STITUTO NAZIONALE DI ASTROFISICA



BEaTriX, the new facility to measure the modular X-ray optics of the ATHENA telescope with an expanded and parallel X-ray beam

Bianca Salmaso, on behalf of the BEaTriX team





Agenzia Spaziale Italiana

INAF
 ISTITUTO NAZIONALE
 DI ASTROFISICA
 NATIONAL INSTITUTE
 FOR ASTROPHYSICS

INAF

BEaTriX: Beam Expander Testing X-ray facility

ISTITUTO NAZIONALE DI ASTROFISICA OSSERVATORIO ASTRONOMICO DI BRERA





G.Pareschi









BEaT

M.Sanchez delRio

F.Christensen



B.Salmaso



S.Basso

D.Spiga





M.Ghigo



C.Ferrari



V.Burwitz



G.Parodi



G.Vecchi

E.Redaelli



L.Paoletti

G.Sironi

D.Sisana

E.Giro







N.C.Gellert





S.Massahi

D.D.M.Ferreira





BEaTriX: Beam Expander Testing X-ray facility

V.Cotroneo

C.Pelliciari



STITUTO NAZIONALE DI ASTROFISICA

INAF

BEaTriX is located in Merate, close to Milano, at the Brera Observatory





At 20 km distance from Media Lario, where the AIT and VERT-X facilities for **ATHENA** are under development





BEat

BEaTriX: Beam Expander Testing X-ray facility







NewATHENA

Advanced Telescope for High Energy Astrophysics

ESA mission to study the hot and energetic universe

Parameter NewAthena Athena NewATHENA X-IFU telescope effective area > 1.1 m² @ 1 keV 1.5 m² @ 1 keV X-IFU Energy resolution requirement $< 4 \, \text{eV}$ 2.5 eV X-IFU Field of view 5 arcmin > 4 arcmin X-IFU pixel size 5 arcsec (> 2300 pixels) 5" (3600 pixels) WFI telescope effective area > 1.1 m² @ 1 keV 1.5 m² @ 1 keV WFI Field of View TBD, comparable to old 40'x 40' XMM-Newton Athena Optics angular resolution (on axis HEW @ 5 arcsec < 9 arcsec 1 keV) Target of Opportunity (ToO) capability Yes Yes [Bavdaz, Proc. SPIE 2023]

PhotonMEADOW 2023

Silicon Pore Optics by cosine B.V. in NL



INAF



BEat

ISTITUTO NAZIONALE DI ASTROFISICA OSSERVATORIO ASTRONOMICO DI BREF

INAF









BEatr

MINERVA @ ALBA



PANTER @ MPE

.... and BEaTriX

PhotonMEADOW 2023

BEaTriX: Beam Expander Testing X-ray facility

6

ISTITUTO NAZIONALE DI ASTROFISICA

INAF

	Facility	Source distance	Beam divergence on 60 mm	V
BEaTriX		4.7 m	~ 2 arcsec	in be so ≻
PANTER	Instruct Chanter and Claim Room	120 m	103 arcsec	
XRCF		518 m	24 arcsec	

What special in BEaTriX

BEatr

In a small lab, we create an X-ray beam that simulates an astronomical source

- Expanded (60 x 170 mm): to illuminate the entire entrance pupil of the optic
- Collimated (~ 2 arcsec): to have double reflection from the entire optic

Conventionally this is obtained by placing the source at very large distance

- Large volumes to be evacuated
- Residual beam divergence at the existing facilities



A&A 664, A173 (2022) https://doi.org/10.1051/0004-6361/202244028 © S. Basso et al. 2022



BEa



TITUTO NAZIONALE DI ASTROFISICA

INAF

First light of BEaTriX, the new testing facility for the modular X-ray optics of the ATHENA mission

