X-ray data analysis

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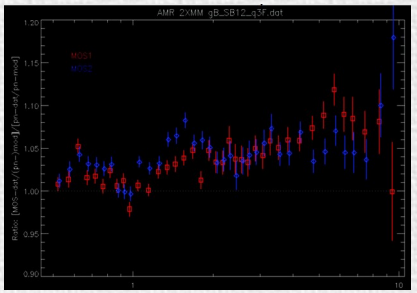
Goal of these lectures

X-ray data analysis

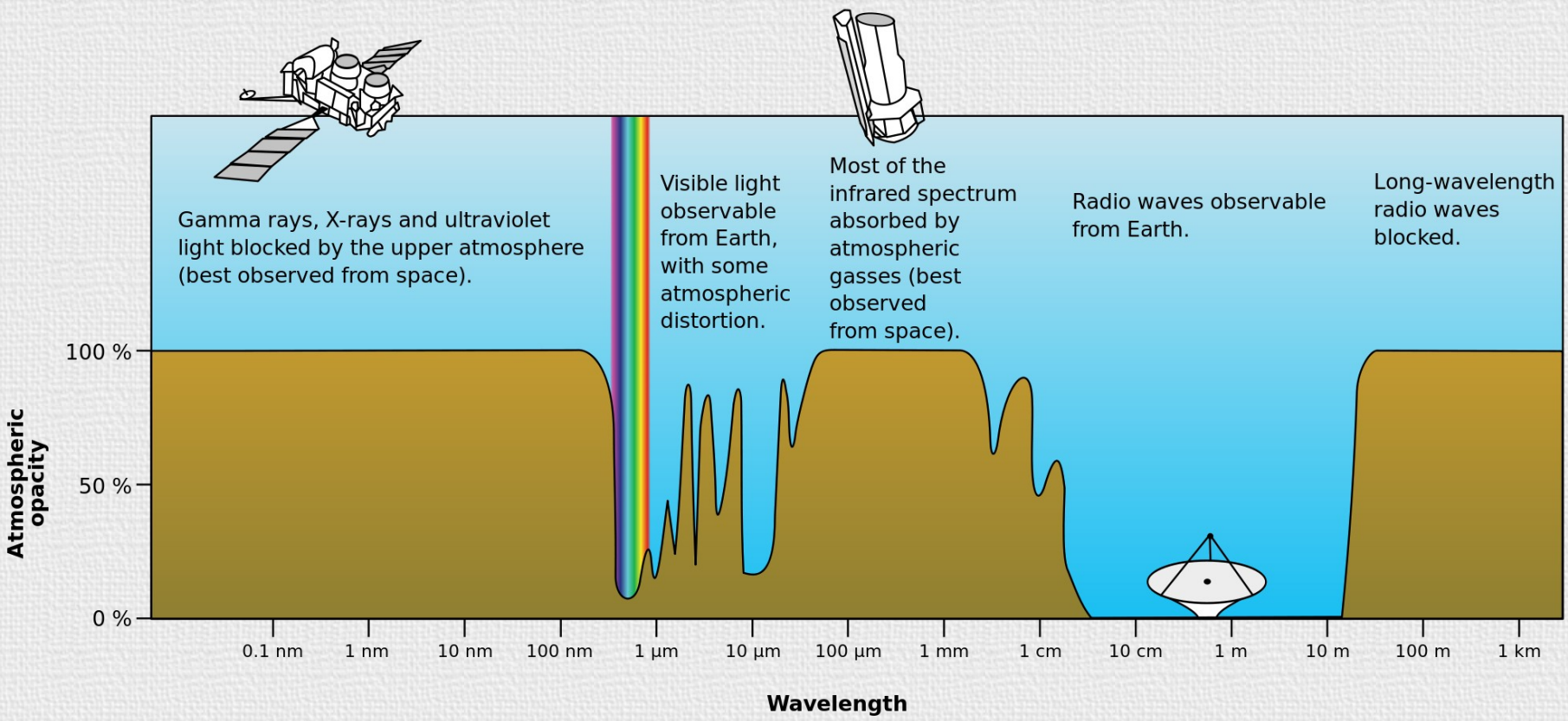
why?

what?

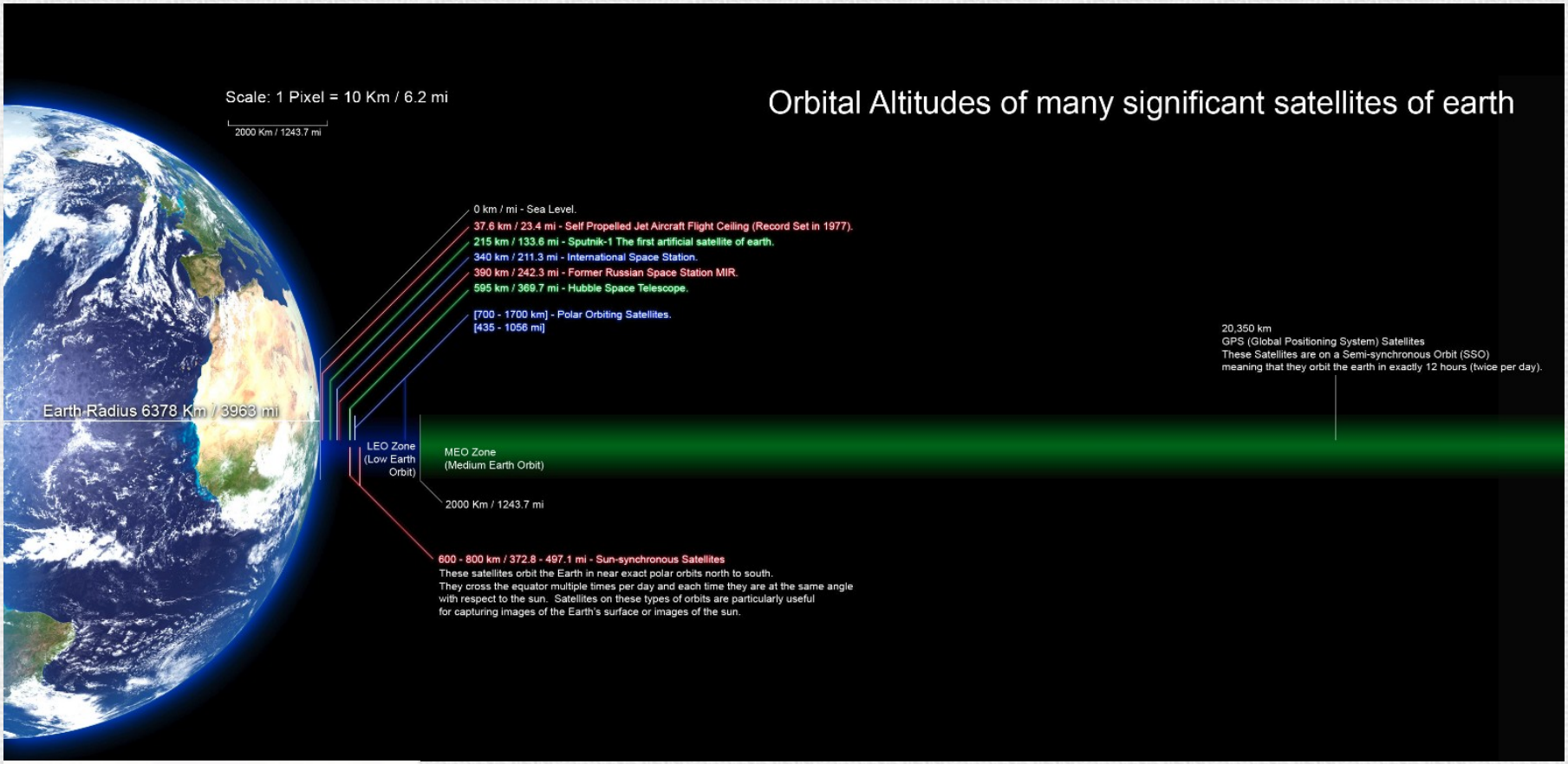
how?

