

# Mirror Development Status

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European Space Agency, for the ATHENA Optics Team

25 September 2018

# Athena requires the largest x-ray optic ever built

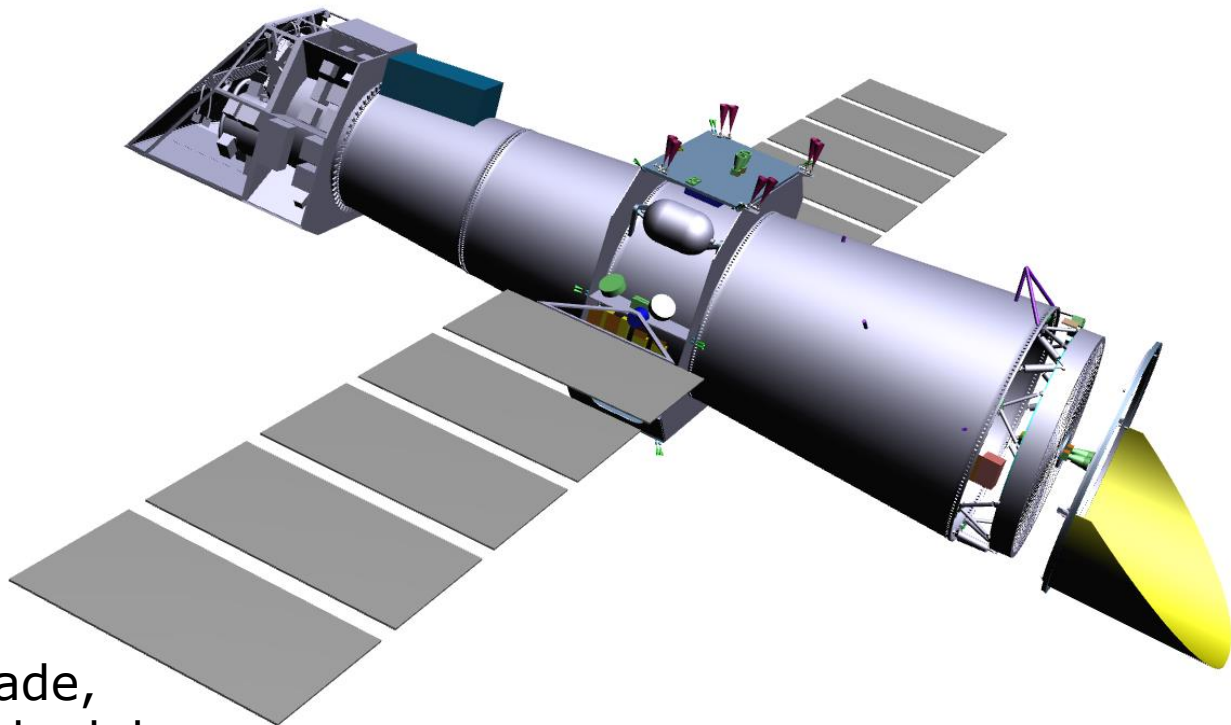


Revolutionary mission:

Community and ESA  
Working together to  
Create new technologies,  
Enabling Athena

Optics development is a  
Joint effort by  
Institutions and industry,  
Led by ESA

Good progress is being made,  
In-line with the mission schedule



# International consortium of industrial and academic partners



We make it visible.



Max-Planck-Institut für extraterrestrische Physik

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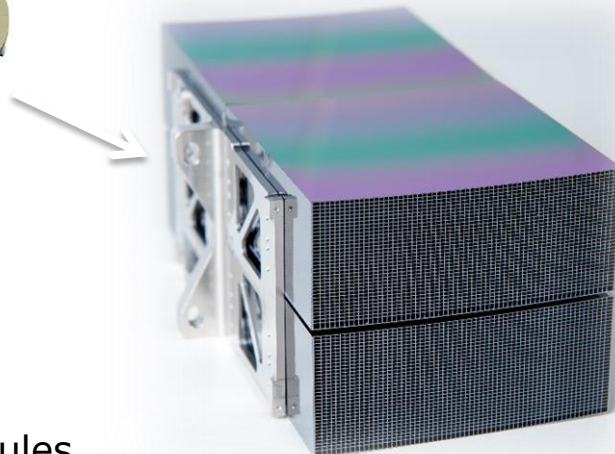
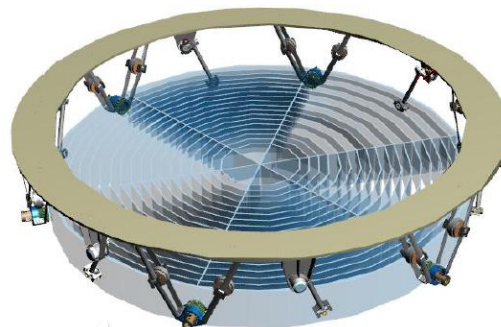
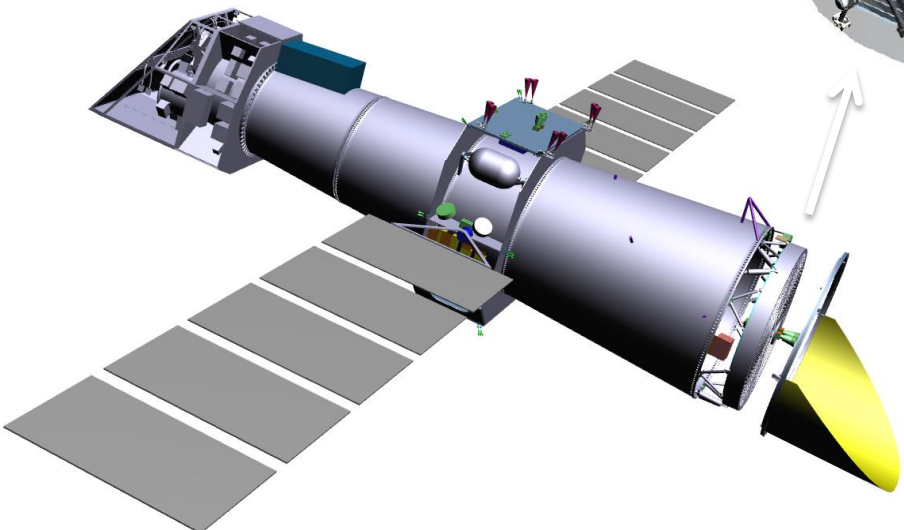
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European Space Agency

# Hierarchical concept build on Silicon Pore Optics

Succeeded in reducing mirror thickness to 0.17 mm, and creating modular optics



Athena mirror:

- 678 mirror modules
- ~ 100,000 mirror plates
- ~ 300 m<sup>2</sup> polished and coated area

