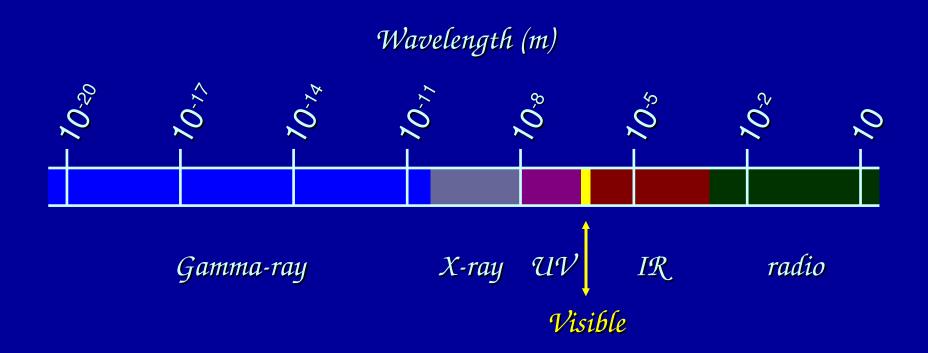


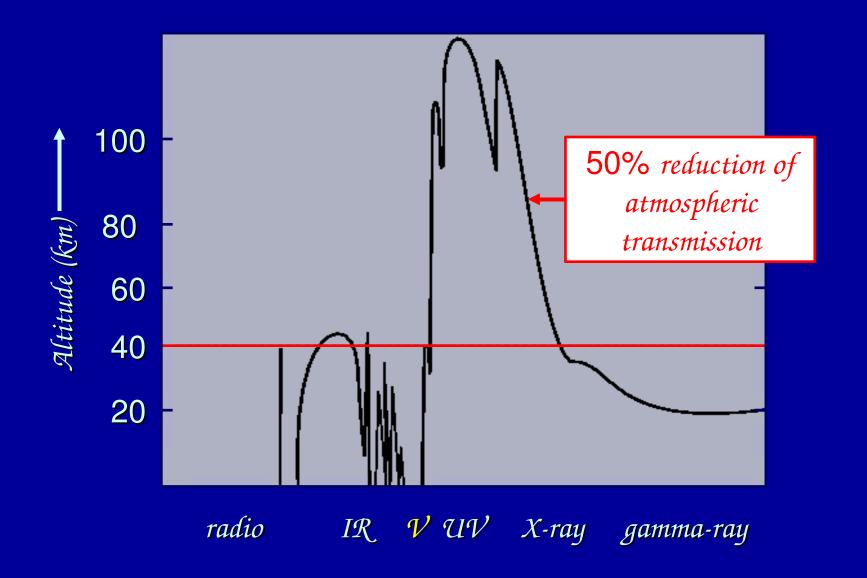


Electromagnetic spectrum for astronomy

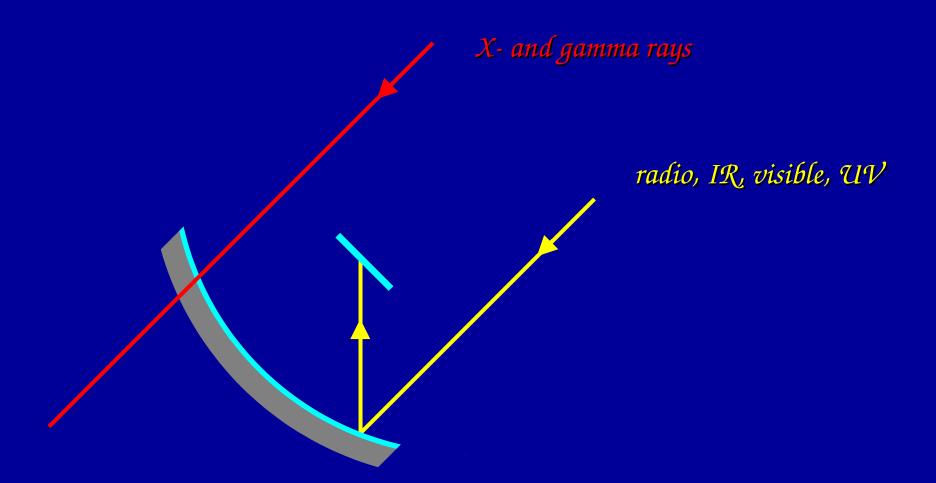


X- and gamma-rays: more than 50% of the usable EM spectrum

The atmospheric screen

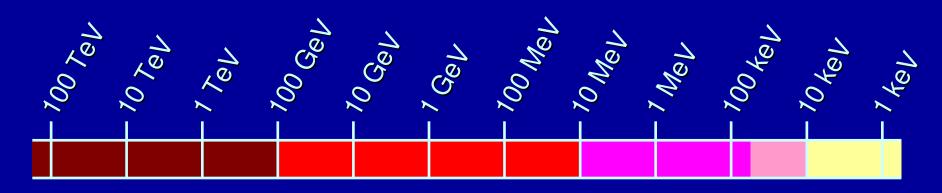


Focusing



Astronomy with X- and gamma-ray photons

Photon energy



very high energy

Gamma rays

high energy

low energy

X-rays

hard soft









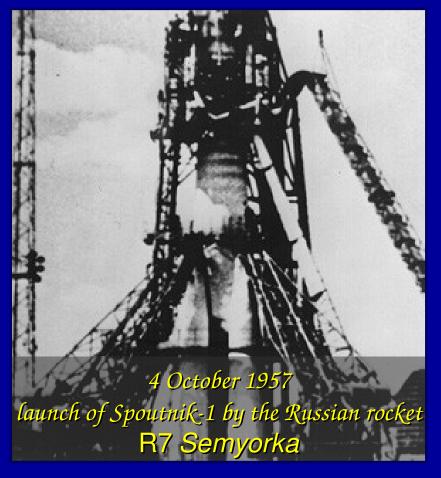


Space conquest

Some dreamed about it...

