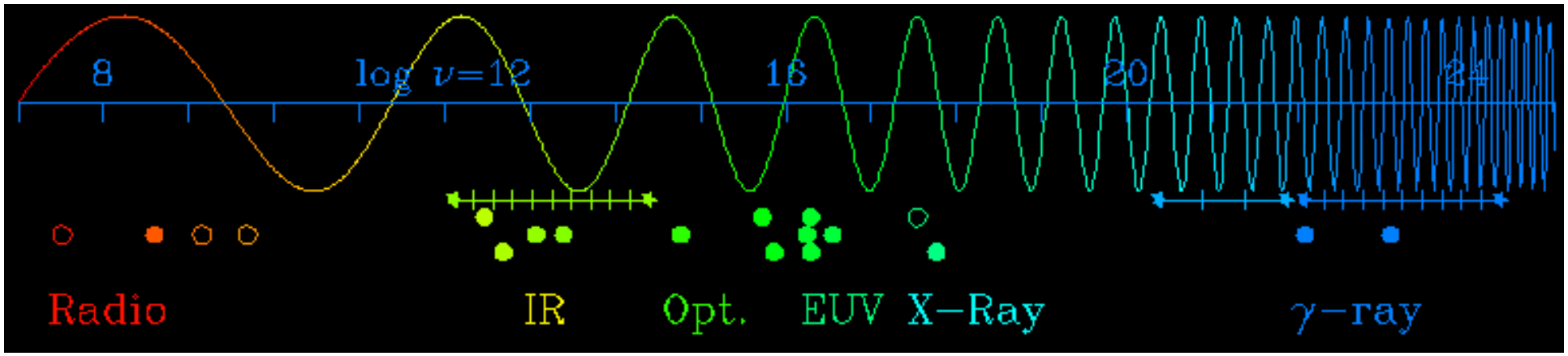
Birth and Growth of High Energy Astrophysics

Taken from Giorgio Palumbo's lessons at the

Università degli Studi di Bologna



X-ray band:

$0.01 \leq \lambda\ (\text{nm}) \leq 10$

$3\text{x}10^{16} \leq \nu\ (\text{HZ}) \leq 3\text{x}10^{19}$

$0.1 \leq E\ (\text{keV}) \leq 100$

γ-ray band:

$\lambda\ (\text{nm}) \leq 0.01$

$\nu\ (\text{HZ}) \geq 3\text{x}10^{19}$

$E\ (\text{keV}) \geq 100$

Photons

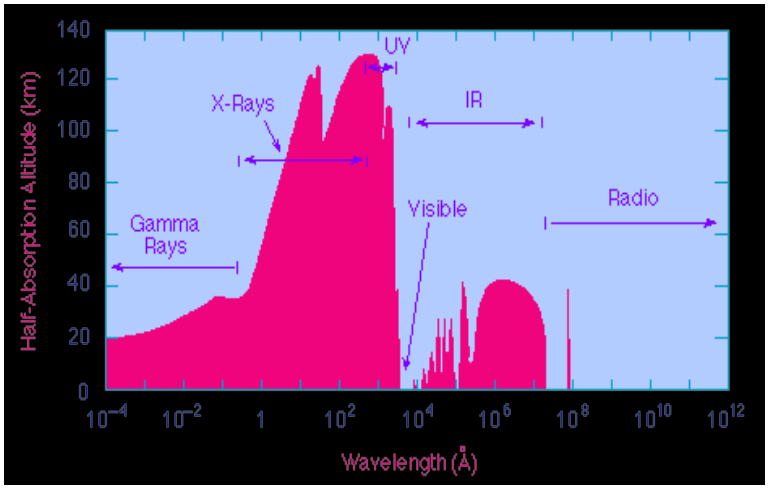
Energy of photon is set by frequency/wavelength

$$E = h\nu = \frac{hc}{\lambda}$$

Unit is electon-volt (eV or keV)

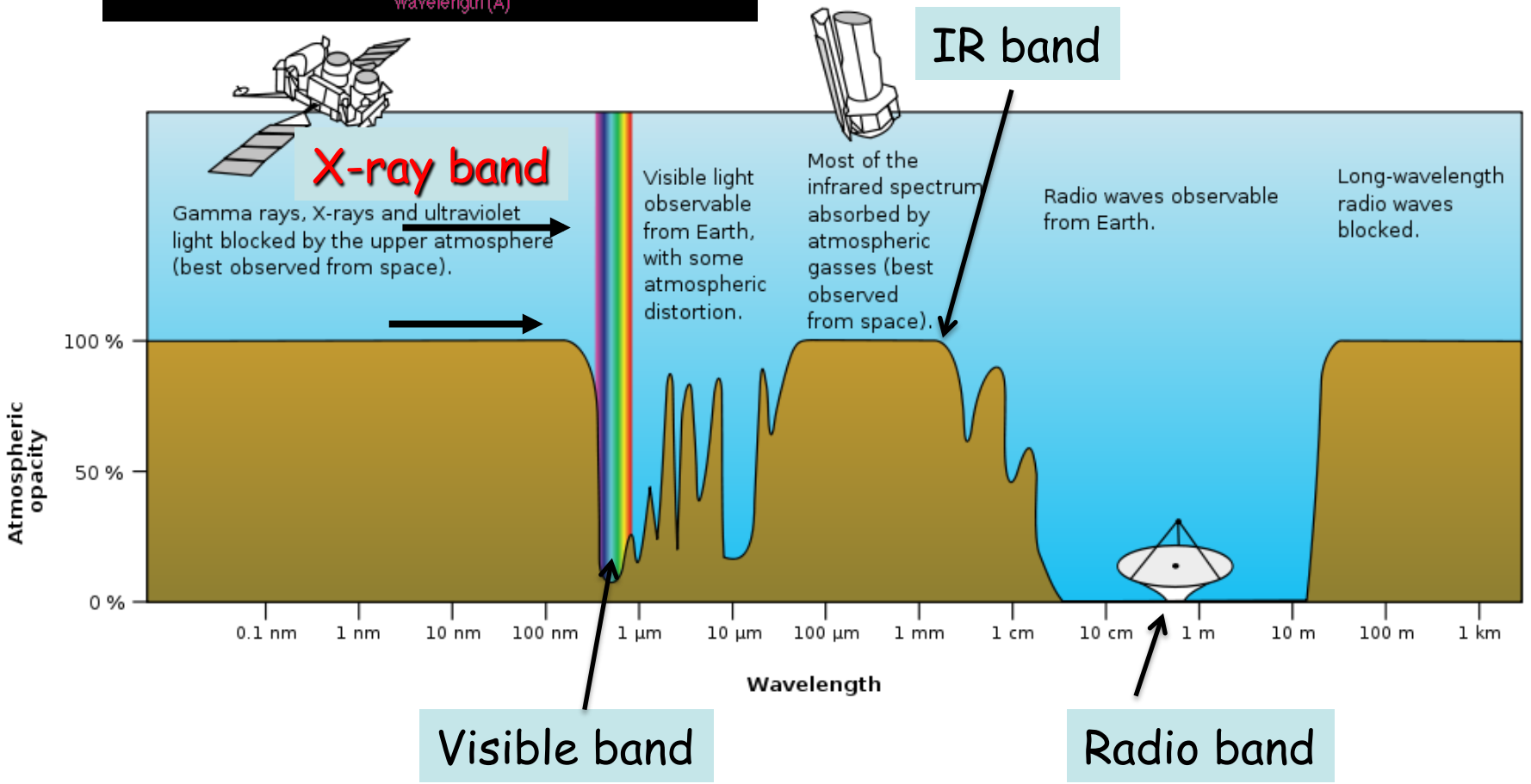
1 eV = 1.6×10^{-19} J = 1.6×10^{-12} erg

$$E(\text{keV}) = \frac{12.4}{\lambda(\text{Angstroms})}$$



Rockets & satellites flying at h ≥ 200 km are necessary to detect X-rays

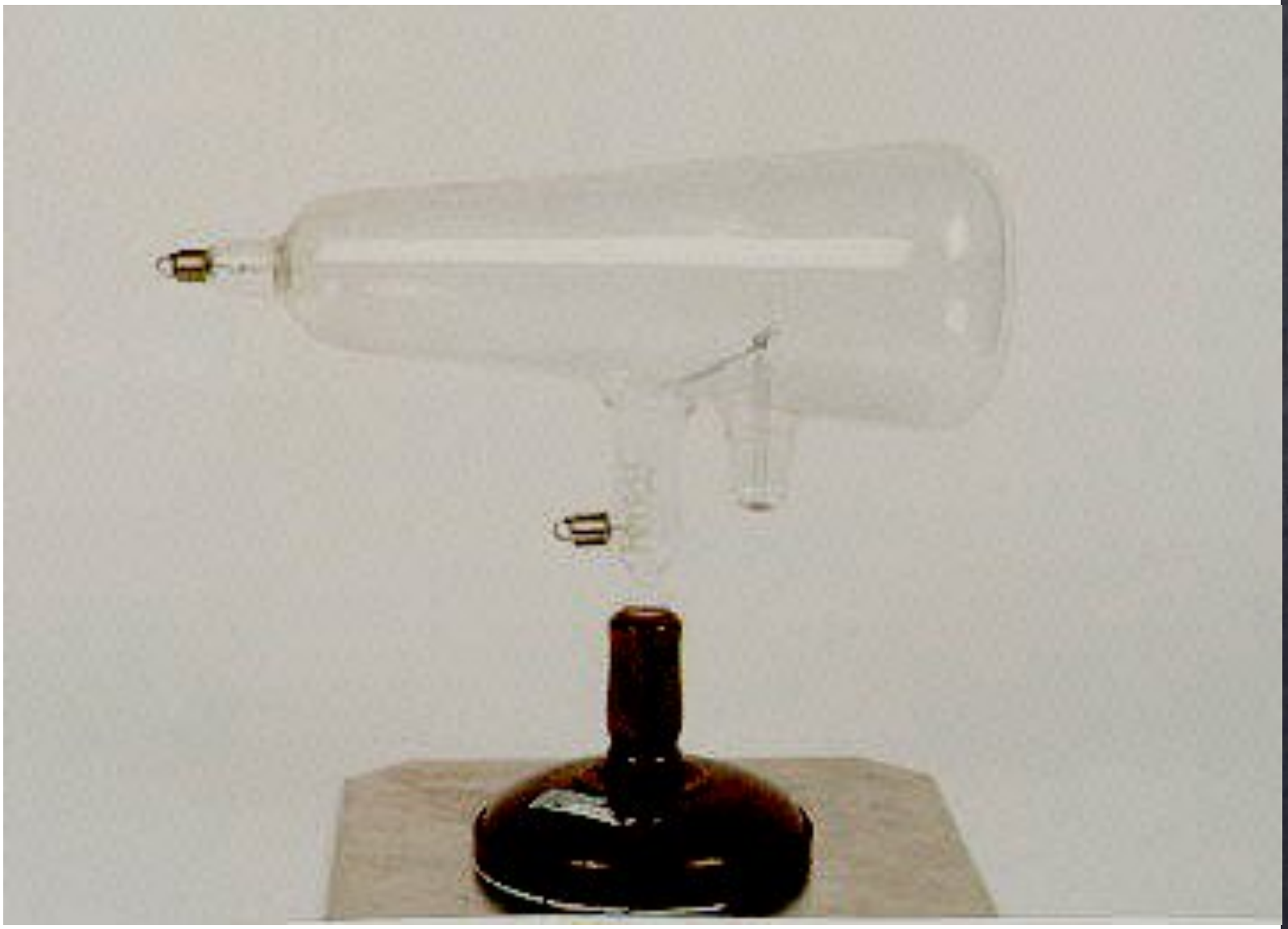
High energy Gamma rays can be detected with balloons



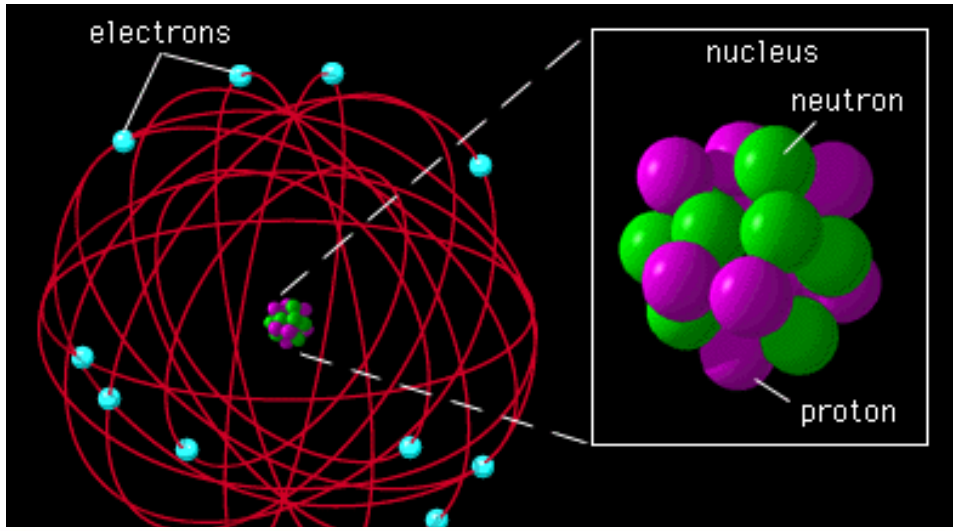
Wilhelm Konrad

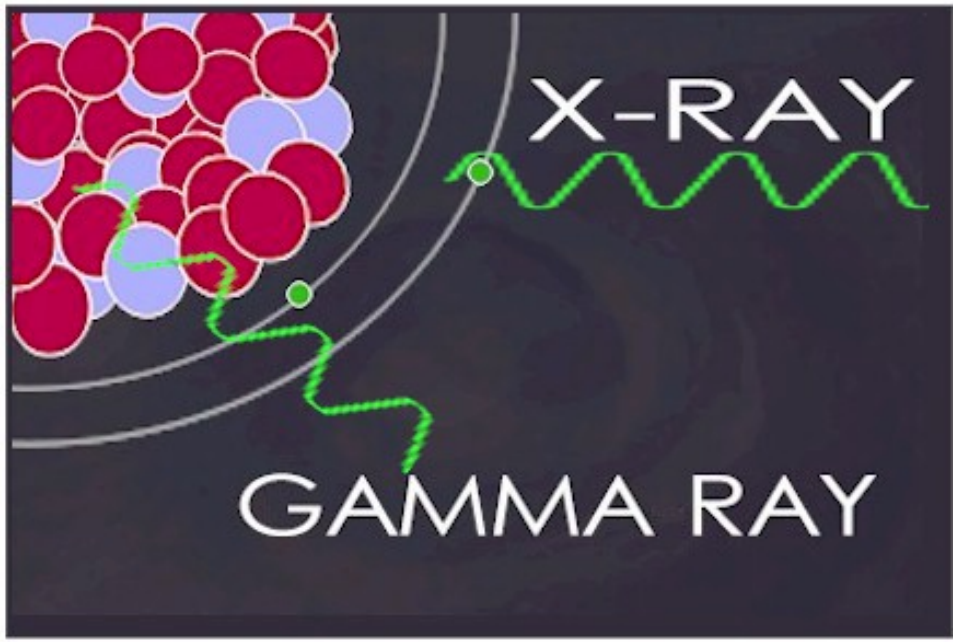
Roentgen 1845-1923

Physics Nobel Price (1901)
for the discovery of X-rays



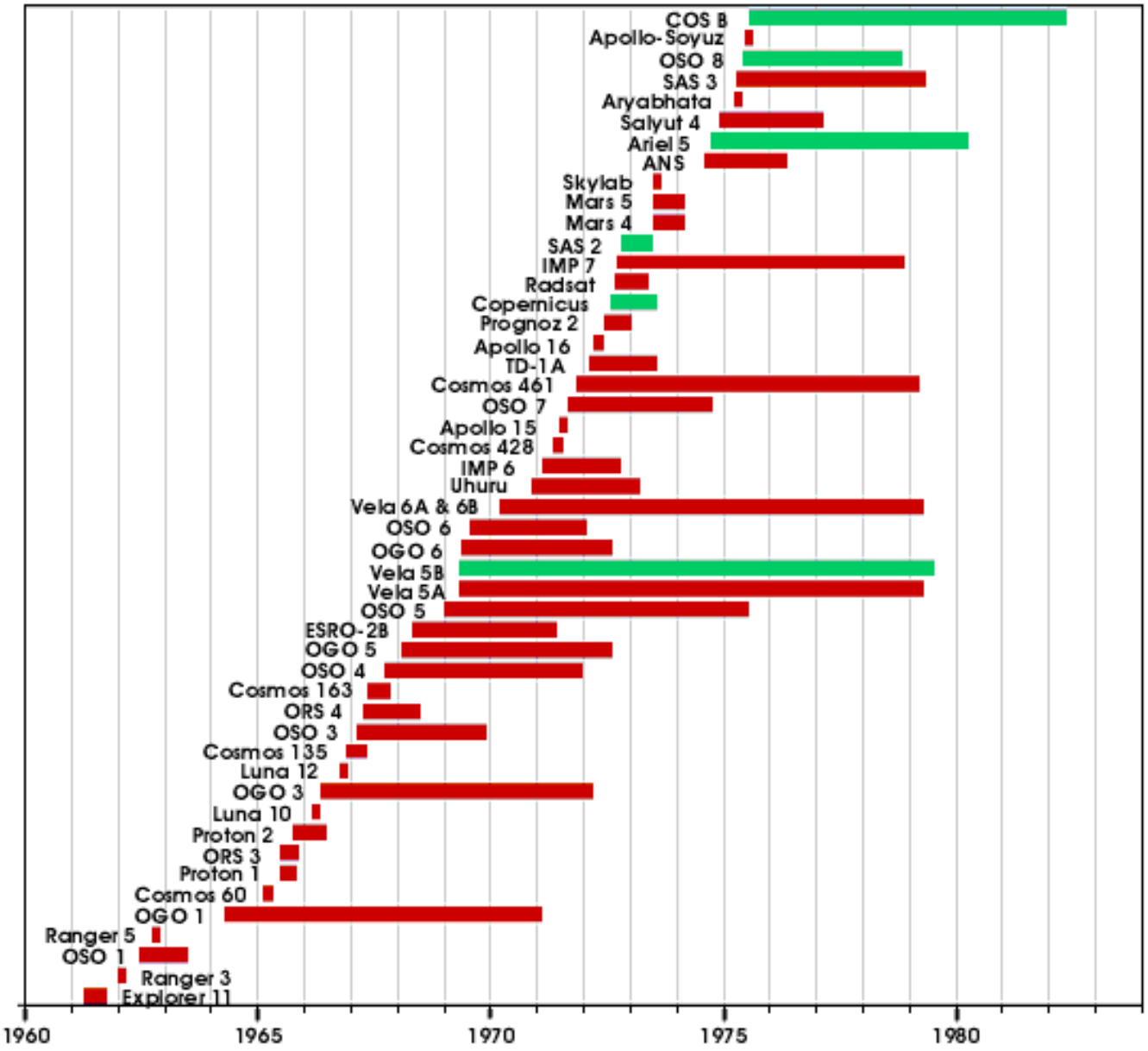
Crookes tube: electrons (produced by high voltage) interact with the walls (glass) and produce fluorescence. Photographic films around are impressed



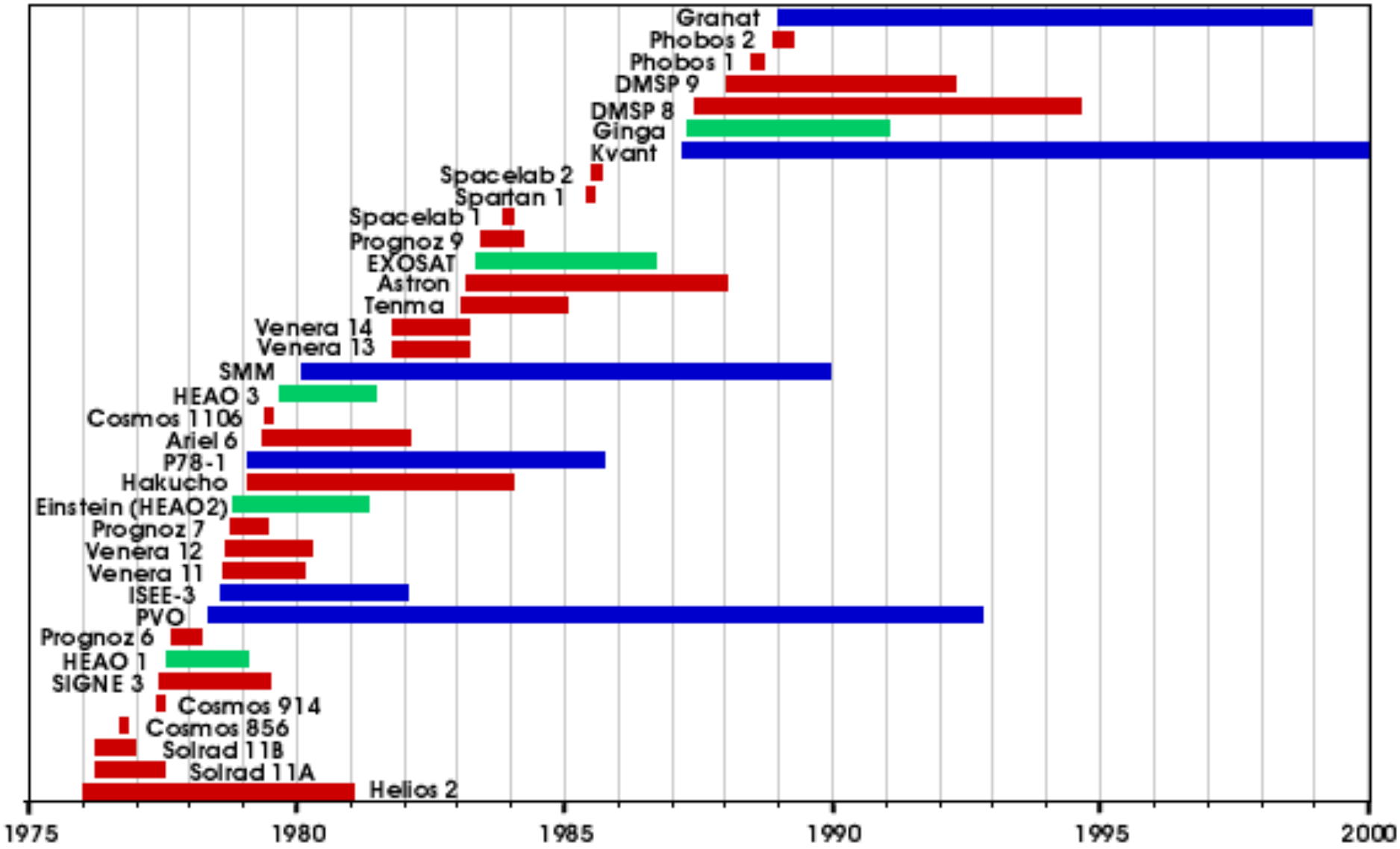


Lord Rutherford 1911, discovery of Gamma Rays

High Energy Astrophysics: the early days

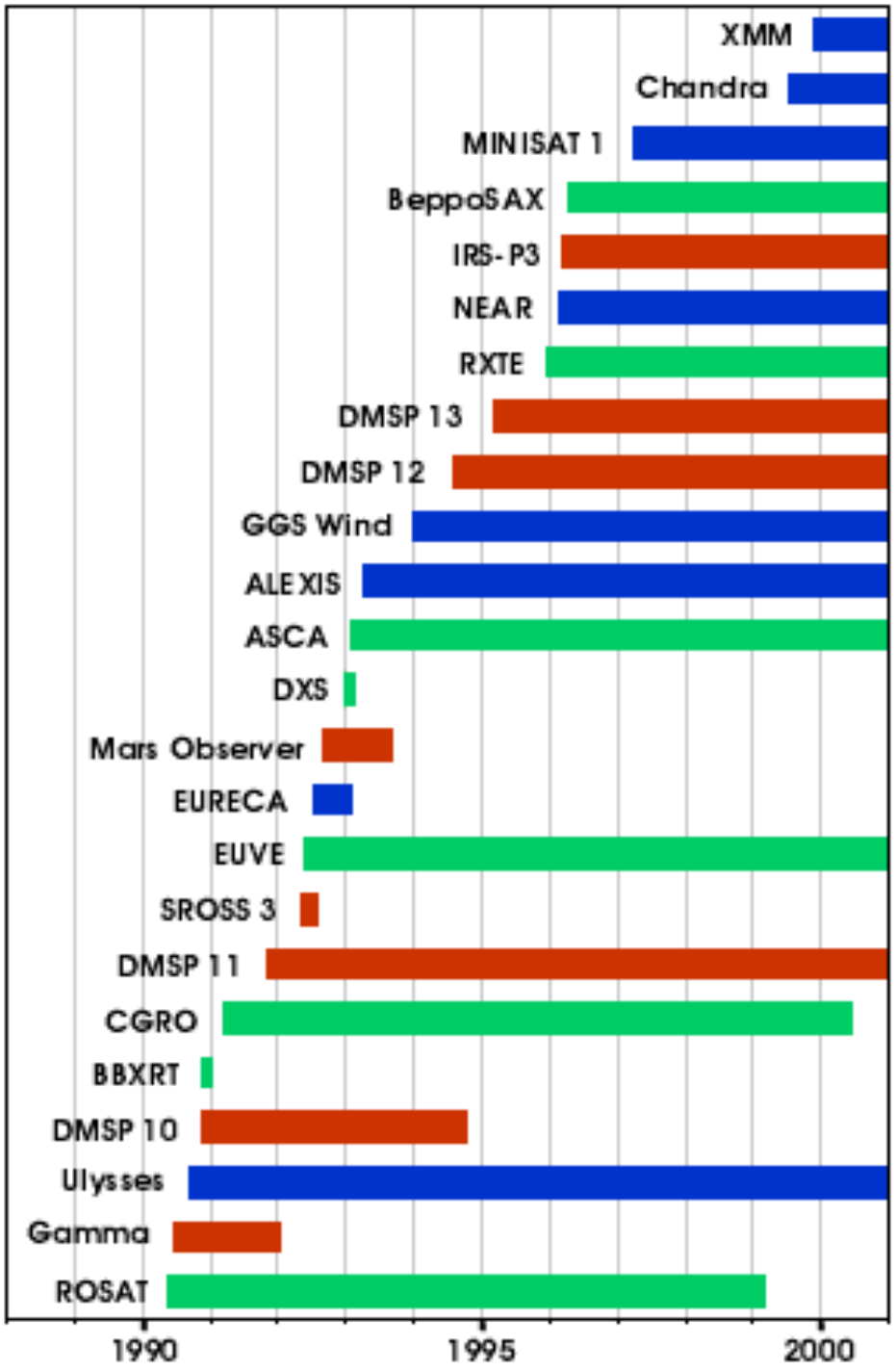


High Energy Astrophysics:
the days of maturity



High Energy Astrophysics:

