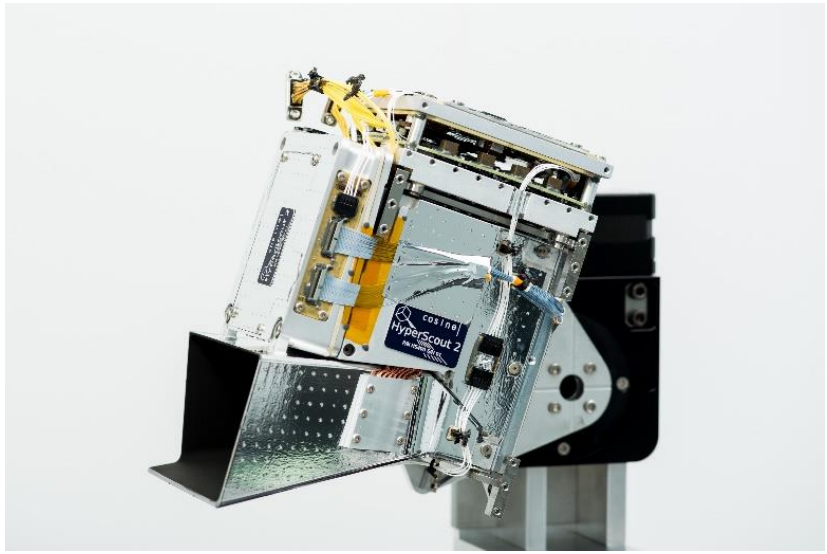
# cosine develops and builds measurement systems



Inspection systems

Spectroscopic and imaging measurement systems

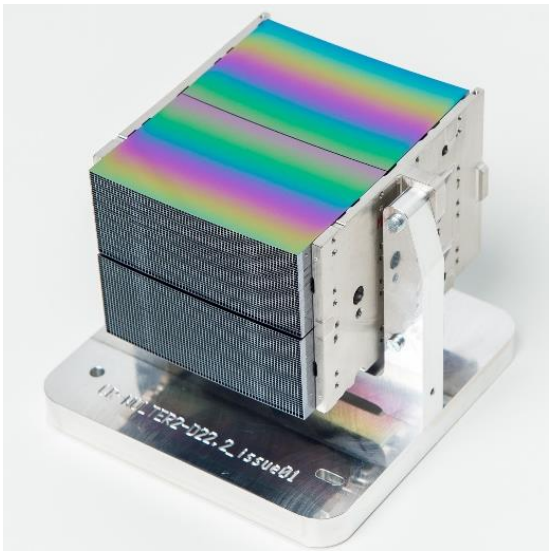
Medical, Oil/Gas, Food & Pharma




Remote sensing systems

Space and air-borne spectral cameras

Agriculture, Environment and Disaster Management



High energy optics

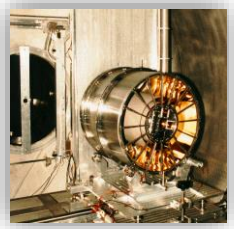
X-ray and gamma-ray optics

Astronomy, Material Analysis and Health

# Large cleanrooms and production facilities available in Sassenheim

- 900 $m^2$ of operational cleanrooms
  - Different classes available (ISO 7 – 5)
  - Room for additional 1,000 $m^2$
  - Cleanrooms used for development and production
- High-tech facilities available
  - Optics, laser, electronics
  - Environmental testing (thermal vacuum, shock, vibration)
  - Industrial magnetron sputtering, wetbenches and semicon equipment
  - Fully automated stacking robots
  - Laser micro-jet CNC
  - 300 mm Ion Beam Figuring machine
- Offices in Germany (Berlin) and Italy (Benevento)
- Staff trained to access many external test facilities
  - 24/7 access to beamlines at BESSY II and ALBA

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



**XMM Science Simulator**

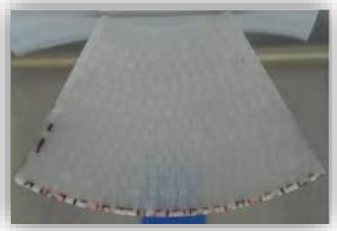
1999

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

**SPO invention**

2002

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



**MPO development**

2005

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

**Stacking robot**

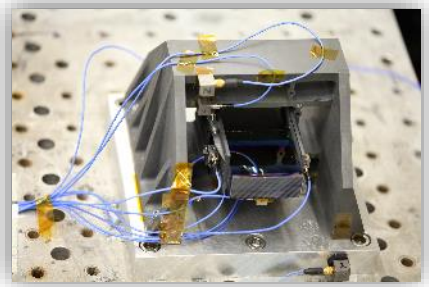
2006

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

**3D cameras**

2009

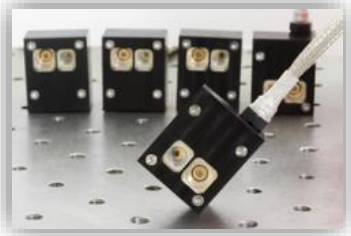
- Gen3 robot f=50 m
- Mirror module assembly
- Vibration testing
- X-ray metrology