Military have done it!





Balloons and rockets

Faster and cheaper access to space



For hard X-rays and gamma rays



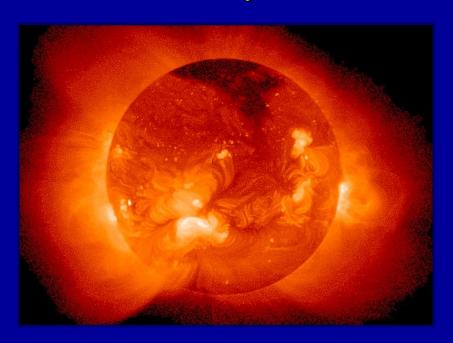
For soft X-rays



First detection of extraterrestrial X-rays

- On 29 September 1949, a set of small Geiger counters (sensitive only to X-rays) was flown onboard a captured German V2 rocket
- Above 87 km, the detector showed a sharply modulated response every time the Sun was in its field of view
- The Sun is a source of X-rays!

 Friedman et al., Phys. Rev. 83, 1025, 1951



It had been proposed few years before (Alfven and Edlen, 1941) that the solar corona should be a 10° K plasma (i.e. hot enough to radiate such X-rays)

Yohko X-ray image of the Sun recorded on 8 May 1992

X-ray astronomy in the early 60's

- In the 50's, the low X-ray output from the Sun discouraged many astronomers to search for X-ray sources outside the solar system
- In 1959, a group led by Riccardo Giacconi at AS&E started work investigate the possibilities for carrying out X-ray astronomy

Estimates of fluxes from sources outside the solar system Giacconi, R., Clark, G.W., and Rossi, B.B. ASE-TN-49, Jan. 15, 1960

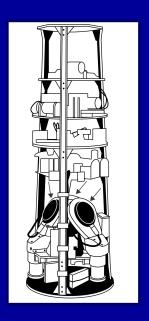
Source	Maximum Wavelength	Mechanism for Emission	Estimated Flux
Sun	< 20 Å	Coronal emission	~ 10 ⁶ cm ⁻² s ⁻¹
Sun at 8 light years	< 20 Å	Coronal emission	$2.5 \times 10^{-4} \text{ cm}^{-2} \text{ s}^{-1}$
Sirius if $L_X \sim \dot{L}_{OPT}$	< 20 Å	?	$0.25~{\rm cm}^{-2}~{\rm s}^{-1}$
Flare stars	< 20 Å	Sun like flare?	?
Peculiar A stars	< 20 Å	Particle acceleration	?
Crab nebula	< 25 Å	Synchrotron	?
Moon	< 23 Å	Fluorescence	0.4 cm ⁻² s ⁻¹
Moon	~ 20 Å	Impact from solar wind e-	$0-1.6 \times 10^3 \text{ cm}^{-2} \text{ s}^{-1}$

Objectif Lune

(Towards the Moon)

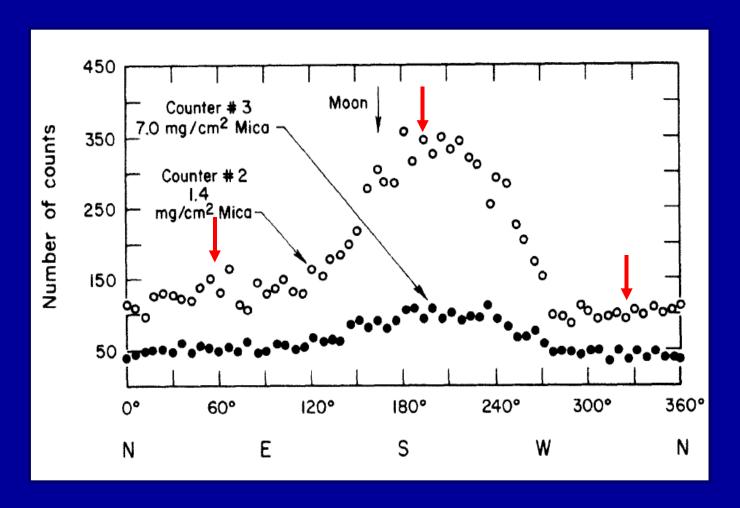


- Undeterred by NASA's rejection of a proposal to search for cosmic X-rays, Giacconi persuaded USAF to fund the project
- To make the project more attractive, the primary goal of the flight was to look for X-rays from the Moon
- The AS&E team's first two X-ray astronomy rocket flight failed