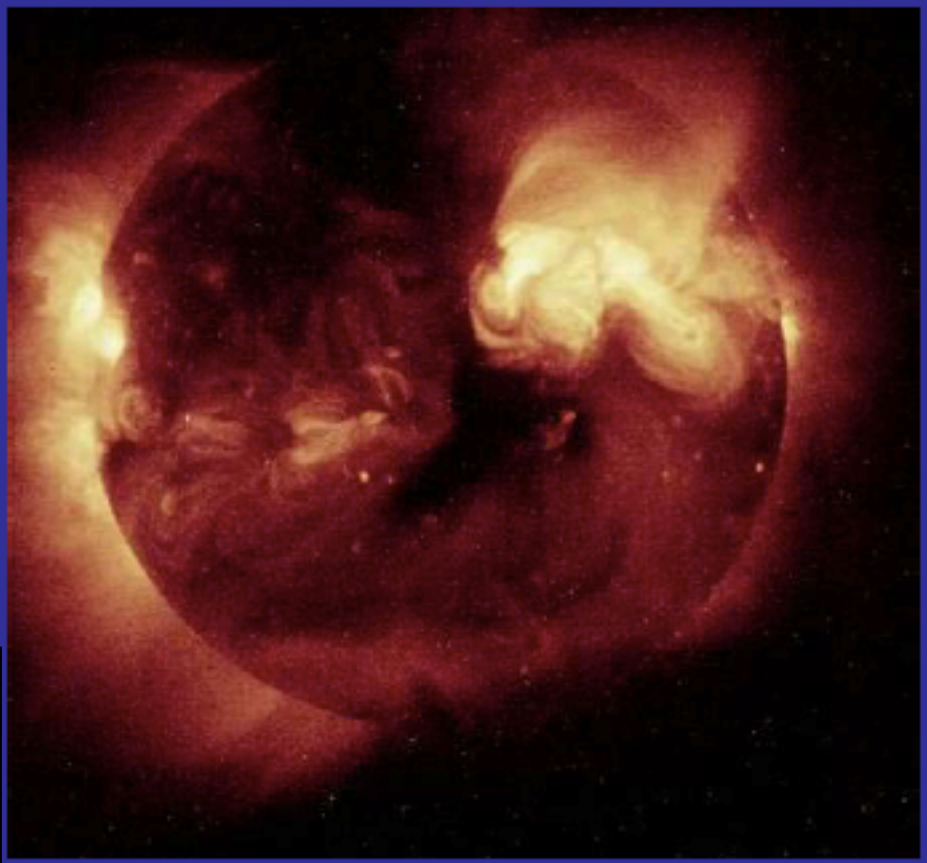
the golden days



The early history of X-ray Astronomy

1948: first observation of (solar) celestial X-rays by Burnight
(photographic emulsion, Aerobee rocket)

The X-ray emission from the Sun was extensively studied in the following ten years by Herbert Friedman and collaborators at the Naval Research Laboratory (Washington)
(Geiger counters on V2 Rockets from Word War II)



- The Sun is an X-ray source
- Proportional counters remained mute up to 85 km in the atmosphere (mostly opaque to X-rays)

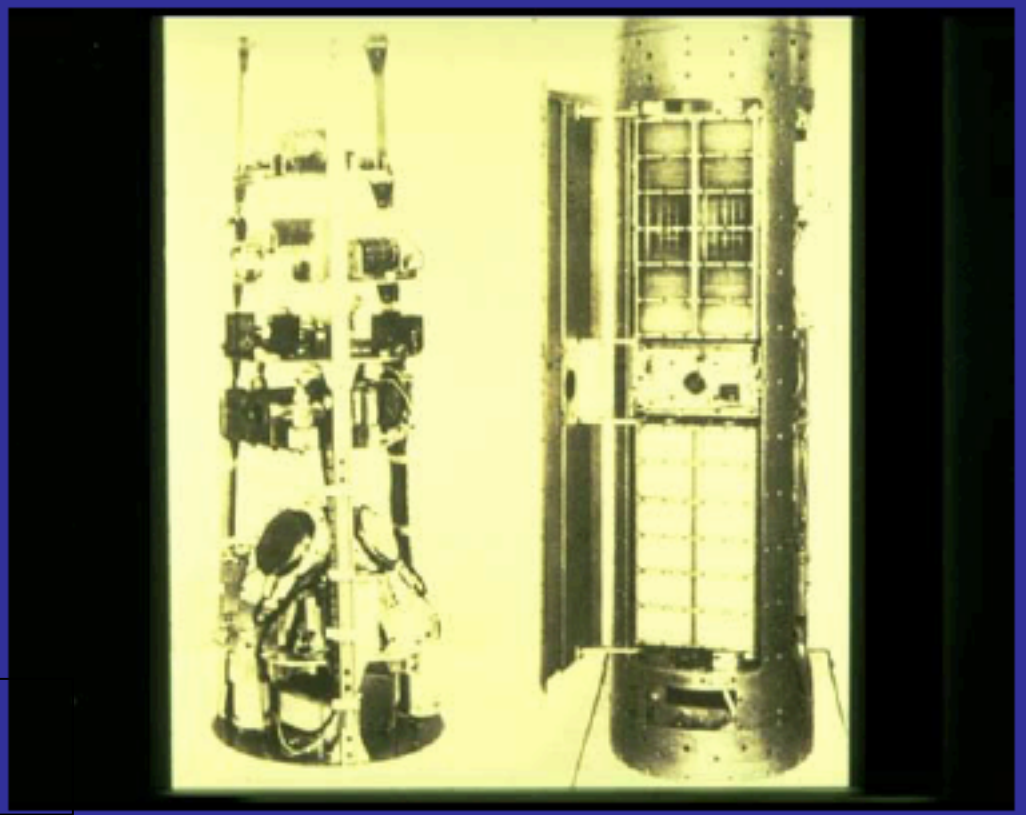
1962 discovery of the first extrasolar X-ray source (Sco X-1) and of a diffuse isotropic background (X-Ray Background, XRB) by Riccardo Giacconi, Bruno Rossi and collaborators at the American Science & Engineering (AS&E, Cambridge)

Aerobee rocket , 3 Geiger counters
(only 2 working during the flight)

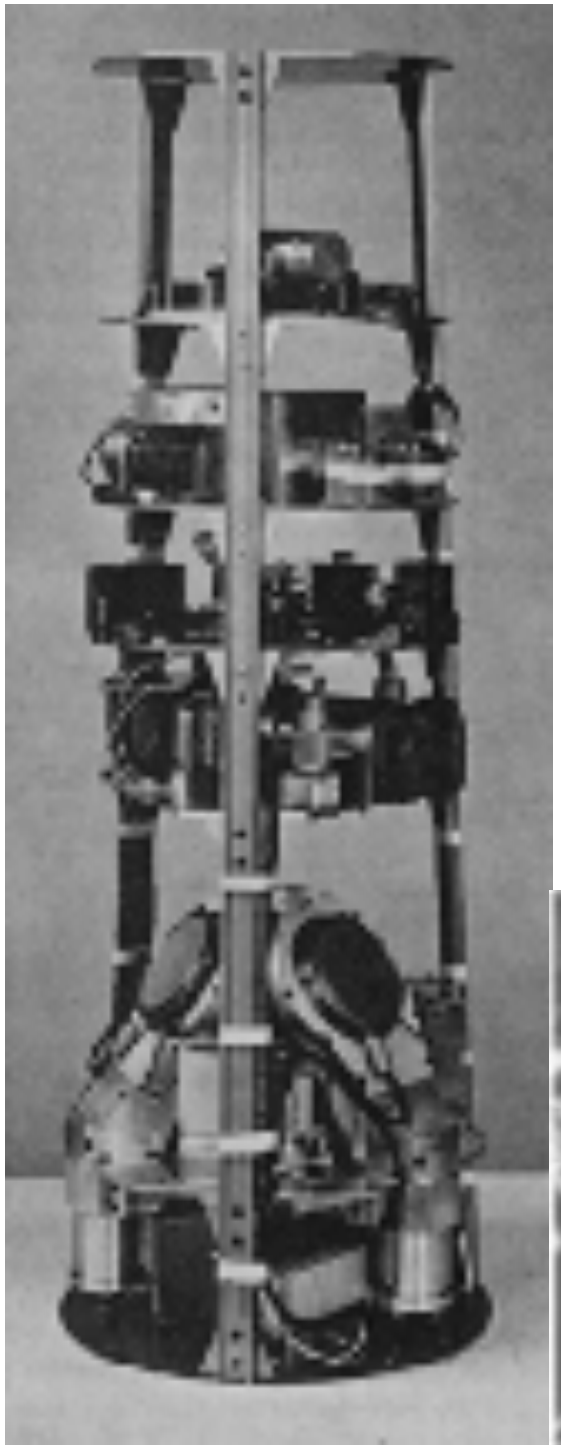
Birth of X-ray astronomy:

- 6 minutes of observation
- 230 km of altitude
- 2 Geiger counters
- 10 cm^2 effective area
- 1.5-6 keV energy band
- anticoincidence scintillator
- Aerobee rocket

Official goal: to detect X-rays from the moon



With this one experiment it is impossible to completely define the nature and origin of the radiation we have observed. […] However, we believe that the data can best be explained by **identifying the bulk of the radiation as soft X-rays from sources outside the solar system.**



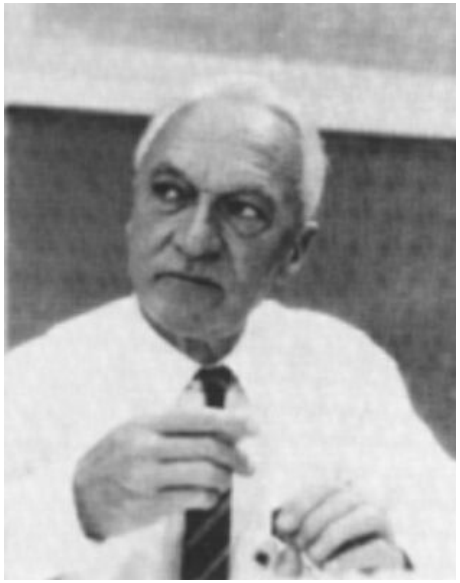
Geiger Counters

1962 Launch

Giacconi, Gursky, Paolini

& Rossi (MIT)

Italian “presence” in the rapidly growing X-ray community



Bruno Rossi

Nato a Venezia (1905-1993)

Ph.D. a Bologna

Parte per gli USA a cause delle leggi razziali

Manhattan Project / Prof. al MIT

Riccardo Giacconi

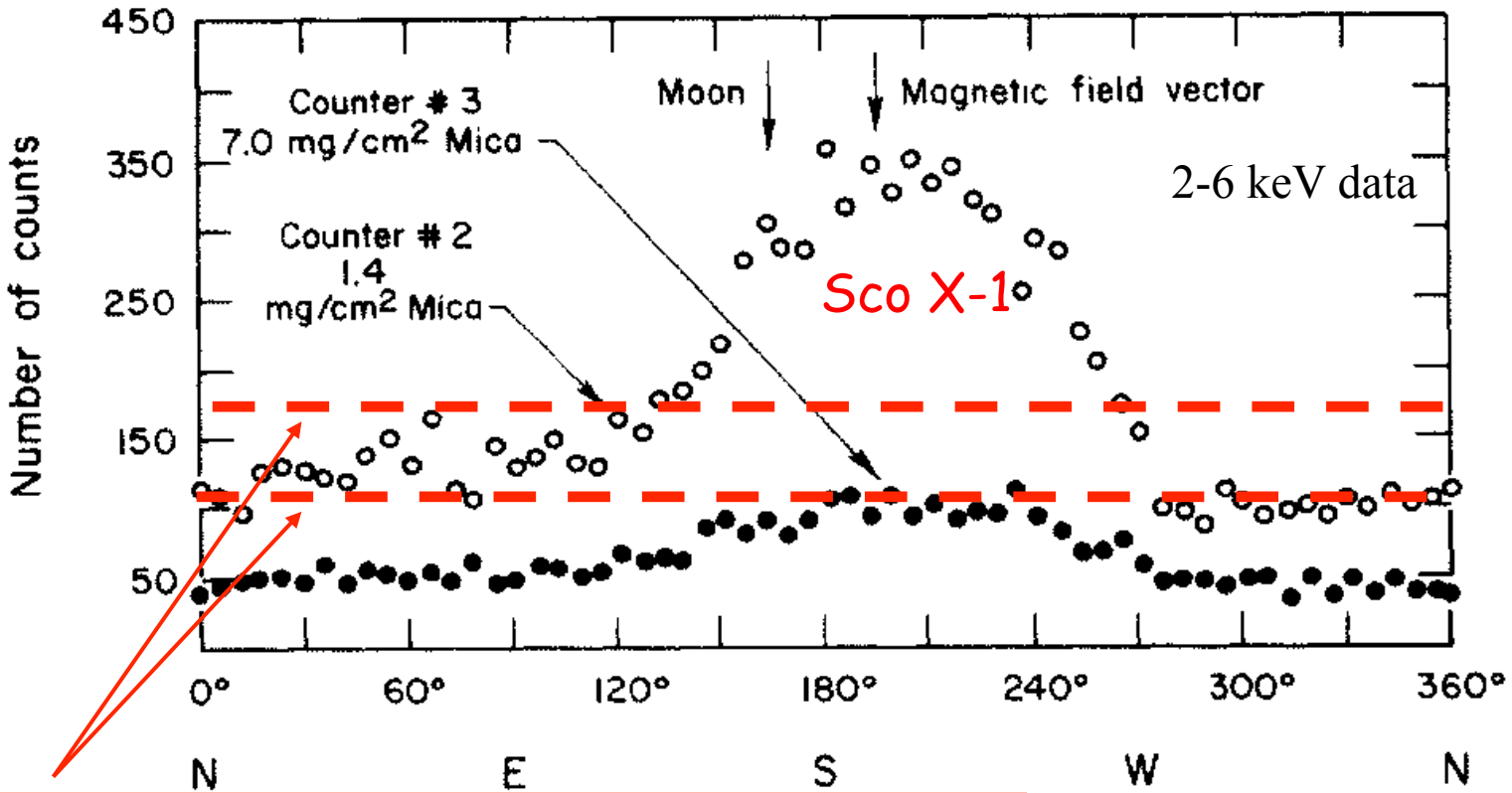
Nato a Genova nel 1931

Ph.D. a Milano (super-visore: Giuseppe Occhialini)

Vari incarichi di prestigio

Premio Nobel per la Fisica nel 2002

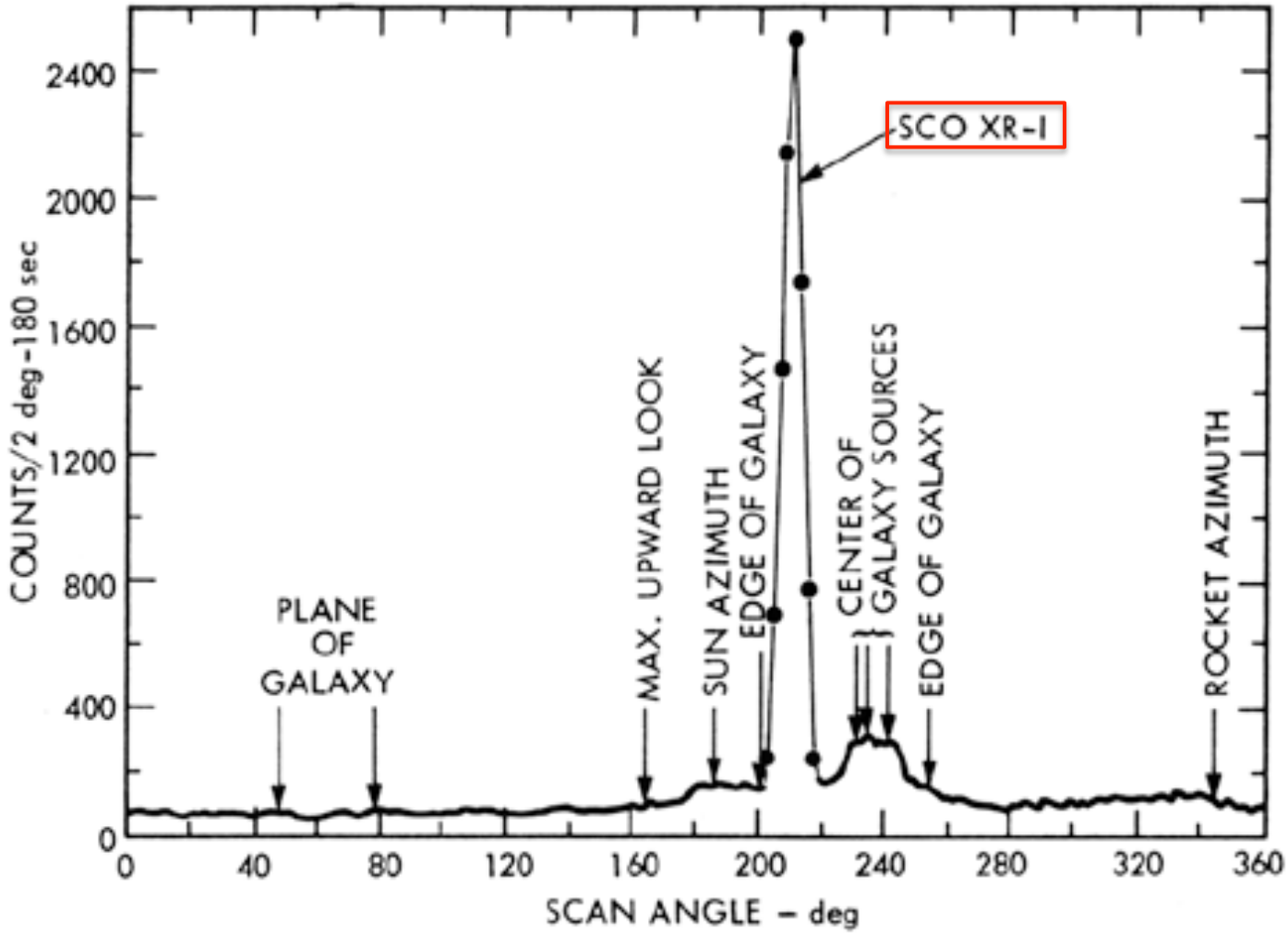
The discovery of the cosmic X-ray background (XRB)



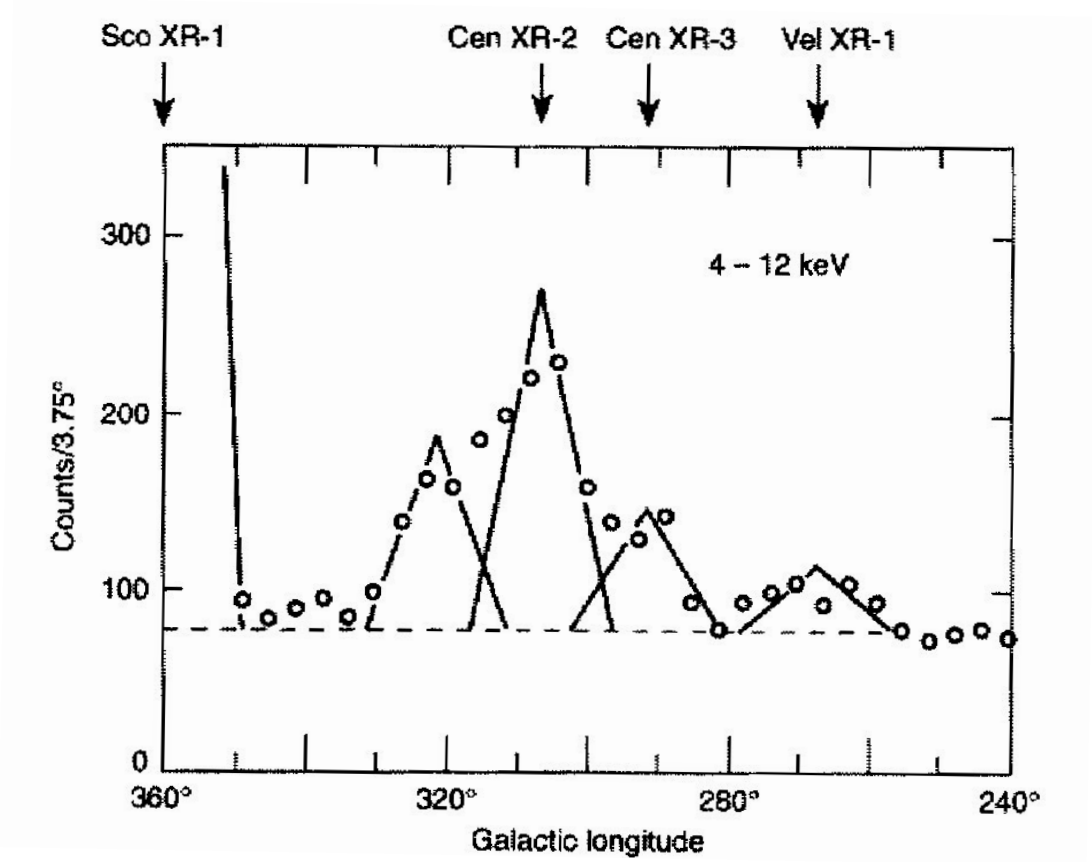
Counts > 0 from all directions ➔ diffuse background radiation

