ATHENA: BIG SCIENCE

enabled by

Precision Engineering

SRON

esa

cosine | measurement systems

15-Nov-2017 Precision Fair

Netherlands Institute for Space Research

Netherlands Organisation for Scientific Research (NWO)

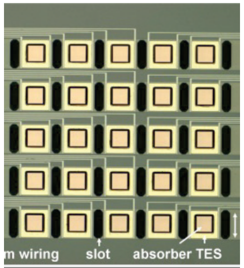
General introduction

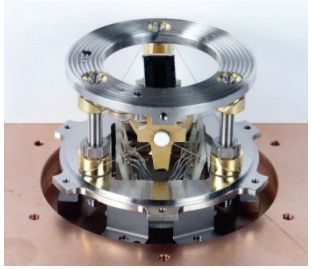
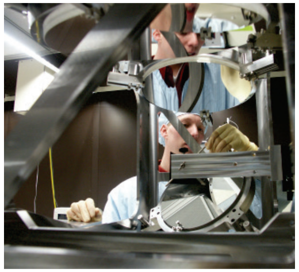
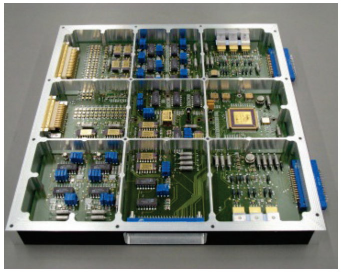
SRON: Space Research Organization Netherlands

- Under the umbrella of NWO-I (OC&W funded)
- Role of SRON:
  - **(Co)-PI roles for scientific research**:
    - **Astrophysics** HIFI-Herschel, SAFARI-Spica, Athena, etc.
    - **Earth Atmosphere** recent launch of Tropomi instrument @Sentinel5P
    - **Exo planetary science** contribution to Ariel ESA M4 mission
  - **Instrument hardware, development & realization** XIFU detector-Athena
  - **Space Engineering support to third parties**

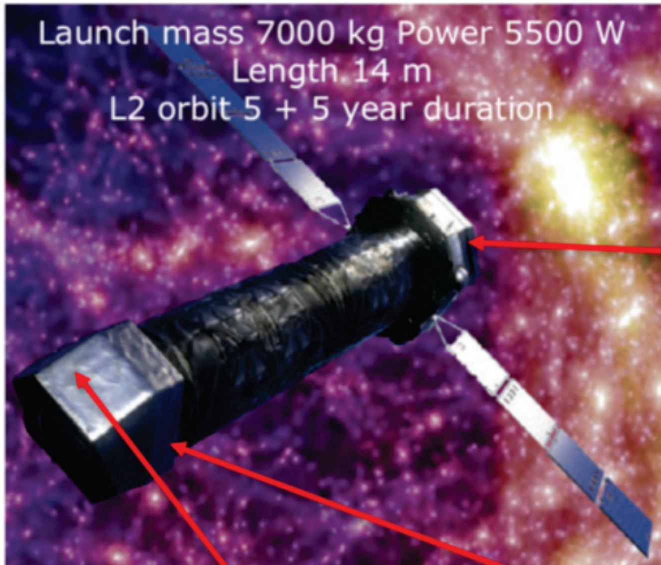
Presenter:

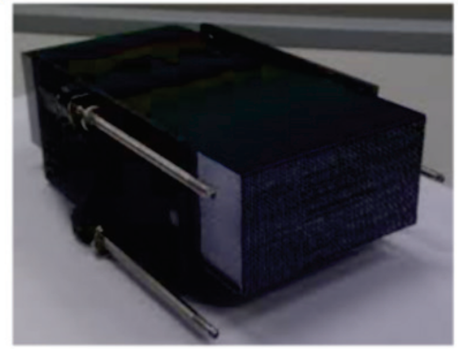
- Ir Coen van Baren
- Structural & thermal background
- Supporting early phases conceptual design, design & analysis, final verification by test



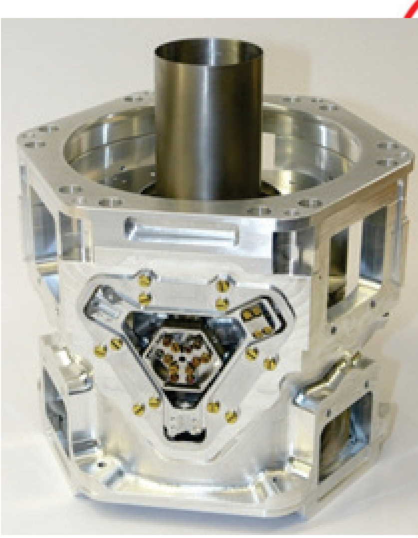




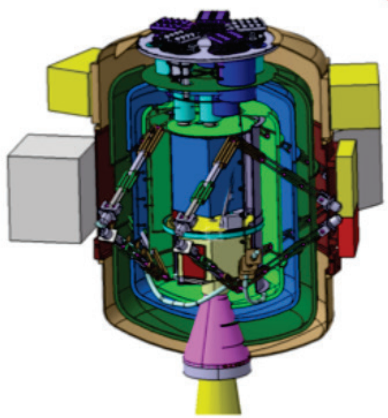

Facts of ATHENA mission



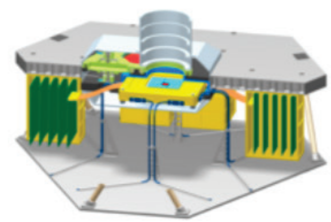


X-ray Telescope
Sensitivity: 3 10^{-17} erg/cm^2/s
2 m^2 at 1 keV
5 arcsec HEW





X-ray Integral Field Unit
ΔE = 2.5 eV
Field of view 5 arcmin Ø



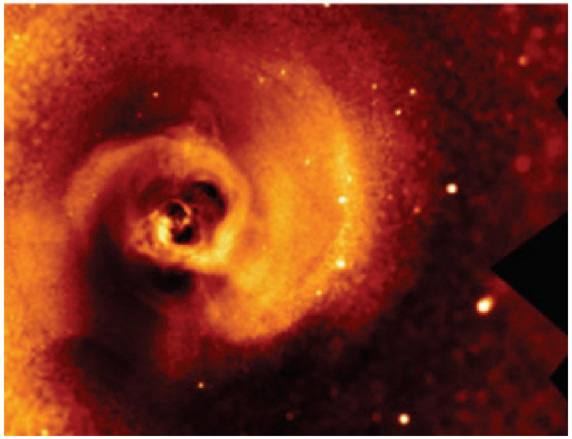
Wide Field of View Imager
ΔE = 125 eV
Field of view 40 x 40 arcmin^2

- ATHENA X-ray observatory: astrophysics science
- One of three L (large) missions in ESA's Cosmic Vision 2015-2025 program
- Launch date 2028
- Mission life 5 years (+5 yrs)

Purpose of ATHENA

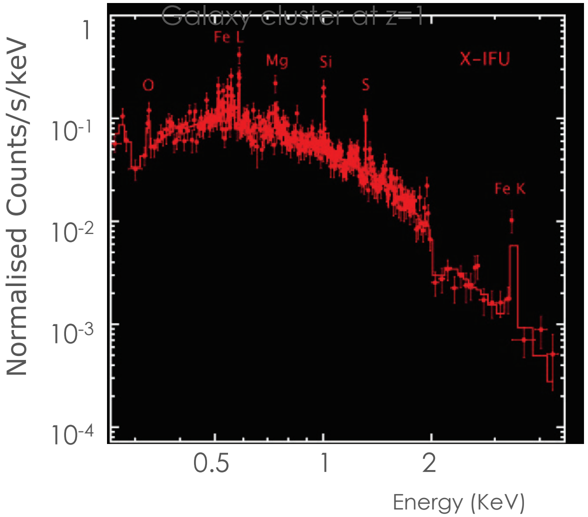
optical

X-ray

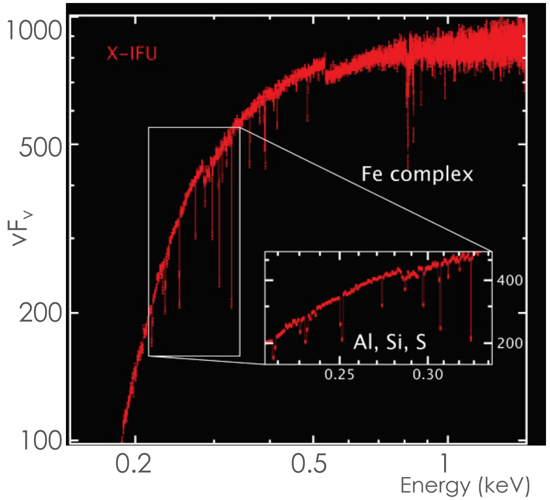


- Athena addresses key scientific challenges on Universe:
  - *How does ordinary matter assemble into large scale structures that we see today?*
  - *How do black holes grow and shape the Universe?*

