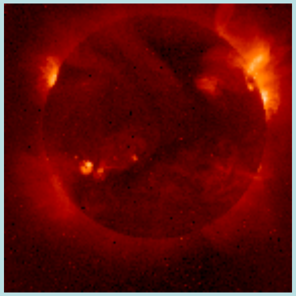
High-Energy Astronomy

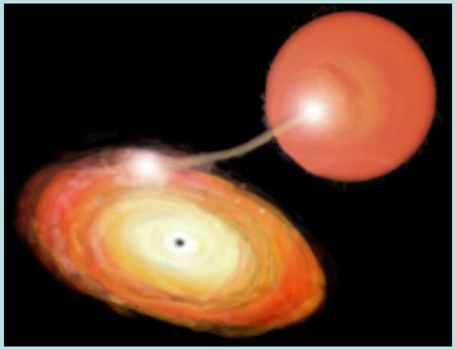
- Definitions: x-rays

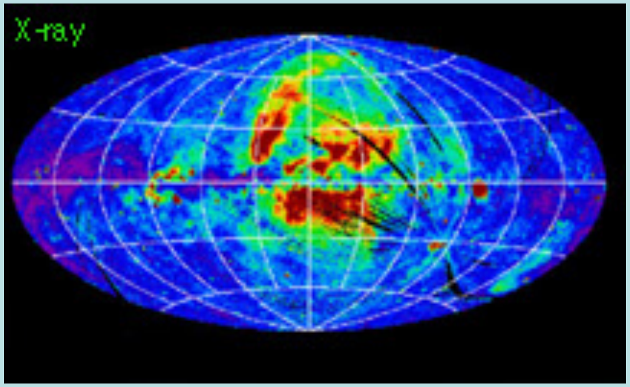
0.1 Kev	1Kev	10 Kev	100Kev
$3x10^{16}$hz	$3x10^{17}$hz	$3x10^{18}$hz	$3x10^{19}$hz
124Å	12.4Å	1.24Å	0.124Å
"soft"	------------------------------		"hard"

Sources



- Stellar coronae ($k_b T \sim 10^6$K)
- Accretion disks of binaries
- AGN (non-thermal)
- SN remnants (cooling of shocked gas)
- Diffuse hot gas (10^6 - 10^8K) in gE galaxies, groups and clusters



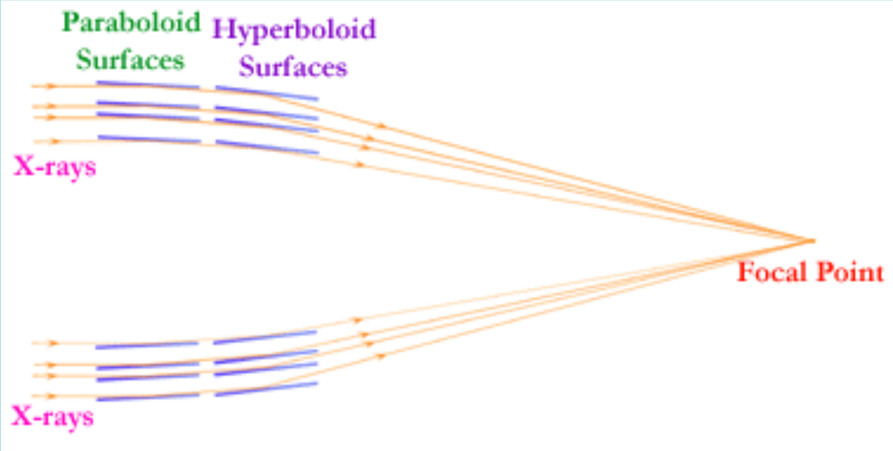


Focusing X-rays

- X-rays penetrate glass, weird things happen at the surface of metals.
- Use the concept of total internal reflectance utilizing the odd fact that n<1 for wavelengths < 2000Å and some conducting materials.

$$\theta_{\text{critical}} = (69.4\sqrt{\rho})/E$$

Density in gm/cm^3 photon energy in keV



Angles are small leading to long focal lengths, dense surfaces are better (Au, Ir), second pass of grazing incidence is useful to decrease focal length.

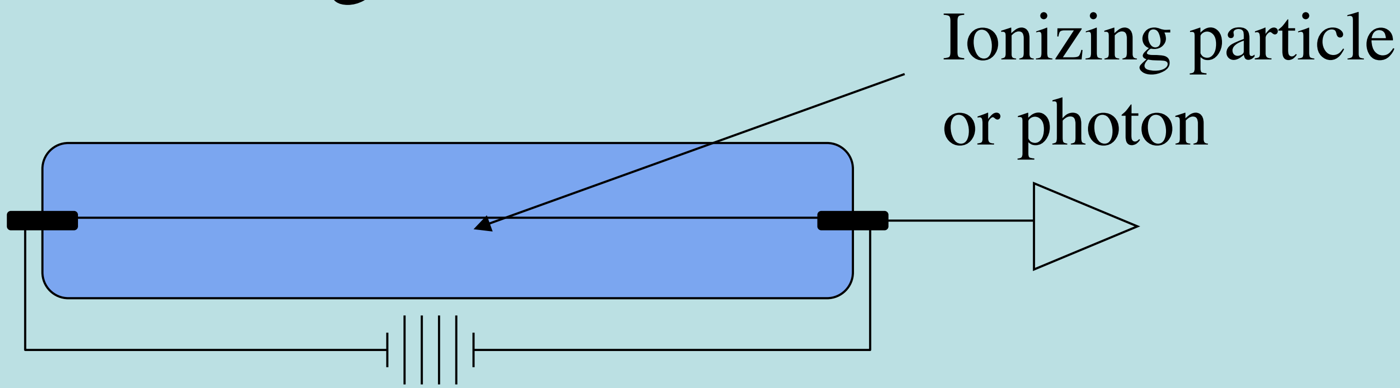
Field is an annulus, so use a nested mirror arrangement.

Surfaces need to be very good and very clean

For CHANDRA, the small-scale smoothness is about 5 iridium atoms RMS…

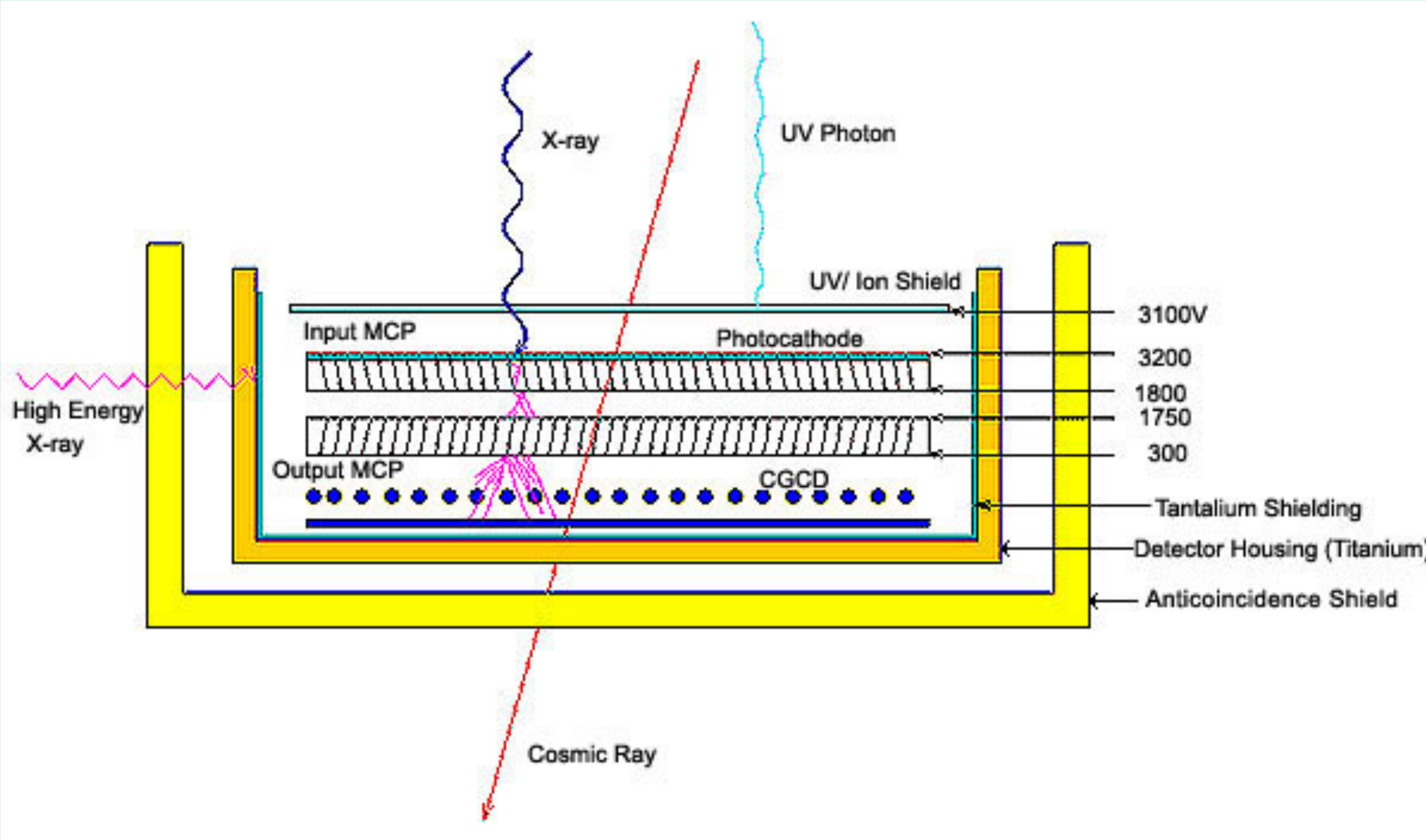
Detectors

- Gas Proportional Counters are the basis of traditional Geiger-Mueller Counters.

