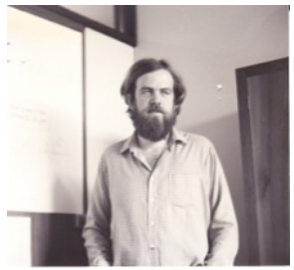
The Development of X-ray Astronomy in the UK

Mike Watson
University of Leicester

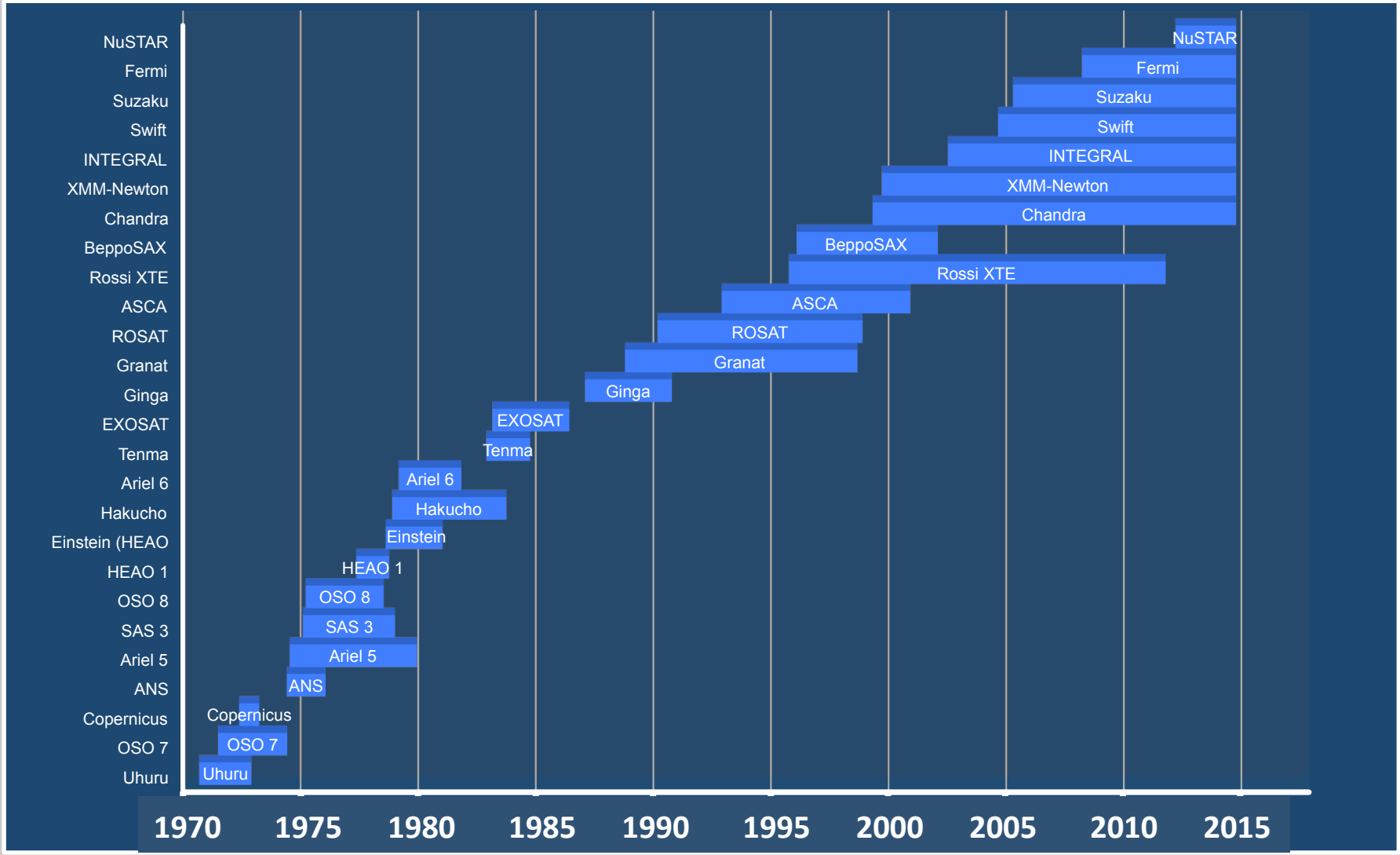
Introduction

- UK active in space science since before 1960
  - Leicester Space Science 50th anniversary 2010
  - solar → cosmic X-ray astronomy
- UK groups involved in X-ray astronomy
  - Leicester, MSSL-UCL, Birmingham, Imperial College, RAL
- Some history & selective highlights (and some lowlights)
  - personal perspective – rather Leicester-centric
- History stops in 1990 …