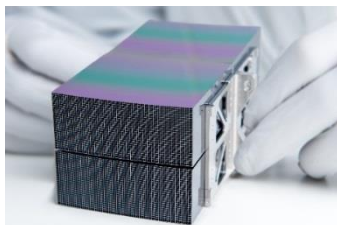
- ⇒ 2 MM / day
- ⇒ (assuming 8h/d, 180 d/y, all MMs in 2 years)

# SPO: from mirror plates to the mirror assembly



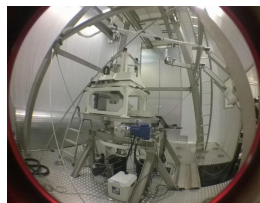
## Mirror plates:

- Achieved required performance
- Demonstrated 3 representative radii
- Produced 2000 mirror plates last year



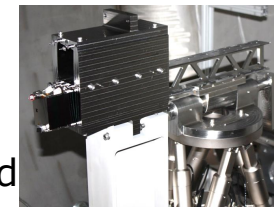
## Mirror modules and stacks:

- Demonstrated environmental compatibility
- Angular resolution steadily improving
- Automated production – scalable for FM phase



## Ancillary technologies:

- Demonstrated AIT approach(es)
- Coating industrialized, recipe being refined
- Test facilities available or being intensively studied/prepared



## Mirror assembly and accommodation:

- Innovative hexapod actuation for instrument selection
- Additive manufacturing of Titanium optical bench
- Shock damping and vibration reduction systems

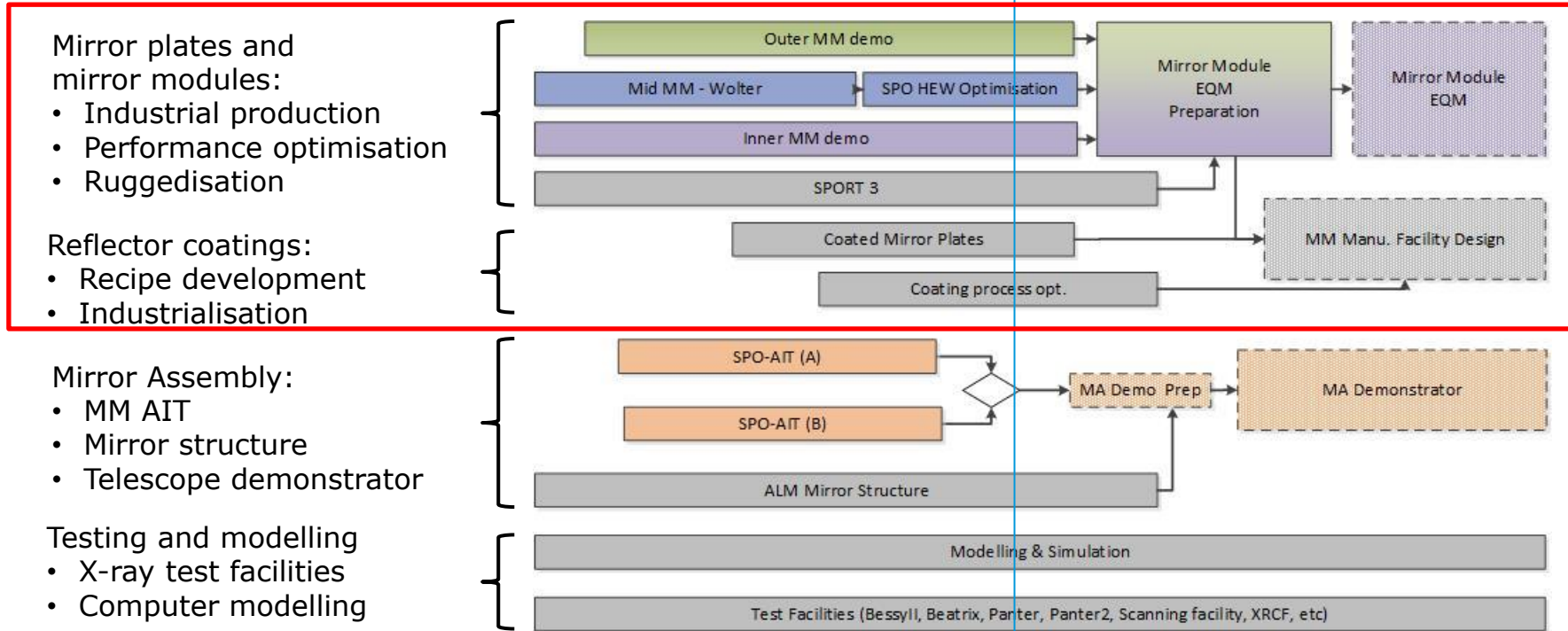


# Orchestrated Development Plan in Place

Activities funded by ESA and implemented in industry and institutions

today

MAR



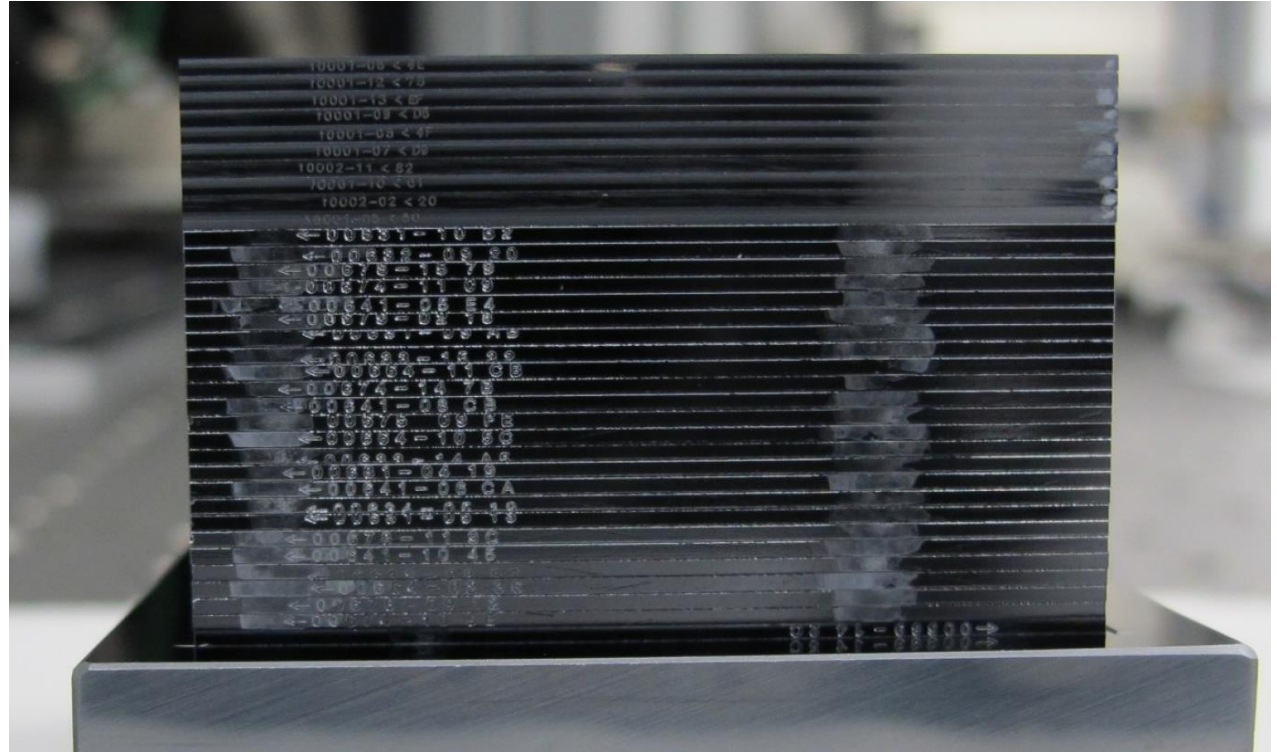
# Gearing up Mirror Plate Production

Scaling up of production being completed (produced 2000 mirror plates in 2017)