First X-ray source: Sco X-1
Detection of the X-ray background

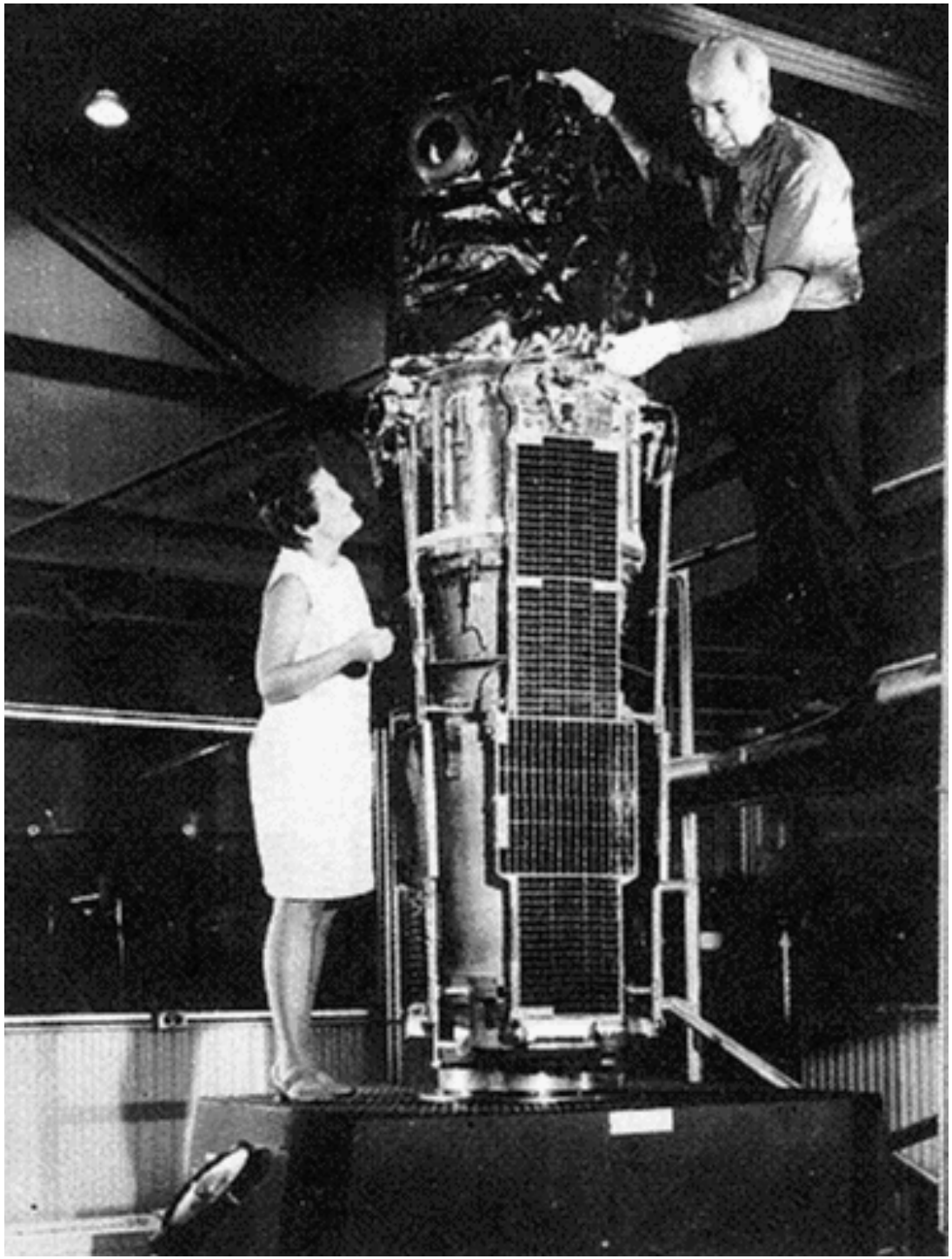
Rocket experiment: Giacconi et al. (1962), Physical Review Letter 9, 439



1967 rocket-borne X-ray detector
(FoV=5°×30°, 3-min observation)



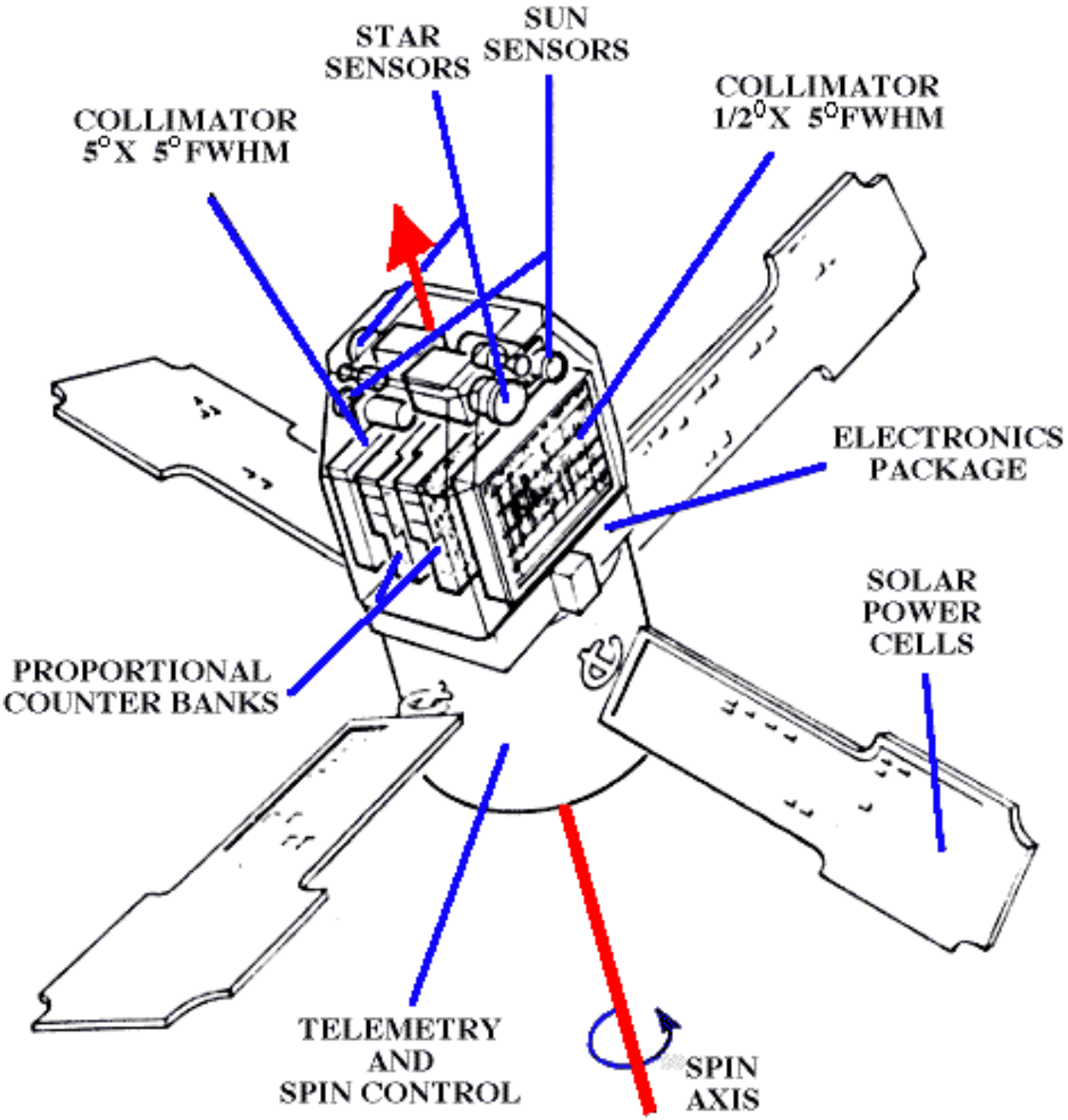
1967 rocket-borne proportional counter
Slat collimator (triangular response)
FoV=10°×30°



Professor Bruno Rossi with assistant working on the OSO-1 UHURU payload [2 – 20 keV]

0.084 m^2 10^{-3} Crab

1970


STAR SENSORS
SUN SENSORS
COLLIMATOR 5°X 5°FWHM
COLLIMATOR 1/2°X 5°FWHM
ELECTRONICS PACKAGE
SOLAR POWER CELLS
PROPORTIONAL COUNTER BANKS
TELEMETRY AND SPIN CONTROL
SPIN AXIS

Small Astronomical Satellite 1 (SAS-1)

UHURU

Lifetime : 12 Dec 1970 - March 1973

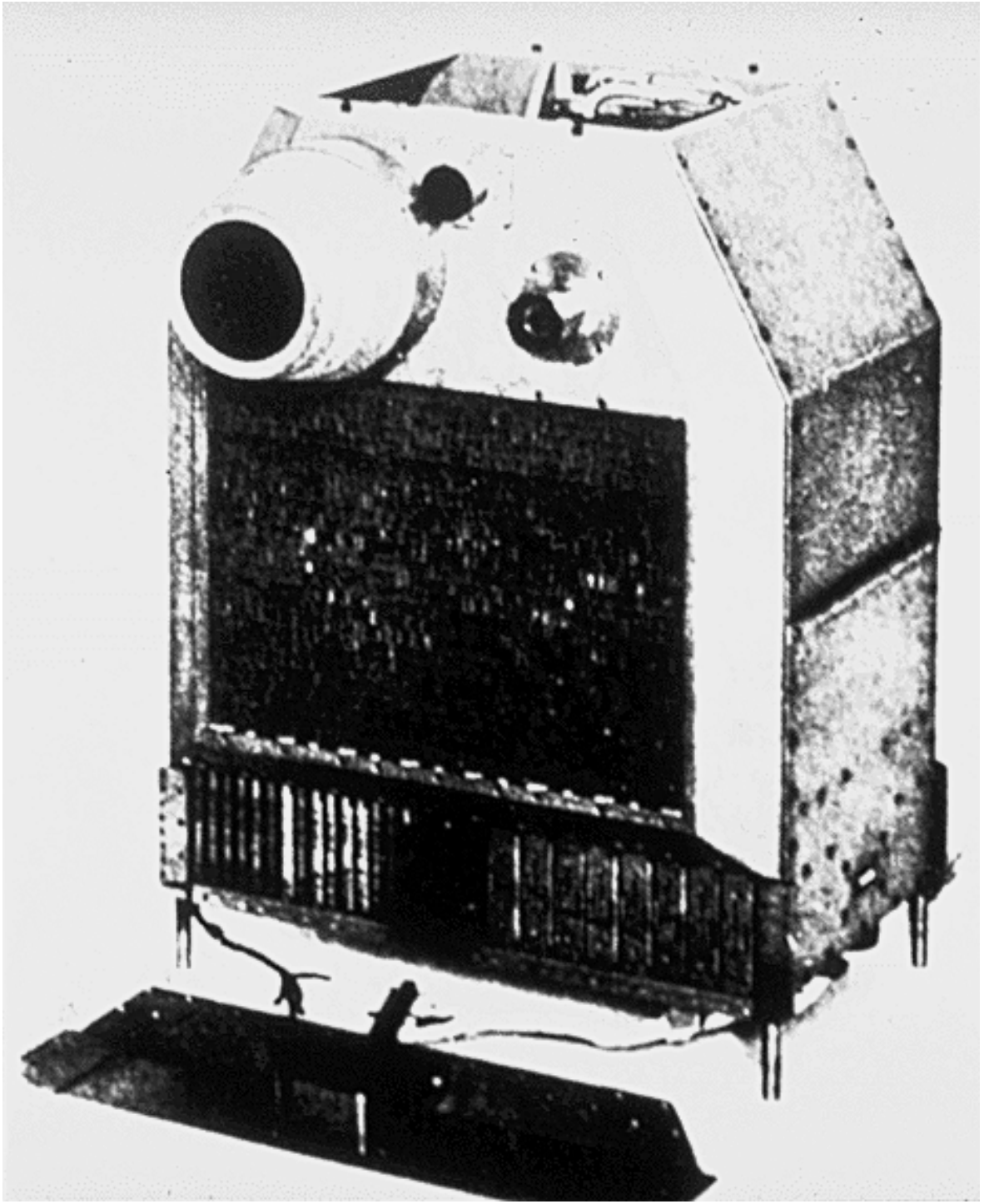
Energy Range : 2-20 keV

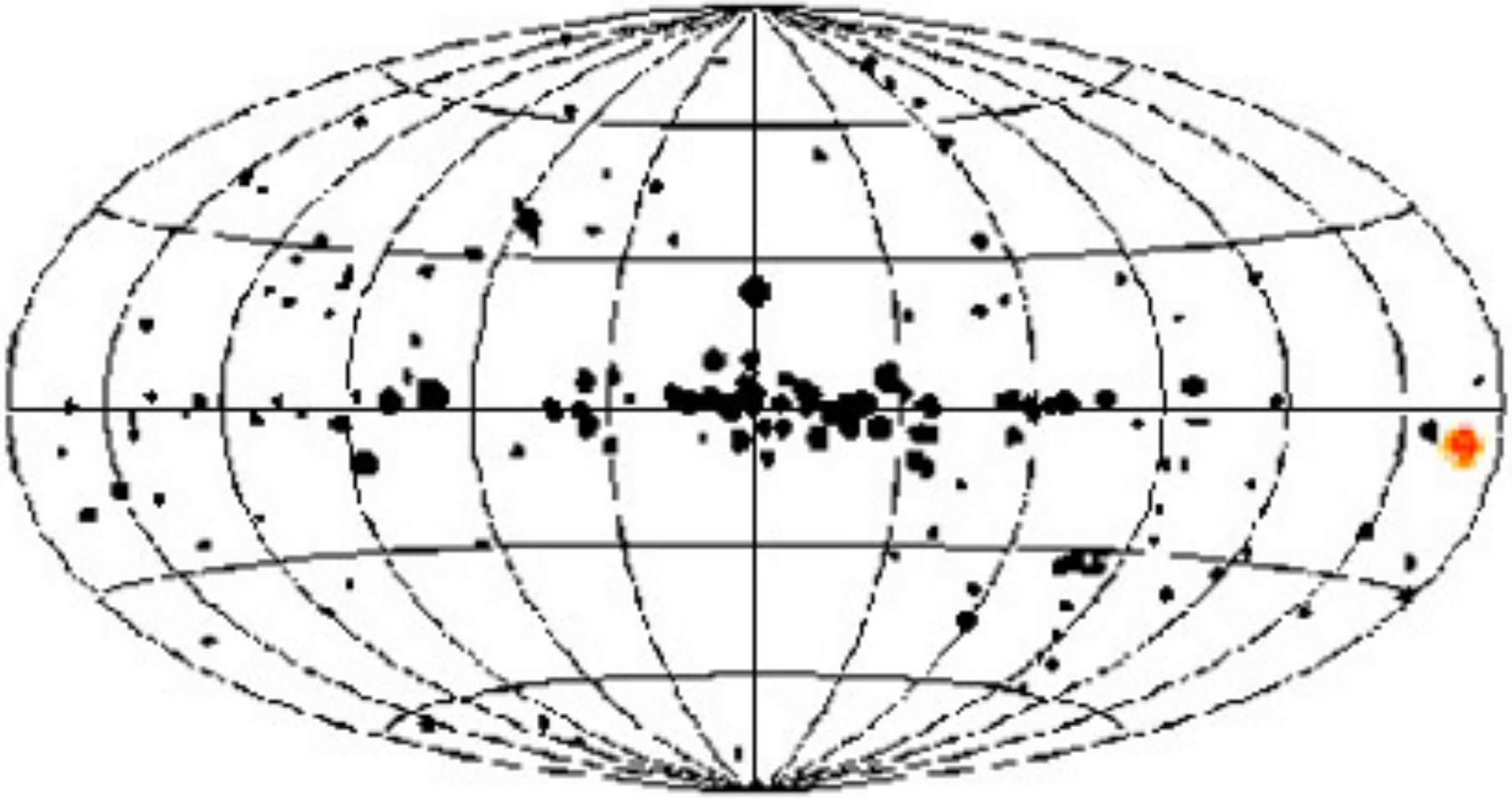
Payload : Two sets of proportional counters

First comprehensive and uniform all sky survey.

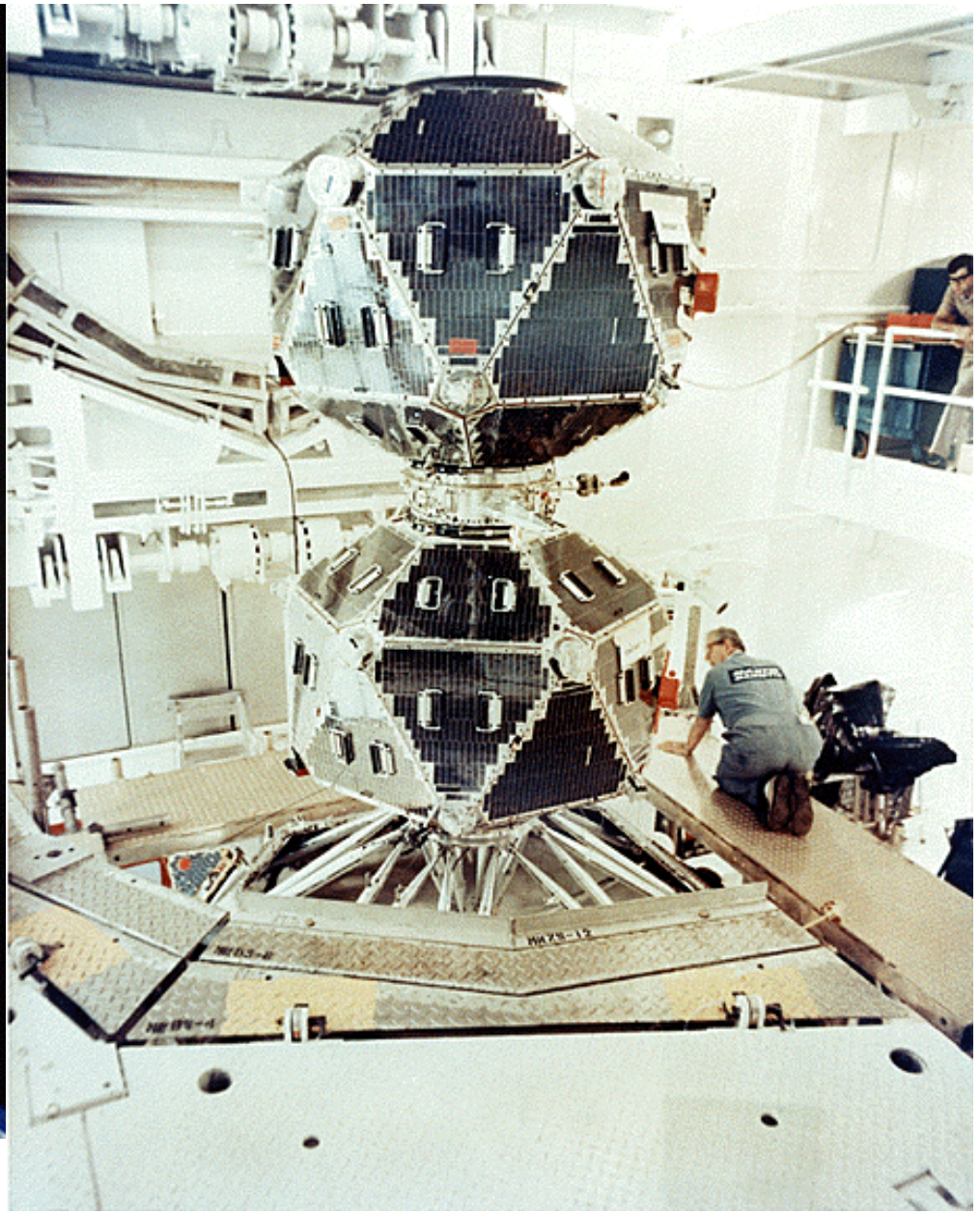
The 339 X-ray sources detected are binaries, supernova remnants, Seyfert galaxies and cluster of galaxies

Discovery of the diffuse X-ray emission from clusters of galaxies





Fourth UHURU Catalog:
339 X-ray sources detected: binaries,
SNR, Seyfert galaxies and cluster of galaxies



Vela 5B

The Vela-5B Satellite

was part of a classified series of US Vela satellites

The Vela-5A and 5B satellites were launched in 1969 and Vela-6A and 6B in 1970 and they operated in spinning mode. Each operated for about a year except Vela-5B which provided data until mid 1979.

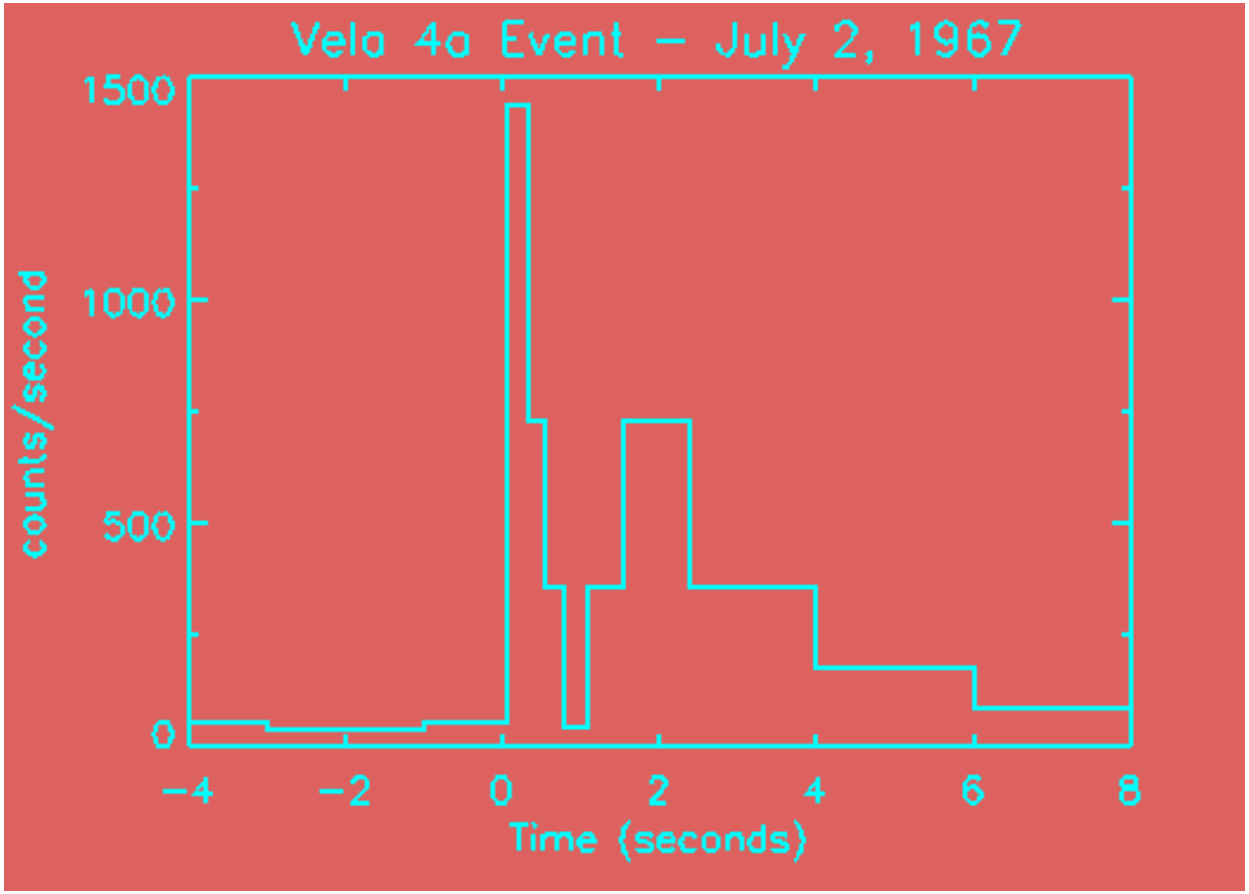
Energy Range : 3-750 keV

Payload : A Scintillation X-ray detector (All-Sky Monitor; ASM) 3-12 keV ~26 cm^2, ~6.1° x 6.1 ° FOV (FWHM)
6 Gamma Ray detectors 150-750 keV
Total volume ~60 cm^3 of CsI

Long lifetime allowed for study of long-term variability of X-ray binaries and X-ray transients

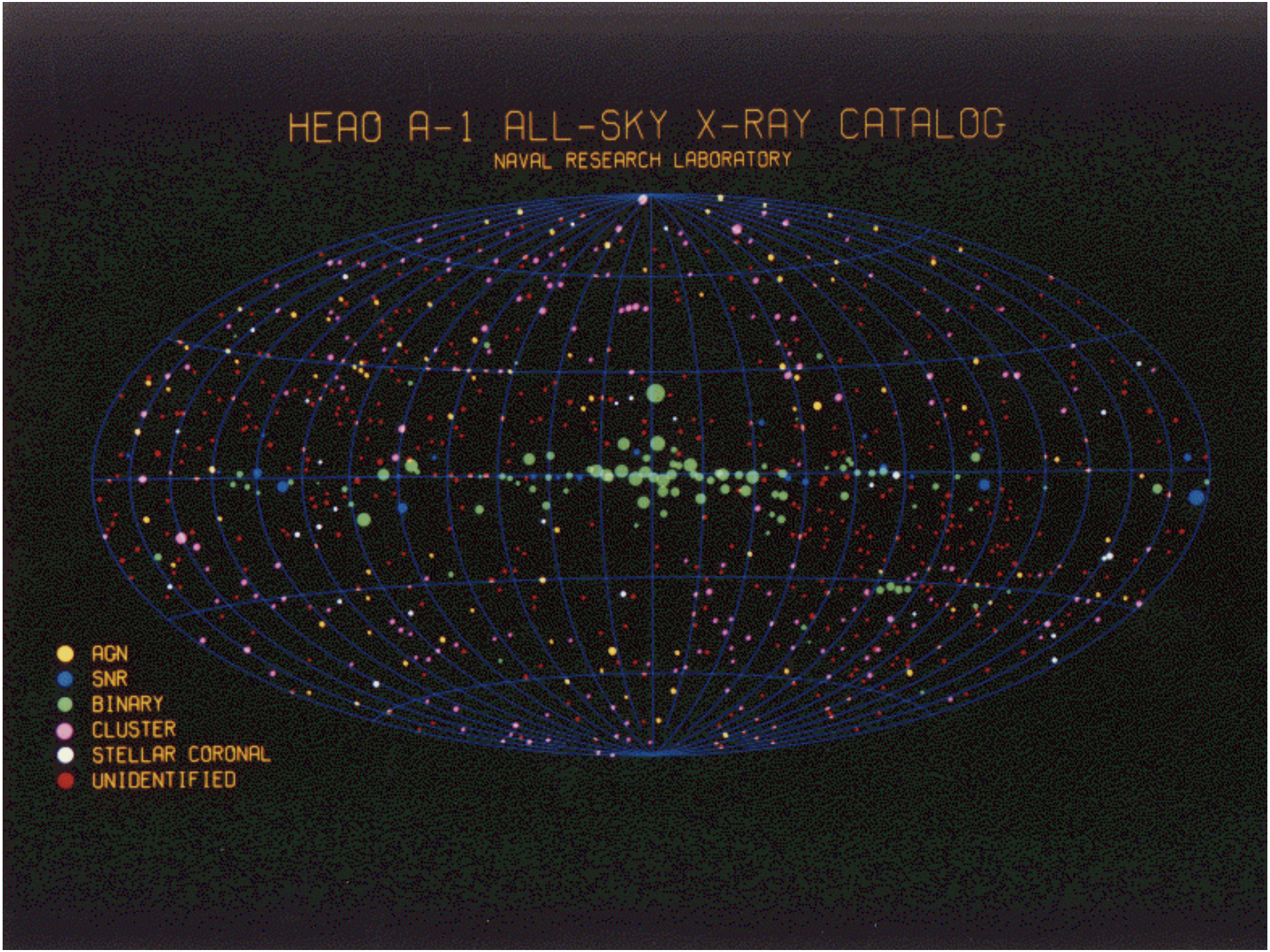
Co-discovered (with ANS) X-ray bursts.