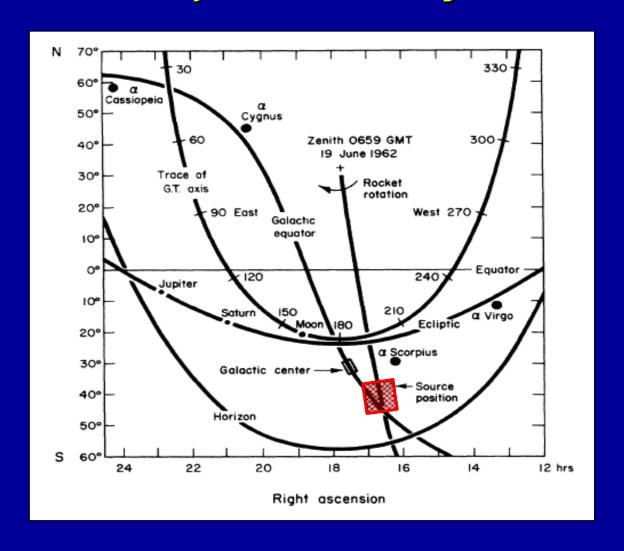
On 18 June 1962, one minute before midnight, a payload consisting of three large area Geiger counters was launched using a USAF Areobee 150 rocket. The rocket was above 80 km for a total of 5 min and 50 sec, and reached a maximum altitude of 225 km. As the spinning rocket climbed above 80 km the doors opened and discovered the first evidence for X-ray radiation from beyond our solar system

350 seconds that shook the world



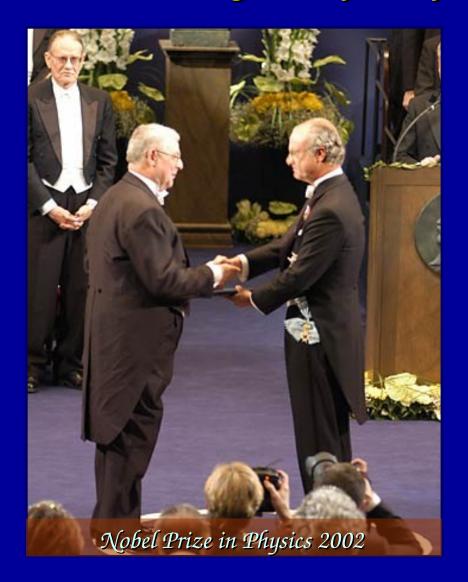
Number of counts versus azimuth angle

A fortuitous discovery



Portion of the sky explored by the counters

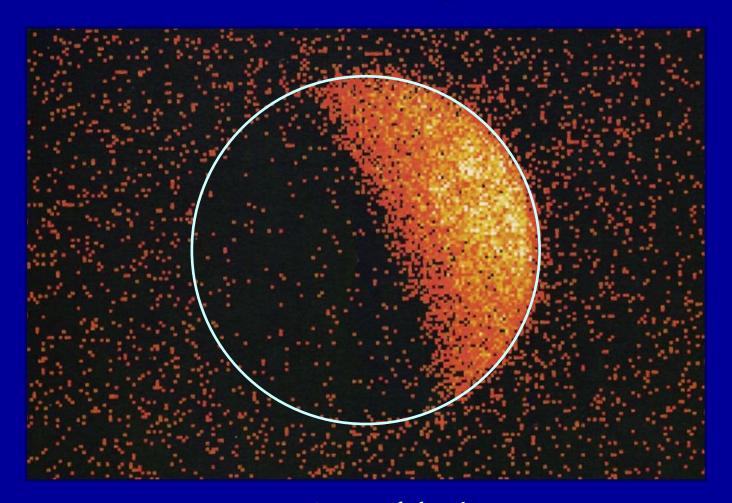
A glorious future for Riccardo Giacconi







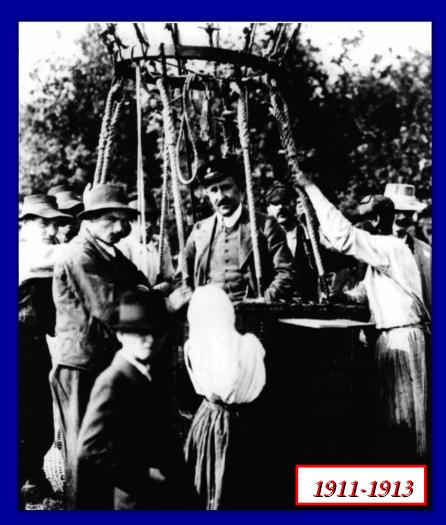
What about the X-ray Moon?



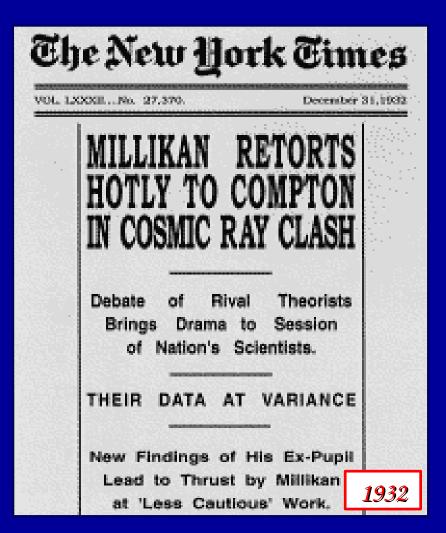
ROSAT image of the Moon Schmitt et al. Nat 349, 583, 1991



A cumbersome heredity



Hess discovery of cosmic rays



Going upstream to CR sources

A long expectation

- 1952 Prediction of the high-energy gamma-ray emission of the Galactic disk via p-p interactions

 Hayakawa, Prog. Theor. Phys. 8, 571, 1952
- 1958 Inventory of the cosmic sites expected to radiate gamma rays:
 It include the Crab Nebula, Cyg A and the Sun
 Morrison, Nuovo Cimento 7, 858, 1958
- 1958 First detection of cosmic gamma rays during a solar flare Peterson & Winckler, Phys. Rev. Let. 1, 205, 1958
- 1967 First exhaustive revue devoted to gamma-ray astronomy

...ten years after the launch of Sputnik 1, one had not succeeded in definitely detecting any gamma rays from cosmic sites localized beyond the solar system...