**SPO ruggedisation**

2014

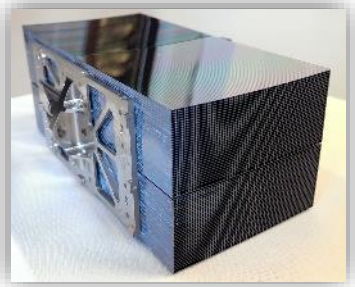
- Optical proximity sensor
- On Mascot lander of DLR inside Hayabusa-2



**GNC sensor asteroid lander**

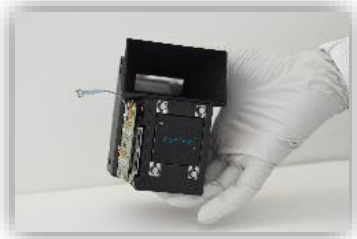
2015

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



**Transition to ATHENA**

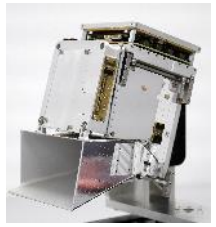
- Hyperspectral imaging for cubesats (GomX-4B sat)
- Built FM including optics and embedded electronics



**Hyperscout 1**

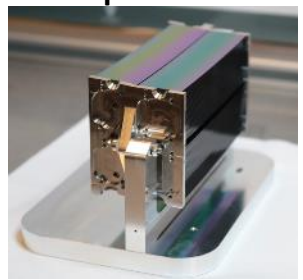
2018

- Hyperspectral imaging including thermal and artificial intelligence



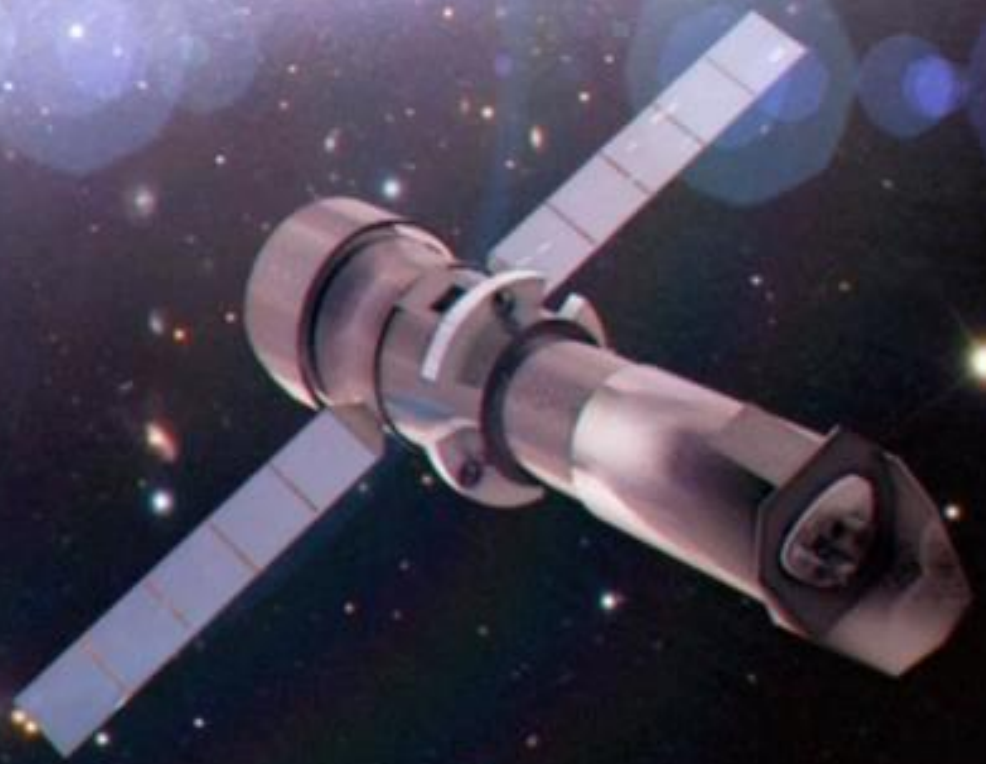
**Hyperscout 2**

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



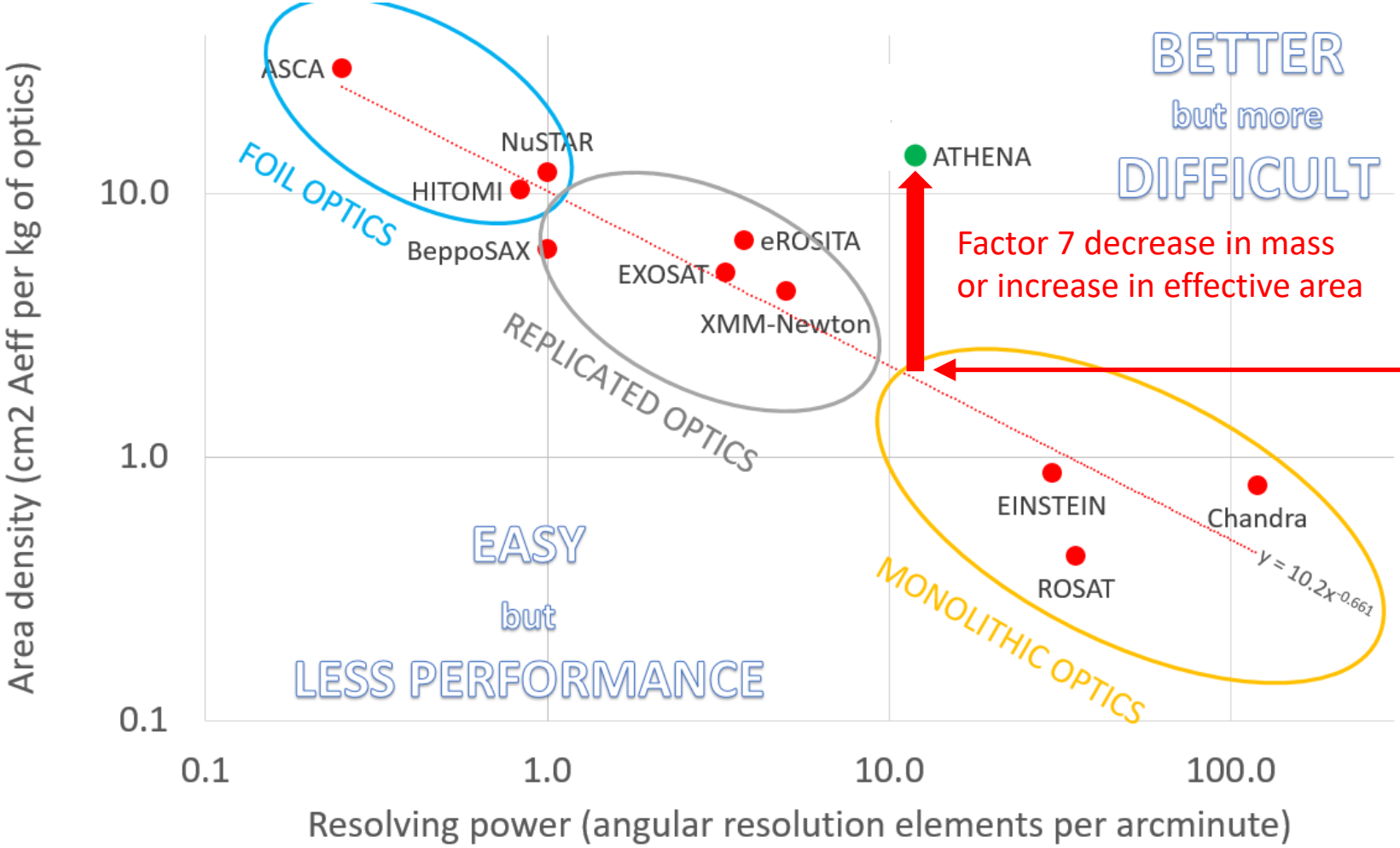
**Preparation for mass production**

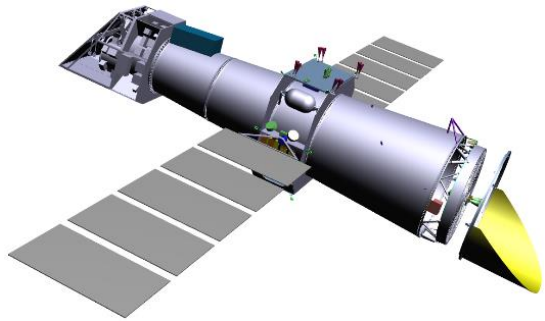
# THE ATHENA+ OBSERVATORY



2nd ESA Large Class Mission
Selected 2014
Launch 2034