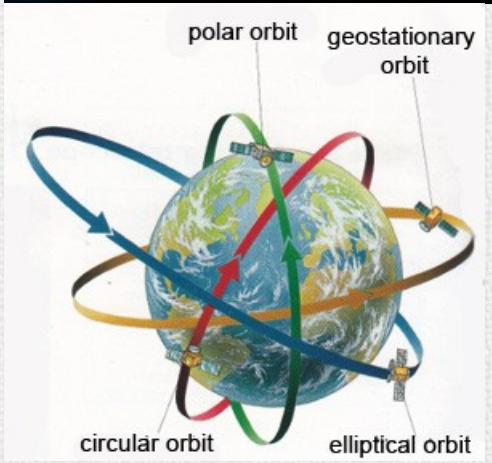


What? Catching the X-rays



What? How to observe X-rays





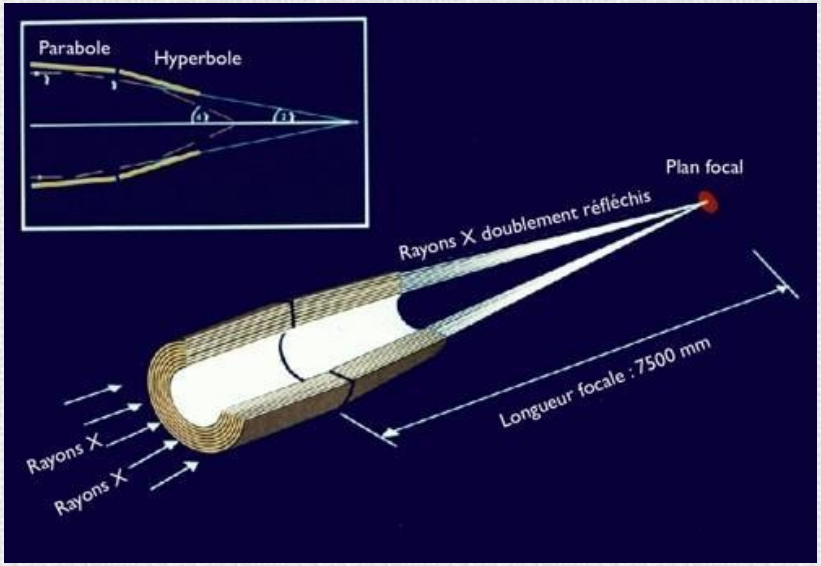
XMM-Newton (1999): Apogee 114000 km, Perigee 7000 km
Chandra (1999): Apogee 134000 km, Perigee 16000 km
NuSTAR (2012): Apogee 624 km, Perigee 607 km

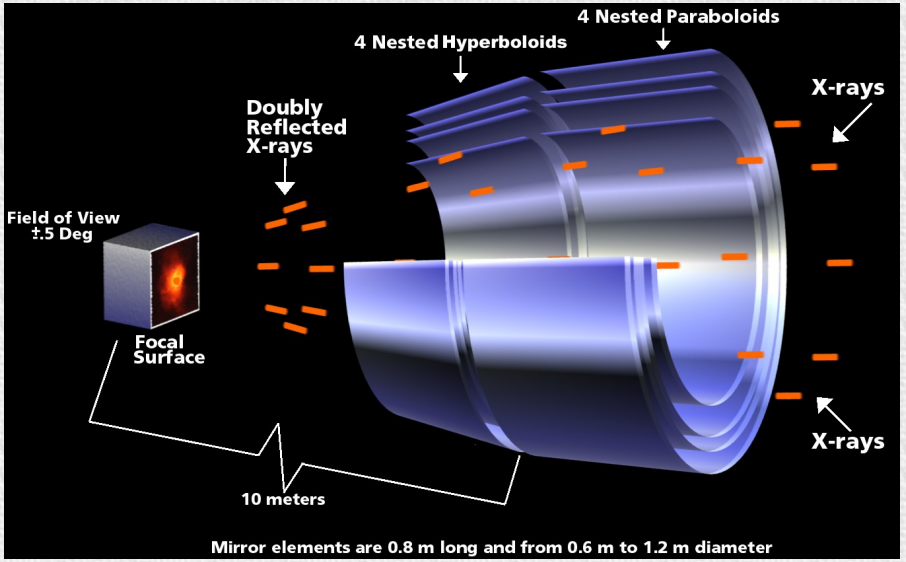
Wolter optics

A Wolter telescope is based on the principle of the grazing incidence.

It is well known, from geometrical optics, that an incident beam of light rays converge in a point (focus) due to its reflection on a paraboloid, whose axis is parallel to the beam.

Better preformances of these particular mirrors come from a second reflecting surface (hyperboloid).



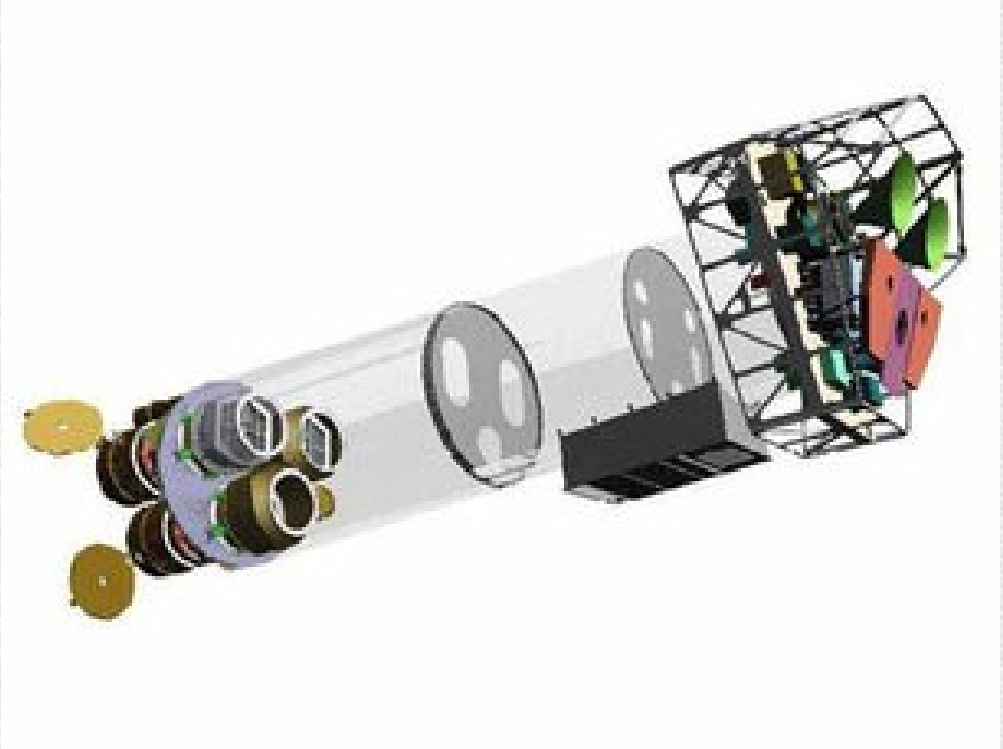


CCD and RGS Detectors

Charge-Coupled Devices

Reflection Grating Spectrometers

Both of them are on board on XMM-Newton:



Charge-coupled devices

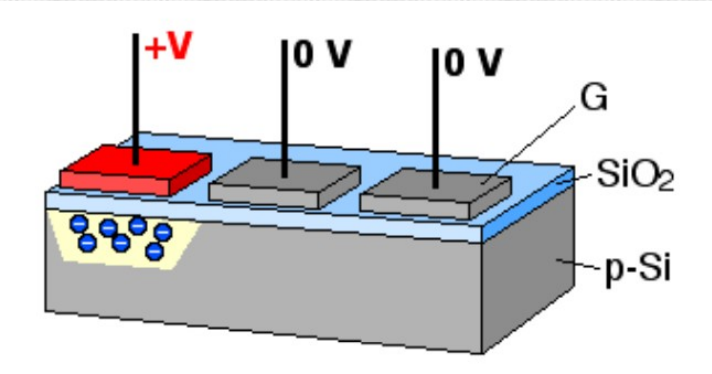
Photon-sensitive electronic devices that placed in the focal plane permit to have digital images of the sky.

They work in a linear regime and have a high sensitivity.

