Space Based X-ray and Gamma-ray Instruments and Missions

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Outline of lecture

- motivation and brief historical background
- X-ray Missions, telescopes and detectors:
  - collimators, concentrators, and grazing incidence telescopes
  - CCD imagers vs. MCPs
  - grating vs. bolometer spectrometers
  - backgrounds and sensitivities
- Hard X-ray Missions, telescopes and detectors:
  - coded aperture wide-field imagers
  - grazing incidence and multilayer optics
  - pixel detector arrays (e.g. CZT)
  - backgrounds and sensitivities: <u>need narrrow vs. wide Surveys to ***EXIST***</u>
- Gamma-ray Missions, telescopes and detectors:
  - Compton telescopes; tracking detectors
  - calorimeters
  - backgrounds and sensitivities
- Proposing and planning a mission
  - prioritizing the science
  - maximizing the instrument while minimizing cost
  - spacecraft, power, telemetry and mission planning
  - cycle of reviews and pressures to cut...
- Summary and References

Motivation for X, γ telescopes in space

- Optical polarization of Crab (Minkowski 1954**) led Schlovsky (1956**) to propose synchrotron origin: TeV electrons likely, so "naturally" γ-rays (from corresponding protons; inverse Compton not yet considered)

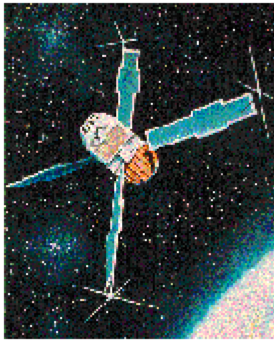
- Cocconi (1958) proposed γ-rays from CRs on GMCs

- Kraushaar & Clark (1961) launch Explorer 11 and detect first cosmic γ-rays (31!) followed (1967) by OSO-3

- Giacconi et al (1962) search for fluorescence X-rays from solar wind impacting Moon resulted in discovery of Sco X-1 (accreting neutron star) and cosmic X-ray background! X-ray astronomy is launched

(dates approximate!)**

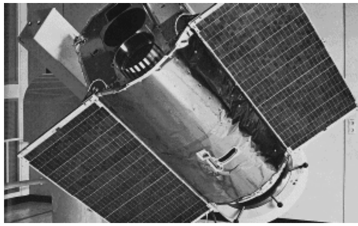
First X-ray Observatories in space



- First was ***UHURU*** (1971-73) [following *many rockets* in 60s]
  - Two proportional counters (840cm^2)
  - 0.5^o and 5^o fields of view
  - *Scanning* for all sky survey: ~350 sources
  - Discovered/identified <u>X-ray binaries & X-rays from clusters</u>

- **Copernicus** (1972-81): US-UK UV & X-ray telescopes
  - Limited X-ray observations, but initial expt. with early focusing X-ray tel.

- **ANS** (1974-77): Dutch-US *pointed* broad-band mission
  - HX prop. ctr., (1-30keV), SX conc. mirror (0.16-0.28keV)
  - Bragg xtal spectrometer; UV telescope
  - Polar orbit: high bkgd. & limited obs. time
  - Discovery of X-ray bursts



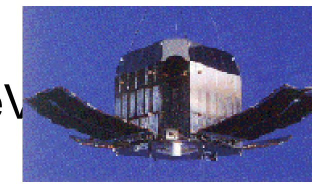
Followup X-ray missions: better positions & sens.

- **SAS-3** (1975-79): ~30arcsec positions; monitoring
  - MIT studies of bursters; discover Rapid Burster
  - Modulation collimator allows IDs of NS & BH LMXBs
  - Slat/tube prop. counters; SX (0.15-1.0 keV) 2.9^o FoV
- **Ariel V** (1974-90): UK-US equatorial launch
  - Rot. Mod. Coll. provides source IDs
  - Pinhole camera for *all sky monitor*: AO620-00=BH trans.
  - Sky survey instr. Detects Fe 6.7keV line from gal. clust.
- **HEAO-1** (1977-79): broad band survey
  - A1 expt. ~1m^2 PC; A2 expt. (6 PCs) measures CXB spec
  - A3 expt. scanning mod. coll. for 30" positions
  - A4 expt. NaI/CsI phoswich scintillators (100cm^2 ea.): 1st HX survey

Increasing size of (non-imaging) proportional counters for timing/spectra

- **Hakucho** (1979-85): first Japanese mission
  - 6 sets of prop. ctrs (0.1-20keV) + scint. (10-100keV)
  - Discovered more X-ray bursters; transients

- **Tenma** (1983-85): 2nd Japanese mission
  - 10 x 80cm^2 *gas scintillation prop. ctrs*. (2X En. Res.); 2-60 keV
  - Discovered 6.4, 6.7 keV Fe lines from LMXBs & gal. ridge



- **Ginga** (1987-91): 3rd Japanese mission
  - 4000cm^2 prop. ctr. array (non-imaging) for high sens.
  - Discovered BH transients; weak NS transients; cycl. Lines

- **RXTE** (1995-): NASA's Rossi X-ray *Timing* Explorer
  - 6000cm^2 prop. ctr. Array; 1600cm^2 scintillators; all sky monitor
  - kHz QPOs from NSs and BHs; accreting millisecond pulsars!

Proportional counters: UHURU → RXTE…

- X-ray interacts in high-Z (Ar or Xe) gas (+ quench) by *K-shell ionization;* photo-electron produces N ~ E/W electron-ion pairs by dE/dx losses, where W ~ 27eV, and thus E resolution

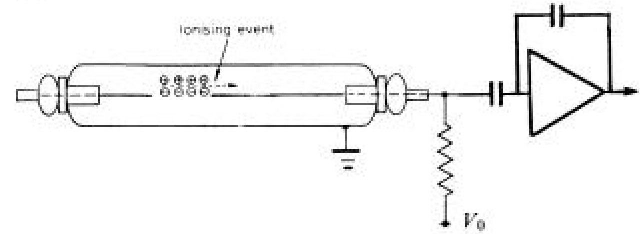
  $E/\Delta E \sim 2.6 E_{keV}^{0.5}$

- GSPCs excite larger N by UV flurorescence: ~2X better E/ΔE

- X-ray FoV defined by *slat collimators* (typ. Θ ~0.5 – 1°); positions by centroid δΘ ~Θ/(S/N)