# The ATHENA Optics Challenge



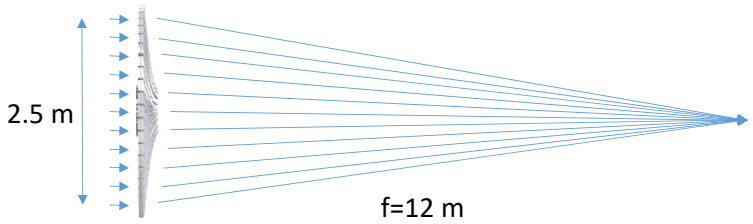
7000 kg

## ATHENA requires truly novel X-ray optics technology

- HEW 5'' & $A_{eff}$ > 1.4 $m^2$ @ 1keV <1 ton
- Established technologies would require a mass of 7000 kg to achieve the required angular resolution

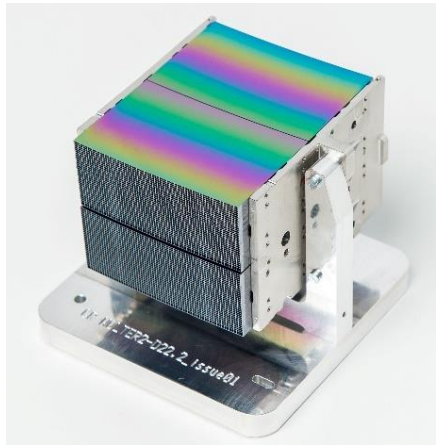
This would be the mass of the complete ATHENA spacecraft!

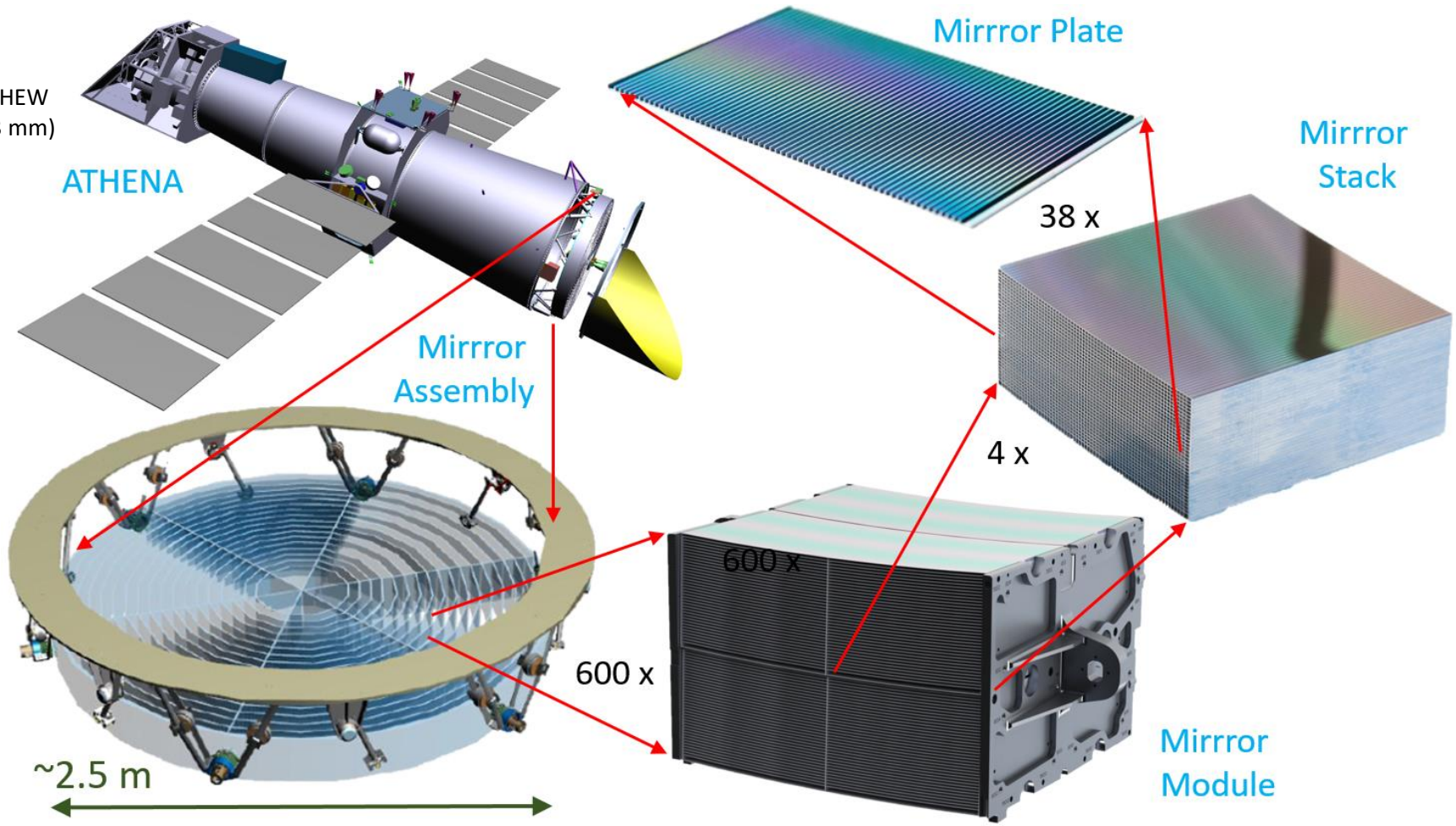
# Modular Silicon Pore Optics for ATHENA




