From zone plates to microcalorimeter:

50 years of cosmic X-ray spectroscopy at SRON

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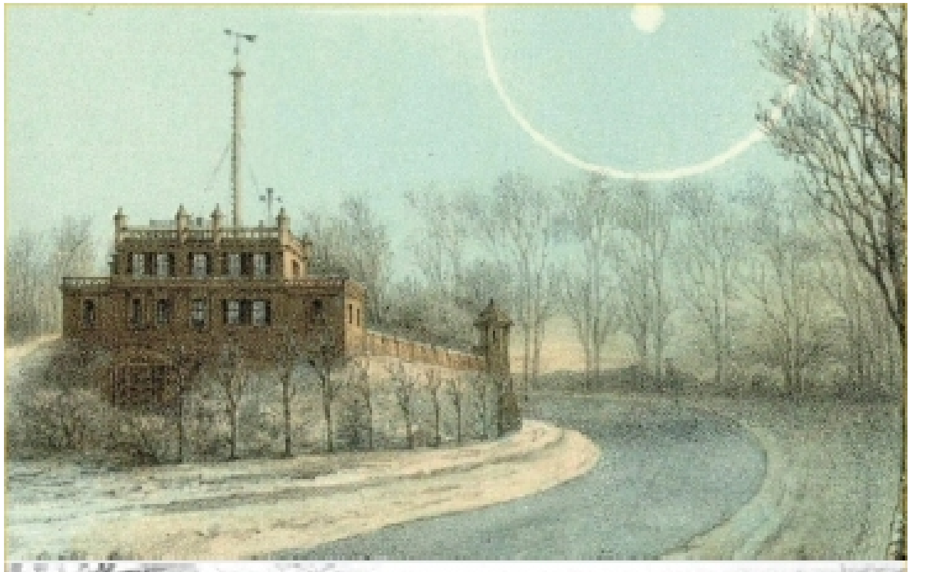
The grass-roots at Utrecht (1)

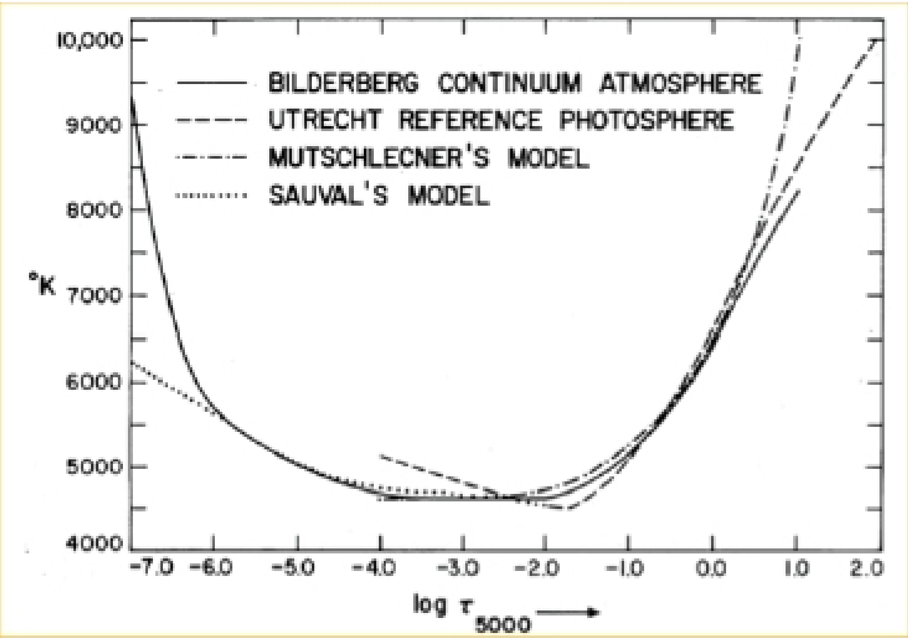
Christophorus Buys Ballot:

- 1853: Sonnenborgh Observatory
  Meteorology and Astronomy
- 1877: New Physics Laboratory
  Mainly: teaching
- → : optical spectroscopy
  (Julius, Moll, Ornstein)
- 1896 : Heliostat spectrograph
  for Fraunhofer lines in
  Solar spectrum
- 1923 : concept of equivalent line
  width **W**(Minnaert)
- 1929 : formulation of curve of
  growth **W=f(N)**
  (Minnaert, Unsöld)



The grass roots at Utrecht (2):
Atlas of the solar spectrum: Marcel Minnaert

1936: ~ 100 photographic plates taken at Mount Wilson Observatory
1940: Utrecht Photometric Atlas of the solar spectrum (Minnaert et al)
1952: Solar atmosphere temperature model (de Jager 1952)
1966: Solar abundances from The Solar Spectrum (Moore et al)



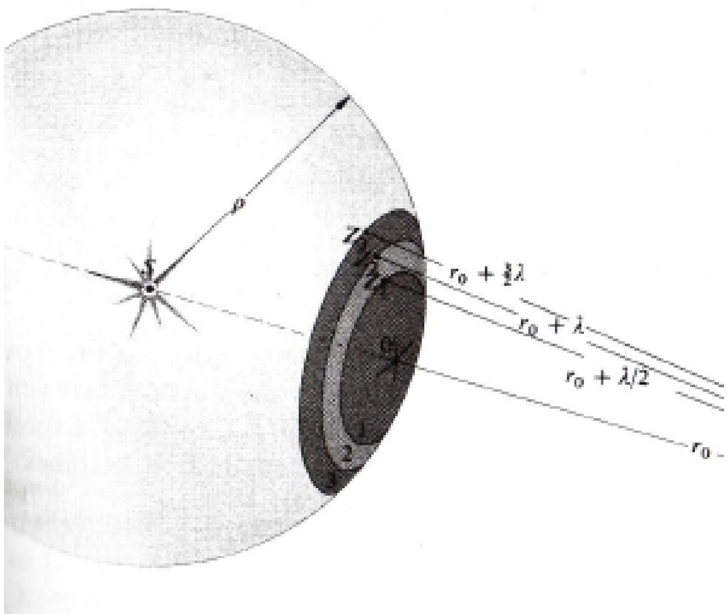
To shorter wavelengths: X-ray spectroscopy

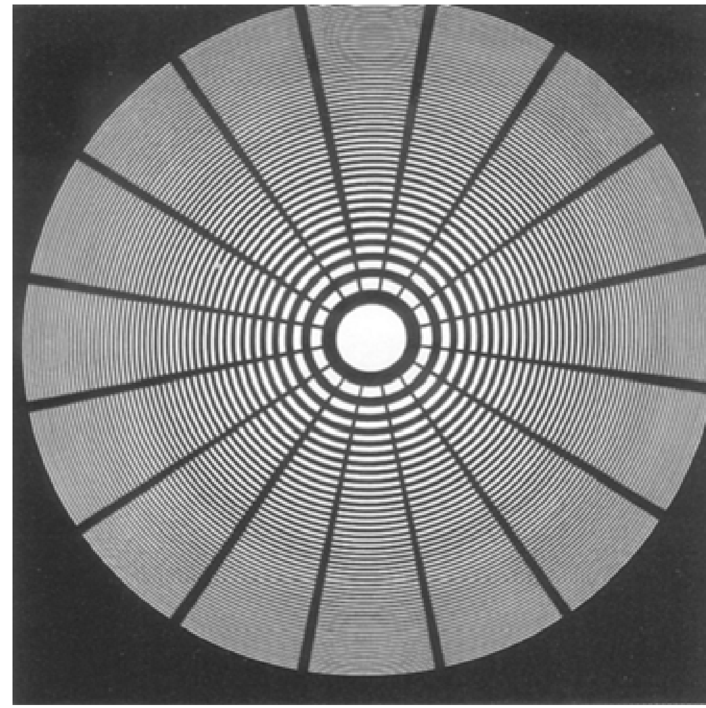
- 1961: Start Space research in Utrecht
- First target: X-ray spectroscopy of the sun

Mid 1960's: Monochromatic XUV-images of the Sun

X-ray lense employing diffraction: Fresnel zone plate

Zone partition of spherical wavefront → block even/odd zones





Radius n^th^ zone: $r_n \simeq \sqrt{nf\lambda}$ *, with* $N = n_{max}$ *= large* →

Focal length(5nm): $f = \frac{2r_N \Delta r_N}{\lambda}$ $\Delta r_N = 1\mu m$ $r_N = 1mm$, $f = 40cm$