- Modulation collimators with wire grids at angular size d/D improve ang. resol. to $\delta\Theta \sim (d/D)/(S/N)_{mod}$ but yield multiple positions within Θ

Gas proportional counter (from Zombeck, Handbook)

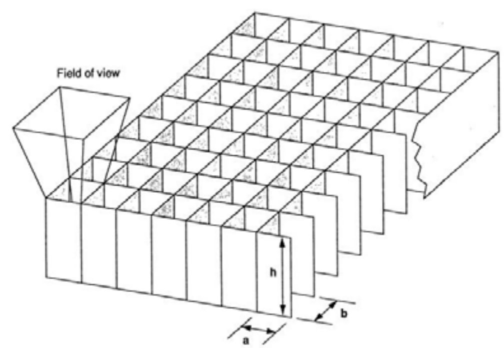


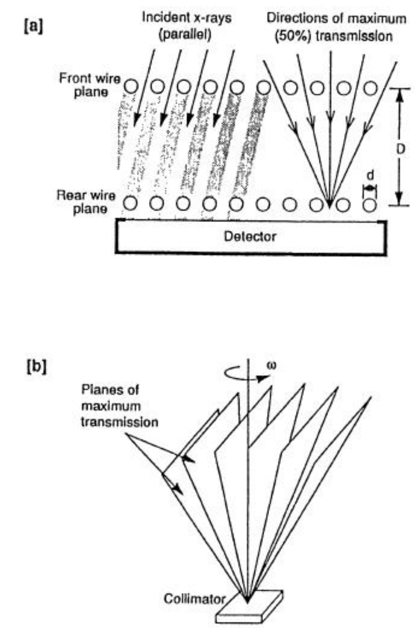
Since a proportional counter has internal gain, the system noise can be neglected and the energy resolution is:

$$(\Delta E)_{\rm FWHM} = 2.35[(F+f)WE]^{1/2}\ {\rm eV},$$

where

E = energy deposited in counter (eV),
F = Fano factor,





Slat collimator (**left**) with FWHM = tan^{-1} (a/h) x tan^{-1} (b/h) vs. modulation collim. (**right**) (from Ramsey et al review)

Sensitivities with non-focusing X-ray detectors

- Backgrounds limited by CR interactions in PC walls; shield by segmented anode-cathodes (optimized for HEAO-A2 and RXTE)

- Energy range limited by:
  - E_{min} ≥0.3keV, typically, from absorption in entrance window and thermal blankets
  - E_{max} by detector depth, atomic number Z since photoioniz. mass abs. coeff. $\sigma/\rho \sim (Z^4/A)E^{-8/3}$, and charge collection efficiency in thick detector

- Net sensitivity over band to signal S(E) with background B(E) and detector efficiency f(E) yielding $N_s = f \cdot S \cdot A \cdot T$ signal cts in detection area A over time t and background cts $N_b = B \cdot A \cdot T$ gives signal to noise $S/N = N_s/(N_s + N_b)^{1/2}$ which increases only as $(A \cdot T)^{1/2}$ for non-focusing detectors

Led to first true focusing X-ray mission…

- **Einstein Observatory** (1978-81): X-ray astronomy *Arrives*
  - Wolter I X-ray telescope (~5" resol.; 0.1 – 4 keV)
  - 4 instruments to rotate into focal plane (one at a time)
    - Two imagers: IPC (75' FoV, $\Delta E/E \sim 1$), HRI (25' FoV; no energy res.)
    - Two spectrometers: Bragg xtal (FPCS) and Solid State (SSS)
  - Monitor proportional counter (MPC; 1-20 keV, $\Delta E/E \sim 0.2$)
    - $A_{geom} = 667\ cm^2$ *non-imaging:* >1mCrab sources
  - Key discoveries:
    - X-ray jets; AGN dominate soft CXB
    - Morphology & evolution of X-ray clusters
    - Stellar coronae; X-ray binary spectra & haloes
    - Morphology of supernova remnants

And then followup lower-resolution focusing missions

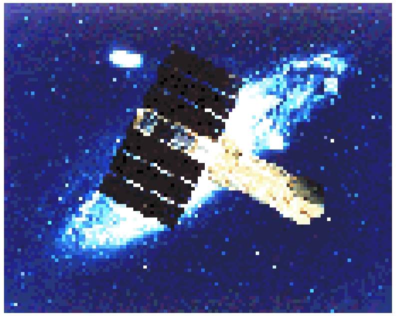
- **EXOSAT** (1983-86): ESA mission, 90h high orbit (long stares)
  - Two Wolter 1 XRTs: (0.05 – 2 keV)
    - PSD (IPC) & CMA (HRI) imagers; & trans. gratings for CMA
  - Non-imaging “Med. En.” prop. Ctr. (1-50 keV; 1600cm^2)
  - Key discoveries:
    - QPOs from X-ray binaries (ME; timing)
    - Fe line (6.4, 6.7keV) from AGN & clusters (ME spectra)

- **BeppoSAX** (1996-2002): Italy-Netherlands mission (1996-02):
  - 1 low energy concentrator + 3 med. energy conc. (conical reflectors)
  - High pressure GSPC & *2 coded aperture WideField cameras (2-20keV)*
  - Phoswich (NaI/CsI stack) hard X-ray detectors
  - Key discoveries: X-ray afterglows from GRBs (WFCs + MECs)

Followed by next Gen Focusing X-ray Telescopes

- **ROSAT** (1990-99): German-US-UK mission
  - Two imagers: PSPC and HRI (larger FoV/res. than Einstein); energy band 0.15 – 2.5keV; astrometry systematics limited positions to ≥10”
  - XUV telescope (5^o diam. FoV), 62 – 206 eV band
  - Key discoveries:
    - <u>All sky survey</u> (9mo.): ~150,000 sources!
    - Isolated NSs (still a challenge)
    - X-rays from comets (charge exch.) ***and more!***