Developing a second mirror plate supplier

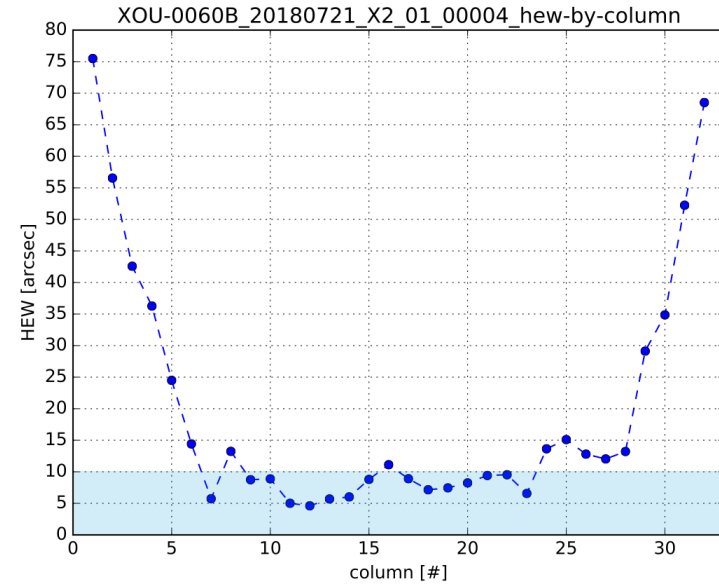
Pushes selection, inspection, cleaning, storage, quality criteria, logistics, logging, statistics

Labelling of each mirror plate for improving QA/PA



# Performance Improvement

- Angular resolution improvement is being regularly reviewed by independent team, involving representatives from the Science Study Team
- Latest stacks with 12-m focal length are now approaching the best performance achieved for the 20-m focal length stacks
- Edge effects dominating the current angular errors; have been amplified from 20-m to 12-m focal length
- Root cause investigated through extensive data analyses from previous stacks, and corrective actions identified



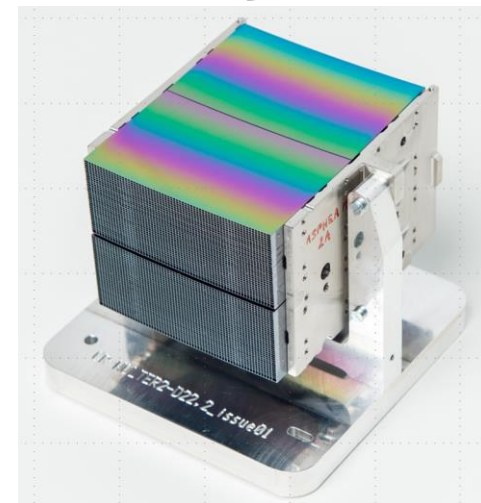
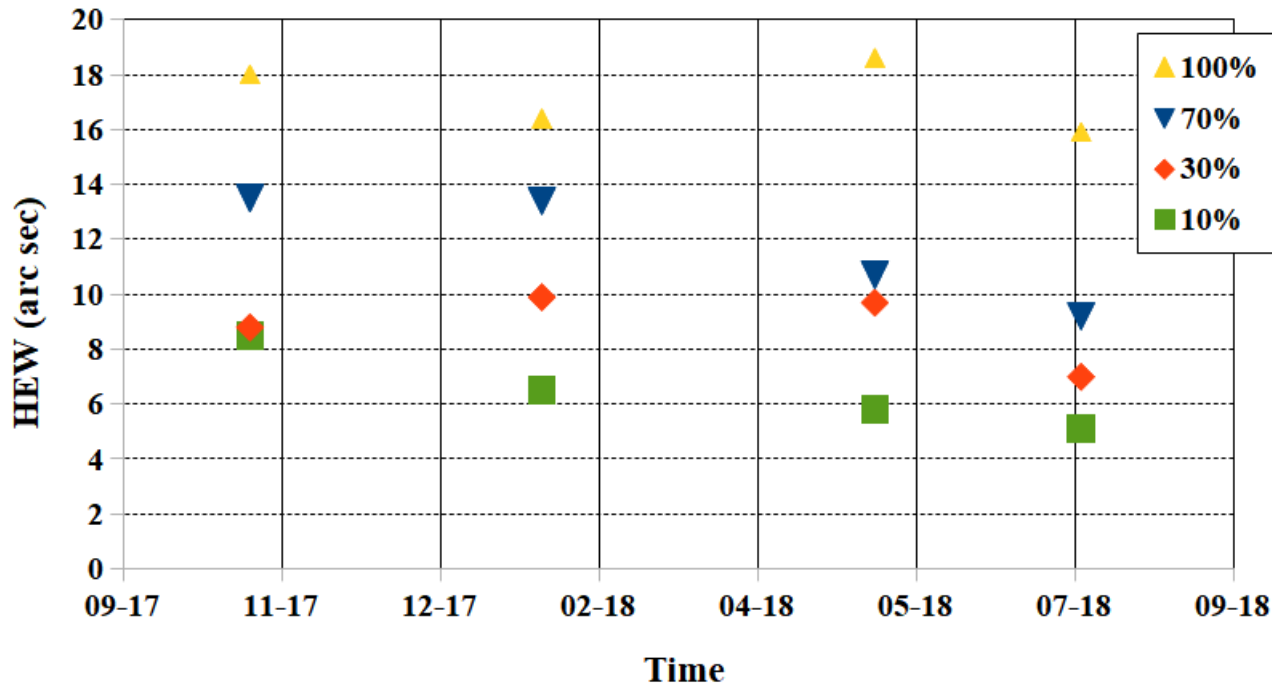
Progress in 5 months

Next iteration results planned for January 2019



# Overall status – angular resolution is improving

### HEW of contiguous area fraction



HEW is current priority

BESSY XPBF 2 data  
Double reflection  
10 plates ( $A_{\text{geom}} 6.6 \text{ cm}^2$ )  
1.64 keV  
 $f=12 \text{ m SPO}$