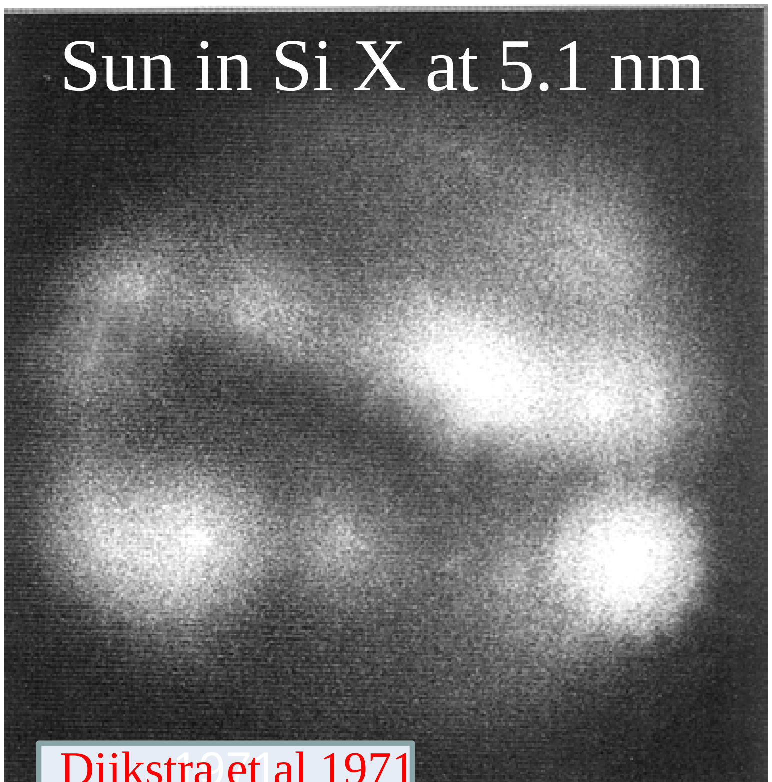
Mid 1960s: Q-monochromatic XUV-images of the Sun

X-ray lense employing diffraction: Fresnel zone plate

Manufacturing:

RQ: transparent zones completely open, width 1-2 μm → radial support

- First successful trials with electron optical imaging, FOV limitations
- Interferogram of two coherent spherical wave fronts: Photolithography



Dijkstra et al 1971

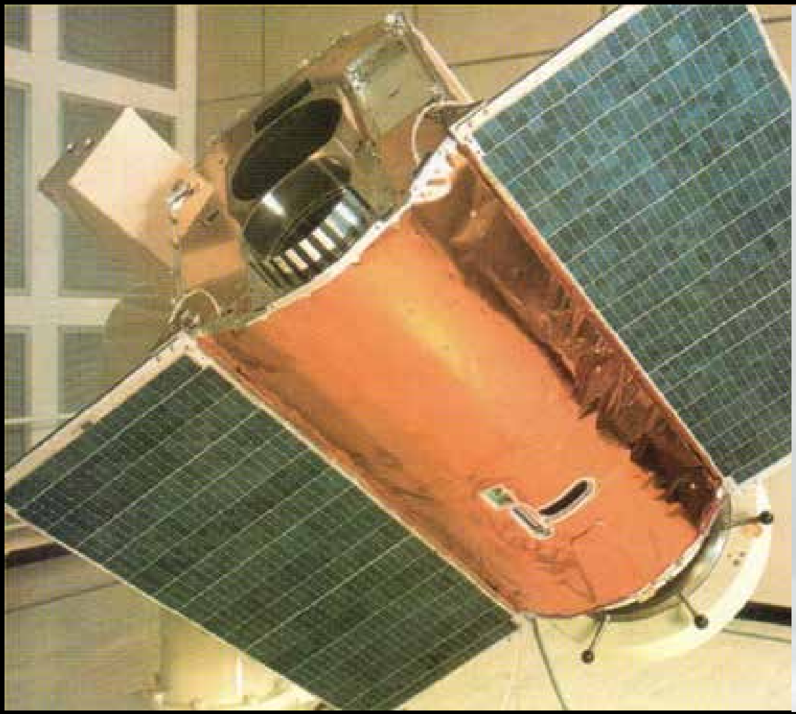
1967: Successful sun stabilized Aerobee rocket experiment

4 Zone plates of 50 metallic rings

f = 40 cm, outer diam. 0.90–3.06 mm

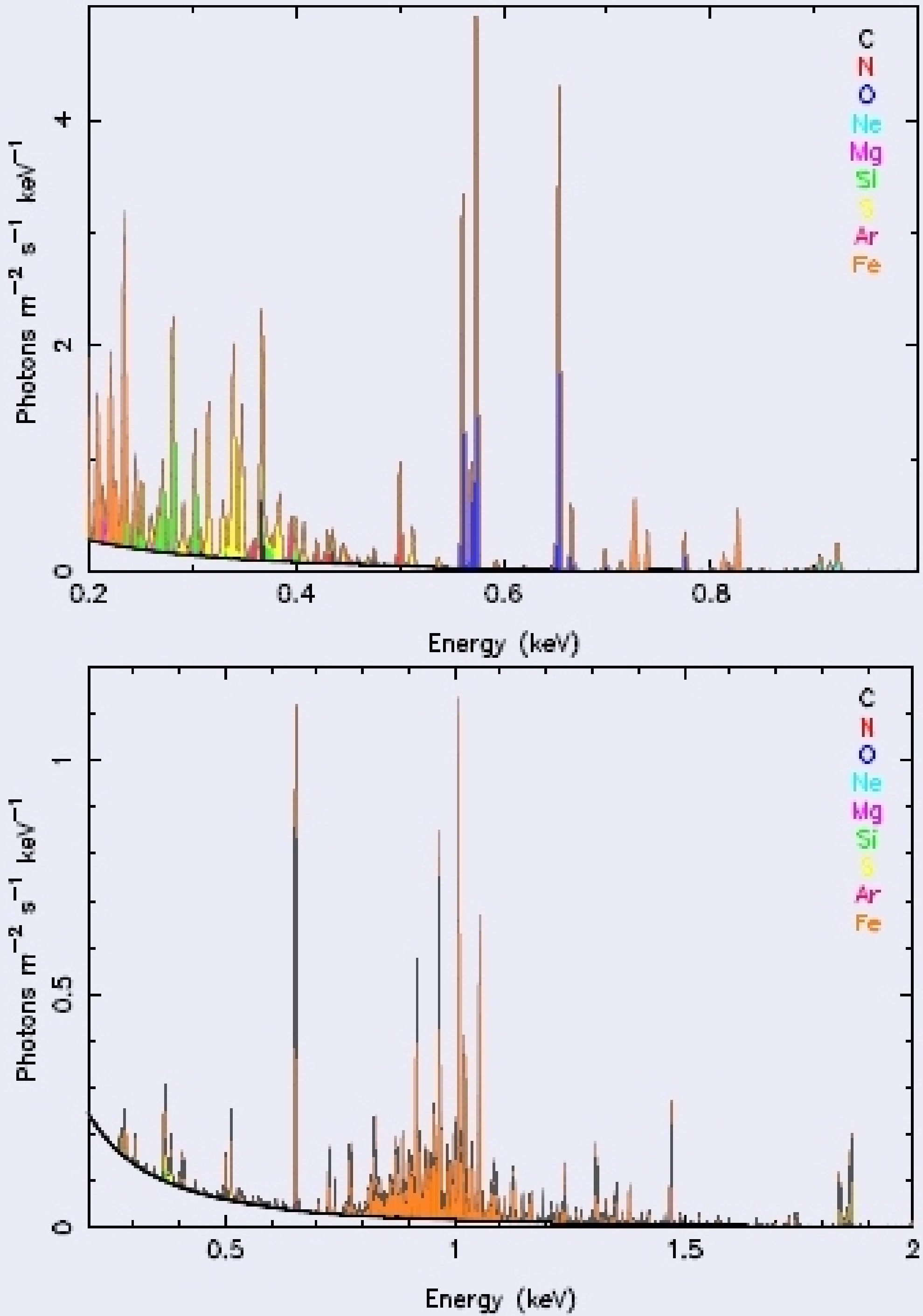
→ Solar Q-monochromatic images in Si X, Fe XI, HeII and HeI lines

The Astronomical Netherlands Satellite (1974)



Major results:

- Type I X-ray bursts
- (soft) X-rays from stellar coronae
- Stellar X-ray flares
- Thermal X-ray distribution in evolved SNRs



1970:

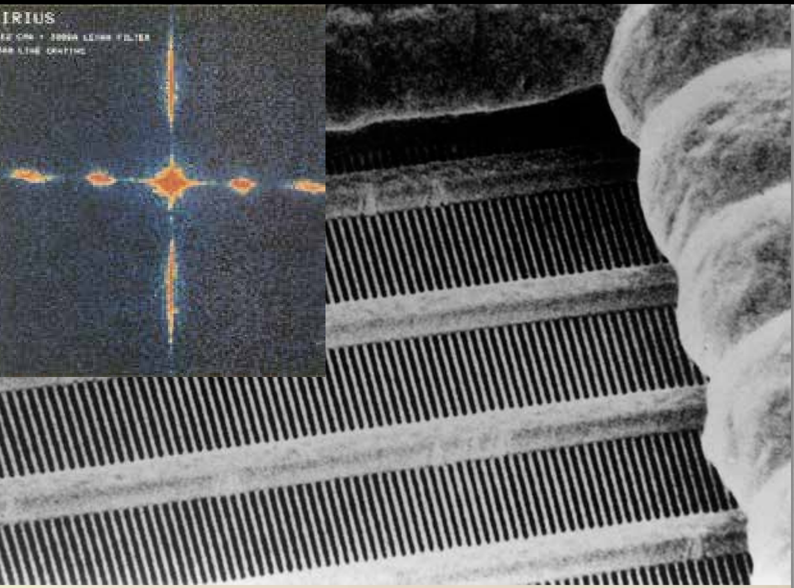
Start development
X-ray spectral codes
at Utrecht by Mewe, Kaastra ,
later joined by Liedahl