- **ASCA** (1993-2000): Japan-US mission
  - First foil X-ray telescope (low mass!); response to 8 keV
  - *First X-ray CCD in space*
  - Key discoveries:
    - Relativistic Fe lines from AGN
    - Non-thermal emission from supernova remnants
    - Abundances in galaxy clusters: TypeII SNe origin



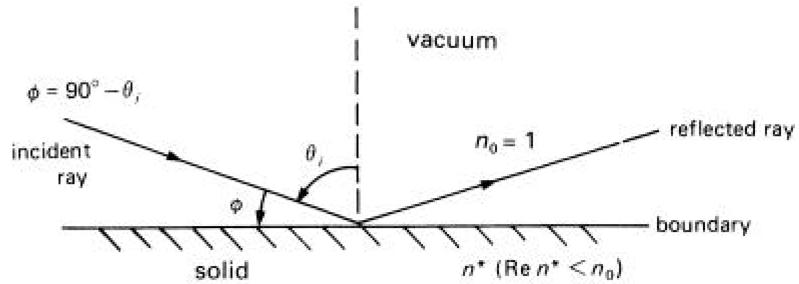
X-ray optics: *large* sensitivity gain but FoV limited

- Grazing incidence X-ray optics described by complex index of refraction, n^*, of reflector, where δ is phase change and β accounts for absorption. Total external refl. at $\cos \varphi_c = 1 - \delta$, and since $\delta \ll 1$, $\varphi_c = \sqrt{2\delta}$ and $\boldsymbol{\varphi_c = 5.6\, \lambda\sqrt{\rho}}$ ***arcmin*** for λ in Angstroms and mirror density ρ in g/cm^3

- Wolter I optics (paraboloid-hyperboloid) gives true focusing over area of *nested mirror shells* as shown here for ROSAT. FoV limited by E_{max} ~2 keV to ≤1^o

- Sensitivity of detector area of $A_{geom} \sim A_{mirror} \cos \varphi_c$ ~1100cm^2 for ROSAT vs. detector bkgd in only ~4cm^2: the *true imaging advantage* of low bkgd.

Reflection of X-rays



In the X-ray band the complex refractive index n^* is usually expressed as:

$$n^* = (1 - \delta) - i\beta,$$

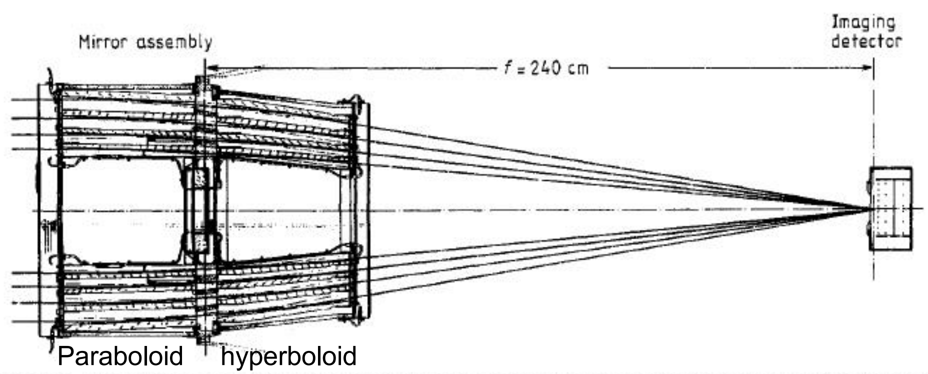
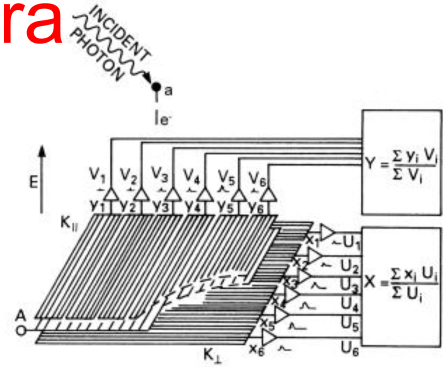


Figure 12. Schematic cross section of the Rosat telescope showing the four nested Wolter type I mirror systems.

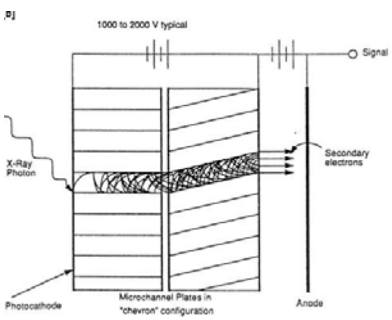
(from Aschenbach 1985 review)

Imaging detectors for Einstein, ROSAT and ASCA, Chandra

- **Imaging PCs** (Einstein IPC, or ROSAT PSPC): crossed anode-cathode planes with differing readouts (e.g. delay lines). Typical PC with ΔE/E ~1 @ 1 keV



- **Microchannel plates** (MCPs): 12.5 micron pore electron multiplier plates on Chandra HRC readout by crossed-grid with 16μs time resolution and essentially no energy resolution



- **CCDs** (e.g. ACIS on Chandra): close-tiled (2 x 2) on ACIS-I; 1 x 6 on ACIS-S; cooled Si detector achieves ~140eV resolution across full 0.3-7keV band and 10X better for grating readout

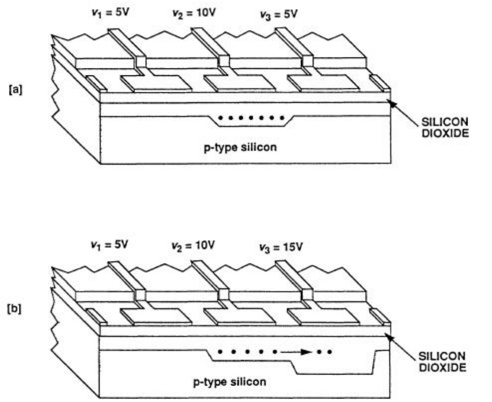
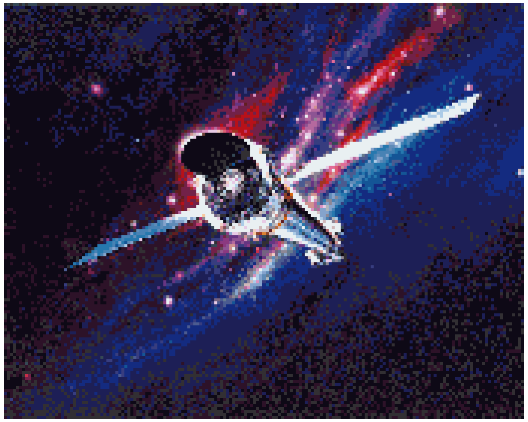