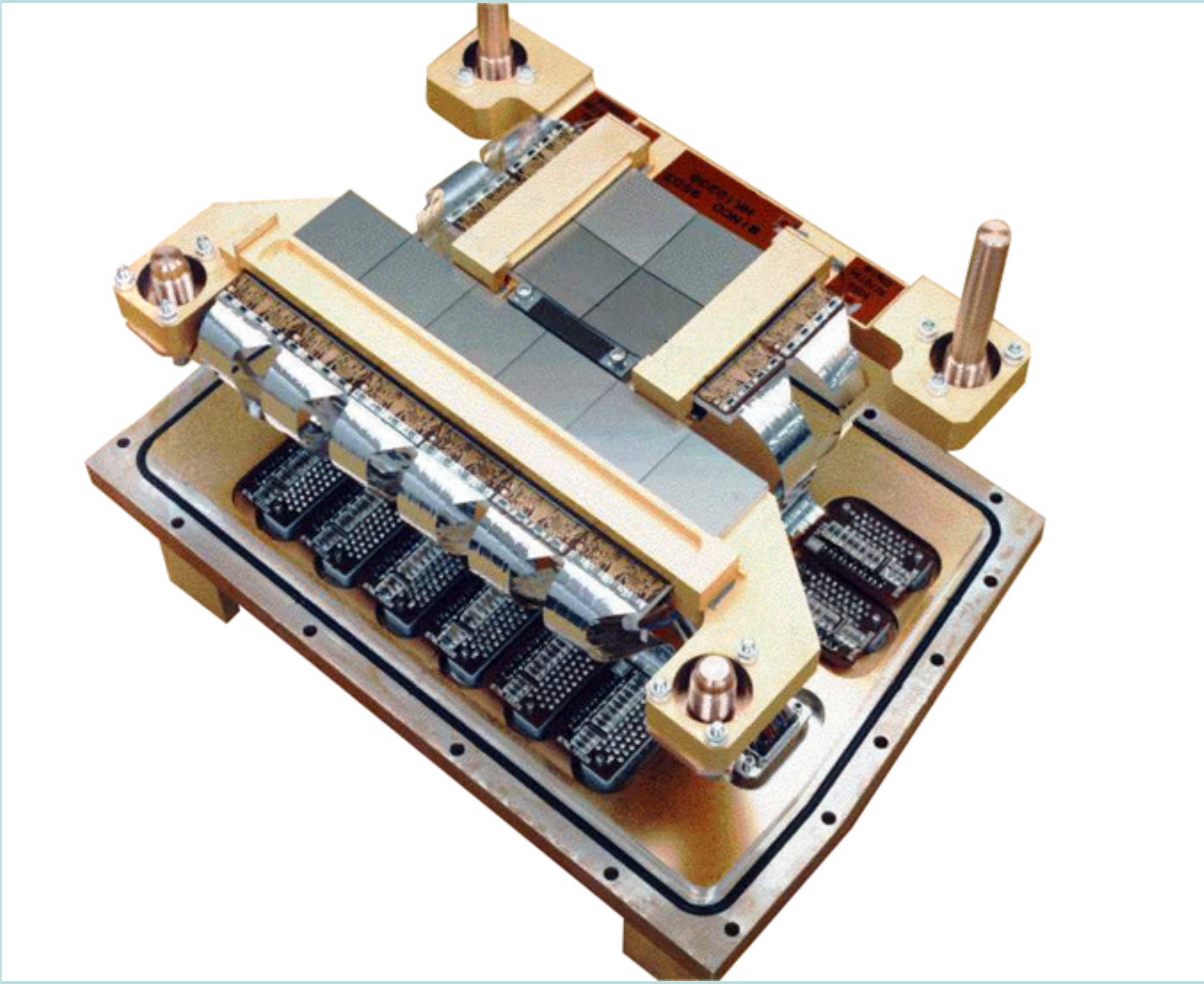


e-/ion pair, high voltage, collisions, amplifier, pulse detection

- Little energy resolution (usually just a lower energy cutoff), little background discrimination.
- Multi-anode-wire versions help to localize ionization event and sort out particles from photons and give some directional information.
- In the last 10 years, most missions have gone to micro-channel plates and CCDs



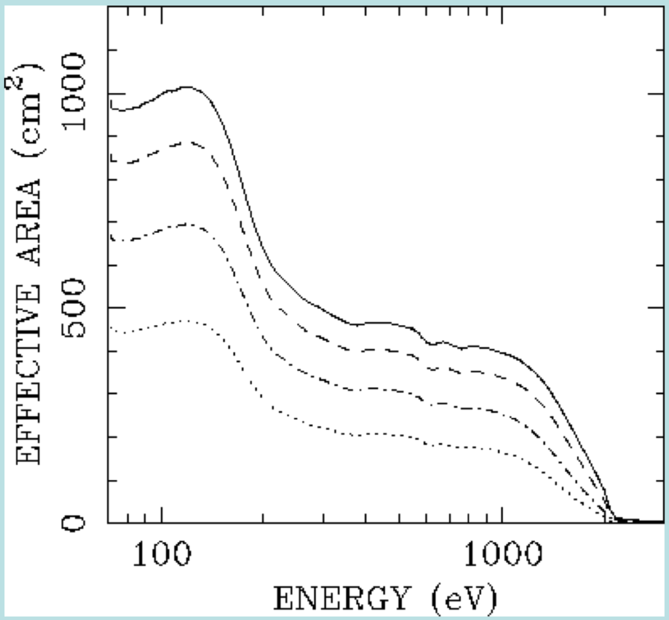
CHANDRA MCP photon detection. OK spatial information, excellent timing information



CHANDRA CCD Array

Effective Area

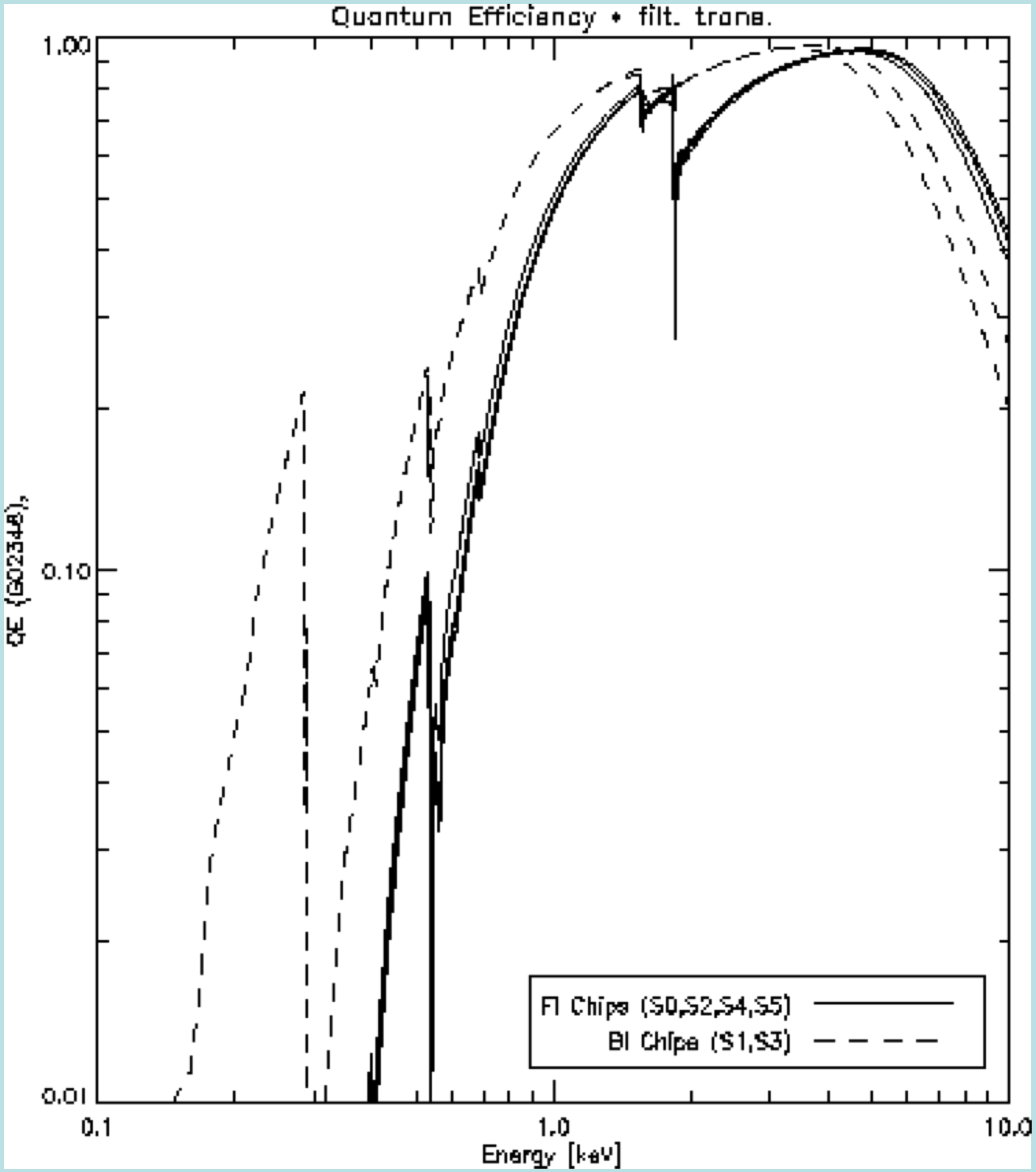
- X-ray types use the "effective area" to characterize their facilities.
- Collecting area x absorption in windows/filters x detector efficiency



