Astrofisica Nucleare e Subnucleare

Gamma ray Bursts – III

BeppoSAX (1995 - 2002)

S A X P/L ACCOMODATION

GSPC - HP

PHOSWICH

CONCENTRATORS

WIDE FIELD CAMERAS

UPPER FLOOR

SHEAR PANEL

CONE

LOWER FLOOR
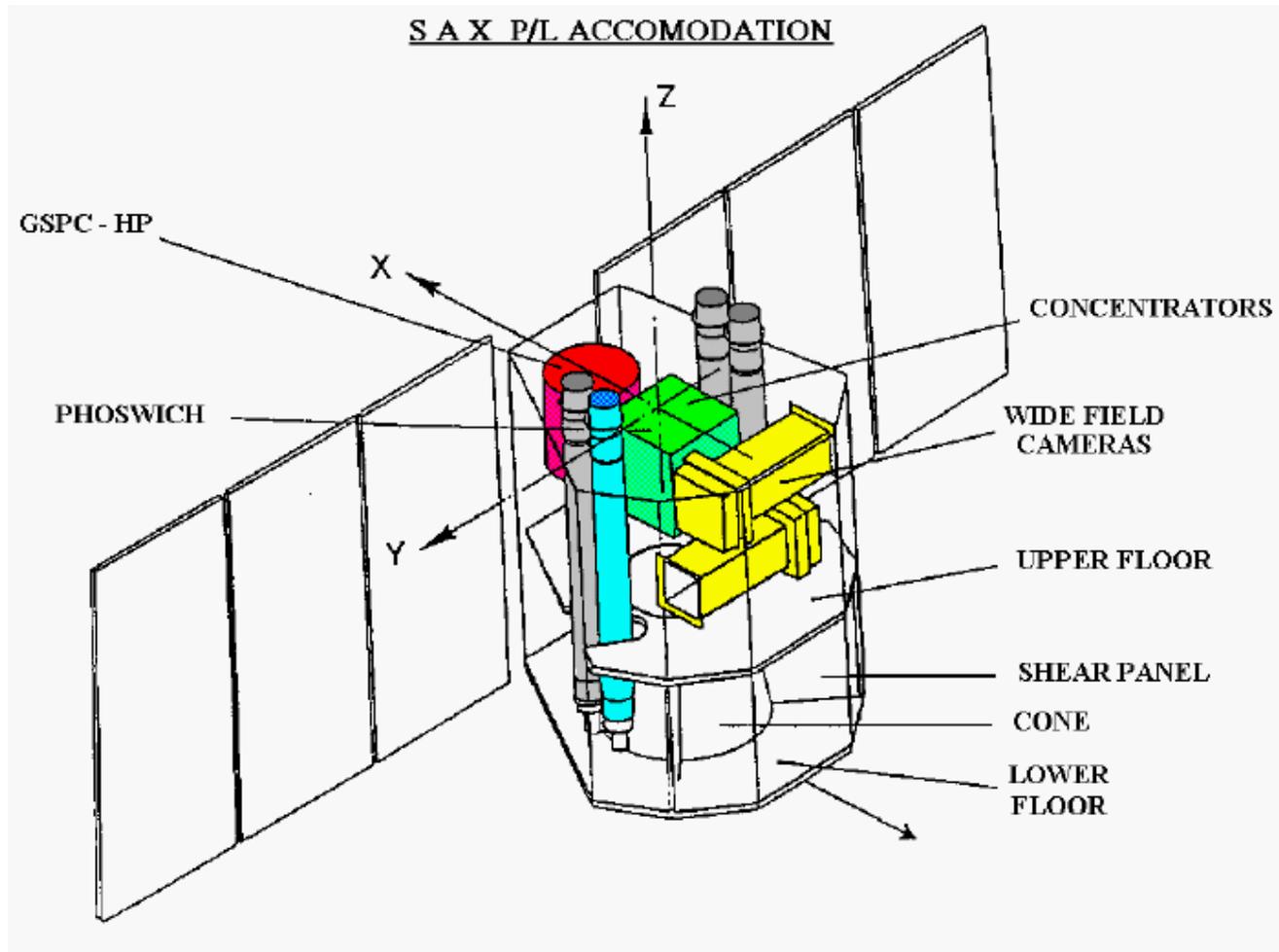
Coded Mask Imaging

The principle of the camera is straightforward: photons from a certain direction in the sky project the mask on the detector; this projection has the same coding as the mask pattern, but is shifted relative to the central position over a distance uniquely correspondent to the direction of the photons. The detector accumulates the sum of a number of shifted mask patterns.

Each shift encodes the position and its strength encodes the intensity of the sky at that position.
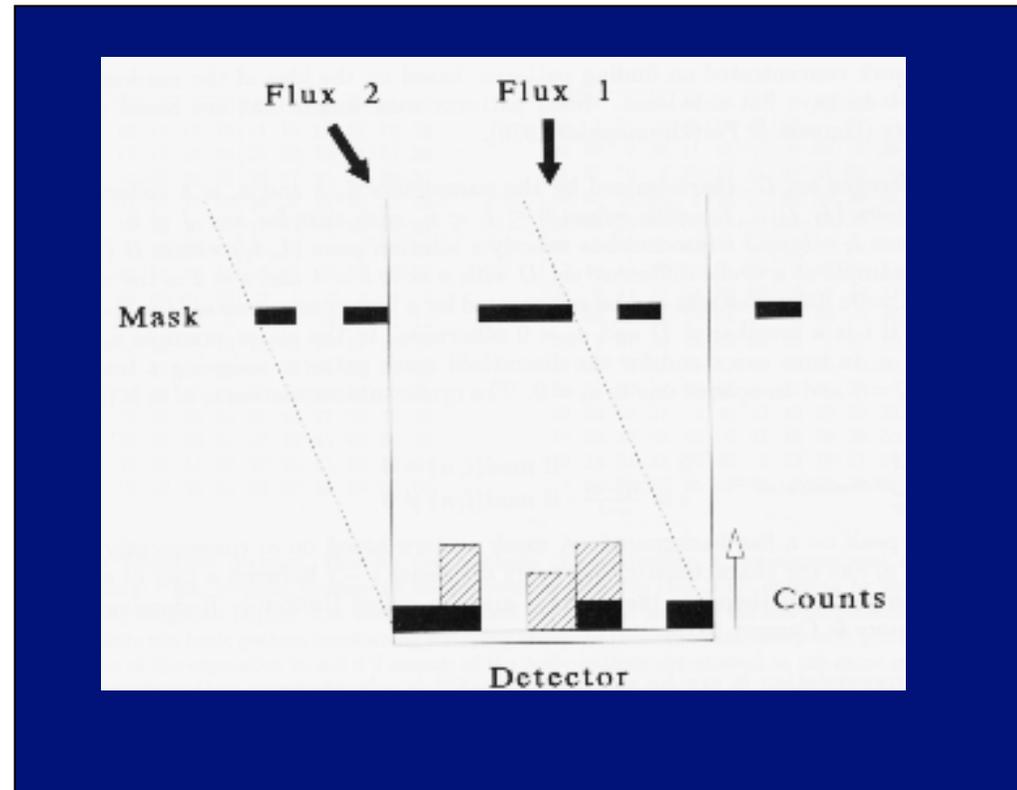
http://asd.gsfc.nasa.gov/archive/cai/coded_intr.html

The GRB phenomenon

- in 1997, thanks to BeppoSAX observations, discovery of fading X-ray, optical, radio emission following the GRB

- photons received during the classical GRB phenomenon are then called "prompt emission" and the subsequent fading emission is called "afterglow emission"

prompt

afterglow
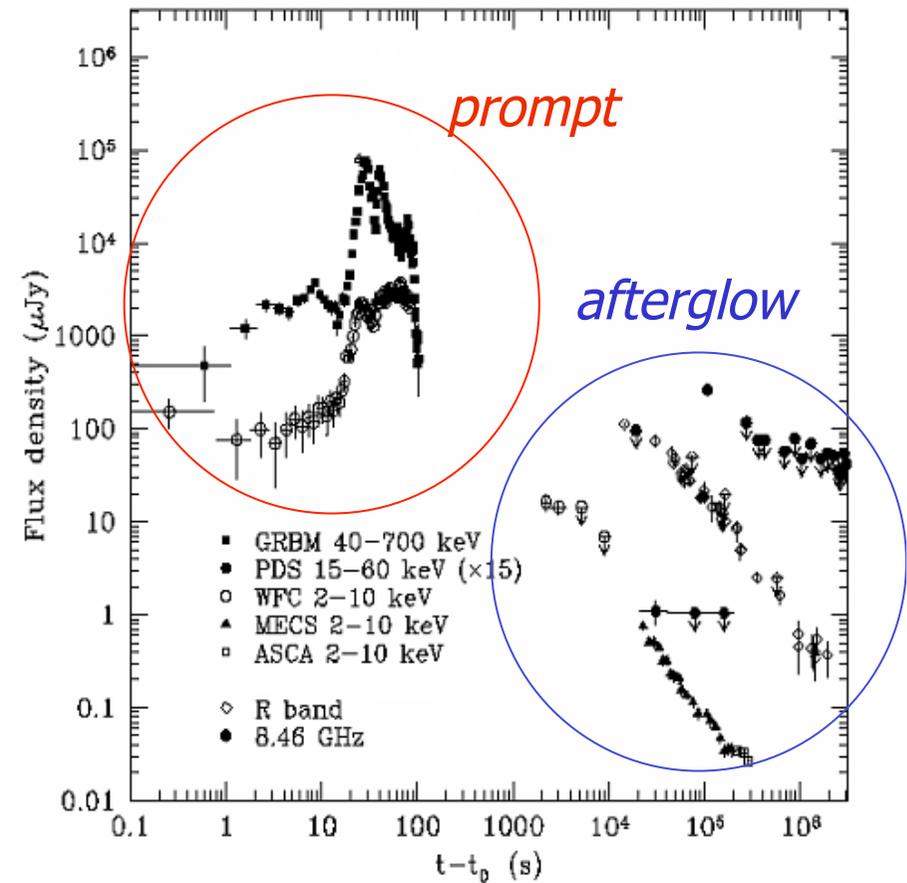
Adapted from Maiorano et al., A&A, 2005

The compactness problem

$$R_i < c\delta t \qquad \gamma\gamma \to e^+ e^-$$

$$\tau_{\gamma\gamma} = \frac{f_p \sigma_T F D_L^2}{R_i^2 m_e c^2} \approx 10^{17} f_p \left(\frac{F}{10^{-6} erg/cm^2}\right)\left(\frac{D_L}{3 Gpc}\right)^2\left(\frac{\delta t}{1 ms}\right)$$

$$\tau_{\gamma\gamma} \gg 1$$

Very High Optical Depth to pair production

Size | Pair fraction

$$\Gamma = \frac{1}{\sqrt{1-\beta^2}} \qquad R_i < \Gamma^2 c\delta t \quad f_p \to f_p \Gamma^{-2\alpha}$$

$$\tau_{\gamma\gamma} = \frac{f_p \sigma_T F D_L^2}{R_i^2 m_e c^2} \approx \frac{10^{17}}{\Gamma^{4+2\alpha}} f_p \left(\frac{F}{10^{-6} erg/cm^2}\right)\left(\frac{D_L}{3 Gpc}\right)^2\left(\frac{\delta t}{1 ms}\right)$$

$$\Gamma \approx 10^2 \div 10^3$$

Piran (1999)

5

Relativistic motion of the emitting region

The Fireball model

- Relativistic motion of the emitting region
- Shock mechanism converts the kinetic energy of the shells into radiation.
- Baryon Loading problem

External Shock
- Synchrotron & SSC
- High conversion efficiency
- Not easy to justify the rapid variability
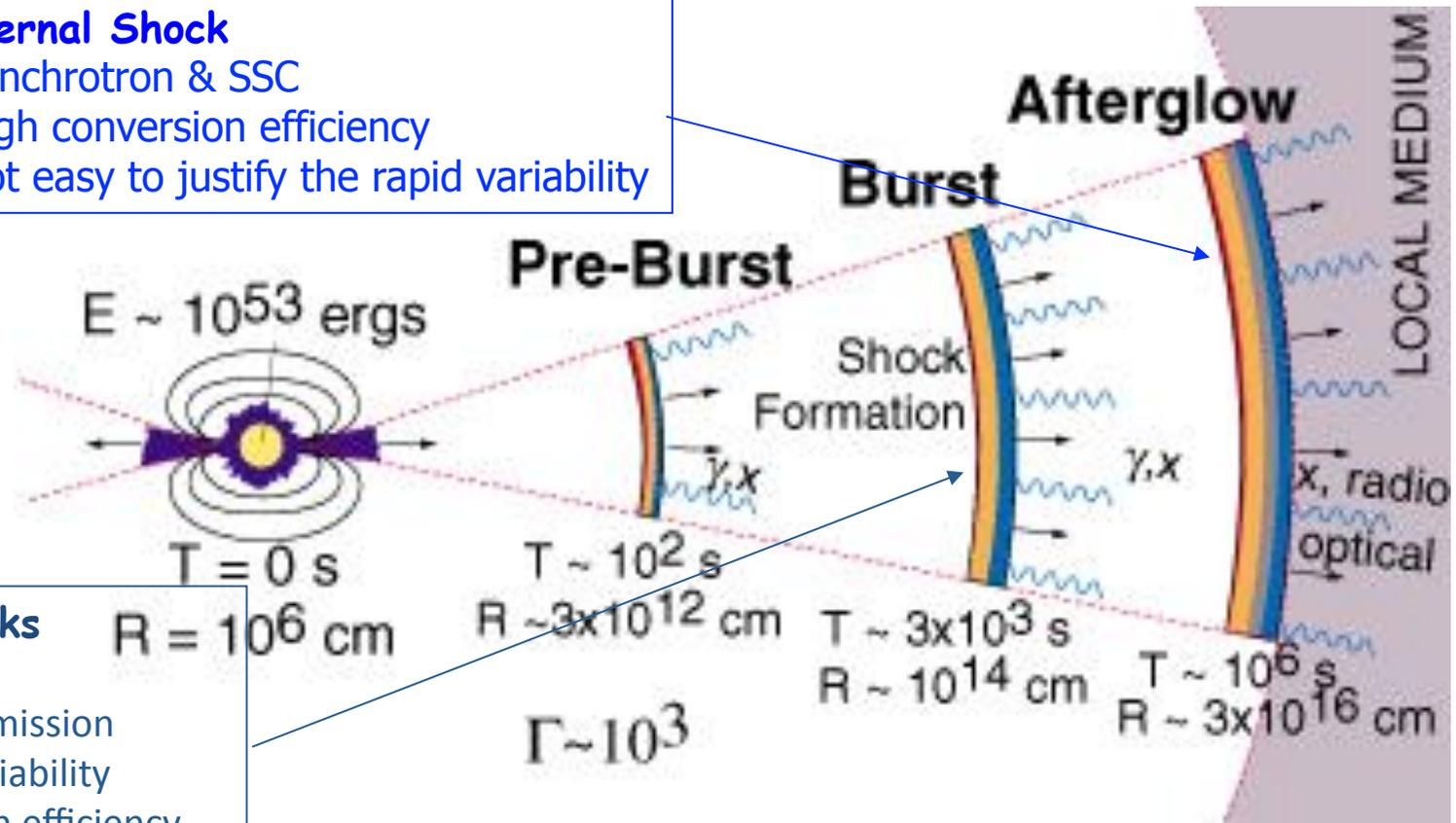
Internal Shocks
- Source activity
- Synchrotron Emission
- Rapid time Variability
- Low conversion efficiency

Afterglow

Burst

Pre-Burst

$E \sim 10^{53}$ ergs

Shock Formation

γ, x

LOCAL MEDIUM

γ, x

x, radio optical

$T = 0$ s
$R = 10^6$ cm

$T \sim 10^2$ s
$R \sim 3 \times 10^{12}$ cm

$T \sim 3 \times 10^3$ s
$R \sim 10^{14}$ cm

$T \sim 10^6$ s
$R \sim 3 \times 10^{16}$ cm

$\Gamma \sim 10^3$

Jet breaks
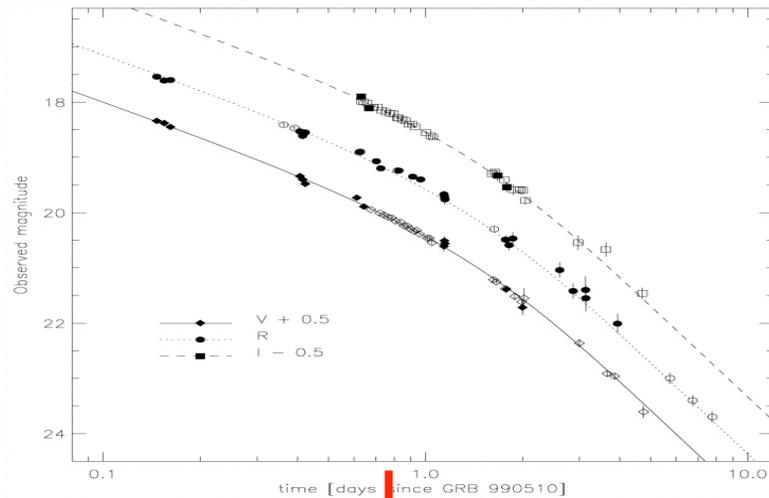
> ➤ breaks in the afterglow decay light curves -> collimation ?

$$\theta = 0.09 \left(\frac{t_{jet,d}}{1+z}\right)^{3/8} \left(\frac{n\,\eta_\gamma}{E_{\gamma,iso,52}}\right)^{1/8}$$

$$E_\gamma = (1 - \cos\theta)E_{\gamma,iso}.$$
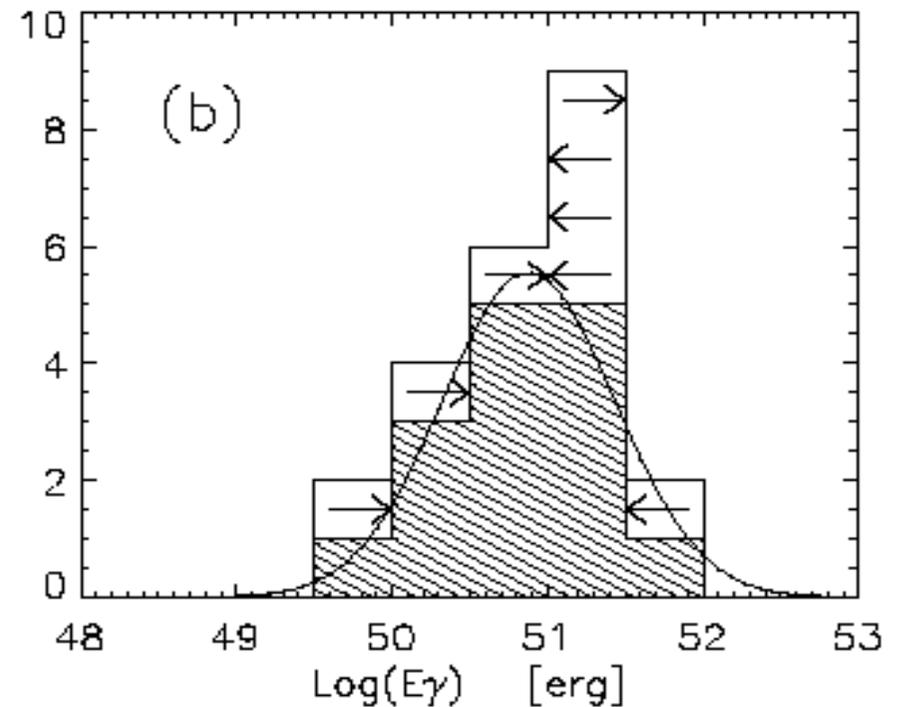
GRB for Cosmology
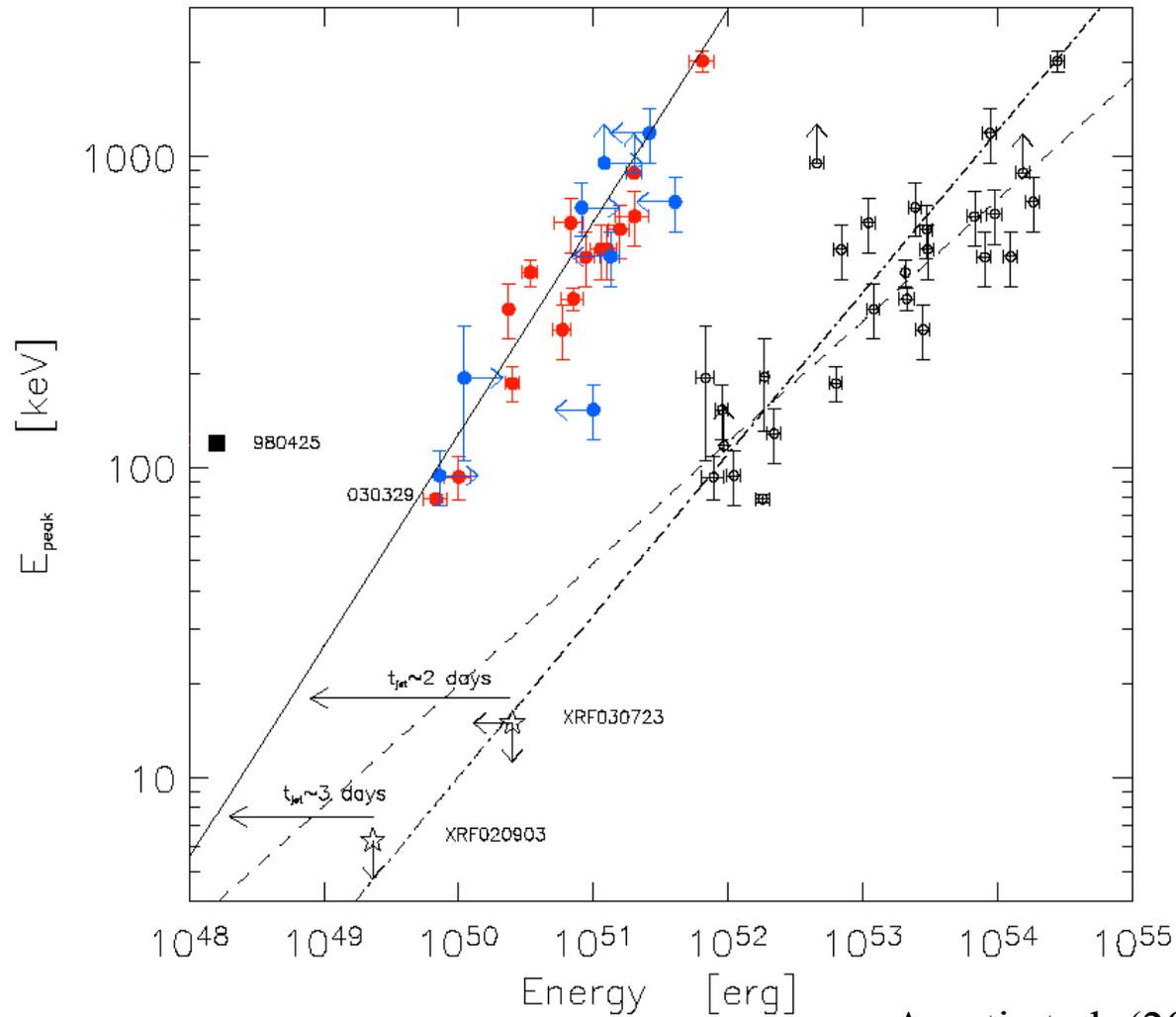
Amati et al. (2002)
Ghirlanda et al. (2004)

8

SN Ia Cosmology

SNe Ia as a "standard candle"

The Phillips relation for SNe Ia

as measured

"stretch-factor" corrected

Riess et al. (2007)
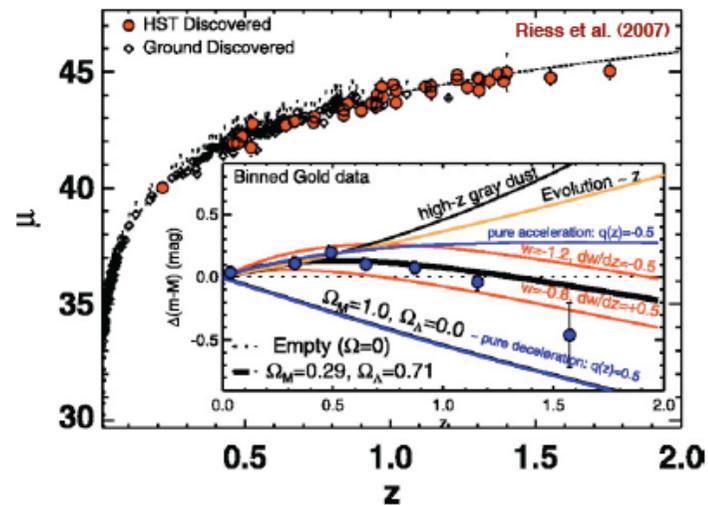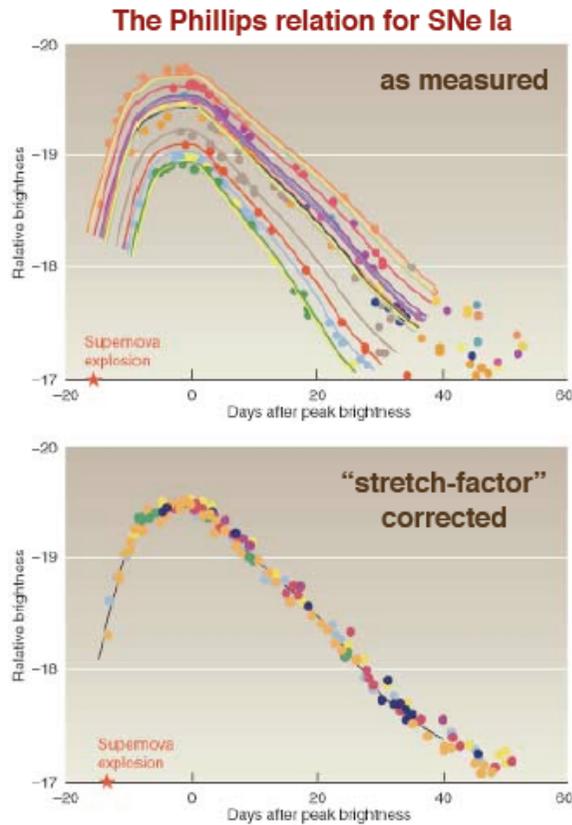
Can we apply GRBs as a standardized candle?