5” HEW
(0.3 mm)

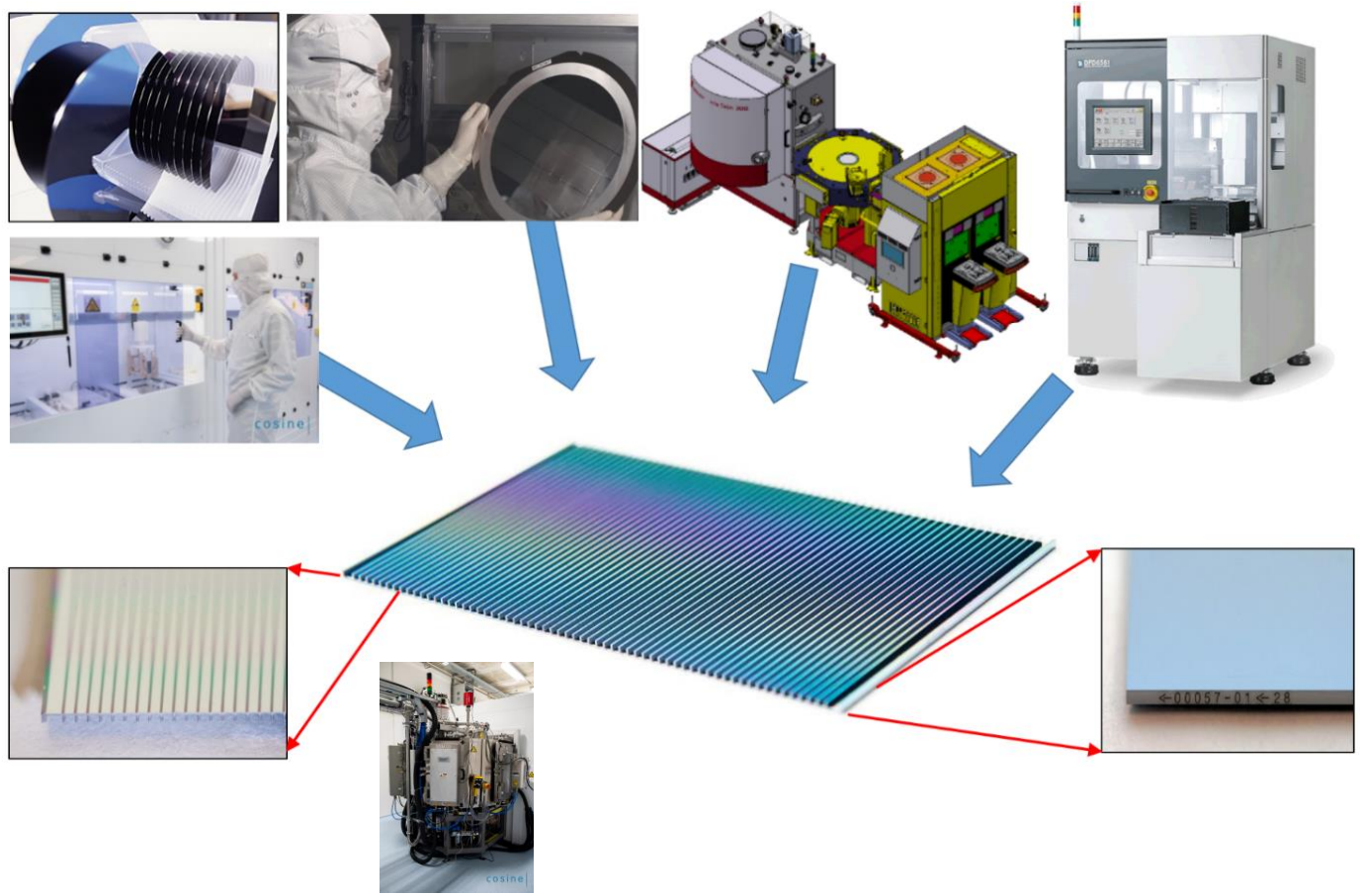
Athena optic consists of 600 mirror modules with a total of ~90,000 mirrors with >300 m$^2$ area
(comparable with 20 m ground based telescope)