# Inner and Outer radius developments

Commissioned inner radius stacking robot in Sep 2016

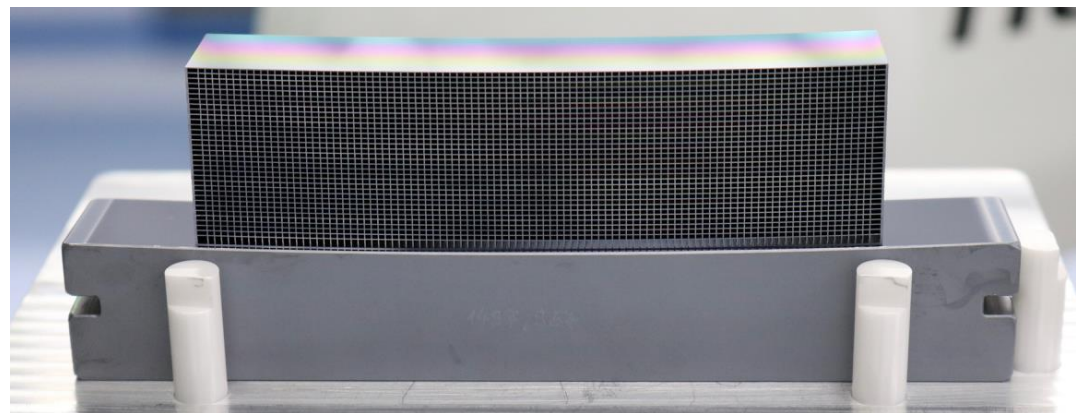
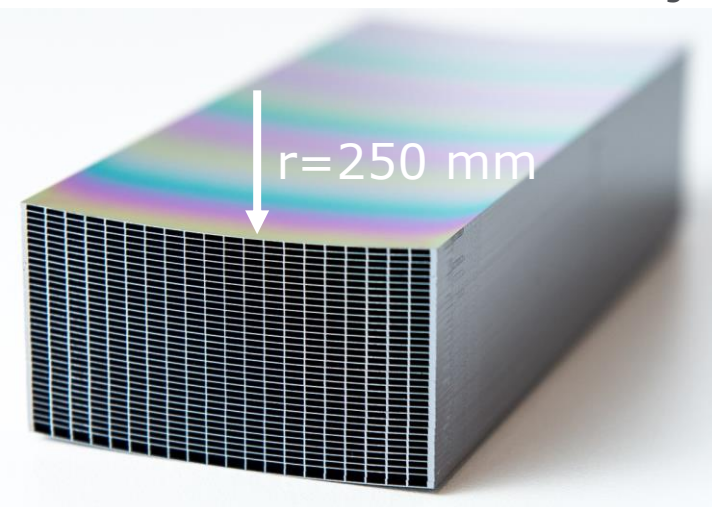
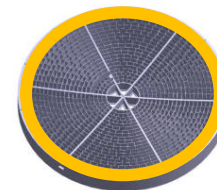
- New changeable head die to adapt to different radii
- New plate type (110 mm long, 49 mm wide, 2.3 mm pore width)
- 250 mm innermost radius

Gradual transition to all radii



Commissioned outer radius stacking robot in early 2018

- Plate width 101.81 mm
- Designed and built novel MM assembly jig

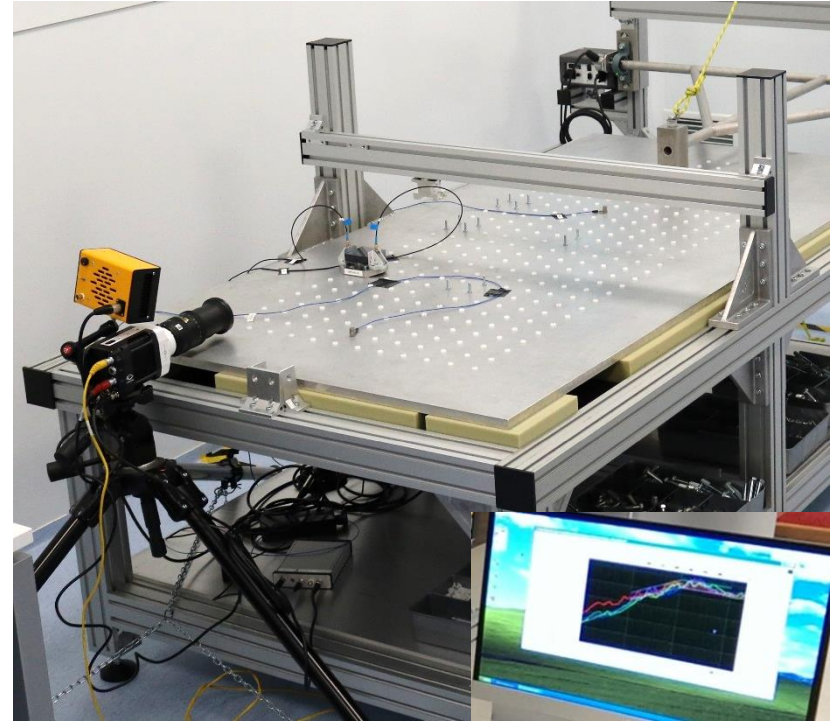
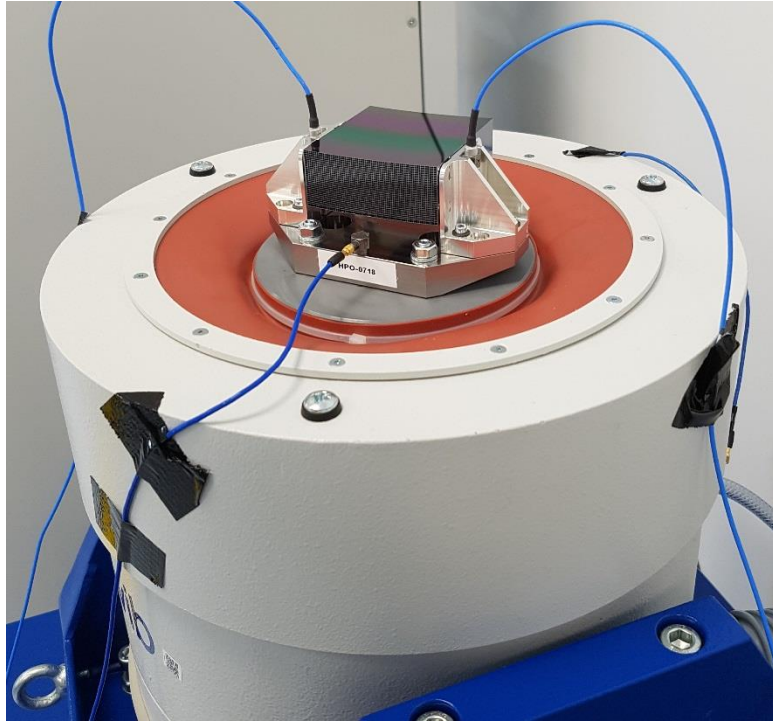