☐ **Method** (e.g., Ghirlanda et al, Firmani et al., Dai et al., Zhang et al.)**:**

$$E_{p,i} = E_{p,obs} \times (1 + z) \,, \; t_{b,i} = t_b / (1 + z)$$

$$E_{\gamma,iso} = \frac{4\pi D_l^2}{(1 + z)} \int_{1/1+z}^{10^4/1+z} E\,N(E)\,dE \quad \text{erg}$$

$$D_l = D_l(z\,, H_0\,, \Omega_M\,, \Omega_\Lambda\,,...)$$

➢ fit the correlation and construct an Hubble diagram for each set of cosmological parameters -> derive c.l. contours based on chi-square
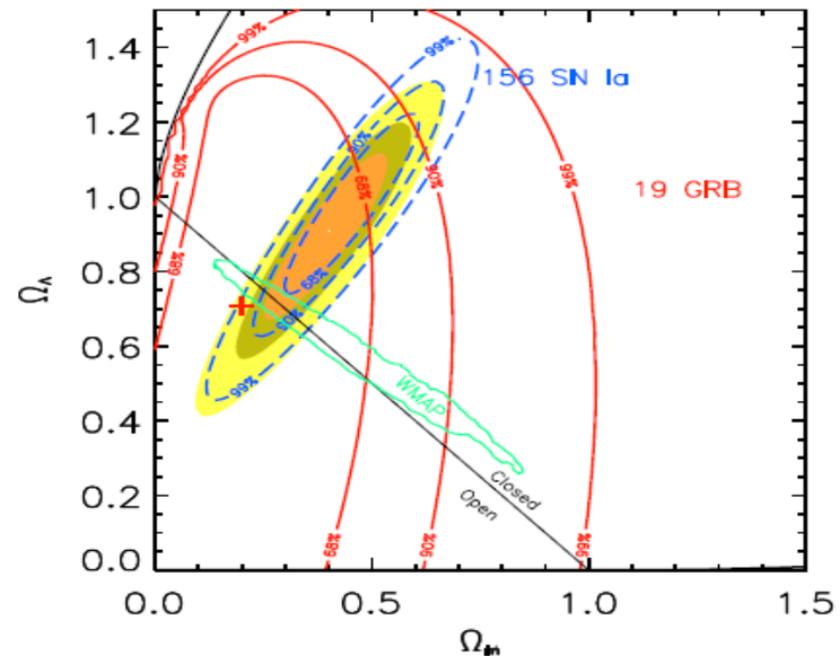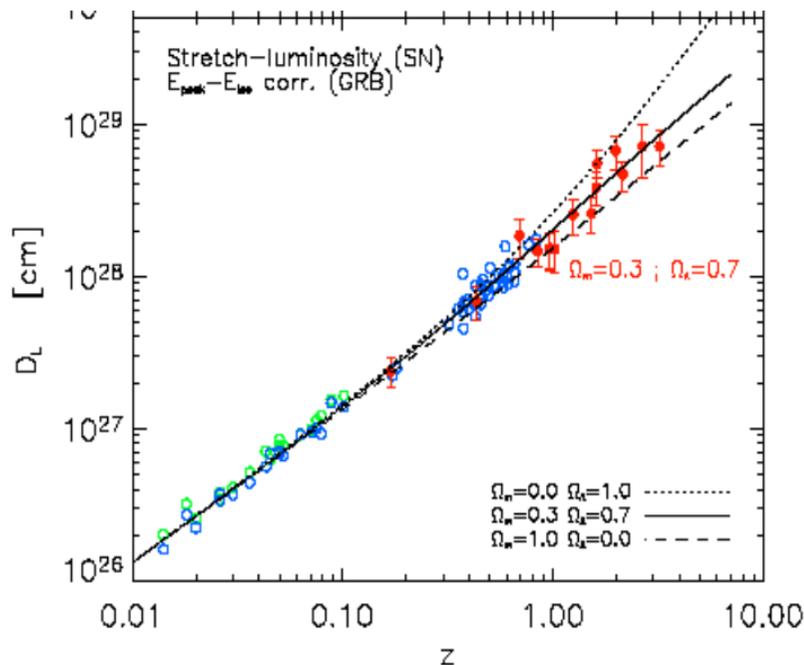
□ results obtainable with 150 GRBs with estimates of z, $E_{p,i}$ and tb
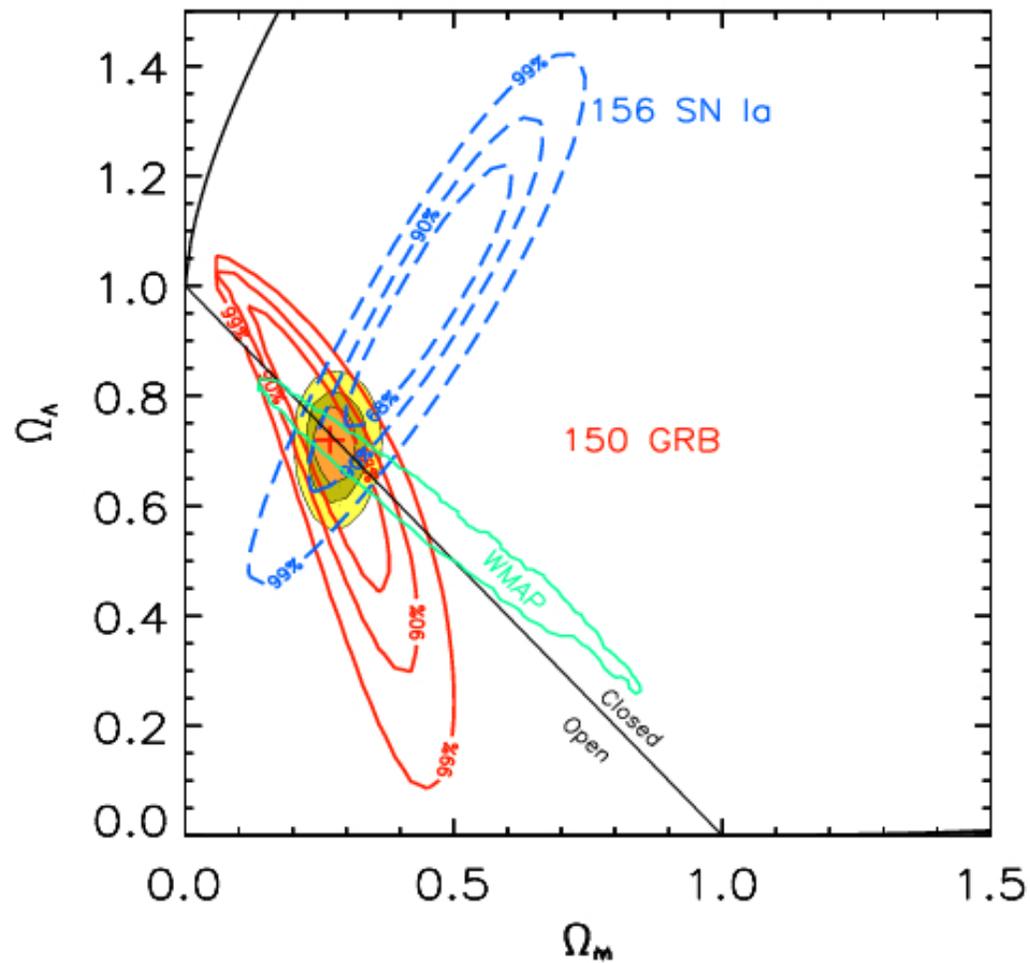
Ghirlanda et al. 2006 A&A

Ghirlanda et al. 2006 JOP Review, GRB Special Issue

Luminosity distance

Distance measures in cosmology

DAVID W. HOGG

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`hogg@ias.edu`

2000 December

1 Introduction

In cosmology (or to be more specific, *cosmography,* the measurement of the Universe) there are many ways to specify the distance between two points, because in the expanding Universe, the distances between comoving objects are constantly changing, and Earth-bound observers look back in time as they look out in distance. The unifying aspect is that all distance measures somehow measure the separation between events on radial null trajectories, ie, trajectories of photons which terminate at the observer.

In this note, formulae for many different cosmological distance measures are provided. I treat the concept of "distance measure" very liberally, so, for instance, the lookback time and comoving volume are both considered distance measures. The bibliography of source material can be consulted for many of the derivations; this is merely a "cheat sheet." Minimal C routines (KR) which compute all of these distance measures are available from the author upon request. Comments and corrections are highly appreciated, as are acknowledgments or citation in research that makes use of this summary or the associated code.

2 Cosmographic parameters

The *Hubble constant* H_0 is the constant of proportionality between recession speed v and distance d in the expanding Universe;

$$v = H_0 \, d \tag{1}$$

The subscripted "0" refers to the present epoch because in general H changes with time.

The Luminosity Distance

$$\Omega_{\mathrm{M}} + \Omega_{\Lambda} + \Omega_k = 1 \qquad z \equiv \frac{\nu_{\mathrm{e}}}{\nu_{\mathrm{o}}} - 1 = \frac{\lambda_{\mathrm{o}}}{\lambda_{\mathrm{e}}} - 1$$

$$E(z) \equiv \sqrt{\Omega_{\mathrm{M}}\,(1+z)^3 + \Omega_k\,(1+z)^2 + \Omega_{\Lambda}}$$

$$H_0 = 100\,h\ \mathrm{km\,s^{-1}\,Mpc^{-1}} \qquad D_{\mathrm{H}} \equiv \frac{c}{H_0} \qquad D_{\mathrm{C}} = D_{\mathrm{H}} \int_0^z \frac{dz'}{E(z')}$$

$$D_{\mathrm{M}} = \begin{cases} D_{\mathrm{H}}\,\dfrac{1}{\sqrt{\Omega_k}}\,\sinh\left[\sqrt{\Omega_k}\,D_{\mathrm{C}}/D_{\mathrm{H}}\right] & \text{for } \Omega_k > 0 \\[2mm] D_{\mathrm{C}} & \text{for } \Omega_k = 0 \\[2mm] D_{\mathrm{H}}\,\dfrac{1}{\sqrt{|\Omega_k|}}\,\sin\left[\sqrt{|\Omega_k|}\,D_{\mathrm{C}}/D_{\mathrm{H}}\right] & \text{for } \Omega_k < 0 \end{cases}$$

$$D_{\mathrm{L}} = (1+z)\,D_{\mathrm{M}}$$

astro-ph/9905116v4

Luminosity distance and redshift
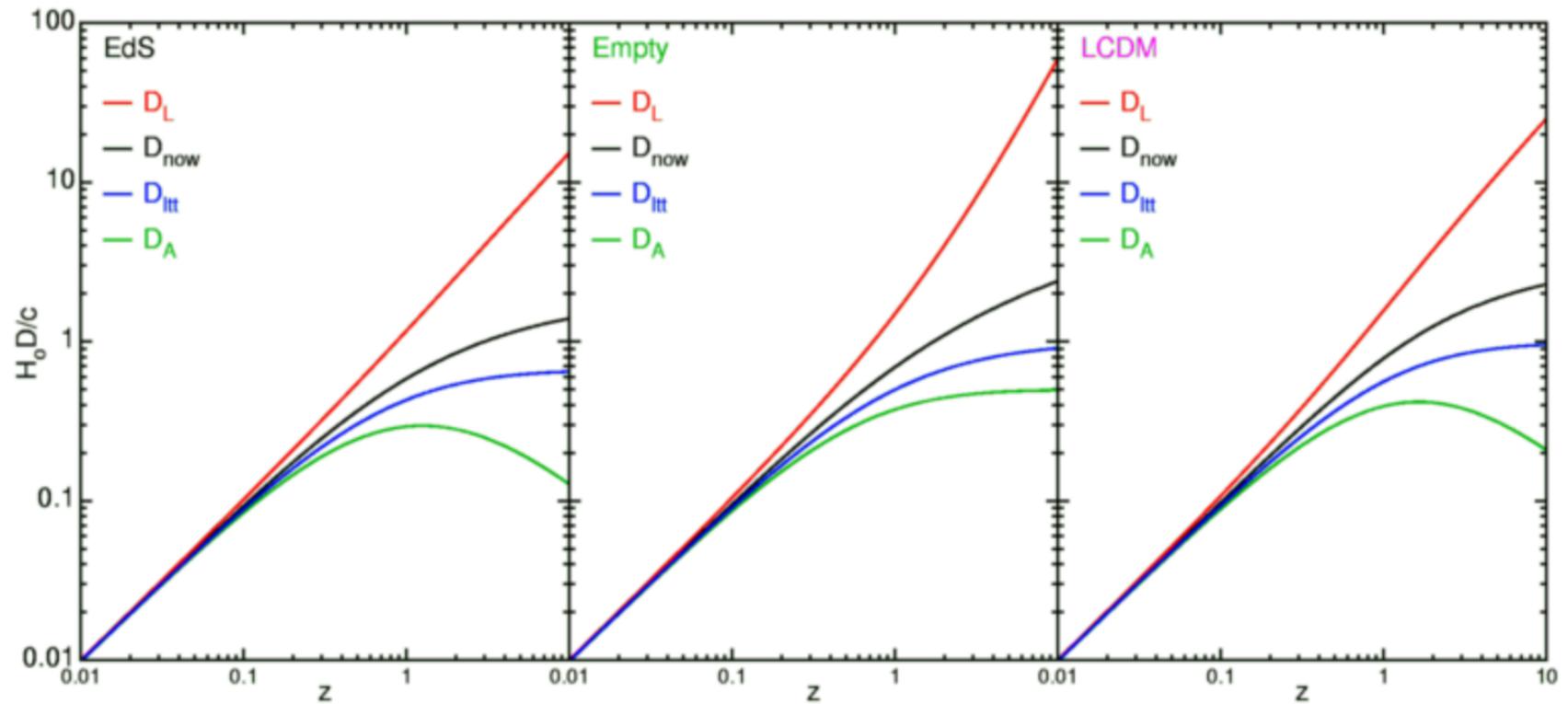
Swift Instruments

Instruments

- **Burst Alert Telescope (BAT)**
  - **New CdZnTe detectors**
  - **Most sensitive gamma-ray imager ever**

- **X-Ray Telescope (XRT)**
  - **Arcsecond GRB positions**
  - **CCD spectroscopy**

- **UV/Optical Telescope (UVOT)**
  - **Sub-arcsec positions**
  - **Grism spectroscopy**
  - **24th mag sensitivity (1000 sec)**
  - **Finding chart for other observers**

Spacecraft

- **Autonomous re-pointing, 20 - 75 s**
- **Onboard and ground triggers**

BAT

UVOT

XRT
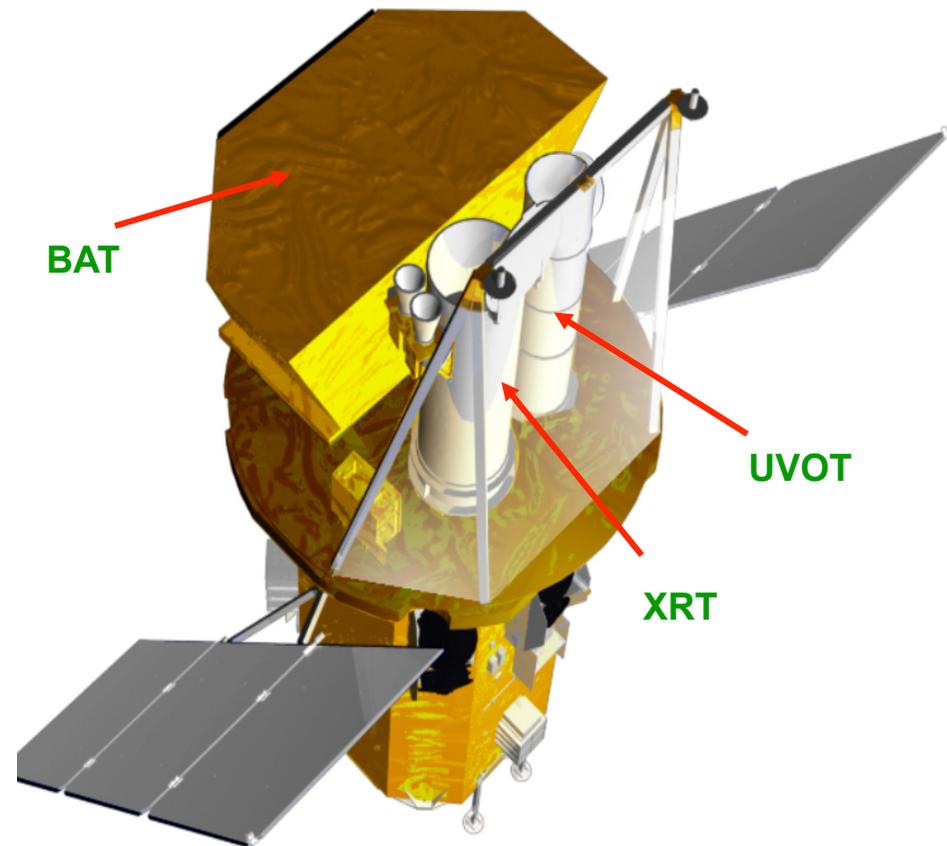
Swift

Details

- **BAT** (15-350 keV). Large (2 sr) field of view – detects bursts with arc min accuracy. And tells observers immediately.

- *Swift* automatically determines if it can view the GRB, and if so, slews to it.

- **XRT** (0.3-10 keV) and **UVOT** (~1000-6000 Å) begin observing typically within 100 s of the trigger.

- XRT can automatically detect afterglows, and downlinks limited data immediately. ~90% of BAT GRBs have promptly detected XRT afterglows.

SWIFT

BAT Field Of View
Partially Coded
Half Coded
Fully Coded
30°
Gamma Ray (arc-minute)

Background-subtracted images
unsubtracted images
10"
part of coarse image (FFT-correlation)
2"
fine small-field (back-projection)

BAT error circle
X-ray (2.5 arc-second)

UVOT (0.3 arc-second)
2'
XRT error circle
5"
Groot, GRB970508 at 1+2 days, WHT

HST, Keck, etc.
UVOT
XRT
10"

17
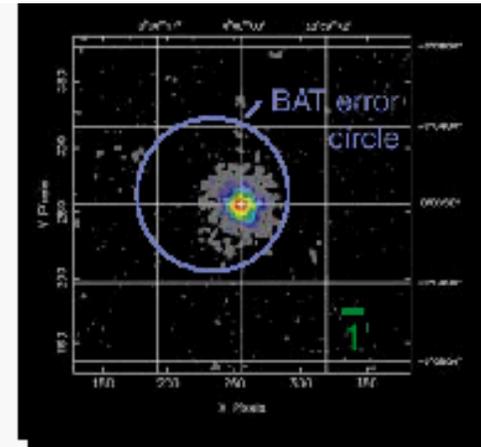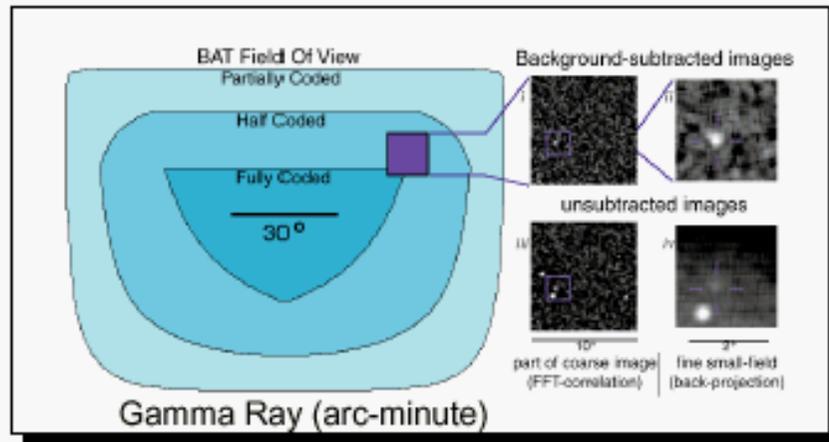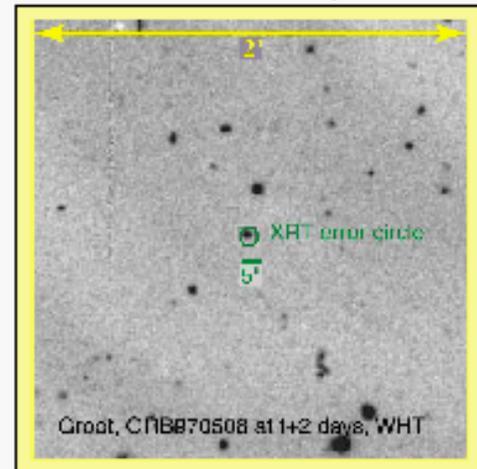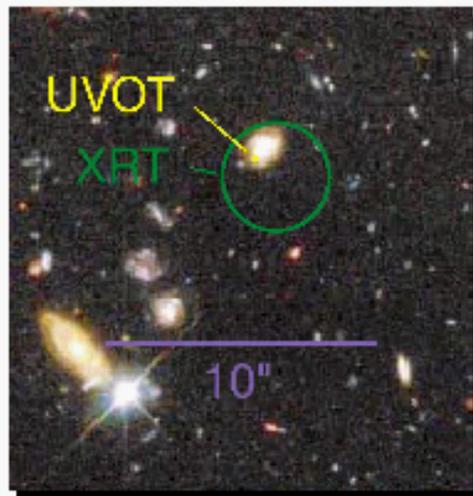
Exercise #3

- Check and navigate into Swift web sites
- Check the recently launched mission Einstein Probe
- Check what SVOM and Theseus missions will be …

SWIFT

https://swift.gsfc.nasa.gov/

SWIFT

https://www.swift.ac.uk/index.php

Swift: Catching Gamma-Ray Bursts on the Fly

U.S. site
Italian site
U.K. site

UNIVERSITY OF LEICESTER
School of Physics & Astronomy

The Neil Gehrels Swift Observatory

As of 3rd March, Swift has resumed normal science operations, with both ToO and GRB response re-enabled. High urgency ToOs can again be submitted. (GCN 31668)

Welcome to the UK Swift Science Data Centre.

The NASA-led Swift satellite discovers Gamma-Ray Bursts (GRBs) and measures their X-ray and optical afterglows to arc-second accuracy within a minute or two, continuing to make spectral observations until they fade from view days, weeks or even months later. Swift has been finding around 90 new bursts a year since launch in November 2004. It has provided the most complete study of GRBs so far, finding the most distant objects in the Universe and rapidly advancing science in this area. Swift is a rapid-response multi-wavelength facility which is ideal for observations of transient and variable sources; it has a Guest Investigator programme and a flexible Target of Opportunity programme which is well used.

On this site you can find out more about the mission and GRBs, as well as obtaining data from the on-board instruments and building X-ray products.

Picture courtesy of Spectrum Astro

One of our team is tweeting about life as a Swift scientist - follow him on Twitter!

Latest Swift Detected GRBs

GRB 220310C
GRB 220310A
GRB 220306B
GRB 220305A
GRB 220302A

Quick Links

Swift in the news
Training Opportunities
GRB and Swift Conferences
Targets of Opportunity
Guest Investigator Program
Build XRT products

Helpdesk

Questions about Swift? Try our guide to Swift or the guide to data processing and analysis. If these don't solve your problem, please feel free to e-mail us at swifthelp@le.ac.uk.

List of acronyms and abbreviations

We are located in the Department of Physics & Astronomy , at the University of Leicester (directions).

SWIFT

https://swift.asdc.asi.it/

Space Science Data Center SSDC ASI Agenzia Spaziale Italiana

Home   About SSDC   News and Communication   Quick Look   Missions   Multimission Archive   Catalogs   Tools   Links   Bibliographic services

Helpdesk   Privacy

Swift: Catching Gamma-Ray Bursts on the Fly — XRT BAT UVOT

U.S. site Italian site U.K. site

Swift Home   About Swift   ASI HQ Swift Home   Swift Data Archive   Swift pointings   Swift Catalogs   Swift Quicklook Data   Swift Data Analysis

Swift Helpdesk   GCN   ToO Request Form   Malindi ground station   Gallery

The Swift Gamma-Ray Burst Mission

ASI Swift Scientific Page (Italian)

Swift is a MIDEX Gamma Ray Burst mission led by NASA with participation of Italy and the UK. The Swift data are available to the scientific community through data centers in the USA, Italy and the UK.

Italy contributes to the mission providing:

- **The XRT X-ray mirror**
- **The Malindi ground station**
- **XRT data reduction and analysis software**

The ASI Science Data Center (ASDC) contributes to the mission providing:

- **Swift Data Archive Mirror**
- **On-line XRT & UVOT data analysis**
- **Swift Quick Look Data (XRT & UVOT Interactive Quick Look)**
- **XRT Burst Support (XBS) and Burst Advocate (BA) activity**

An artist rendering of the Swift satellite catching a Gamma-ray Burst

High z - searches

High-z Universe: searching for the best probe

Galaxies

Pros

★ Multiband data are available (some)

★ Refurbished HST

★ Different technique (LBG/Lyα emission)

★ Do not "disappear"

Cons

★ Small region of the sky (11 arcmin^2)

★ Required several hours of observations

★ Very faint objects

★ Galaxy templates are complex

★ Difficult determination of
   Age/dust/SFR

Gamma-ray Bursts

Pros

★ Very bright

★ Happens everywhere

★ Can be followed quickly from
   space and ground (now at least)

★ **Have a very simple spectrum**
   (synchrotron, simple power-law)

★ Allow better investigation of τ_{HI}

Cons

★ Rare (few "good ones")

★ Fade fast, ~minute position
   identification (space mission)

★ Require multiband observations

High redshift GRB

GRB & Cosmology

History of the Universe

Redshift	Time		
			Big Bang - Hot ionized gas
1000 -			The Universe becomes neutral and opaque
100 -	17 Myr	Dark Ages	
			Stars and galaxies form Reionization starts
10 -	480 Myr		
			Cosmic Renaissance Dark Ages end
5 -	1.2 Gyr		Reionization complete
			Galaxies evolve
0.5 -	8.7 Gyr		Solar System forms
0 -	13.7 Gyr		

Djorgovski et al.