Galaxy cluster at z=1



Primordial stellar populations
GRB afterglow follow up at z=7



Spectral simulations

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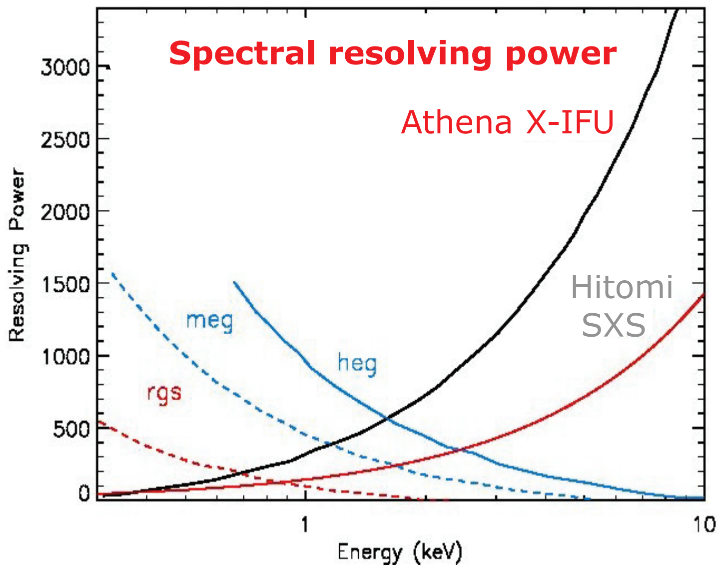
ATHENA instrumentation: X-IFU (adjacent to WFI)

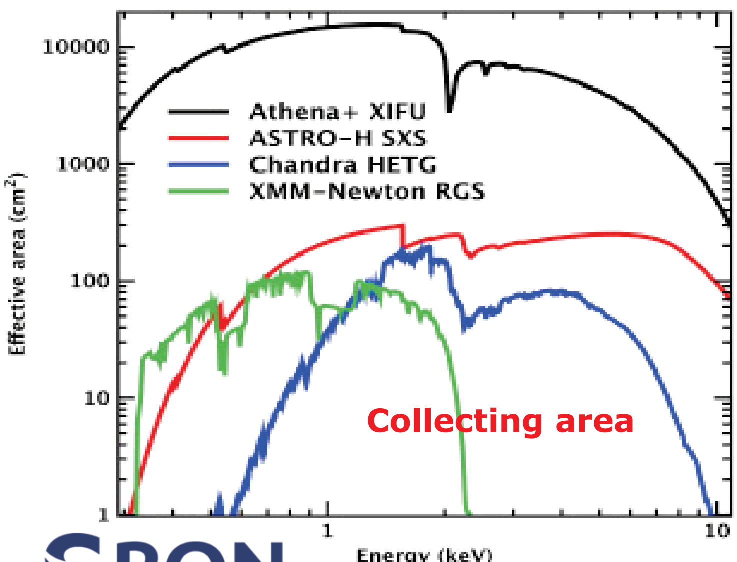


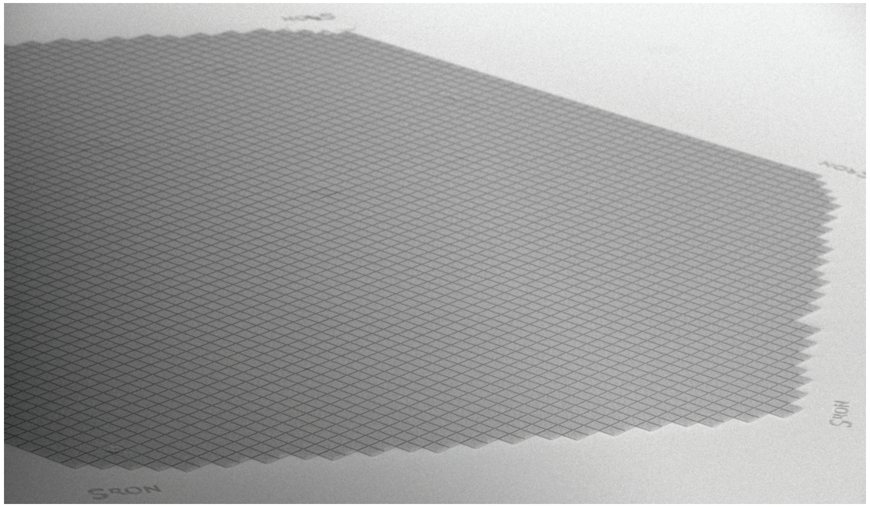
Significant improvements in:

- resolving power,
- effective area
- angular resolution
- relative large field of view

Using a large X-ray detector array

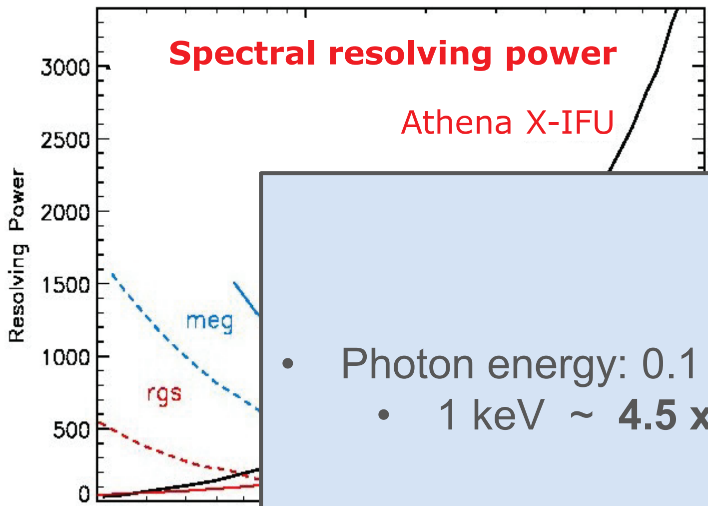
- 3840 pixels
- unprecedented energy resolution:
  - < 2.5 eV/pixel (at 1 keV)





X-IFU pixel array developed by SRON

ATHENA instrumentation: X-IFU (adjacent to WFI)



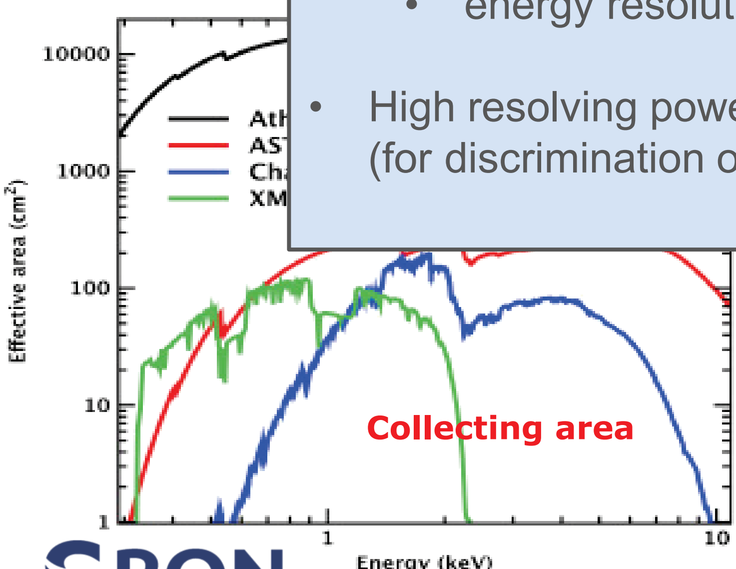
Significant improvements in:

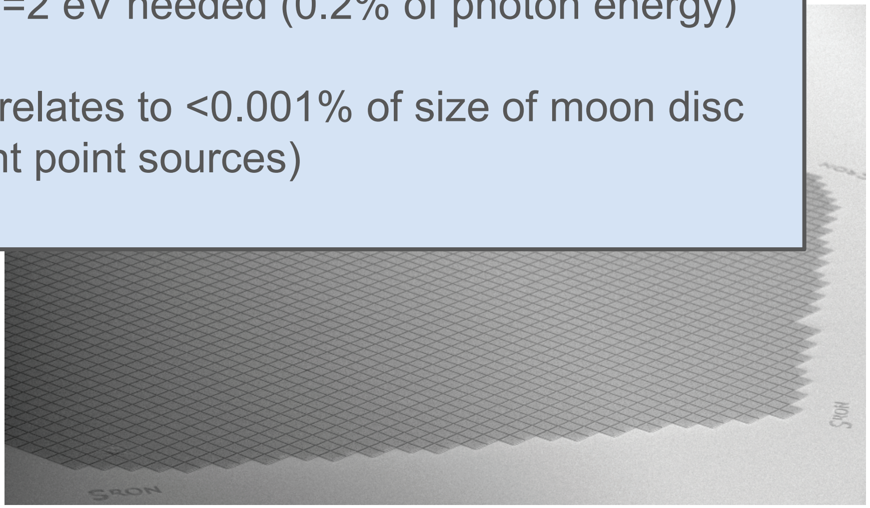
- resolving power,
- effective area

For engineers:

- Photon energy: 0.1 to 10keV
  - 1 keV ~ **4.5 x 10^{-20} Wh** → **~1 Wh**

- Measuring the 'color' of the photon
  - energy resolution of ΔE=2 eV needed (0.2% of photon energy)
- High resolving power of <5" relates to <0.001% of size of moon disc (for discrimination of adjacent point sources)





X-IFU pixel array developed by SRON

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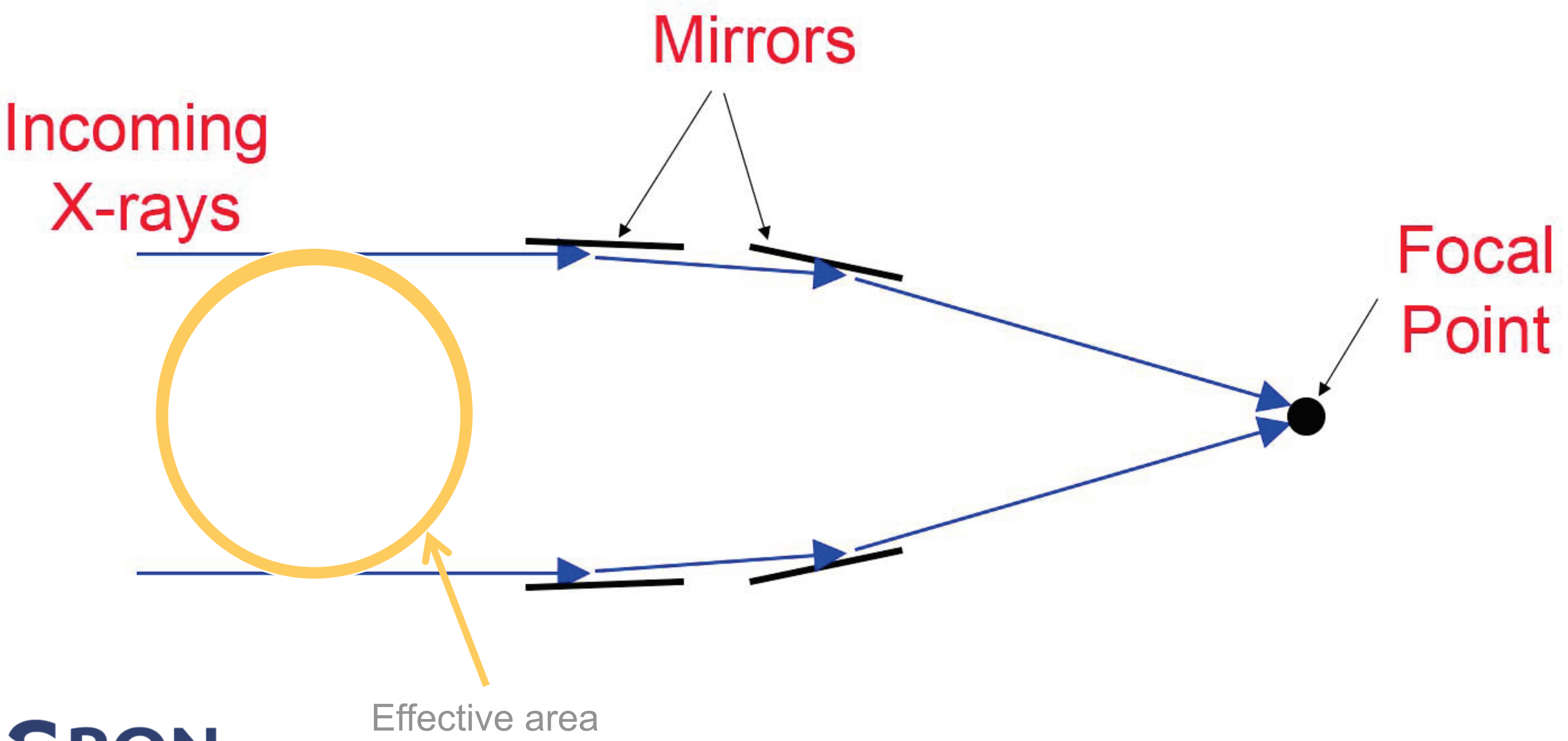
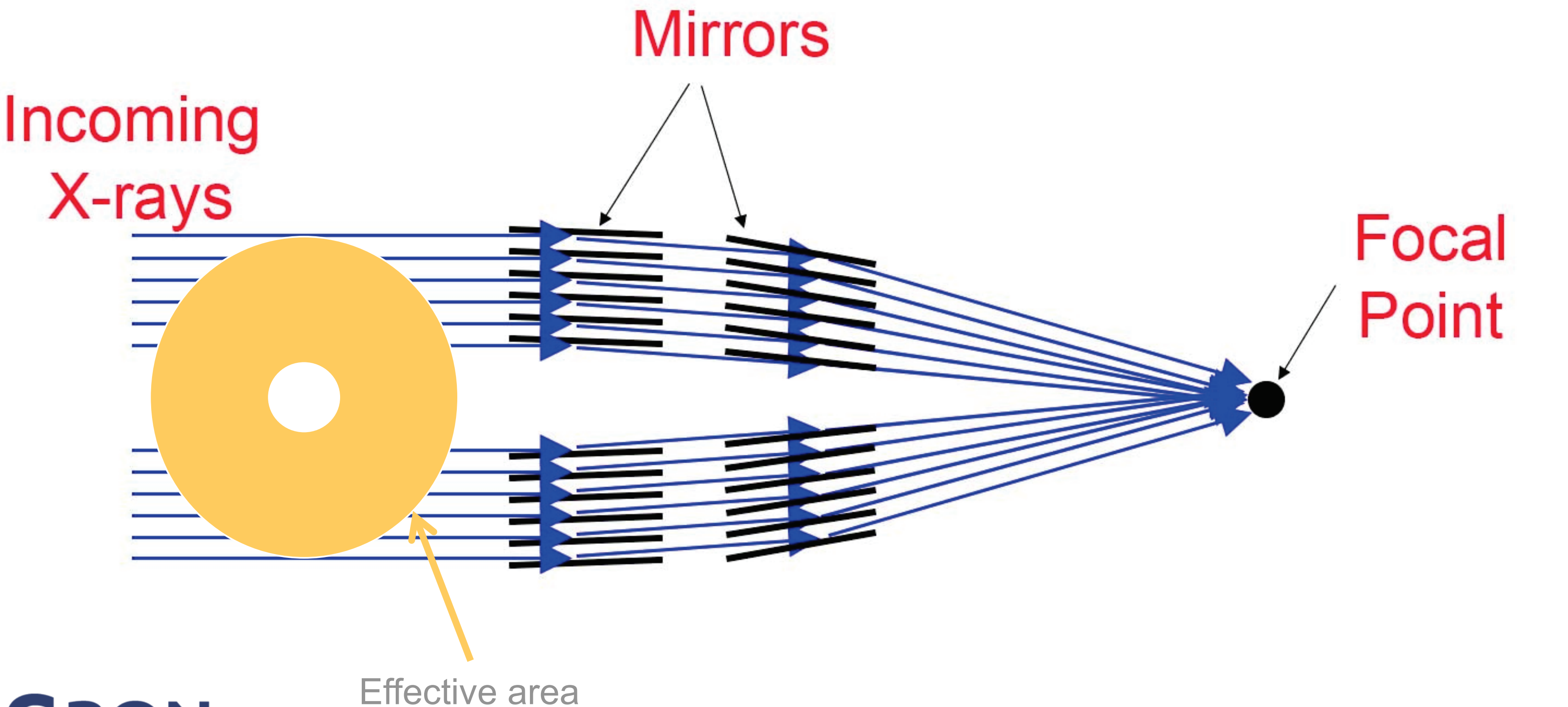
X-ray telescope principle

- X-rays can only be focused by reflection at small angles of incidence
- Maximum reflection angle (assuming coating)
  - Soft X-rays of 10 keV at ~1.5°
  - Hard X-rays of 0.1 keV at ~0.3°



X-ray telescope principle

- Effective area maximized by multiple concentric shells



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Why Silicon Pore Optics Mirror Modules?