Fazio, ARA&A 5, 481, 1967

Specificities of the gamma-ray domain

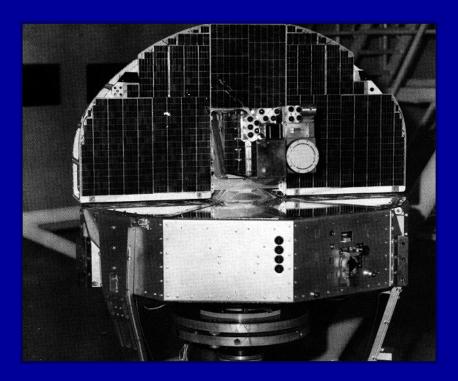
In comparison with X-ray observations, gamma-ray observations have to suffer from two additional difficulties:

- At equal radiated power, a celestial body active in the gamma-ray domain radiates much less photons
- Large devices and long observing times
- Much more than for X-ray detectors, the cosmic rays are for all gamma-ray detectors a huge source of background that cannot be entirely suppressed even at the expense of massive shields
- Heavy devices and very long observing times

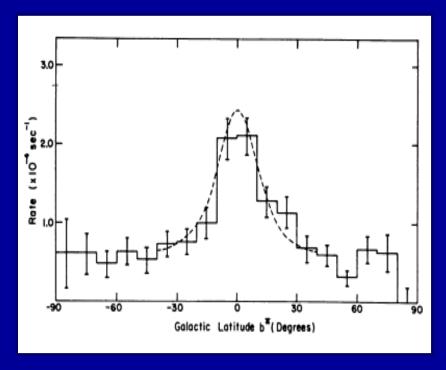
Fruitful measurements of cosmic gamma rays imply long duration balloon flights or, much better, in orbit observations

First detection of cosmic gamma rays (1)

1968 Discovery of the high-energy (> 100 MeV) Galactic gamma-ray emission with a pair-production detector aboard OSO III Clark et al., ApJ 153, L203, 1968



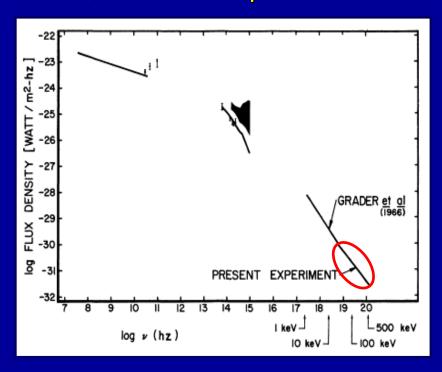
OSO III (1967-1969)



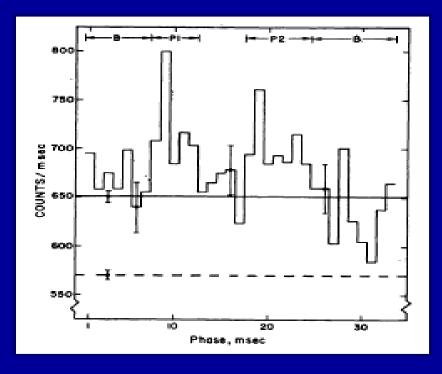
Galactic emission latitude profile

First detection of cosmic gamma rays (2)

1968 Balloon hard X-ray and low-energy gamma-ray (< 500 keV) detection of the Crab nebula and pulsar Haymes et al., ApJ 151, L9, 1968
Fishman et al. ApJ 153, L61, 1969



Overall Crab spectrum



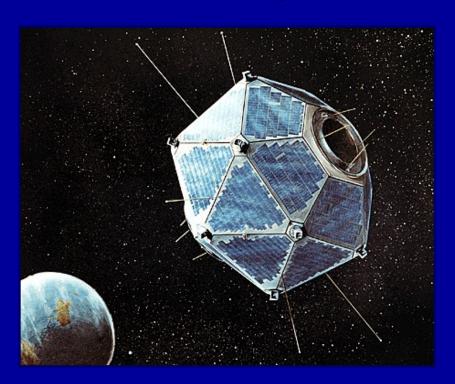
Light curve of the Crab pulsar

First detection of cosmic gamma rays (3)

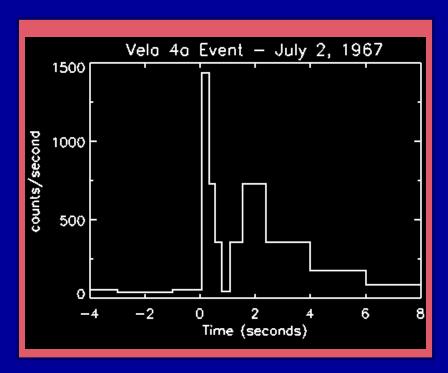
1967 First localization of a cosmic GRB by Vela 5A and Vela 5B