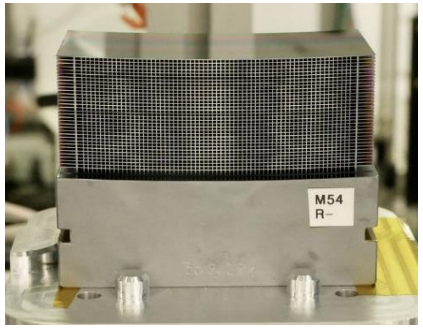
# Technology Spin-in is key to SPO Development

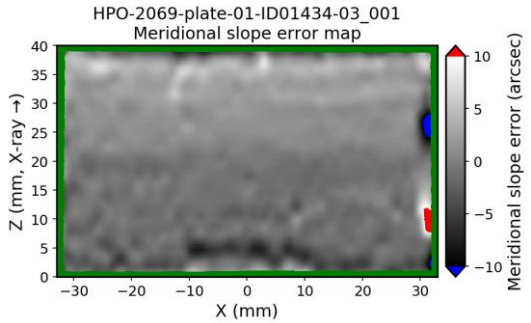
- Proven equipment, processes and materials utilised:
  - Mirror plates are made from latest generation commercial silicon wafers, using semicon processes and equipment (currently ~2500 mirror plates per year)
  - Mandrels are polished from silicon (semicon) using established optical manufacturing (Zeiss)
  - Coating uses solar panel and display industry technology and equipment
  - Stacking uses semicon cleaning and robotics processes and tools
  - Metrology based on automotive and display industry measurement systems