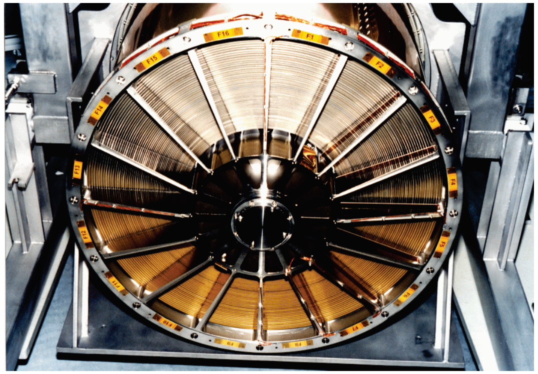
- Science asks for larger effective area (∅ 2.5 m)
- Combined with high optical quality
- Limited launch mass (even with new Ariane 6)

Large diameter shells

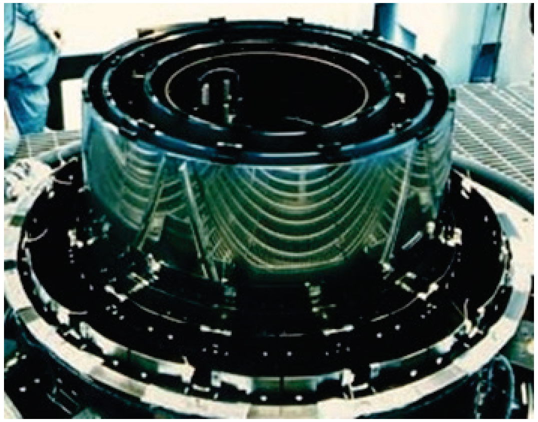
- Large size monolithic shells not (yet) possible
- If possible: extremely expensive

Modular approach

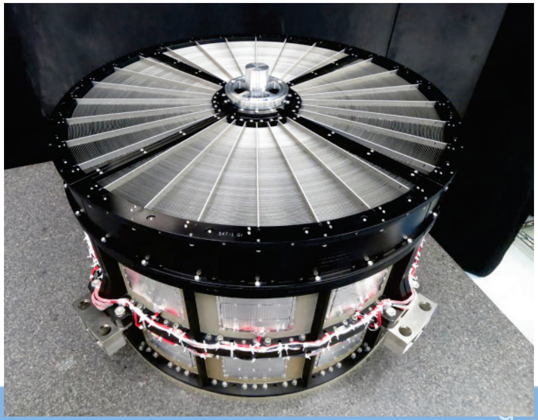
- Wafers: optimum optical quality & relatively cheap
- Low mass density of Silicon (2.33 gr/cm3)
- Mass production
- Intrinsic robustness (compared to 'free' standing mirrors)
- Replaceable units (on ground only)



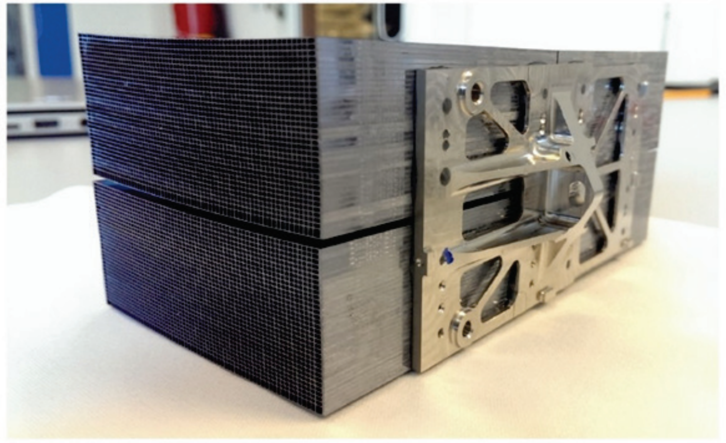
XMM Newton X-ray (1999)
∅0.7 m nickel (ESA)

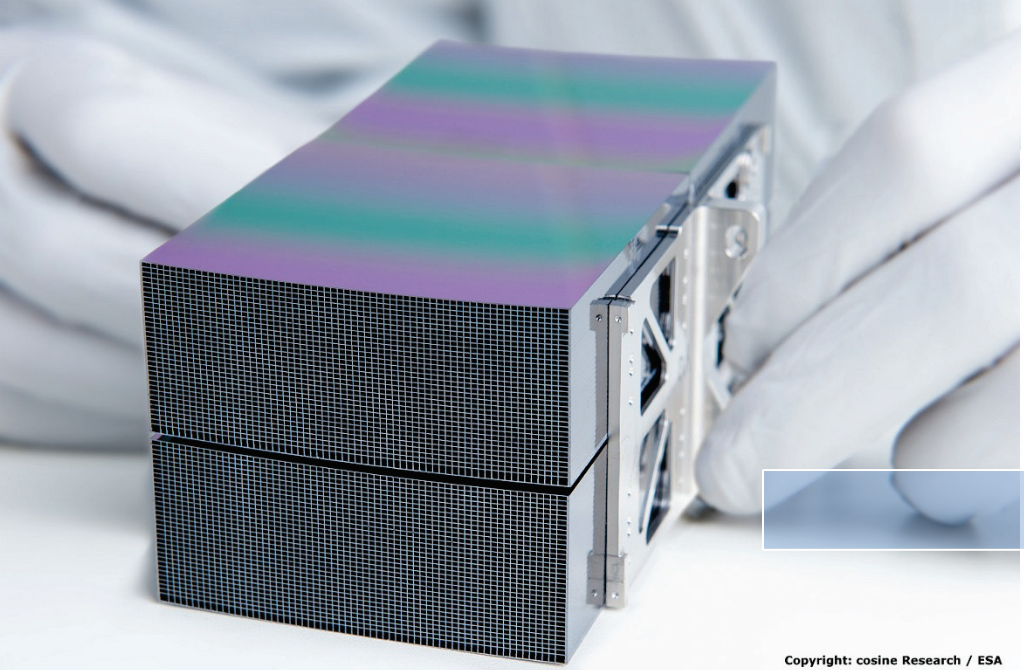


Chandra X-ray Observatory 1999
∅1.1 m Zerodur (NASA)