1973 First report on the detection of cosmic gamma-ray bursts

Klebesadel et al., ApJ 182, L85, 1973



Artist view of a Vela satellite



Light curve of GRB 670702



X-ray astronomy before the satellite era (1)

From 1963 to 1970, rocket and balloon detections of tens of extra solar X-ray sources

- 1963 First detection of the Crab nebula (Rocket–NRL)

 Boyer et al., Nat 201, 1307, 1964
- 1964 Discovery of the Crab Nebula spatial extension (R-NRL)
 Boyer et al., Science 146, 912, 1964
- 1964 Detection of 8 new sources, Kepler SNR, Cyg X-1 (R-NRL)
 Boyer et al., Science 147, 394, 1965
- 1965 First detection of extragalactic sources, M87, Cyg A (R-NRL)

 Byram et al., Science 152, 66, 1966
- 1965 Detection of the Coma cluster of galaxy (Balloon-GSFC)
 Boldt et al., Phys. Rev. Let. 17, 447, 1966
 The emission comes from a hot (108 K) intra cluster gas
 Felten et al., ApJ 146, 955, 1966

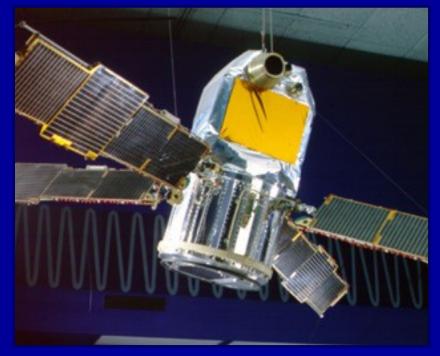
X-ray astronomy before the satellite era (2)

- Arc min. measurement Sco X-1 position (R-AS & E-MIT) 1966 Gursky et al., ApJ 146, 310, 1966 Optical identification of Sco X-1: a blue star with unusual lines Sandage et al., ApJ 146, 316, 1966 Sco X-1 emission: accretion onto a NS in a binary system Shklovskii et al., Astronomicheskii Zhurnal 44, 930, 1967
- Detection of the quasar 3C 273 (R-NRL) Friedman & Byram, Science 158, 257, 1967
- Detection of the X-ray emission from the Crab pulsar 1969 Bradt et al., Nat 222, 78, 1969
- Detection of QPO in the X-ray emission of Sco X-1 (R-KPNO) Angel et al., ApJ 169, L57, 1971
- Launch of SAS-1, the first X-ray astronomy satellite on 12 December, the 7th anniversary of the Kenyan independence. the satellite was named **Uhuru**, the Swahili word for freedom

Uhuru: the first X-ray observatory

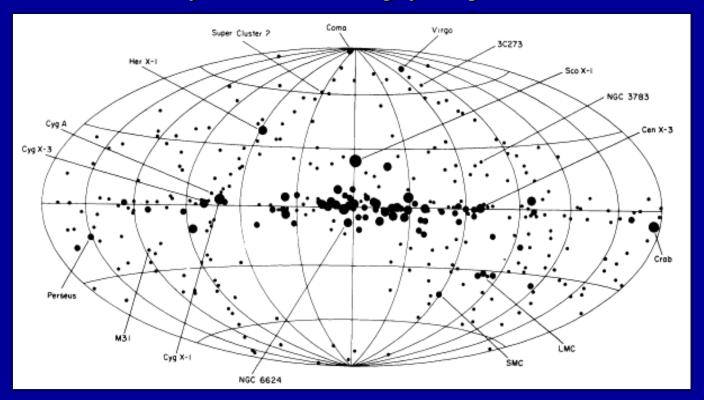
- Launched by a Scout rocket from the Italian San Marco platform
- 840 cm² of proportional counters operating in the 2-20 keV band
- The mission operated over two years and ended in March 1973





Uhuru major outcomes

The fourth Uhuru catalog of X-ray sources



Forman et al., ApJS 38, 357, 1978

- Existence of neutron stars and black holes in binary systems
- Accretion as a dominant source of energy

Other explorer satellite missions

- 1974 Launch of ANS (Astronomische Nederlandse Satelliet)
 Discovery of X-ray bursters
- 1974 Launch of the British Ariel V

 Discovery of the brightest black hole X-ray nova (A0620-00)
- 1975 Launch of SAS-3
 Study of X-ray bursters







High-energy gamma-ray observatories of the 70's

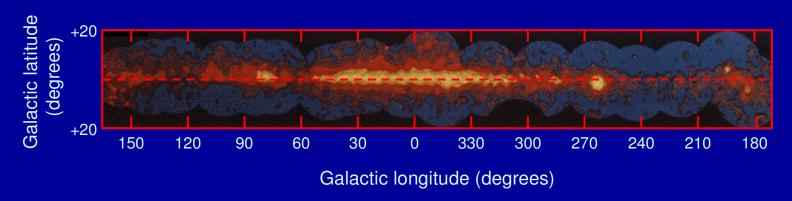
1972 Launch of SAS-2, interruption of the data collection after only eight months due to the failure of a low-voltage power supply

