Astrostatistics: The Intersection of Statistics and Outer Space

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Joint work with Y. Chen (Michigan), X. Wang (Two Sigma Inc.), D. van Dyk (Imperial College London), H. Marshall (MIT)

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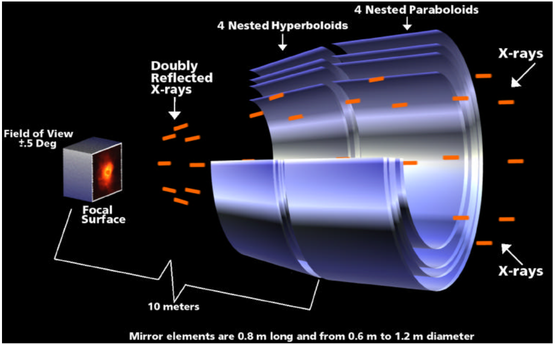
On the nature of High-Energy Astro data: Telescopes

X-rays and γ-rays are easily absorbed by matter, so can't have simple mirror telescopes. High-energy photons are brought to a focus via grazing reflection through a pairs of nested parabolic and hyperbolic surfaces.



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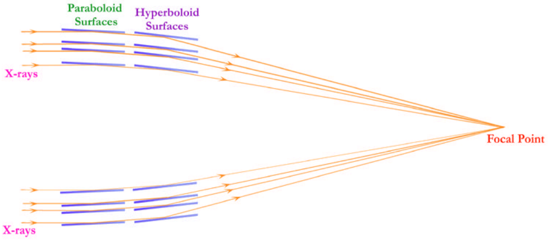

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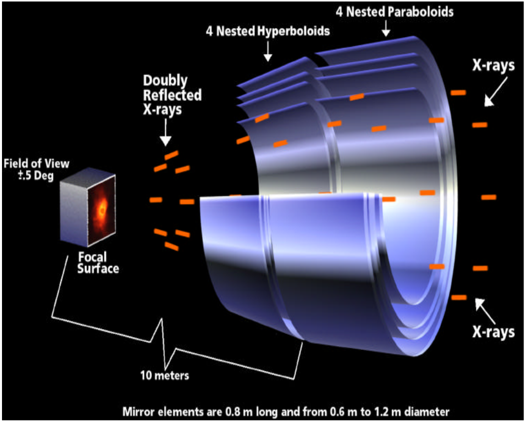

On the nature of High-Energy Astro data: Photons

- **High-energy photons are rare**
  - One X-ray photon at 10Å is worth 600 green photons at 6000Å
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  - Histograms made from arrival time information are *light curves*, from deposited-energy information are *spectra*, and from pixel location information are *images*

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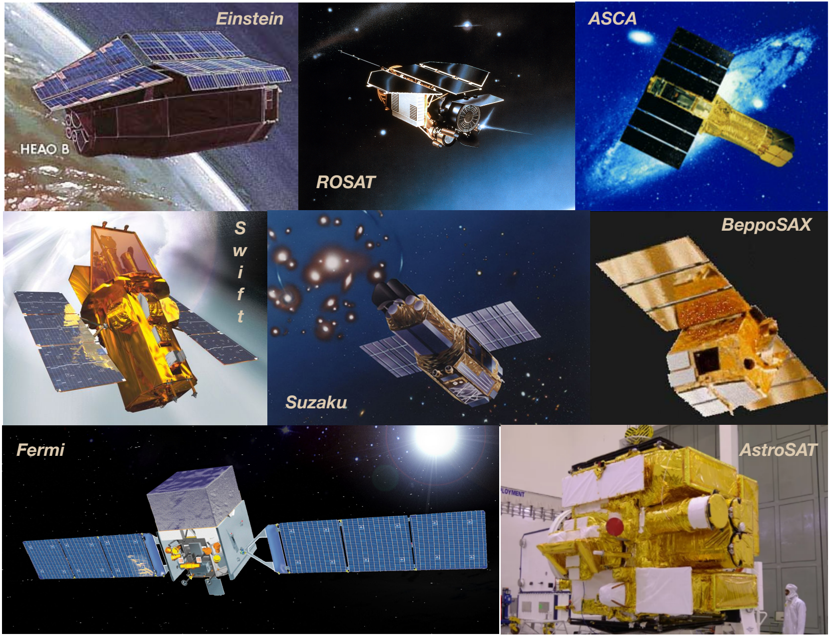
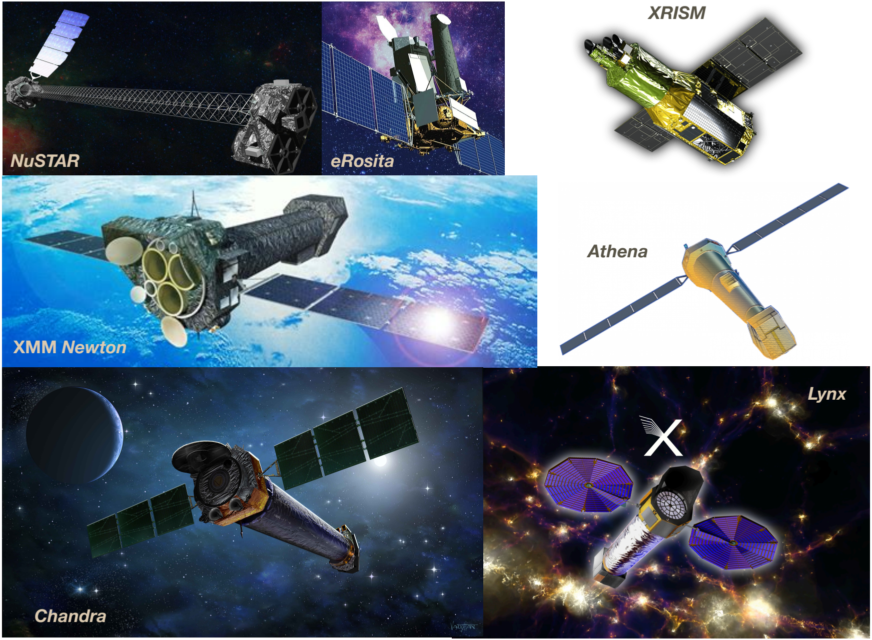
- Imaging X-ray astronomy started with the *Einstein* X-ray Observatory