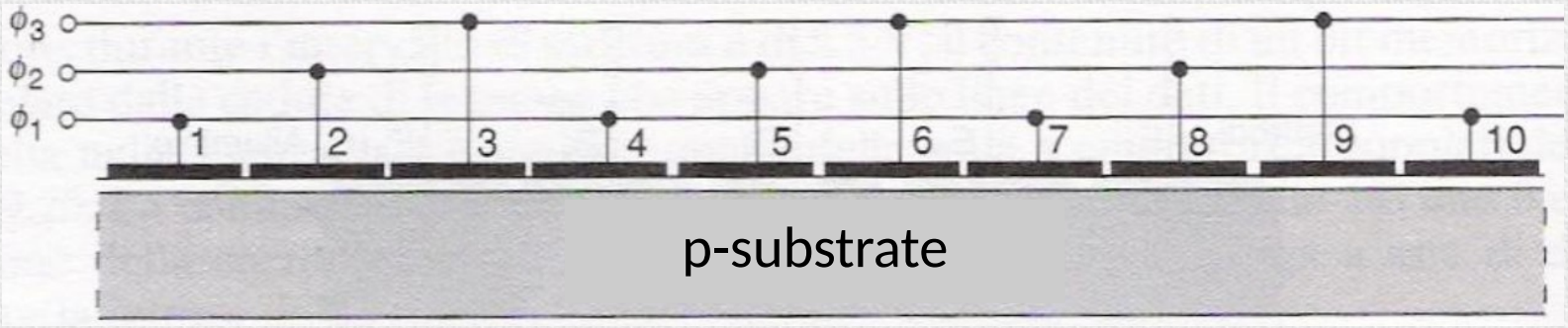
They are composed by a matrix of sensitive elements (pixel) which reacts using the photoelectric effect. Every X-ray photon produces, in the arrival pixel, a photoelectron.

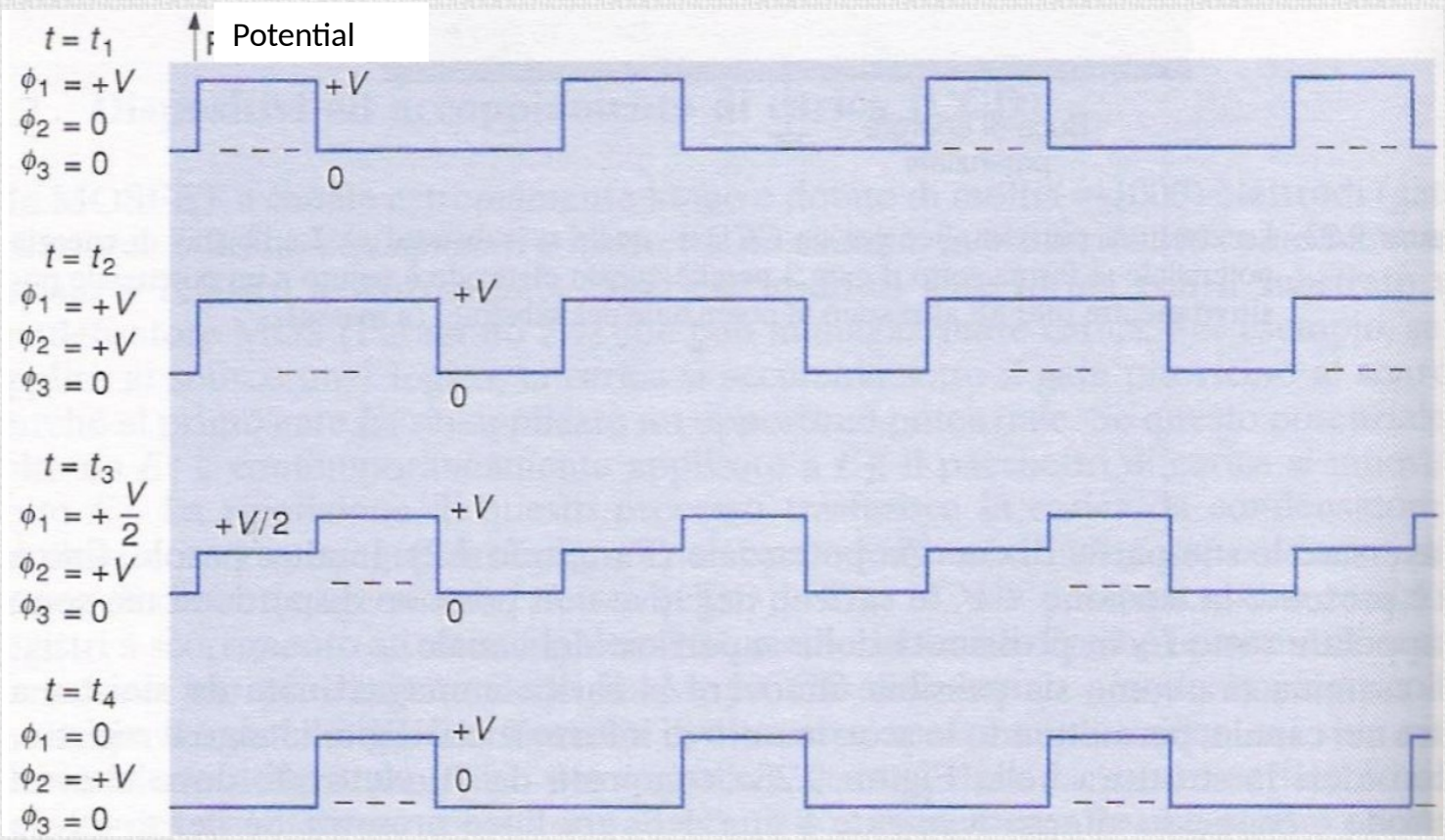
A CCD is composed of:

- A MOS/pn capacity to generate photoelectrons, store these charges and trasmit them to the reading circuit
- A read-out circuit to transport the stored charges
- An electronic control to synchronize pixels' read-out

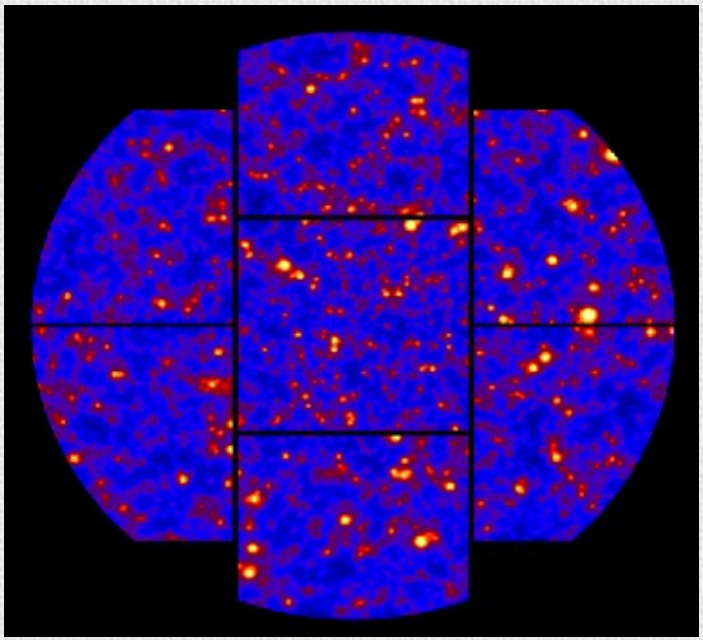


Charged-coupled devices (read-out)