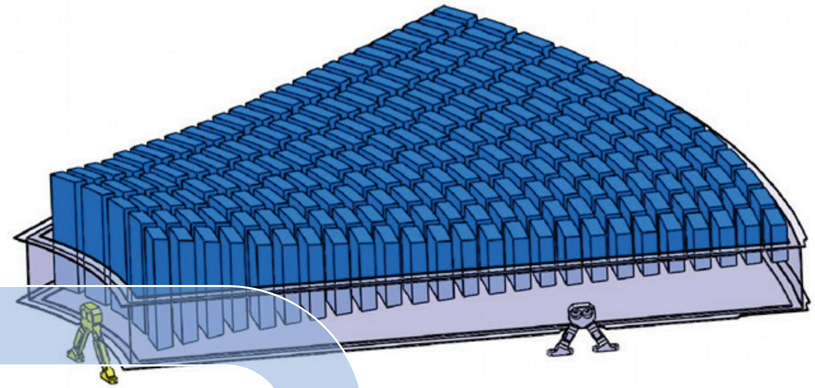


Hitomi (2016, JAXA)
∅0.45 m aluminum





ATHENA optics assembled from ~1000 mirror modules

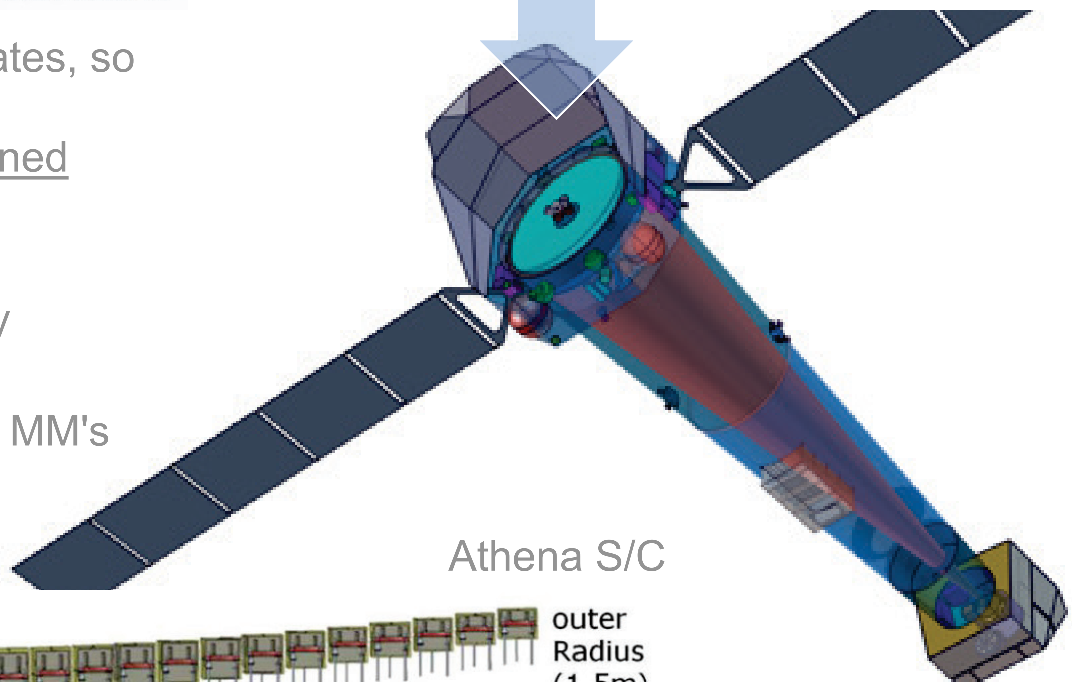


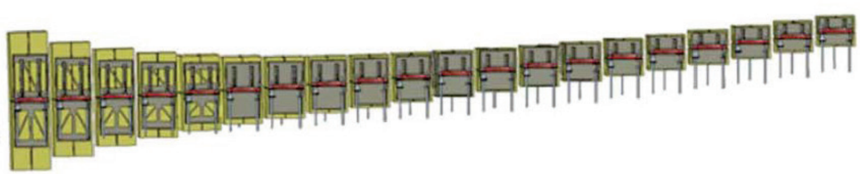
- Each module consists of 140 silicon plates, so

  140,000 mirror plates very well aligned

  500 m² total mirror surface

- Each MM is manufactured and optically characterized (cosine Research BV)
- Accurate co-alignment of the individual MM's


Athena S/C



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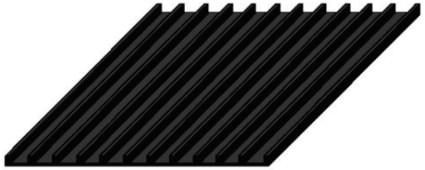
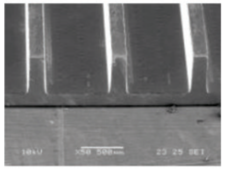
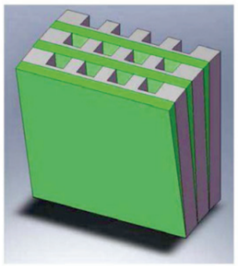
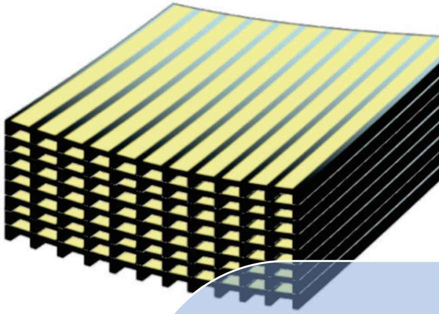
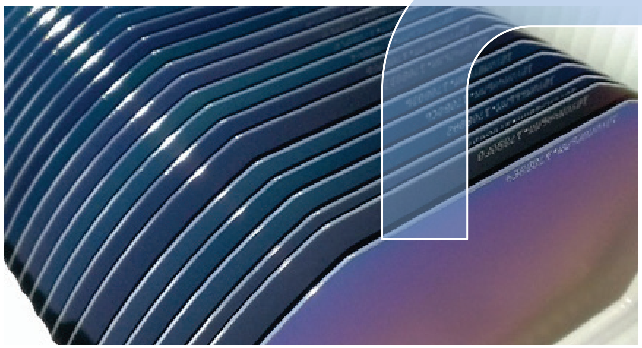
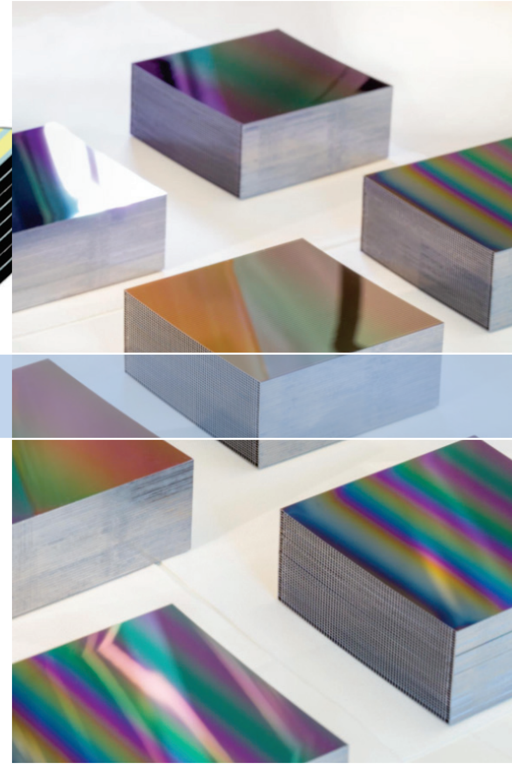
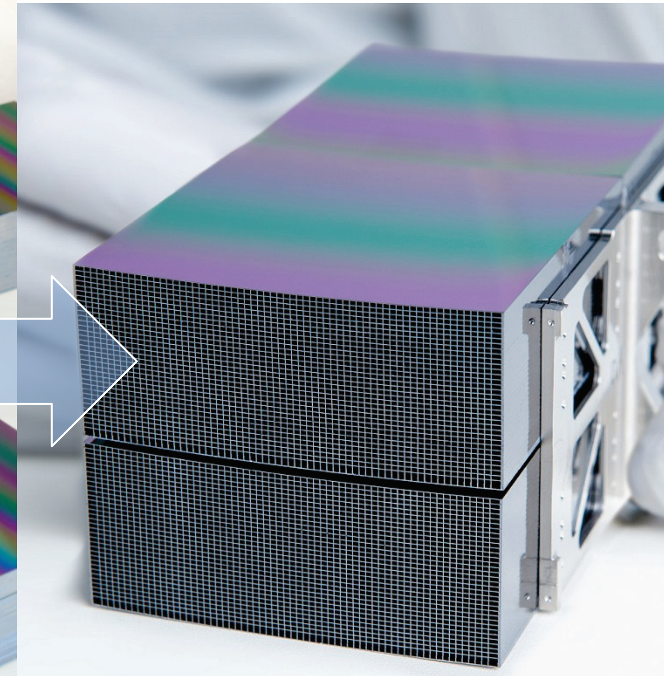
SPO Manufacturing and MM alignment process by cosine Research B.V.

- High optical quality 775 micron **silicon wafers**
- Wafers are **ribbed**, wedged, diced (Micronit Microtechnologies B.V.)
- Ribbed plates **stacked** by high precision & fully automated robot (cosine Research BV)
- Stacks of pre-shaped ribbed plates hold by **covalent bonds** (silicon oxide hydrophilic diffusion bond)