Einstein Probe

Einstein Probe

Report of the first month of EP in-orbit commissioning phase

During the first month, the satellite has been confirmed to be in good condition.
- Basic satellite function testing has been completed.
- Attitude control stability and maneuvering speed meet the scientific requirements.
- Transmission of the links between the satellite and ground channels is stable.

Six of the twelve WXT modules have completed one week of bake-out, respectively.
- Calibration observations are currently being conducted on the SNR Crab.
- Data from the calibration observations have been successfully transmitted to the ground.
- All levels of data products have been automatically produced.

The FXT payload has successfully completed the unlocking of the sunshield flipping mechanism.
- FXT refrigeration cooled the pn-CCD down to -90 °C, and the pnCCD operated normally.
- Particle background data were collected with the telescope cover on.
- All levels of data products have been automatically produced.

https://ep.bao.ac.cn/ep/
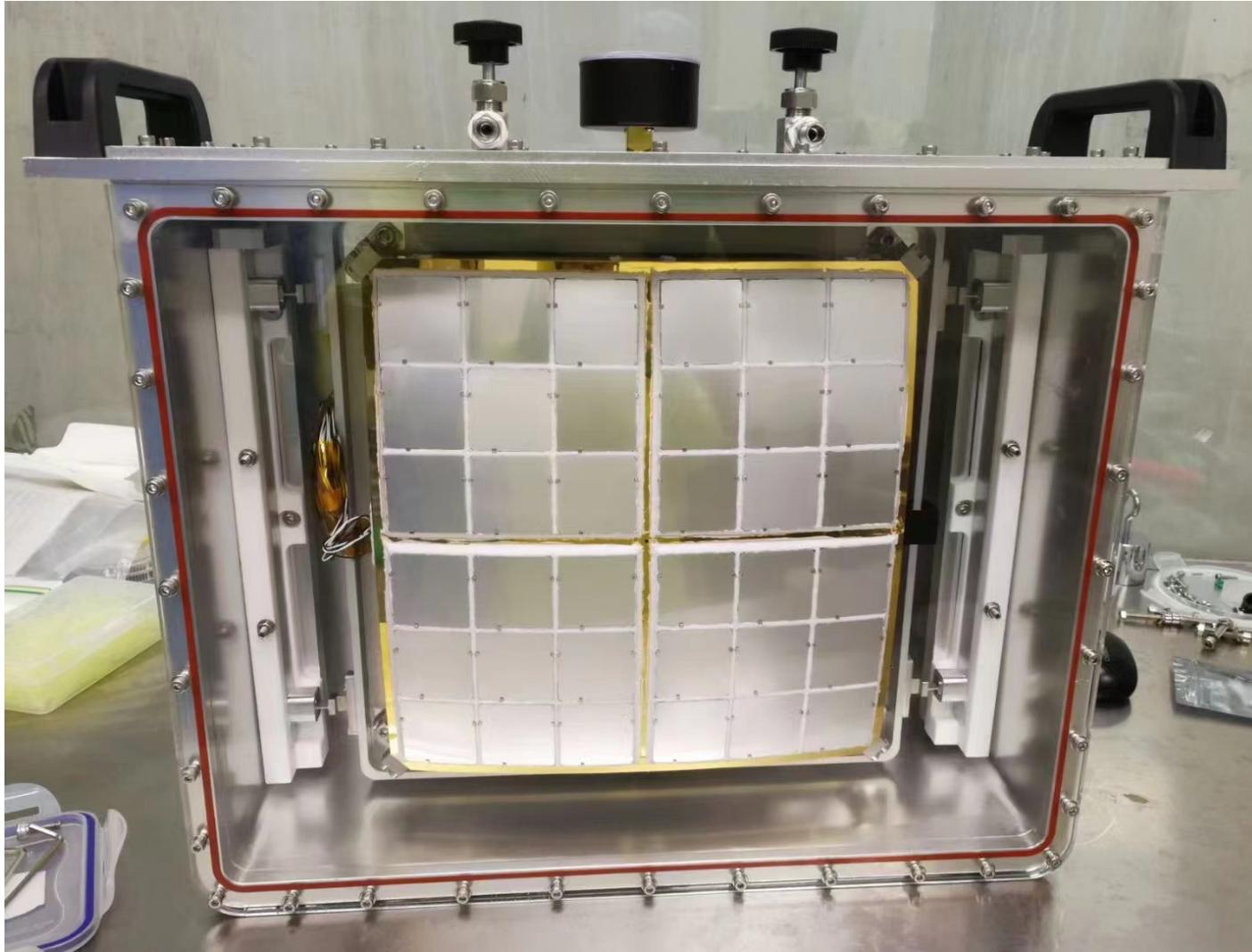
Einstein Probe
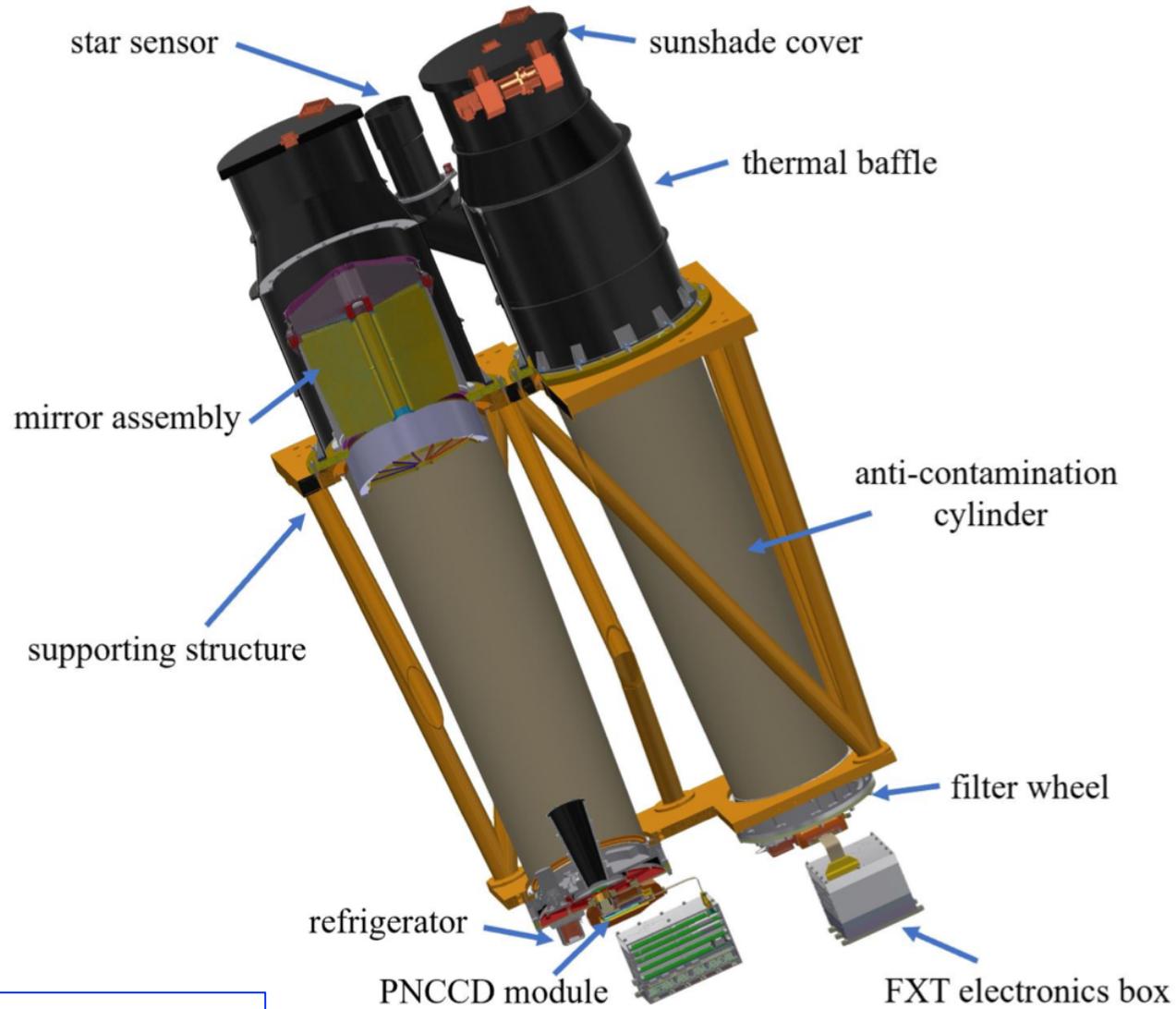
Einstein Probe

Einstein Probe

News

MORE

EP-WXT detected a fast X-ray transient EP240315a	[2024-03-17]
EP-WXT Detected a Bright X-ray Flare EP240305a	[2024-03-08]
EP-WXT Detected a Bright X-ray Flare in its Commissioning Phase	[2024-02-22]
EP Performs as Expected in the First Month of the In-orbit Commi…	[2024-02-09]

General Coordinates Network

Missions   Notices   Circulars   Documentation   Sign in / Sign up

New Announcement Feature, Code of Conduct, Circular Revisions. See news and announcements

https://ep.bao.ac.cn/ep/

← Back   Text   JSON   Cite (ADS)   Request Correction

GCN Circular 35936

Subject X-ray transient EP240315a: VLT/X-shooter spectroscopic redshift of z = 4.859
Date 2024-03-17T06:54:26Z (13 hours ago)
From Andrea Saccardi at Observatoire de Paris <andrea.saccardi@obspm.fr>
Via Web form

A. Saccardi (GEPI/Obs. de Paris), A. J. Levan (Radboud Univ. & Warwick Univ.), Z. Zhu (NAOC), B. P. Gompertz (U. Birmingham), S. D. Vergani (GEPI/Obs. de Paris & IAP & INAF/OABr), G. Pugliese (API), D. Xu (NAOC), D. B. Malesani (DAWN/NBI and Radboud Univ.), report on behalf of the Stargate collaboration:

We observed the field of the ATLAS optical counterpart AT2024eju (Srivastav et al., GCN 35932) of the fast X-ray transient EP240315a reported by the WXT instrument during the commissioning phase of the Einstein Probe mission (Zhang et al, GCN 35931) using the ESO/VLT UT3 (Melipal) equipped with the X-shooter spectrograph. Our spectra cover the wavelength range 3000-21000 AA, and consist of 4 exposures of 1200 s each. Observations started at 01:02:52 UT on Mar 17 2024 (~29 hr after the trigger). We detect a clear continuum across both VIS and NIR arms. From the detection of a Lya absorption at ~7120 AA and multiple absorption features, which we interpret as being due to OI, SiII, NV, CIV and SiIV, we infer a redshift of z = 4.859. We also note the presence of additional absorption features likely due to multiple intervening systems. The high redshift of the transient suggests a highly energetic event and potentially links this Fast X-ray Transient to a GRB-like phenomena.

We acknowledge the excellent support from the ESO staff in Paranal, in particular Joe Anderson and Matias Jones.

SVOM
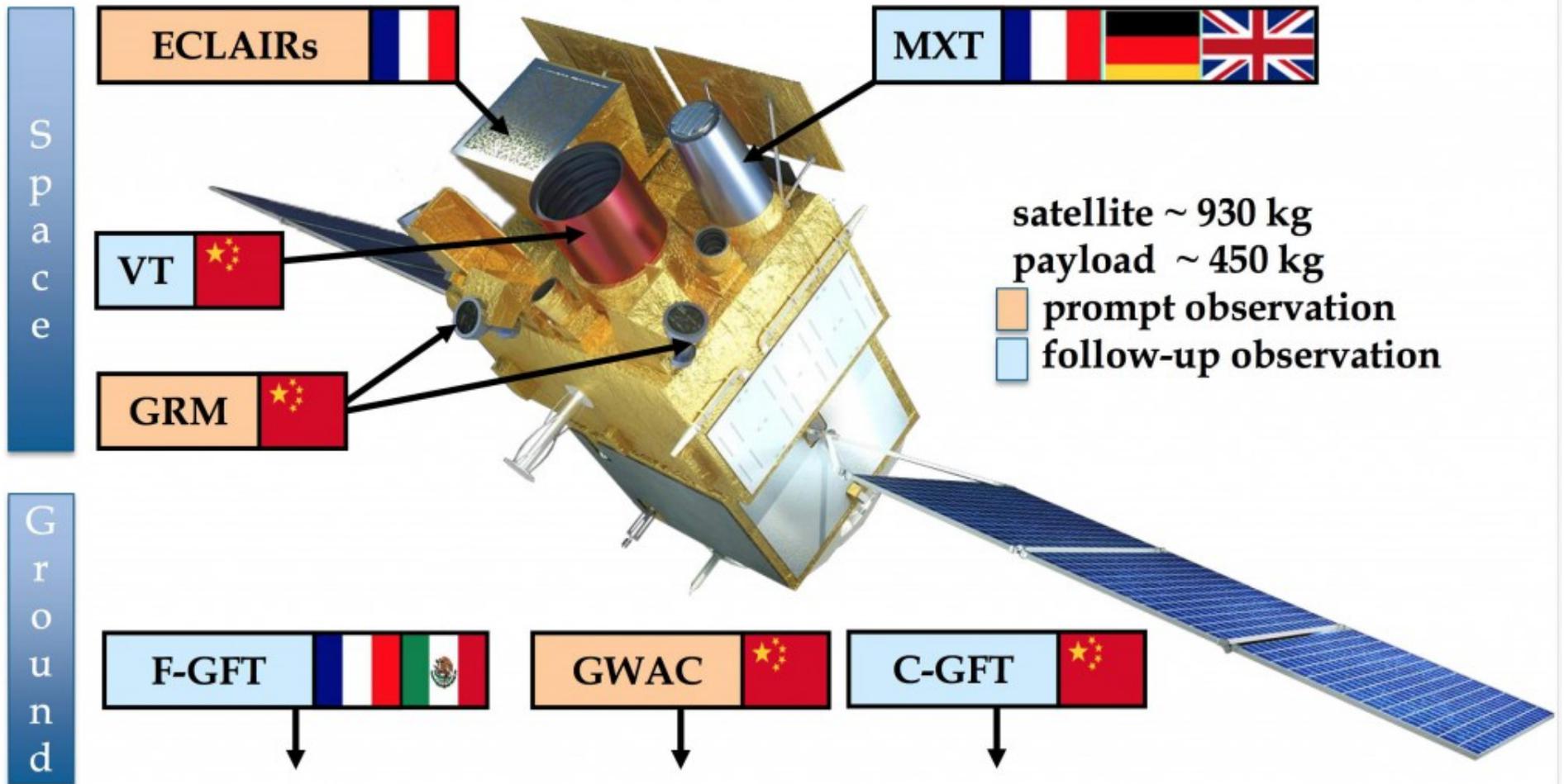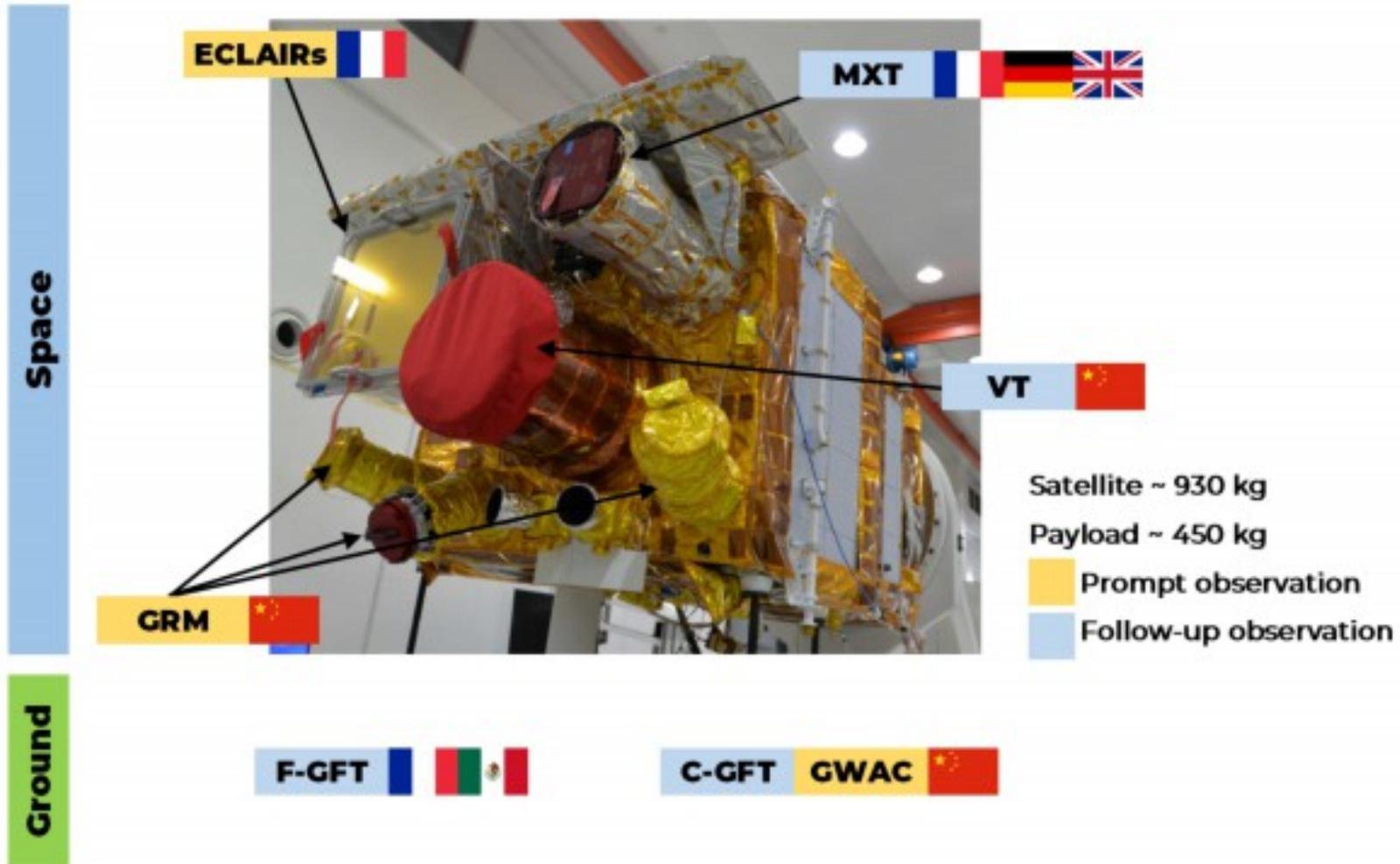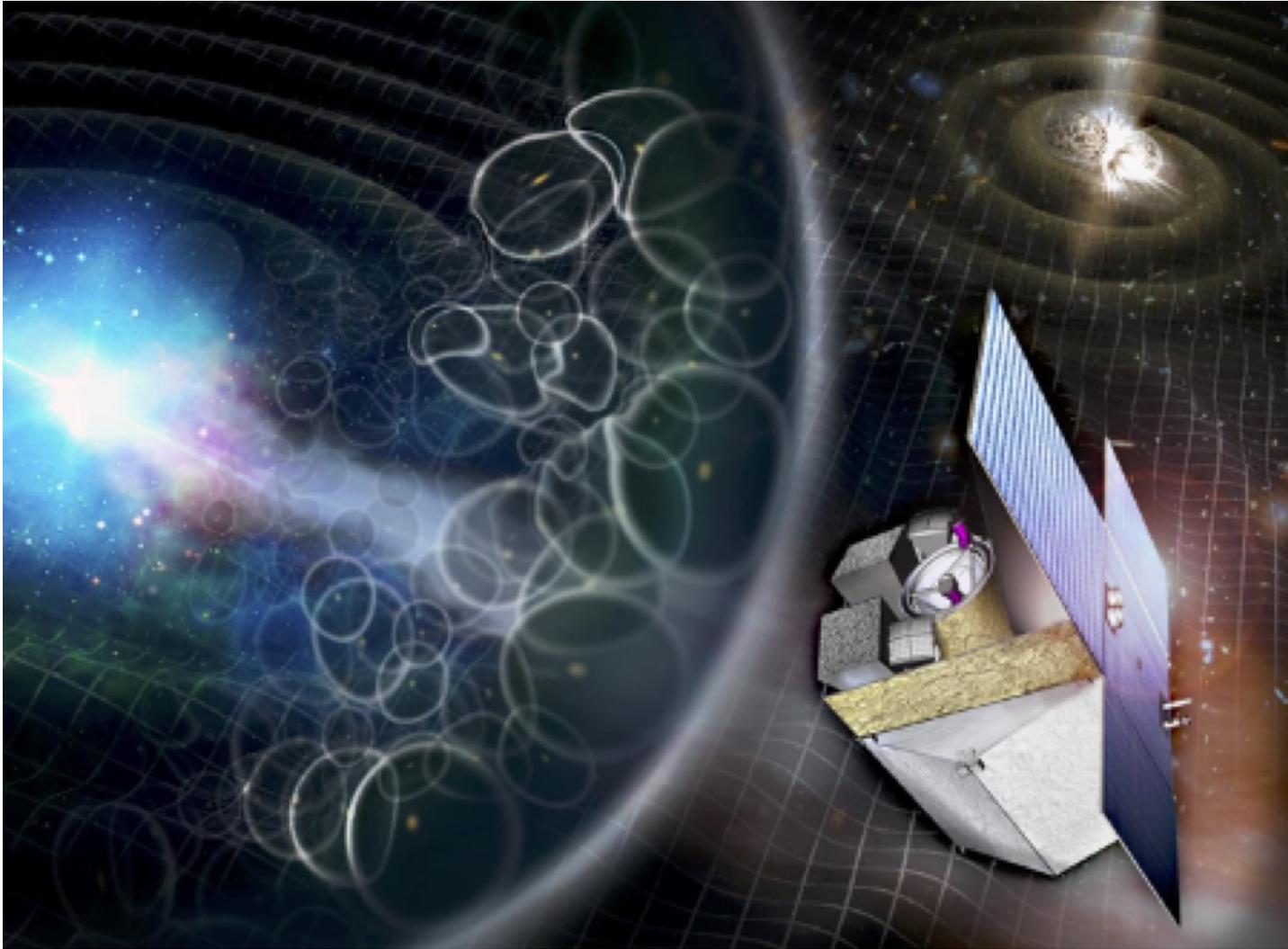
ECLAIRs

MXT

VT

GRM

satellite ~ 930 kg
payload ~ 450 kg

prompt observation
follow-up observation

Space

Ground

F-GFT

GWAC

C-GFT

https://www.svom.eu/en/the-svom-mission/

SVOM

https://www.svom.eu/en/the-svom-mission/
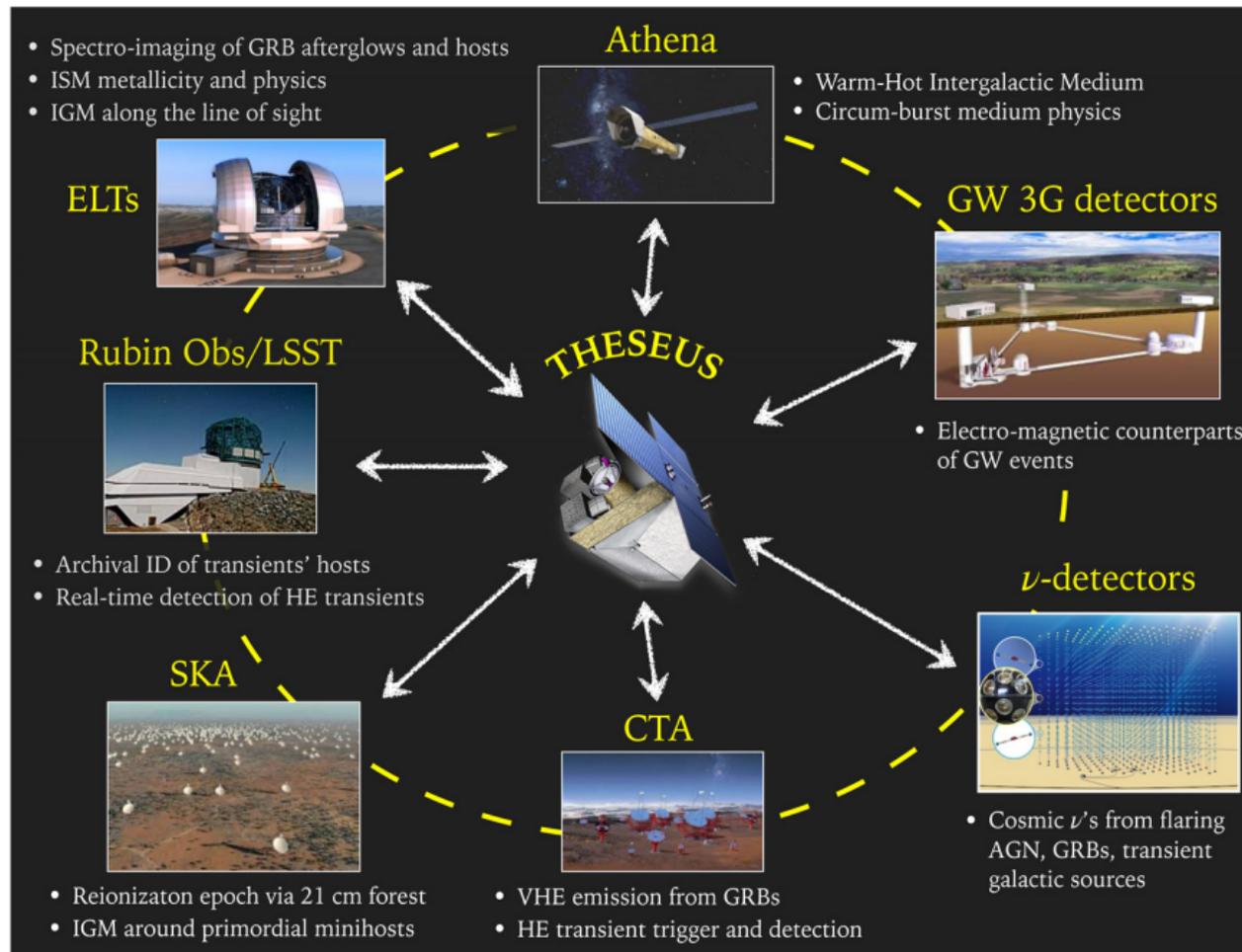
THESEUS