Einstein
HEAO B
ROSAT
ASCA
Swift
Suzaku
BeppoSAX
Fermi
AstroSAT


NuSTAR
eRosita
XRISM
XMM Newton
Athena
Chandra
Lynx

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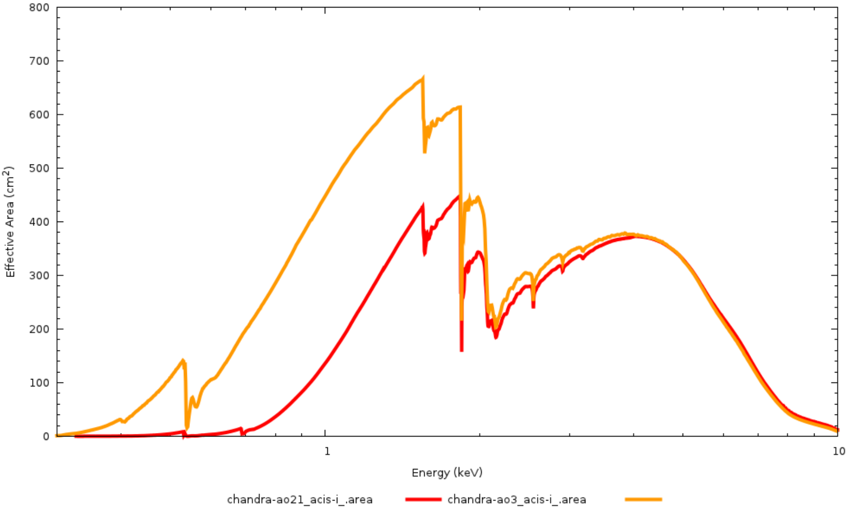
- The efficiency with which a photon of a given energy E is detected varies with E, is different for different instruments, and often varies with age for a given instrument (and sometimes decreases for bright objects)
- This efficiency is encoded and stored as an area [cm^2], called *Effective Area*, A_{eff}
- Maximum theoretical efficiency is 100% of the geometric aperture area, and is *never* achievable in practice.

On the nature of High-Energy Astro data: Example A_{eff}

Chandra/ACIS-I: current vs 2001



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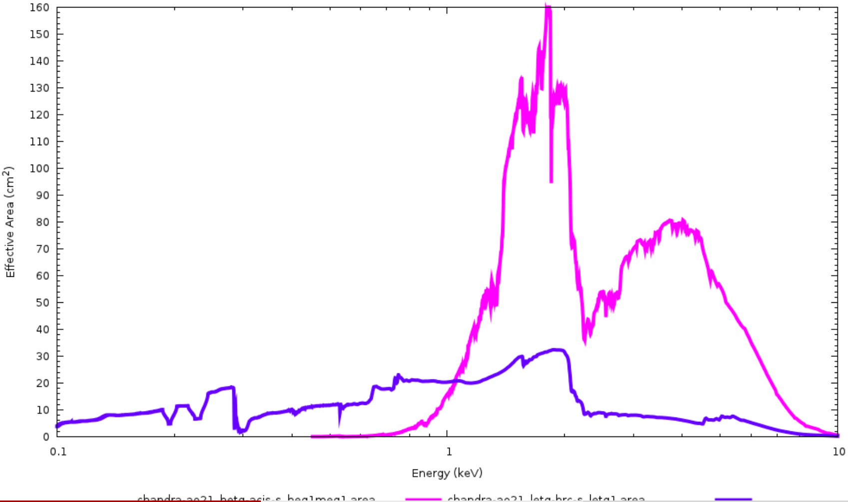
Chandra gratings: LETGS+HRC-S vs HETGS+ACIS-S



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- The Effective Area is measured on the ground pre-flight, and monitored during flight
- Our best estimates of A_{eff} are written into a file and shared with all observers, who use it to infer the properties of the astrophysical source they are investigating

On the nature of High-Energy Astro data: FEq

The fundamental equation of observational astronomy

All of astronomy, until very recently, has been about inferring, from the observed photons, the nature of the object that is emitting the photons. Spectra are the biggest hammer in our toolbox.

Spectra are recorded as digitized amplifier signals over a range of *channels*.

The expected counts in digitized detector channels $i : j$,

$$\lambda_{i:j} = \tau \sum_{k=i}^{j} \int dE \ \{A_{\rm eff}(E) \cdot f(E; \mathbf{\Theta})\} \ p(k|E)$$

$>$ $A_{\rm eff}(E)$ [cm^2] is the effective area at photon energy E [keV],
$>$ τ [sec] is the duration of the observation,
$>$ $p(k|E)$ is the probability of registering the photon in detector channel k,
$>$ and $f(E; \mathbf{\Theta})$ [photons cm^{-2} sec^{-1} keV^{-1}] is the astrophysical model spectrum defined at each E
$>$ via astrophysical parameters $\mathbf{\Theta}$

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Astrostatistics to the rescue!

Xiao-Li will next discuss the consequences of this problem, and show how we are dealing with it.