SRON: Mechanical support of Mirror Modules

Requirements

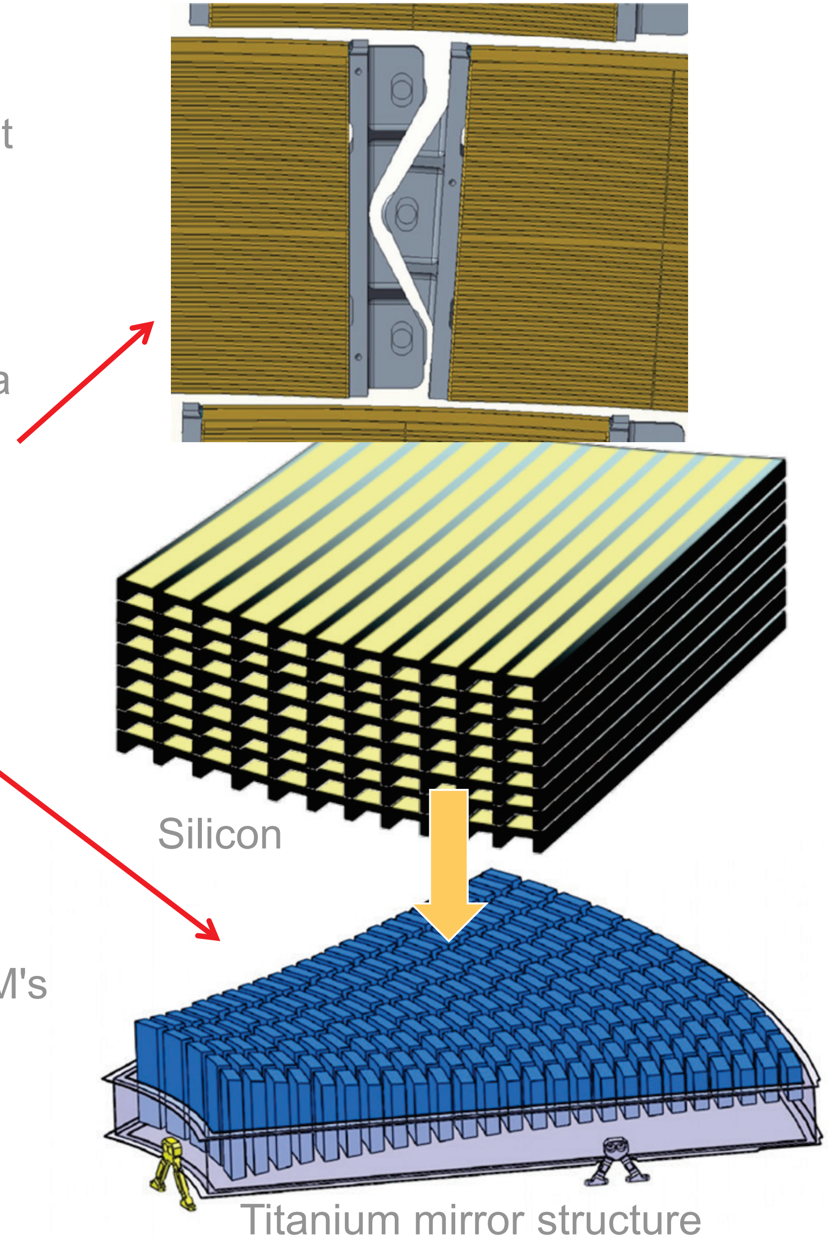
- Severe launch environment:
  - 50g static, 20g vibration, 100g+ shock
- Not sensitive to variations in thermal environment
  - e.g. launch RT+/-20 °C, orbit +/-5 °C

Design aspects

- High stacking density for maximum effective area
- Exchangeable MM's
  - Allowing repair during integration
- Mounted to large titanium structure:
  - Different CTE
  - Low frequency dynamics during launch
- Alignment & integration into higher level unit at rate of >1 per day (3 years assembly time)

Reliability

- If failure probability 0.1% ➔ 1 failure on 1000 MM's
- Failure is not an option
- Risk of mission loss by failure propagation



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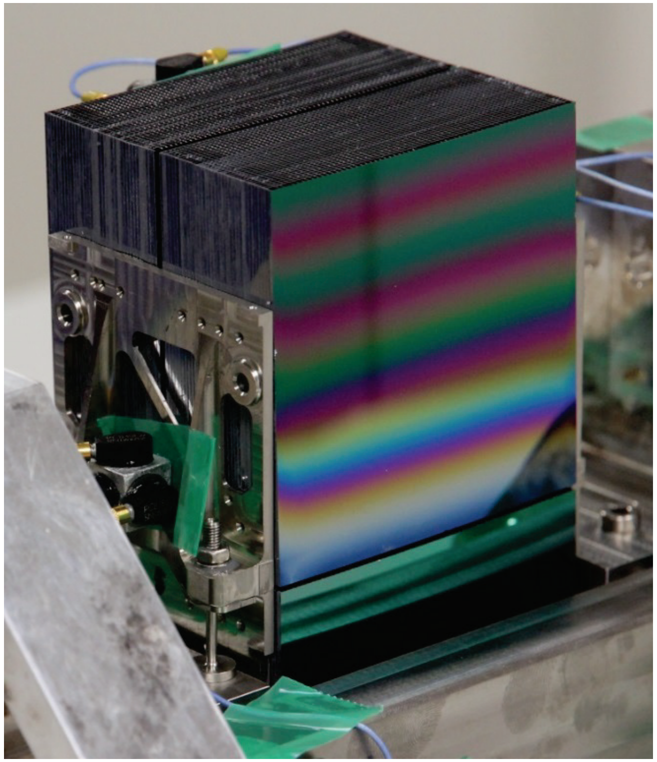
SRON: Mechanical support of Mirror Modules

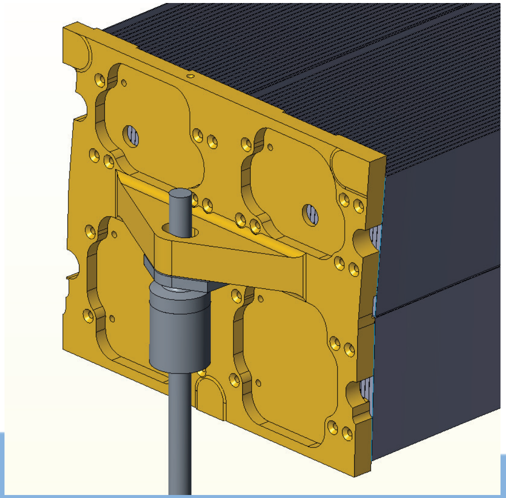


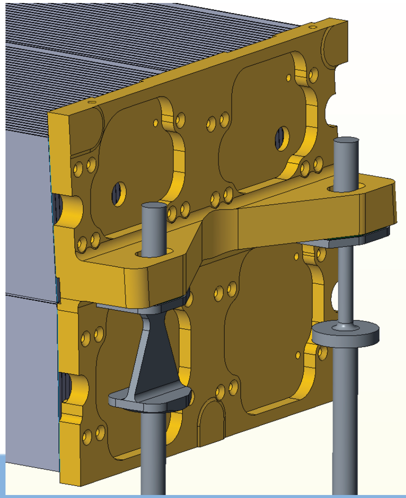
MM design based on

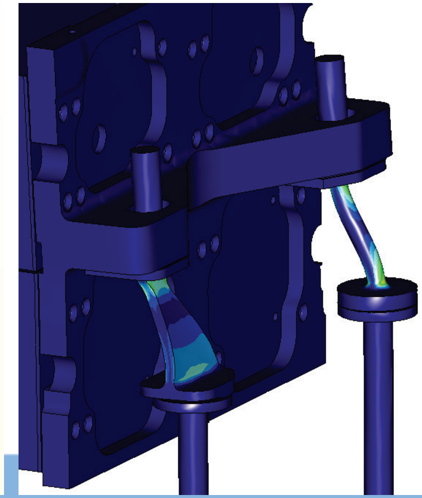
- Holding the stacks of silicon plates between low CTE brackets (Invar 36)
- Mechanical support by kinematic mounts (flexures of Invar 36 or Ti-AL6V4)
- Glue shimming: assembly by adhesive bonds to:
    - Allow alignment
    - Accommodate manufacturing tolerances

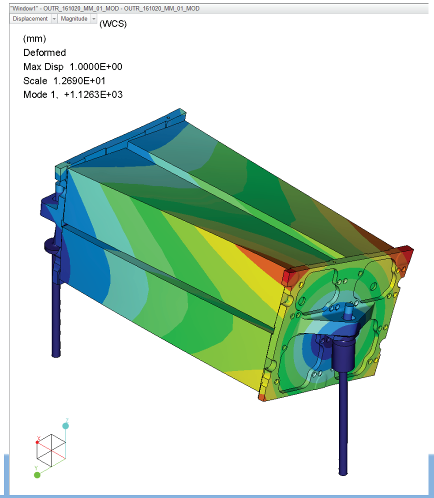
Mechanical support

- Mounting to mirror structure (titanium support frame)
- 6 d.o.f. kinematic mount allowing relative displacements (see next slide)