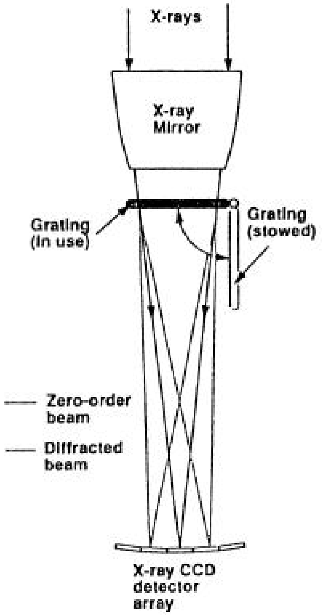
Fig. 3.14. Diagram illustrating how charge is transferred in a three-phase charge coupled device (CCD). (a) Electrons lie in the potential well formed by high voltage on v_2. (b) Increased voltage on v_3 causes charge to be transferred to the lower potential region.

And the ultimate(?) X-ray telescope: *Chandra*

- **Chandra** X-ray Observatory (1999 -):
  - 1.2m outer-shell, 4-shell zero-dur mirrors, polished to <2 Angstrom surface errors for imaging psf ~0.35" FWHM. 10m focal length!
  - Two CCD imagers: ACIS-I (16' x 16' FoV) = 2 x 2 front-side illuminated CCDs + ACIS-S = 1 x 6 CCDs including 2 front-side CCDs, for readout of dispersed spectra
  - HRC-I (microchannel plate detector) improved from ROSAT for high time-res. Soft (<3keV) imaging + readout HRC-S array for LETGS grating
  - Three transmission gratings for spectroscopy: HETGS, METGS (both for ACIS-S) and LETGS (read out by HRC-S)
  - **Science:** too rich to summarize; in NASA's top 10 accomplishments over its 50y history!

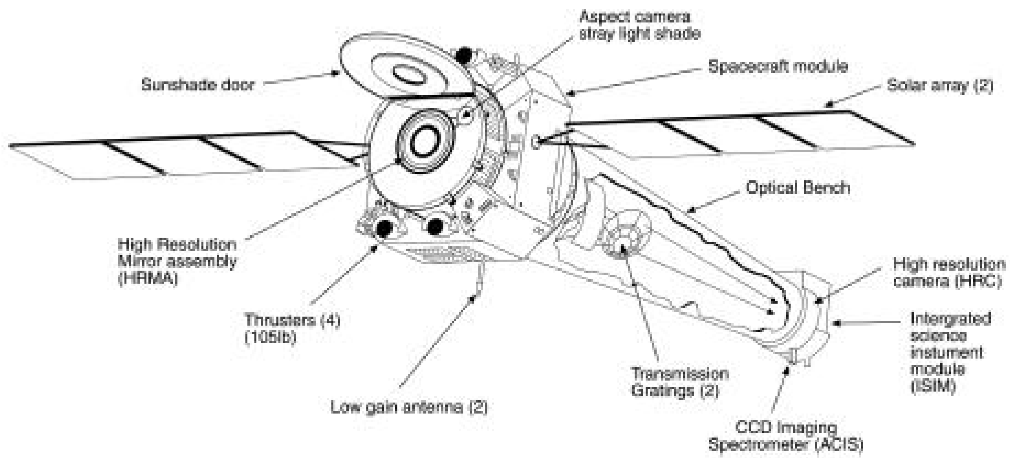


Obligatory artists conception…



Chandra **transmission grating** Spectrometers (HETGS, LETGS)

Chandra Instrument Layout and Parameters



Aperture Diameter (m)	Geometric Area (cm^2)	Focal Length (m)	Spatial Resolution (FWHM) (arcsec)	FOV (arcmin)	Energy Range (keV)	Spectral Resolution (Å)
1.2	1100	10.0	0.3	30	0.1-10	0.01-0.05

Chandra X-ray Observatory characteristics—an overview

Instrument	ACIS-I	HRC-I	ACIS-S$^{(1)}$	HRC-S$^{(2)}$
Bandpass (keV)	0.15–10	0.08–10	0.4–10	0.070–10
$E/\Delta E$	~ 50	1 @ 1 keV	65–1070	> 1000
Field of View arc min	16.9×16.9	30×30	8.3×50.6	6×99
Effective Area cm^2	600 @ 1.5 keV	227 @ 1.5 keV	200 @ 1.5 keV	1–25
Time Res.	2.85 ms	16 μs	2.85 ms	16 μs
Sensitivity$^{(4)}$	$4 \times 10^{-15(5)}$	$1 \times 10^{-15(6)}$	–	–

$^{(1)}$with the HEG and MEG, $^{(2)}$with the LETG, $^{(3)}$for 0.070–0.2 keV, $^{(4)}$in erg cm^{-2} s^{-1}, $^{(5)}$ in 10^4 s, $^{(6)}$in 3×10^5 s.

(From the Chandra X-ray Center's (CXC) Users' Guide, 2004.)