ROSAT effective area

CCDs and Xrays

- CCDs have about 100% QE for most of the xray band. Don't need gas supply, no threshold in energy level.
- Main problem is that CCDs are sensitive to low energy photons too. The solution is to use filters (polycarbonate + aluminum). These filters have some odd transmission curves.

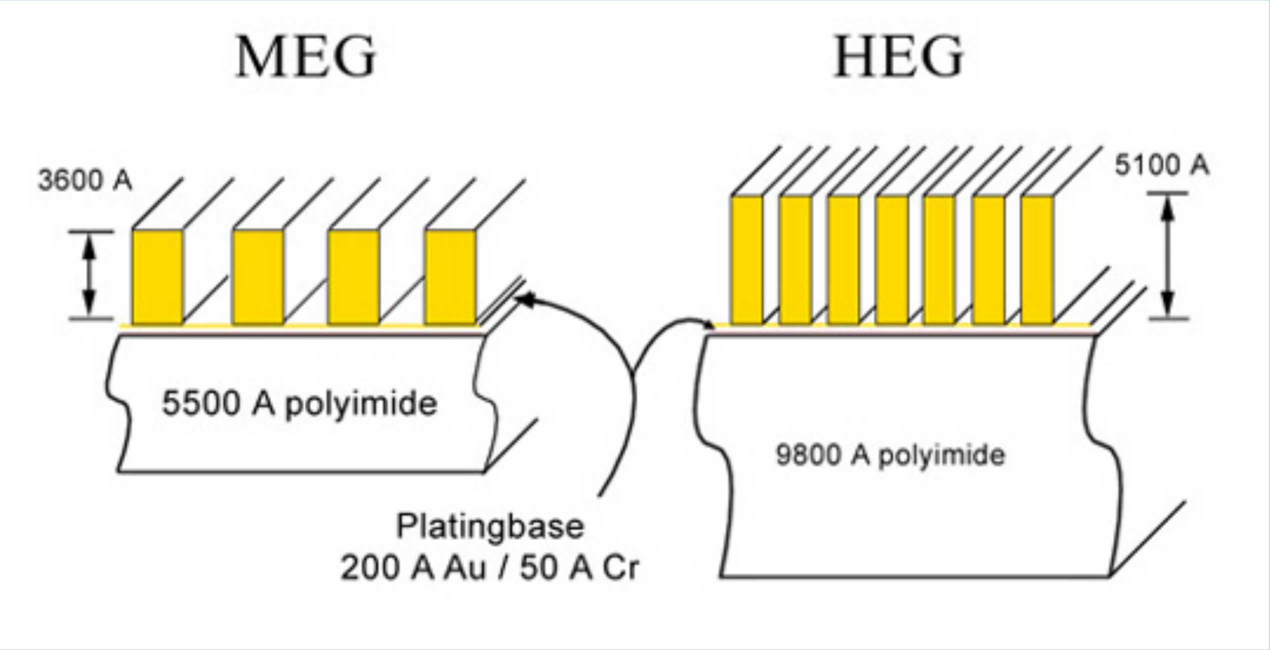


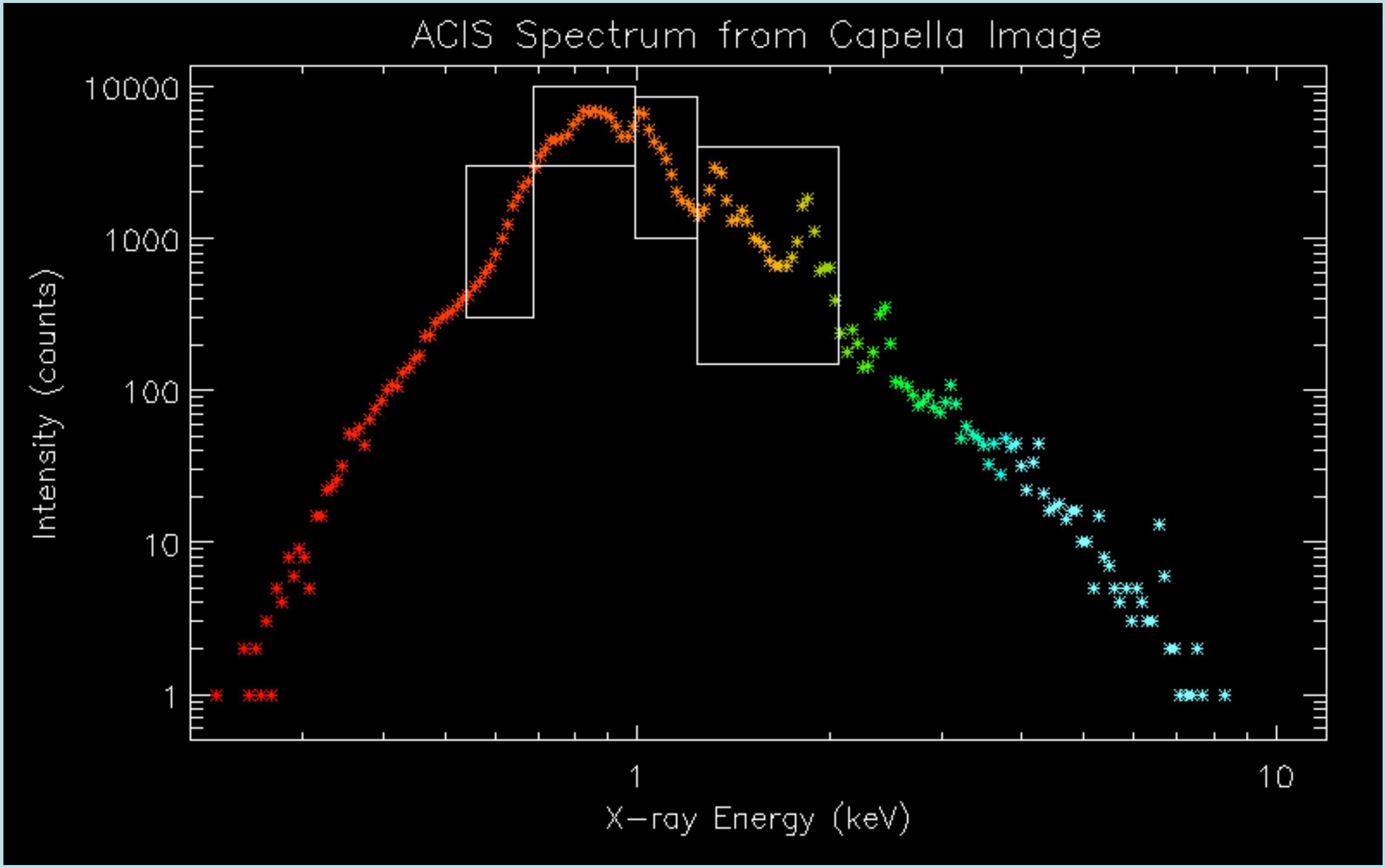
Absorption edges are the photoelectric effect. The crossection for absorption takes a jump at the ionization energy of a particular atomic level, then decreases approximately like ν^{-3} at higher energies (till the next edge is reached).