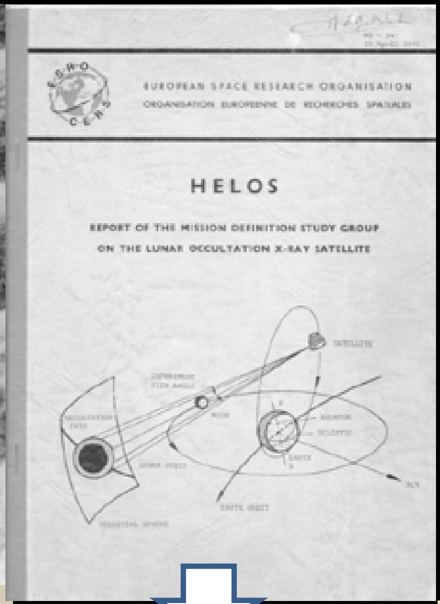
MeKaL code

Basis of SPEX fitting

Grating spectrometers on Einstein and EXOSAT:

Capitalizing on the photo-lithographic zone plate technology




EUROPEAN SPACE RESEARCH ORGANISATION
ORGANISATION EUROPEENNE DE RECHERCHES SPATIALES

HELOS

REPORT OF THE MISSION DEFINITION STUDY GROUP
ON THE LUNAR OCCULTATION X-RAY SATELLITE

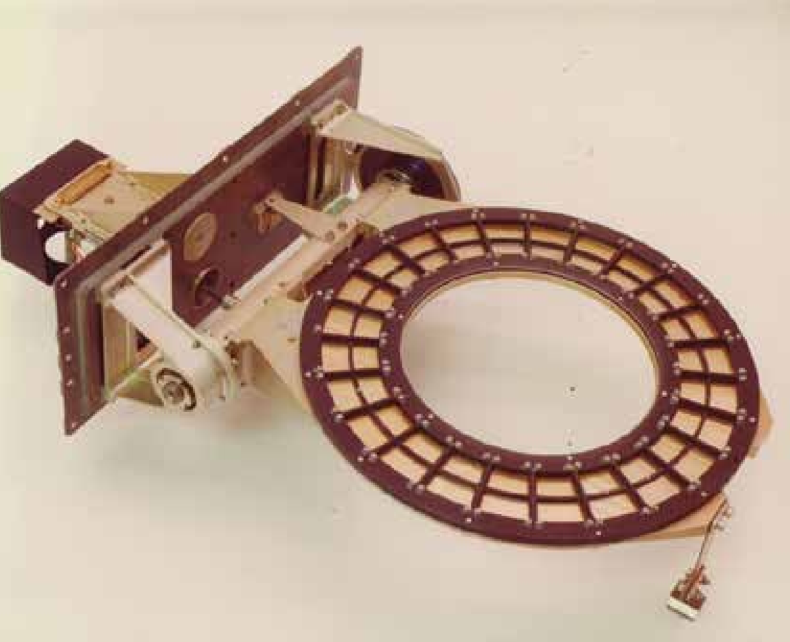
Also:

First development of light -weight replica Wolter I X-ray optics:

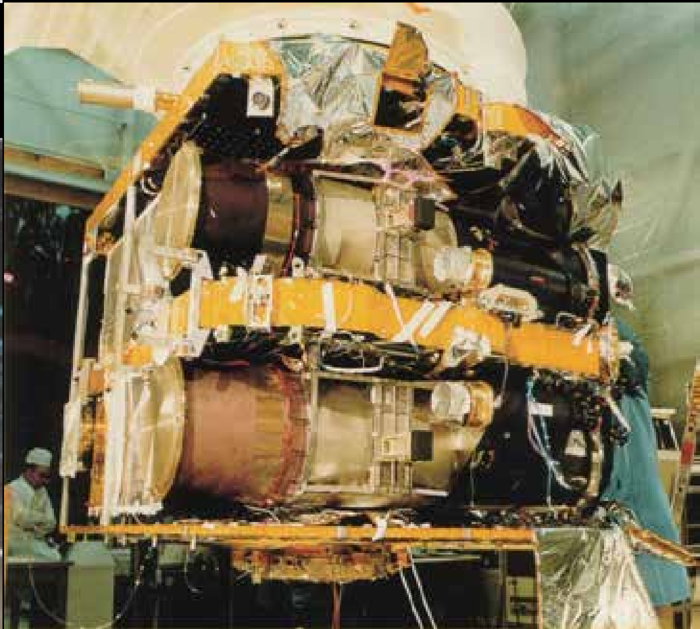
Carrier : Beryllium

Layer : Epoxy

Coating : Gold



EXOSAT

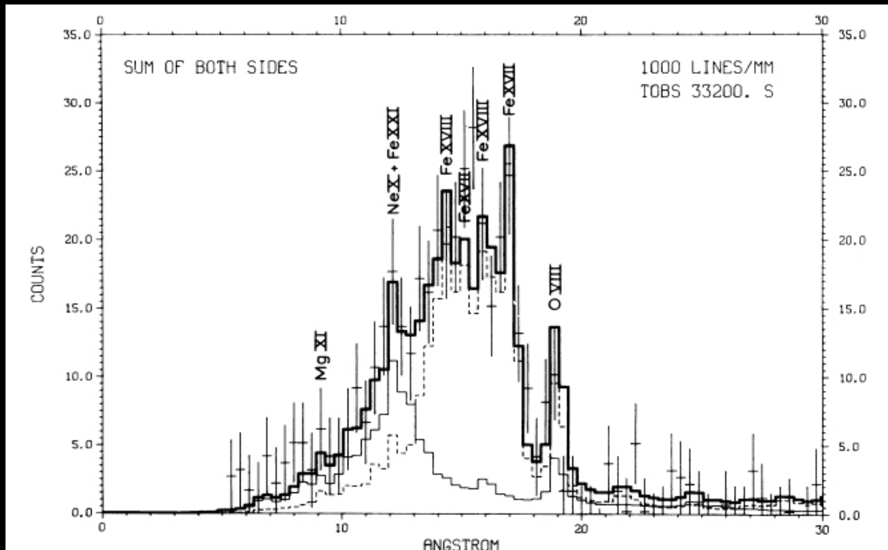


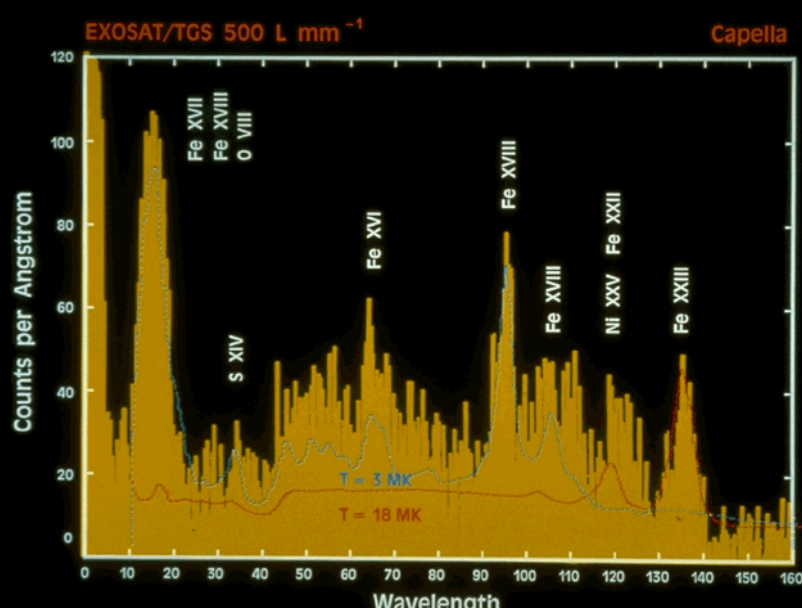
Coronal spectra

- emission measure as function of temperature: DEM

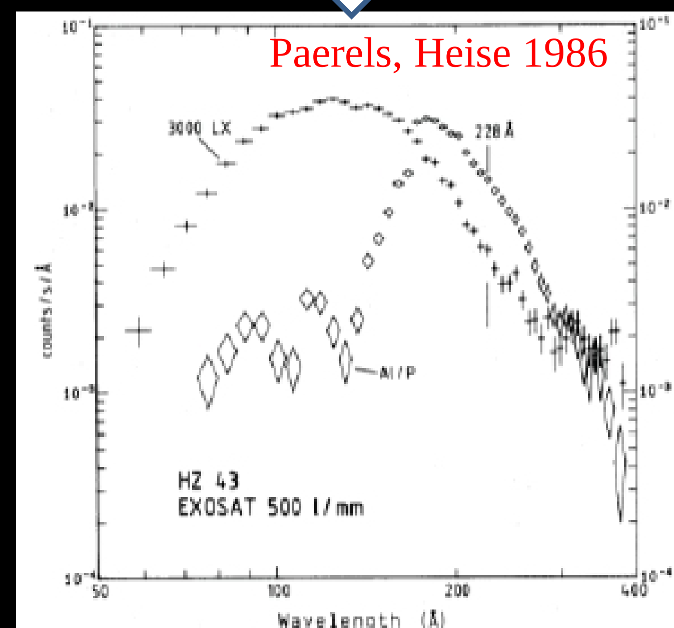
White dwarf atmospheres

- helium abundance
- interstellar absorption





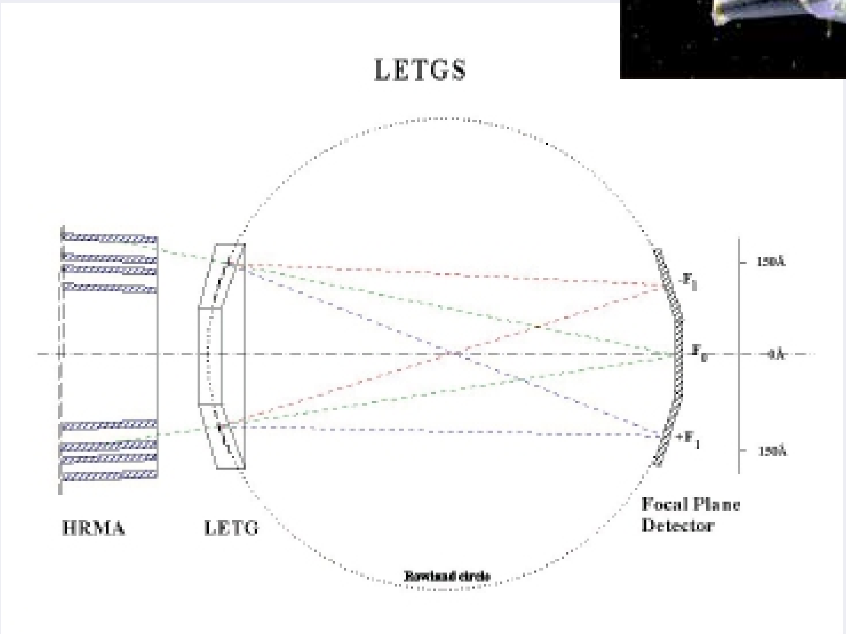
Lemen, Mewe et al. 1989

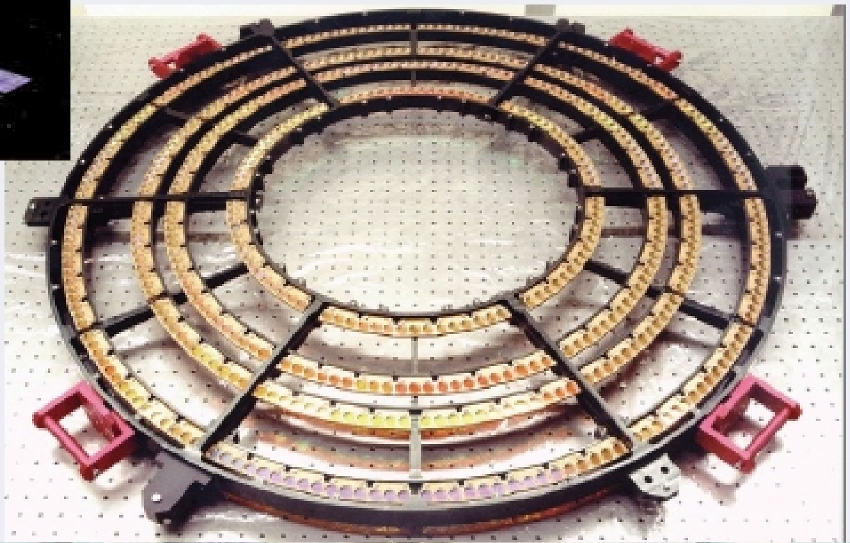


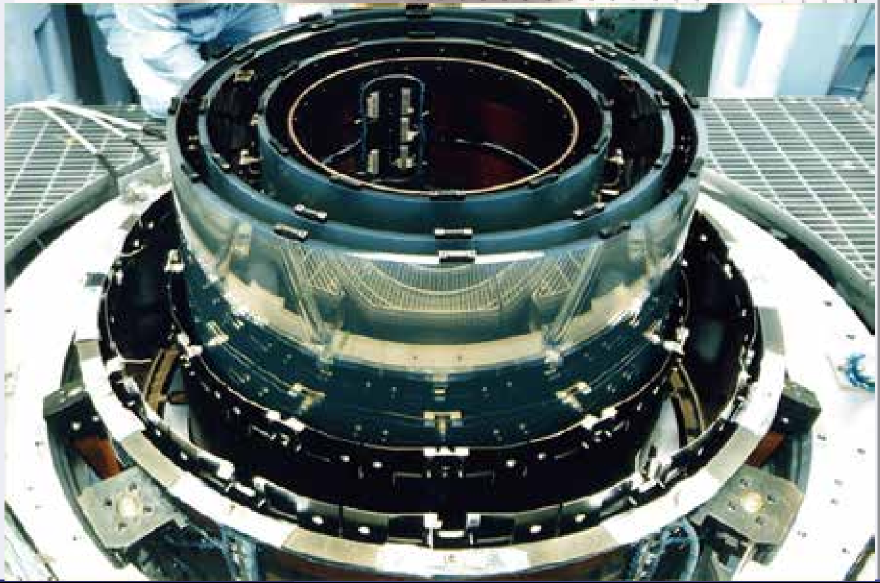
Paerels, Heise 1986

LETG on Chandra: SRON (PI) & MPE-Garching

optical configuration





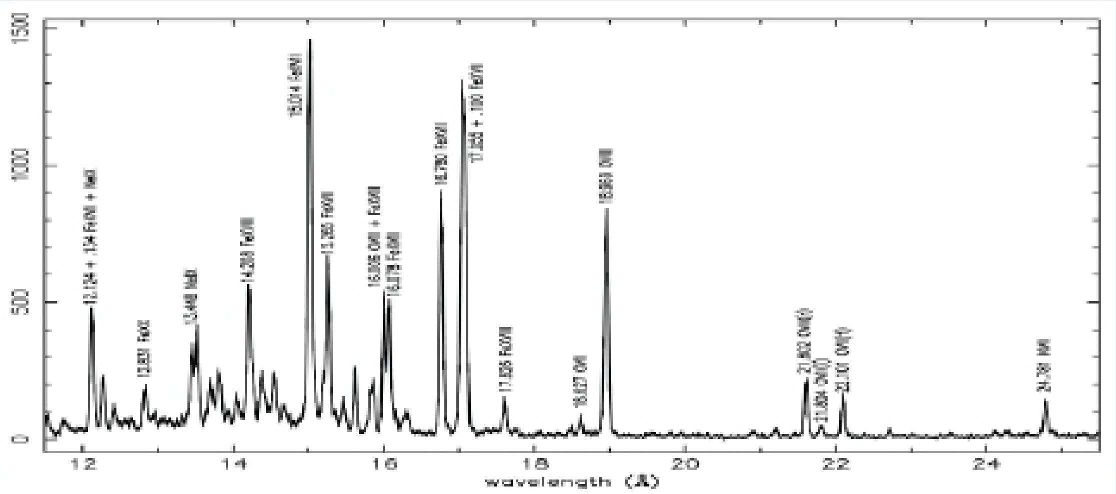


grating ⇒

- 1000 lines/mm (Au)
- 25 μm/2 mm pitch supports

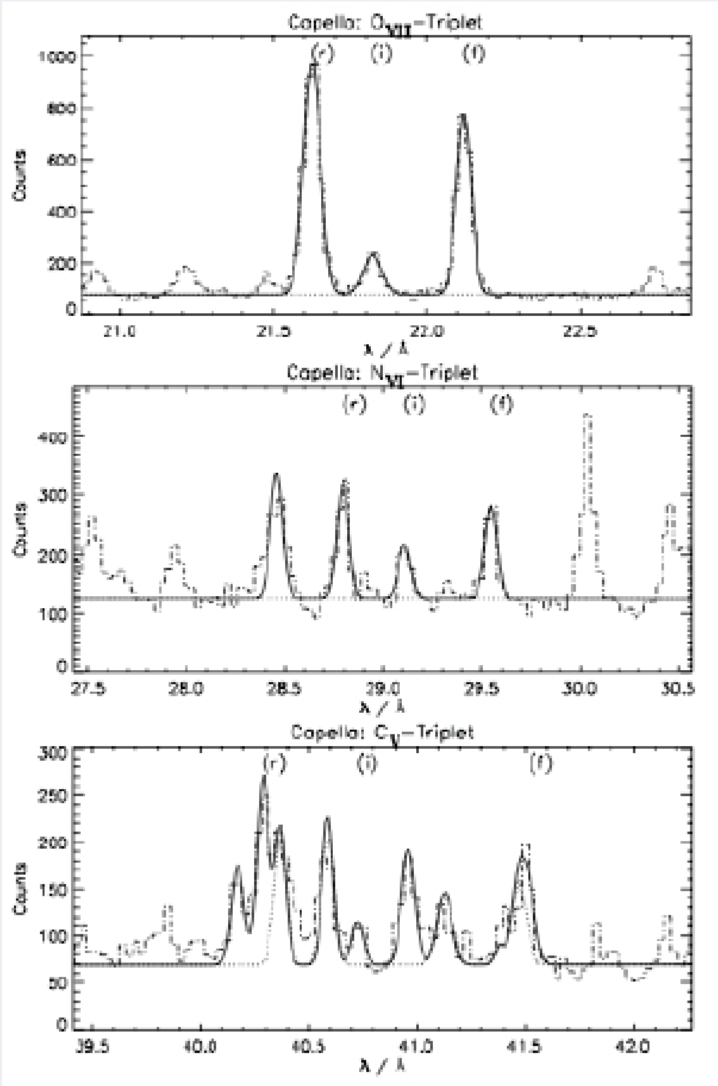
LETG on Chandra: resolving He-triplets in Coronae