# Environmental Testing – component to MM level



Ruggedisation of stacks and mirror modules in parallel to process development

Dedicated environmental test facilities available (vibration, shock, thermal, pull-tests, etc)



# Coating Industrialisation

Just installed a large magnetron sputtering coating machine

Able to coat ~100.000 plates per year

Can handle 300 mm wafers and all ATHENA types of rectangular plates

DTU develops the coating recipe, cosine performs the coating

Rotating drum system, loaded with carriers

Have two magnetrons (max 3), for Ir, B<sub>4</sub>C and SiC

Has plasma pre-cleaning to remove resists residuals

Lithography process optimization taking place in parallel at plate suppliers

System being commissioned in Q2/Q3 2018



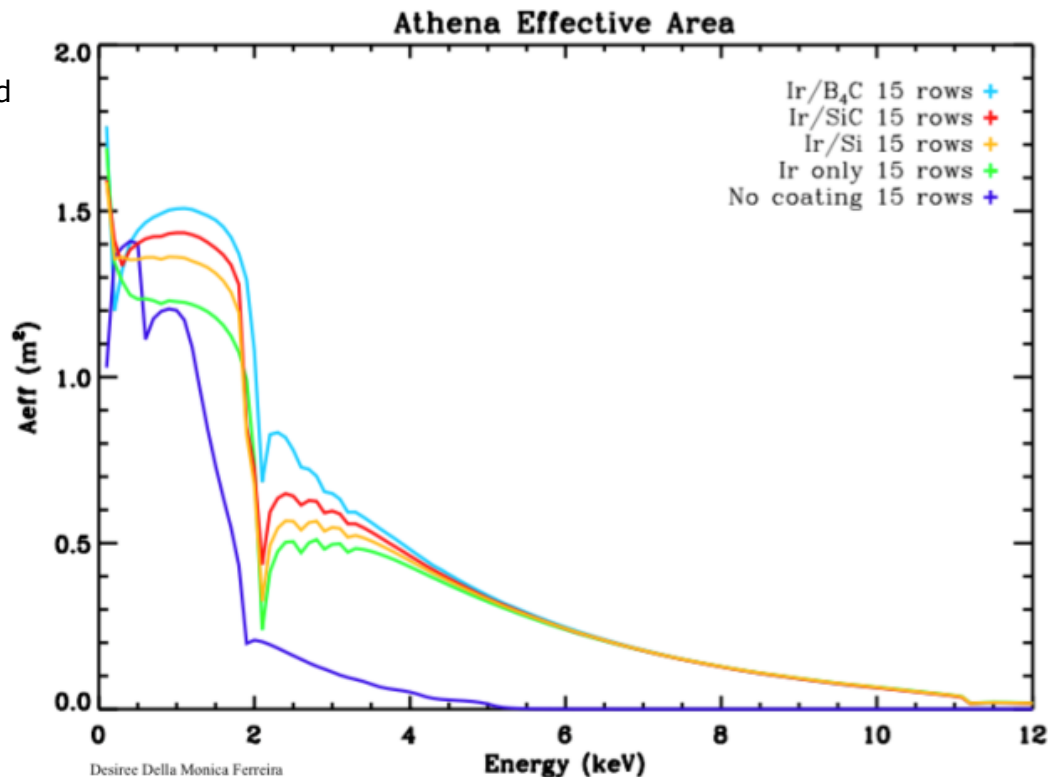
# Coating options

- B<sub>4</sub>C is not stable in the required layer thickness
- SiC is being studied as an alternative
- First Ir/SiC produced and characterisation commenced
- DTU current contract is searching best alternative to B<sub>4</sub>C (note: adding in-house low-energy reflectometer + plasma cleaner + manpower → will allow quicker turnaround)

Athena Effective Area

	1 keV (m <sup>2</sup> )	6 keV (m <sup>2</sup> )
Ir/B <sub>4</sub> C 20 rows	2.3093	0.2469
Ir/B <sub>4</sub> C 15 rows	1.5067	0.2468
Ir/SiC 15 rows	1.4344	0.2424
Ir/Si 15 rows	1.3612	0.2428
Ir 15 rows	1.2271	0.2394
no coating	1.2008	0.0003

Desiree Della Monica Ferreira  
DTU Space, 27-11-2017



Desiree Della Monica Ferreira  
DTU Space, 27-11-2017

# Orchestrated Development Plan in Place

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## Mirror plates and mirror modules:

- Industrial production
- Performance optimisation
- Ruggedisation

## Reflector coatings:

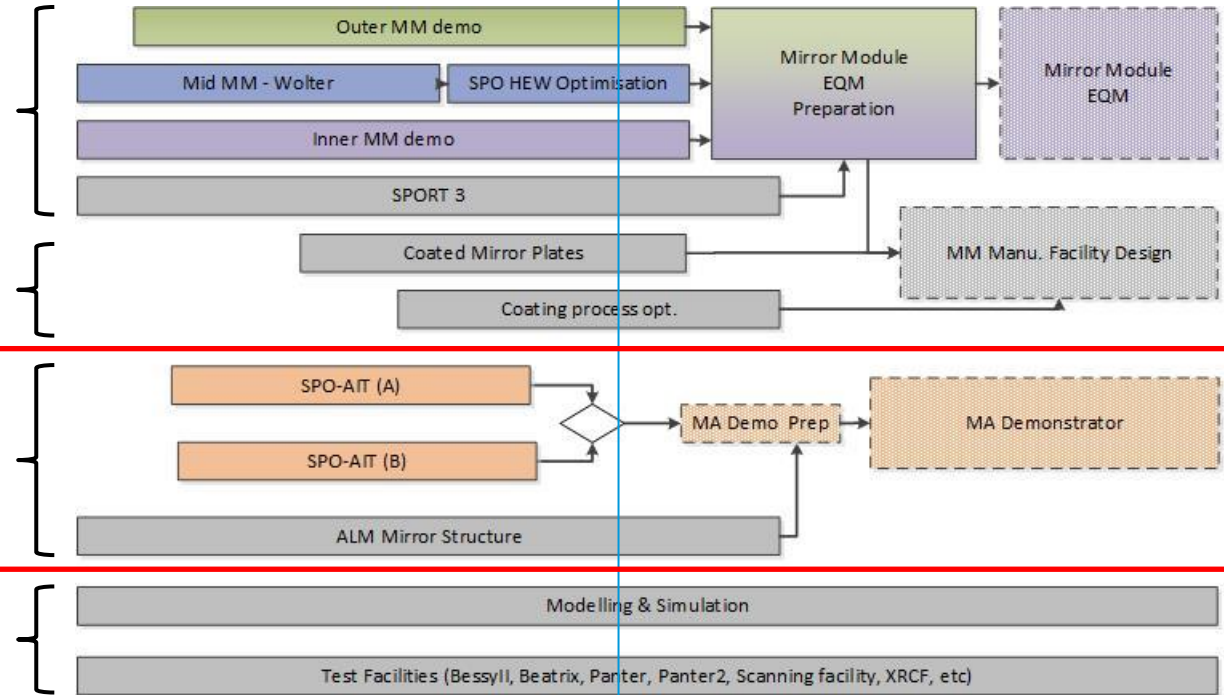
- Recipe development
- Industrialisation