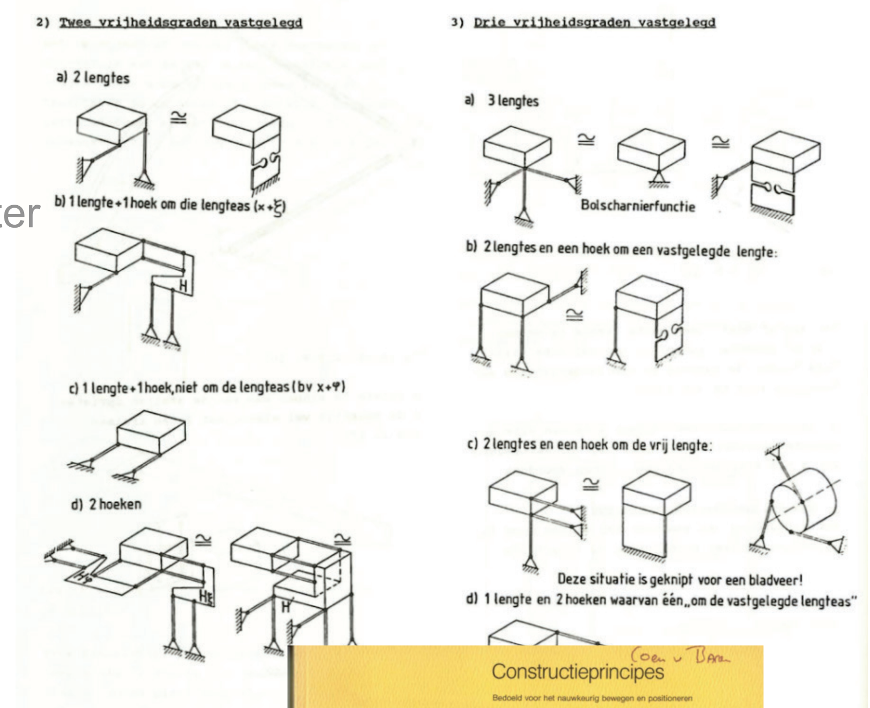




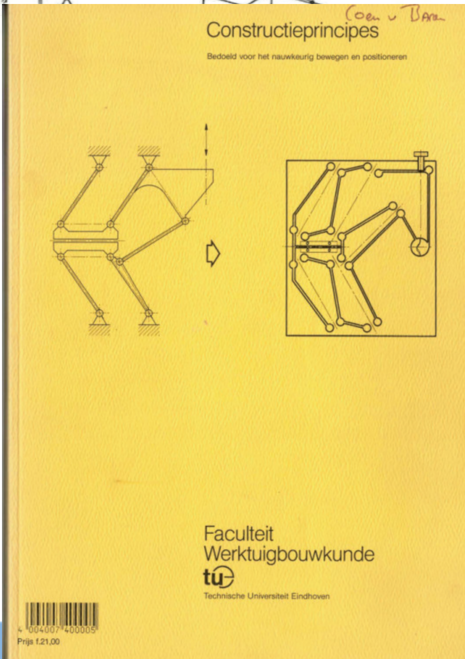
Mechanical support: kinematic design

Kinematic design (a.k.a. iso-static)

- 'Founding fathers': prof. W. van der Hoek & R. Koster
- "Sprieten en gatscharnieren"
- Now common 'toolbox' for designers
- ***Always fun to find the optimum design***



- ***WHY?***
  - Provides stable optical alignment
  - Allows (thermal) dimensional changes
  - Hysteresis free design (repeatability)
  - Clear load path
  - Forces in design elements can be well predicted/controlled
  - Ideal for thermal decoupling to minimize/control heat leaks



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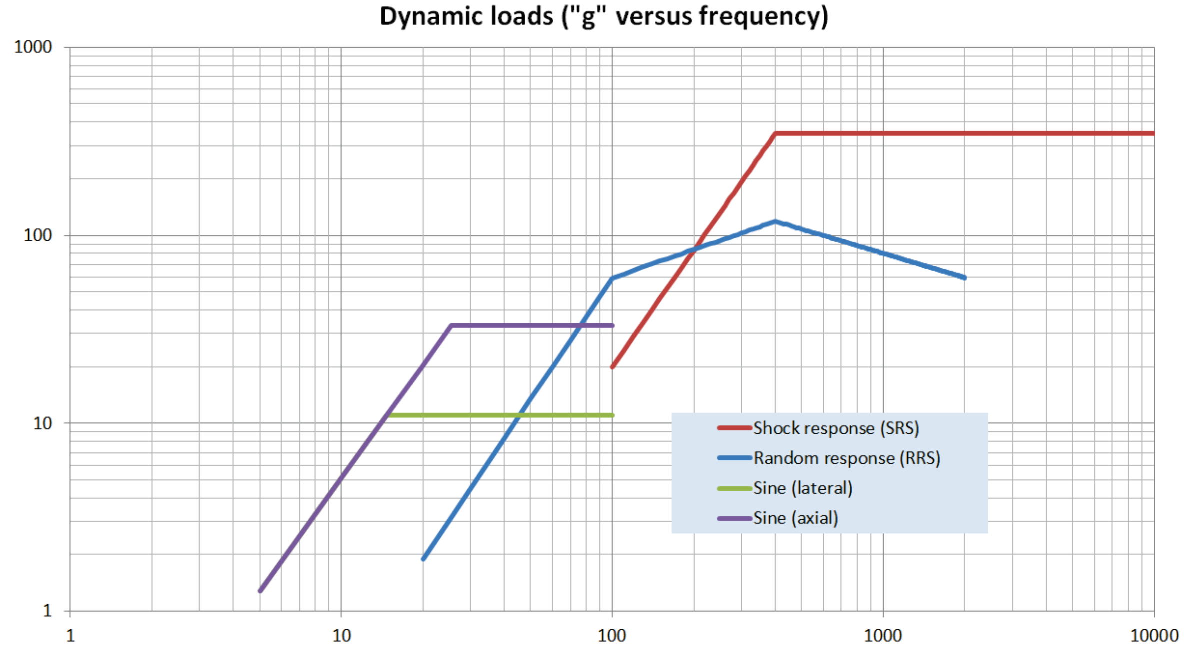
Launch environment

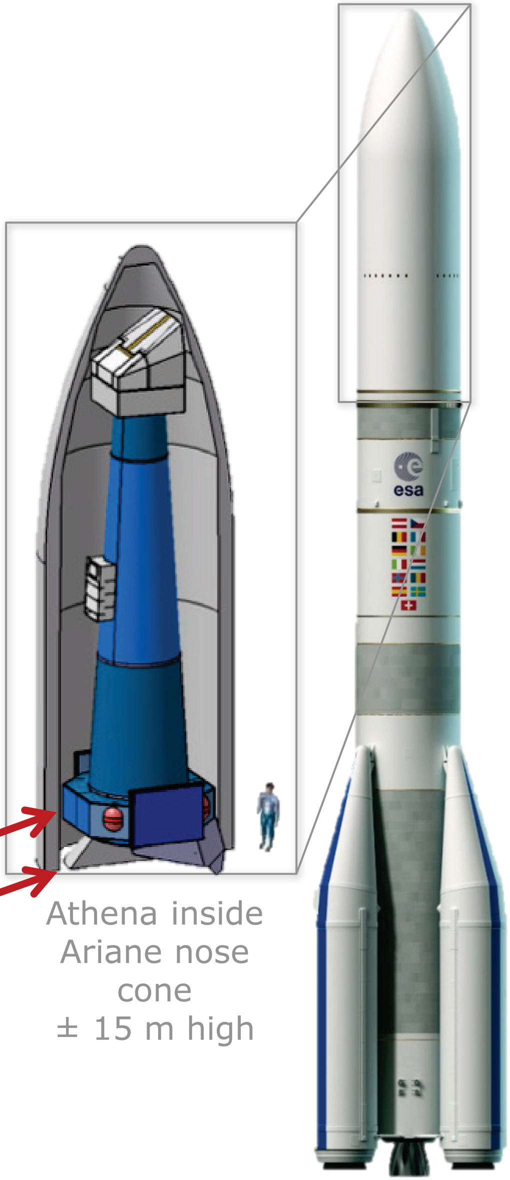
Ariane 6
± 63 m high



Launch environment dynamics:

- **Low frequency sine** (<100Hz), launcher dynamics
- **Mid frequency random** (<2kHz), acoustically induced vibration
- **High frequency shock** (<10 kHz), fairing separation, clamp band release

- Mirror position close to launcher interface
- Clamp band release induced shock



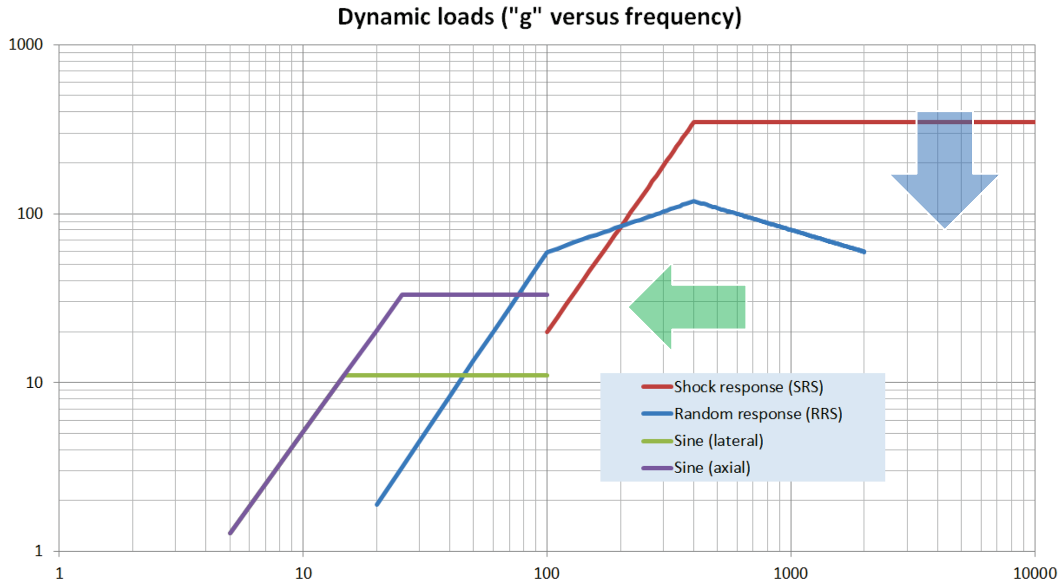
Athena inside Ariane nose cone
± 15 m high