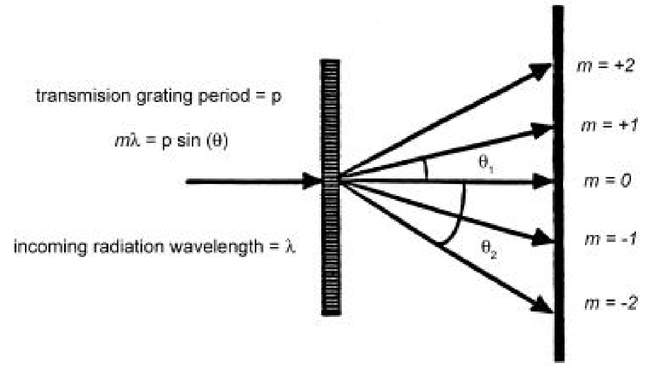
Chandra Orbit:

2.5d period; **0.3d loss of observations during perigee passage through trapped radiation belts.**

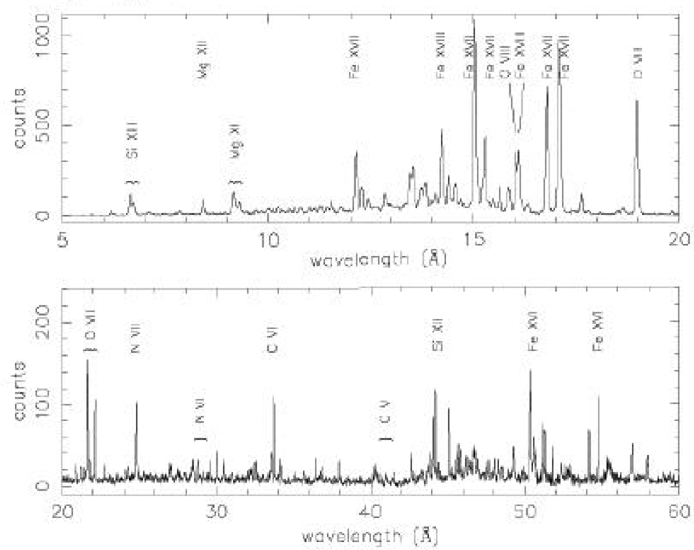
Chandra Transmission grating spectroscopy

Transmission grating spectroscopy

Principle of the X-ray transmission grating. **m** is the diffraction order.



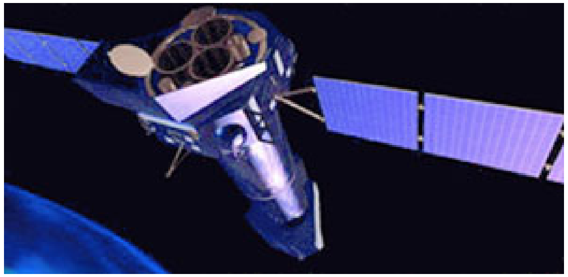
An example partial spectrum (binary star Capella) produced by the Chandra X-ray Observatory's Low Energy Transmission Grating Spectrometer (LETGS). The spectral resolving power is > 1000 in the wavelength range 50–160 Å.



(From Brinkman *et al.*, 2000, ApJ, **530**, L111)

XMM as most recent XRT, as well as future (IXO), step back to ROSAT resolution (~6”)

- **XMM-Newton** (1999 -): launched 5mo after Chandra, XMM has complementary characteristics: larger throughput, higher time resolution, but lower spatial and spectral resolution
  - 3 replicated telescopes (mandrel production): 2 for spectroscopy, 1 for high time resolution imaging. Effective area @1keV ~ 2X Chandra
  - Reflection gratings for dispersive R ~200 – 800 spectroscopy
  - PN CCDs on imaging telescope for fast timing
  - Optical monitor telescope (30cm) with 17’ FoV and 180 - 650 nm coverage



  - **Science:** Again, broad reach: from stars to MSPs (X-ray pulse profiles vs. energy constrain NS-EOS!) to AGN spectra, clusters and deep surveys…

Onto the Hard X-ray/Soft γ-ray band: ~10-600 keV

- **HEAO-A4** scanning all-sky survey (1977-79) on HEAO-1:
  Crossed "slat" scintillators (phoswich: NaI/CsI) detected ~80 sources, all known previously from 2-10keV observations. Flux limit: ~30mCrab **(**)**

- **OSSE** pointed phoswich detectors, Compton GRO (1990-99):
  large FoV (~3 x 11deg) NaI/CsI detectors detected ~150 sources over 9y as well as diffuse 511 keV in galactic bulge. Flux limit: ~10 mCrab

- **HEXTE** rocking (on/off) phoswich detectors on RXTE (1995-):
  2 x 800 cm^2 phoswich detectors chopping on/off pointings on sources detects some ~150 sources. Flux limit: ~3mCrab

- **PDS** (phoswich detector system) on BeppoSax (1996 – 02):
  detects ~100 sources. Flux limit: ~5 mCrab

****1mCrab = 2 x 10^{-11} erg/cm^2-sec)**

Hard X-ray missions operating, cont.

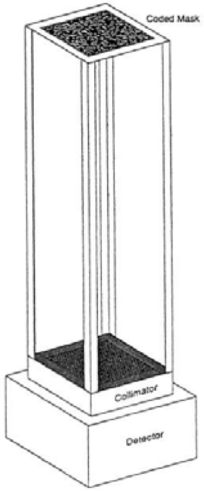
- **HXD** GSO/BGO phoswich on Suzaku (Japan-US; 2006 -): Well-type shielding (BGO, active collimator) gives very low background. Point-stare (*not* on/off source) obs. and bkgd. modeling achieve flux limit ~1 mCrab in ~1d exposure.

HXD flight unit

Above all require separate background measures, with systematic uncertainties. ⇨ coded mask ***imaging***

- **IBIS** CdTe/CsI stacked on INTEGRAL(2002-): coded mask telescope, with Uniformly Redundant Array (URA) cyclic mask. Source(s) cast shadow on pixel CdTe (4 x 4 x 2mm crystals; 10-200keV) on top of CsI bars (0.1-1MeV) for correlation imaging (12' resolution in 9^o FoV) and *simultaneous* background measure

URA coded mask



Schematic coded mask teles.

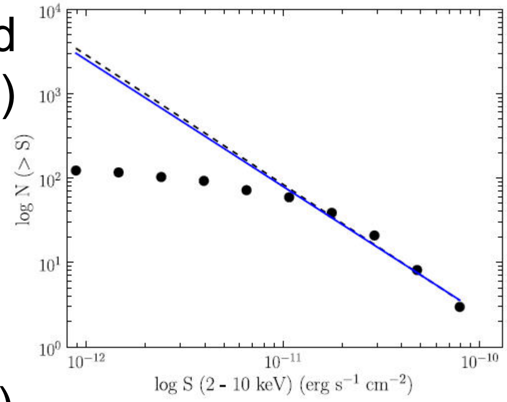
Culminating now in *Swift/BAT*

- **Swift/BAT (& XRT/UVOT):** US-Italy-UK Midex
  Burst Alert Telescope (BAT) is coded mask telescope (15 – 150 keV) with Cd-Zn-Te (CZT) detectors (4 x 4 x 2mm) to image ~70^o x 70^o with 22' resolution for rapid detection of Gamma Ray Bursts (GRBs) and location to ~3' for slew of X-ray Telescope (XRT) and UV-Optical Telescope (UVOT) to obtain ~1-2" locations and identifications for ground-based redshifts.