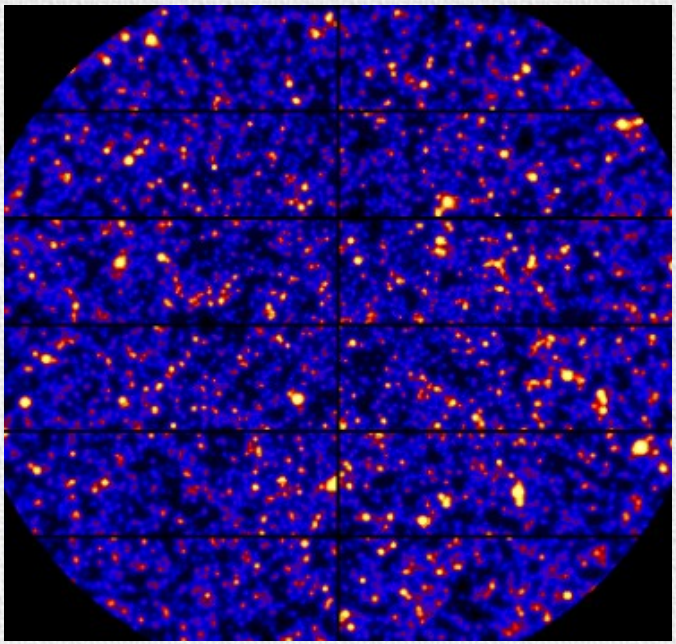




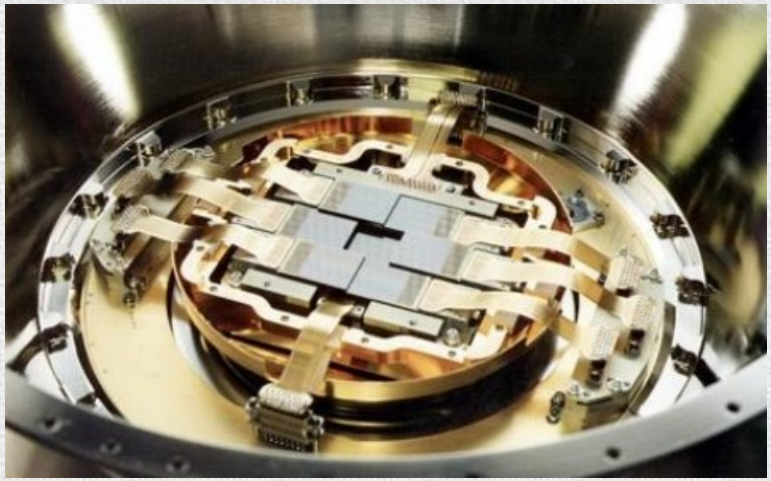
EPIC (European Photo Imaging Camera) pn and MOS



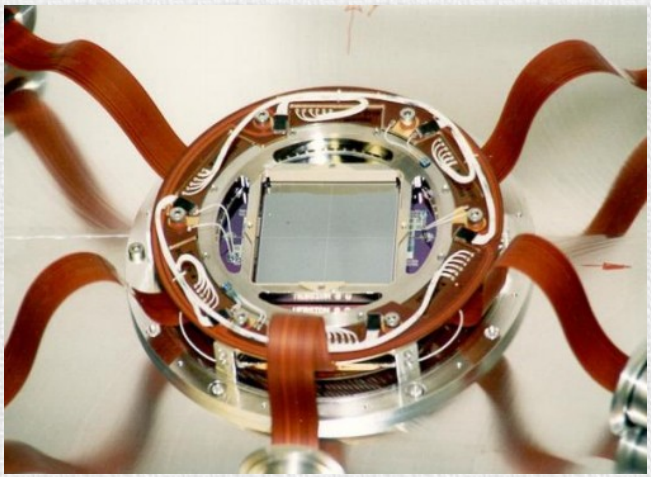
7 CCD MOS front-illuminated



12 CCD pn back-illuminated



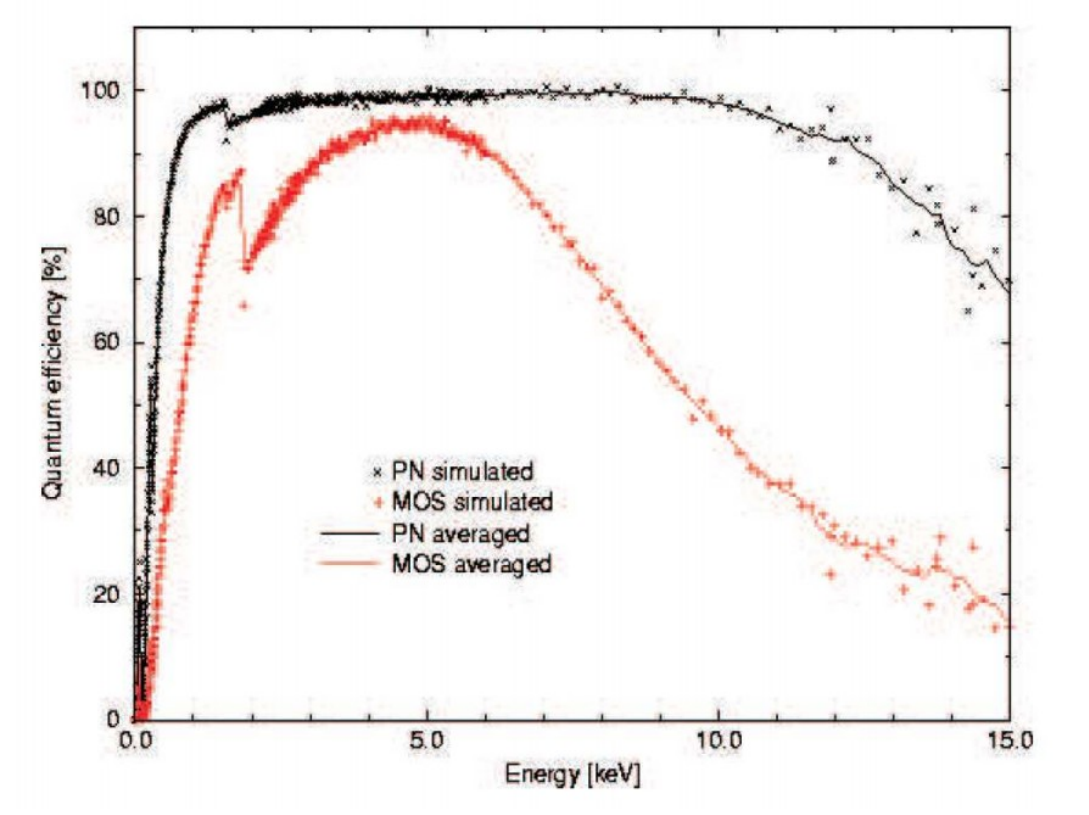
Buffered read-out (~2 s),
35 μm deep substrate



Single CCD read-out (~80 ms),
~300 μm deep substrate

EPIC (European Photo Imaging Camera) pn and MOS

All these differences converge to a different quantum efficiency:

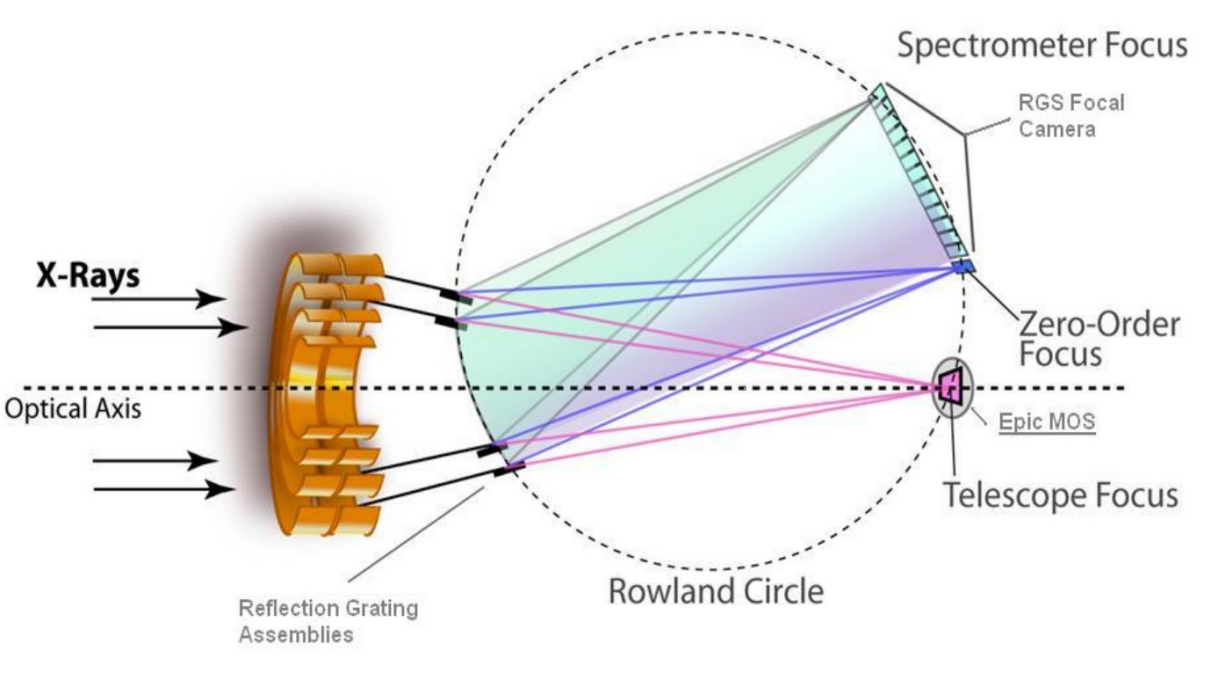


Reglection Grating Spectrometers (RGS)

