KB X-ray Optics for Astrophysics: Recent Status

Abstract

X-ray optics in KB (Kirkpatrick Baez) arrangement represent promising alternative to Wolter optics in common use. We present some new results including KB module developed and tested within the EU AHEAD project.

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Alternative Design for Astronomical X-ray Telescopes: Kirkpatrick-Baez (KB) X-Ray Optics

- First X-ray imaging system proposed (1948)
- Frequently used in laboratory and synchrotron as imaging system with high angular resolution
- In space used only on rockets so far
- Various modifications exist (parabolic vs. elliptical, various number of reflections, 2 to 4)

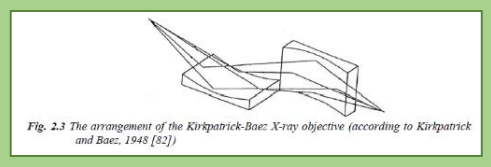
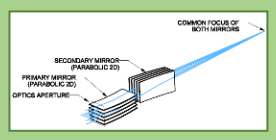


Fig. 2.3 The arrangement of the Kirkpatrick-Baez X-ray objective (according to Kirkpatrick and Baez, 1948 [82])

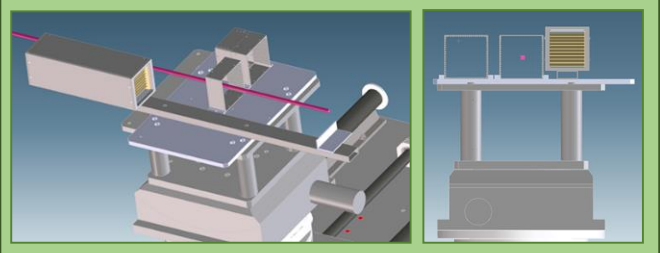
Kirkpatrick-Baez X-ray Optics

- Double reflection X-ray Optics consists of two mirror sets – one is aligned vertically and the second is aligned horizontally.

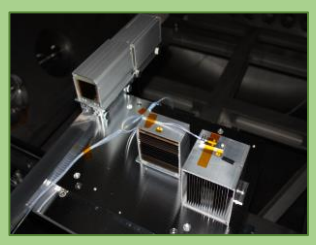


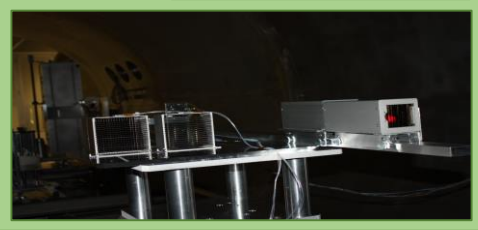
- The quality of the focal spot image depend on quality of substrates (shape, microroughness).
- Both mirrors are curved parabolically – the first mirror focuses in vertical plane and the second mirror focuses in horizontal plane. Single focal point is formed in the crossection of the two focal planes. Nested systems possible.
- Technology is not necessarily based on precise and expensive mandrels (almost flat plates, curvatures ~ kms) hence
- Cost-effective manufacture (recent requirements of space agencies) High angular resolution ~5 arcses at affordable cost

The setup at PANTER – from left to right REX optics, KB 1D optics, KB 2D optics



AHEAD KB modules in PANTER facility

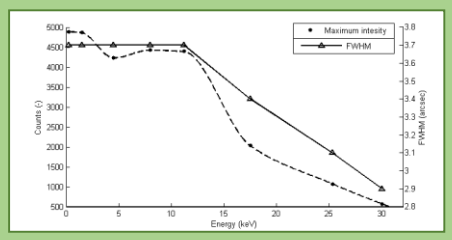




KB modules – ray tracing simulations

Energy (eV)	Maximum Intensity (counts)	FWHM (arcsec)
100% reflection	5329	3.8
280 (C)	4893	3.7
1 500 (Al)	4865	3.7
4 500 (Ti)	4235	3.7
8 000 (Cu)	4432	3.7
11 200 (Se)	4394	3.7
17 500 (Mo)	2036	3.4
25 300 (Sn)	1075	3.1
30 000	575	2.9

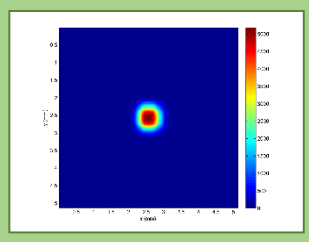
Dependence on energy



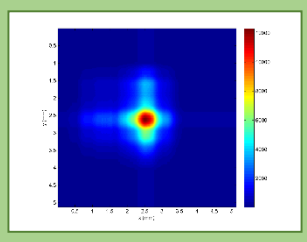
- Input parameters (mirror material properties, arrangement of mirrors in modules, experiment geometry, …) are the same as in the experiment
- Point source was considered