THESEUS

Astrofisica Nucleare e Subnucleare
"X-ray" Astrophysics

Nobel prize 2002 – R.Giacconi
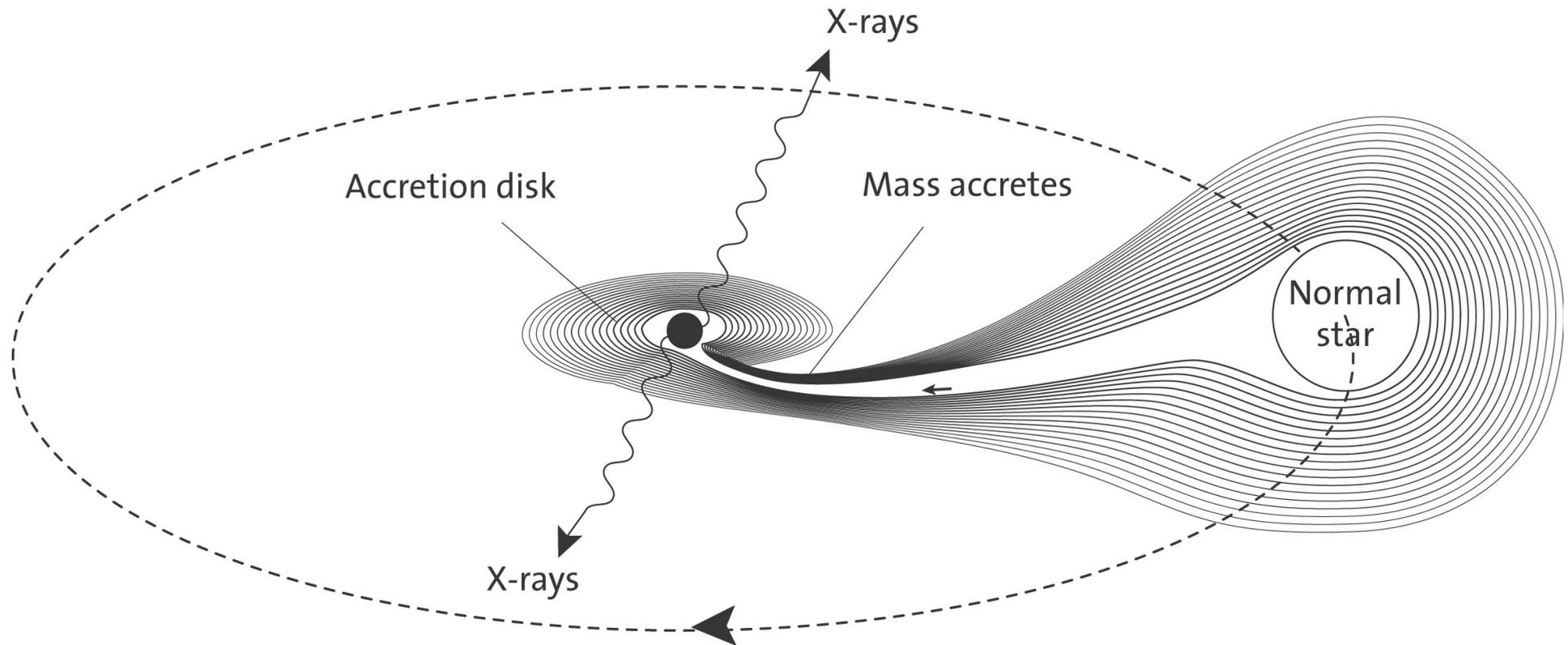
" … for pioneering contributions to astrophysics,
which have led to the discovery of cosmic X-ray sources"

Detector Project
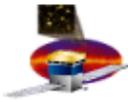
Definition of Terms

◆ **Effective Area:**

A_{eff}

A = area
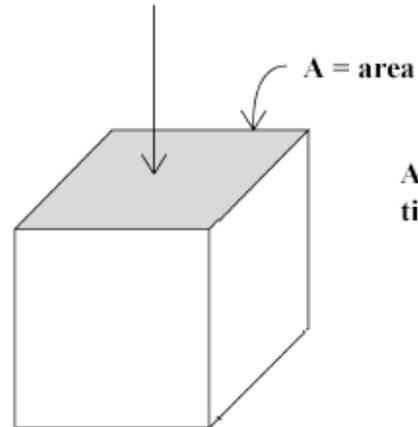
Area at normal incidence times detection efficiency.

◆ **Energy Resolution:**

E_R
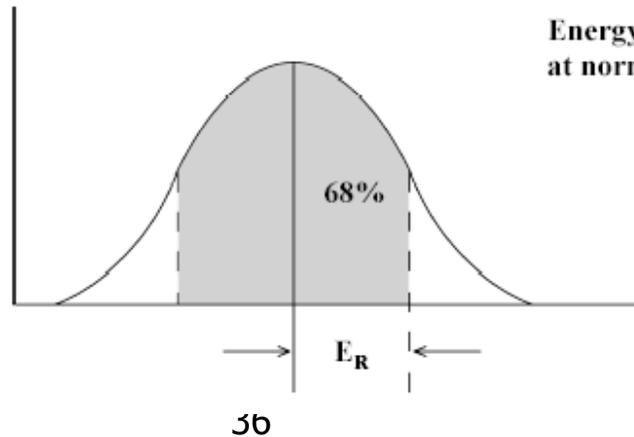
Energy 68% spread at normal incidence.

68%

E_R

Detector Project
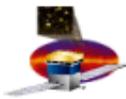
Definition of Terms

◆ **Angular Resolution:**

Θ_R
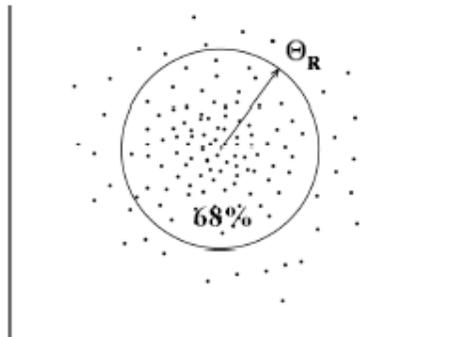
Space angle for 68% containment at normal incidence.

◆ **Field of View:**

FOV
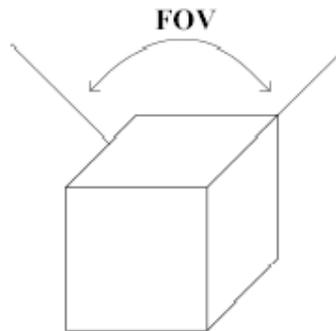
Integral effective area over solid angle divided by peak effective area.

◆ **Sensitivity:**

Flux of weakest source that can be detected at 5 sigma significance.

Scanning with Slat Collimators

- Imaging the sky with non-imaging X-ray instruments as a goal

- Linear scanning means position is determined in one direction

- At least a second scanning, preferentially in the direction perpendicular to the previous one

- First all-sky survey in X-rays by Uhuru (1970-72): 2 prop. counters with metal collimators (0.5°×5°, 5°×5° FWHM)
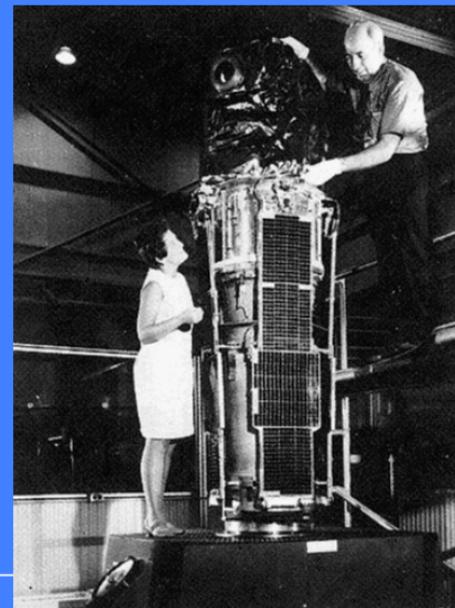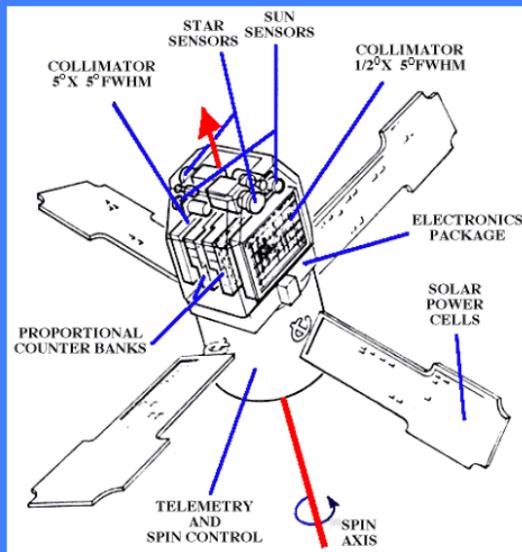
Scanning Grid Collimators

- **Two or more plane ("grid" of absorbing rods) collimators to improve angular resolution**

- **Higher resolution with three or more grids (e.g., 4 in HEAO-1 A-3 experiment)**

- **Two-dimensional measurements need scans in two or more directions**
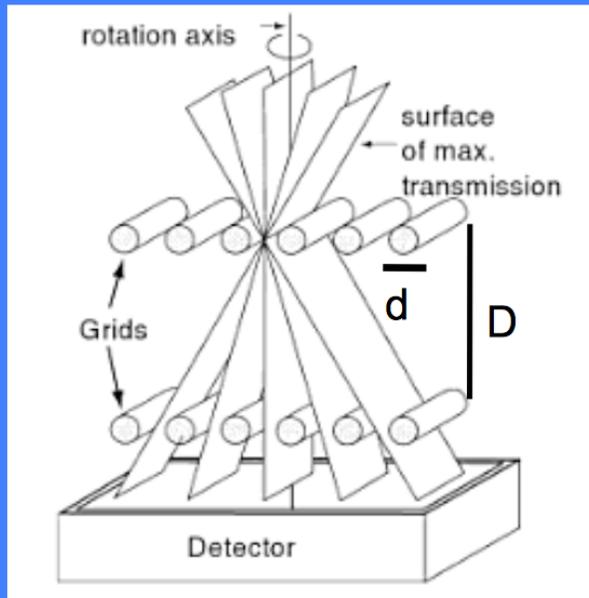
Double-grid collimator
Transmission Function of triangular shape
Angular resolution: d/D
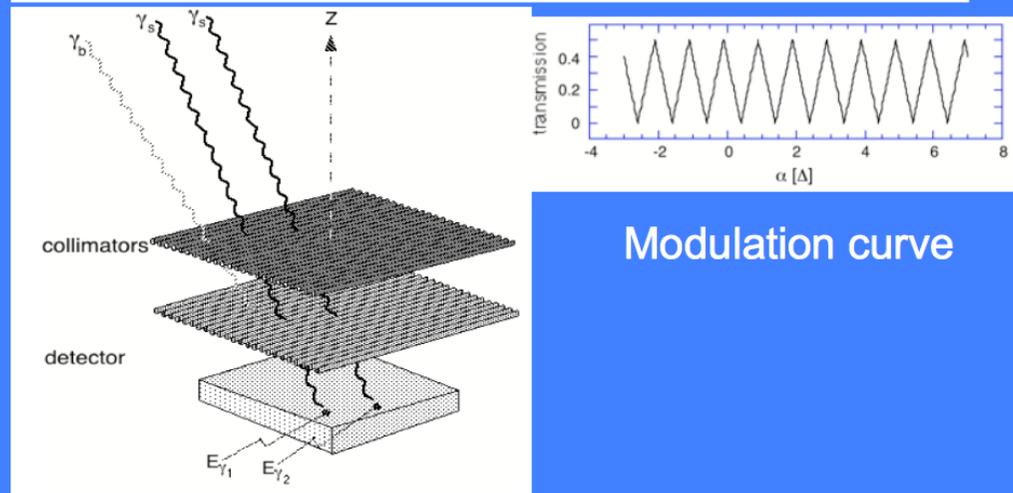
Modulation curve

Sensibilità - 1

- **Sensibilità = flusso minimo rivelabile**
  - Emissione nel continuo: fotoni cm^{-2} s^{-1} keV^{-1}
  - Emissione di righe: fotoni cm^{-2} s^{-1}

- C_S =   Tasso di conteggi di sorgente

- C_{Bkg} =   Tasso di conteggi di fondo

  assumendo una statistica poissoniana

$$SNR = n_\sigma = \frac{C_S}{\sqrt{C_S + C_{Bkg}}}$$

In realta' quello che si misura e'   (S+B)-B in un dato intervallo di tempo

$$S = (S + B) - B \longrightarrow \sigma_S^2 = \sigma_{S+B}^2 + \sigma_B^2 =$$

$$= (\sqrt{(S+B)})^2 + (\sqrt{B})^2 = S + B + B = S + 2B$$

$$SNR = S/\sigma_S = S/\sqrt{(S+2B)}$$

Sensibilità – 2 – "basic" dependencies

$$S = \varepsilon \ A \ T \ \Delta E \ F_{src}$$
$$B = \quad A \ T \ \Delta E \ F_{bkg}$$

ε=efficienza di rivelazione fotoni della sorgente
A=area efficace
T=tempo di esposizione
ΔE=banda energetica
F_{src}=flusso della sorgente
F_{bkg}=fondo strumentale

$B \ll \varepsilon \ F_{src}$

$$SNR = \frac{S}{\sqrt{S+2B}} \approx \sqrt{S} \propto \sqrt{F_{src} T}$$

the source dominates the signal

$B \gg \varepsilon \ F_{src}$

$$SNR = \frac{S}{\sqrt{S+2B}} \approx S/\sqrt{2B} \propto \sqrt{T}(F_{src}/\sqrt{2F_{bkg}})$$

Backg-dominated obsn.

$$SNR = n_\sigma \approx \frac{\varepsilon \cdot A \cdot T \cdot \Delta E \cdot F}{\sqrt{A \cdot T \cdot \Delta E \cdot B}} \to F_{Min} = \frac{n_\sigma}{\varepsilon} \sqrt{\frac{B}{A \cdot T \cdot \Delta E}}$$

to give an idea of the main dependencies of the limiting flux (sensitivity)

In the "real world", the background is not only instrumental but also cosmic

S=source flux density [counts/m^2 s]
A=area of the detector
Ω=solid angle subtended by the beam of the telescope on the sky
B_1=instrumental (particle) background [counts/s]
B_2=cosmic background (XRB) [phot/m^2 s ster]
T=exposure time
SOURCE=S×A×T (photons related to the source)
BACKGROUND=B$_1$×T + B$_2$×A×Ω×T (photons related to the backgrounds)

$$N = \sqrt{(B_1 + B_2 A\Omega) \times T}$$

$$S/N = \frac{SAT}{\sqrt{(B_1 + B_2 A\Omega) \times T}} = \frac{SA^{1/2}T^{1/2}}{\sqrt{\left(\dfrac{B_1}{A}\right) + \Omega B_2}}$$

$$S/N = 5 \Rightarrow S_{min} = 5\sqrt{\frac{B_1/A + \Omega B_2}{AT}}$$

Focalizzazione vs collimazione
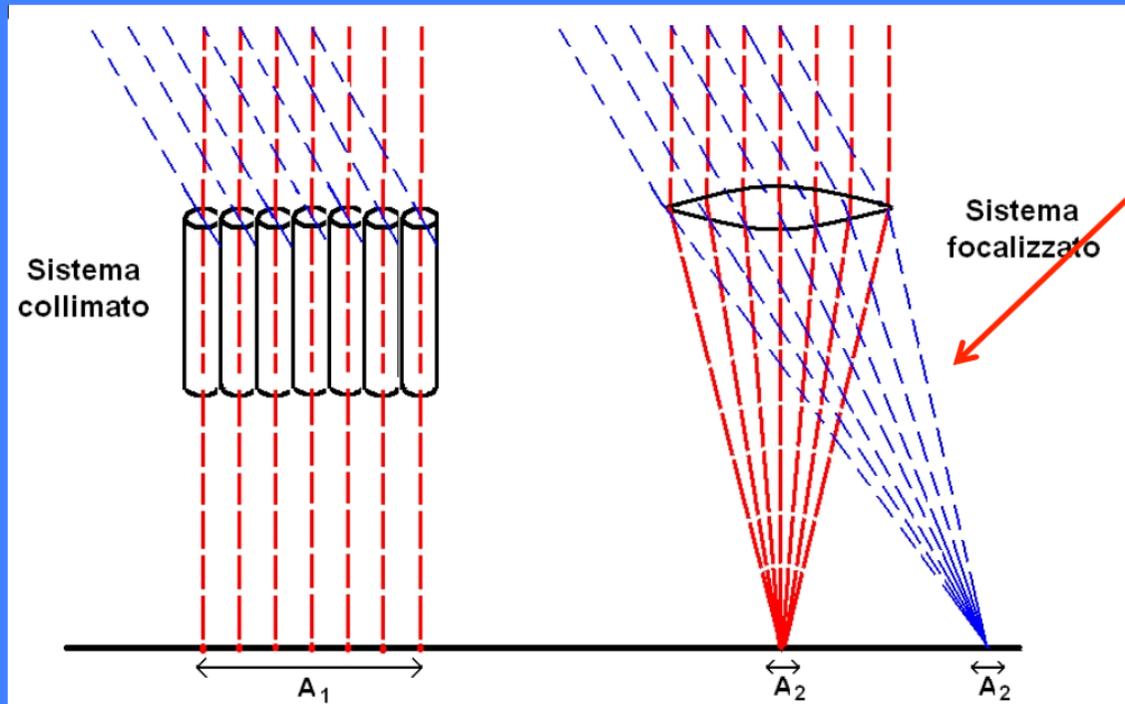
Proper imaging of X-rays below 20-40 keV

A_d = PSF projected on the focal plane

$$F_{min} \approx n_\sigma \frac{\sqrt{2B}}{\sqrt{A_{det} T_{int} \Delta E}}$$

$$F_{min} \approx n_\sigma \frac{\sqrt{B A_d}}{A_{eff} \sqrt{T_{int} \Delta E}}$$

Sistema collimato: limita la regione di cielo da cui puo' provenire un segnale, (quindi limita il background), non incrementandone la "densita"

Sistema focalizzato: fa corrispondere ad ogni sorgente un punto nel piano focale, e "concentra" il segnale, producendo un'immagine

$$C_B = B\,A_d\,\Delta E\,\Delta t$$

Background counts from a collimated telescope with detector area A_d, sensitive over the band ΔE, in a time interval Δt

$$\sigma(C_B) = C_B^{1/2}$$

The counts obey the Poisson statistics

$$C_S = S_E\,A_d\,\Delta E\,\Delta t\,\eta_E$$

Source counts collected from a source with flux S_E in the same conditions (QE=η_E)

$$C_{meas} = (C_S + C_B) - C_B$$

Measured counts (backg-subtracted)

$$\sigma^2(C_{meas}) = 2\sigma^2(C_B)$$

Background dominates fluctuations

$$S/N = n_\sigma = \frac{C_S}{\sqrt{2C_B}} = \frac{S_E\,A_d\,\Delta E\,\Delta t\,\eta_E}{\sqrt{2B\,A_d\,\Delta E\,\Delta t}}$$

$$S_{E,min} = \frac{n_\sigma}{\eta_E}\frac{\sqrt{2B}}{\sqrt{A_d\,\Delta t\,\Delta E}}$$

X-Ray Mirrors

4 Nested Paraboloids

4 Nested Hyperboloids

Doubly Reflected X-rays

X-rays

Field of View ±.5 Deg

Focal Surface

10 meters

X-rays

Mirror elements are 0.8 m long and from 0.6 m to 1.2 m diameter
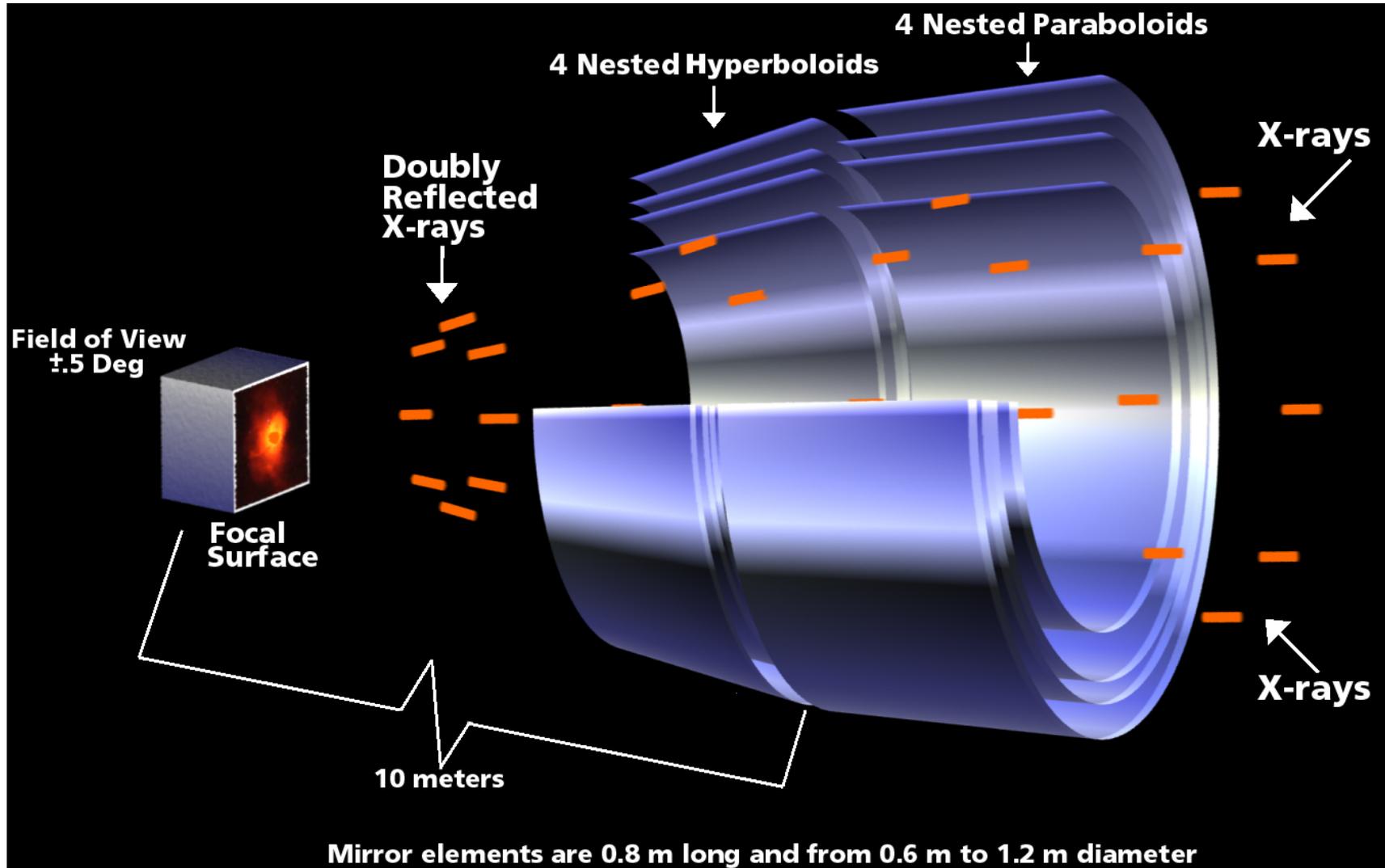
Why do we use X-ray optics

- To achieve the best 2-dim angular resolution

    - To distringuish nearby sources or different regions of the same source
    - To perform morphological studies

- As a collector to "gather" weak fluxes (case of limited photon statistics)

- As a concentrator, so that the image photons may interact in a small region of the detector, thus limiting the influence of the background

- To serve with high spectral resolution dispersive spectrometers such as transmission or reflection gratings

- To simultaneously measure both the source(s) of interest and the contaminating background in other (source-free) regions of the detector

X-ray optical constants

• X-rays are hard to refract or reflect: the refractive index of all materials in X-rays is very close to 1 and only slightly less than 1 ➔ X-rays are above the characteristic energy of bonded e- in atoms

• complex index of refraction of the reflector to describe the interaction X-rays /matter (see, for a review, Aschembach et al. 1985, Rep. Prog. Phys. 48, 579)

$$n=1-\delta+i\beta$$

where δ describes the phase change and
β accounts for the absorption

δ and β depend on the wavelength
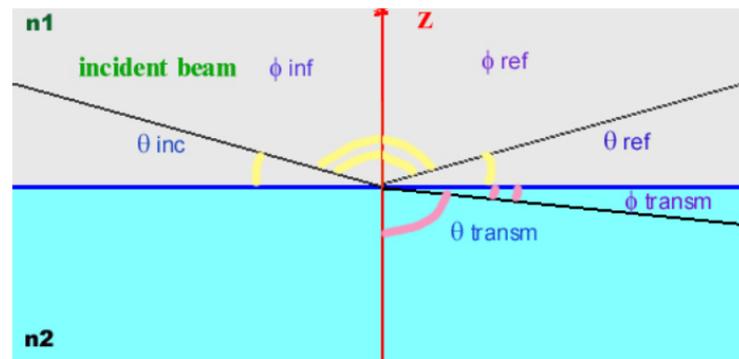
• the amplitute of reflection is described by the Fresnel's equations

P

normal

θ₁

interface O

n₁ v₁

n₂ v₂

θ₂

Q

n = 1 − δ + i β

n = 1

grazing angle θᵢ

refracted (transmission)