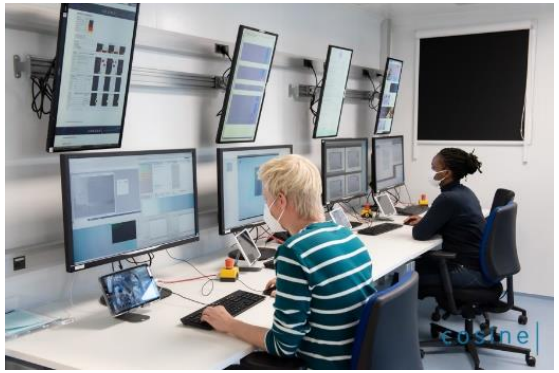


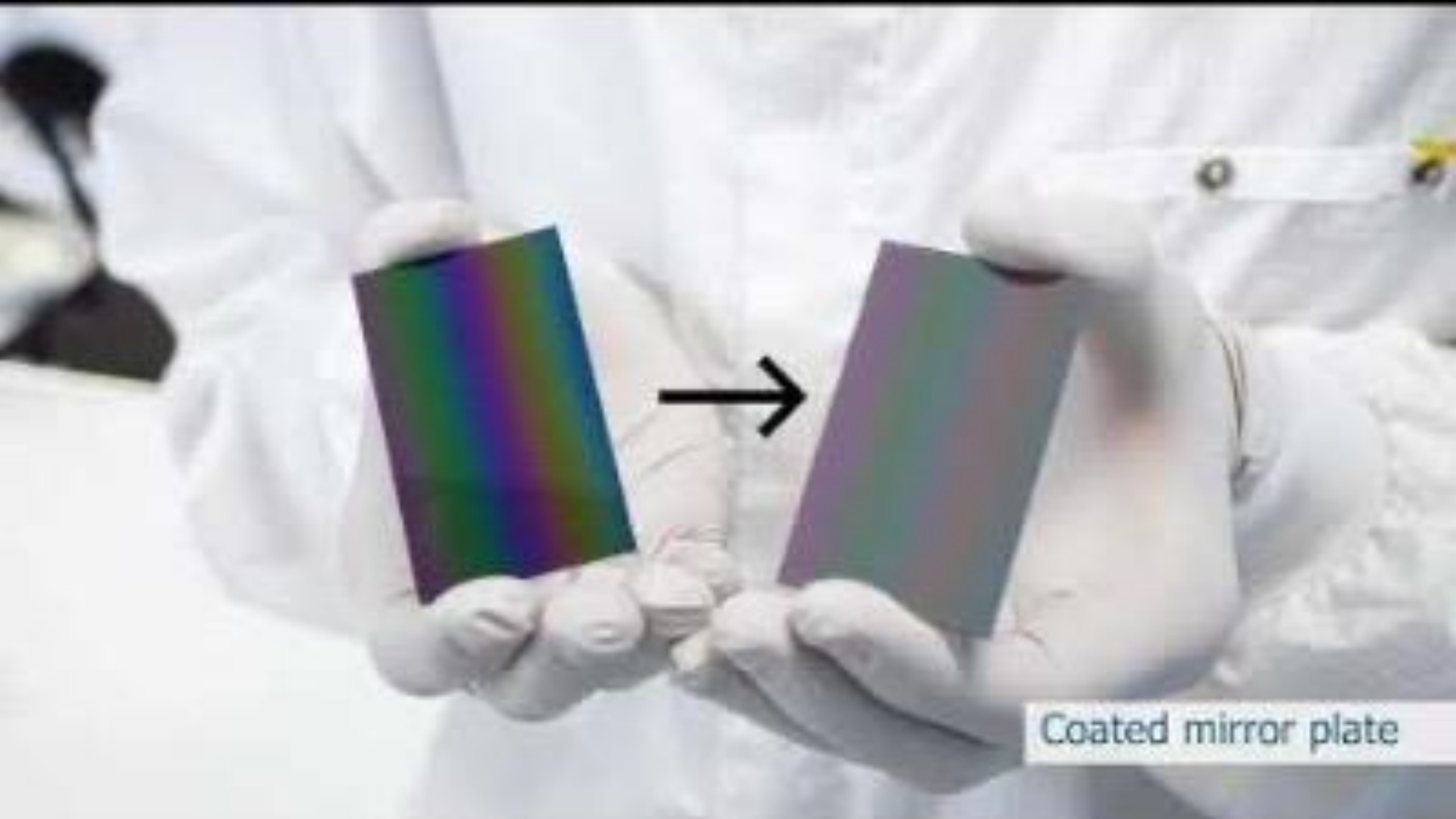
ZEISS siltronic perfect silicon solutions micronit MICROFLUIDICS TELEDYNE e2v Everywhereyoulook™