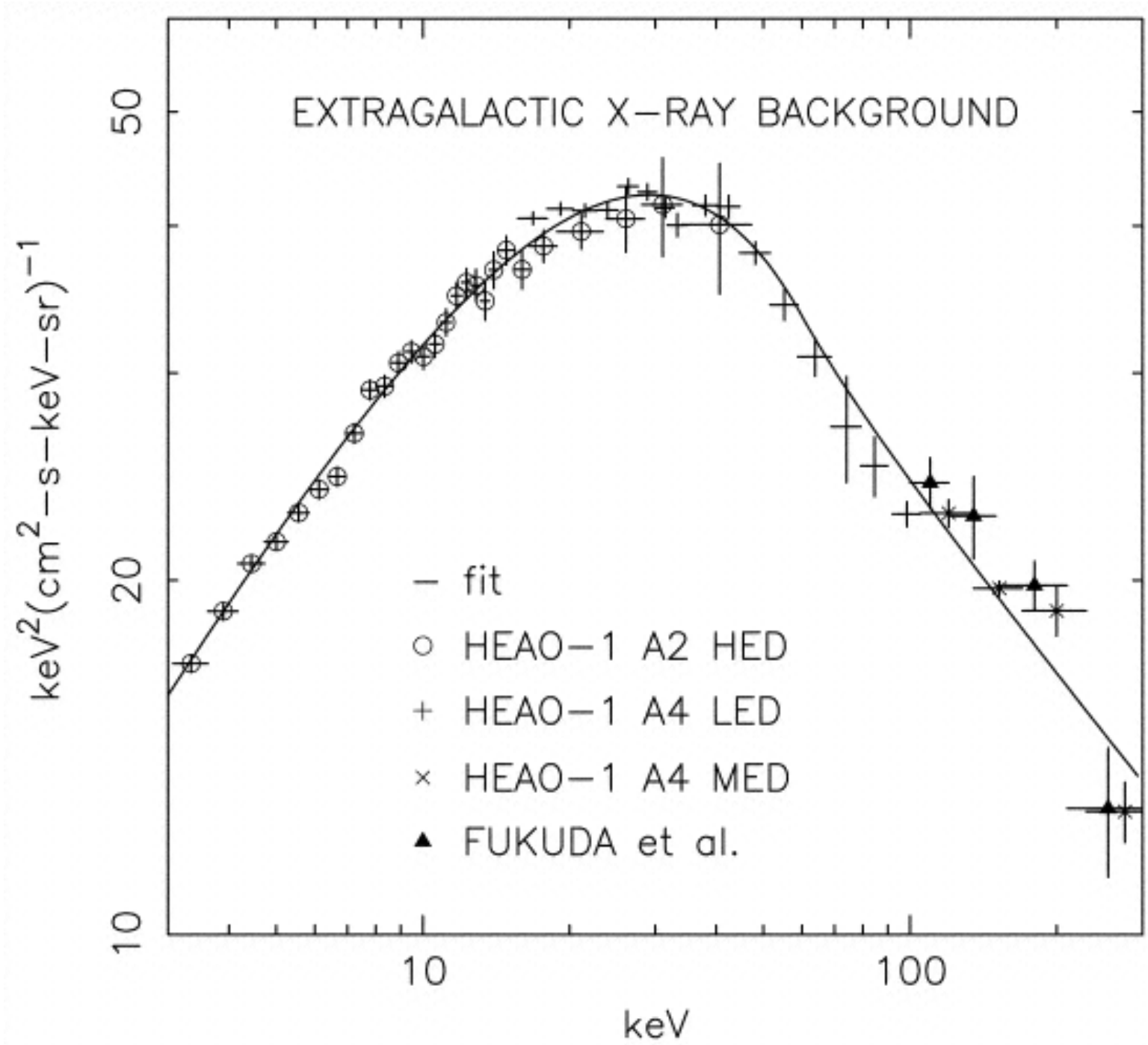
One of the first satellites to detect gamma-ray bursts

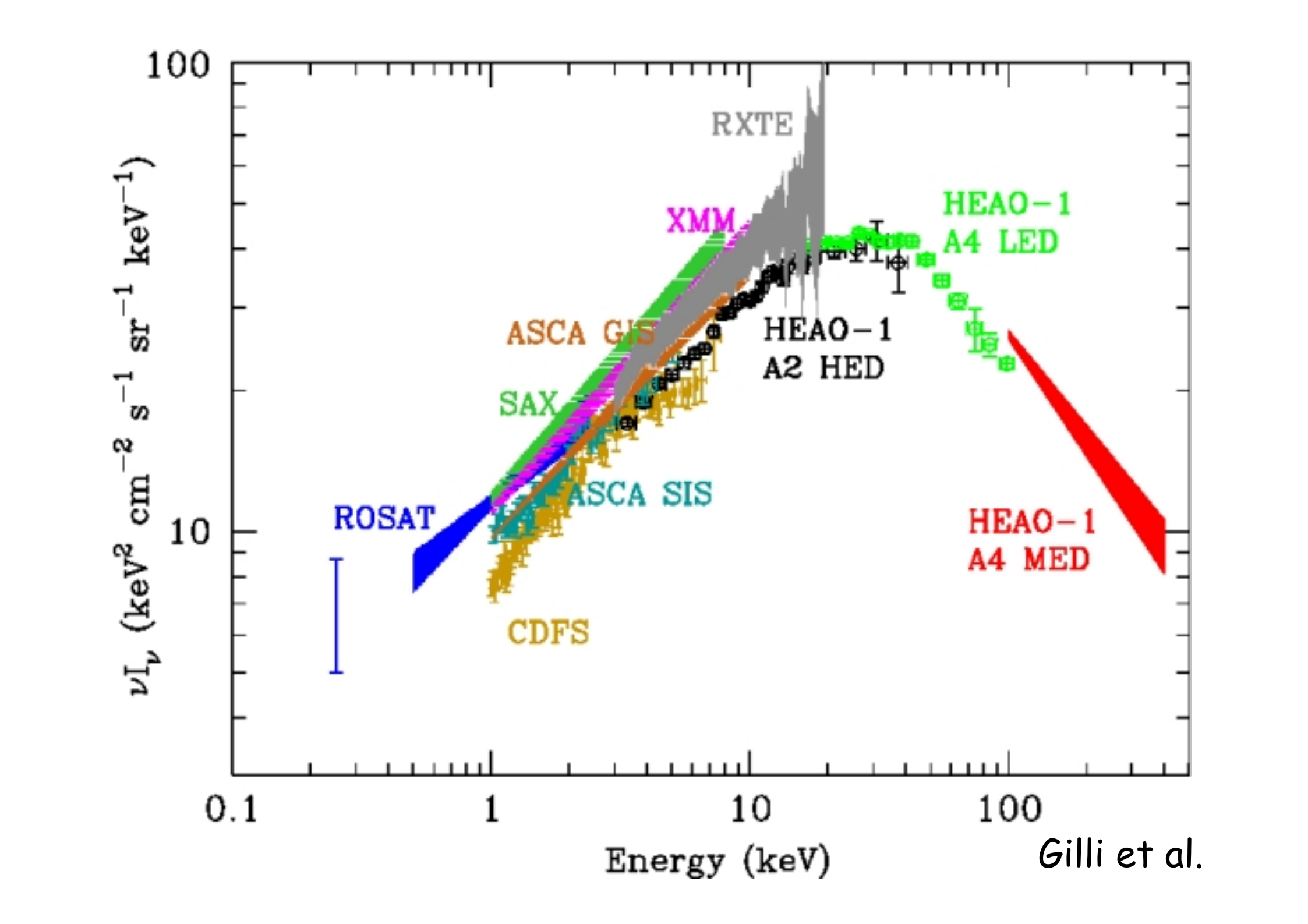


Several satellites after …

HEAO-1 satellite


HEAO A-1 ALL-SKY X-RAY CATALOG
NAVAL RESEARCH LABORATORY
AGN
SNR
BINARY
CLUSTER
STELLAR CORONAL
UNIDENTIFIED


EXTRAGALACTIC X-RAY BACKGROUND
keV²(cm²-s-keV-sr)⁻¹
50
20
10
10
100
keV
fit
HEAO-1 A2 HED
HEAO-1 A4 LED
HEAO-1 A4 MED
FUKUDA et al.


100
10
0.1
1
10
100
Energy (keV)
νI_ν (keV^2 cm^{-2} s^{-1} sr^{-1} keV^{-1})
RXTE
XMM
HEAO−1
A4 LED
ASCA GIS
HEAO−1
A2 HED
SAX
ASCA SIS
ROSAT
HEAO−1
A4 MED
CDFS

Gilli et al.

HEAO-1

Lifetime : 12 August 1977 - 9 January 1979

Energy Range : 0.2 keV - 10 MeV

A1 - Large Area Sky Survey experiment (LASS) : 0.25-25 keV, eff. area 7 modules each of 1350 - 1900 cm2, FOV varied between 1° X 4° to 1° x 0.5° for finest collimators.

A2 - Cosmic X-ray Experiment (CXE) : six separate proportional counters

Low Energy Detectors (LED) 0.15-3.0 keV, eff. area 2 detectors of 400 cm^2 each

Medium Energy Detector (MED) 1.5-20 keV, eff. area 1 detector at 800 cm^2

High Energy Detector (HED) 2.5-60 keV, eff. area 3 detectors at 800 cm^2 each

MED and HEDs had various FOV settings, 1.5° x 3°, 3° x 3° and 3° x 6°

A3 - Modulation Collimator (MC) :
0.9-13.3 keV, eff. area 2 collimators 400 cm2 (MC1) & 300 cm² (MC2), FOV 4° X 4°

A4 - Hard X-Ray / Low Energy Gamma Ray Experiment :
seven inorganic phoswich scintillator detectors

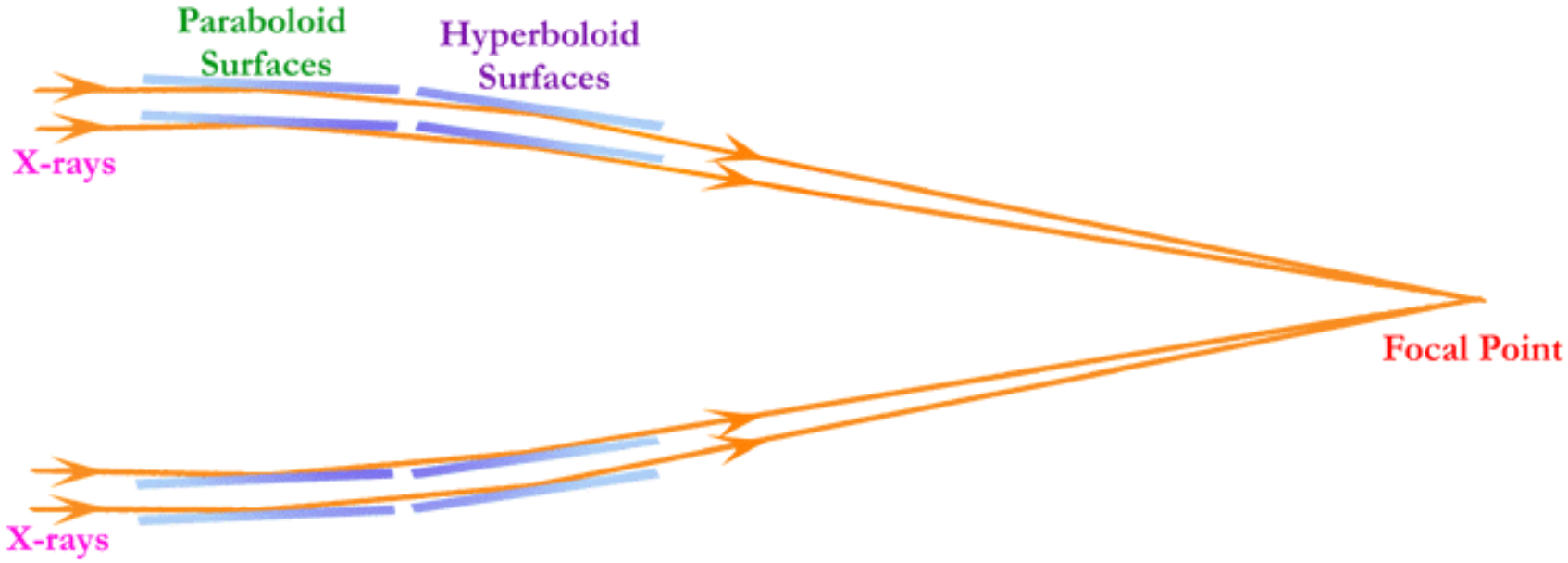
Low Energy Detectors 15-200 keV, eff. area 2 detectors 100 cm² each, FOV 1.7° x 20°

Medium Energy Detectors 80 keV - 2 MeV, eff. area 4 detectors 45 cm² each, FOV 17°

High Energy Detector 120 keV - 10 MeV, eff. area 1 detector 100 cm², FOV 37°

First X-ray imaging telescope:

Einstein (HEAO-2)



HEAO-2, later renamed Einstein, photo Perkin-Elmer Corp.

First X-Ray telescope to produce images

12 November 1978
April 1981

The Einstein Observatory (HEAO-2)

First high resolution spectroscopy and morphological studies of supernova remnants.

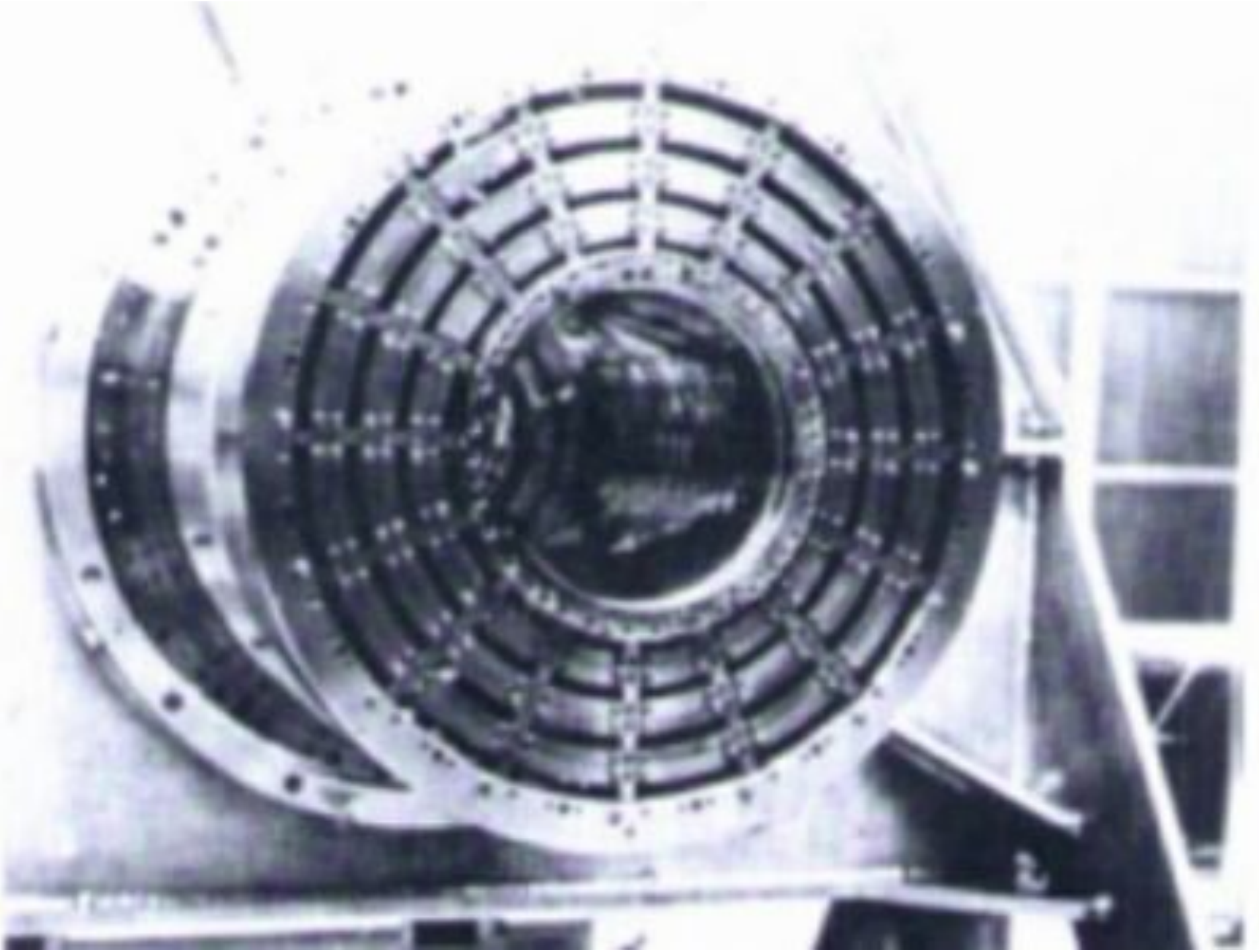
Recognized that coronal emissions in normal stars are stronger than expected.

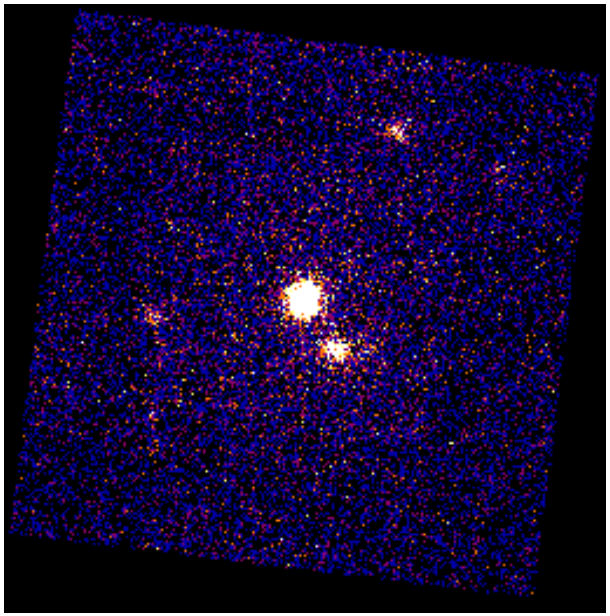
Resolved numerous X-ray sources in the Andromeda Galaxy and the Magellanic Clouds.

First study of the X-ray emitting gas in galaxies and clusters of galaxies revealing cooling inflow and cluster evolution.

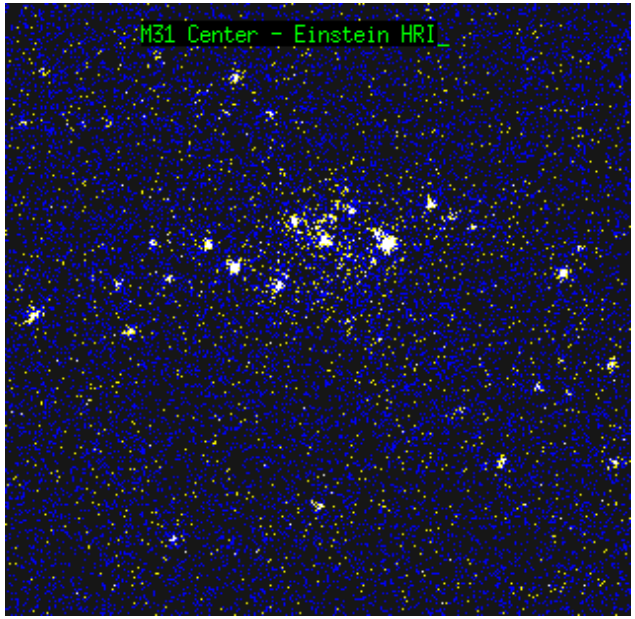
Detected X-ray jets from Cen A and M87 aligned with radio jets.
First medium and Deep X-ray surveys