1975 Launch of COS-B, the first European Space Agency satellite

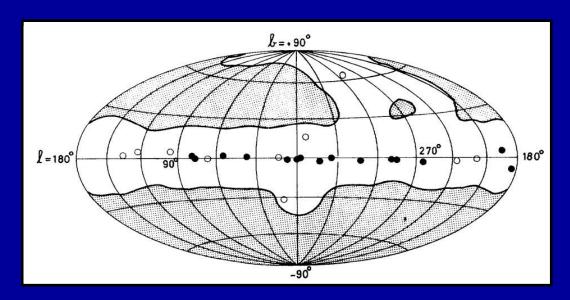




COS-B major outcomes



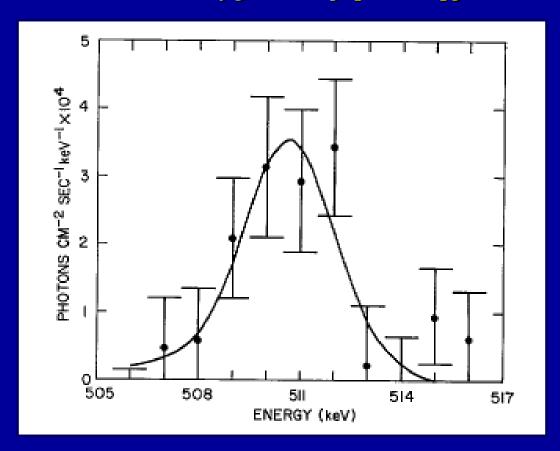
Mayer-Hasselwander et al, A&A 107, 390, 1982



Swanenburg et al, ApJ 243, 69, 1981

Balloon gamma-ray observations still at work!

The advent of gamma-ray spectroscopy

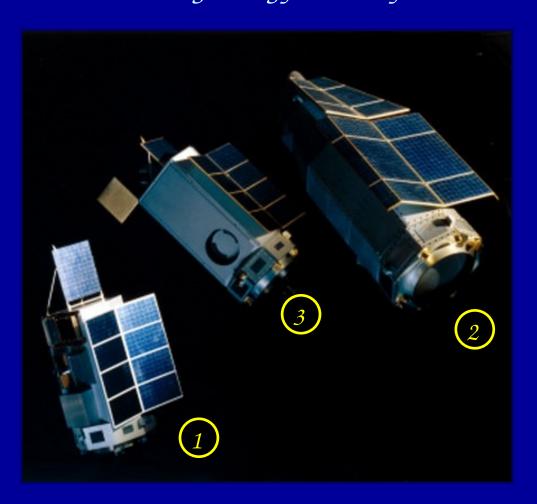


Discovery of a site of e⁺ e⁻ annihilation emission Leventhal et al., ApJ 225, L11, 1978



The HEAO series

Beginning in 1977, NASA launched a series of very large scientific satellites called High Energy Astronomy Observatories (HEAO)



HEAO-1

August 1977-January 1979

 $\mathcal{HEAO}-2$

November 1978-April 1981 Named Einstein after launch

HEAO-3

1979-1981

The Einstein observatory

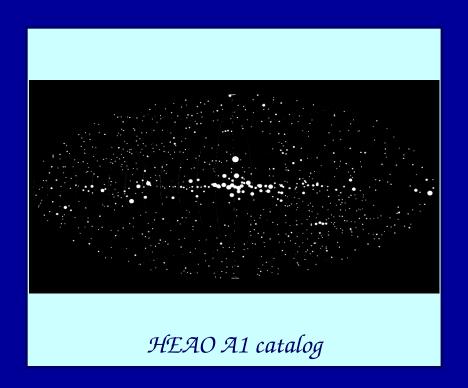
- First fully imaging X-ray telescope put into space
- First high-energy mission to have a Guest Observer program
- It completely changed the view of the X-ray sky!

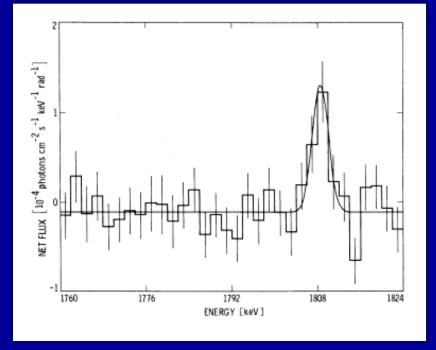
Classes of objects observed with the Einstein Observatory Giacconi, Nobel Lecture, December 8, 2002

- Aurora in Jupiter
- X-ray emission from all type of main sequence stars
- Novae and supernovae
- Pulsars
- Binary X-ray sources and supernovae in other galaxies
- Normal galaxies
- Nuclei of active galaxies
- Quasars
- Groups and clusters of galaxies
- Sources of the extragalactic background

Two other selected HEAO outcomes

- Comprehensive catalog of X-ray sources
 Wood et al., ApJS 56, 507, 1984
- Discovery of a nuclear line emission from the inner Galaxy Mahoney et al., ApJ 286, 578, 1983





Japanese and European attempts

1979 Launch of the X-ray satellite Hakucho, the first of a coherent program of X-ray Japanese high-energy astronomy missions