φᵣ

θᵣ

φᵢ φₒ

incident
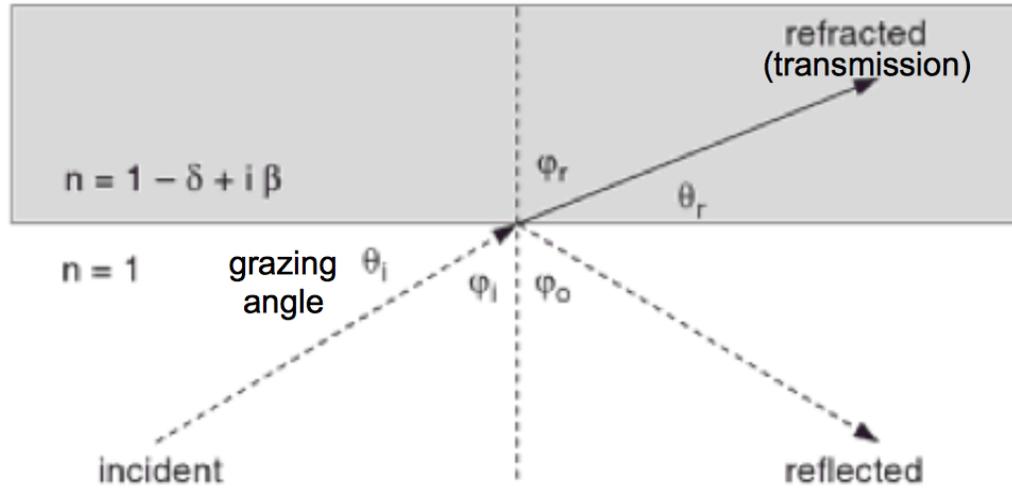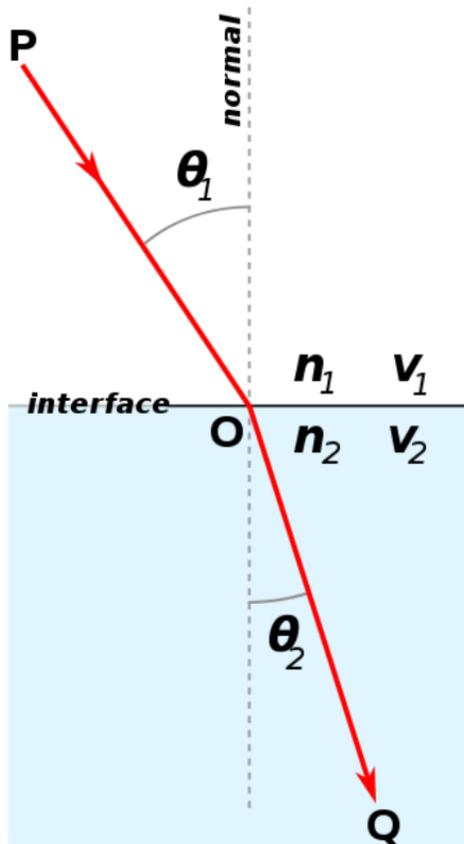
reflected

Snell's Law of Refraction:
relationship between the angles of incidence and refraction in a medium

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
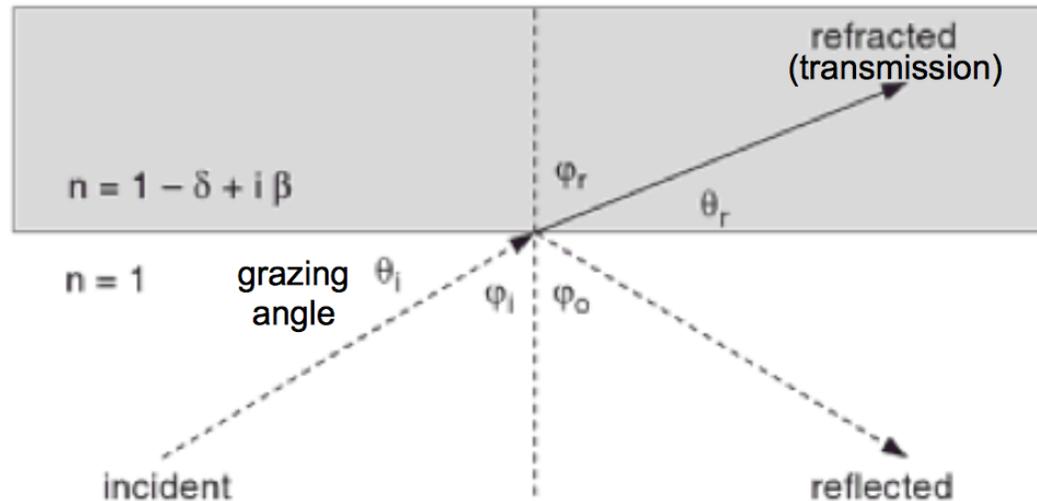
$$n_1 = 1, \ n_2 = (1-\delta) \ \rightarrow \ \sin\phi_i = (1-\delta)\sin\phi_r$$

$$\vartheta = (\pi/2) - \phi$$

$$\cos(90 - \phi_i) = \cos\vartheta_i = (1-\delta)\cos(90 - \phi_r) = (1-\delta)\cos\vartheta_r$$

$$\Rightarrow \cos\vartheta_i = \cos\vartheta_r(1-\delta)$$

Total reflection if no real solution for ϑ_r

$\delta > 0$, $\cos\theta_r \leq 1$ ➜ There is a **critical angle θ_c** below which refraction is impossible and total external reflection occurs (grazing angle, $\theta_i = \theta_c$)

Extreme case for low θr values

$$1 = \cos\vartheta_r = \cos\vartheta_c / (1-\delta) \rightarrow \cos\vartheta_c = 1 - \delta$$

Total X-ray reflection at grazing incidence

• Real part of n slightly less than unity for matter at X-rays, =1 in vacuum (total external reflection); $\delta \ll 1$

• Snell's law ($n1 \cos\theta_1 = n2 \cos\theta_2$) to find a critical angle for total reflection

• (Total) external reflection in vacuum for angles < critical angle: $\boxed{\cos\theta_{crit} = 1 - \delta}$

• X-ray partially reflected also for $\theta > \theta_{crit}$; also, some absorption in the material

• $\boxed{\cos(\theta_{crit}) = 1 - \theta_{crit}^2/2 = 1 - \delta} \xrightarrow{\text{low angles}} \boxed{\theta_{crit} = \sqrt{2\delta}}$

• Far from fluorescent edges: $\boxed{\delta \approx \dfrac{N_0 Z r_e \rho \lambda^2}{2\pi A}}$

where N_0=Avogadro's number
  Z=atomic number
  r_e=electron radius
  ρ=density
  λ=wavelength of the incoming photon
  A=atomic weight

Critical angle:

• Inversely dependent on energy
• Higher Z materials reflect higher energies, for a fixed grazing angle
• Higher Z materials have a larger critical angle at any energy

X-ray mirrors with parabolic profile
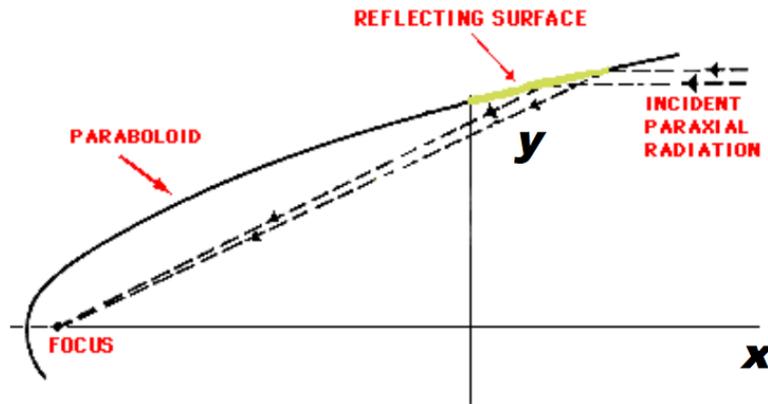
- perfect on-axis focusing

- off-axis images <u>strongly</u> affected by coma
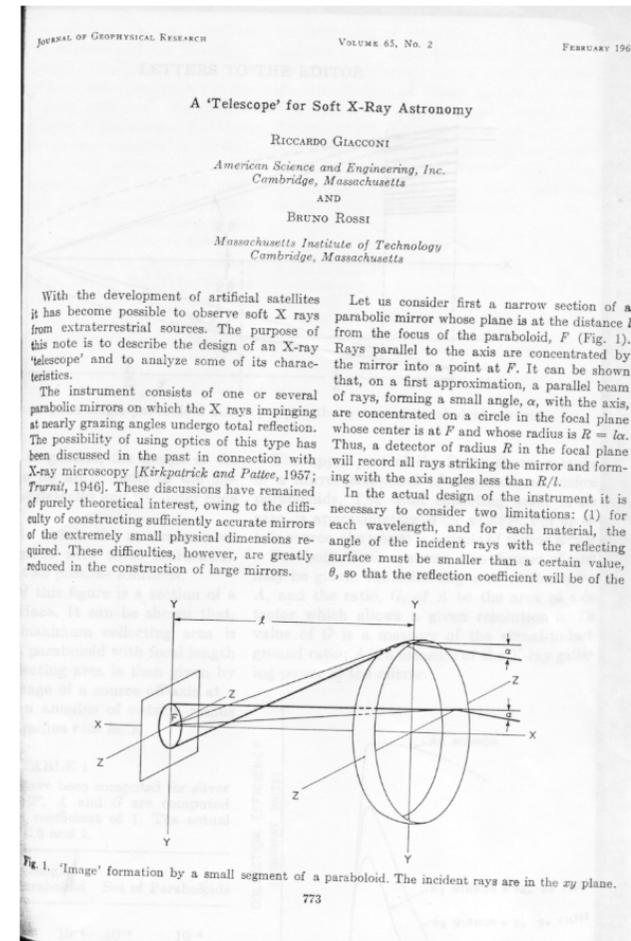
Wolter, 1952

Wolter's solution to the X-ray imaging
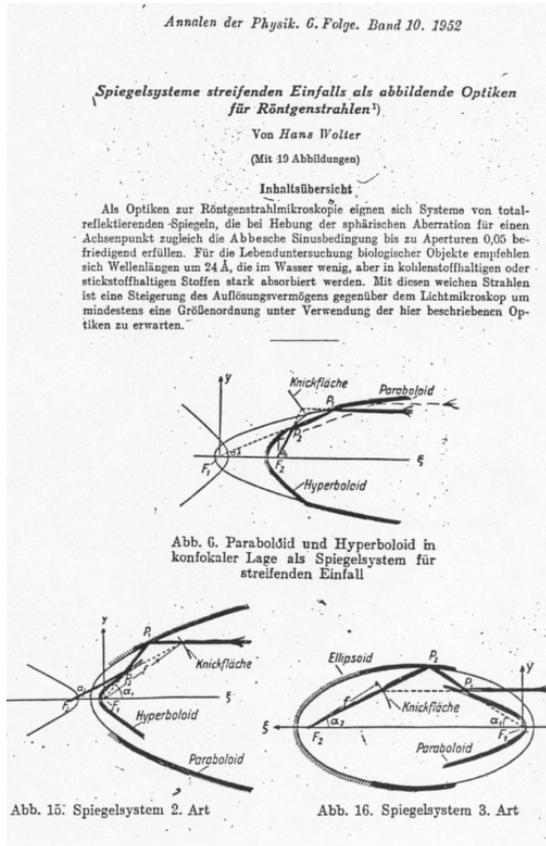
Fine for
X-ray astronomy
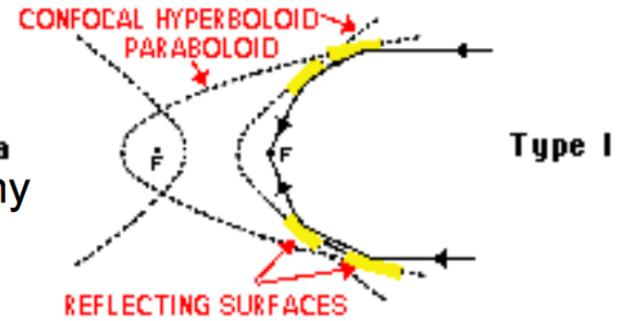
Applied in solar
X-ray telescopes
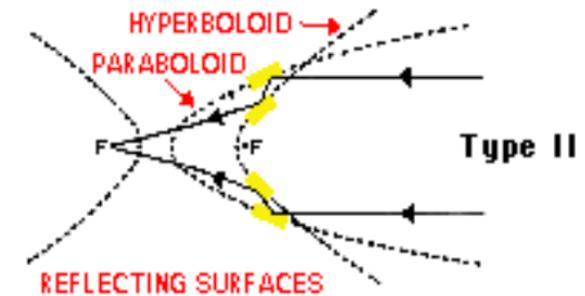
Not adopted
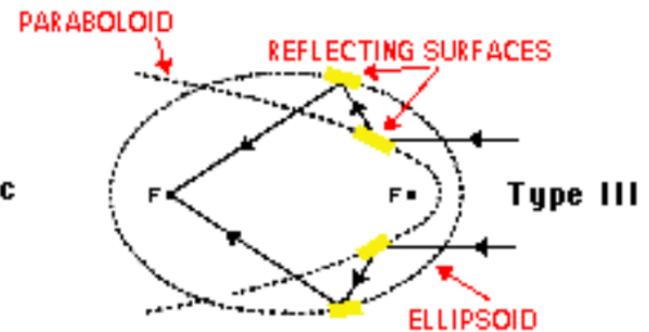
H. Wolter, Ann. Der Phys., NY10, 94 (1952)

TYPE I

CONFOCAL HYPERBOLOID

PARABOLOID

F

F

REFLECTING SURFACES

TYPE II

CONFOCAL HYPERBOLOID

PARABOLOID

F

F

REFLECTING SURFACES
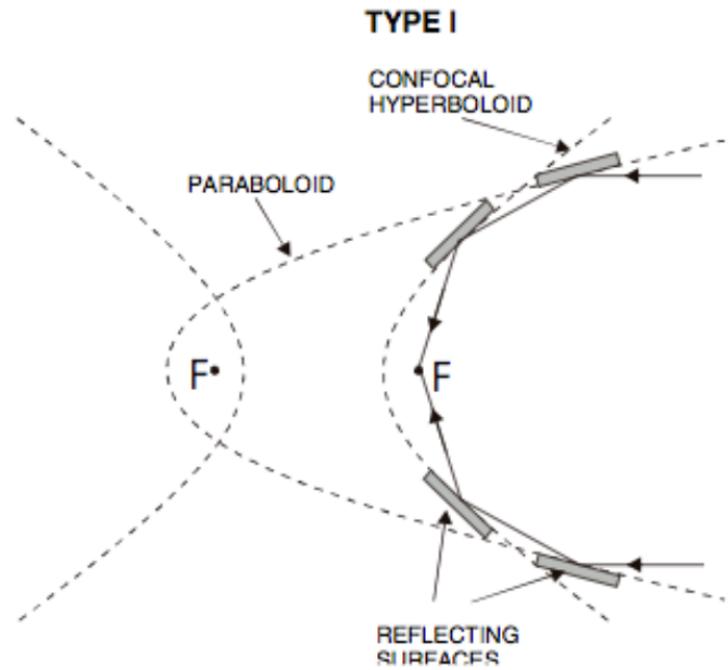
Wolter-I optics
Paraboloid ➜ Hyperboloid
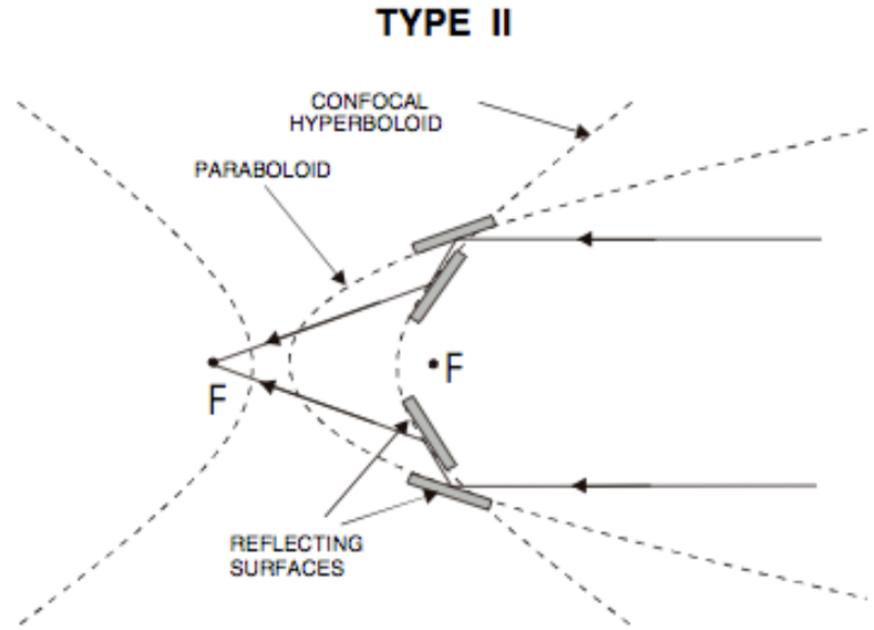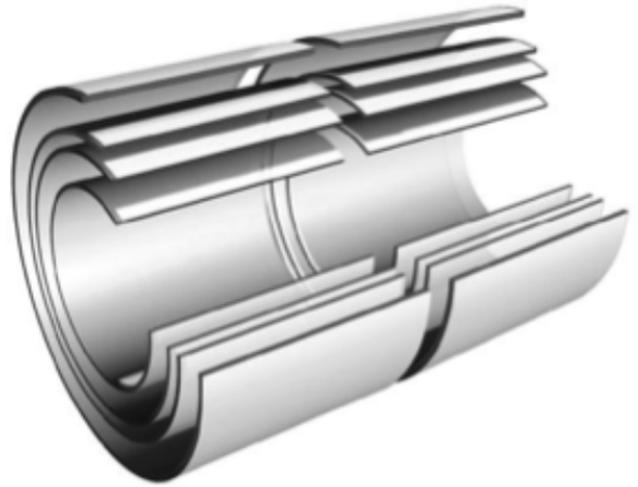
Wolter-II optics
Paraboloid ➜ Hyperboloid (ext. surface)

A_{geom} x Reflectivity
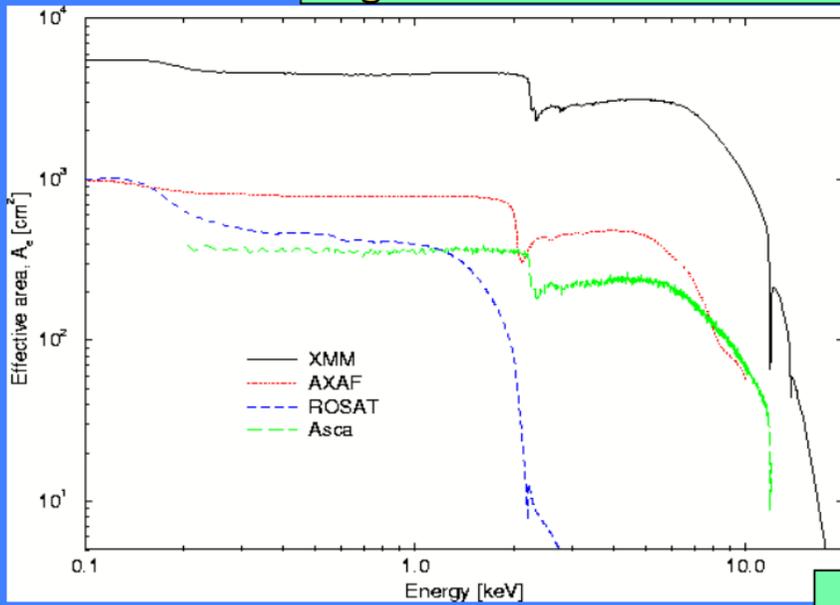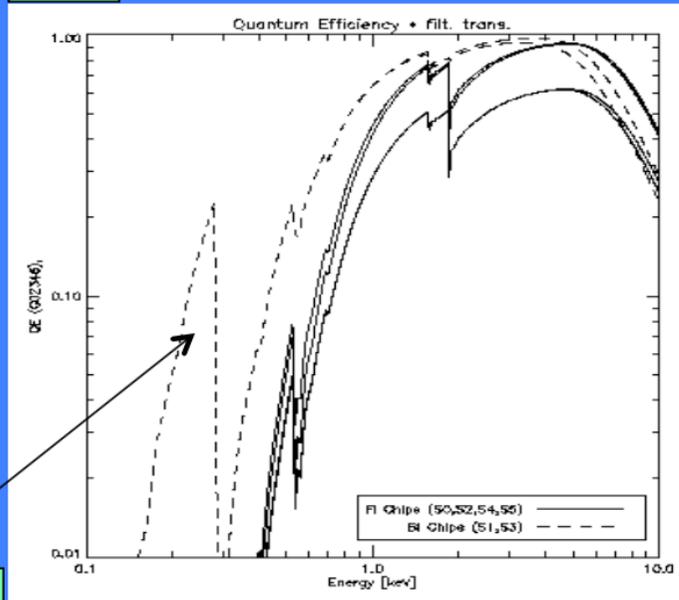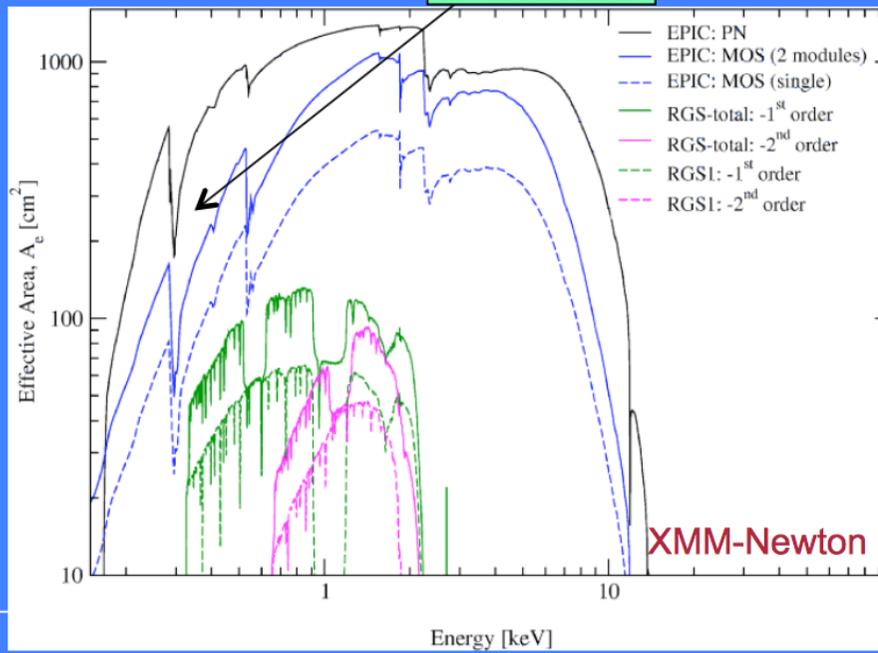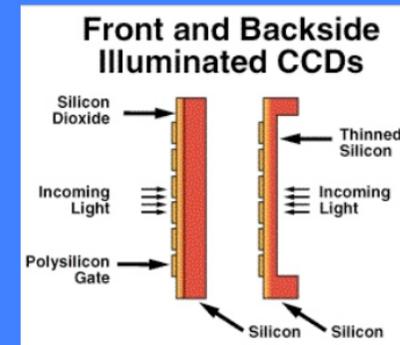
QE

x

$A_{effective}$

CCD

Front and Backside Illuminated CCDs

=

XMM-Newton

Focalizzazione vs collimazione

Sistema collimato

Sistema focalizzato

A_1

A_2 A_2
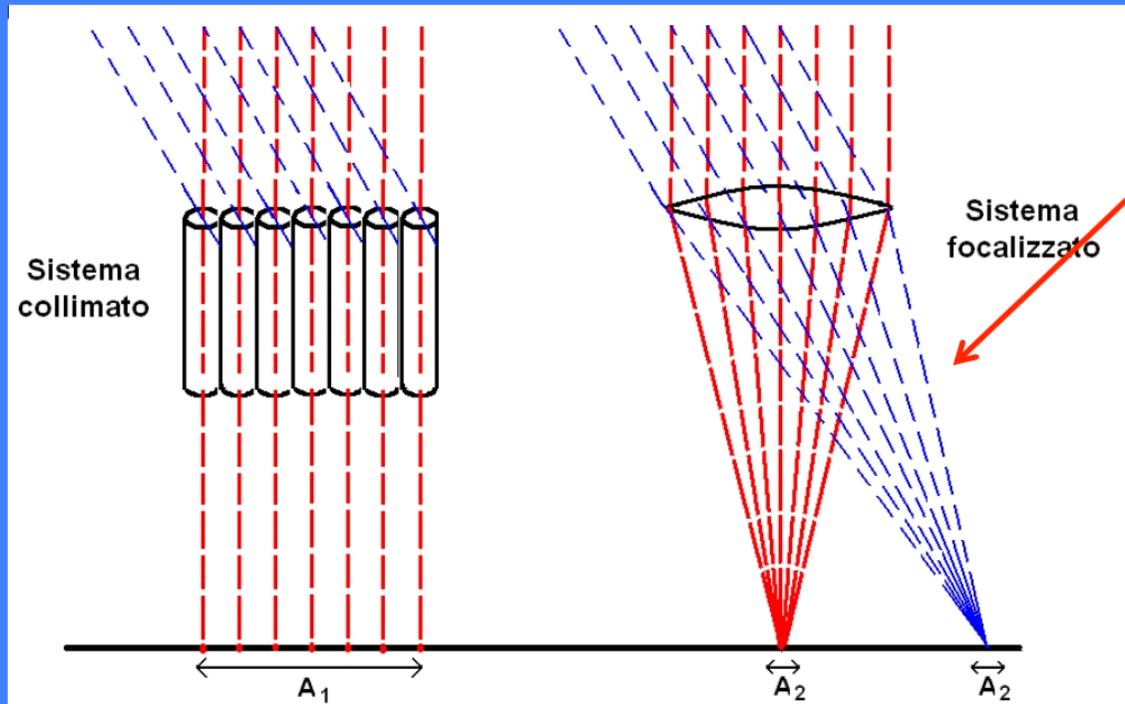
Proper imaging of X-rays below 20-40 keV

A_d= PSF projected on the focal plane

$$F_{\min} \approx n_\sigma \frac{\sqrt{2B}}{\sqrt{A_{\det} T_{\mathrm{int}} \Delta E}}$$

$$F_{\min} \approx n_\sigma \frac{\sqrt{B A_d}}{A_{\mathit{eff}} \sqrt{T_{\mathrm{int}} \Delta E}}$$

Sistema collimato: limita la regione di cielo da cui puo' provenire un segnale, (quindi limita il background), non incrementandone la "densita"

Sistema focalizzato: fa corrispondere ad ogni sorgente un punto nel piano focale, e "concentra" il segnale, producendo un' immagine

$$C_S = S_E \, A_e \, \Delta E \, \Delta t \, \eta_E$$

Detected signal

$$C_B = B \, \varepsilon \, A_d \, \Delta E \, \Delta t$$

Background signal (ε: region of the detector where B counts are focused)

$$S/N = n_\sigma = \frac{C_S}{\sqrt{C_S + 2C_B}} \approx \frac{S_E \, A_e \, \Delta E \, \Delta t \, \eta_E}{\sqrt{2B \, \varepsilon \, A_d \, \Delta E \, \Delta t}}$$

$$S_{E,\min} = \frac{n_\sigma}{\eta_E} \, \frac{1}{A_e} \sqrt{\frac{2B \, \varepsilon \, A_d}{\Delta t \, \Delta E}}$$