Capella Procyon ⇒



Mewe et al. 2001

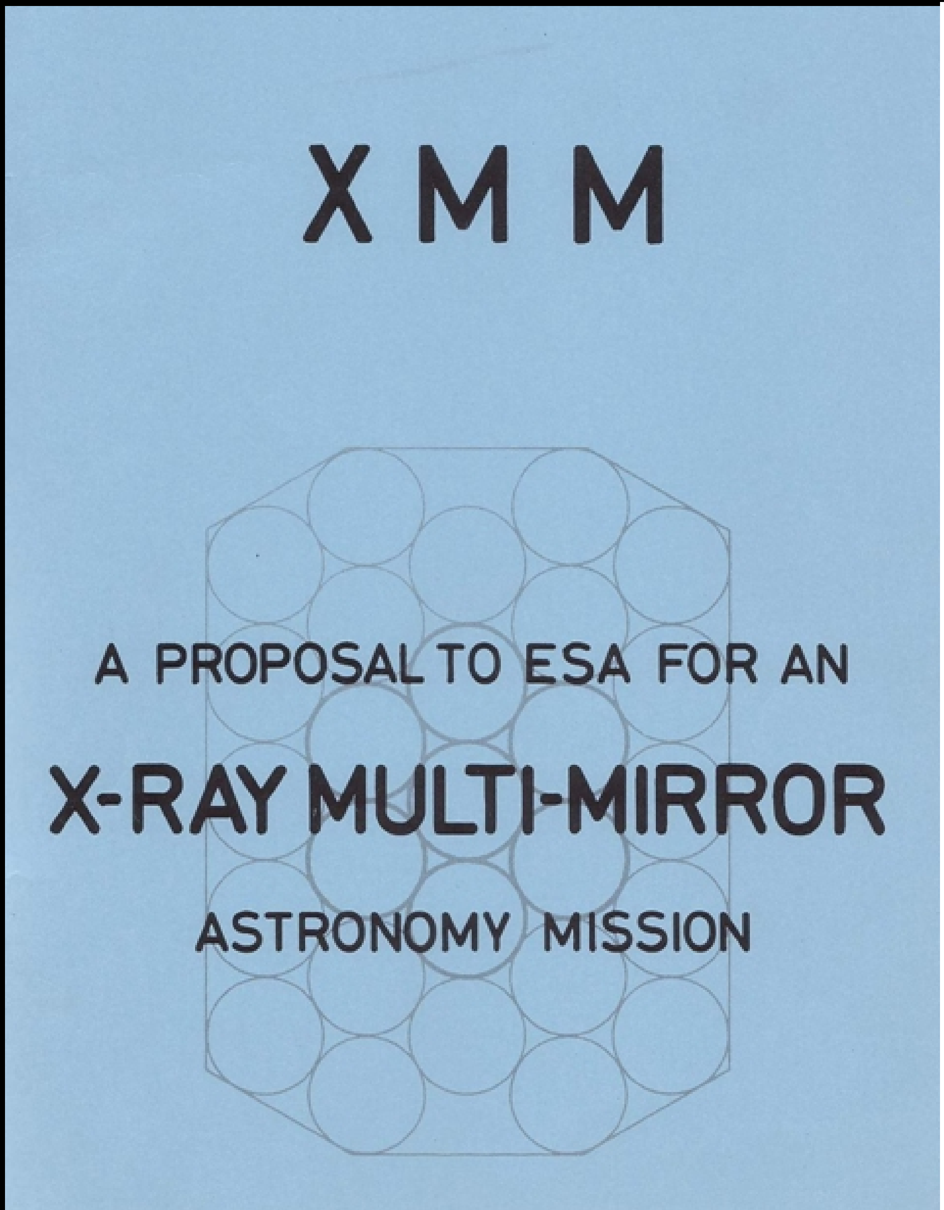
- He-like ion triplets give densities and temperatures
- ⇒ similar to solar



Ness et al. 2001

High throughput cosmic X-ray spectroscopy in Europe

HERITAGE: the successful development of light-weight replica-optics for EXOSAT



XMM

A PROPOSAL TO ESA FOR AN

X-RAY MULTI-MIRROR

ASTRONOMY MISSION

Submitted by

J.A.M. Bleeker, Leiden
A.C. Brinkman, Utrecht
J.L. Culhane, MSSL
L. Koch, Saclay
K.A. Pounds, Leicester
H.W. Schnopper, Lyngby
G. Spada, Bologna
B.G. Taylor, SSD/ESA
J. Trümper, Garching