At x-ray energies, the transitions are mostly from the l and k shells

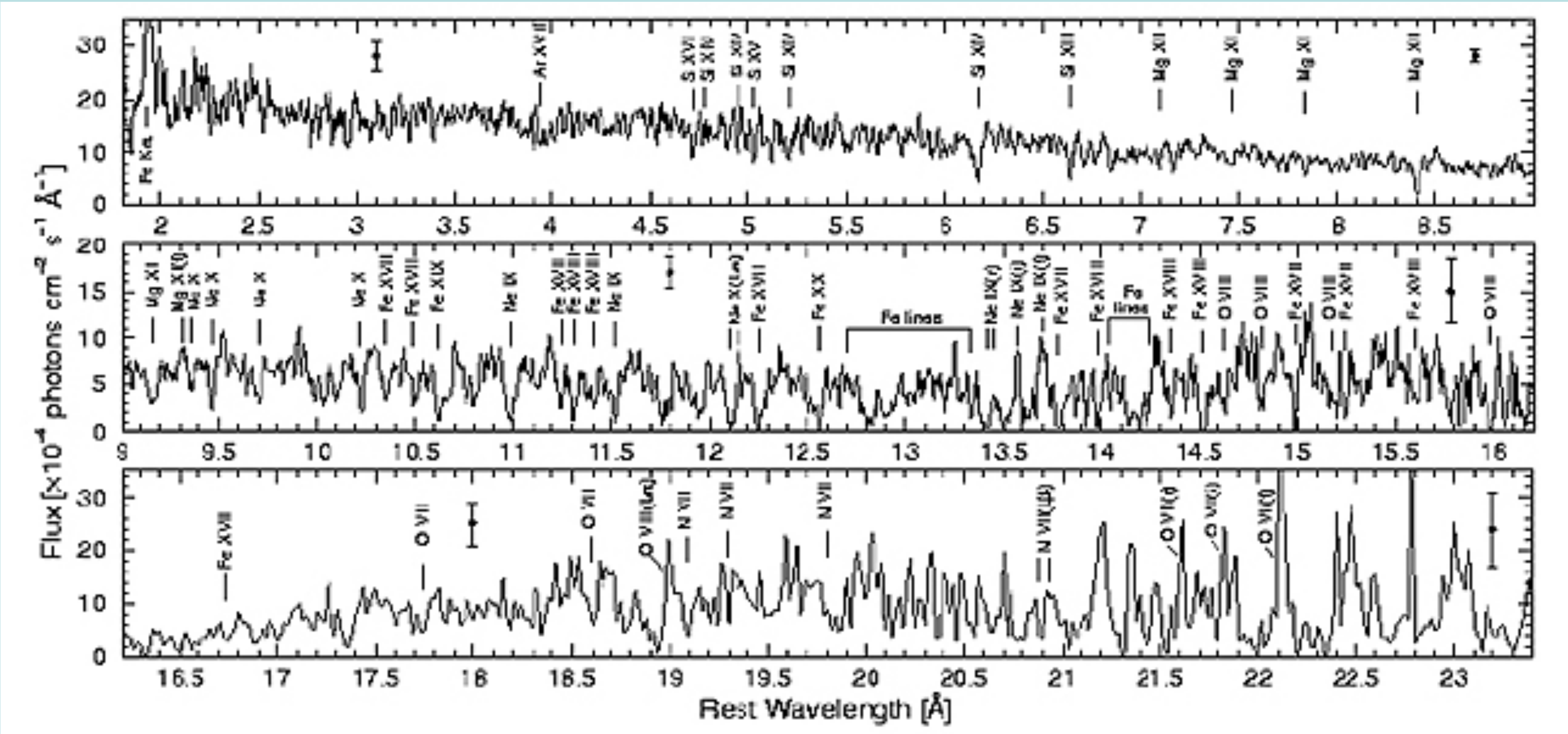
Spectral Resolution

- With IPCs, the pulse height was a vague indication of photon energy, but it was basically broad-band work (hard or soft) for the first generations of x-ray observatories.
- At a throughput price, you can grating disperse x-rays to get good spectral resolution.





ACIS Spectrum from Capella Image
10000
1000
100
10
1
Intensity (counts)
1
10
X-ray Energy (keV)