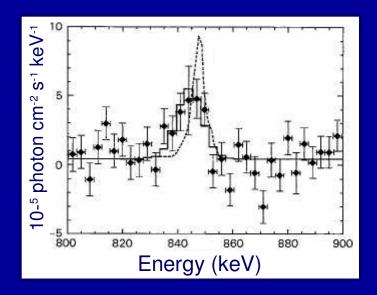
1983 Launch of EXOSAT the first
ESA X-ray observatory
1780 observations of a wide
variety of objects
Discovery of QPO in LMXB
Measurement of iron line in
several kinds of sources



The supernova that occurred at the worse time

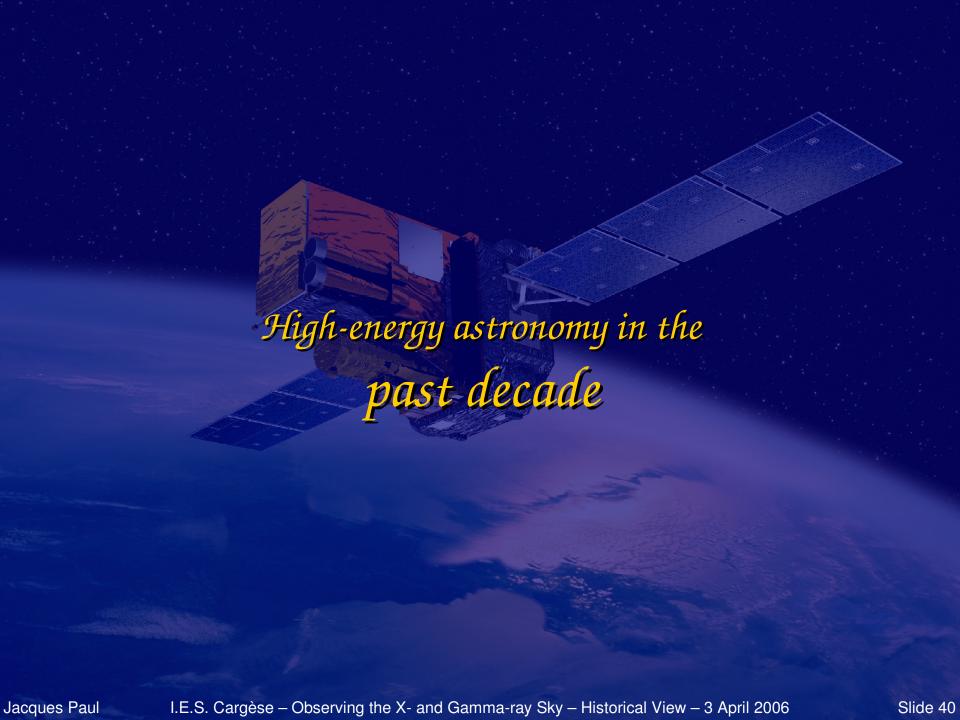
- SN1987A, the nearest known supernova in several years, appear on 24 February 1987 in the absence of large HE observatories. Nevertheless, SN1987A was detected by Ginga, SMM, and by the Kvant 1 module attached to the Soviet Mir space station. See e.g. Sunyaev et al., Nat 330, 227, 1987
- Excellent result from the balloon gamma-ray spectrometer GRIS

 Tueller et al., ApJ 351, L41, 1990



GRIS data for the 847 keV line from the decay of ⁵⁶Co shown for day 613

- Nucleosynthesis theory confirmed
- The line is larger than expected
- The line has been detected earlier than expected (~ 6 months)



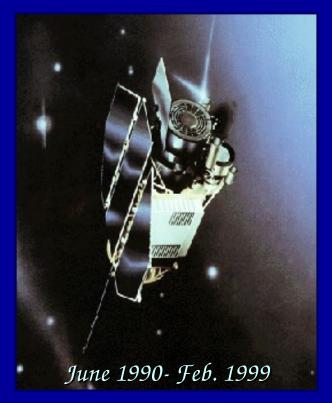
Rosat: the large X-ray telescope of the 90's

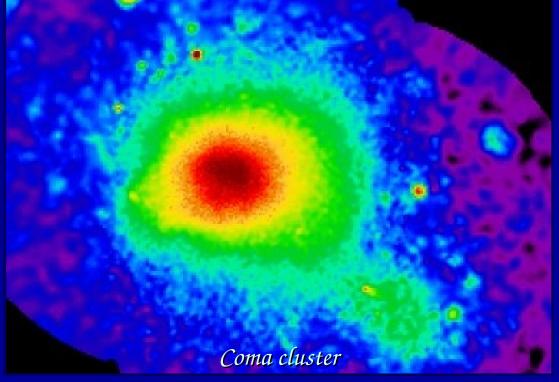
1990 Launch of ROSAT (RÖntgenSATellit)

X-ray all-sky survey catalog, more than 150000 objects

Detailed morphology of Supernova remnants

Detailed morphology of clusters of galaxies





Golden age of gamma-ray astronomy

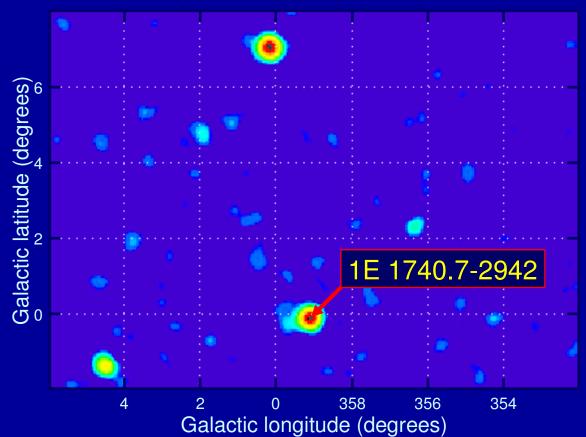
- A new generation of telescopes aboard GRANAT and CGRO
- GRB studies: the BeppoSAX era
- Advent of ground based astronomy