## Mirror Assembly:

- MM AIT
- Mirror structure
- Telescope demonstrator

## Testing and modelling

- X-ray test facilities
- Computer modelling

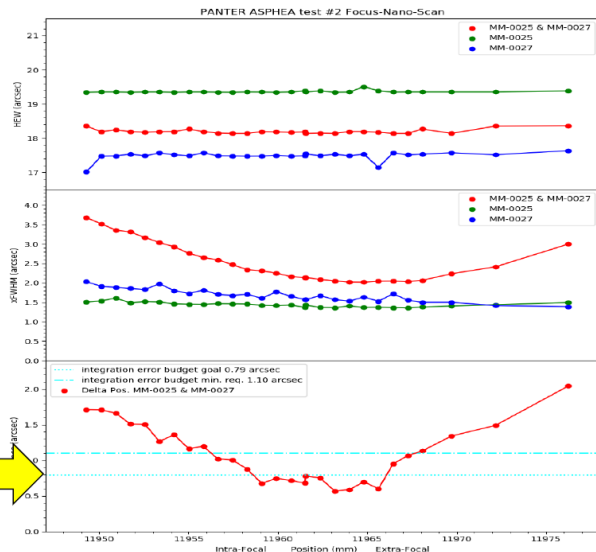


# Media Lario Mirror: Module AIT successful

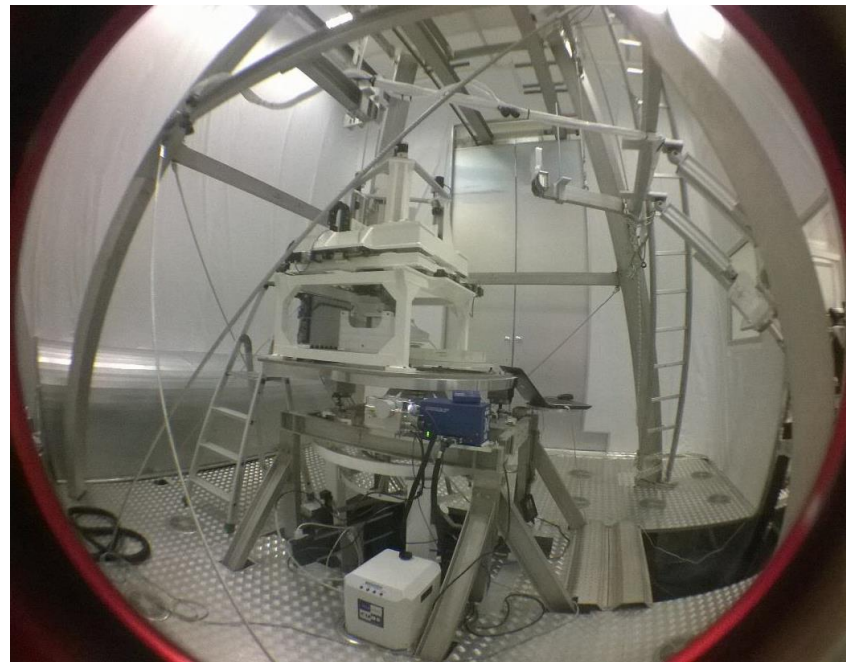
Final Review completed successfully on 27 March 2018

- Demonstrated co-alignment compliance using Panter metrology
- Demonstrated removal and re-installation of MM

## X Ray test at Panter



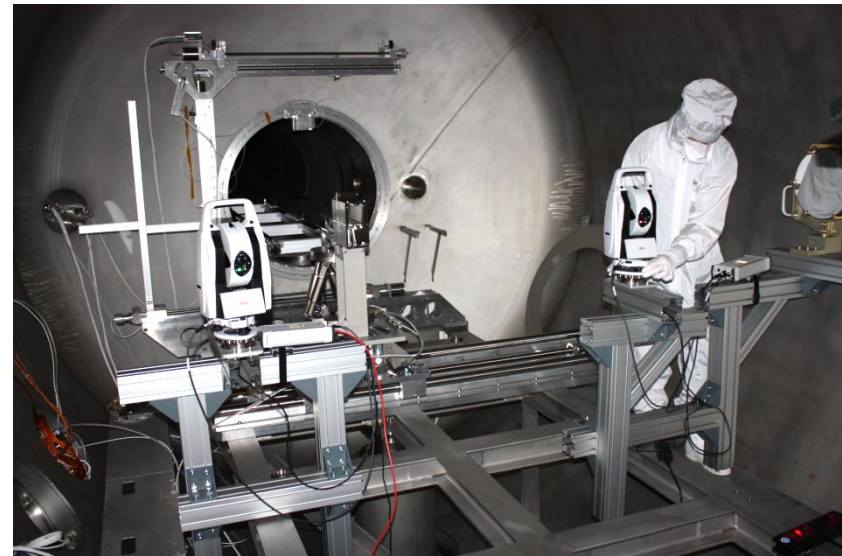
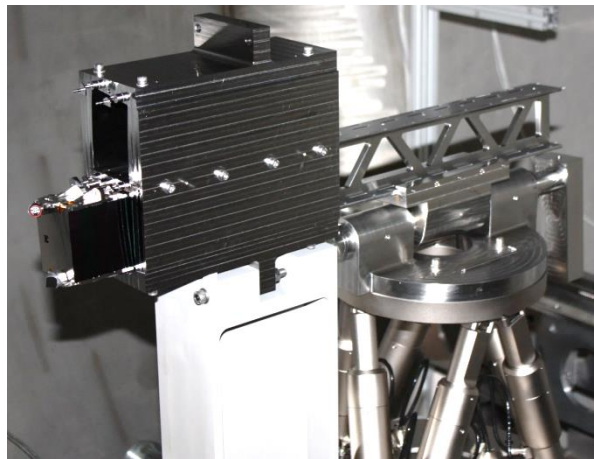
Single MM and combined HEW, x-FWHM and centroid distance at 1.5 keV vs focal length



# TAS-CH: Mirror Module AIT successful

Final Review completed successfully on 05 June 2018

- Demonstrated co-alignment compliance using Panter metrology
- Both indirect metrology approach and direct X-ray alignment method were successful





# Mirror Bench Hybrid Manufacturing Facility



Passed CDR in May 2018

Hybrid (additive & subtractive) manufacturing of the Titanium mirror structure for the Athena mirror