Weak sources

Old slide but *Chandra* and XMM-*Newton* still working
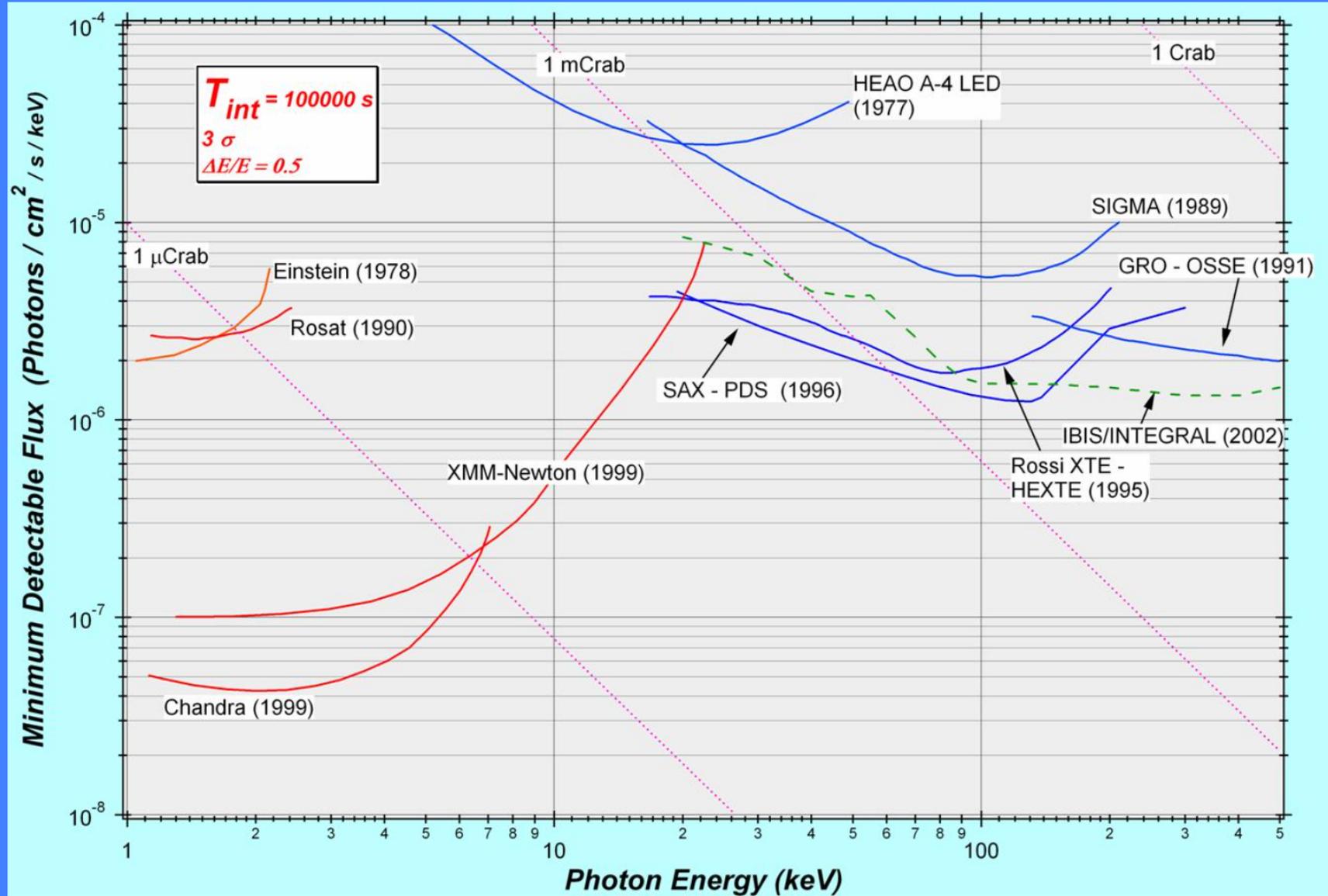
X-ray spectroscopy

Telescopes and instruments

Dispersing elements – Bragg Crystal spectroscopy/1

(more details on dispersive spectrometers: Giacconi & Gursky, p. 81-90)

The reflection of X-rays from a crystal lattice follows the Bragg's law, and therefore the name Bragg spectrometer is usually given to the device with this kind of reflection grating.

Here the macroscopic shaping (grooves) of a metallic plate, which is used in longer wavelengths, is replaced by a material with regular lattice structure of atoms (crystal material). The reflection takes place by the same principle as from a macroscopic lattice, leading to a wavelength-dispersed output from a white light input.

The lattice of the crystal forms a 3-dimensional diffraction array which reflects X-rays of wavelength λ within a narrow range of wavelength satisfying the Bragg condition

$$n\,\lambda = 2d\,\sin\theta \quad , n = 1,2,3,... \text{ (order of diffraction)}$$

where d is the crystal lattice spacing.
In practice, order n=1 is used.

Incident X-rays

Detector   reflected X-ray
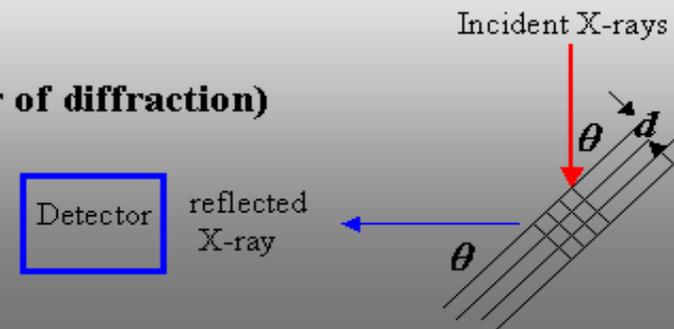
X-ray spectroscopy

Dispersing elements – Diffraction gratings/1

Ordinary diffraction gratings can also be used from from long wavelengths up to soft X-rays (< 1 keV, in practice).

The grating equation is

$$n \lambda = (1/N) \, (\sin\theta - \sin\theta_o), \quad n = 1,2,3,... \text{ (order of diffraction)}$$

where N is the grating constant (lines/cm), θ is the diffraction angle and θ_o is the angle of incidence. For X-rays this is usually rearranged in form valid for small angles

$$n \lambda N = \theta - \theta_o$$

There are two geometries usually applied in X-ray optics,

1. Conventional Johann mount geometry
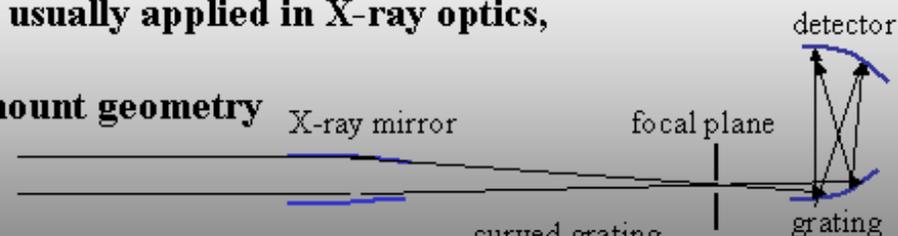
2. Curved grating producing a line image

detector

X-ray mirror   focal plane

curved grating   grating

focal plane

n=0

n=1
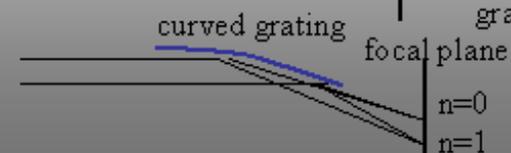
Single photon calorimeter

Individual X-ray photons are absorbed by a crystal which is maintained at a T very close to absolute zero (<0.1 K).
➔ 2-3 year lifetime

We measure the increase of T which is proportional to the energy of the X-ray photon

Energy resolution ~ 3 eV

High efficiency

The best spectral resolution of any non-dispersive (grating) spectrometer

Diagram showing the essential elements of a calorimeter. Inset shows temperature response to an X-ray hit.
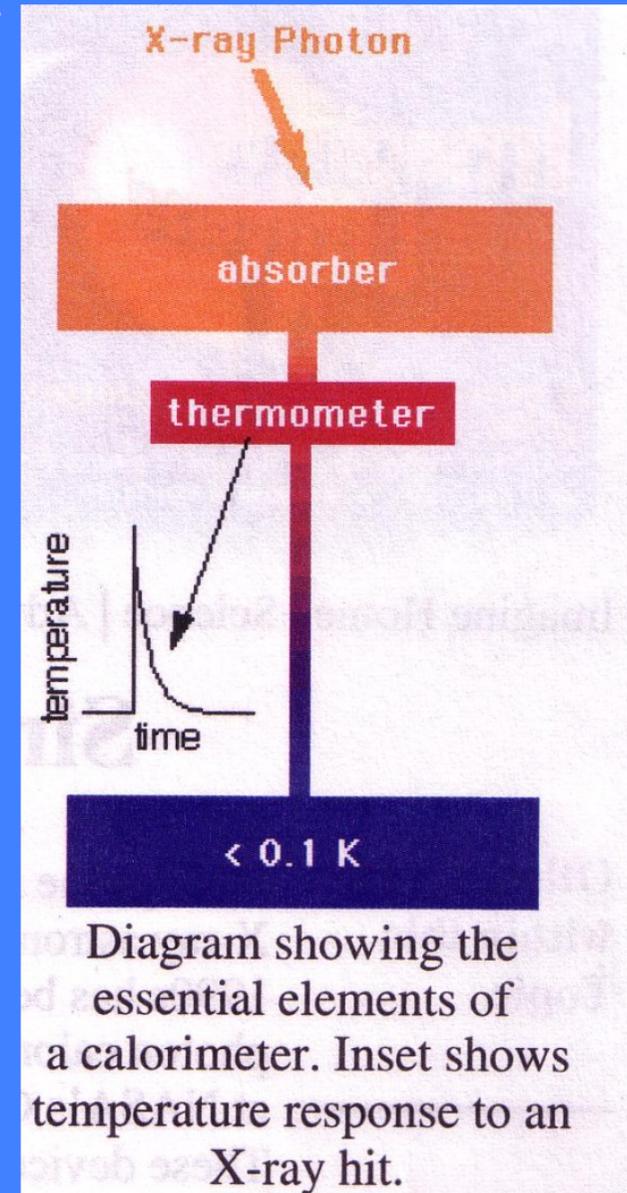
Onboard *Suzaku* – calibration source (^{55}Fe)

FWHM≈7 eV
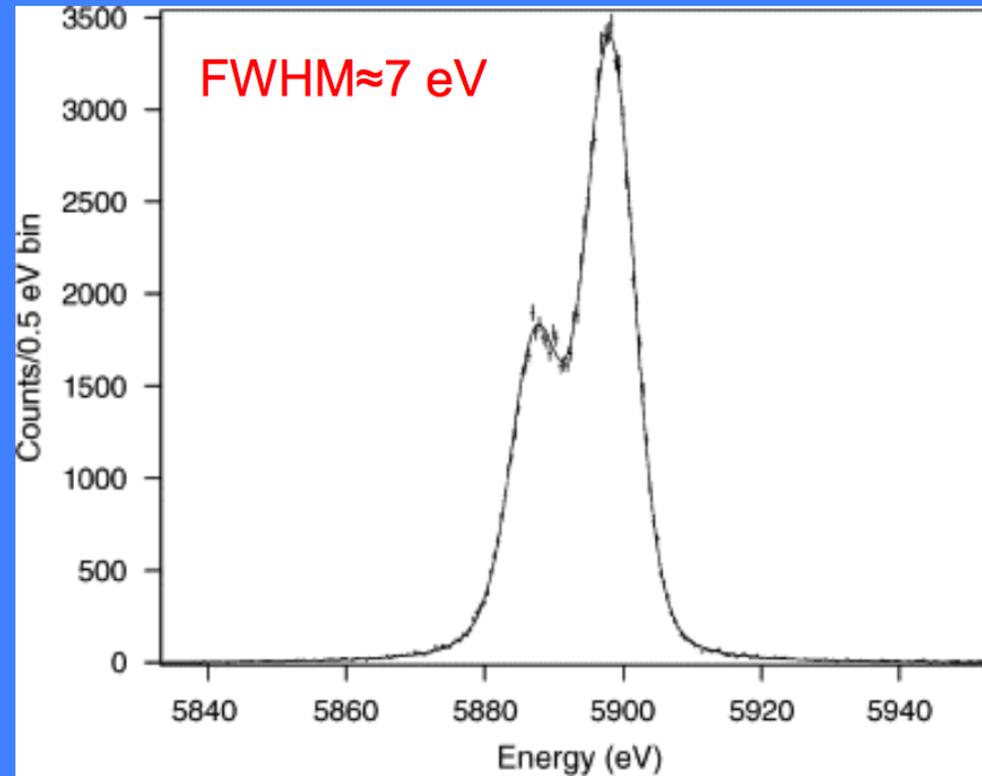
Expected spectral resolutions ≤2-3 eV in next-generation
X-ray calorimeters (e.g., *Athena*)

Onboard of the Japanese mission ASTRO-H/*Hitomi* (Last year ☹)

X-ray polarimetry

Distribution in space of K-shell photo-electrons after the absorption of a polarized photon beam.

Costa et al. 2001

65
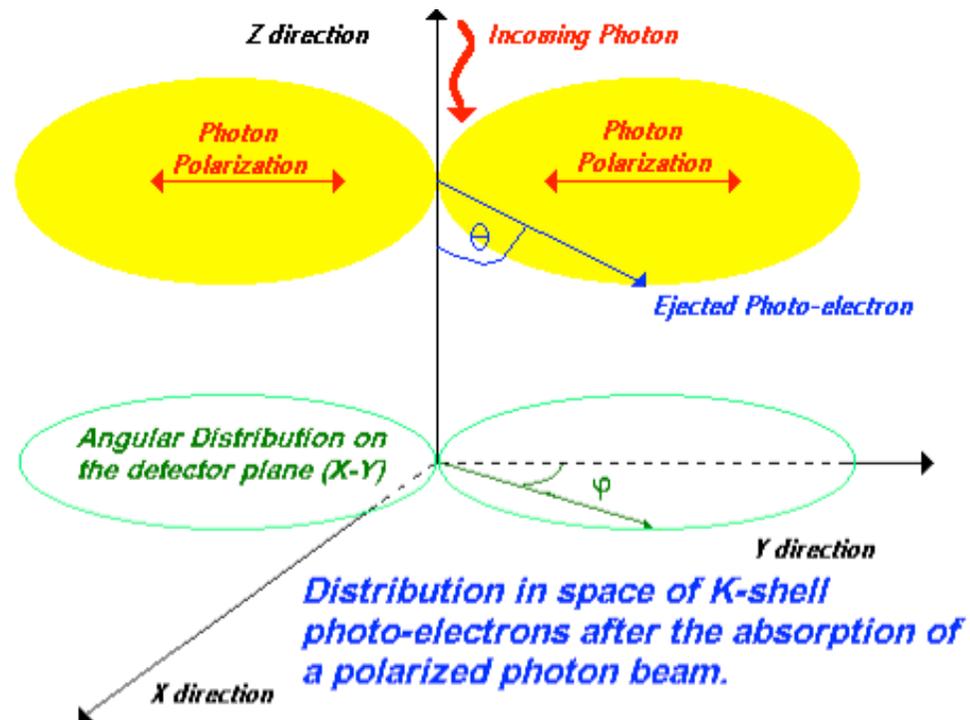
X-ray polarimetry
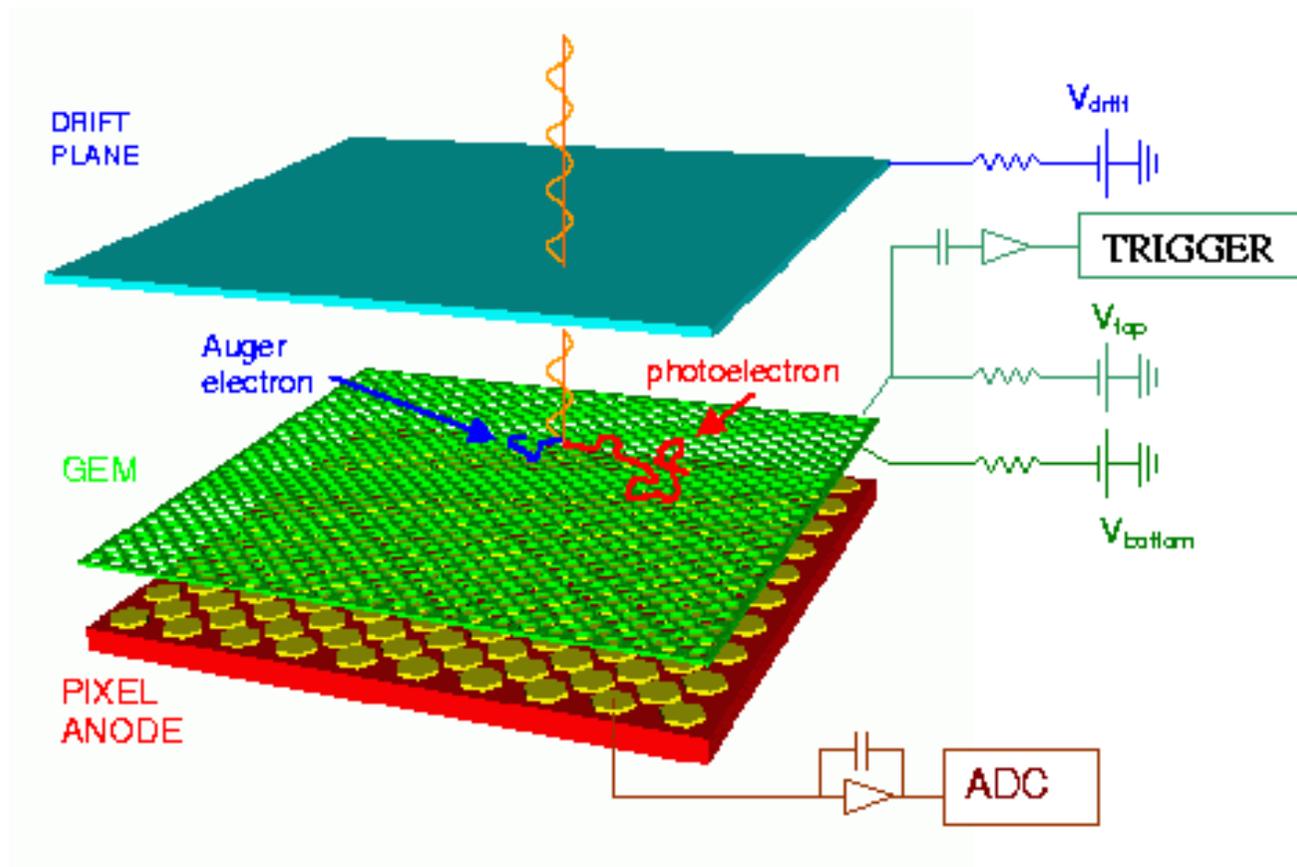
X-ray imaging
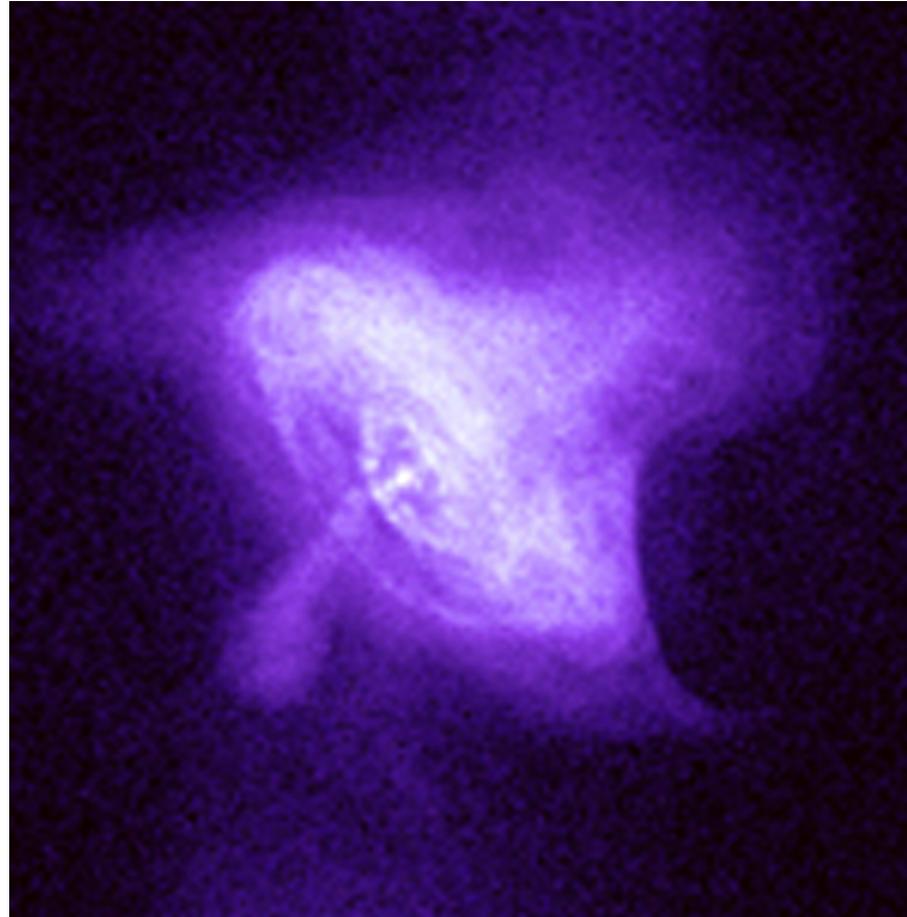
Crab nebula, 2.5", 0.3 – 3 keV

La risoluzione angolare in astronomia X: da *ROSAT* a *Chandra*
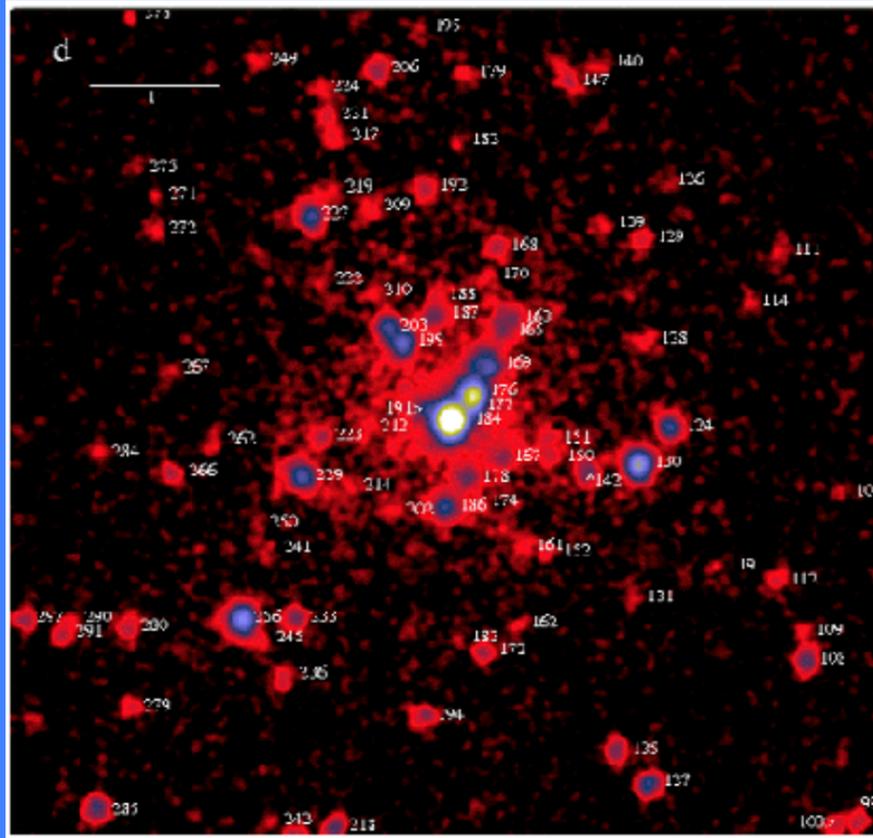
Osservazione di Orion con ROSAT HRI (47 ks)
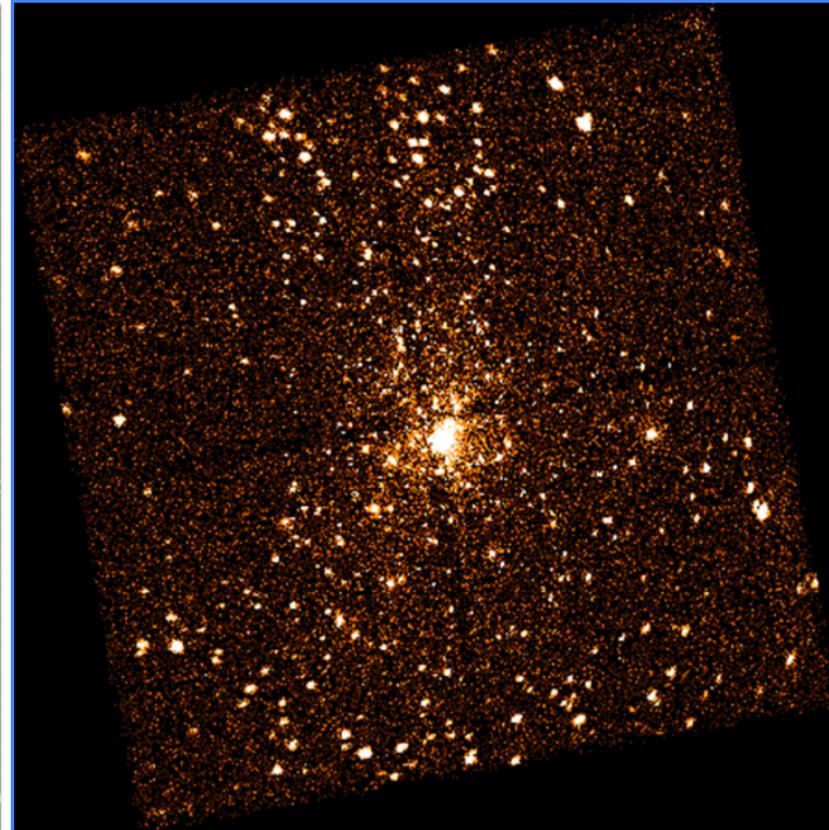
Osservazione di Orion con Chandra ACIS (13.7 ks)