Flux [×10⁻⁴ photons cm⁻² s⁻¹ Å⁻¹]
Rest Wavelength [Å]
Fe lines

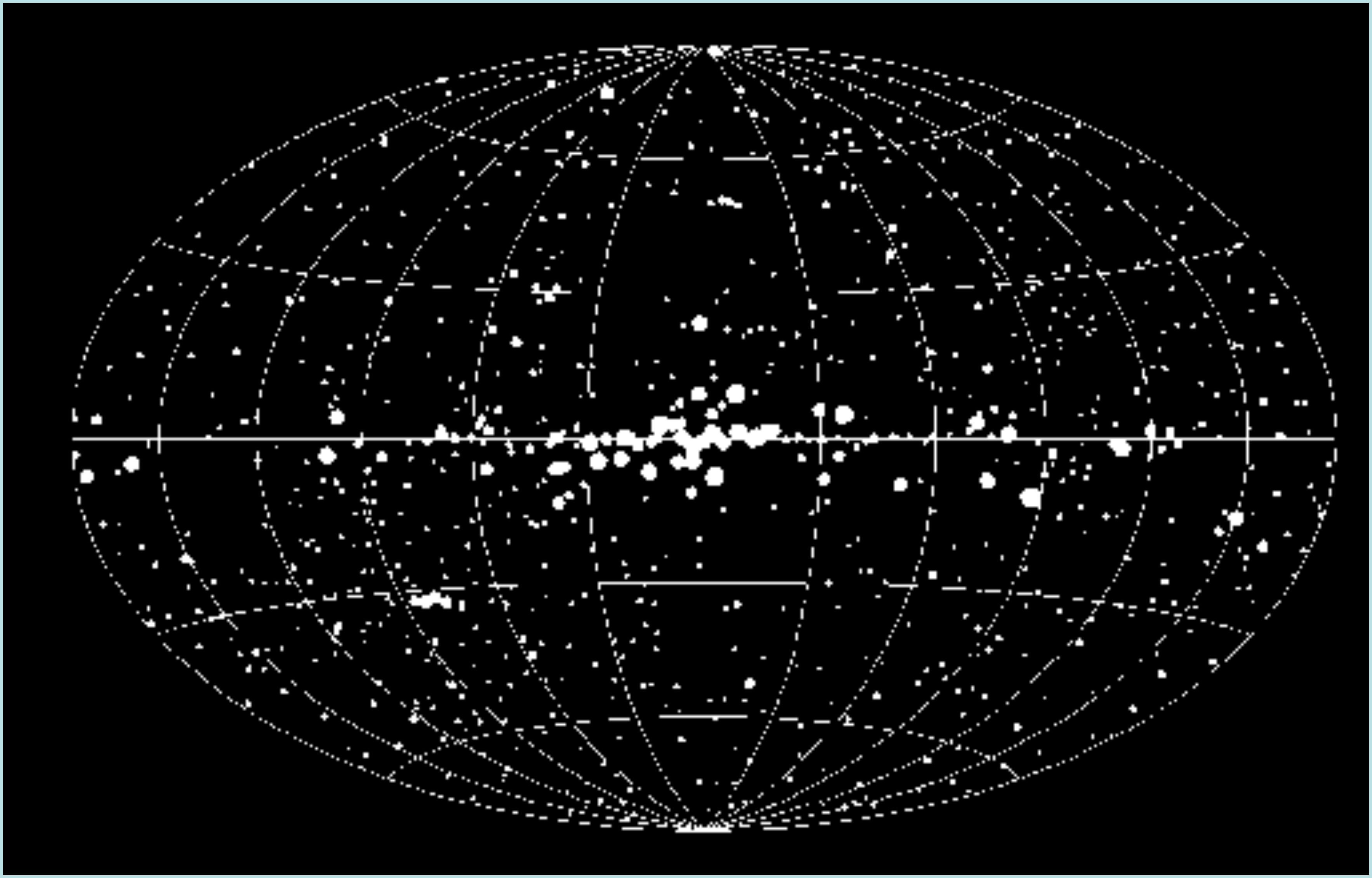
X-ray missions

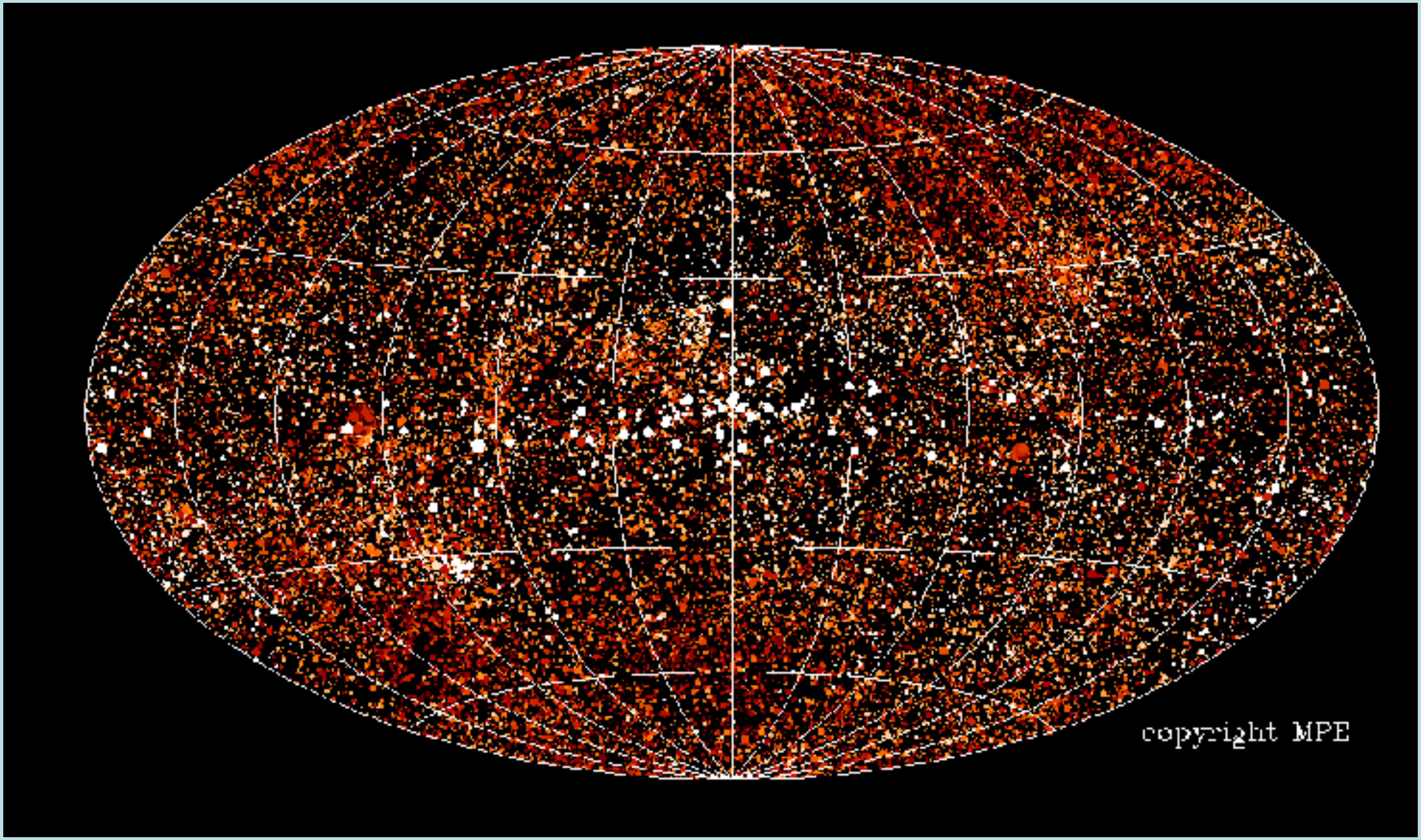
- It was assumed that interstellar gas would limit our view of the x-ray world to very near the Sun.
- 1949: Gieger counters on V-2 rocket measured x-rays from the Sun
- 1962: 1st extra-solar X-ray detection, SCO-X1 plus the diffuse x-ray background
- 1973: Uhuru was the first satellite x-ray mission (400 sources)

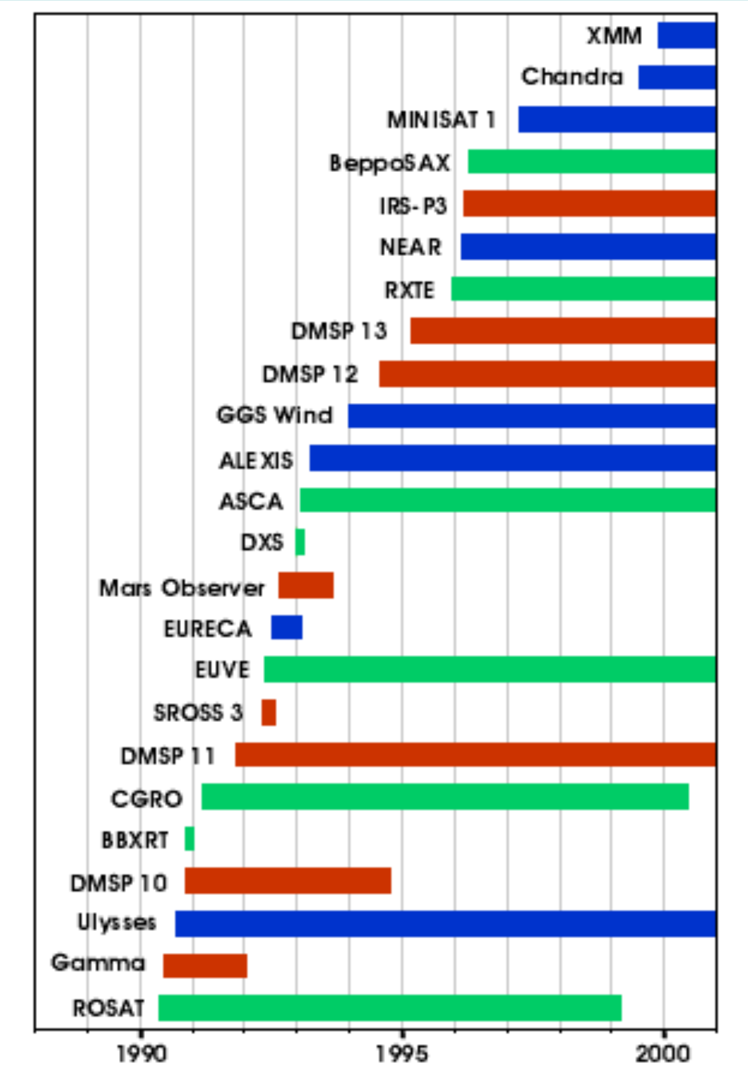
- Vela (DOD): x-ray and gamma ray bursts
- Then there was a whole slew of satellites.
- HEAO-2 (Einstein): 1977, spectral indices and imaging (first satellite with focusing mirrors). (7000 sources)
- Now: CHANDRA, XMM, HETE-2

Angular resolution:VELA: 1°, CHANDRA:1”