Discovery of thousands (>7000) of "serendipitous" sources

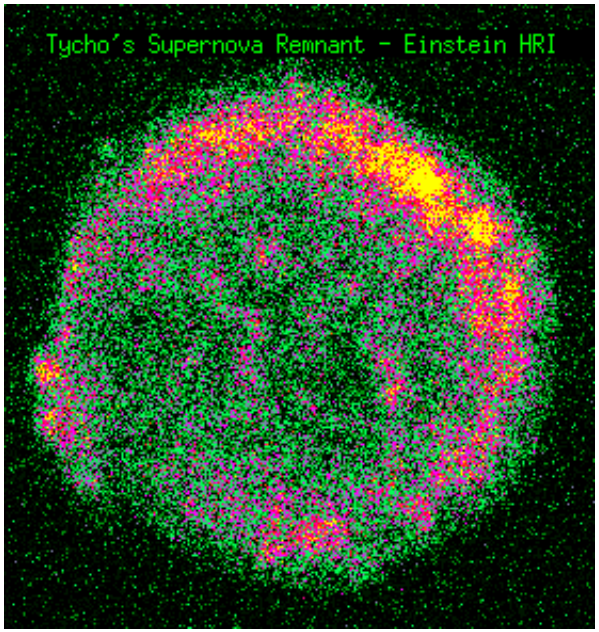




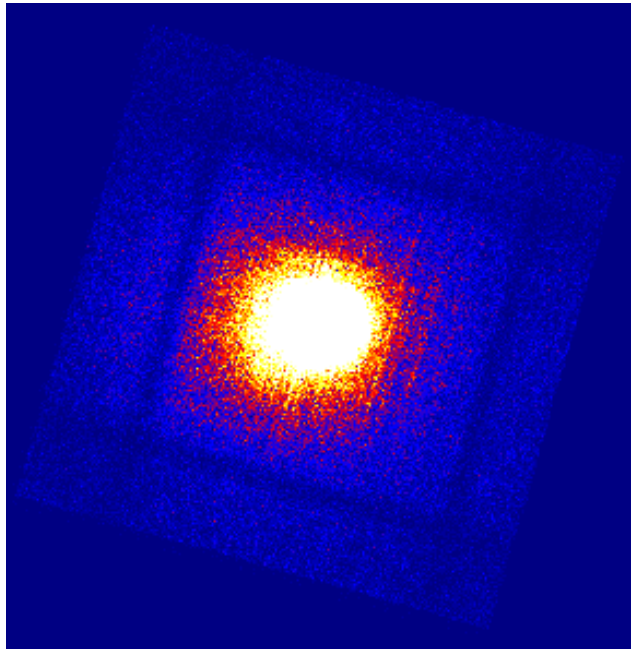
Hyadis star cluster



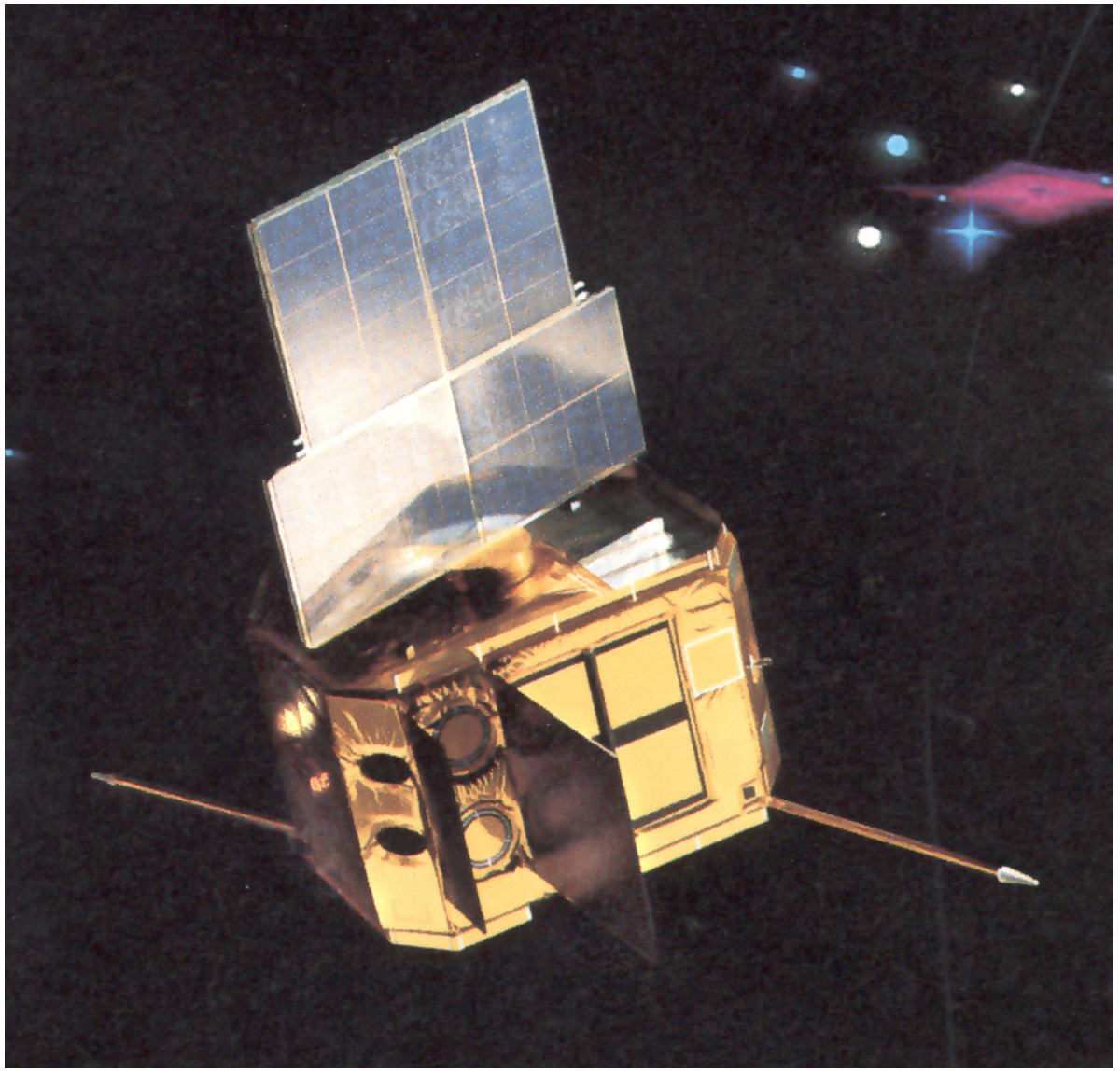
Andromeda galaxy



Tycho Supernova Remnant



Perseus cluster of galaxies



EXOSAT ESA

launch: 26 may 1983

End 9 april 1986

Very eccentric: orbit duration 90 h

Energy range: 0.05-2 keV & 1-50keV

EXOSAT

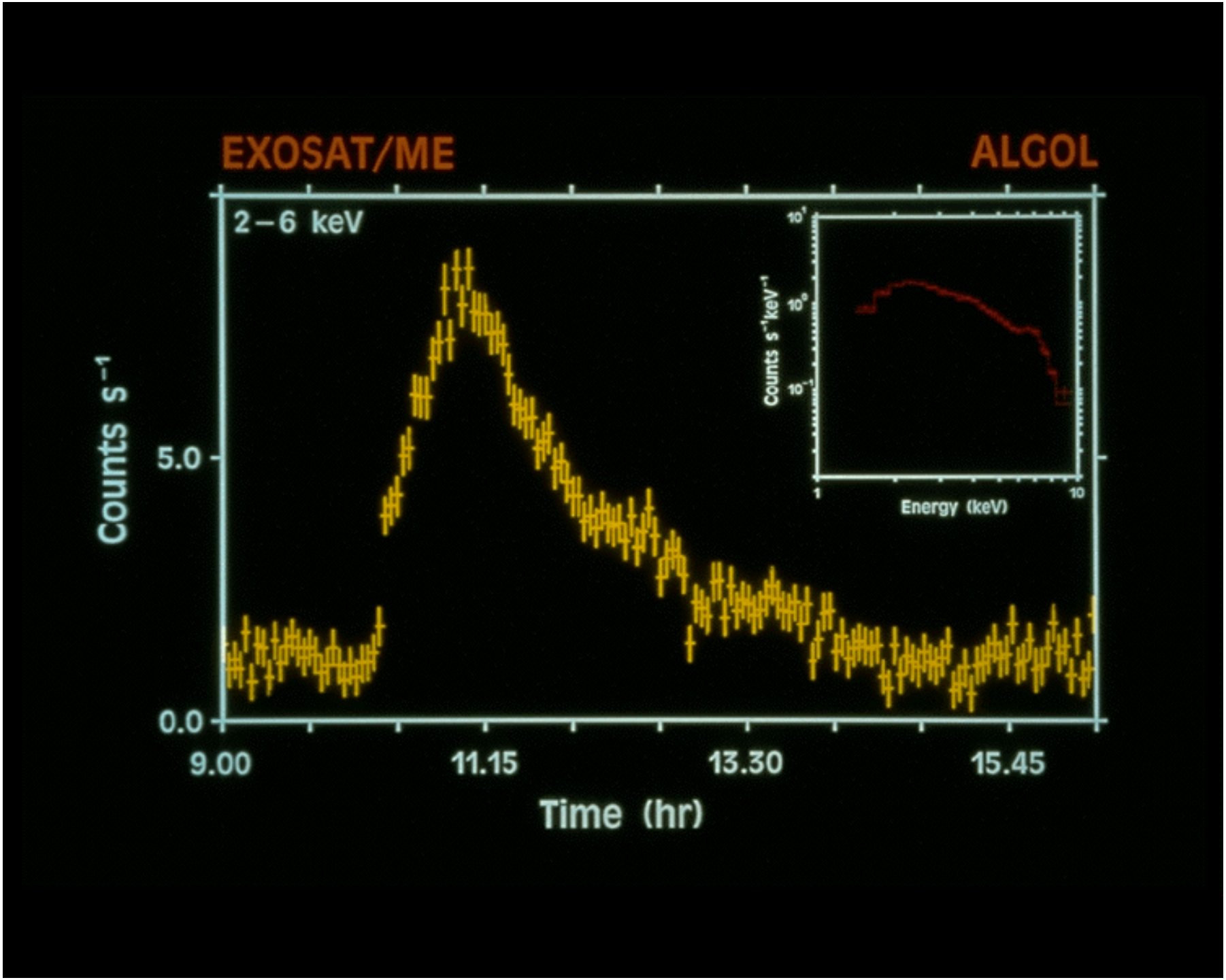
Discovery of the Quasi Period Oscillations in LMXRB and X-ray Pulsars

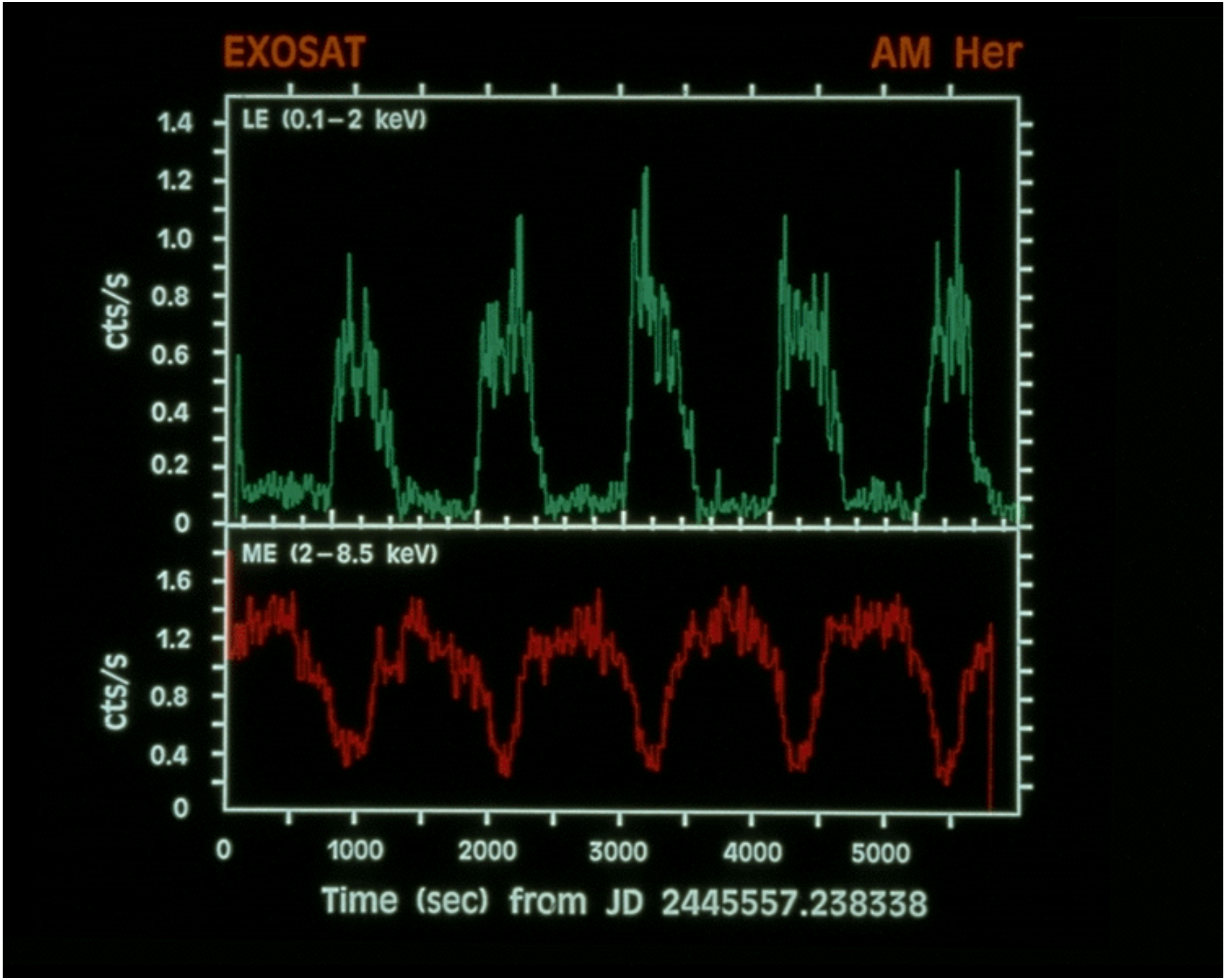
Comprehensive study of AGN variability

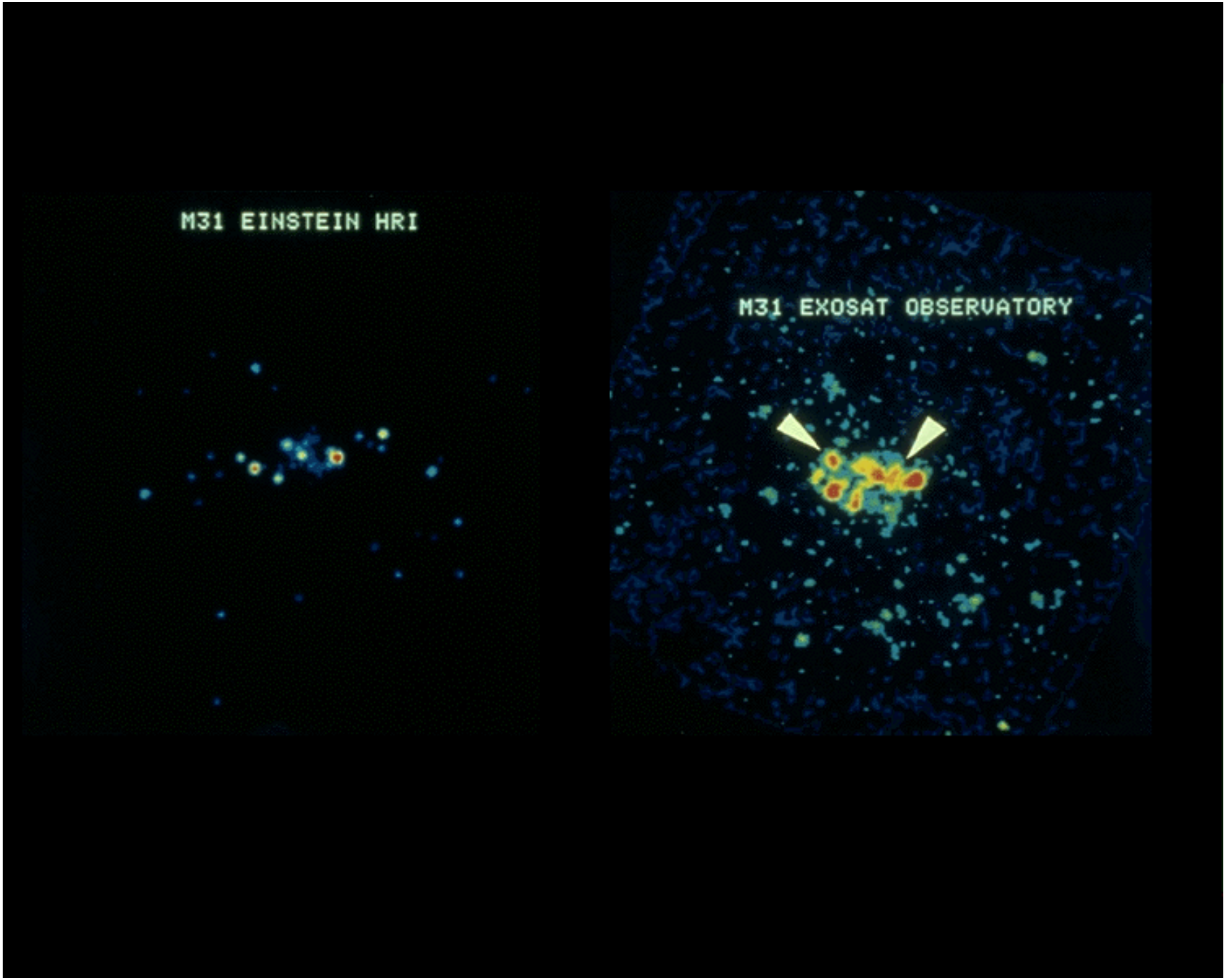
Observing LMXRB and CV over many orbital periods

Measuring iron line in galactic and extra galactic sources

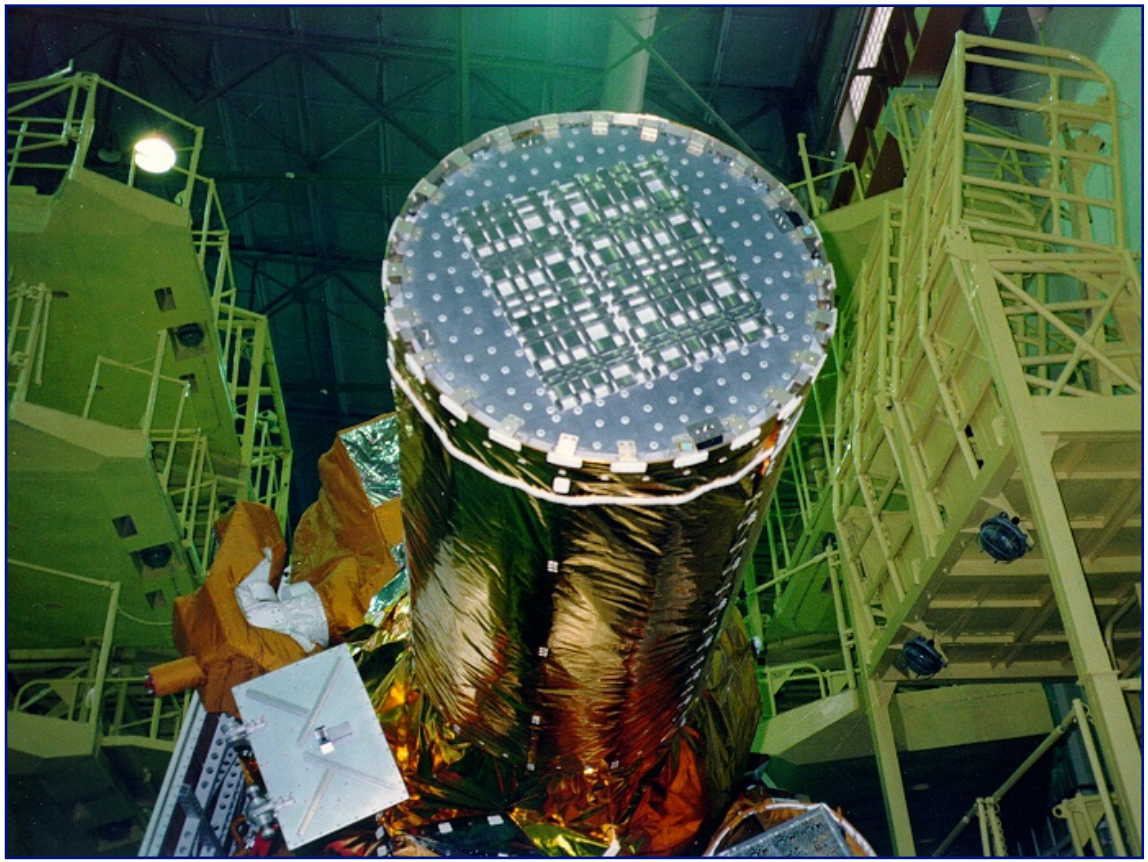
Obtaining low-energy high-resolution spectra


EXOSAT/ME
ALGOL
2 – 6 keV
Counts s⁻¹
5.0
0.0
9.00
11.15
13.30
15.45
Time (hr)
Counts s⁻¹keV⁻¹
Energy (keV)


EXOSAT
AM Her
LE (0.1–2 keV)
ME (2–8.5 keV)
cts/s
cts/s
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
1.6
1.2
0.8
0.4
0
0
1000
2000
3000
4000
5000
Time (sec) from JD 2445557.238338


M31 EINSTEIN HRI
M31 EXOSAT OBSERVATORY

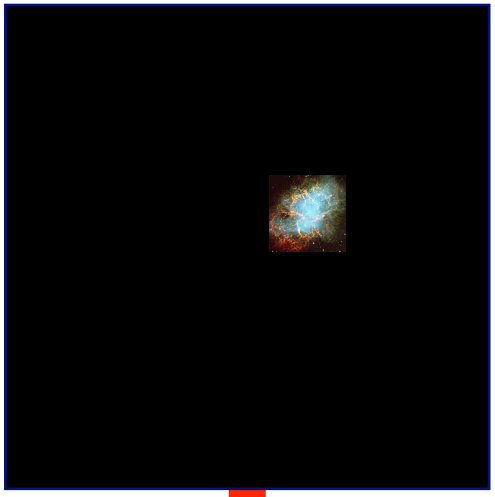
SIGMA aboard GRANAT: The precursor



First space coded-mask telescope in operation from 1990 to 1997

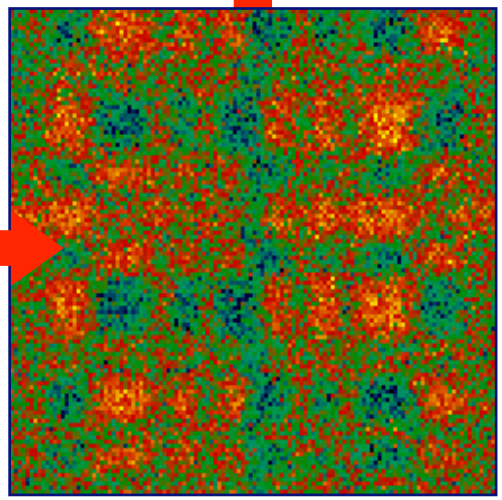
Energy range: 35 keV - 1.3 MeV
Source location accuracy: 30″ - 5′

It works!

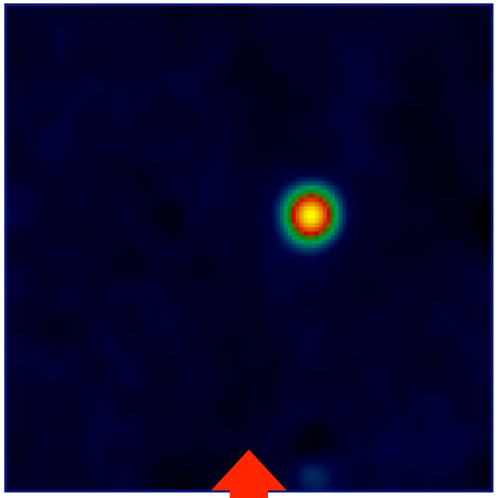


observation

transmission



deconvolution



The Ginga Satellite

Lifetime : February 5, 1987 - November 1, 1991

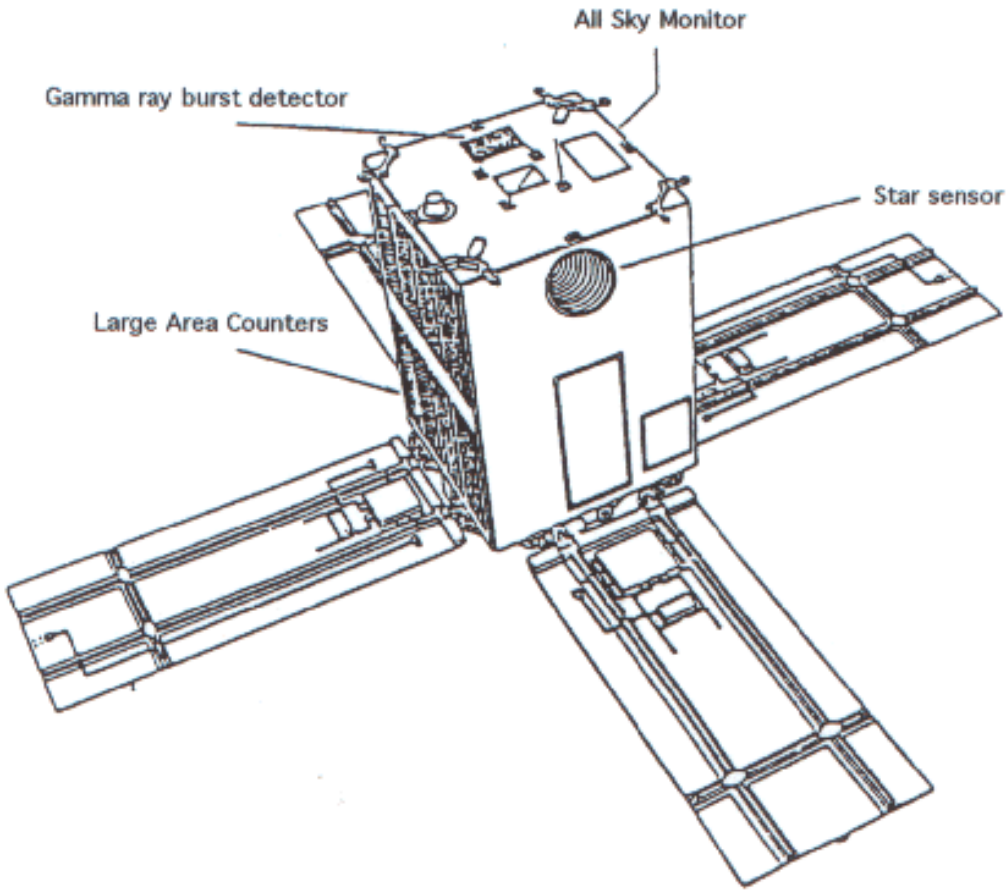
Energy Range : 1 - 500 keV

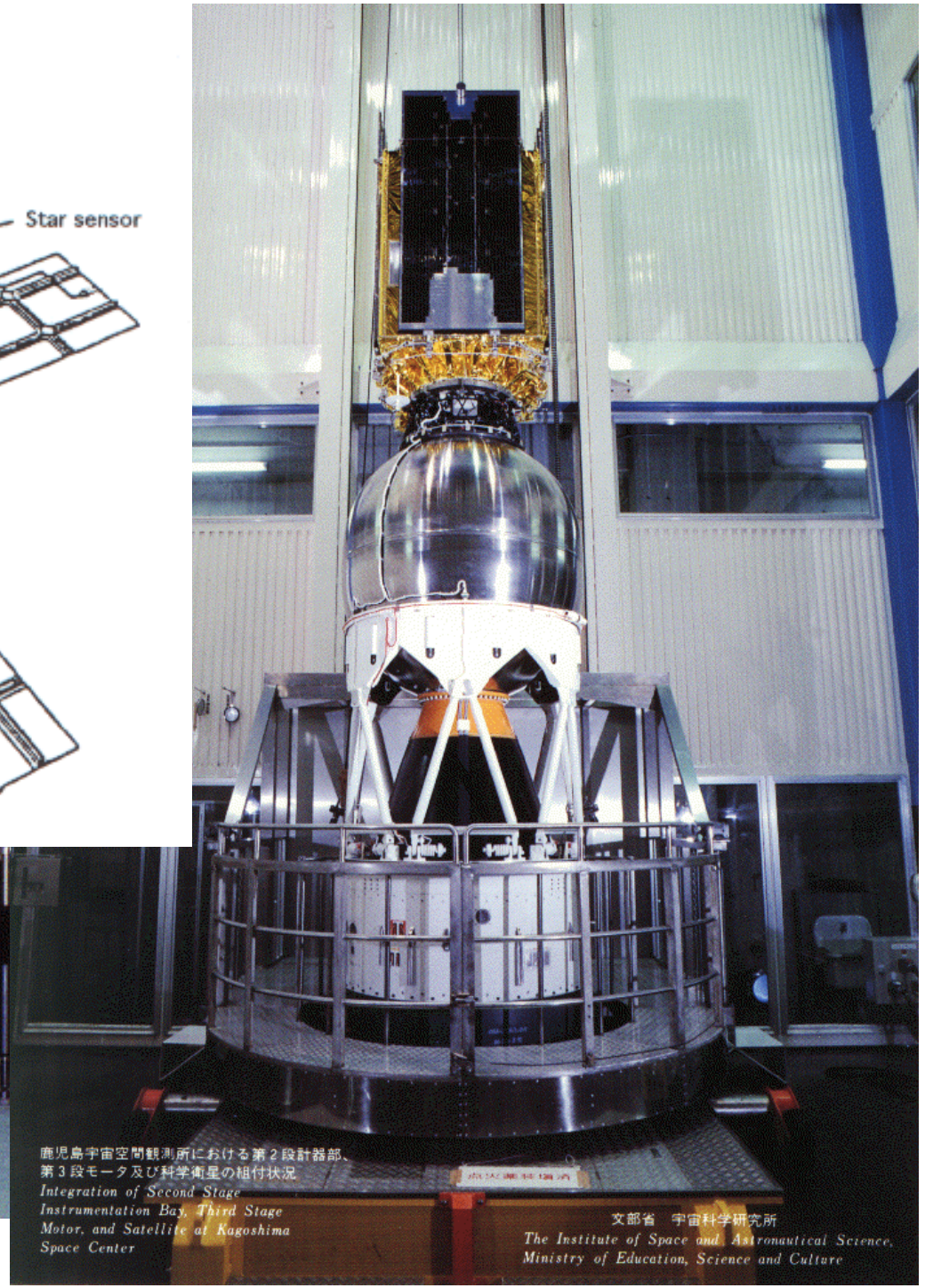
Payload :