X-ray spectroscopy
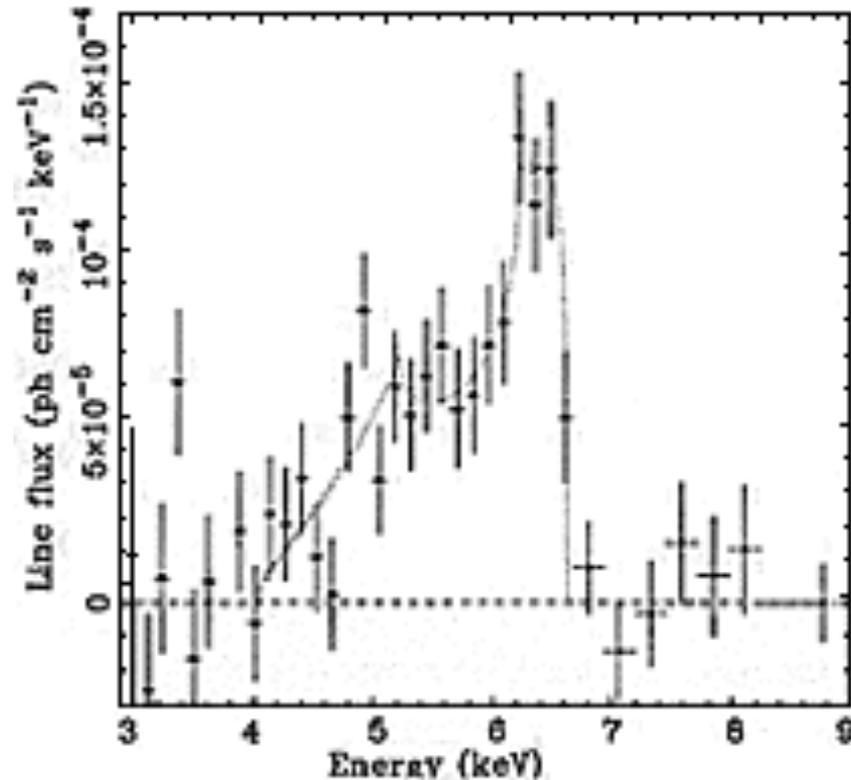
The Fe line profile of K-alpha in the X-ray emission from the active nucleus of the galaxy MCG 6-30-15 in the constellation Centaurs is powered by matter accreting into a black hole.   69

ROSAT   http://www.mpe.mpg.de/xray/wave/rosat/
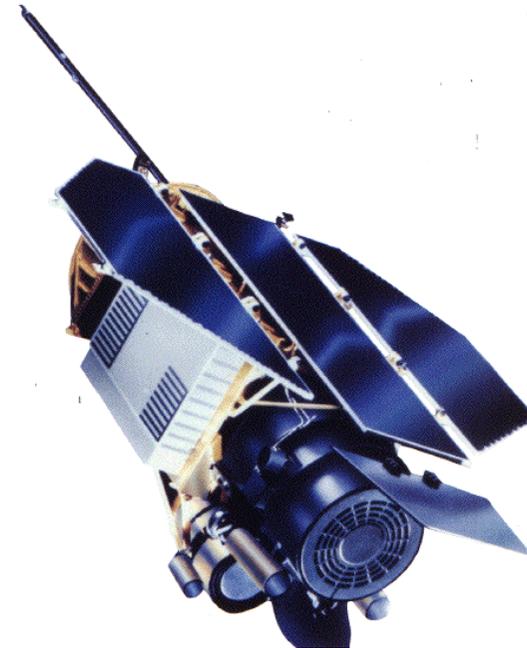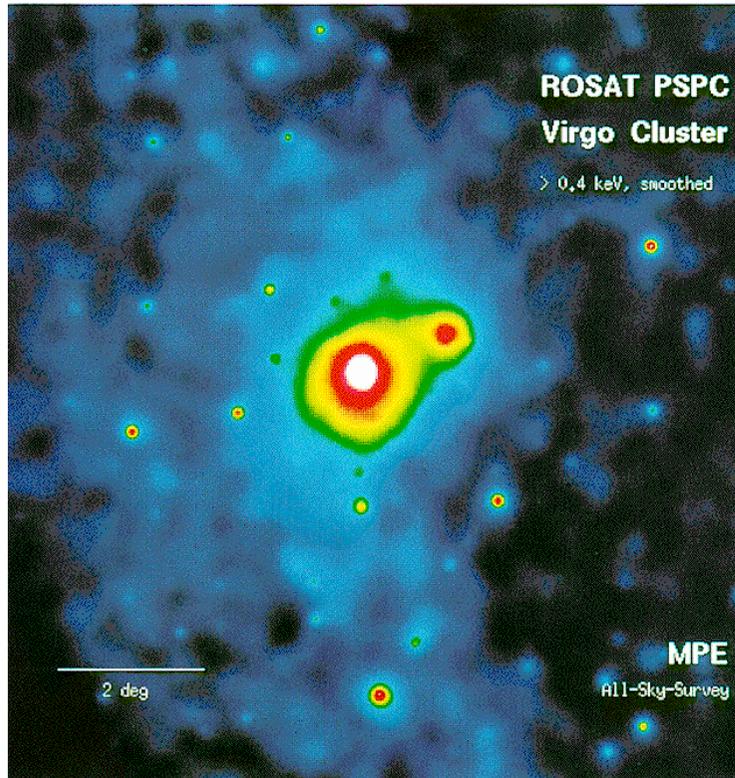
The scientific payload consists two coalligned scientific experiments, the The X-Ray Telescope which is used in conjunction with one of the focal plane instruments:
- The Position Sensitive Proportional Counter
- The High Resolution Imager

and the The Wide Field Camera which has its own mirror system and star sensor.
ROSAT provides a ~ 2 degree diameter field of view with the PSPC in the focal plane, and ~ 40 arcmin diameter field of view with the HRI in the focal plane. The ROSAT mission began with a six-month, all-sky PSPC survey, after which the satellite began a series of pointed observations that continued for the duration of the project.

ROSAT results

ROSAT ALL-SKY SURVEY Bright Sources

Aitoff Projection
Galactic II Coordinate System

Energy range: 0.1 - 2.4 keV
Number of RASS-II sources: 18811
Hardness ratio: -1.0 I -0.4 I -0.2 I 0.2 I 0.6 I 1.0   (soft -> hard : magenta - red - yellow - green - cyan)
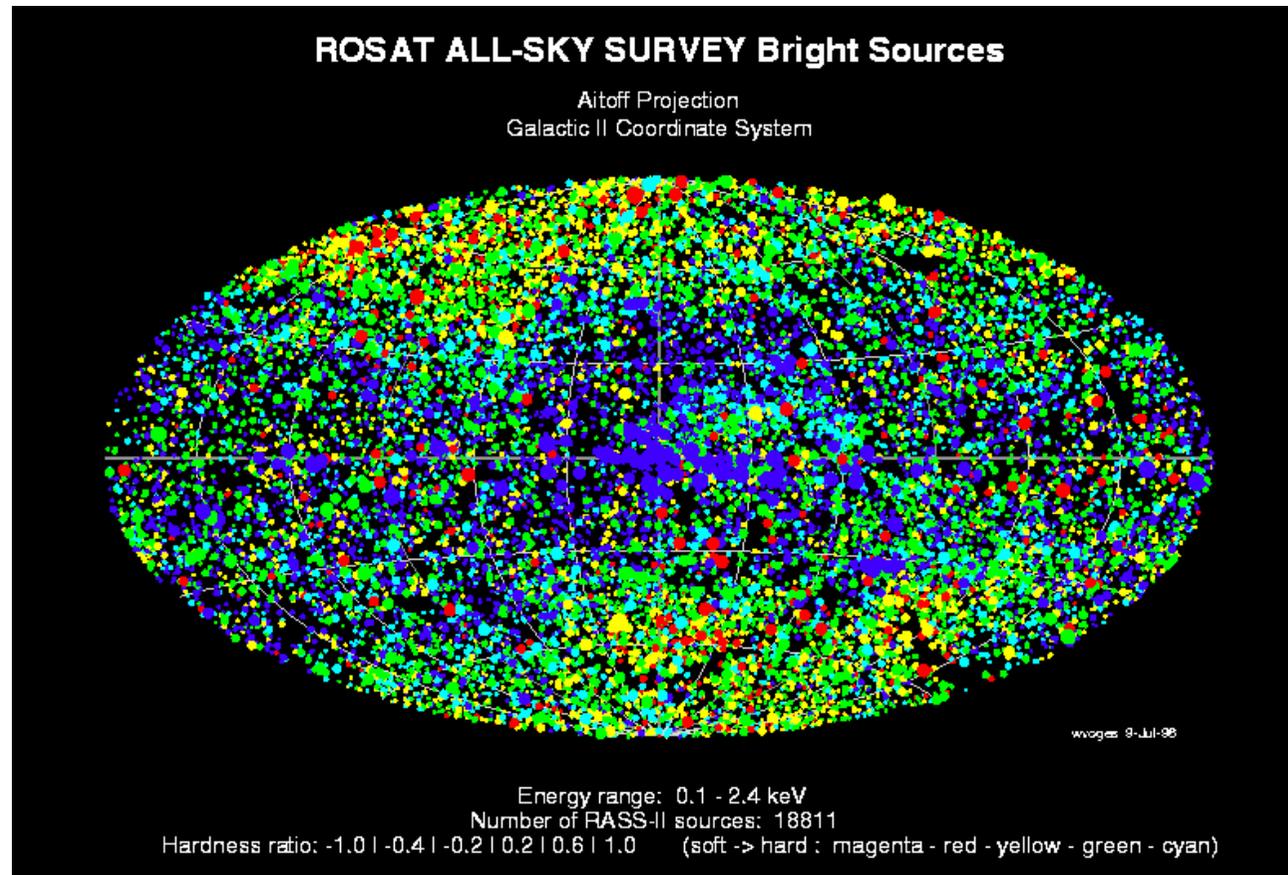
The ROSAT All-Sky Survey Bright Source Catalogue (RASS-BSC, revision 1RXS) is derived from
 the all-sky survey performed during the first half year of the ROSAT mission in 1990/91.
18,811 sources are catalogued, with a limiting ROSAT PSPC countrate
of 0.05 cts/s in the 0.1-2.4 keV energy band. 71

RXTE

http://heasarc.gsfc.nasa.gov/docs/xte/xtegof.html

XTE Spacecraft

High-gain antenna
HEXTE
Star trackers
PCA (1 of 5)
ASM
Solar-power array
Low-gain antenna
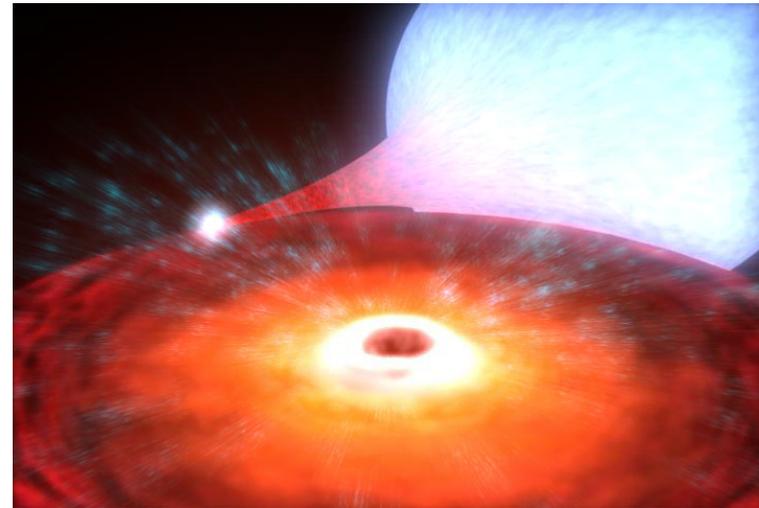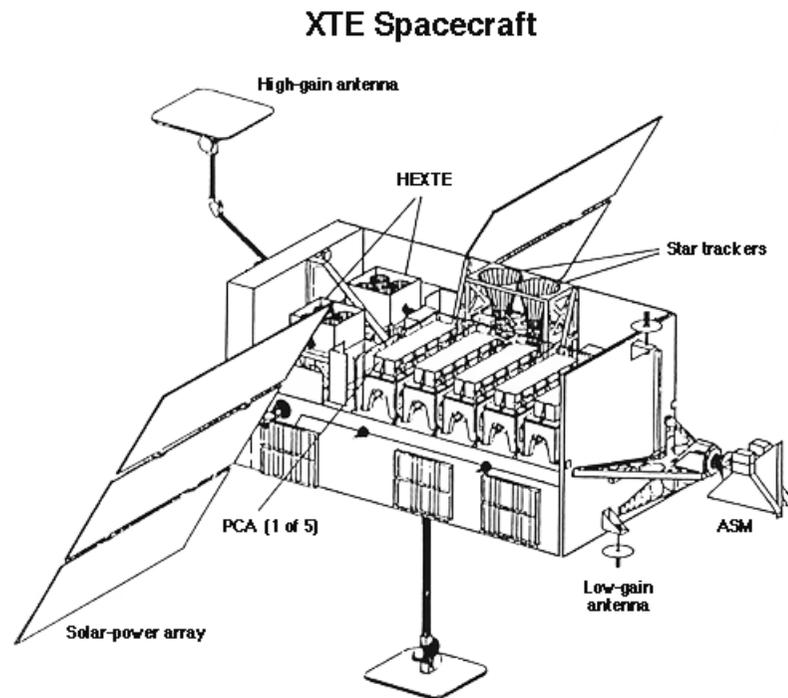
The lowest-mass known black hole belongs to a binary system named XTE J1650-500. The black hole has about 3.8 times the mass of our sun, and is orbited by a companion star

The Rossi X-ray Timing Explorer (RXTE) was launched on December 30, 1995.
RXTE features unprecedented time resolution in combination with moderate spectral resolution to explore the variability of X-ray sources. Time scales from microseconds to months are covered in an instantaneous spectral range from 2 to 250 keV.
Originally designed for a required lifetime of two years with a goal of five, it operated up to 2012

BeppoSAX
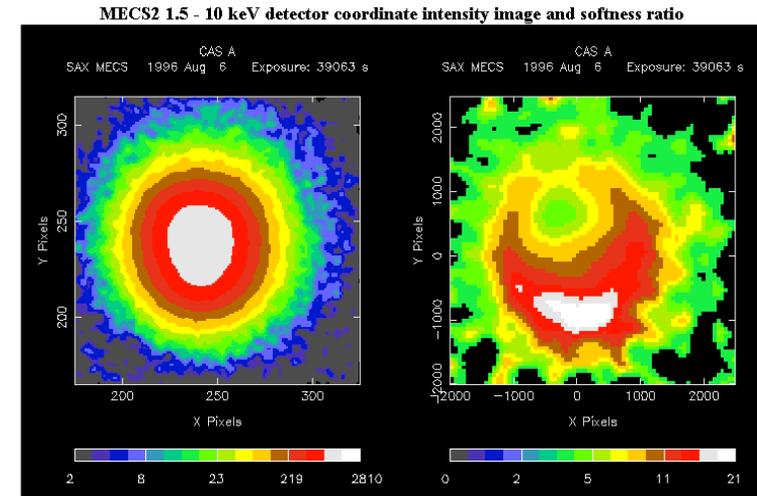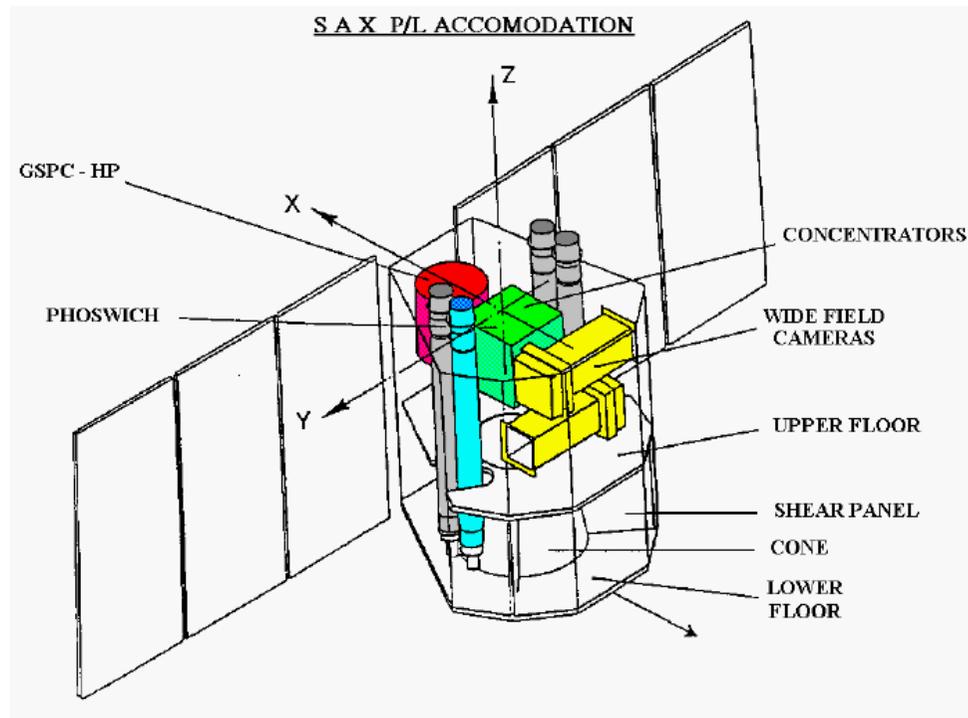
- **Energy Range 0.1 to 200 keV**
- **Imaging capabilities (1') in the range of 0.1-10 keV.**
- **High energy (3-300 keV)**
- **Narrow fields and point in the same direction (Narrow Field Instruments, NFI).**
- **Monitoring large regions of the sky with a resolution of 5' in the range 2-30 keV**
  - two coded mask proportional counters pointing in diametrically opposed directions
  perpendicular to the NFI
- **Anticoincidence scintillator shields of the PDS will be used as a gamma-ray burst monitor**
  in the range 60-600 keV.

BeppoSAX results
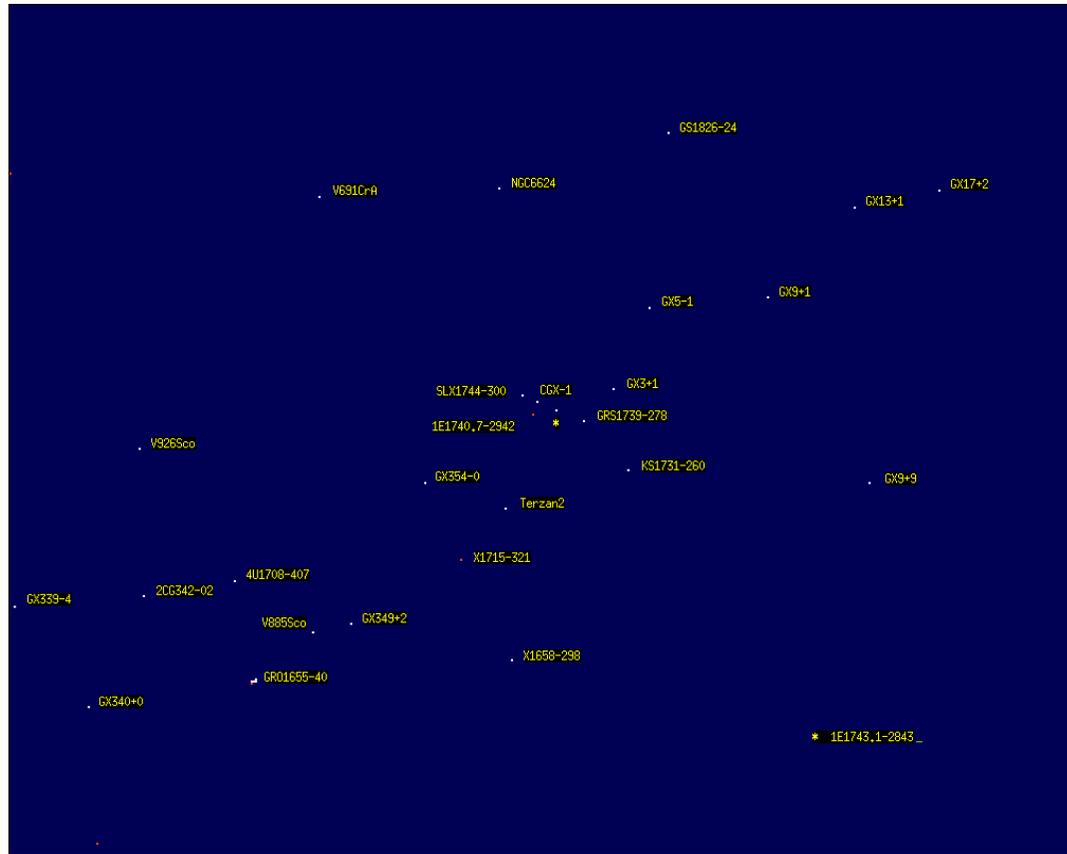
The Galactic Centre has been observed with the Beppo SAX Wide Field Camera 1 (WFC1) in August 1996.
Here an image is shown of the 40 degrees by 40. The observation period was from 22-8-1996 07.54 UT through to 23-8-1996 11.38 UT,
 while the effective exposure totalled about 51 kiloseconds. The number of accepted events was 1.7955 x 10^7 in the energy
 range of 5.4 - 11.3 keV. The legenda for the galactic centre source indicated with a yellow star (1E1743.1-2843), is given at lower right in
the image.

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To our knowledge this is the largest field ever imaged in X-rays in a single pointing.

Chandra X-ray Telescope

http://chandra.harvard.edu/
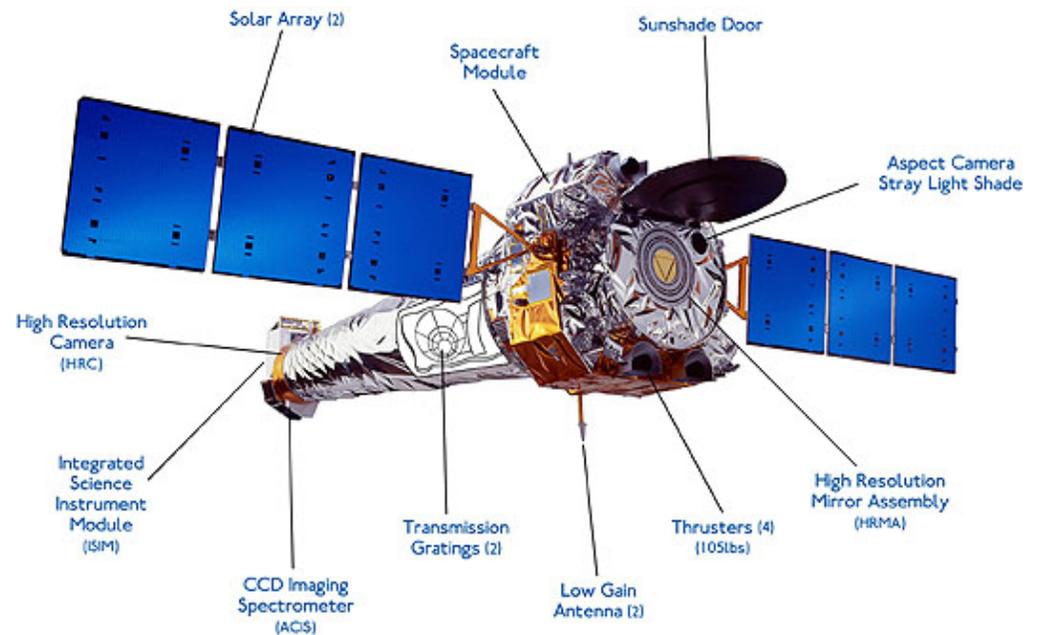
High resolution mirror
two imaging detectors
two sets of transmission gratings.
Spatial resolution: 0.5"
Good sensitivity from 0.1 to 10 keV
High spectral resolution E/ΔE = 1000

XMM-Newton

http://sci.esa.int/xmm-newton/

XMM carries the X-ray telescopes with the largest effective area.
58 thin nested mirror shells in each X-ray telescope.
Moderate and high spectral resolution.
Simultaneous optical/UV observations
Spatial resolution: 6"
Energy Range 0.2 to 12 keV
High Spectral resolution at LowE E/ΔE = 300
Wide FoV

Comparison

The following table compares XMM with selected previous X-ray satellites:

	ROSAT	ASCA	Chandra	XMM
Mirror effective area @ 1.0 keV (cm2)	400	350	800	4650
Imaging effective area @ 1.0 keV (cm2)	200	...	400	2400
Spectroscopy effective area @ 1.0 keV (cm2)	-	-	50	185 (orders 1+2)
Spectroscopic resolving power at 0.5 keV (E/dE)	(1)	9	400-1000	500
Mirror Resolution (arcsec)	3.5	73	0.2	6
CCD energy range (keV)	0.1-2.4	0.5-10	0.1-10	0.1-15
Orbit target visibility (hrs)	1.3	0.9	50	40