S. Basso¹, B. Salmaso¹, D. Spiga¹, M. Ghigo¹, G. Vecchi¹, G. Sironi¹, V. Cotroneo¹, P. Conconi¹, E. Redaelli¹,
A. Bianco¹, G. Pareschi¹, G. Tagliaferri¹, D. Sisana², C. Pelliciari³, M. Fiorini⁴, S. Incorvaia⁴, M. Uslenghi⁴, L. Paoletti⁵,
C. Ferrari^{6,1}, R. Lolli⁶, A. Zappettini⁶, M. Sanchez del Rio⁷, G. Parodi⁸, V. Burwitz⁹, S. Rukdee⁹, G. Hartner⁹, T. Müller⁹,
T. Schmidt⁹, A. Langmeier⁹, D. Della Monica Ferreira¹⁰, S. Massahi¹⁰, N. C. Gellert¹⁰, F. Christensen¹⁰,
M. Bavdaz¹¹, I. Ferreira¹¹, M. Collon¹², G. Vacanti¹², and N. M. Barrière¹²



MM-0042





The BEaTriX X-ray beam



Large beam:V60 mm × H170 mmMonochromatic: $\Delta \sim 36$ meVCollimation:Vert. < 2 arcsec</td>Hor. < 2.5 arcsec</td>Compact lab: ~ 9 m × 18 mSmall volumes to be evacuated

Fully covering the MM entrance pupil

PhotonMEADOW 2023

ISTITUTO NAZIONALE DI ASTROFISICA OSSERVATORIO ASTRONOMICO DI BRER.

INAF

4.51 keV beamline

The BEaTriX recipe



BEaTr

4.51 keV beamline



The BEaTriX recipe for beam expansion Asymmetrically cut crystal



BEaTri

The BEaTriX recipe for monochromation Symmetrically cut crystals

The Si(220) reflectivity has a point like peak close to 100% => the reflectivity peak is almost unchanged after several diffractions



[Pelliciari, C. et al, Proc. SPIE 9603, 96031P (2015]

The needed monochromation is obtained with 4 diffractions on silicon crystals with symmetric cut wrt (220) planes



STITUTO NAZIONALE DI ASTROFISICA

INAF

Channel cut crystals: Si (220) symmetrically cut

4.51 keV beamline

Two configurations are possible high flux – high collimation





By changing the pitch of CCC-2, the X-ray beam bandwidth decreases and the horizontal collimation improves, at the expenses of the flux

	Flux	HEW-vert	HEW-hor
High flux / mid-collimation (CCC2 pitch = 0)	60 ph/s/cm ²	< 2 arcsec	~ 4 arcsec
Low flux / <u>high-collimation</u> (CCC2 pitch = 10 arcsec)	10 ph/s/cm ²	< 2 arcsec	~ 2.5 arcsec

BEat

ISTITUTO NAZIONALE DI ASTROFISICA

4.51 keV beamline

4.51 keV beam line – commissioning completed

Flux and divergence

INAF

Measured with Hartmann test





-2

0

Angle (arcsec)

2

4

$$HEW = \sqrt{HEW_{centr}^2 + HEW_{hole}^2}$$

0.00 -

-10

-6

-4

6

10

BEatr

STITUTO NAZIONALE DI ASTROFISICA

4.51 keV beamline



4.51 keV beam line – commissioning completed

Flux and divergence

INAF

Measured with Hartmann test



HEW and Effective Area

Capability to measured PSF and Eff.Area 8min to reach 10⁵ ph





Throughput

> Capability to measured PSF and Eff.Area for 2 energies at 3 MM/d

Thermal test

Capability to measure in the temperature range of 20±25°C





Basso – Spiga – Ghigo - Salmaso

PhotonMEADOW 2023

BEaTriX: Beam Expander Testing X-ray facility



4.51 keV beam line – open to user

Free of cost until June 2024

AHEAD 2020 program (Integrated Activities in the High Energy Astrophysics Domain)

Trans National Access (TNA)

http://ahead.astropa.inaf.it/index.php/facility-tna-call-ahead-2020/ https://ahead.iaps.inaf.it/?page_id=2503