Swift/BAT blasted by a GRB

  – BAT sensitivity: Flux limit (5σ) ~ 3mCrab/T(days)$^{1/2}$, limited ~ 0.5mCrab (1y,systematics)

  – Corresponding AGN all-sky number (from logN-logS) for full sky BAT limiting survey is ~3000 *if systematics not dominant. Consistent with detection of 153 AGN in 9mo sample of partial exp. and coverage* (cf. Winter et al, arXiv)



XRT logN-logS normalized to 2-10keV for BAT AGN

Hard X-ray detectors: CZT vs. scintillators

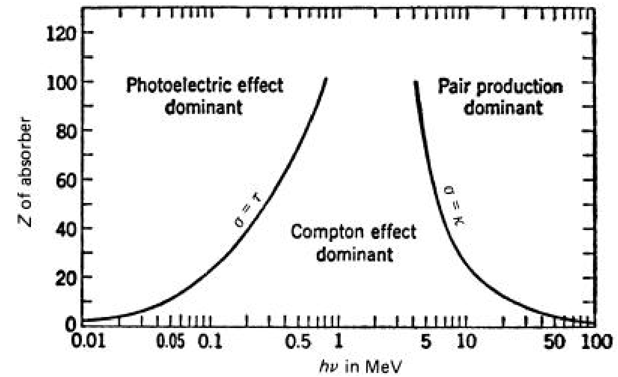
Properties of scintillation and solid-state detector materials

Material	Density ($g\ cm^{-3}$)	Band gap (eV)	λ of max. emission (Å)	Decay time[a] (μs)	Index of refraction[b]	Energy[c] (eV)	K-edge (keV)	Scintillation conversion[d] efficiency (%)	Notes
SCINTILLATORS									
NaI(Tl)	3.67	5.38	4100	0.23	1.85	–	1.07, 33.2	100	Hygroscopic
CaF_2 (Eu)	3.18	–	4350	0.94	1.47	–	0.68, 4.04	50	Non-hygroscopic
CsI(Na)	4.51	5.67	4200	0.63	1.84	–	33.2, 36.0	80	Hygroscopic
CsI(Tl)	4.51	5.67	5650	1.0	1.80	–	33.2, 36.0	45	Non-hygroscopic
Plastics	1.06	–	3500–4500	0.002–0.020	Varies	–	0.284	20–30	Non-hygroscopic
Liquids	0.86	–	3500–4500	0.002–0.008	Varies	–	0.284	20–30	Non-hygroscopic
SOLID-STATE									
Si(Li)	2.35	1.21	–	–	–	3.6	1.84	–	LN_2 required during operation
Ge(Li)	5.36	0.785	–	–	–	2.9	11.1	–	LN_2 required during operation
CdTe	5.85	1.44	–	–	–	4.43	26.7, 31.8	–	INTEGRAL/IBIS
CdZnTe (CZT)	5.81	1.6	–	Room temp. operation	–	4.6	26.7, 9.7, 31.8	–	Swift/BAT, ***EXIST***

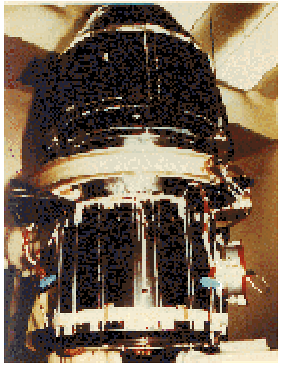
[a]Room temperature, exponential decay constant.
[b]At emission maximum.
[c]Per electron-hole pair.
[d]Referred to NaI(Tl) with S-11 photocathode.
(Adapted from *Harshaw Scintillation Phosphors*, The Harshaw Chemical Company.)

And, finally, *Gamma-ray Missions!*

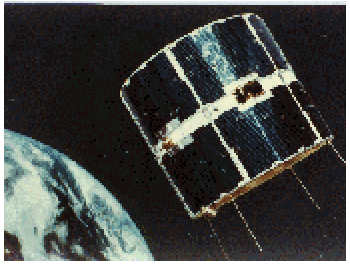
(from the Compton to pair regimes)



- **SAS-2** (following OSO-7) did 1st γ-ray Survey (1972-73):
  - Spark chamber (32 layers, aligned with satellite spin axis)
  - Energy range ~20 MeV – 1 GeV, A_{eff} = 540cm^2
  - detected Crab and Crab pulsar and Vela-X
  - mapped diffuse emission in Galaxy & background

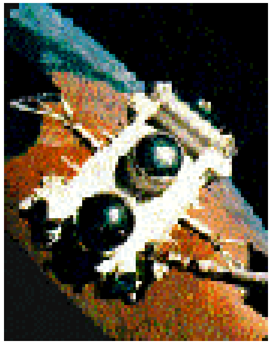


- **Cos-B** ESA mission carried out surveys (1975-82):
  - Magnetic core, wire matrix spark chamber, ~30 MeV – 5 GeV
  - X-ray proportional counter (2 – 12 keV)
  - Crab, Vela pulsars; discovered Geminga
  - First detailed map of Galaxy



Culminating in Compton GRO

- **Compton Gamma-ray Observatory** (1991-2000):
  - 4 instruments:
    - **EGRET:** spark chamber covering ~30 MeV – 10 GeV
    - **COMPTEL:** Compton telescope, 0.8 – 30 MeV
    - **OSSE:** NaI scintillators, 0.05 – 10 MeV
    - **BATSE:** NaI scintillators (8), 20 – 1000 keV



  - **Key Science:**
    - Isotropic distribution of GRBs; likely cosmologically distant sources
    - Blazars as dominant feature of ~100 MeV sky
    - New pop of gal. plane sources (pulsars?) & gal. diffuse emission
    - ^{26}Al decay line (1.8MeV) mapped throughout Galaxy
    - Black hole transients and X-ray binary HX variability vs. states

Which led to….the ultimate… *GLAST*

(and why we are here…)

- 2 main instruments:
  - LAT: ~8000cm^2 Si tracker & CsI calorimeter with ~10X sensitivity and spatial resolution of EGRET
  - GBM: Optimized (long triggers, etc.) BATSE already matching it for GRB rates

- Key science (guesses from GUG chair):
  - Pulsars all over the disk (but *not* MSPs…)
  - *Flaring Blazars*; LBLs can match PKS2155 !
  - (Many) more LSI-61+xxx type Be-HMXBs
  - ULX/MicroBlazars in Local Group: Flaring Jets

And what do we need next ?