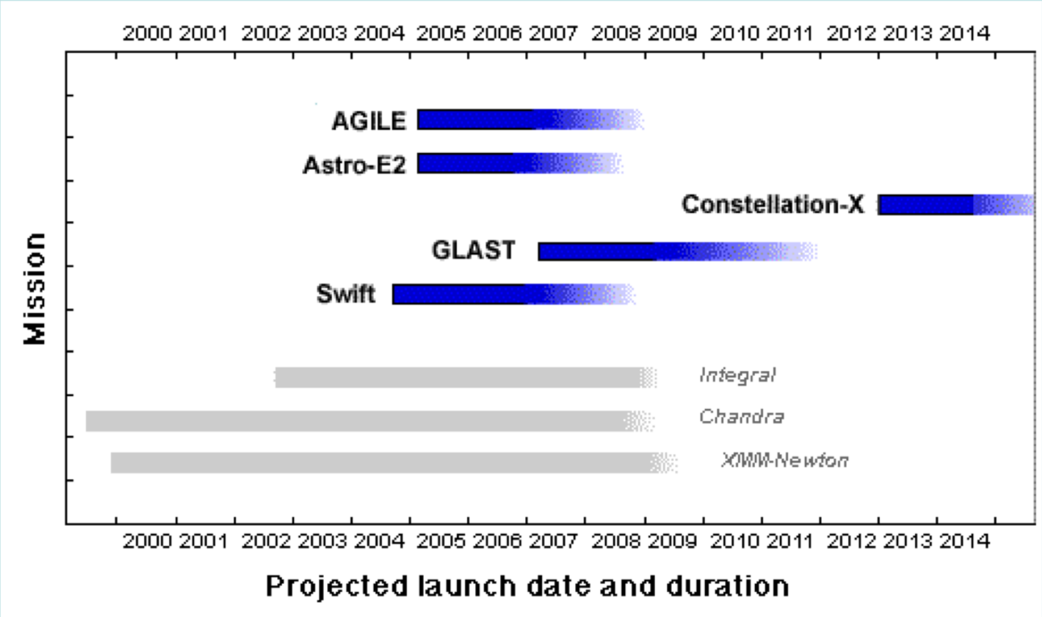
Energy Resolution: VELA: 2 , ASCA: 500



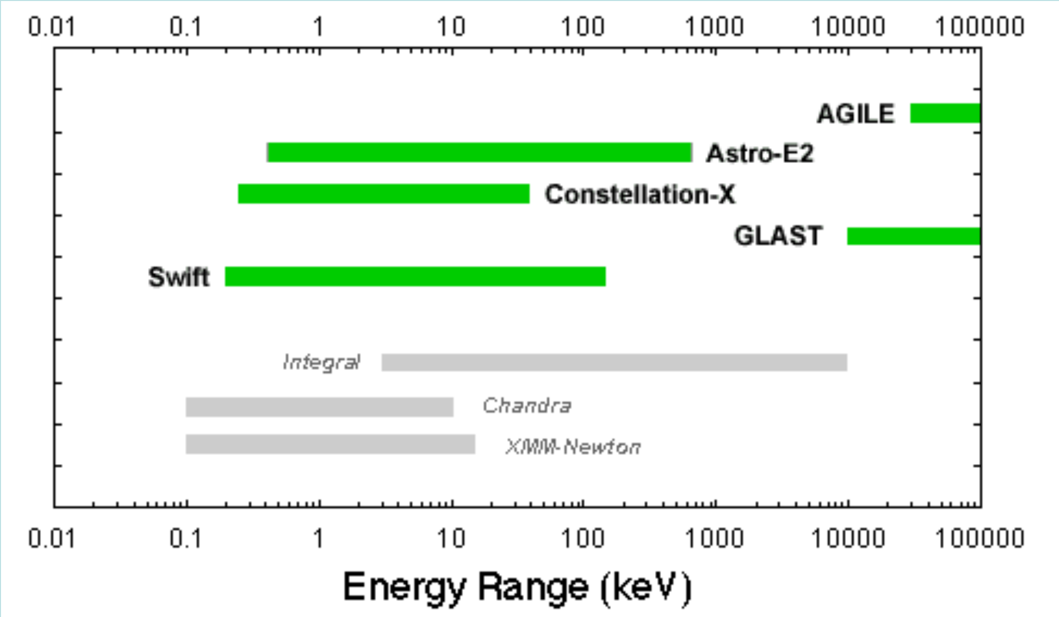

copyright MPE



XMM
Chandra
MINISAT 1
BeppoSAX
IRS-P3
NEAR
RXTE
DMSP 13
DMSP 12
GGS Wind
ALEXIS
ASCA
DXS
Mars Observer
EURECA
EUVE
SROSS 3
DMSP 11
CGRO
BBXRT
DMSP 10
Ulysses
Gamma
ROSAT
1990
1995
2000



2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014
Mission
AGILE
Astro-E2
Constellation-X
GLAST
Swift
Integral
Chandra
XMM-Newton
Projected launch date and duration



0.01 0.1 1 10 100 1000 10000 100000
AGILE
Astro-E2
Constellation-X
GLAST
Swift
Integral
Chandra
XMM-Newton
Energy Range (keV)

Data Reduction Skills: The Future of Groundbased Astronomy is here!

HEASARC Software Packages

HEAsoft – A unified release of the FTOOLS and XANADU packages

FTOOLS – General FITS file utility programs and mission-specific data analysis tools

XANADU – Suite of spectral (xspec), timing (xronos), and image (ximage) analysis programs

XSELECT – Multipurpose tool for filtering event files and generating images, spectra, and light curves

XSTAR – Program for calculating physical conditions and emission spectra in photoionized gases

fv – Interactive editor and viewer for astronomical data files in FITS format

Hera – Enables complete interactive analysis over the Internet of data products retrieved from the Browse data archive

MAKI – A multi-mission observation visualizer and planning utility

FITSIO – A subroutine library for reading and writing FITS files for C and Fortran programmers

Other Useful Multi-mission Software

IRAF/PROS – X-ray data analysis package developed and maintained by the ROSAT Science Data Center at CFA

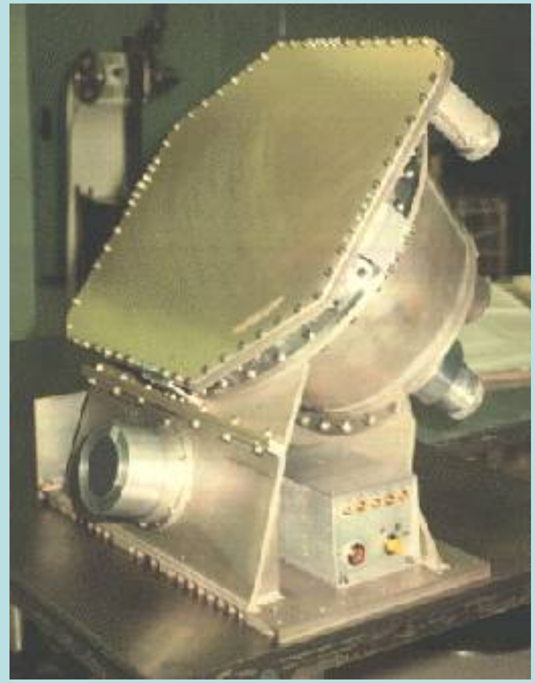
EXSAS – Extended X-ray Scientific Analysis System for spacial, spectral, and timing analysis. Maintained by a team of the X-ray astronomy group of the MPE at Garching

Gamma-Ray Astronomy

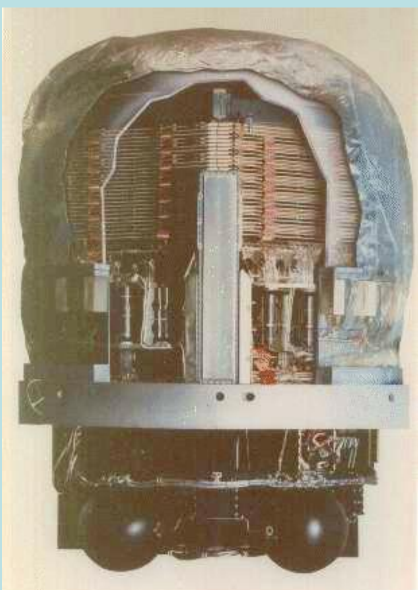
- Explorer X-1, 1961 detected 100 photons
- Vela satellites sent up to monitor nuclear weapons testing set the modern stage. Lots of sources away from the Earth, uniformily distributed on the sky
- 1991, Compton Gamma Ray Observatory was launched.

Compton GRO

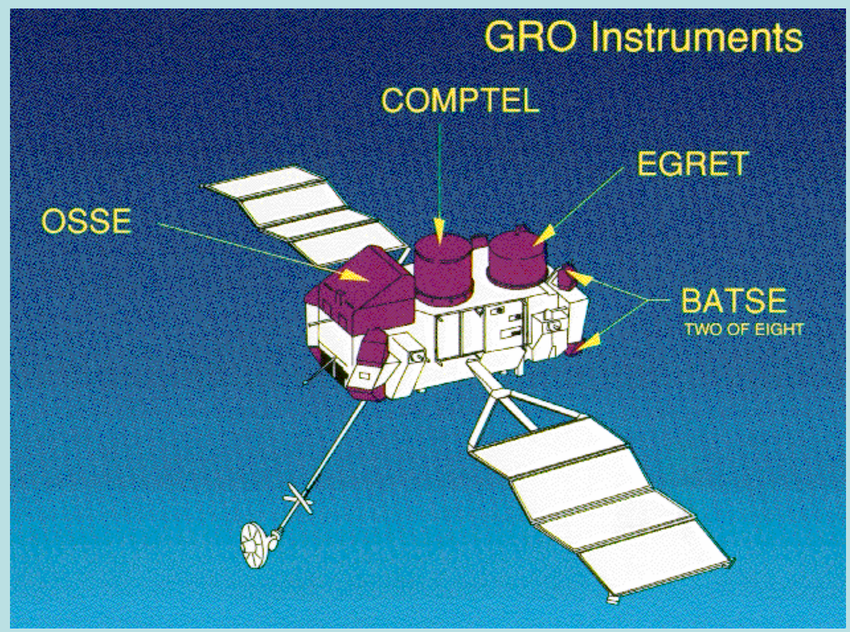
- BATSE: Burst and transient, all sky 20-600KeV
- OSSE: 0.05-10MeV
- COMPTEL: 1-30MeV + 1 degree resolution
- EGRET: 20-30MeV and 10′ resolution