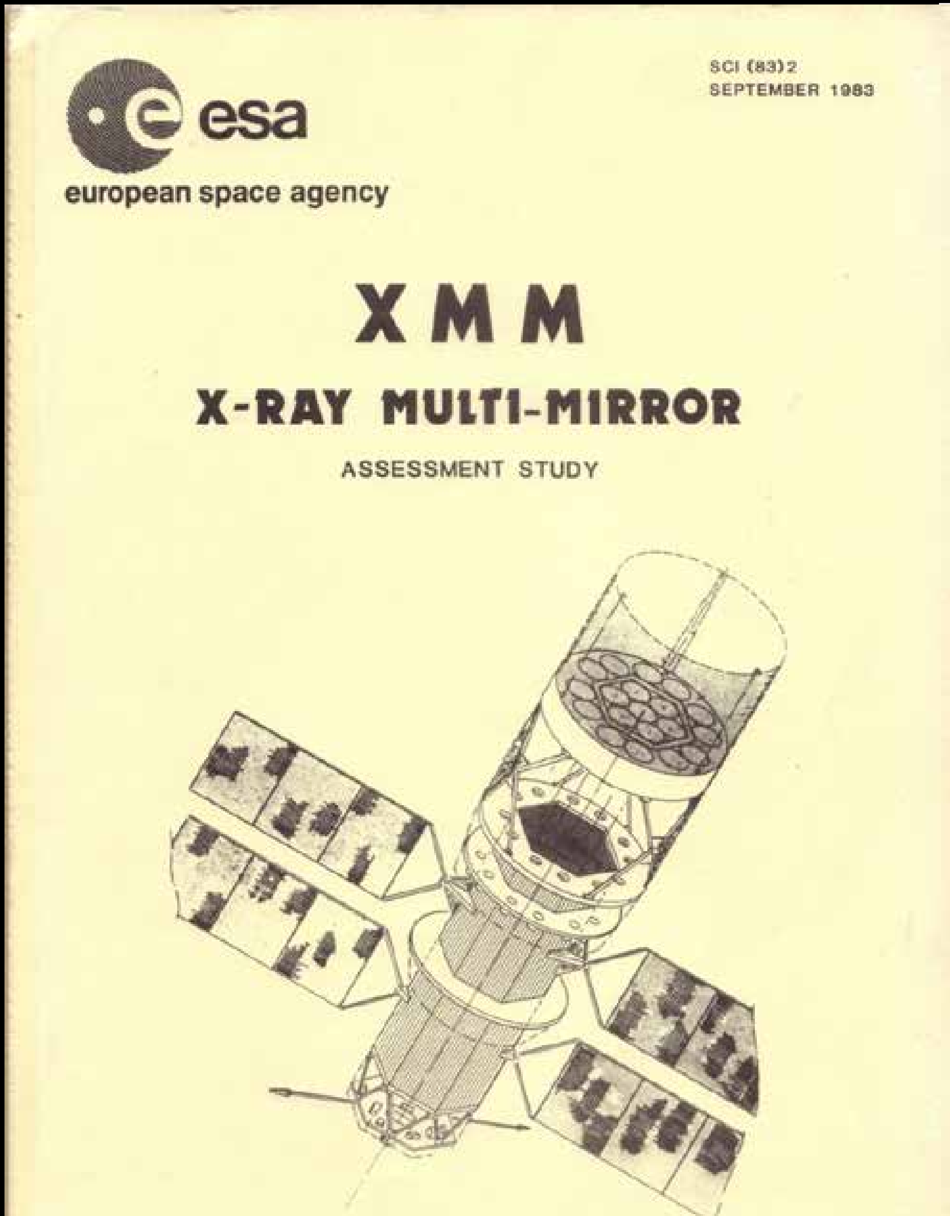
through

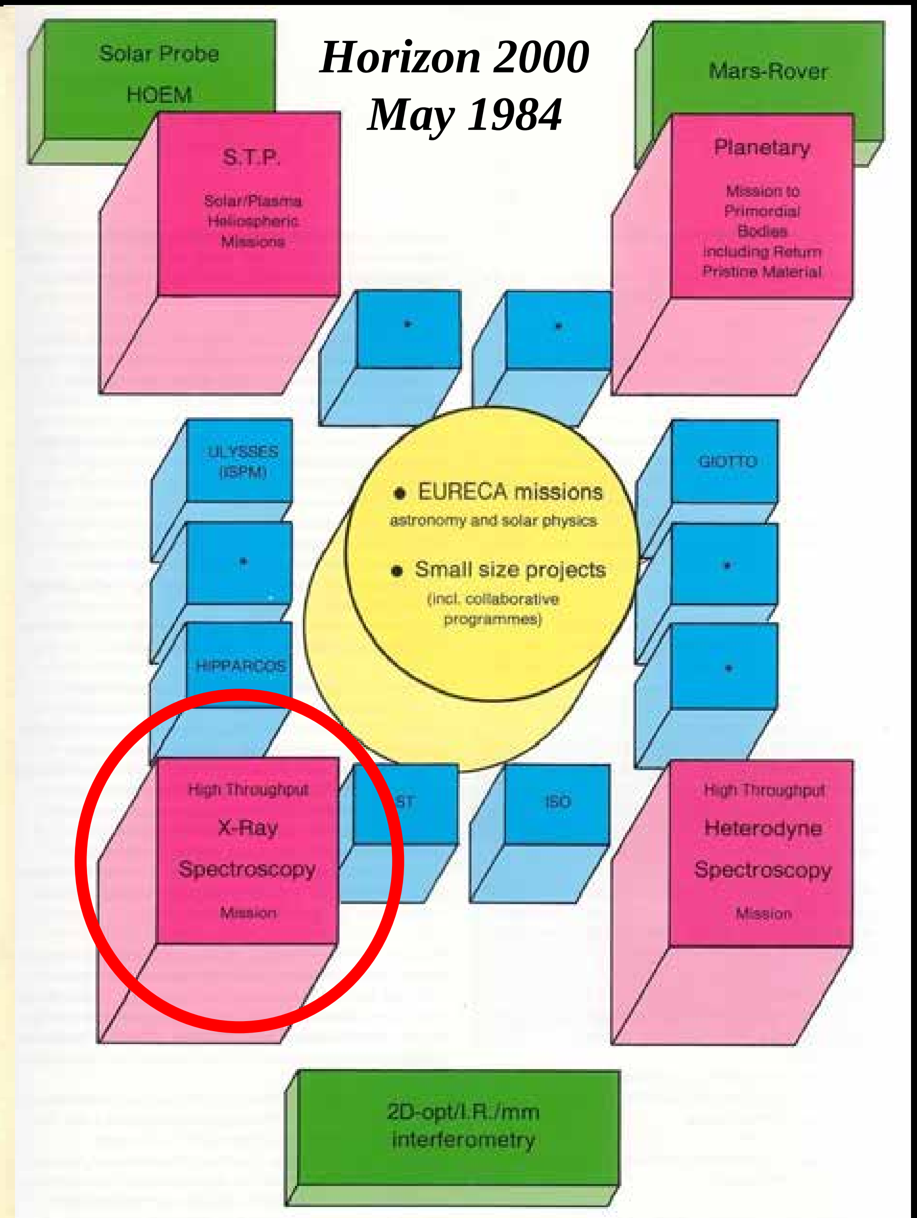
J.L. Culhane
Mullard Space Science Laboratory
Holmbury St. Mary
Dorking, Surrey, England

Telephone: 306-70292
Telex: 859185

November, 1982

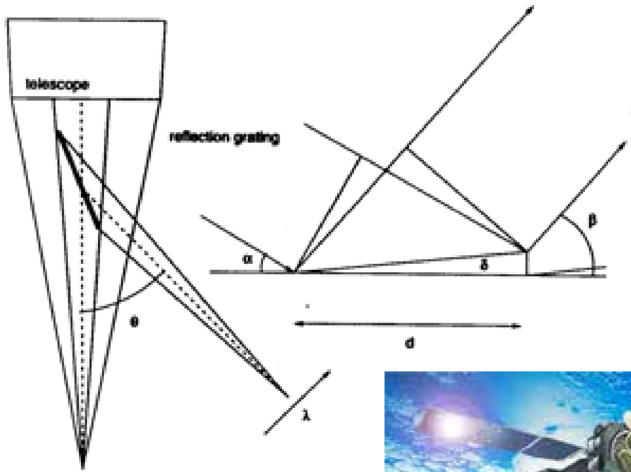
High throughput cosmic X-ray spectroscopy in Europe:
A strategic choice !

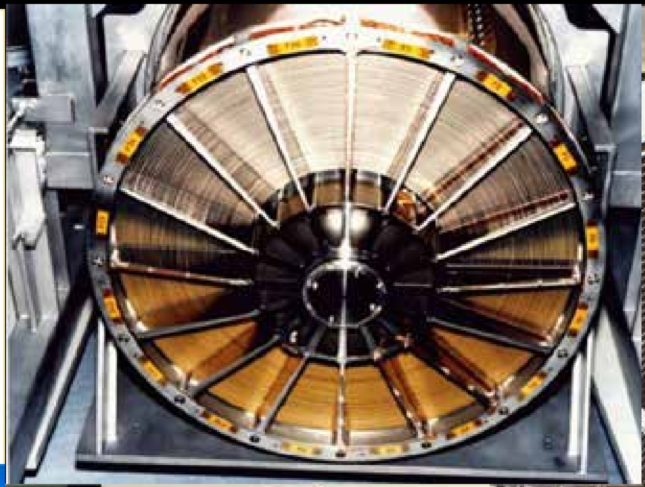


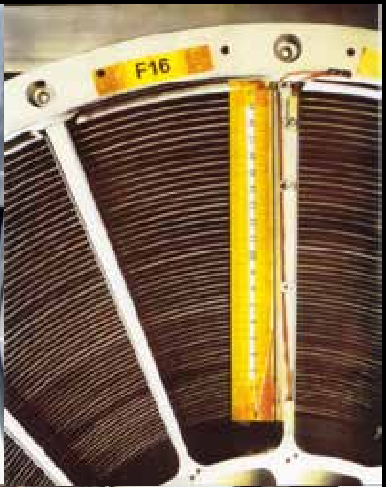


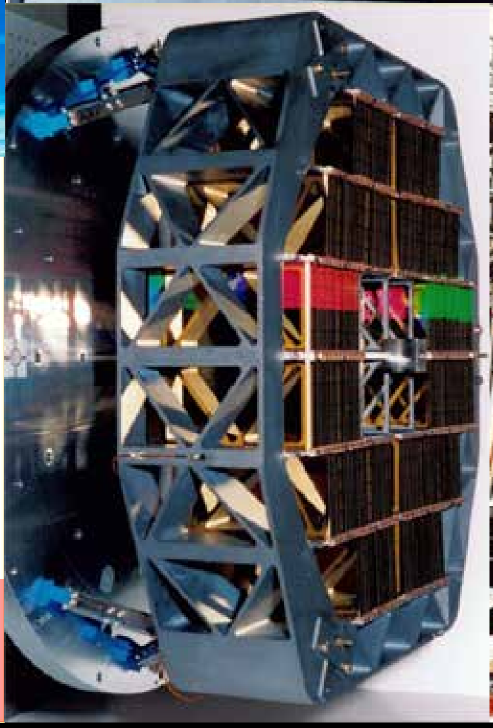
High-dispersion X-ray spectroscopy on XMM: SRON(PI) & UCBerkeley/LawrenceLivermore NL

Reflection grating









"Grazing" incidence

DE: $m\lambda = d(\cos\beta - \cos\alpha)$

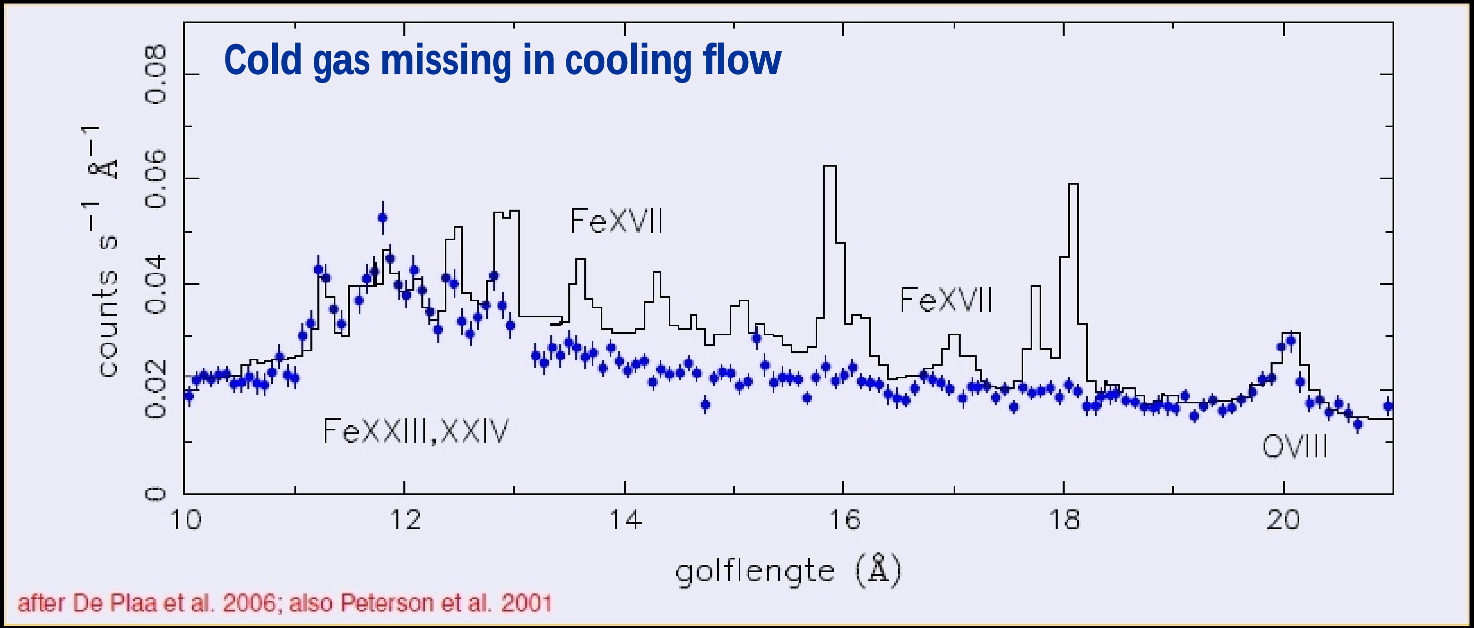
BW: $\Delta\alpha \rightarrow \Delta\lambda = \frac{d}{m}\sin\alpha\Delta\alpha$