- **NuSTAR** and the focusing HX telescope (2012?) for deep surveys at ~1arcmin resolution for AGN at fluxes F(20-40 keV) ~ 5 x 10^{-14} erg/cm^2-sec, for ~30 AGN per sq. degree or sample N ~1000 AGN in ~5 x 5 degrees which will probe z ~1 – 2 for obscured fraction and constrain evolution of SMBH growth

- ***EXIST***(**) as the ultimate wide-field coded aperture HX telescope for full-sky (every 2 orbits) surveys reaching F(20-40 keV) ~ 5 x 10^{-13} erg/cm^2-sec, for ~1 AGN per sq. degree or sample N ~40,000 AGN for which 50% are at z >0.2 and ~1-2% at z >2. Constrain SMBH growth by *unique survey for Type 2 QSOs: do they EXIST?*

(**Energetic X-ray Imaging Survey Telescope)

What else would ***EXIST*** do ?

(unsolicited advertising…)

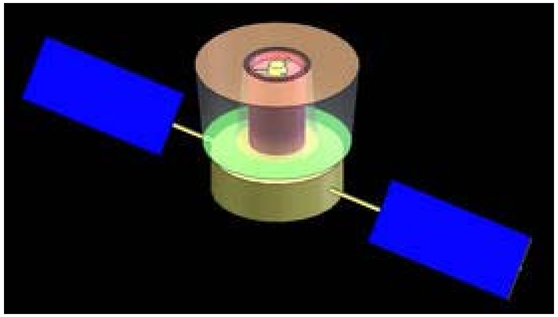
- Complement GLAST surveys for flaring Blazars and measure synch. vs. IC variable peak for Jet physics *and required measurement for EBL*

- With a 1.1m IRT (optical-IR imager/spectroscopy telescope for prompt GRB redshifts), and rapid (~100sec) pointing, *EXIST* is the ultimate multi-wavelength HEA observatory: spectra from NIR, 2.5μ to 0.3μ and 5-600 keV, with *possible* addition of an XRT (0.3 – 7 keV) from Italy!

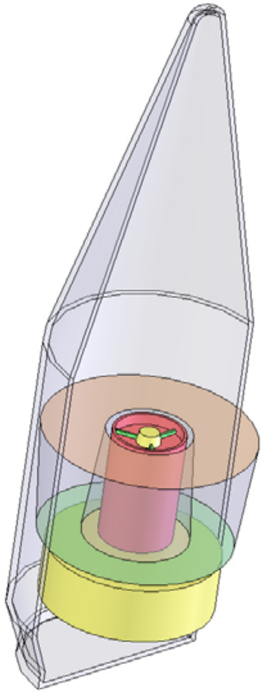
- And much more…. (as the upcoming Decadal Survey will hear)

Current Baseline design for ***EXIST***

- Large area (5.5m^2) imaging CZT detector, close-tiled 0.6mm pixels. 5σ survey limit sources located to R(90%) ≤15"



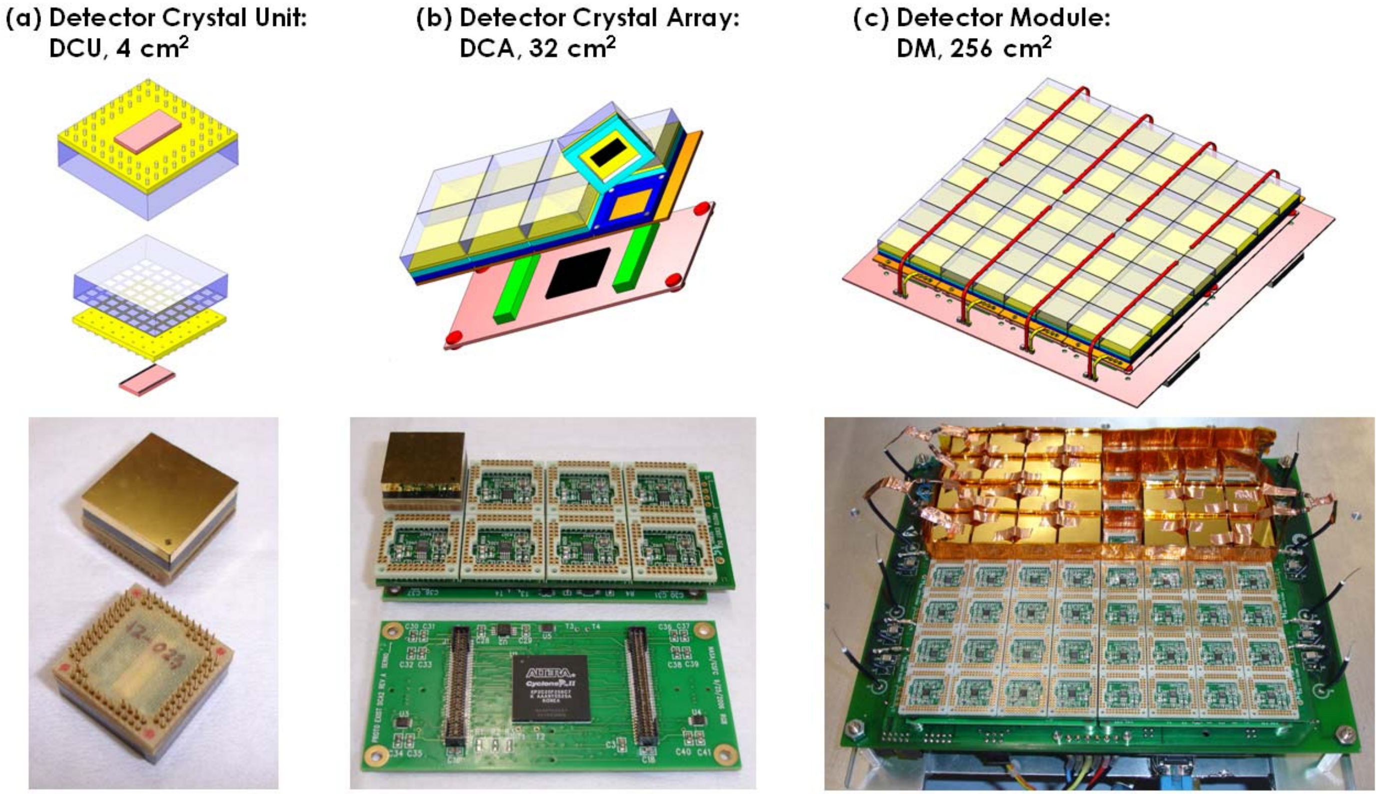
- Central 1.1m opt-NIR telescope, cooled passively (cold sky) to -30C for sky-limited backgrounds at <2.2μ. AB(H) ~24 in 100s! ~10X faster than Keck. Obj. prism and IFU for low/high res. spectra of GRBs & AGN sample. NIR *needed* for high-z GRBs and obscured AGN