GRANAT major outcomes

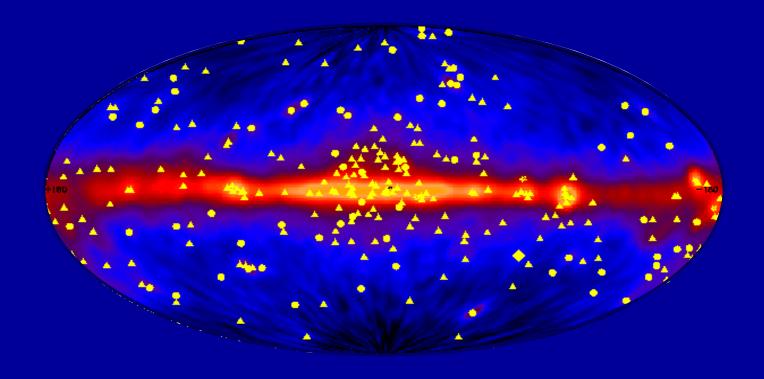
- Low-energy studies of accreting stellar black holes Goldwurm et al., Nat 371, 589, 1994
- Contribution to the discovery of microquasars
 Mirabel et al., Nat 358, 215, 1992



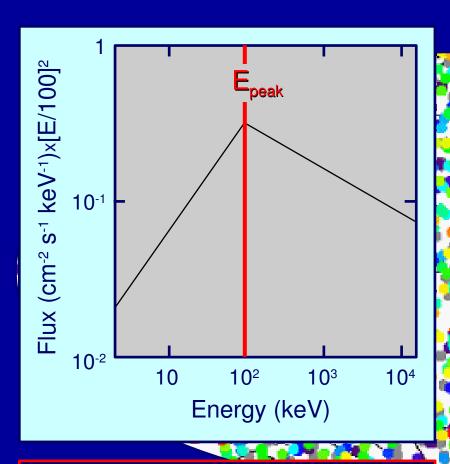


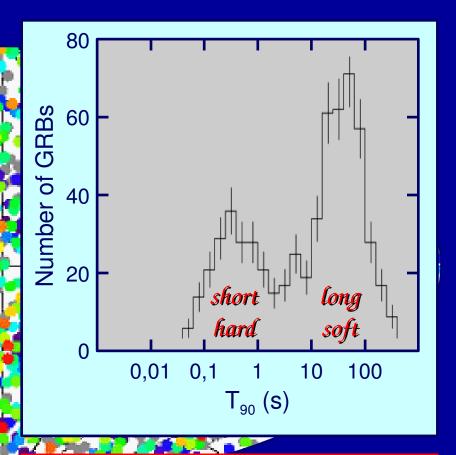
CGRO major outcomes (1)

- COMPTEL map of the galactic aluminum-26 line emission Oberlack, Ph.D. Thesis, Technische Universität München, 1997
- EGRET High-energy gamma-ray survey revealing tens of blazars Hartman et al., ApJS 123, 79, 1999



CGRO major outcomes (2)

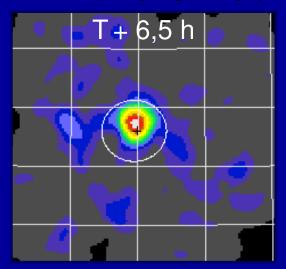


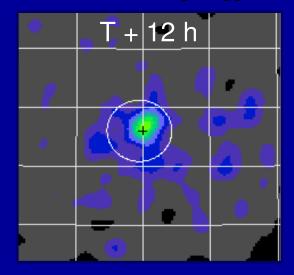


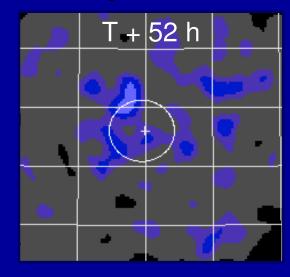
Energy radiated in the low energy gammaray band Bimodal distribution of GRB durations

GRB understanding: The cosmological revolution

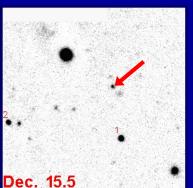
Afterglow of GRB 971214 detected by BeppoSAX in the X-ray band

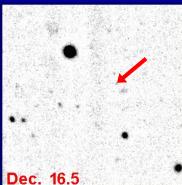






Afterglow in the visible band





- Detection of host galaxies
- Redshift measurements
- Cosmological distances
- Most energetic events
- 10⁴⁴ J radiated in gamma rays

Advent of ground based gamma-ray astronomy

1989 First detection of the Crab nebula TeV emission

90's Rapid progress attested by the observing time required to detect the Crab nebula







Whipple 1989: 50 h

CAT 1997: 10 min

HESS 2003: 15 s

2001 First catalog of TeV sources (7 SNRs, 1 X-ray binary), 9 AGNs Weekes, astro-ph/0010431