The instrument consists of the following units:

- Reflection Grating Assemblies (RGAs)
- RGS Focal Cameras (RFCs)

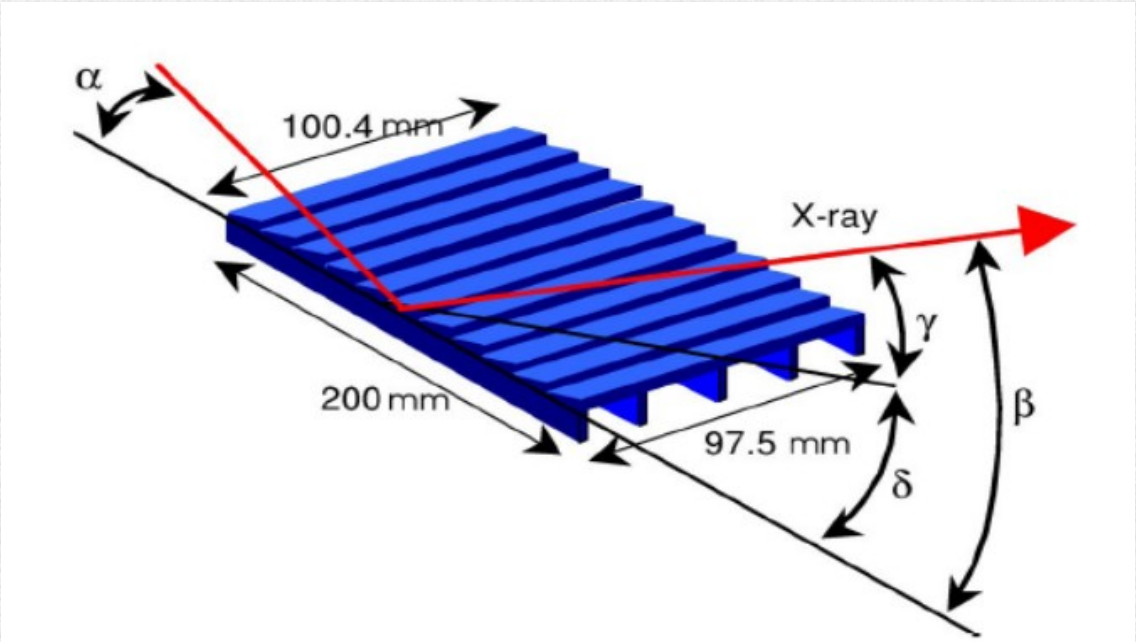
The grating stack consists of 182 identical gratings, mounted at grazing incidence to the beam in the classical configuration. The gratings are located in a toroidal surface, formed by rotating the Rowland circle about an axis passing through the telescope focus and the first order blaze focus.



Reglection Grating Spectrometers (RGS)

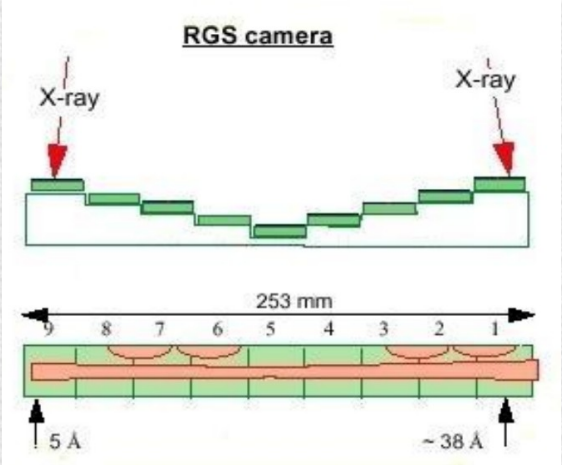
Every reflecting grating intercepts almost the 58% of the incident light and they are ~ 654 per mm. The dispersion equation for the spectrometer is given by:

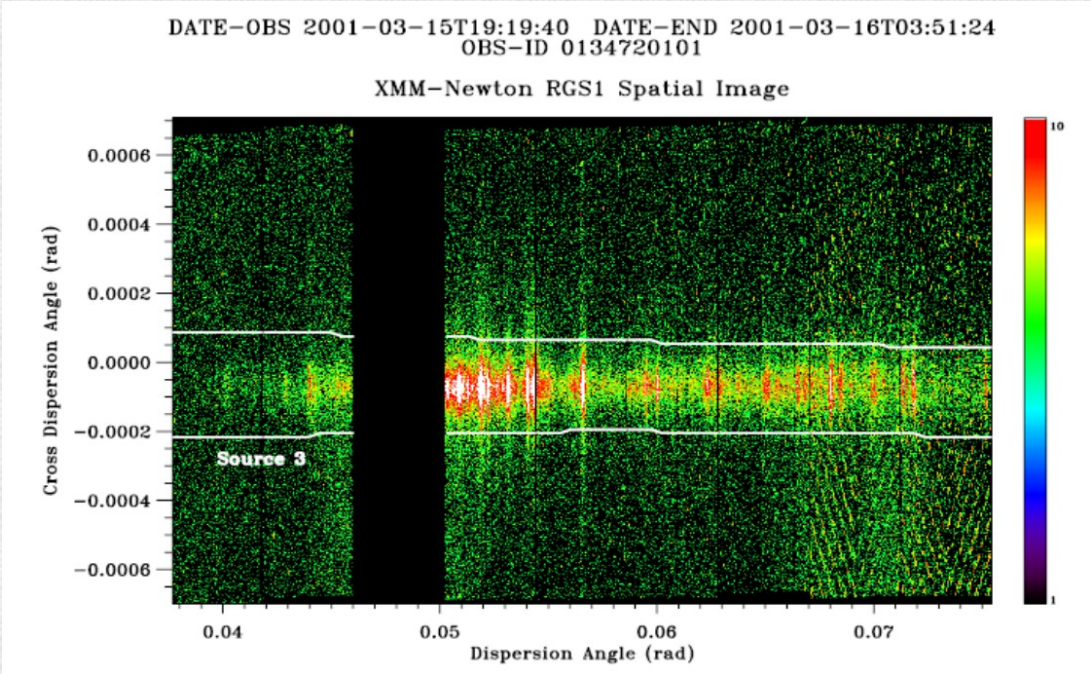
$$\cos\beta = \cos\alpha + m\lambda/d$$



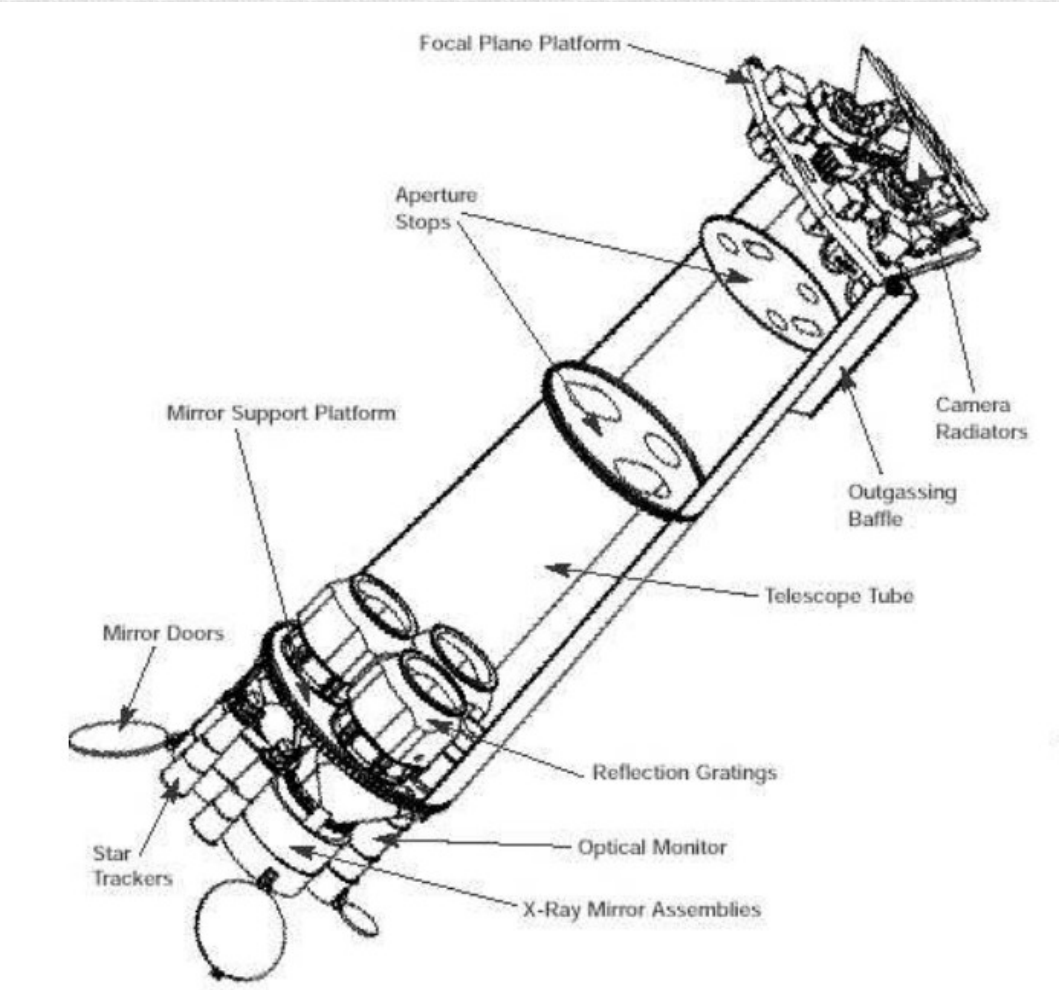
Reglection Grating Spectrometers (RGS)

Different wavelenghts will result in different angles (β).





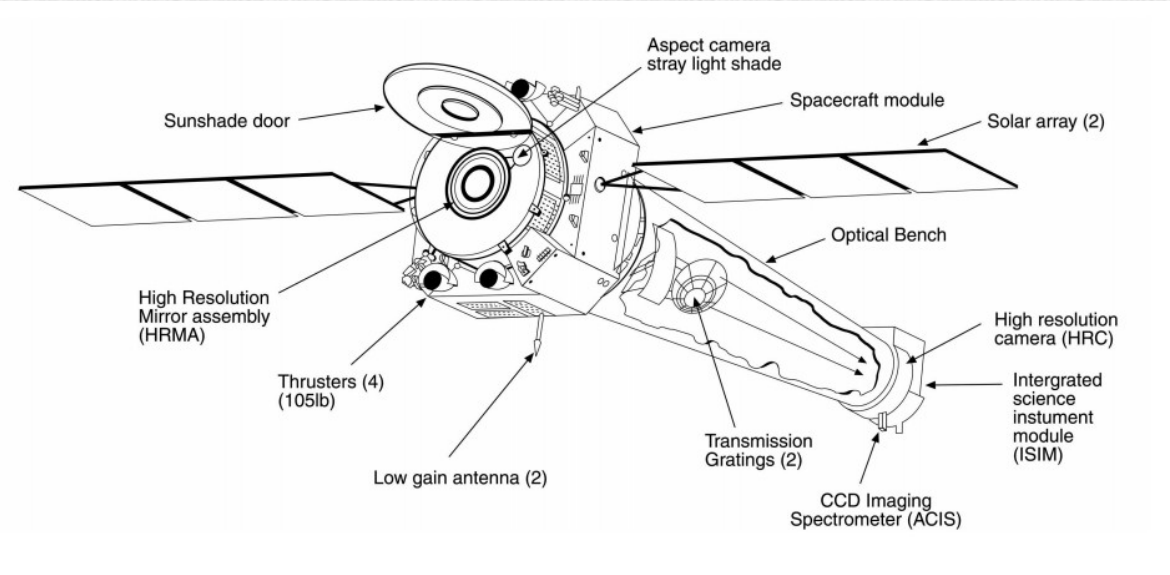
The XMM-Newton Observatory



Instrument	Main Purpose	Energy Range/ Bandwidth	Spectral Resolution (E /ΔE)	Spatial Resolution (arcsec)	Sensitivity	Total Mass/Power
EPIC	High-throughput non-dispersive imaging/ spectroscopy	0.1 - 15 keV 1 - 120 Å	5 - 60	14 (Half Energy Width)	10^{-14} erg/cm^2 sec	235 kg 240 W
OM	Optical/UV imaging	160 - 600 nm	50 -100 (with grisms)	1	< 24 magnitude	82 kg 60 W
RGS	High-resolution dispersive spectroscopy	0.35 - 2.5 keV 5 - 35 Å	200 - 800 (400/800 at 15 Å in 1st/2nd order)	N.A.	3 x 10^{-13} erg / cm^2 s	248 kg 140 W

The Chandra Observatory

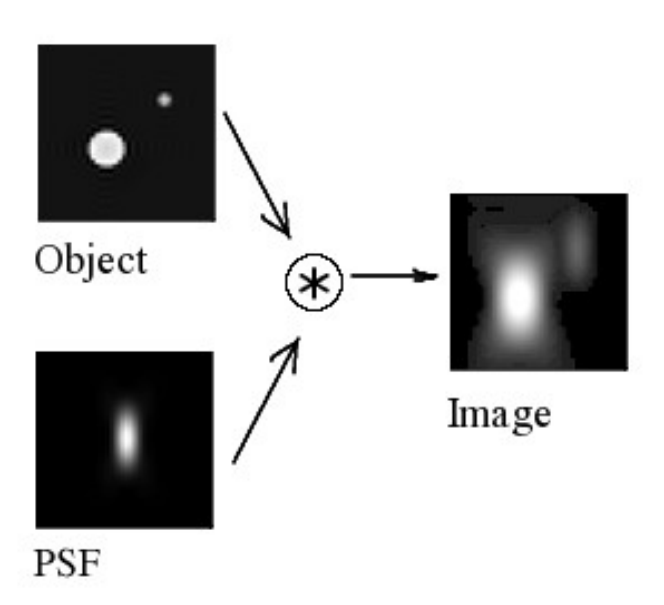
The mirror consists of four pairs of nested reflecting surfaces, arranged in the usual Wolter type 1 geometry but with an unprecedented resolution of 0.5 arcseconds.

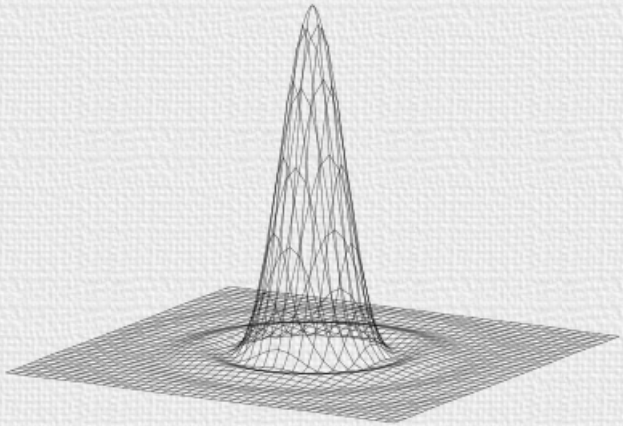


HETGS range	0.4 - 10.0 keV (31 - 1.2)
High Energy Grating (HEG) range	0.8 - 10.0 keV (15 - 1.2)
Medium Energy Grating (MEG) range	0.4 - 5.0 keV (31 - 2.5)
Effective area (MEG+HEG first orders, with ACIS-S)	
@ 0.5 keV	7 cm^2
@ 1.0 keV	59 cm^2
@ 1.5 keV	200 cm^2
@ 6.5 keV	28 cm^2
Resolving power ($\frac{E}{\Delta E}$)	
HEG	65 - 1070 (1000 @ 1 keV, 12.4)
MEG	80 - 970 (660 @ 0.826 keV, 15)
Resolution	
$\Delta\lambda$, HEG	0.012 FWHM
$\Delta\lambda$, MEG	0.023 FWHM
Absolute wavelength accuracy	
HEG	±0.006
MEG	±0.011
Wavelength scale	
HEG	0.0055595 / ACIS pixel
MEG	0.0111185 / ACIS pixel

The (Chandra) Point Spread Function

The point spread function (PSF) describes the response of an imaging system to a point source or point object.