- Fits in 3.7m fairing of Atlas401 or ESA-Soyuz (possible Italian launch from Kourou?)

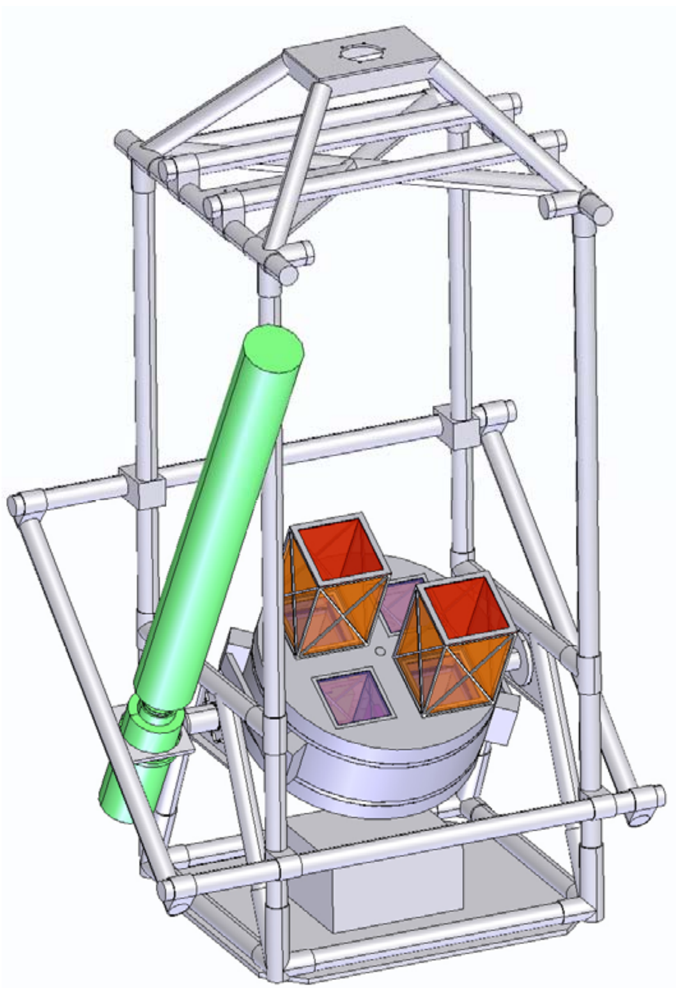
Could we (or anyone) build 5.5m^2 of imaging CZT?

- **ProtoEXIST** (balloon-borne prototype) is teaching us how:



- **Balloon flight** test for 2 sub-telescopes in May, 2009

Integrate detectors, electronics into pressure vessel and pointing system for *ProtoEXIST1*



- **Demonstrate the technology for large array CZT detectors with small pixels covering 10 – 600 keV**

  ProtoEXIST1 **~ 500 cm^2 (2.5 mm pixel)**
  ProtoEXIST2 **> 256 cm^2 (0.6 mm pixel)**
  to enable ***EXIST*** **~ 5 m^2 (0.6 mm pixel)**

- **Determine the optimal shielding configuration for HETs in *EXIST* (active vs. passive side shields? Optimum rear active shields & GRB spectroscopy)**

- **Further demonstrate continuous scanning coded-aperture imaging technique (already "proven" with BATSS! But optimize scanning & analysis techniques)**

  ProtoEXIST1 1st flight: Spring 2009

Proposing/selling a mission (e.g. *EXIST*)

- **Unique science?** Yes: **1.** GRBs as probes of z >7 Universe; Constrain epoch of re-ioniz. from pre-QSOs; **2.** BH and Jet physics of extremes; **3.** *Discover and identify the transient Universe: BH novae to SMBH tidal flares*

- **Technology ready?** Yes, though close-tiling & vertical integration is challenging; ASICs @ required ~20μW/ch not yet available (but within factor of ~2)

- **Time is "right"?** Yes, unique synergies with GLAST, LSST, and JWST

- **Is it affordable?** Yes, as "Medium Mission", particularly if Italian collaboration provides XRT, anti-co rear shield (BGO), OR launch

Summary

- X-ray astrophysics has prospered (and not *all* missions were listed above!). HEA is deservedly "rich" given the cutting edge fundamental science it probes
- GLAST has set a great example; it was proposed at the same time (1994) as Con-X and EXIST…
- The success of Swift/BAT (and INTEGRAL), the unique power of wide-field imaging, argue strongly for the next push for the HX band, both focusing (NuSTAR, NEXT) and ***EXIST*** to close the all-sky gap in "νF_ν" between ROSAT and GLAST.

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