Chandra results
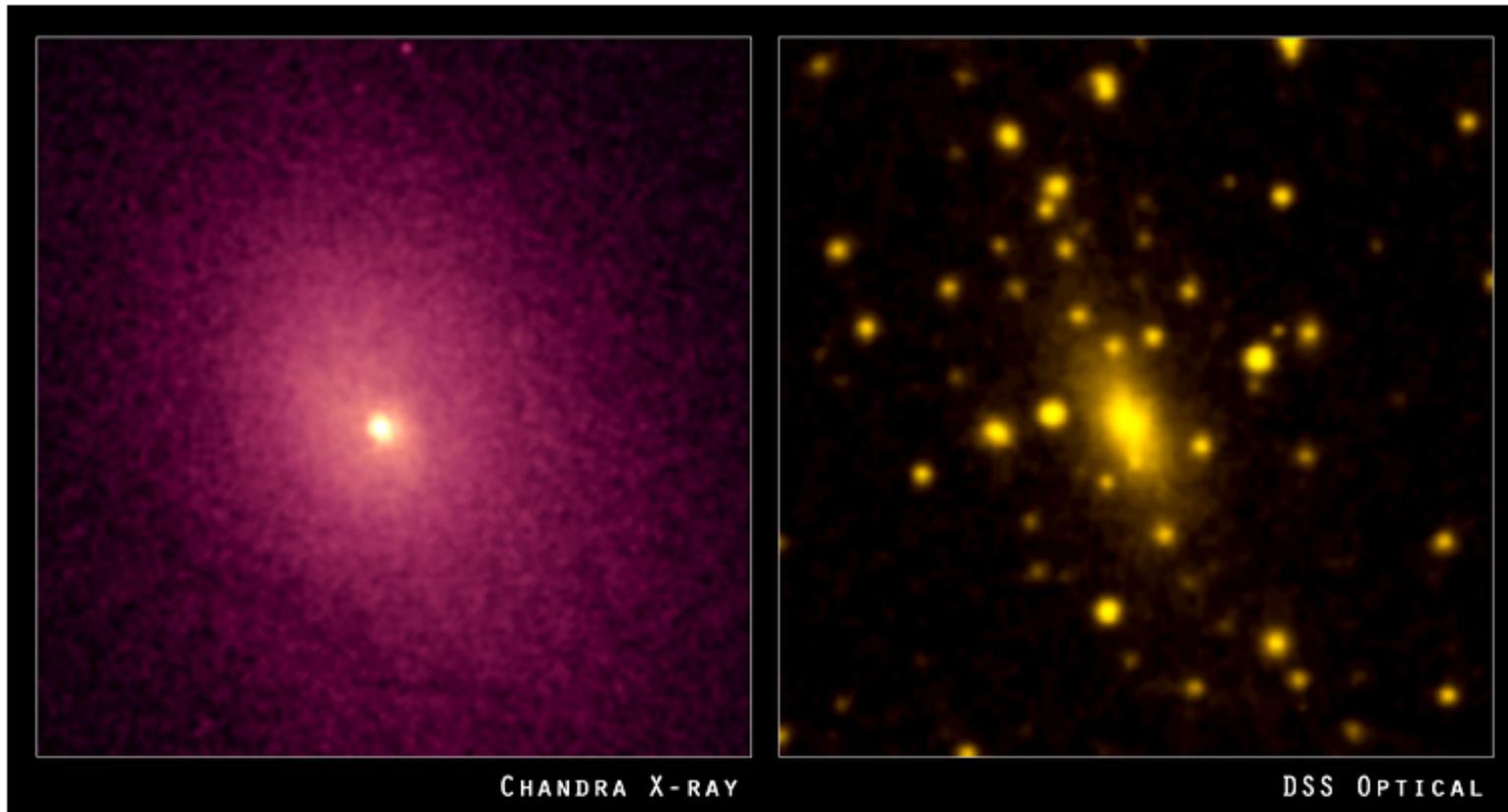
The galaxy cluster Abell 2029 is composed of thousands of galaxies (optical image) enveloped in a gigantic cloud of hot gas (X-ray image)

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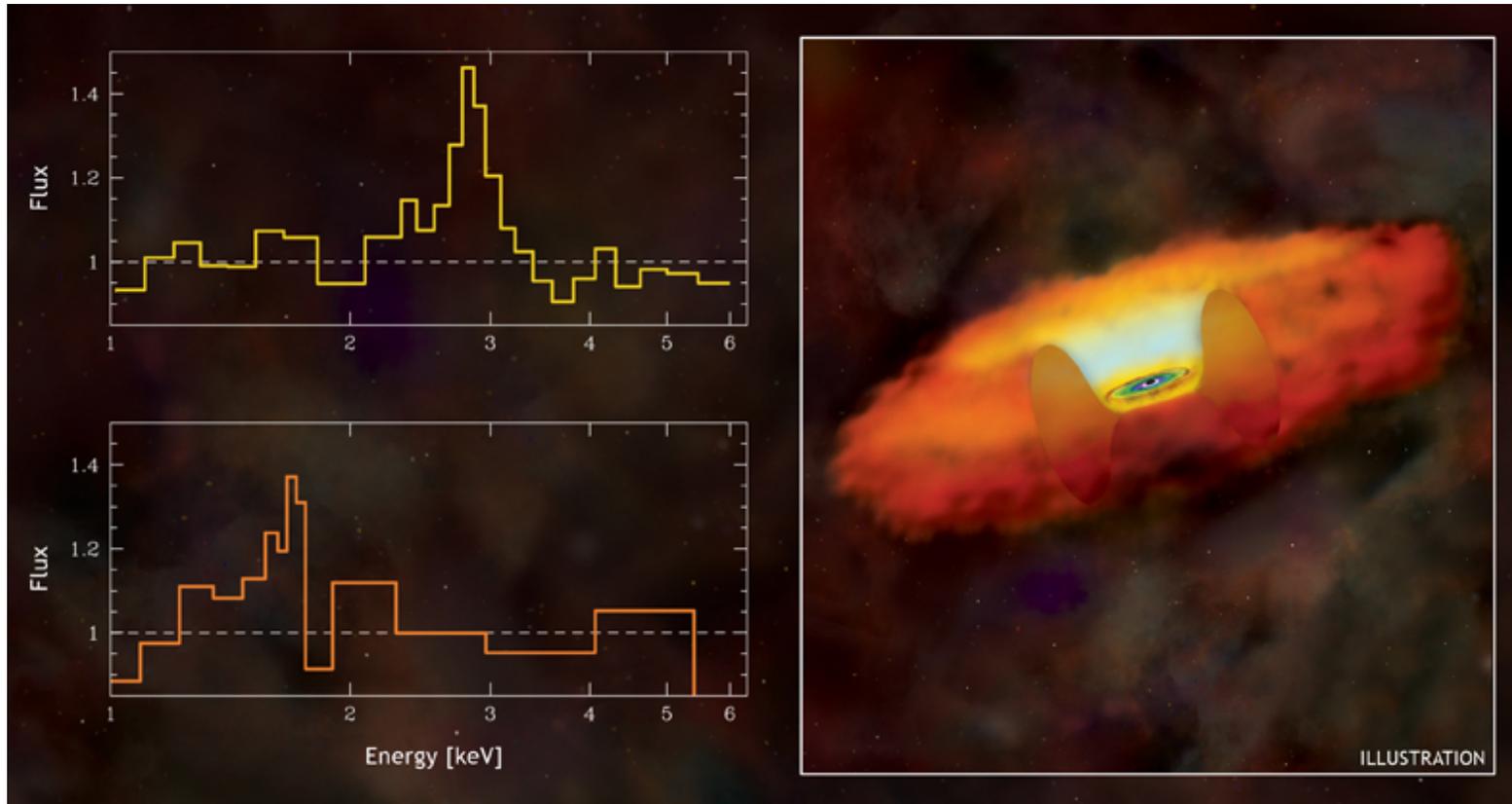
Chandra results

The left side of the above graphic shows portions of X-ray spectra from a subset of 50 black holes about 9 billion light years away (upper panel), and another group of 22 black holes that are about 11 billion light years away (lower panel).

Chandra results

The Tycho and G292.0+1.8 supernova remnants show expanding debris from an exploded star and the associated shock waves.The images of the Crab Nebula and 3C58 show how neutron stars produced by a supernova can create clouds of high-energy particles.

XMM results

- The XXL project, the largest XMM-Newton observing programme to date, set itself the ambitious task of mapping galaxy clusters back to a time when the Universe was just half of its present age. Its aim was to trace the evolution of the large-scale structure of the Universe.
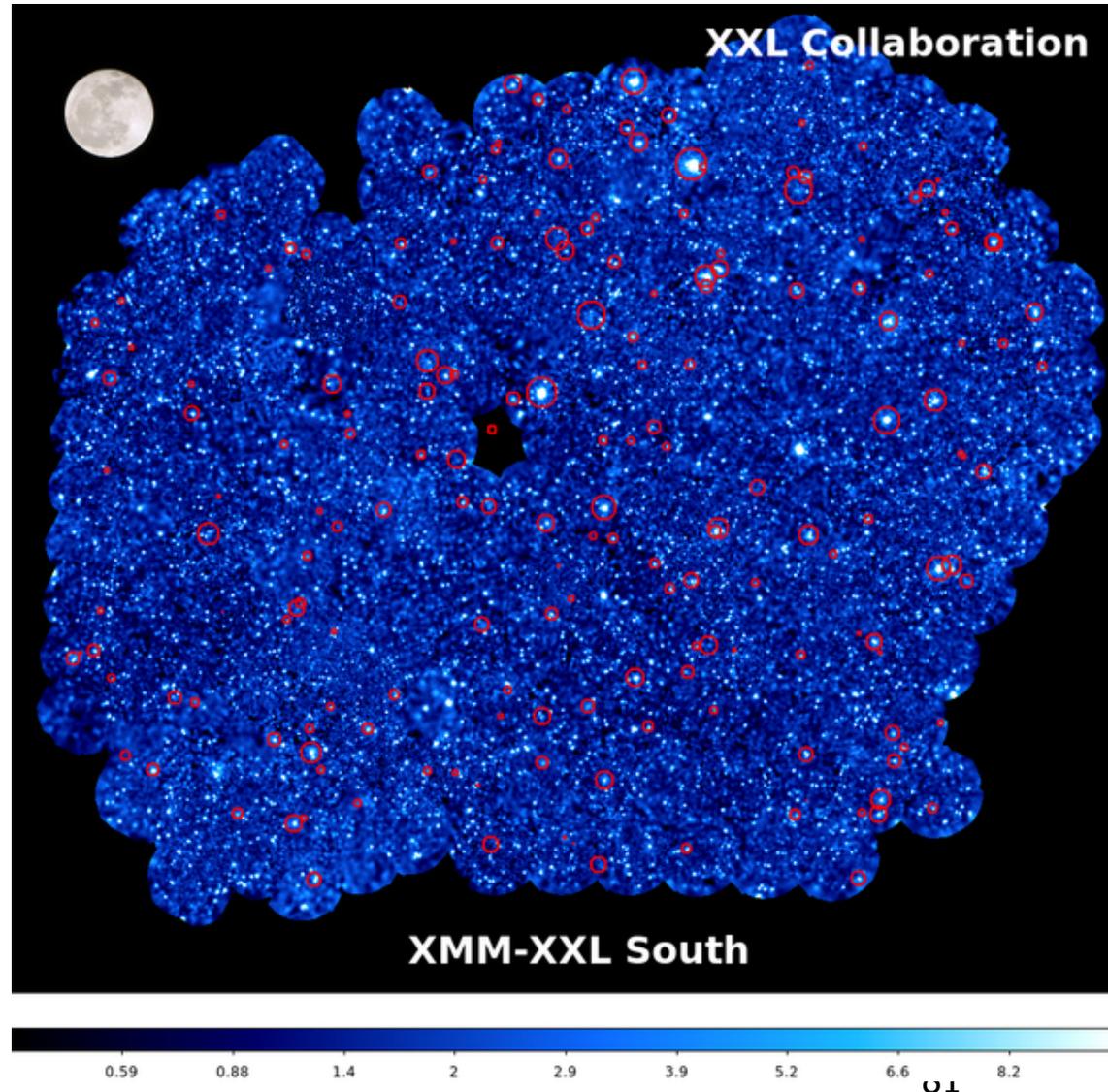
XMM results

Components of the galaxy cluster Abell 2744, also known as the Pandora Cluster: galaxies (white), hot gas (red) and dark matter (blue).
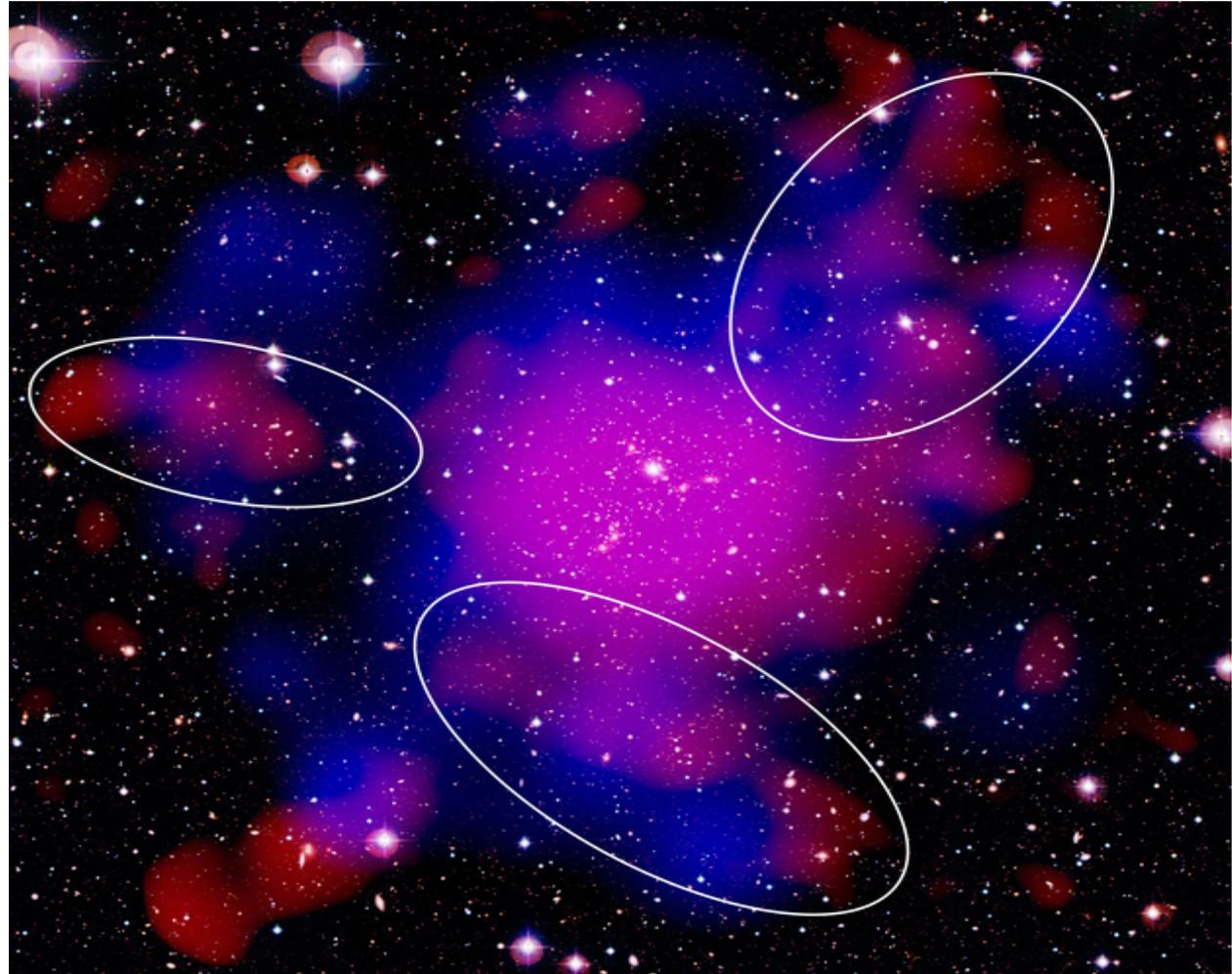
X-ray science highlights

Chandra Images by Category

Solar System (9 listings)
Comets and planets

Normal Stars & Star Clusters (30 listings)
Stellar coronas, clusters of stars and hot gas produced by outflow from young stars.

White Dwarfs & Planetary Nebulas (10 listings)
Hot gas associated with the final stages of evolution of Sun-like stars, novas, and other white dwarfs in binary star systems.

Supernovas & Supernova Remnants (34 listings)
X-ray sources produced by the violent explosions of massive stars.

Neutron Stars/X-ray Binaries (26 listings)
Hot, isolated neutron stars, rotation-powered pulsars, and neutron stars accreting matter from a nearby companion star.

Black Holes (27 listings)
Stellar black holes, mid-mass black holes, and supermassive black holes.

Milky Way Galaxy (14 listings)
Images related to the Galactic Center and other features of the structure and evolution of the Milky Way Galaxy.

Normal Galaxies & Starburst Galaxies (39 listings)
Images of spiral, elliptical, and irregular galaxies that show X-ray sources associated with collapsed stars and star formation.

Quasars & Active Galaxies (33 listings)
Galaxies with unusually energetic activity, including high-energy jets, that is related to a central supermassive black hole.

Groups & Clusters of Galaxies (33 listings)
Vast clouds of hot gas embedded with numerous galaxies.

Cosmology/Deep Fields/X-ray Background (13 listings)
The sky as observed in X-rays is not dark, but gives off a glow thought to be from many distant sources. Deep surveys with the Chandra X-ray Observatory should reveal the cause of this glow.

Miscellaneous (8 listings)
Objects that don't fit in the above categories, such as brown dwarfs & gamma-ray bursts.

X-ray science highlights
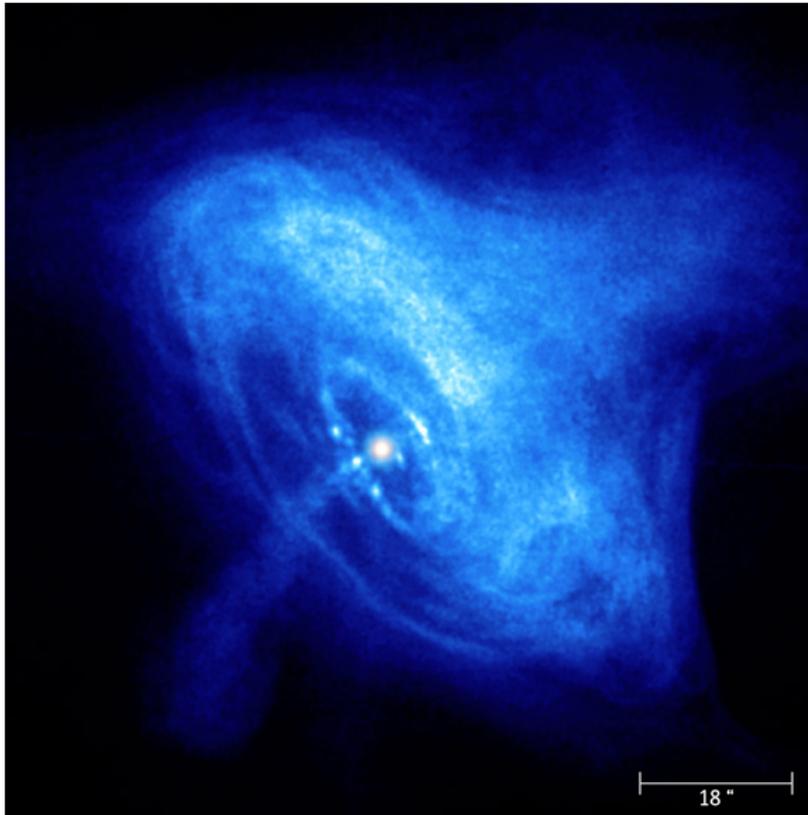
This image provides a view of the activity in the inner region around the Crab Nebula pulsar, a rapidly rotating neutron star seen as a bright white dot near the center of the images.

A wisp can be seen moving outward at half the speed of light from the upper right of the inner ring around the pulsar.
The wisp appears to merge with a larger outer ring that is visible in both X-ray and optical images.

The inner X-ray ring consists of about two dozen knots that form, brighten and fade. As a high-speed wind of matter and antimatter
particles from the pulsar plows into the surrounding nebula, it creates
a shock wave and forms the inner ring.
Energetic shocked particles move outward to
brighten the outer ring and produce an extended X-ray glow.

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X-ray science highlights
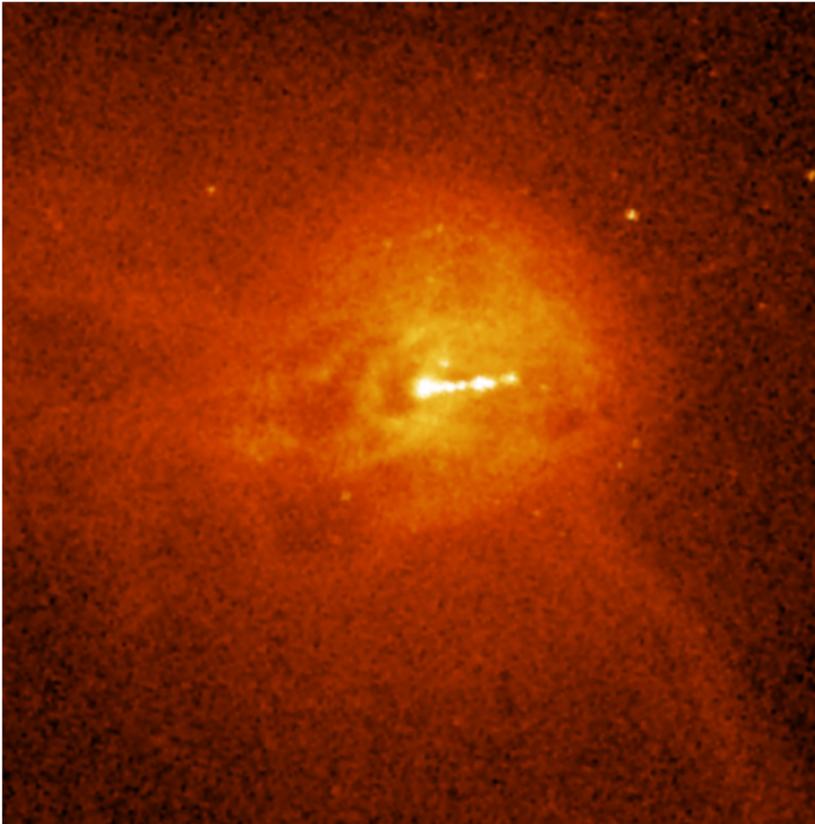
This close-up of M87 shows the region surrounding
the jet of high-energy particles in more detail.
The jet is thought to be pointed at a small angle to the
line of sight, out of the plane of the image.
This jet may be only the latest in a series of jets
that have been produced as magnetized
gas spirals in a disk toward the supermassive black hole

X-ray science highlights
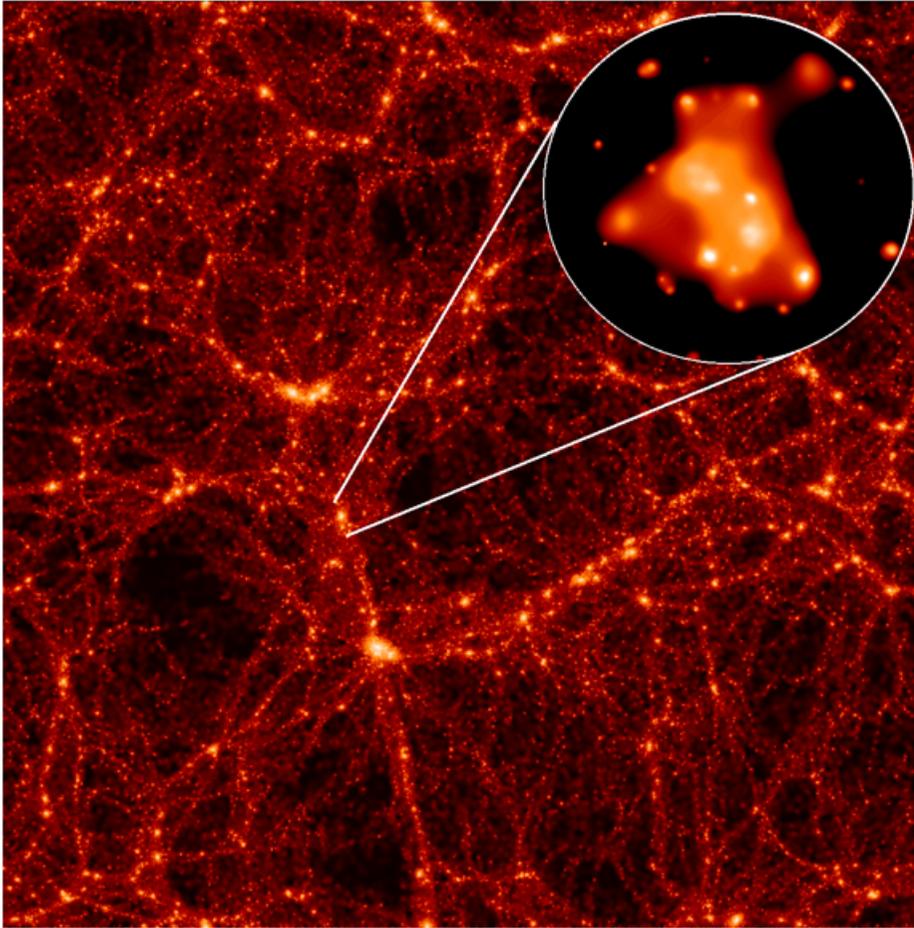
This image shows a computer simulation of a large volume of the Universe.
An XMM-Newton X-ray image of a real galaxy cluster from the study is superimposed to illustrate the formation of galaxy clusters in the densest parts of the universe.

Dark Matter and Cosmo Simulations

http://www.illustris-project.org

http://www.tng-project.org

Dark Matter and Cosmo Simulations

Numerical Simulations of the Dark Universe:
State of the Art and the Next Decade

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Abstract

We present a review of the current state of the art of cosmological dark matter simulations, with particular emphasis on the implications for dark matter detection efforts and studies of dark energy. This review is intended both for particle physicists, who may find the cosmological simulation literature opaque or confusing, and for astro-physicists, who may not be familiar with the role of simulations for observational and experimental probes of dark matter and dark energy. Our work is complementary to the contribution by M. Baldi in this issue, which focuses on the treatment of dark energy and cosmic acceleration in dedicated N-body simulations.

Truly massive dark matter-only simulations are being conducted on national supercomputing centers, employing from several billion to over half a trillion particles to simulate the formation and evolution of cosmologically representative volumes (cosmic scale) or to zoom in on individual halos (cluster and galactic scale). These simulations cost millions of core-hours, require tens to hundreds of terabytes of memory, and use up to petabytes of disk storage. Predictions from such simulations touch on almost every aspect of dark matter and dark energy studies, and we give a comprehensive overview of this connection. We also discuss the limitations of the cold and collisionless DM-only approach, and describe in some detail efforts to include different particle physics as well as baryonic physics in cosmological galaxy formation simulations, including a discussion of recent results highlighting how the distribution of dark matter in halos may be altered. We end with an outlook for the next decade, presenting our view of how the field can be expected to progress.

http://arxiv.org/pdf/1209.5745v2.pdf

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