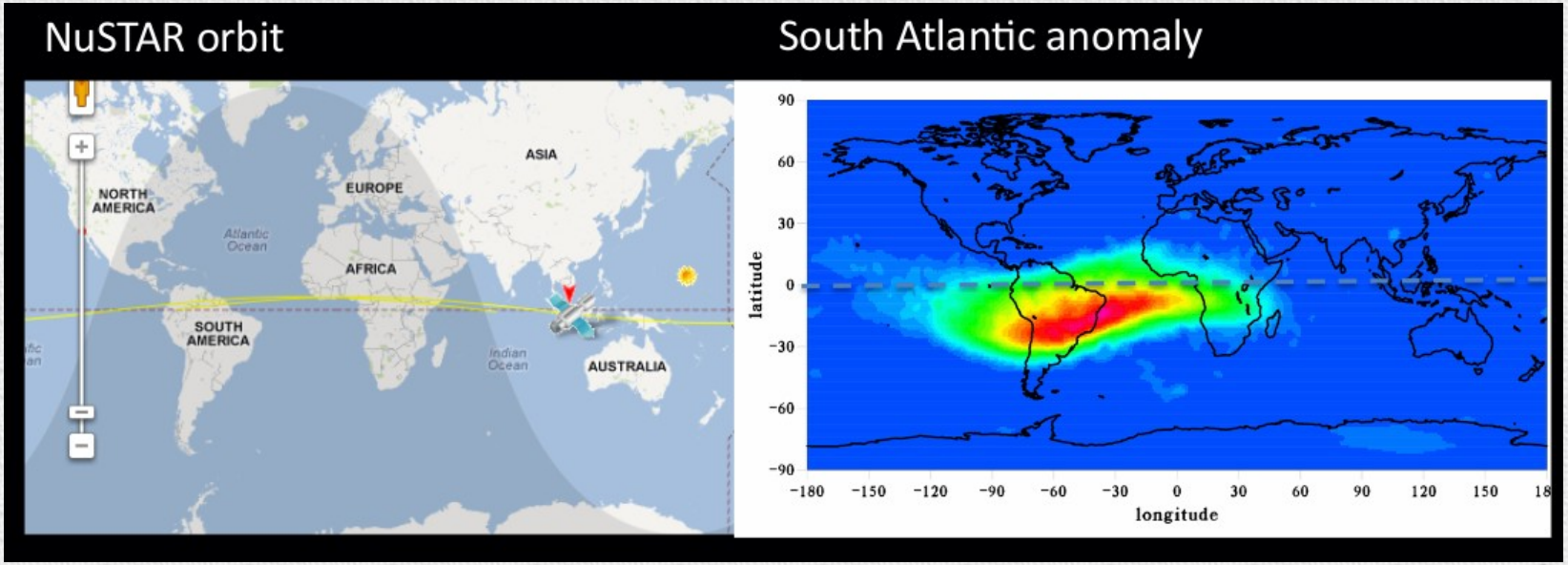


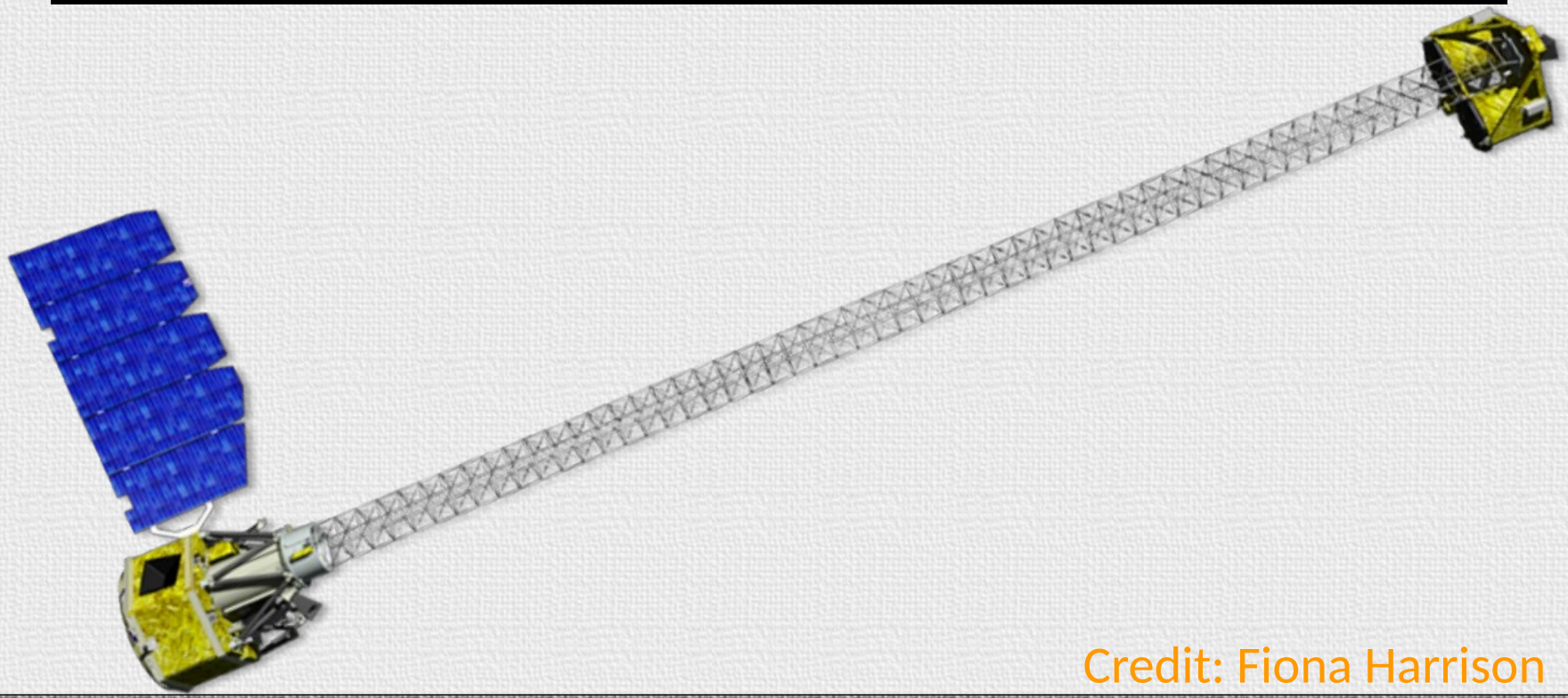


Airy function

Chandra has the best angular resolution (0.5 arcsec) ever achieved in X-ray astronomy.