Large Area Proportional Counter (LAC) 1.5-37 keV
Eff. area = 4000 cm^2, FOV = 0.8° x 1.7°

All-Sky Monitor (ASM) 1-20 keV
Eff. area = 70 cm^2, FOV = 1° x 180°

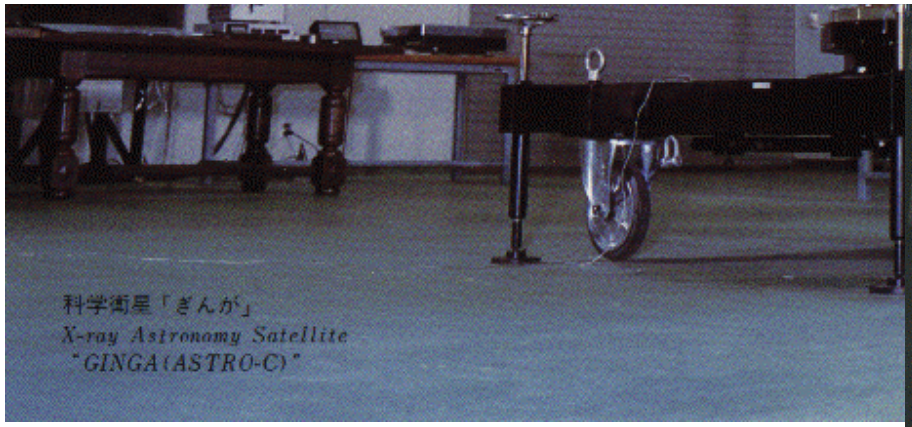
Gamma-Ray Burst Detector (GBD) 1.5-500 keV
Eff. area = 60 cm^2 (SC) and 63 cm^2 (PC), FOV = All-sky





鹿児島宇宙空間観測所における第２段計器部、
第３段モータ及び科学衛星の組付状況
Integration of Second Stage Instrumentation Bay, Third Stage Motor, and Satellite at Kagoshima Space Center

文部省　宇宙科学研究所
The Institute of Space and Astronautical Science, Ministry of Education, Science and Culture



科学衛星「ぎんが」
X-ray Astronomy Satellite "GINGA (ASTRO-C)"

GINGA

Discovery of transient Black Hole Candidates and study of their spectral evolution.

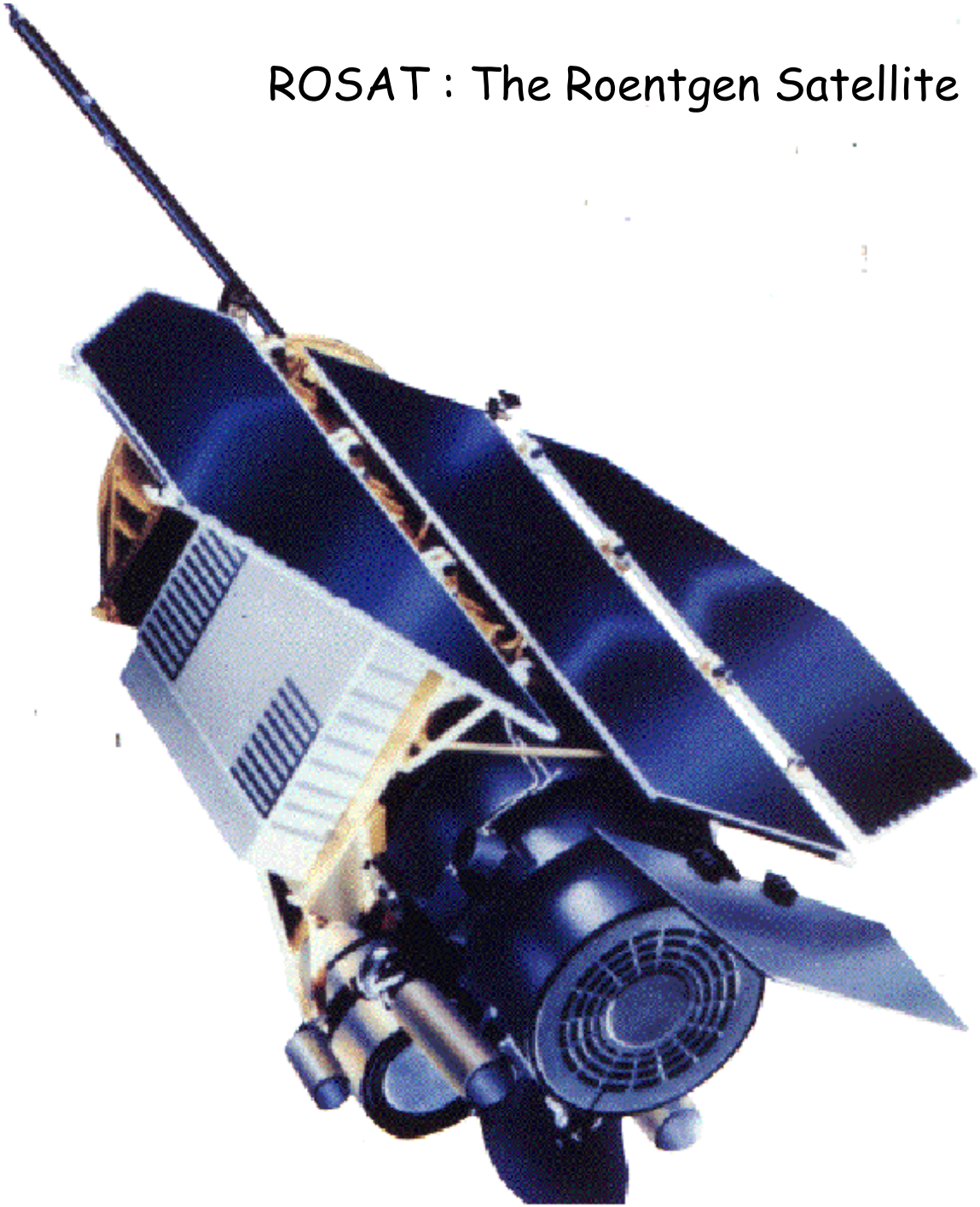
Discovery of weak transients in the Galactic ridge.

Detection of cyclotron features in 3 X-ray pulsars: 4U1538-522, V0332+53, and Cep X-4.

Evidence for emission and absorption Fe feature in Seyfert probing reprocessing by cold matter.

Discovery of intense 6-7 keV iron line emission from the galactic center region.

ROSAT : The Roentgen Satellite



Lifetime: 1 June 1990 - 12 February 1999

Energy Range: X-ray 0.1 - 2.5 keV , EUV 62-206 eV

Special Feature: **All sky-survey in the soft X-ray band**

An X-ray telescope used in conjunction with one of the following instruments (0.1-2.5 keV)

Position Sensitive Proportional Counter (PSPC) 2 units : detector B, used for the pointed phase, & detector C ,used for the survey FOV 2 ° diameter eff area 240 cm^2 at 1 keV energy resolution of deltaE/E=0.43 (E/0.93)-0.5

High Resolution Imager (HRI) FOV 38 ' square ; eff area 80 cm^2 at 1 keV
~ 2 arcsec spatial resolution (FWHM)

A Wide Field Camera with its own mirror system - (62-206 eV) FOV 5 ° diameter

X-ray all-sky survey catalog, more than 150000 objects
XUV all-sky survey catalog (479 objects)

Source catalogs from the pointed phase (PSPC and HRI) containing ~ 100000 serendipitous sources

Detailed morphology of supernova remnants and clusters of galaxies.

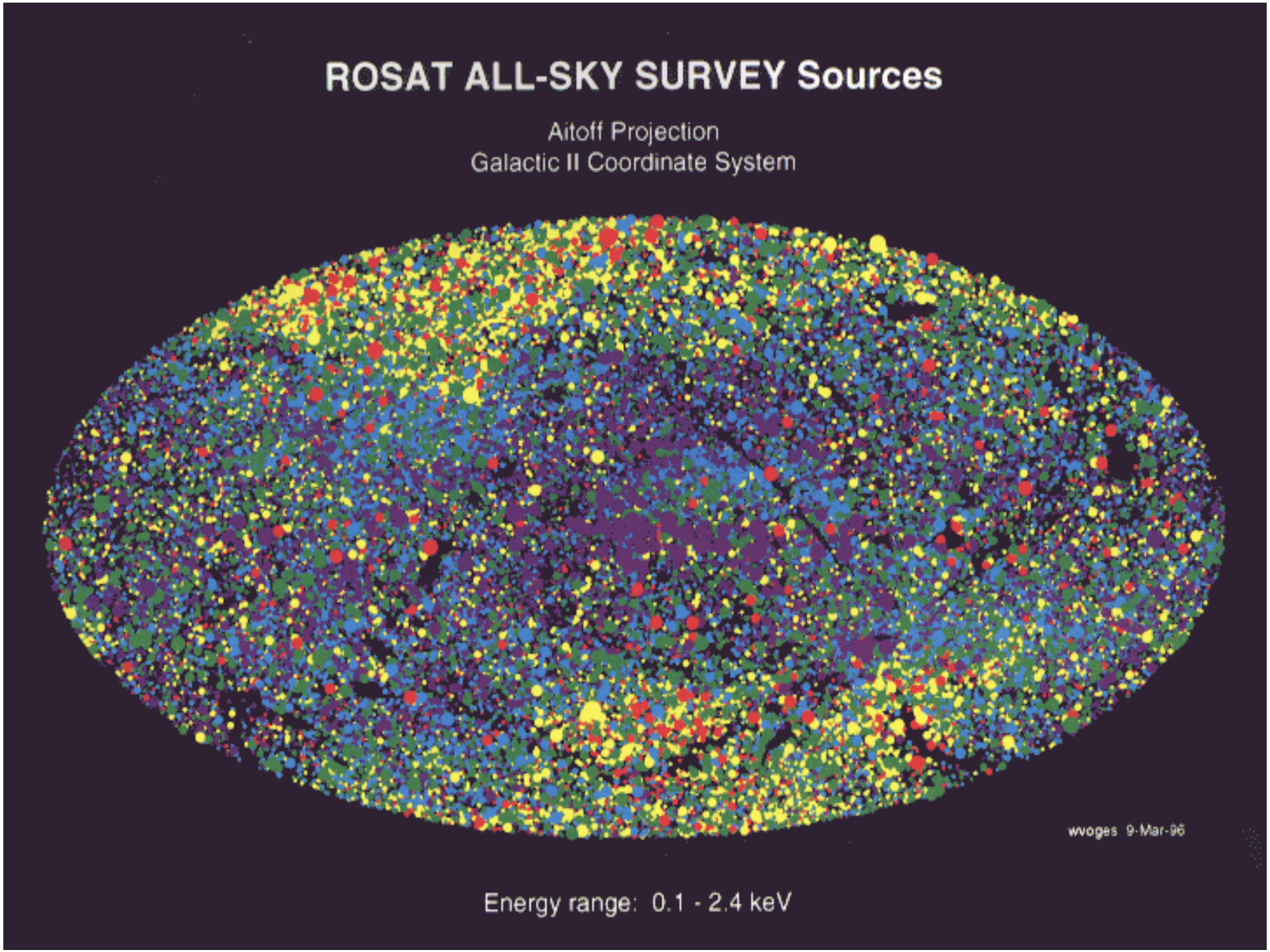
Detection of shadowing of diffuse X-ray emission by molecular clouds.

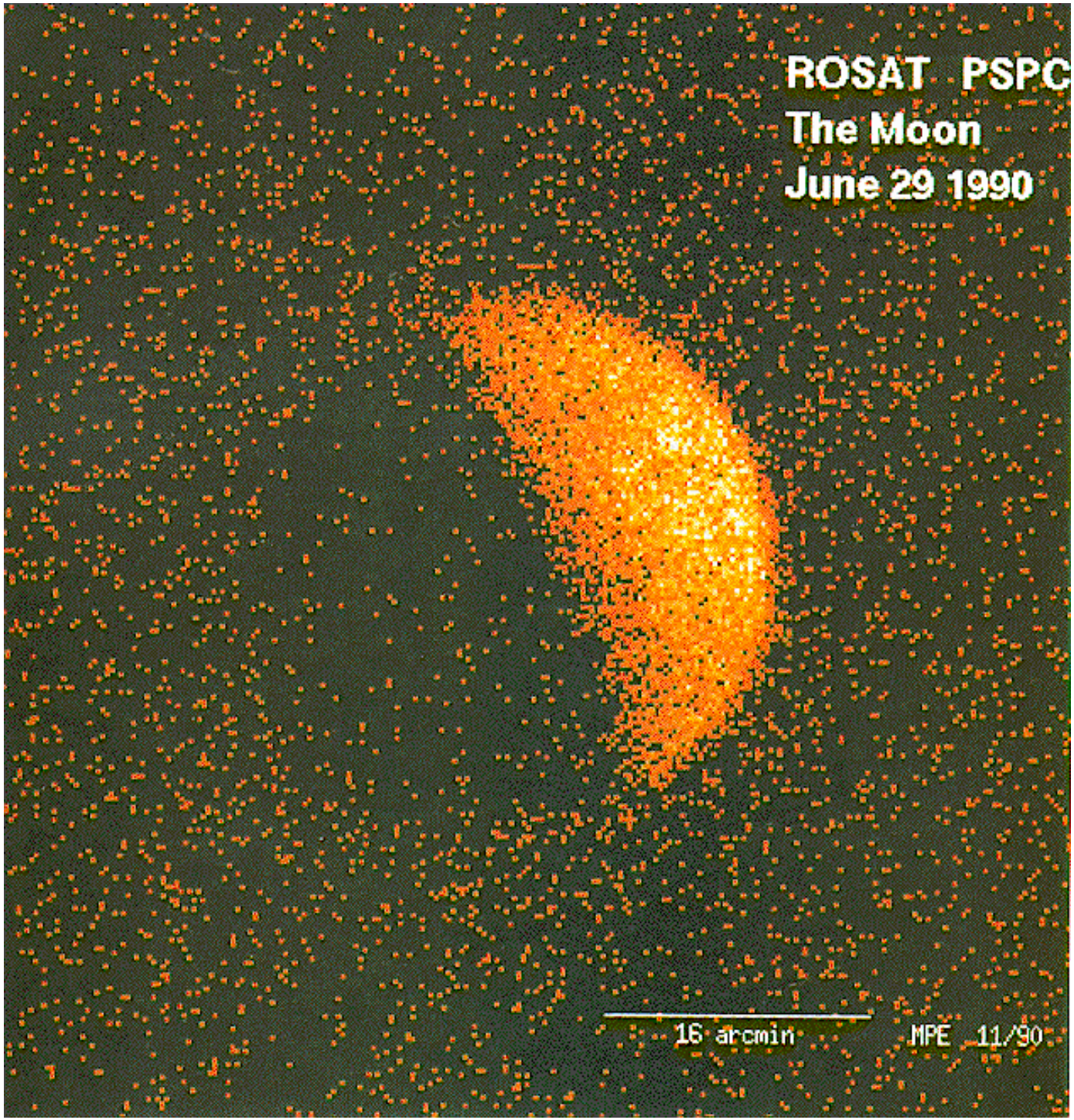
Detection (finally!) of pulsations from Geminga.

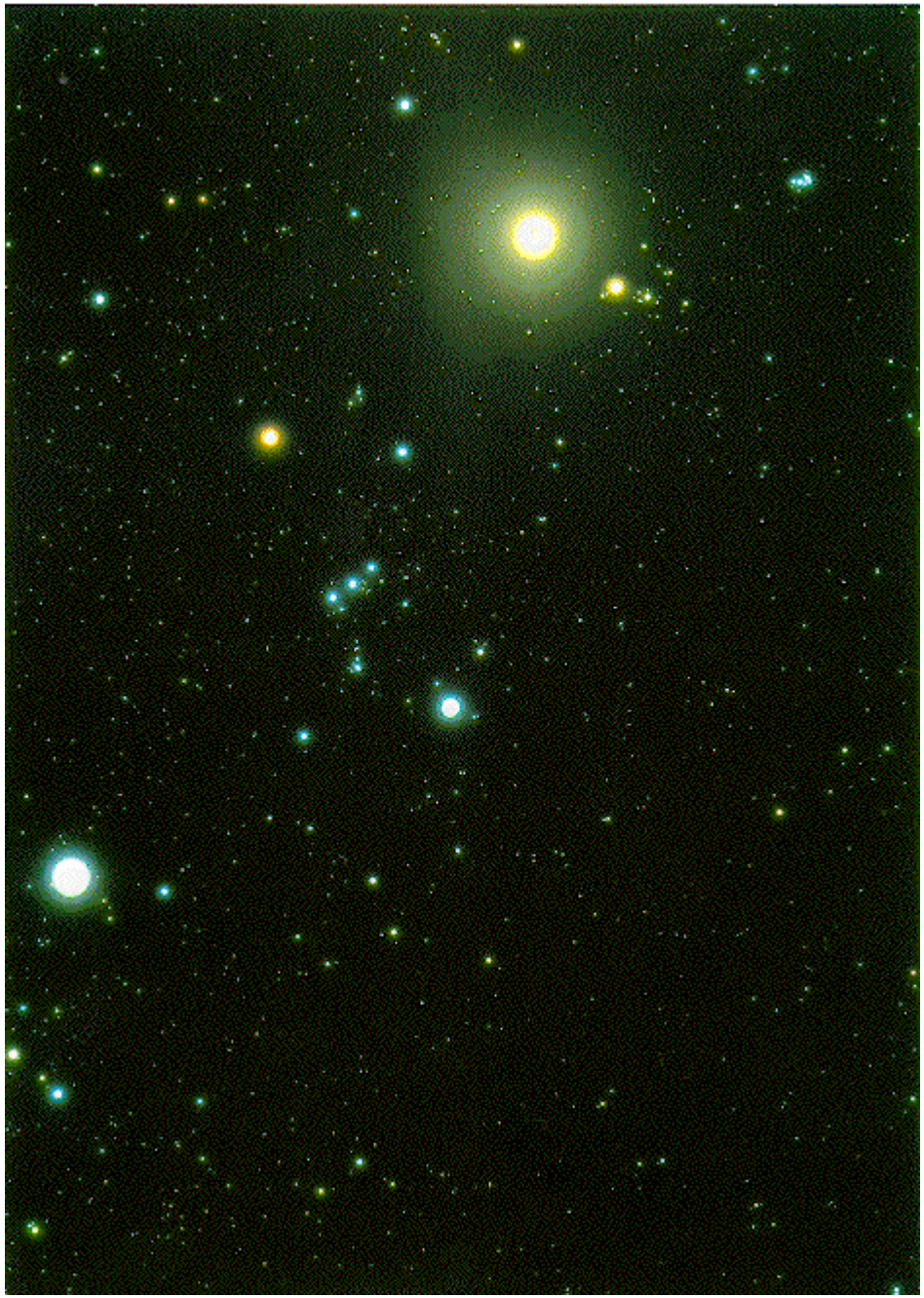
Detection of isolated neutron stars.

Discovery of X-ray emission from comets.