Integrated metrology capability

Will demonstrate technology on 60 degree sector with representative geometry

# Orchestrated Development Plan in Place

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## Mirror plates and mirror modules:

- Industrial production
- Performance optimisation
- Ruggedisation

## Reflector coatings:

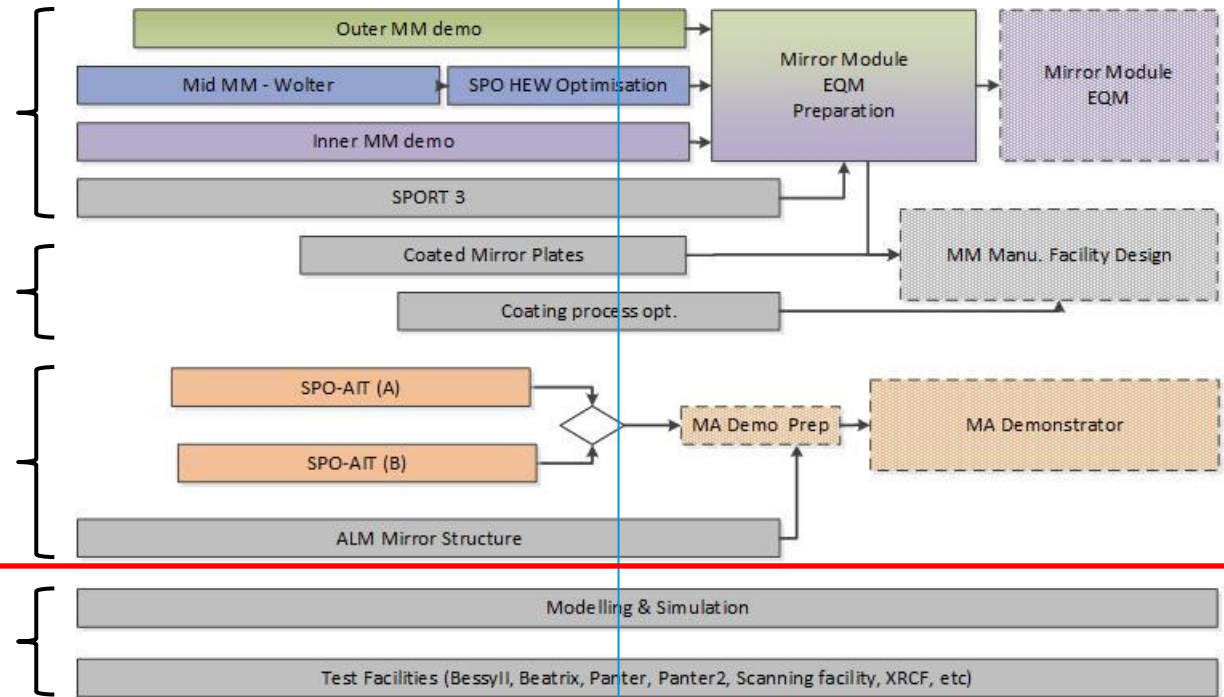
- Recipe development
- Industrialisation

## Mirror Assembly:

- MM AIT
- Mirror structure
- Telescope demonstrator

## Testing and modelling

- X-ray test facilities
- Computer modelling



# 12 m Beamline at Bessy-II

The new beamline successfully commissioned on 20 March 2018

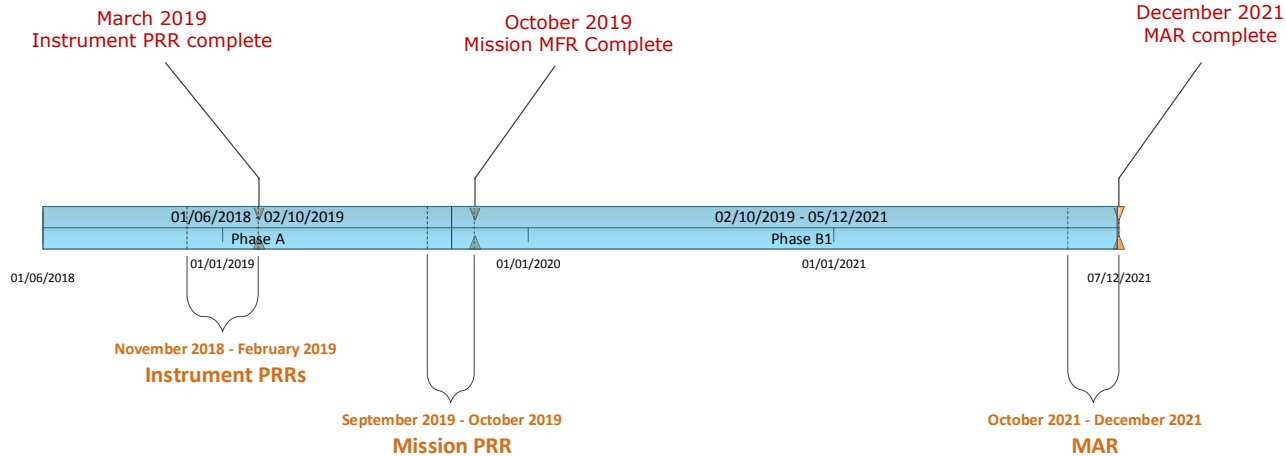


# Adoption Preparation for Athena in full swing



Targeting demonstration at Mission Adoption Review (MAR, 2021):

- Performance compliance
- Technology readiness (require TRL 5/6)
- Compliance with cost/risks/schedule constraints
- For all mission elements (spacecraft, payload – including optics)