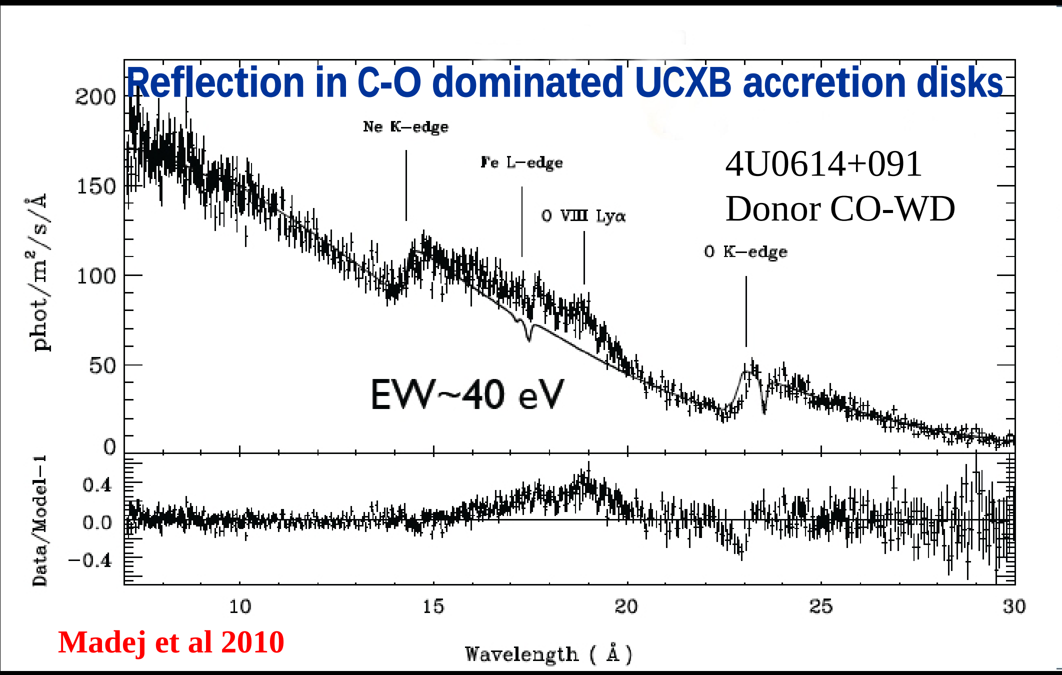
RP: $\lambda/_{\Delta\lambda} = \frac{\cos\alpha - \cos\beta}{\sin\alpha\Delta\alpha}$

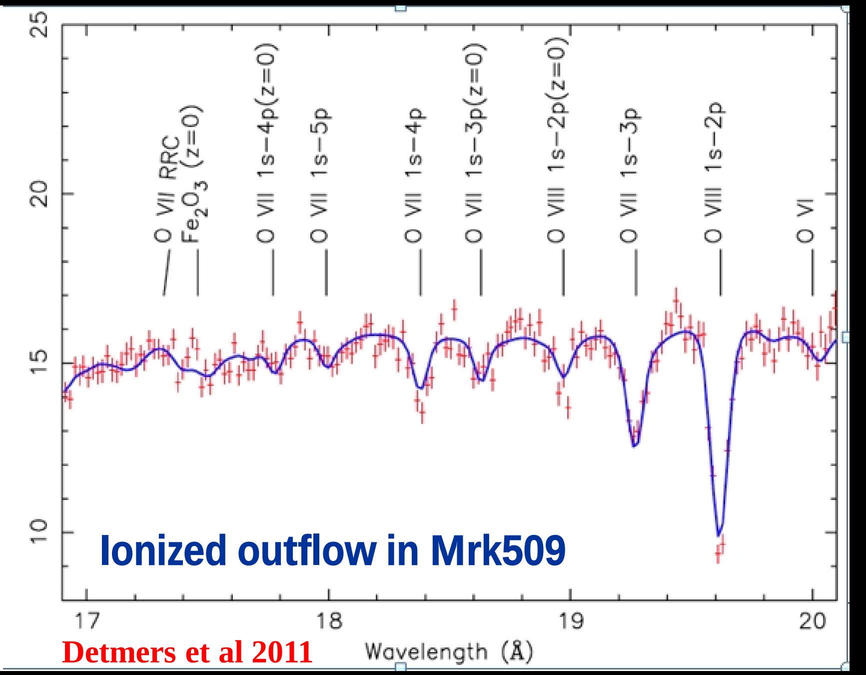
→ effective grating period: $d\sin\alpha$

→ effective line density: $\rho = \frac{\rho_r}{\sin\alpha}$ (ρ_r = ruling density)

XMM: cooling flows, accretion disks, ionized outflows

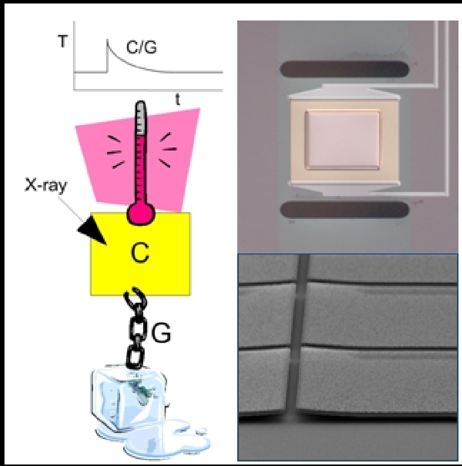


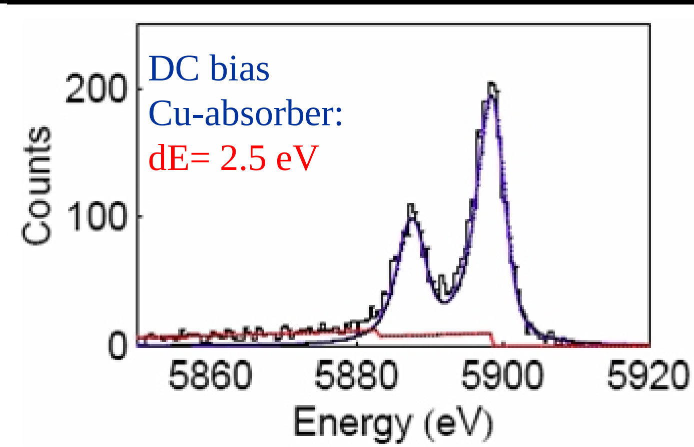


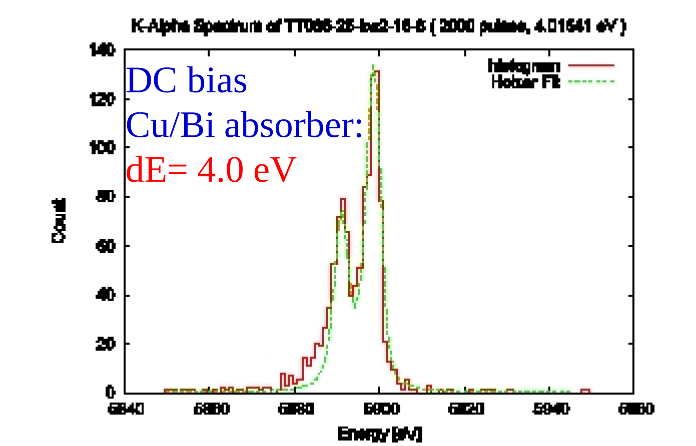


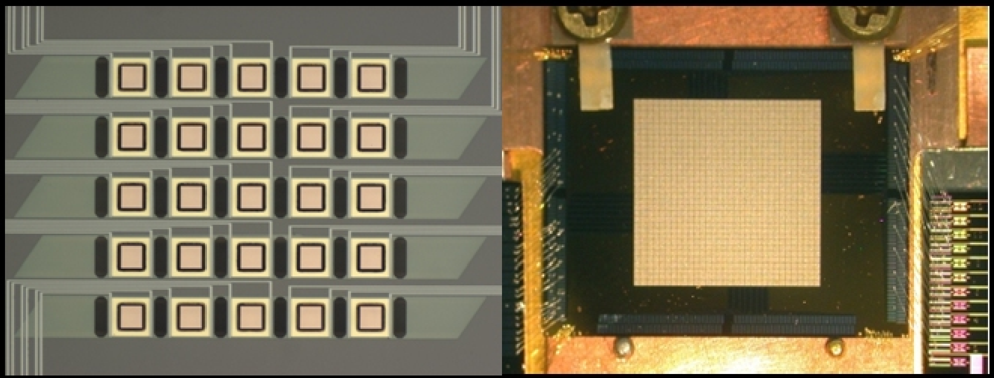
Early 1990's: start development non-dispersive technologies for image–resolved X-ray spectroscopy