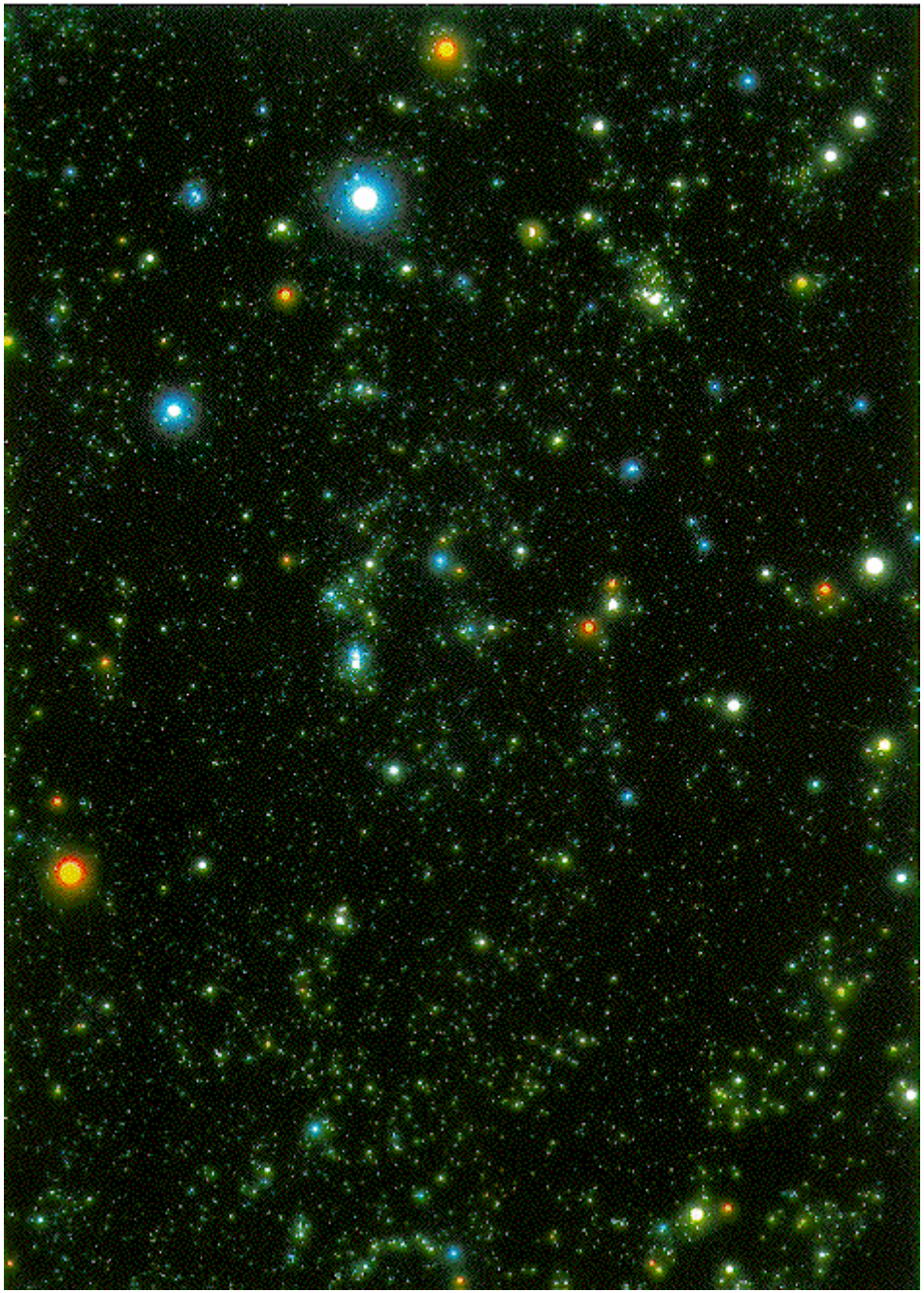
Observation of X-ray emission from the collision of Comet Shoemaker-Levy with Jupiter


ROSAT ALL-SKY SURVEY Sources
Aitoff Projection
Galactic II Coordinate System
wvoges 9-Mar-96
Energy range: 0.1 - 2.4 keV


ROSAT PSPC
The Moon
June 29 1990
16 arcmin
MPE 11/90

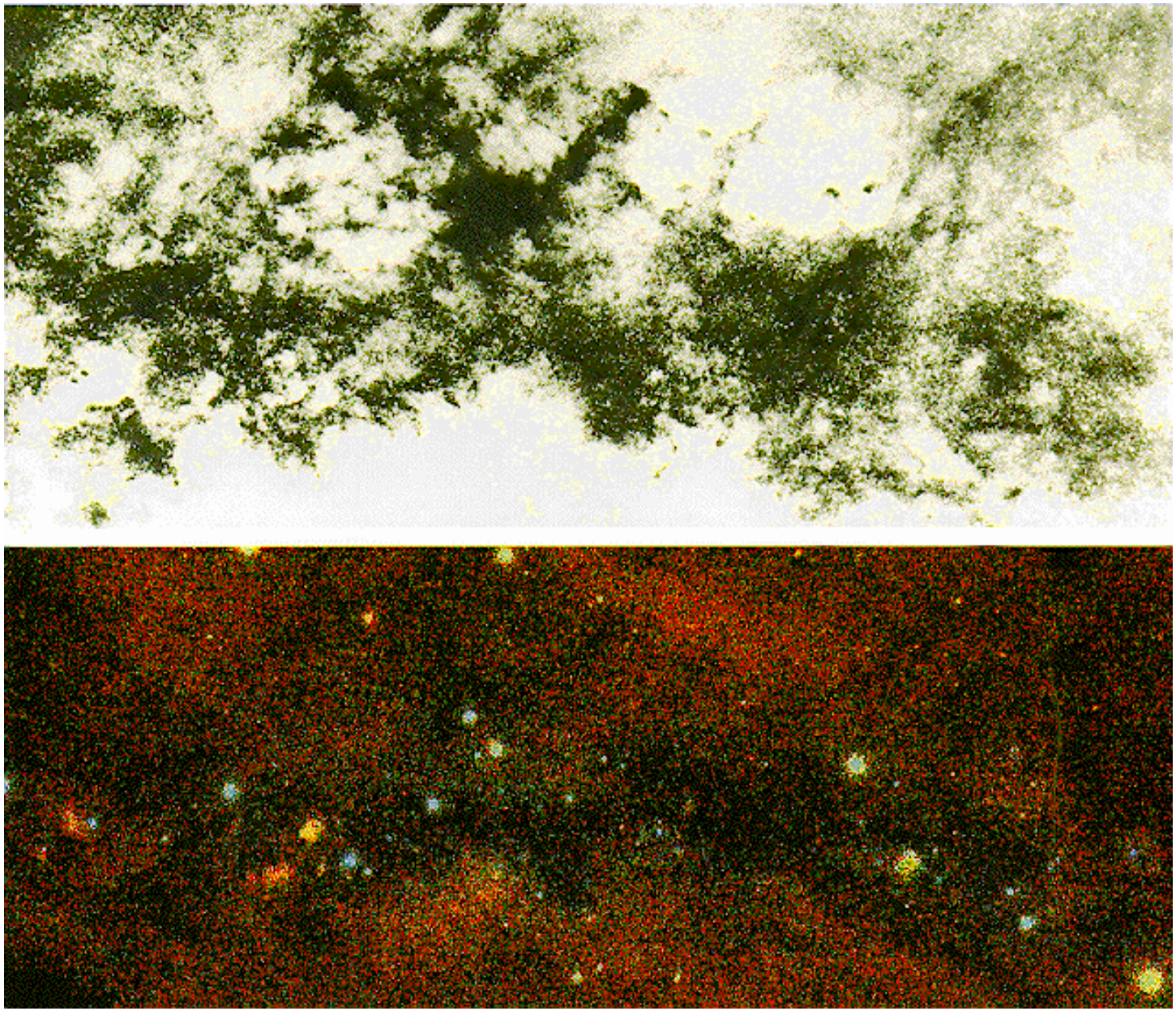


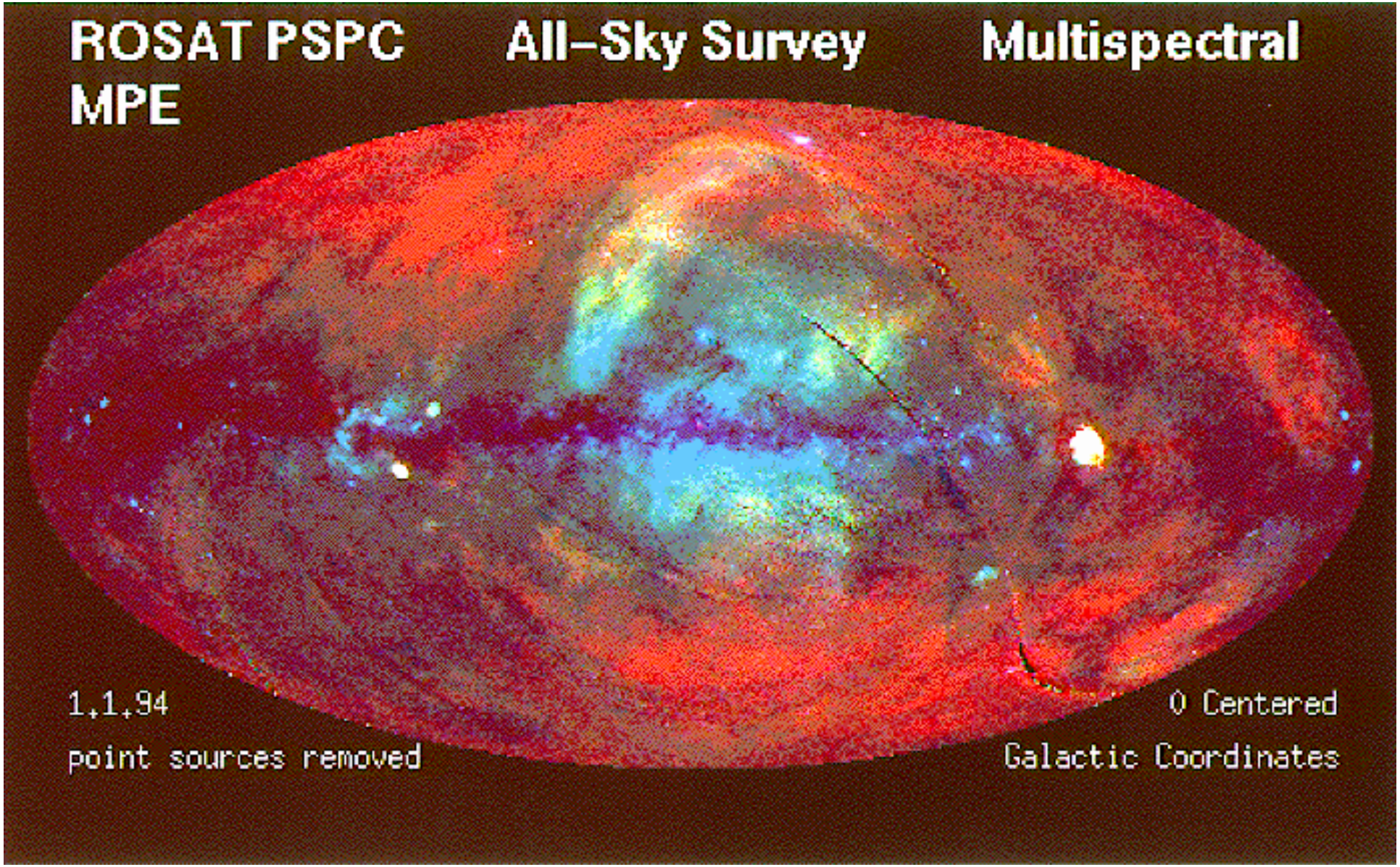
Orion optical image

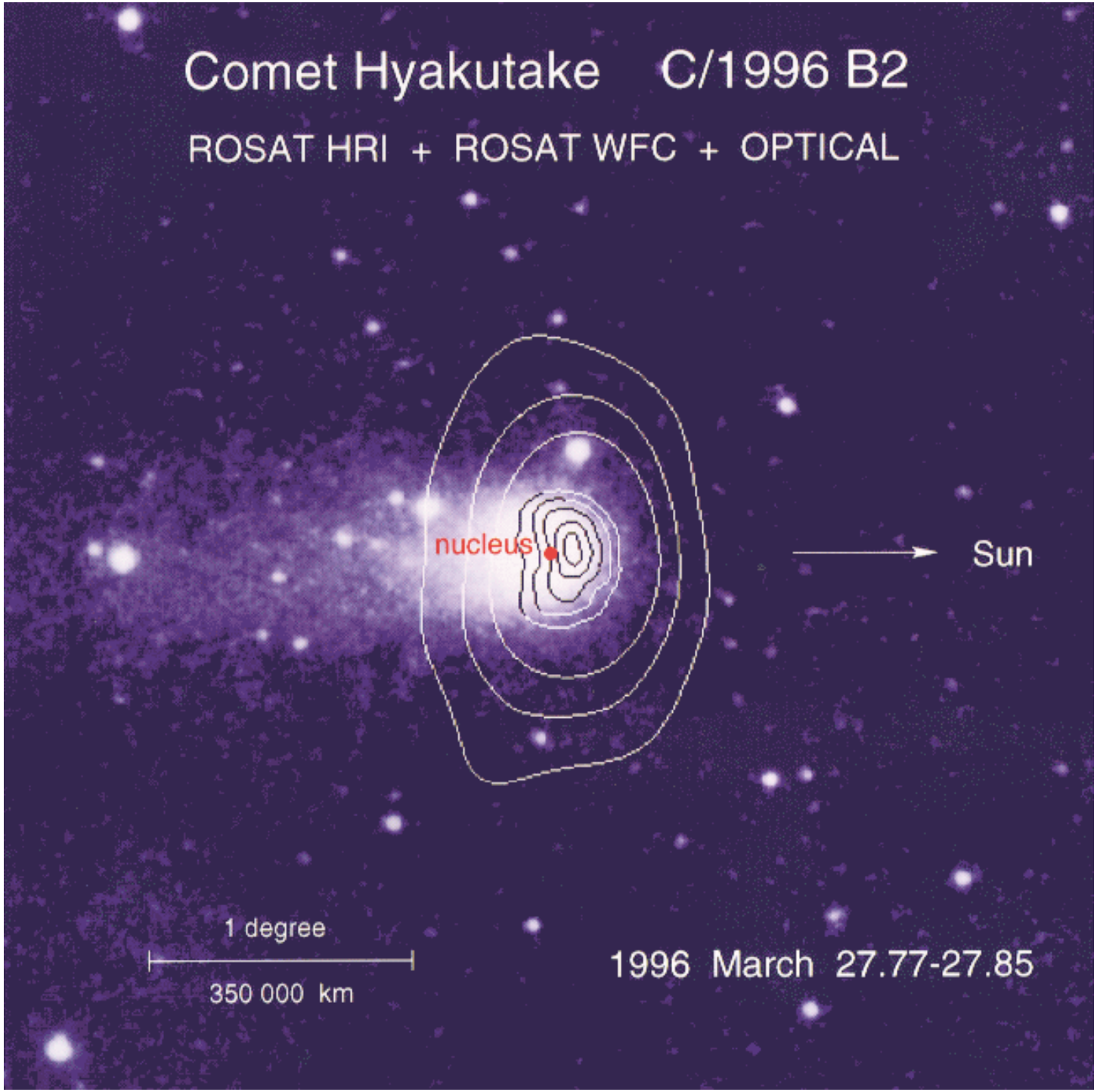


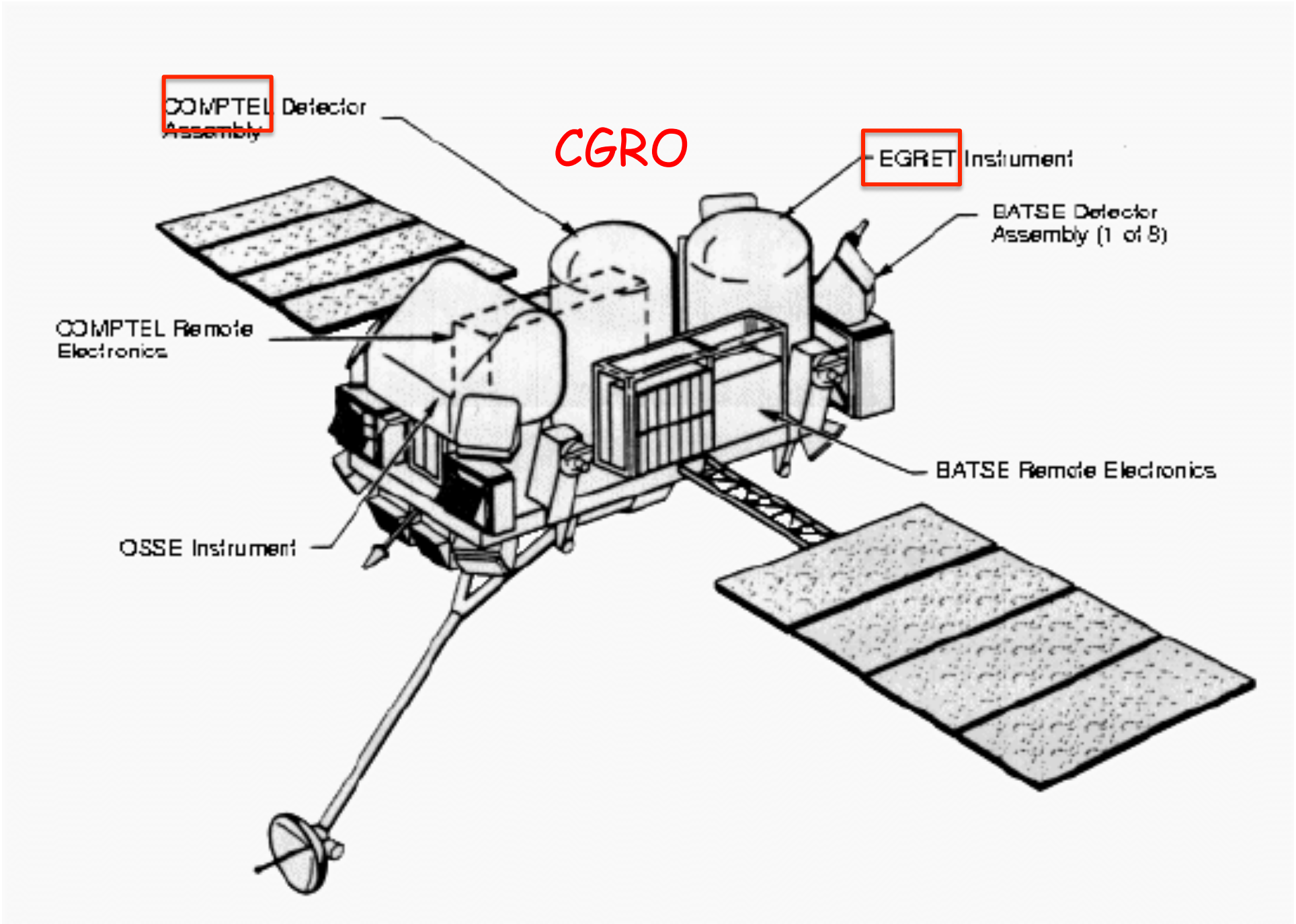
Orion X-Ray image

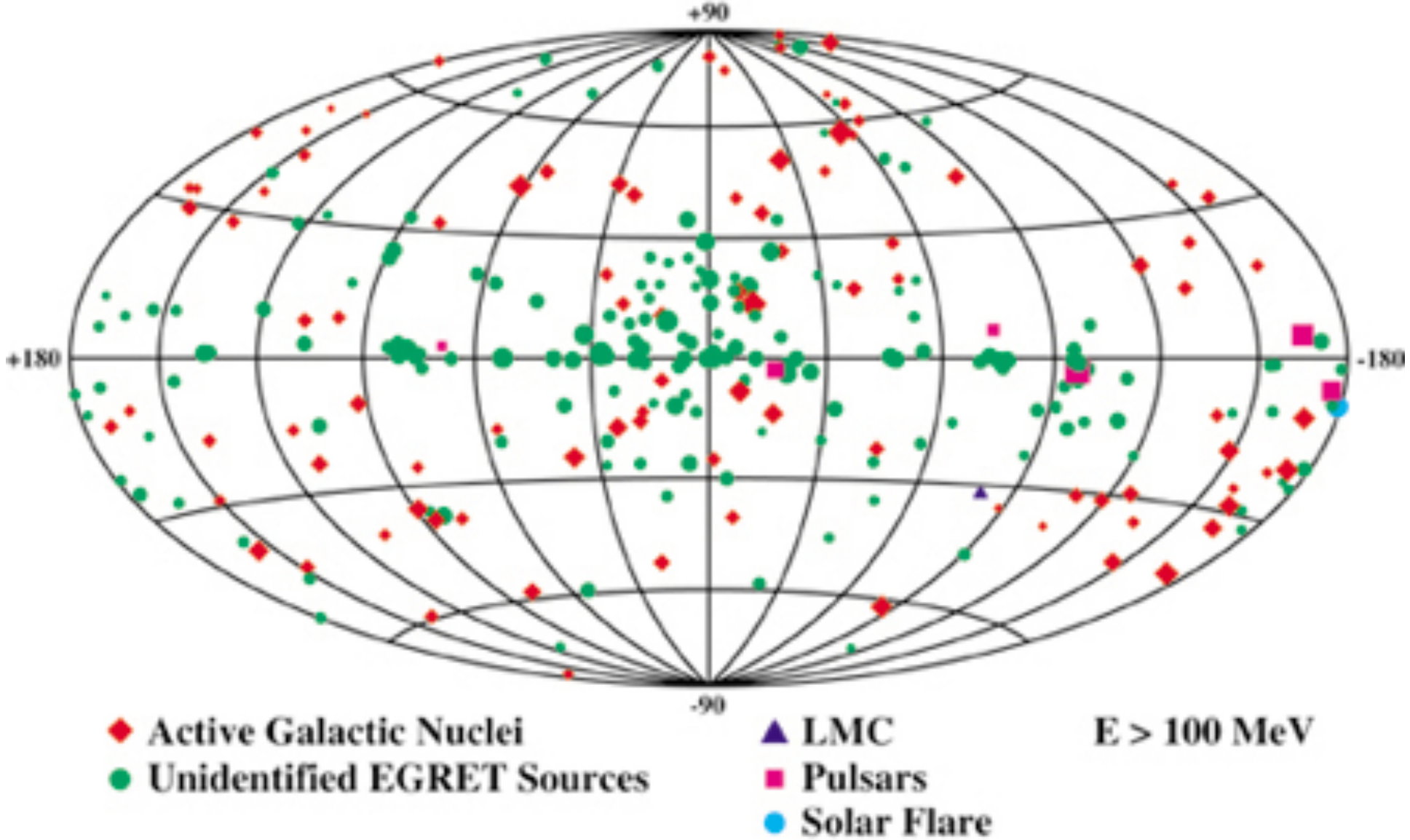
Galactic Center: optical and ROSAT view

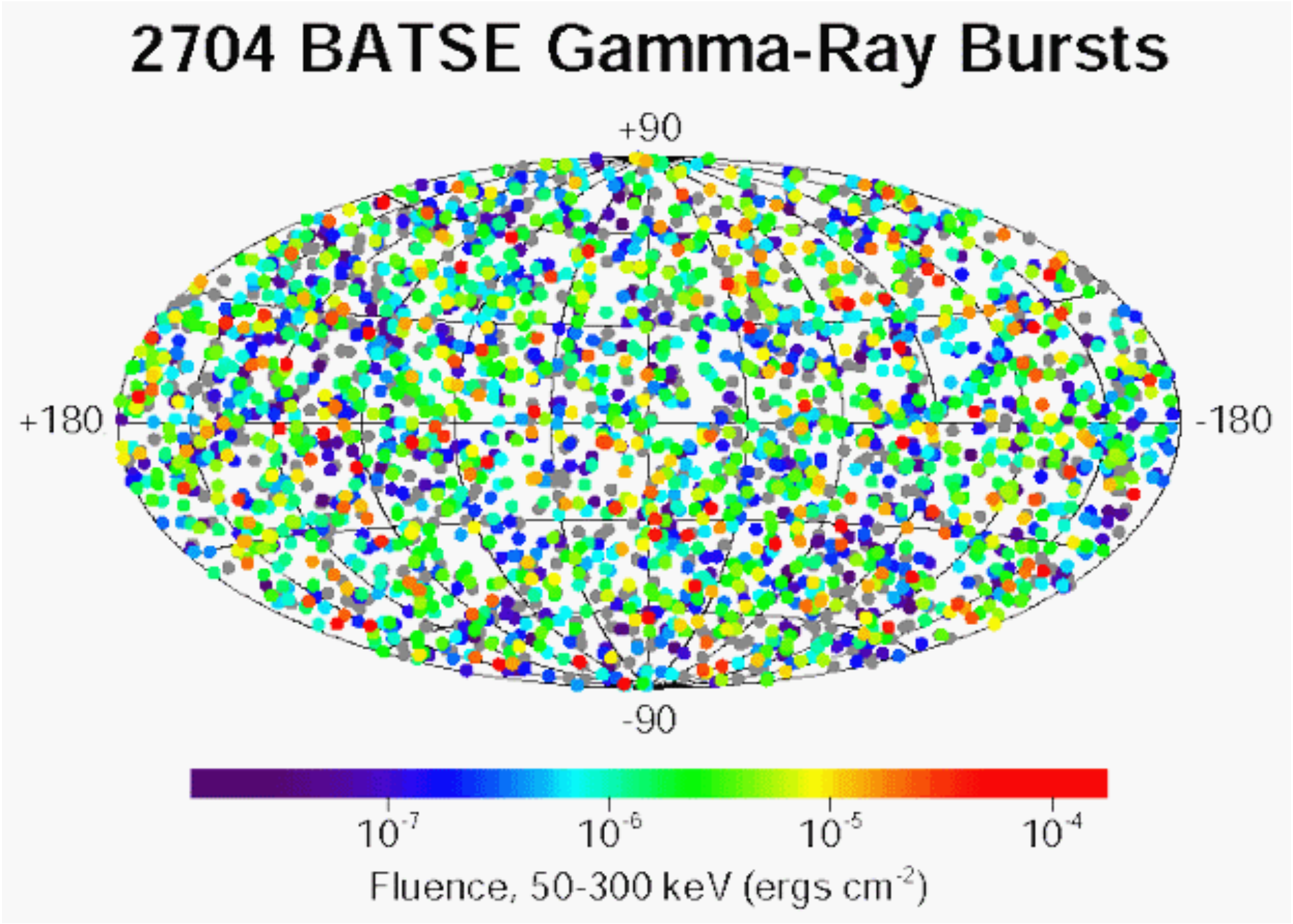



ROSAT PSPC All-Sky Survey Multispectral
MPE
1.1.94
point sources removed
0 Centered
Galactic Coordinates


Comet Hyakutake C/1996 B2
ROSAT HRI + ROSAT WFC + OPTICAL
nucleus
Sun
1 degree
350 000 km
1996 March 27.77-27.85


COMPTEL Detector Assembly
CGRO
EGRET Instrument
BATSE Detector Assembly (1 of 8)
COMPTEL Remote Electronics
BATSE Remote Electronics
OSSE Instrument


+90
+180
-180
-90
Active Galactic Nuclei
Unidentified EGRET Sources
LMC
Pulsars
Solar Flare
E > 100 MeV


2704 BATSE Gamma-Ray Bursts
+90
+180
-180
-90
10^{-7}
10^{-6}
10^{-5}
10^{-4}
Fluence, 50-300 keV (ergs cm^{-2})

Compton Gamma-Ray Observatory (CGRO)