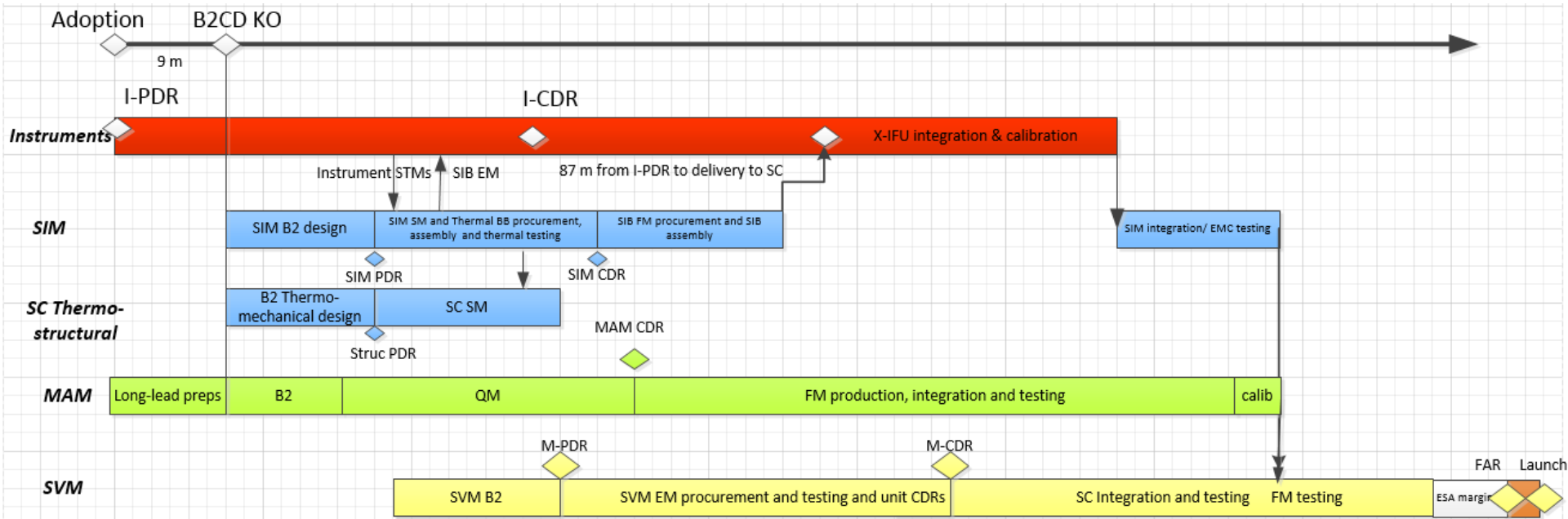


# Athena Implementation Phase



Optics technology developments and planning already preparing for post adoption

- Mirror plate production already based on automatic production ( need ~100 000 mirror plates!)
- Mirror Module industrial production: tools already developed or being refined
- Facilities implementation (designs will be ready before adoption!)
- Will maintain tight connection to industry and institutions



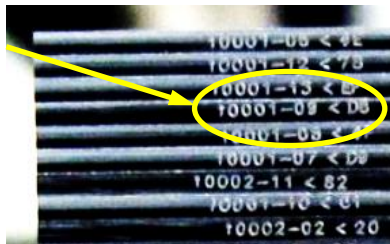
# Optics R&D: Smooth Evolution into Flight Production



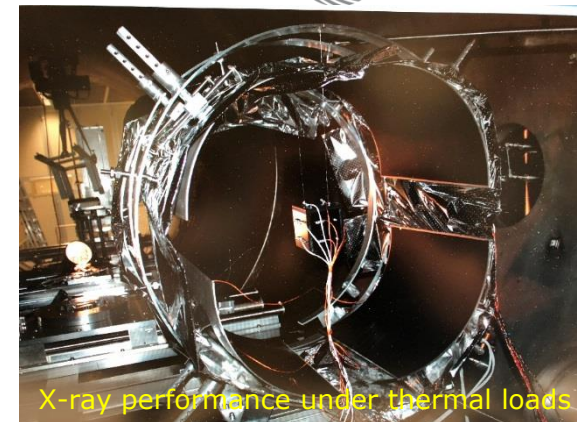
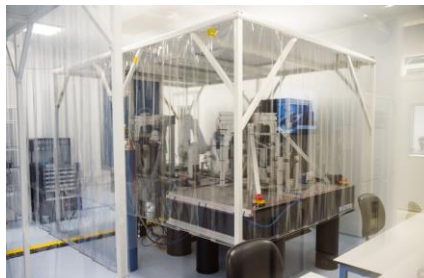
Industrial production of Mirror Plates



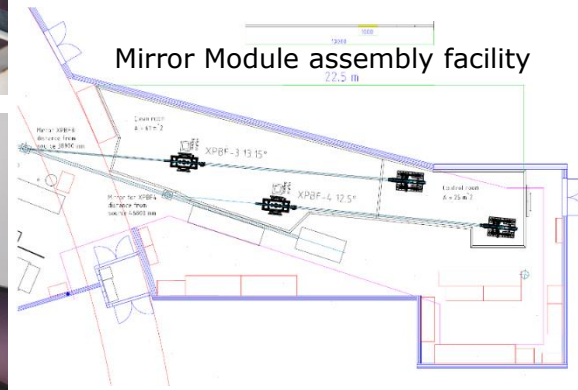
Considering future PA/QA (e.g. accurate tracing)



Automated production of Mirror Stacks and Modules



X-ray performance under thermal loads



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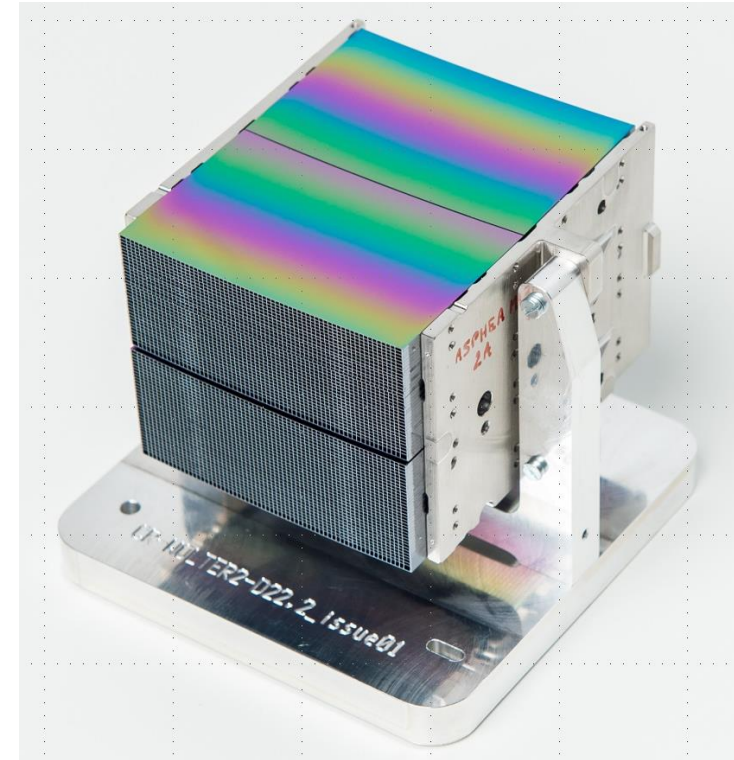
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# Athena Mirror Development Status

- Have solid and funded Technology Development Plan in place
- All aspects of Athena optics are being worked on
- Good progress being made - on all fronts
- Current focus:
  - HEW improvement (goal 5")
  - Larger rib spacing (2.3 mm, all radii)
  - Improved coatings
- Confident that optics will allow achievement of Athena scientific objectives







# Focus of HEW Improvement



Two main contributors identified:

## (1) Side effects

- Confirmed to originate from outer ribs touching and bonding prior to central parts of plate (causing initially unbonded area in between)
- Evolving die structure to improve controlled plate deposition

## (2) Meridional curvature

- Improved metrology identified excess meridional curvature in stacks produced
- HEW very sensitive to meridional curvature
- Further investigations ongoing