# 4 fully automated stacking robots at 5 min per plate in ISO 5

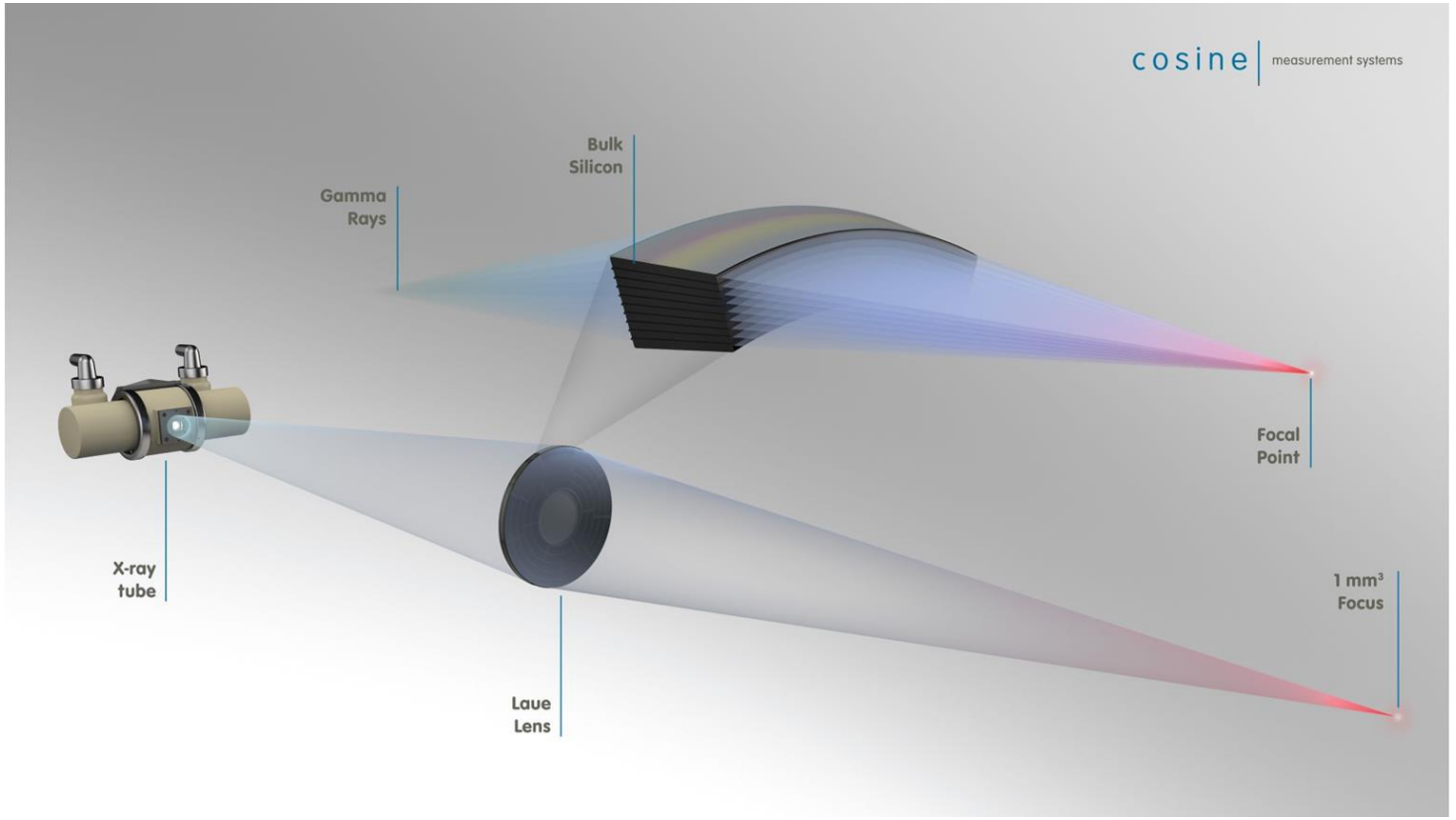




Coated mirror plate

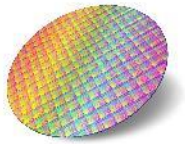
# Focusing gamma rays with SPO technology

- SPO technology is now also being used to create a gamma-ray lenses
- The lenses uses Bragg diffraction within the crystal lattice of stacked silicon plates
- Superior focusing capabilities can be obtained owing to the curvature of the plates
- Application to radiation therapy, where accurate dose delivery can be achieved
    - High added value for early-stage brain tumor therapy



# Further developing SPO for other applications






Athena

Arcus II

…

Synchrotrons

Material analysis

Semicon

Medical

Research

Optical bench

XUV optics

Laue lenses

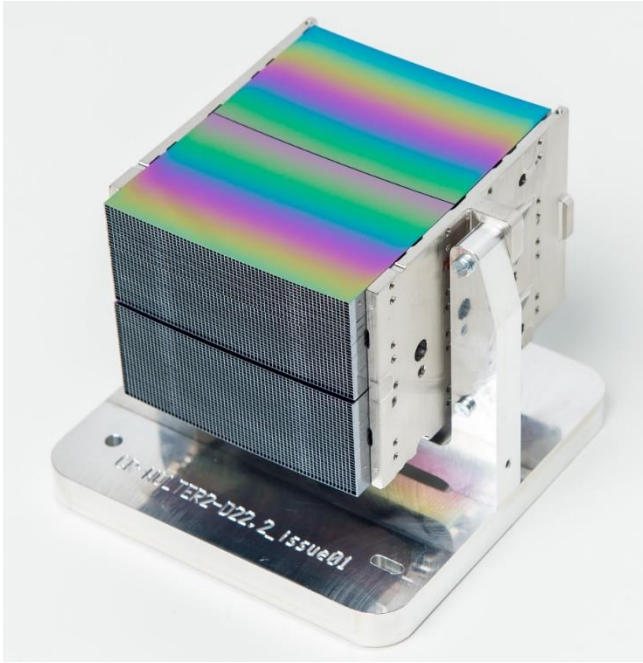
Neutron optics

Space

Non-space

# Summary

- Fully funded ESA technology development results in revolutionary new x-ray optics technology, long term vision of ESA tech program
  - Technology has reached a Readiness Level (TRL) of ~6
  - Ready for adoption of largest ESA telescope
- ESA development program works on all required topics in parallel
  - Performance improvement
  - Mass production readiness
  - Cost and schedule compliance
- ESA as first customer enables cosine to develop other applications with same technology
  - Supply x-ray optics for other space based missions, to NASA, …
  - Further develop technology for gamma-ray, soft x-ray applications for the medical market, material research etc
- cosine has 20+ years of experience in designing and mass producing x-ray optics
  - World-leading role for the Netherlands



cosine

# measurement systems

cosine
Warmonderweg 14
2171 AH Sassenheim
The Netherlands

Tel. +31 71 528 49 62
Fax. +31 71 528 49 63
info@cosine.nl