The Discovery of an isotropic distribution of the Gamma-ray burst events

Mapping the Milky Way using the 26 Al Gamma-ray line

Discovery of Blazar Active Galactic Nuclei as primary source of the highest energy cosmic Gamma-rays

Discovery of the "Bursting Pulsar"

ASCA (Advanced Satellite for Cosmology and Astrophysics) Japan & USA

Lifetime : February 20, 1993 - March 2, 2001

Energy Range : 0.4 - 10 keV

Special Features :
First X-ray mission to combine imaging capability with broad pass band, good spectral resolution, and a large effective area

Payload :

Four X-ray telescopes each composed of 120 nested gold-coated aluminum foil sufaces (total eff area 1,300 cm² @ 1 keV, spatial resolution 3´ half power diameter, FOV 24´ @ 1 keV) working in conjunction with one of the following detectors:

Gas Imaging Spectrometer (GIS; 0.8-12 keV)
Two Imaging Gas Scintillation Proportional Counters (IGSPC)
FOV 50´, spatial resolution ~0.5' at 5.9 keV,and energy resolution of 8 % at 5.9 keV,Eff area (GIS+XRT) 50 cm² @ 1 keV

Solid-state Imaging Spectrometer (SIS; 0.4-12 keV)
Two CCD arrays of four 420 X 422 square pixel chips,
FOV 22´ X 22´ ,
Spatial resolution 30", energy resolution of 2 % at 5.9 keV ,
Eff area (SIS+XRT) 105 cm²

ASCA

Broad Fe lines from AGN, probing the strong gravity near the central engine

Lower than solar Fe abundance in the coronae of active stars

Spectroscopy of interacting binaries

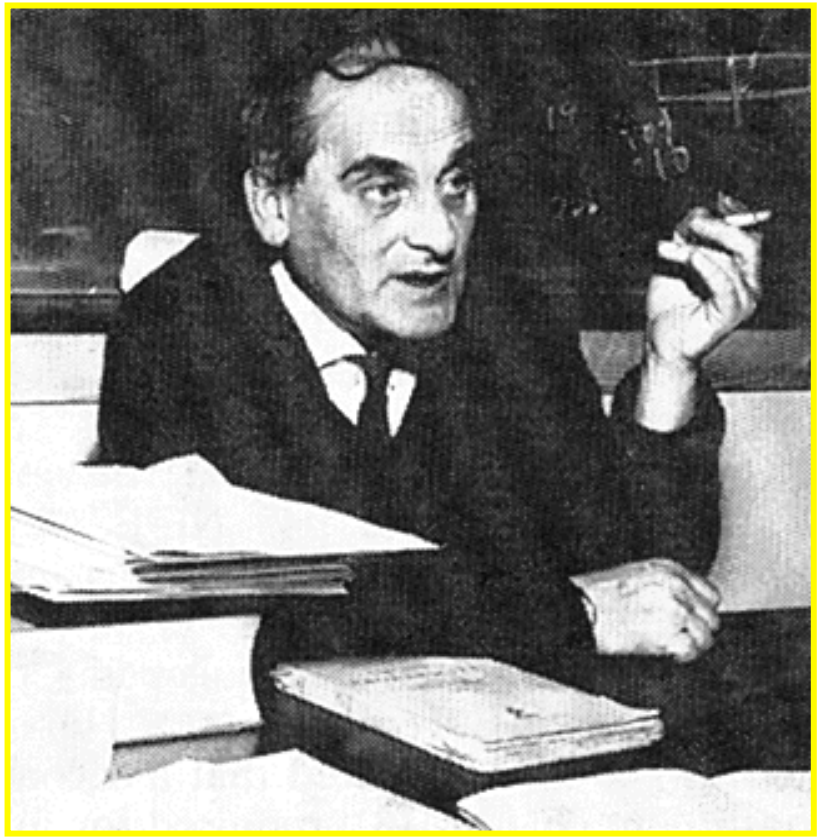
Non-thermal X-rays from SN 1006, a site of Cosmic Ray acceleration

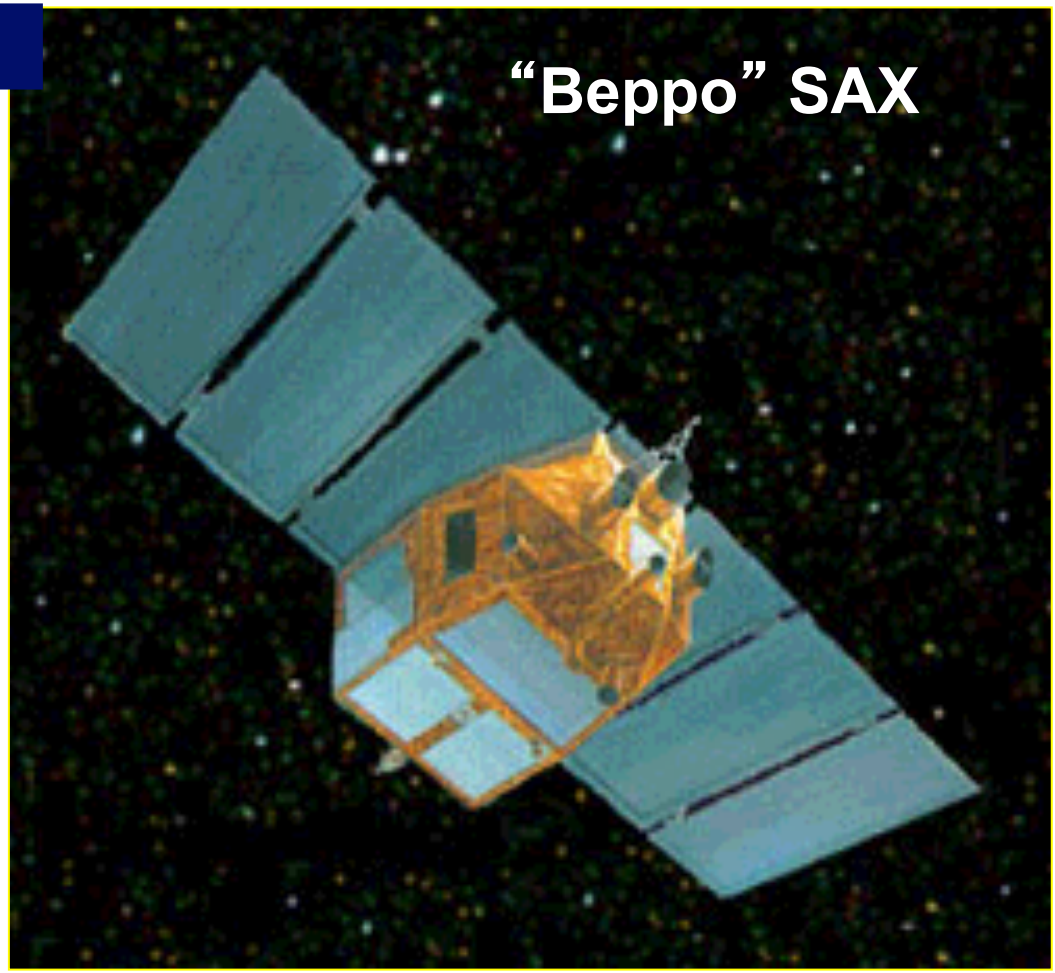
Abundances of heavy elements in clusters of galaxies, consistent with type II supernova origin

Starting of "modern" X-ray astrophysics with sensitive X-ray detectors for spectroscopy

Beppo-SAX

Giuseppe “Beppo” Occhialini





SAX

First arc-minutes position of GRBs.

Position determination on rapid time scale

First X-ray follow-up observations and monitoring of the GRB

Broad band spectroscopy of different classes of X-ray sources

Lifetime: 30 April 1996 - 30 April 2002

Energy Range: 0.1 - 300 keV

Special Features: Broad-band energy

Payload :

The Narrow field Instruments (**NFI**):

Four X-ray telescopes working in conjnction with one of the following detectors:

Low Energy Concentrator Spectrometer (LECS) (one unit) 0.1-10 keV, eff area 22 cm^2 @ 0.28 keV, FOV 37´ diameter, angular resolution 9.7´ FWHM @ 0.28 keV.

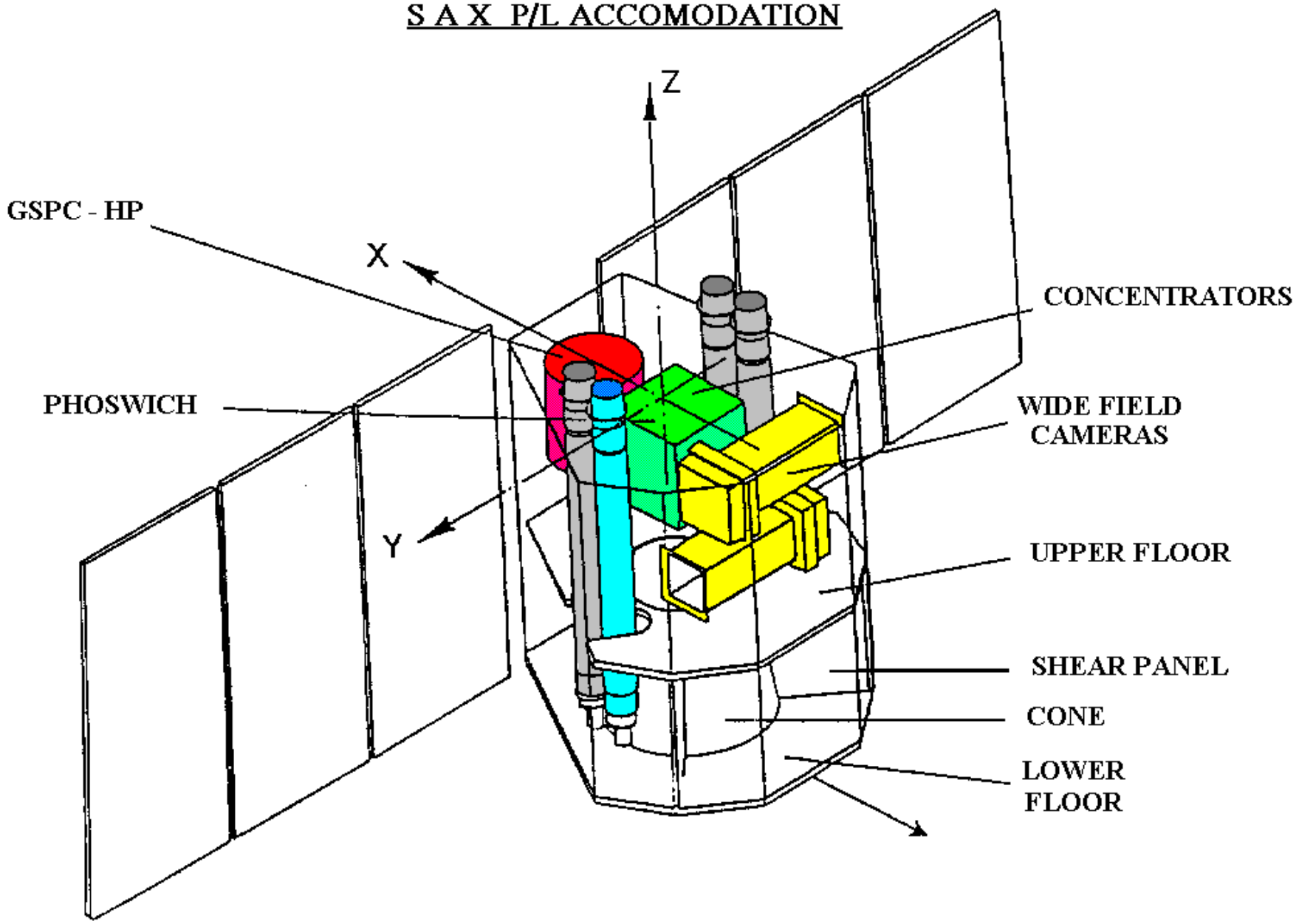
Medium Energy Concentrator Spectrometer (MECS) (three units) 1.3-10 keV, eff area total 150 cm^2 @ 6 keV, FOV 56´ diameter, angular resolution for 50% total signal radius 75" @ 6 keV.

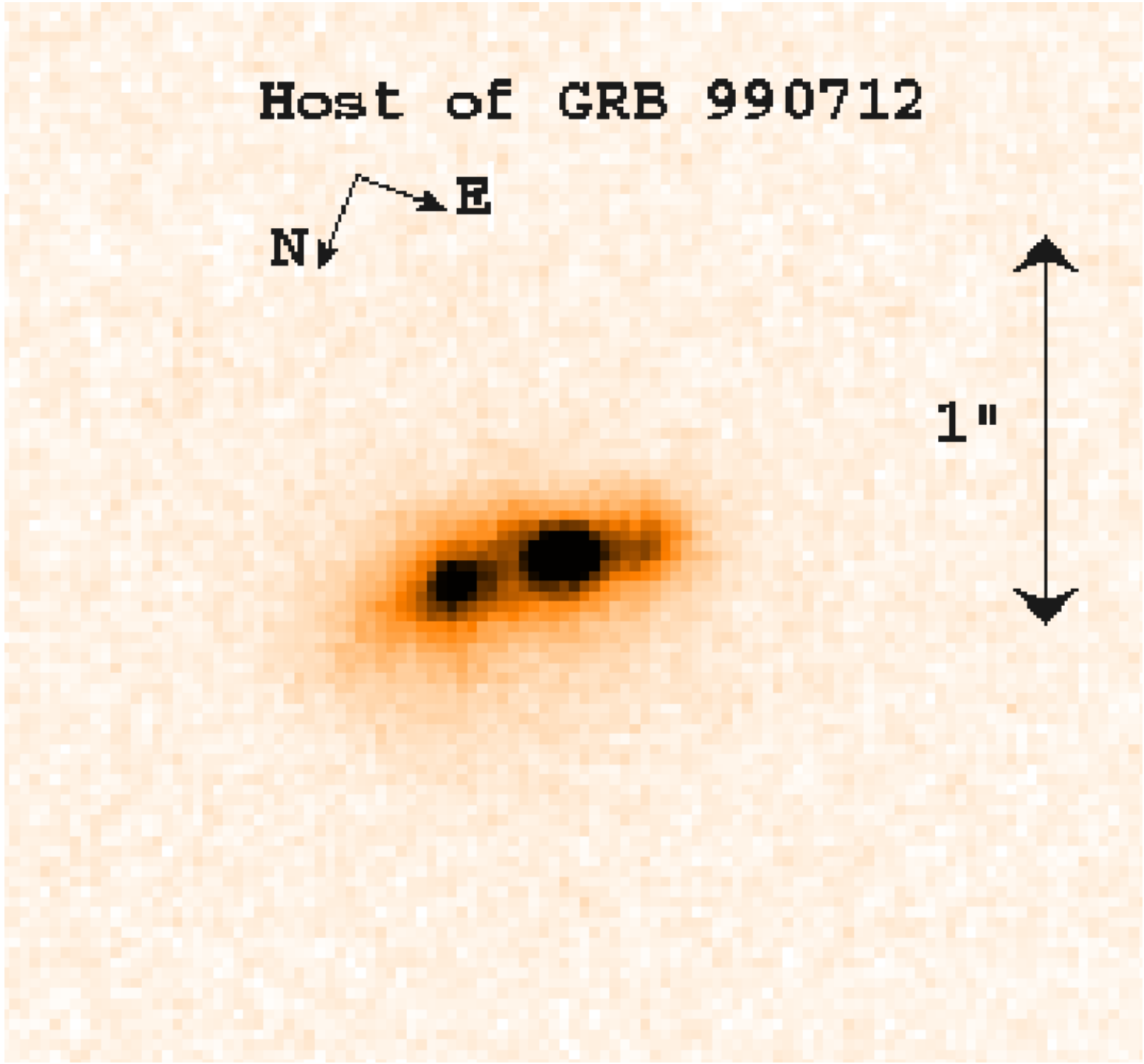
High pressure Gas Scintillator Proportional Counter (HPGSPC) 4-120 keV, eff area 240 cm^2 @ 30 keV

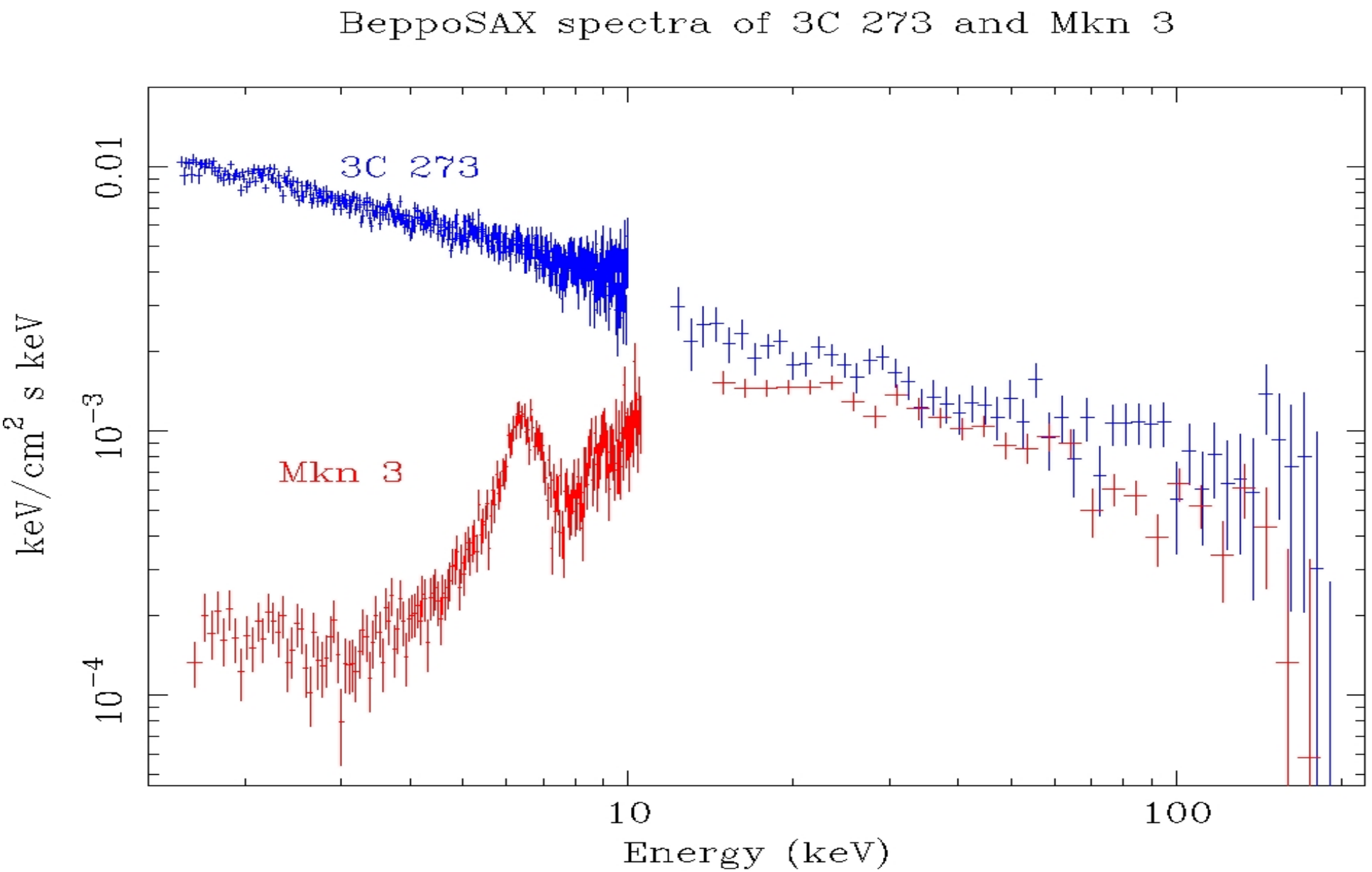
Phoswich Detection System (**PDS**) 15-300 keV. The lateral shields of the PDS are used as gamma-ray burst monitor in the range of 60-600 keV. Eff area 600 cm^2 @ 80 keV

Wide Field Camera (**WFC**, 2 units) 2-30 keV with a field of view 20 deg X 20 deg. The WFC are perpendicular to the axis of the NFI and point in opposite directions to each other. Eff area 140 cm^2.

S A X P/L ACCOMODATION




Host of GRB 990712
N
E
1"


BeppoSAX spectra of 3C 273 and Mkn 3
3C 273
Mkn 3
0.01
10^{-3}
10^{-4}
keV/cm^2 s keV
10
100
Energy (keV)

Missioni al momento "attive"

XMM-*Newton* (ESA)

International Gamma-ray Laboratory (*INTEGRAL*, ESA)

Chandra (NASA)

Swift (NASA)

Golden Age of X-ray Astronomy

Fermi (GLAST, NASA)

AGILE (Italia)

NuSTAR (NASA)

eROSITA (Germany+Russia)

recently launched

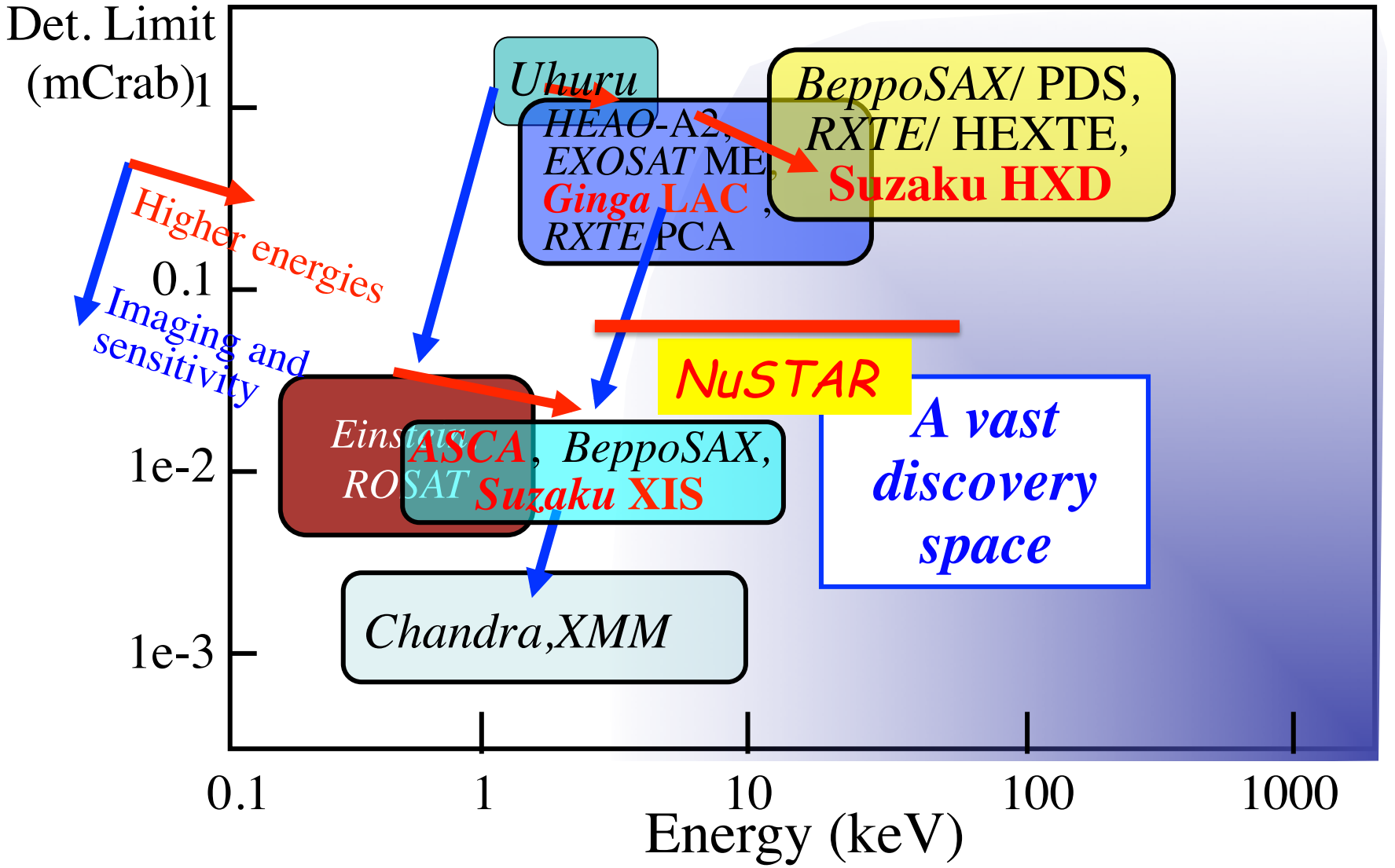
Rossi X-ray Timing Explorer (RXTE, NASA)

Suzaku (Astro-E2, JAXA/Giappone)

Astro-H (*Hitomi*, JAXA)

not active anymore

Evolution of missions



Courtesy of Makishima