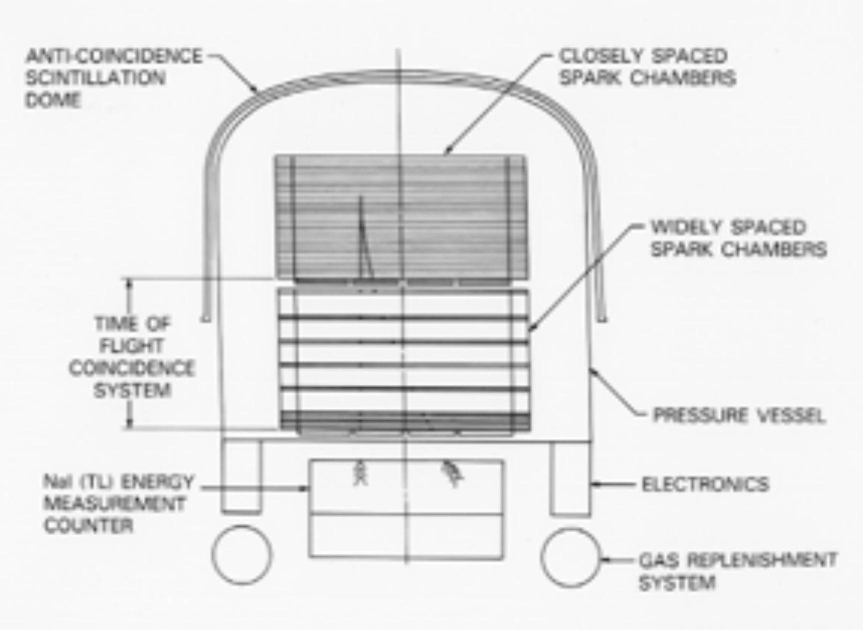


BATSE
NaI + PMT



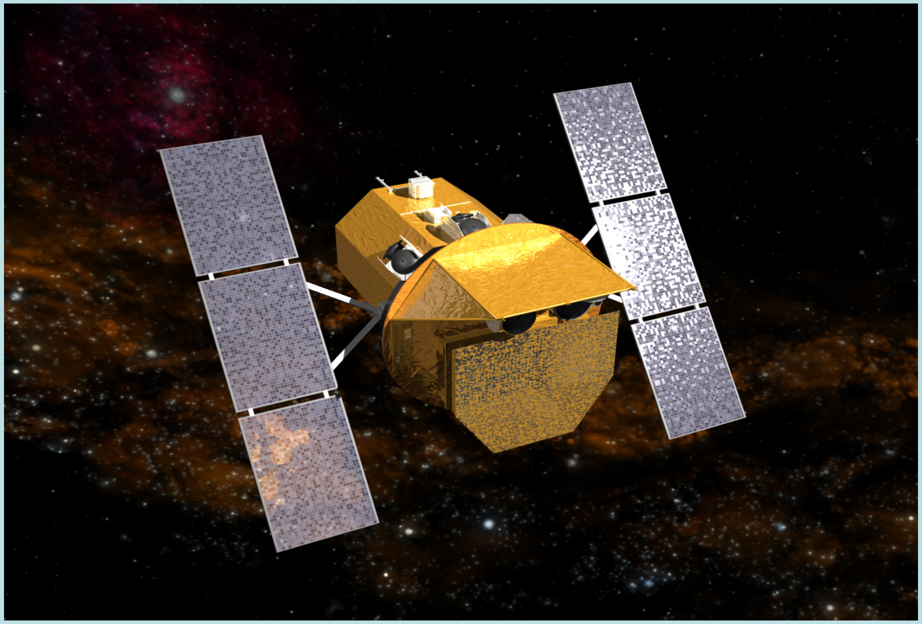
EGRET





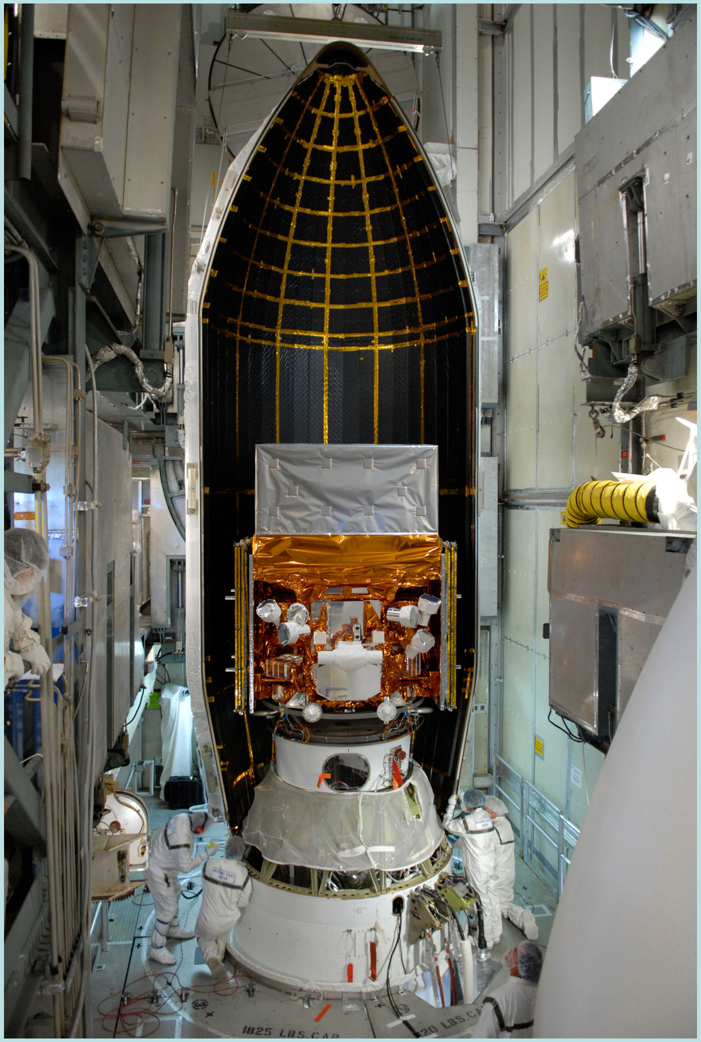
- For EGRET spatial and energy resolution, there is layer of spark wire grids behind tantalum foils. Electron-positron pairs produced in the foil and paths tracked through the grids.

SWIFT



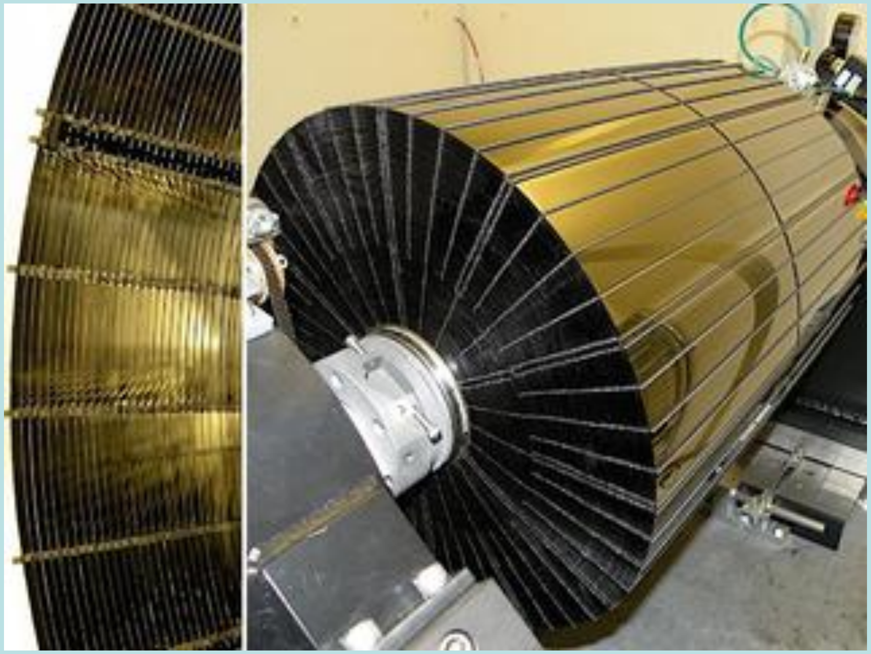
- MIDEX mission 2004 launch
- Gamma-ray, X-ray and optical to go after gamma-ray bursts and afterglows

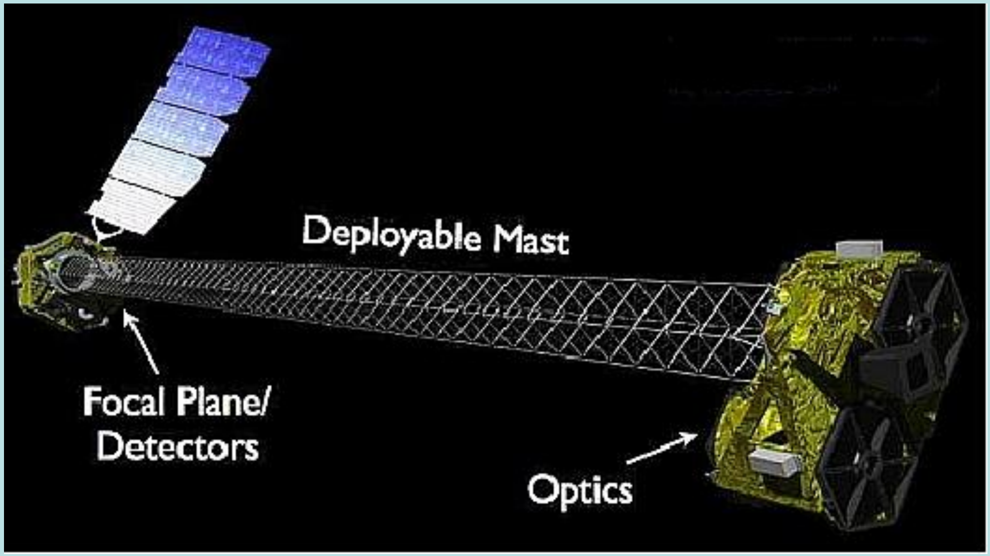
FERMI (GLAST)