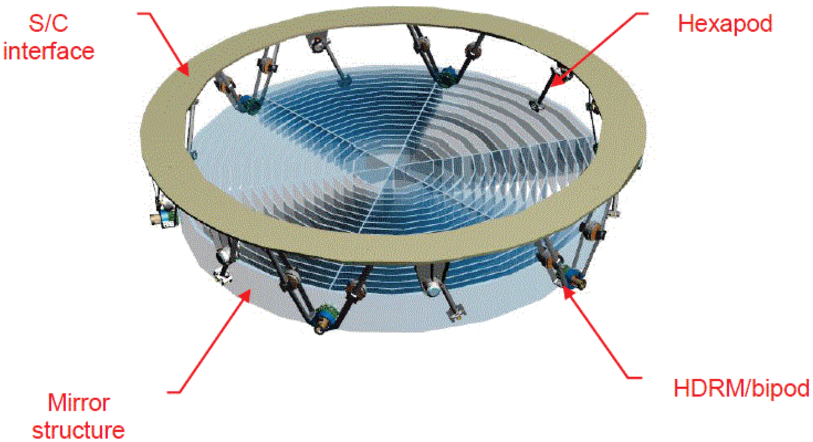
Structural optimization

Challenge to make MM compliant with dynamic environment

Three way approach:

- **Reduction of environment**
  - Direct cooperation with ESA (at mirror structure level)
- **Reduction of transients through MM structural support**
  - Dynamic isolation (by resonance frequency reduction)
- **Improvement of rigidity at MM level (next slide)**





Athena S/C mirror structure with kinematic mount including dampers (concept, courtesy of ESA)

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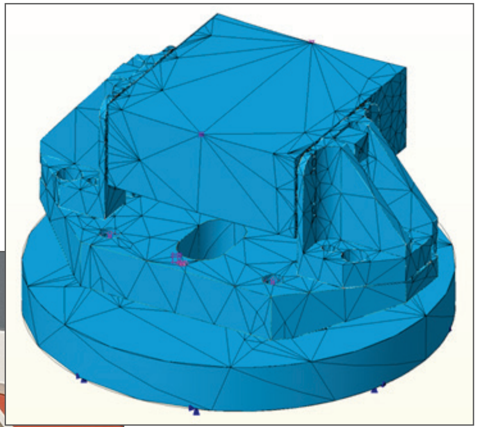
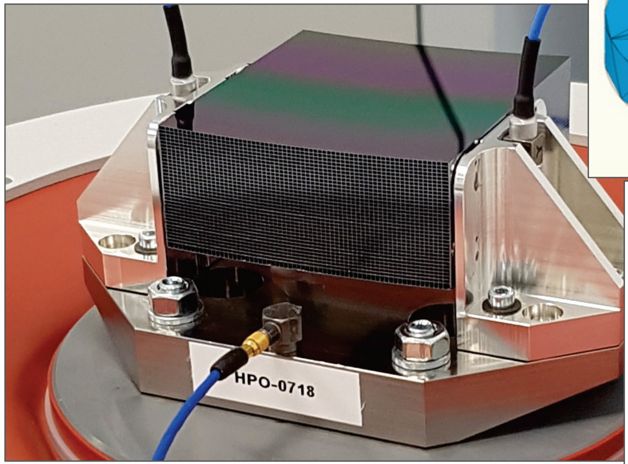
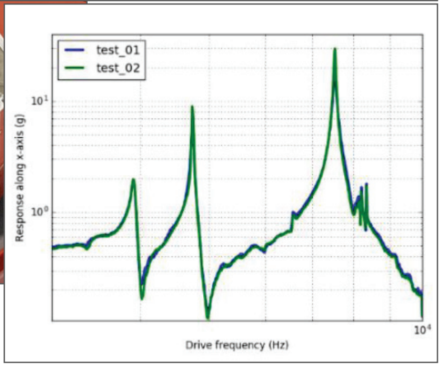
Structural optimization

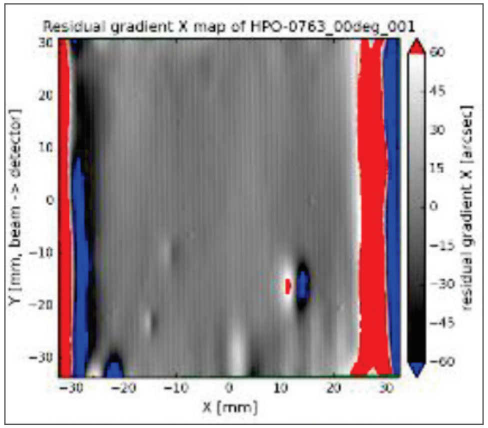
- Sub unit tests shock and X-ray tests
- Improvement of SPO robustness
- First test results are very promising!



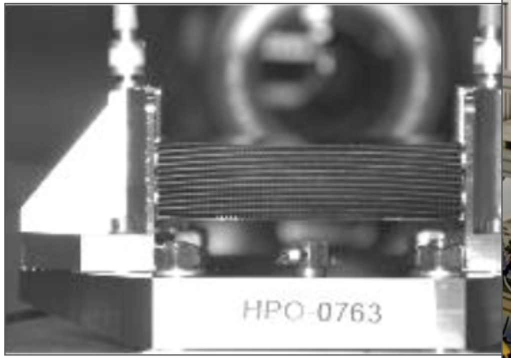


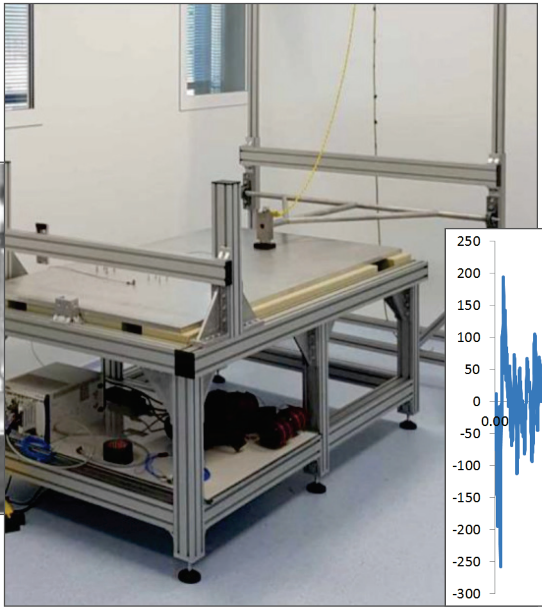


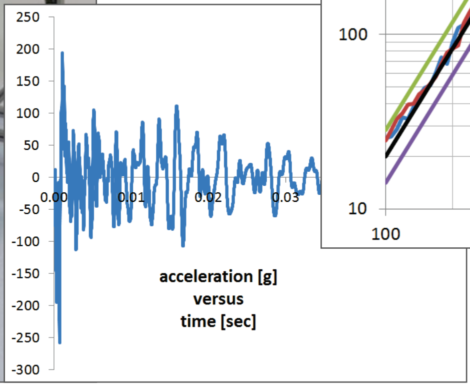
Frequency signature test & analysis

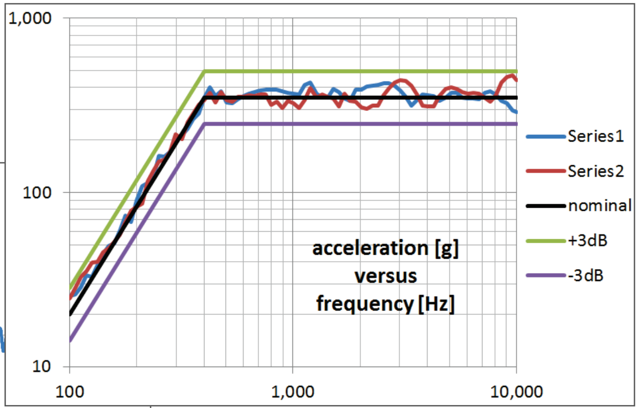


FRT surface scan









Shock test

Pictures: courtesy of ESA, cosine Research BV, SRON

Thank you for your attention

Questions?