BEaTriX, the new facility for X-ray testing with an expanded and parallel beam

The webinar will be held on 17 November 2023, 10:00-12:00



A Webinar is organized to - explain BEaTriX in details - motivate users to access it - collect needs from the X-ray community (what we can do for you / what you can do for us)

Info and participation form are published in the AHEAD and INAF-OAB WEB page





1.49 keV beam line – the challenge

BEaTriX was designed and realized to enable an upgrade, adding the second beamline at 1.49 keV





Sketch of the components inside the Optical Chamber

More challenging for:

- X-ray source: high brilliance (35um focal spot, > 5×10¹¹ ph/s/sr) from Al anode
- crystals for the monochromator: Quartz (100) with asymmetric cut
- crystals for the expansion: APD (101) with asymmetric cut



1.49 keV beam line – the expansion stage



Silicon cannot be used at 1.49 keV because of too small d spacing

ADP (Ammonium Dihydrogen Phosphate) was selected in 2019 after a characterization (mosaicity and planarity) performed by IMEM-CNR-Italy on Saint Gobain samples

[Ferrari, C., et al., J. of Appl.Crystallogr, 52, 599-604 (2019)]



ADP crystal with asymmetric cut wrt (101) planes

$$\Delta \vartheta_{out} \sim \frac{\sin \alpha}{d \sin \vartheta_{out}} \lambda \frac{\Delta E}{E} = 160 \ \Delta E \frac{arcsec}{eV}$$

For $\Delta \vartheta_{out} = 1$ arcsec $\bigtriangleup \Delta E = 6$ meV3-4 times narrower than required for 4.51 keV !! ($\Delta E = 21$ meV) [Spiga, D., et al, Proc. SPIE ICSO 12777, 127773E (2023)]

Two ADP crystals are now being produced by Saint Gobain – Luxium 2x: 80-80-20 mm versus 1x:140-70-20 mm

ISTITUTO NAZIONALE DI ASTROFISICA OSSERVATORIO ASTRONOMICO DI BREI

INAF

1.49 keV beam line – the monochromator





This tight monochromation is obtained with

Quartz crystals with asymmetric cut wrt (100) planes



The Quartz crystals are now being manufactured by Saint Gobain – Luxium

BEat



1.49 keV beam line – the challenge



Ideal X-ray beam @ 1.49 keV HEW-hor = 3.3 arcsec HEW-vert = 0.86 arcsec Flux = 2.3 ph/s/cm² (for source of 1×10^{11} ph/s/sr)

BEa

Ideal X-ray beam @ 4.51 keV HEW-hor = 1.54 arcsec HEW-vert = 0.72 arcsec Flux = 10 ph/s/cm² (for source of 1×10^{11} ph/s/sr) with possibility of high flux configuration

 X-ray source with Al anode and high brilliance (35um focal spot, > 5×10¹¹ ph/s/sr) to have flux 12 ph/s/cm²

- crystals for the monochromator: Quartz (100) with asymmetric cut

- crystals for the expansion: APD (101) with asymmetric cut

1.49 keV beamline

1.49 keV beam line – the parabolic mirror







BEat

Manufacturing tolerances: aiming at 2 arcsec (no coating needed) 3 arcsec already obtained on the 4.51 keV mirror with Cr+Pt coating









Feasibility study for a BEaTriX#2 at cosine (NL) with 6.4 and 1.49 keV beamlines

BEaTriX#1 in Merate - Italy

BEaTriX#2 in Sassenheim – The Netherlands



A possible scenario

Quality control tests on selected MM's

Industrial acceptance tests on all MM's before and after vibrational tests





Conclusions

1) BEaTriX @ 4.51 keV:

It is operative @ INAF-OAB in Merate (Italy) and open to users Free of cost until June 2024 through the AHEAD project Webinar on 17Nov2023: subscription open

2) BEaTriX @ 1.49 keV:

realization @ INAF-OAB in Merate (Italy) has started

3) BEaTriX#2 @ cosine (NL):

a feasibility study to replicate BEaTriX in cosine at 1.49 keV – 6.4 keV is on-going