The NuSTAR Observatory





Credit: Fiona Harrison

The NuSTAR Observatory

Imaging

HPD	58”
FWHM	18”
Localization	2” (1-sigma)

Spectral response

energy range	3-79 keV
threshold	2.0 keV
ΔE @ 6 keV	0.4 keV FWHM
ΔE @ 60 keV	1.0 keV FWHM

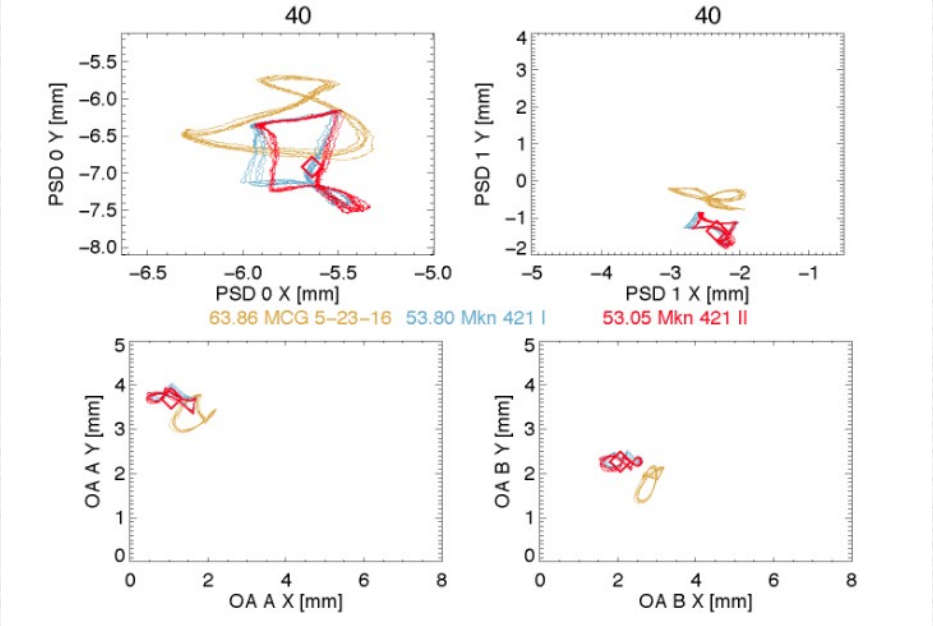
Field of View

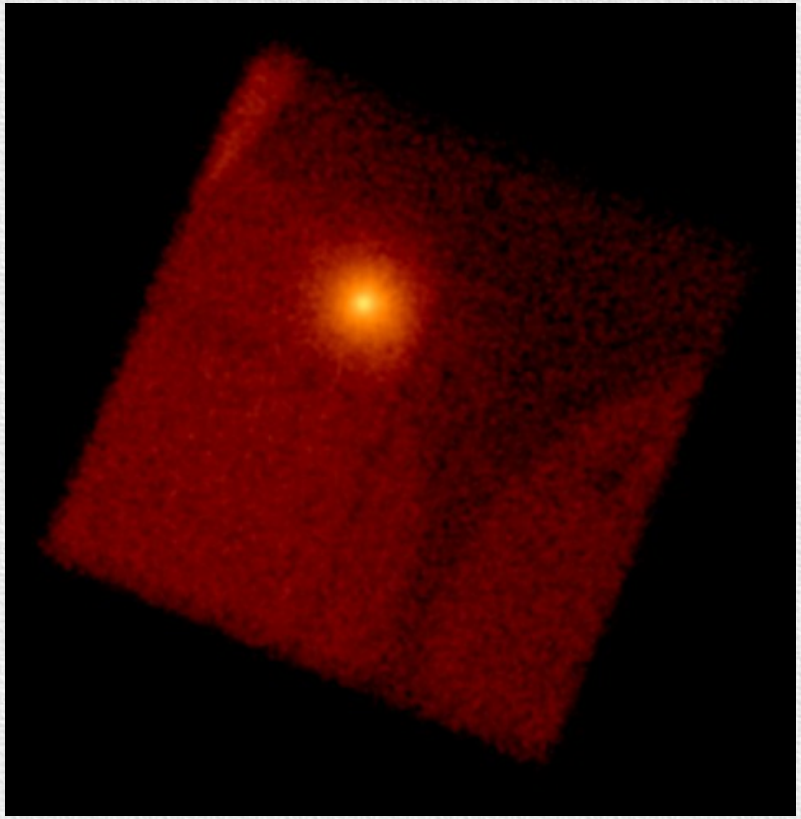
FWZI	12.5’ x 12.5’
FWHI	10’ @ 10 keV
	8’ @ 40 keV
	6’ @ 68 keV

Target of Opportunity

response	<24 hr (reqmt)
typical	6-8 hours
80% sky accessibility	

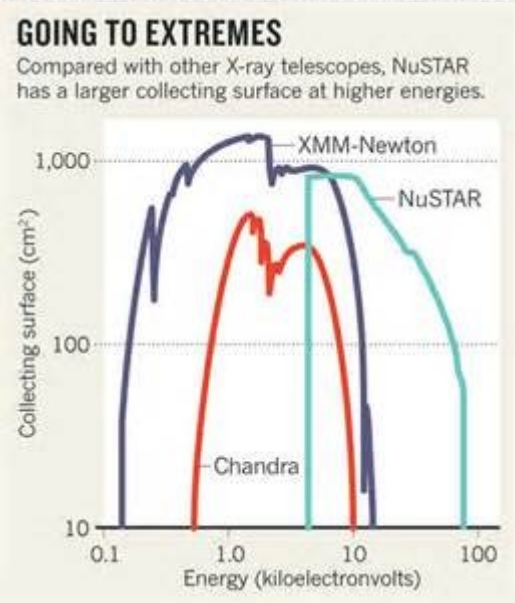
The NuSTAR Observatory

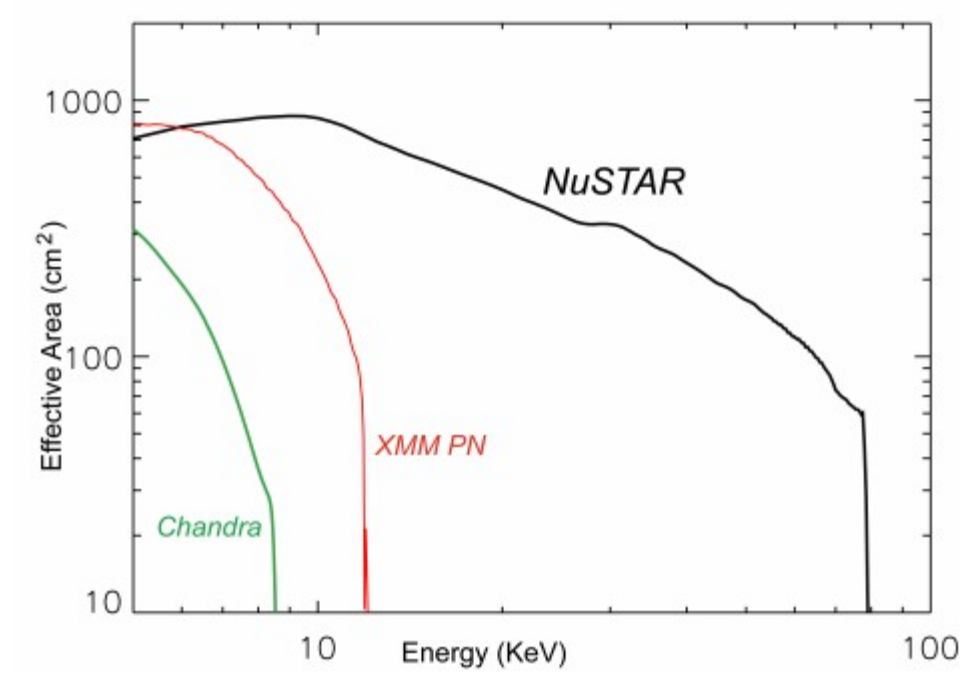




No PILE-UP!

Collecting areas





Where are the data?

High energy Astrophysics Science Archive Research Center
(CALDB, CCF, Missions' Status, News)
http://heasarc.gsfc.nasa.gov/

Where to look for an observation:
http://heasarc.gsfc.nasa.gov/cgi-bin/W3Browse/w3browse.pl

XMM-Newton Science Archive (XSA):
http://www.cosmos.esa.int/web/xmm-newton/xsa

XMM-Newton Science Archive Threads
(i.e. everything you wanted to ask about XMM data reduction):
http://www.cosmos.esa.int/web/xmm-newton/sas-threads

Chandra X-ray Center (CXC):
http://cda.harvard.edu/chaser/

Chandra Interactive Analysis of Observations (CIAO):
http://cxc.harvard.edu/ciao/

Chandra Interactive Analysis of Observations Science Threads
(i.e. everything you wanted to ask about Chandra data reduction)
http://cxc.harvard.edu/ciao/threads/index.html