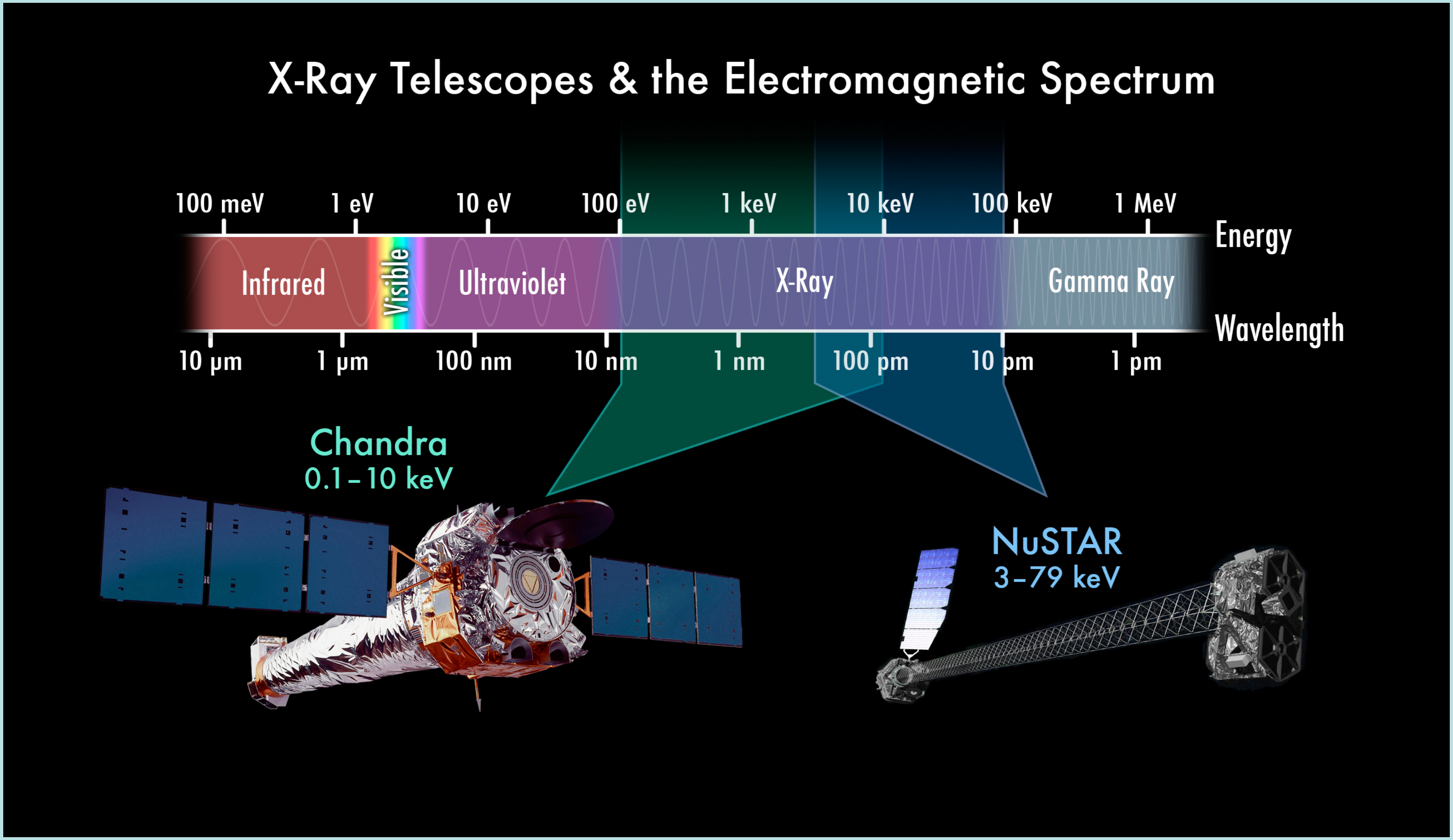
- Launched in 2008
- 8KeV – 300GeV
- Good spatial resolution
- Good time resolution
- Clever anti-coincidence sheilds (very high cosmic-ray density at these energies)
- Beyond gamma-ray bursts and into high-energy astrophysics

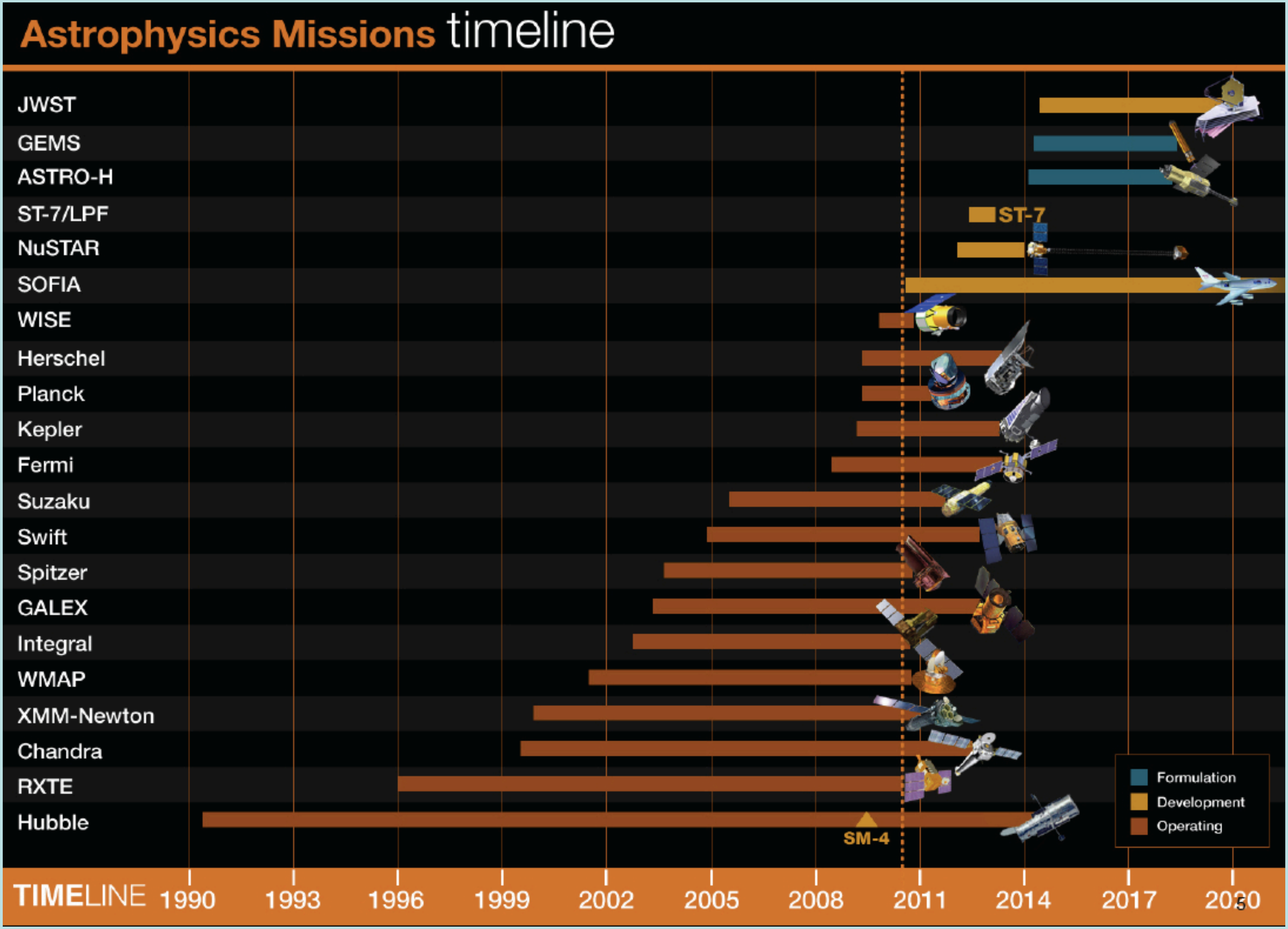
NUSTAR





- Small Explorer Class
- Higher spatial resolution (Wolter-1 telescope) 9 arcsec
- Higher spectral resolution
- Better sensitivity
- 3 – 80 KeV


X-Ray Telescopes & the Electromagnetic Spectrum
100 meV
1 eV
10 eV
100 eV
1 keV
10 keV
100 keV
1 MeV
Energy
Infrared
Visible
Ultraviolet
X-Ray
Gamma Ray
Wavelength
10 μm
1 μm
100 nm
10 nm
1 nm
100 pm
10 pm
1 pm
Chandra
0.1–10 keV
NuSTAR
3–79 keV



Astrophysics Missions timeline
JWST
GEMS
ASTRO-H
ST-7/LPF
NuSTAR
SOFIA
WISE
Herschel
Planck
Kepler
Fermi
Suzaku
Swift
Spitzer
GALEX
Integral
WMAP
XMM-Newton
Chandra
RXTE
Hubble
ST-7
SM-4
Formulation
Development
Operating
TIMELINE
1990
1993
1996
1999
2002
2005
2008
2011
2014
2017
2020