KB modules – ray tracing simulations

- Input parameters (mirror material properties, arrangement of mirrors in modules, experiment geometry, …) are the same as in the experiment
- Energy 453 eV (Ti Lα)



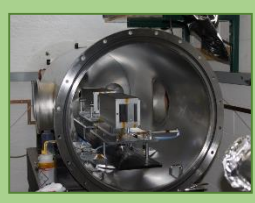
Theoretical focus:
FWHM = 0.58 mm
≈ 3.7 arcsec

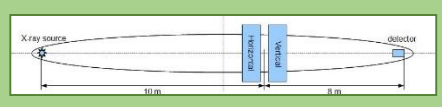


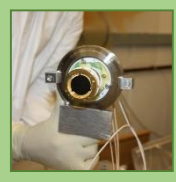
Theoretical focus with 0.2 mm source diameter and 2 μm manufacturing errors:
FWHM = 0.59 mm

KB test modules – Boulder tests experimental arrangement

- Modules were tested in vacuum chamber at CASA (University of Colorado at Boulder)
- Elliptical geometry
- Source to optics distance: 10 m
- Optics to detector distance: 8 m
- Module position adjustment done with visible light (Xe lamp)
- MCP detector, diameter 1''

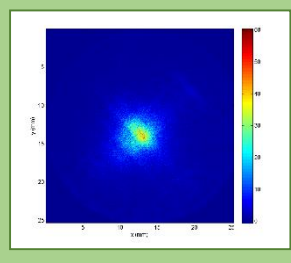


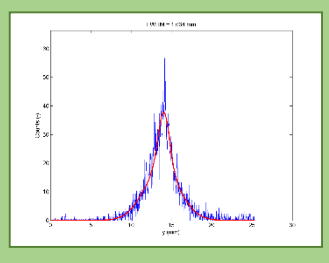




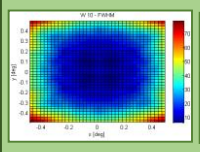
KB modules – Boulder X-ray test results

- MCP detector, diameter 1''
- Energy of X-rays: 453 eV
- FWHM = 1.63 mm
  Anglular resolution: 10.2 arcsec (after ellips. correction)

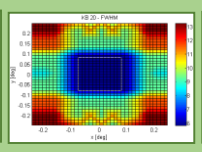




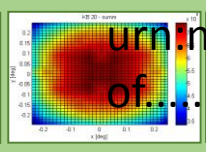
Comparison K-B vs. Wolter



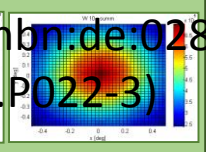
Wolter system - FWHM (F = 20 m)



KB system - FWHM (F = 20 m)



KB system – SUM (F = 20 m)



Wolter systém – SUM (F= 10 m)

	D [m]	A [m^2]	F [m]	A_{eff} [m^2]*	A_{rel} [%]**	A_{eff} [m^2]***	A_{rel} [%]**
W10	dia 1.8	2.6	10	0.70	26.63	0.66	25.11
W20	dia 3.6	10.9	20	2.83	25.89	2.76	25.26
KB20	1.8 x 1.8	3.3	20	0.93	27.80	0.62	18.49
KB40	3.6 x 3.6	13.9	40	3.11	22.33	2.46	17.66

* for detector 100 x 100 mm

** proportion of effective area to aperture

*** for peak (area 4 x 4 mm)

K-B vs. Wolter: comparable ef area at f = 2f, comparable angular resolution

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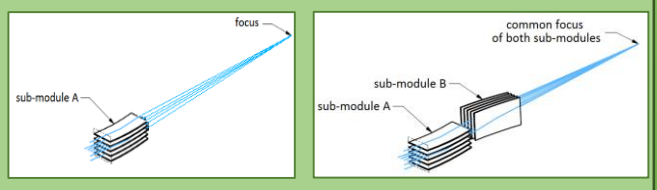
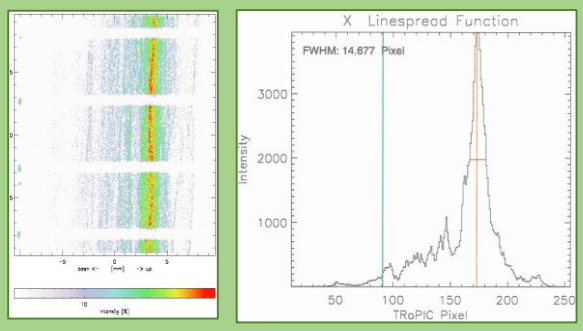
1D and 2D KB arrangements



1D (left) and 2D (right) X-ray optics of Kirk-Patrick Baez (KB) type – both sub-modules (A and B) have common focus.

AHEAD KB X-ray optics – the best 1D focus in y direction (horizontal), FWHM = 1.1 mm (18 arcsec) at 1.49 keV



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