- Superconducting tunneling junctions (STJ): abandoned after 5 yrs
- Bolometers with phase-transition thermometers: TES calorimeter



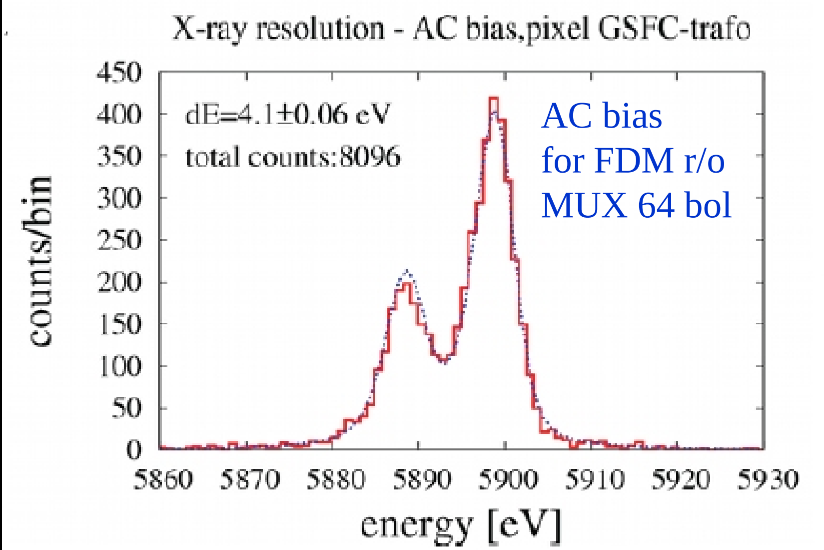






5 x 5 TES-matrix (2007)

32 x 32 TES-matrix 93% fill (2009)



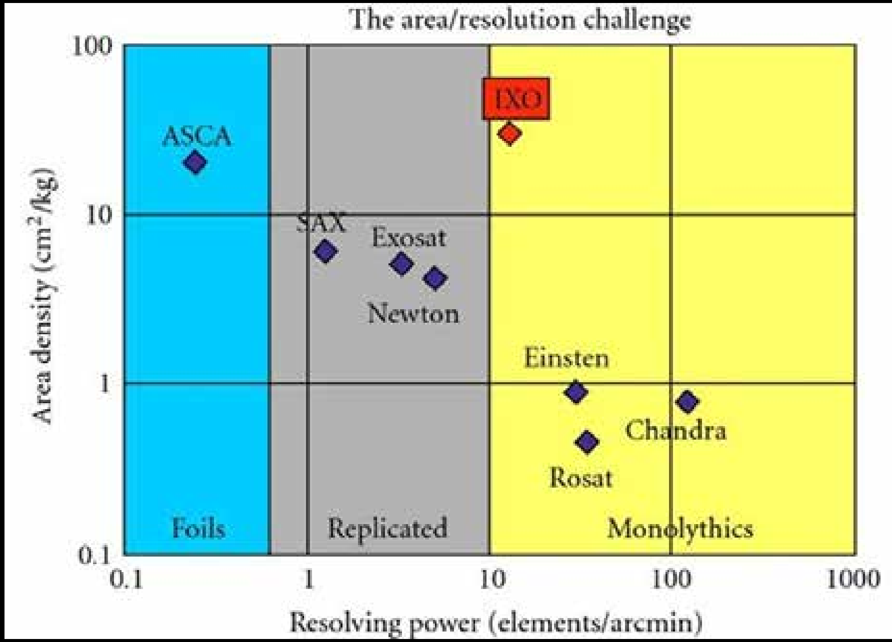
The Next Generation of X-ray Observatories

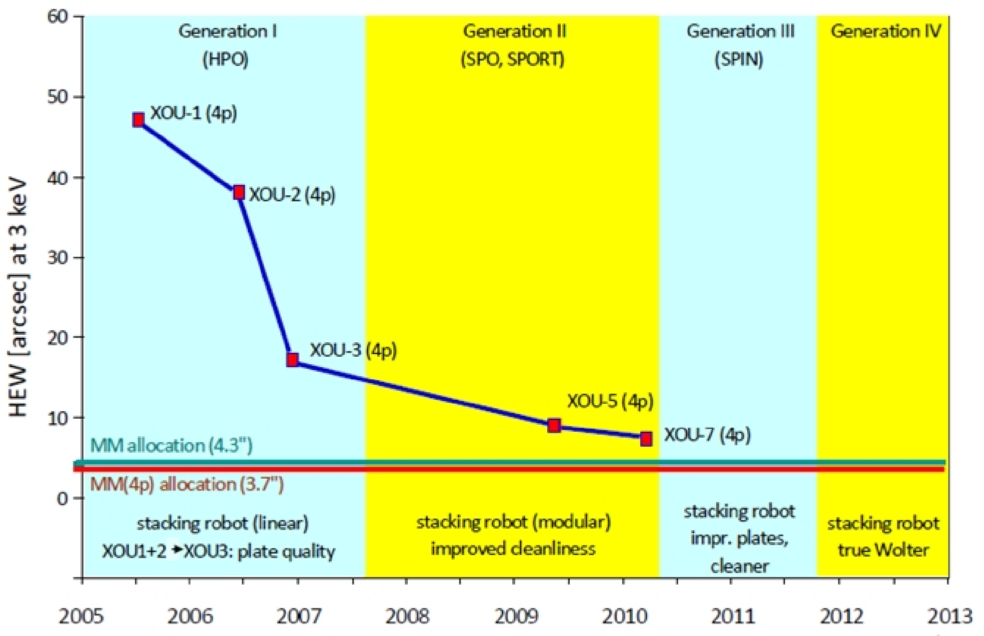
Proceedings of a workshop held at
Beaumont Hall, University of Leicester
July 10-12 1996

Edited by
M J L Turner & M G Watson

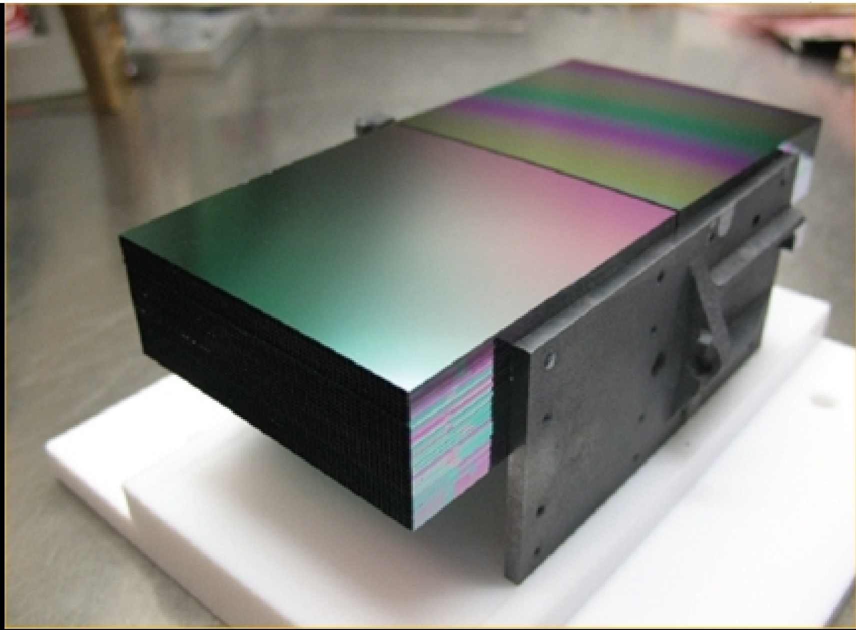
Leicester X-ray Astronomy Group
Special Report XRA97/02

Optics for the next generation X-ray Observatory





- Large area optics: > 5m² @ 1keV, >1m² @ 6keV
  Angular resolution <5 (2) arcsec
- Science driver: detection of SMBHs at z > 8, enrichment history of the Universe
- No conventional technology: excessive mass
- New technologies: Si-pore optics, slumped glass
- Si-pore most mature, baseline IXO → ATHENA



Lessons learned ⇨ outlook (1)

- R&D on enabling technologies (X-ray optics, dispersers, sensors) key success factor
- Long lead times: tension between R&D and implementation (TRL)
- Mission level coordination (cooperation) has so far been regional (NASA, ESA, national)
- Over the past decades, X-ray astronomy has evolved into an establishes branch of main-stream astronomy
- During the first 50 years, cutting edge X-ray space observatories were relatively abundant, however those days are over!

Lessons learned ⇨ outlook (2)

Challenges

- Innovative instrumental technology, both in terms of magnitude (throughput, bandwidth) and complexity
- Increased competition from other (" new") branches in space astronomy (we are now part of the usual suspects)
- Lack of *successful* strategic planning and coordination on the global level, both among scientists in the astronomical discipline and between space agencies (e.g. the saga of Constellation –X, XEUS, IXO and Athena over the past 10-15 yrs)
- Shrinking budgets due to the economic recession in most space faring countries.