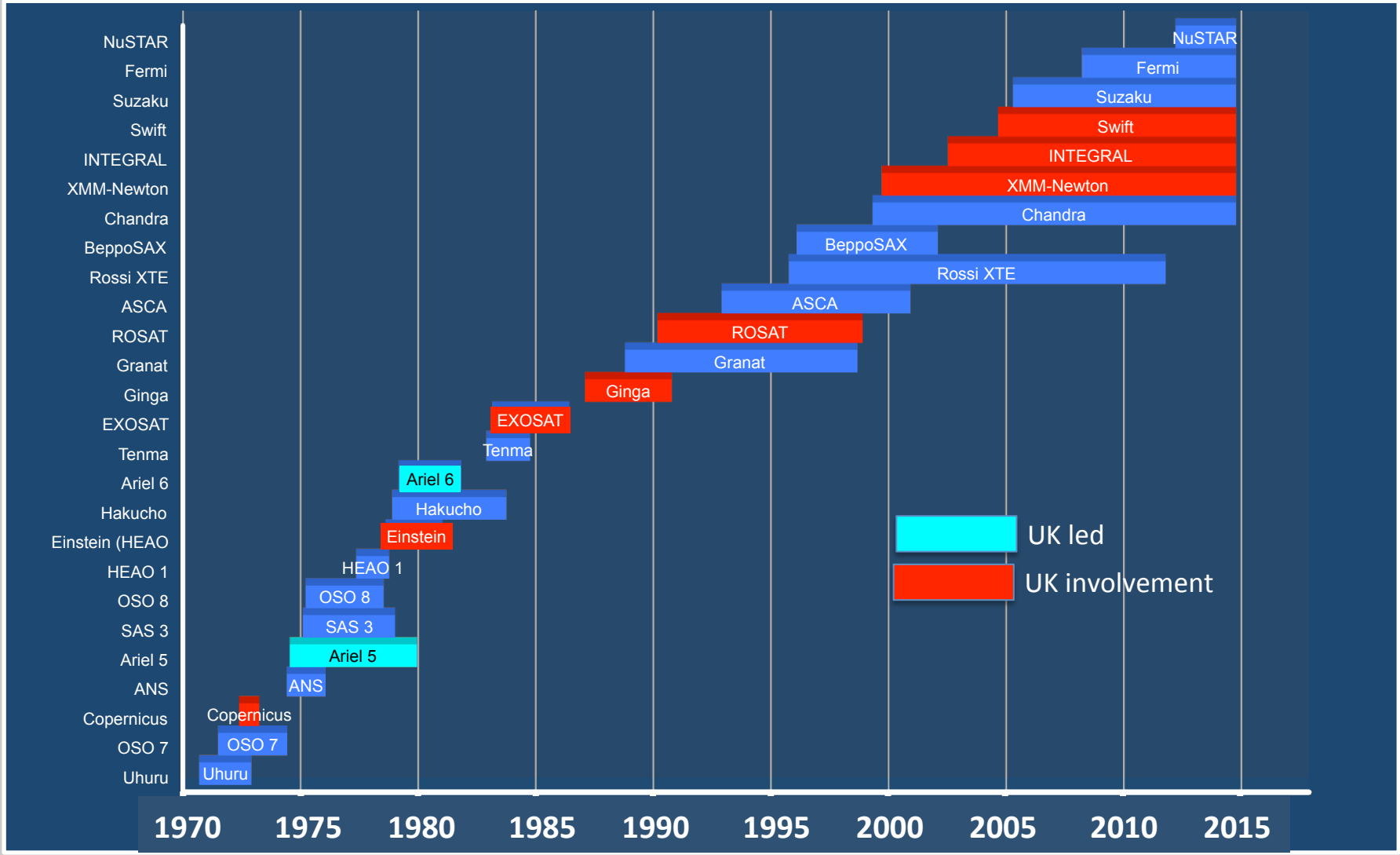


Credits: lots of material from Ken Pounds (slides from his Mykonos talk and other presentations) + Nick White's talk at the Leicester 50th anniversary meeting

Major high energy astrophysics missions since 1970

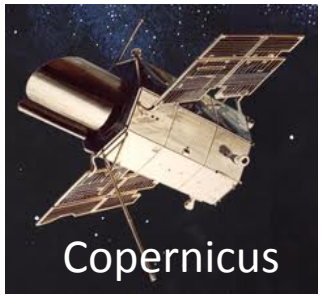


Major high energy astrophysics missions since 1970



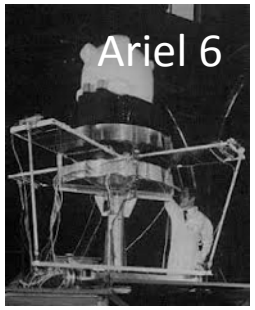
UK roles in X-ray astronomy missions

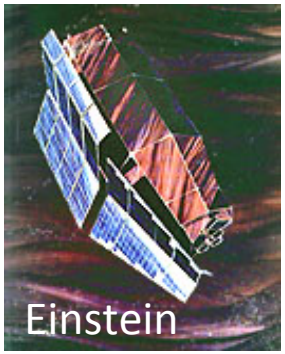

sounding rockets


Copernicus

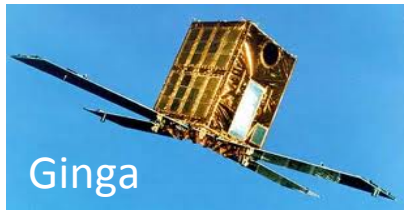

Ariel V

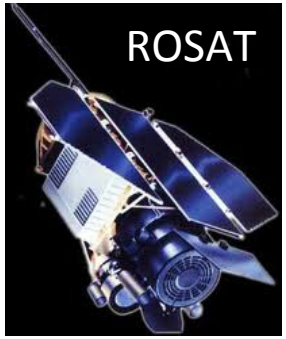

Spacelab 2


Ariel 6

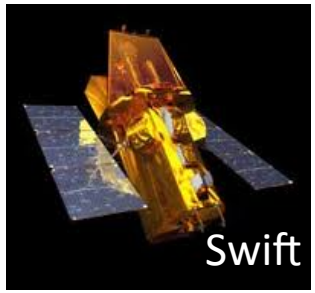

Einstein


EXOSAT


Ginga


ROSAT


XMM-Newton


Swift

University of Leicester

UCL MSSL

UNIVERSITY OF BIRMINGHAM

Imperial College London

Science & Technology Facilities Council
Rutherford Appleton Laboratory

The 1960s

Pioneering rocket experiments

Solar X-rays → cosmic X-ray studies

Beginnings at Leicester

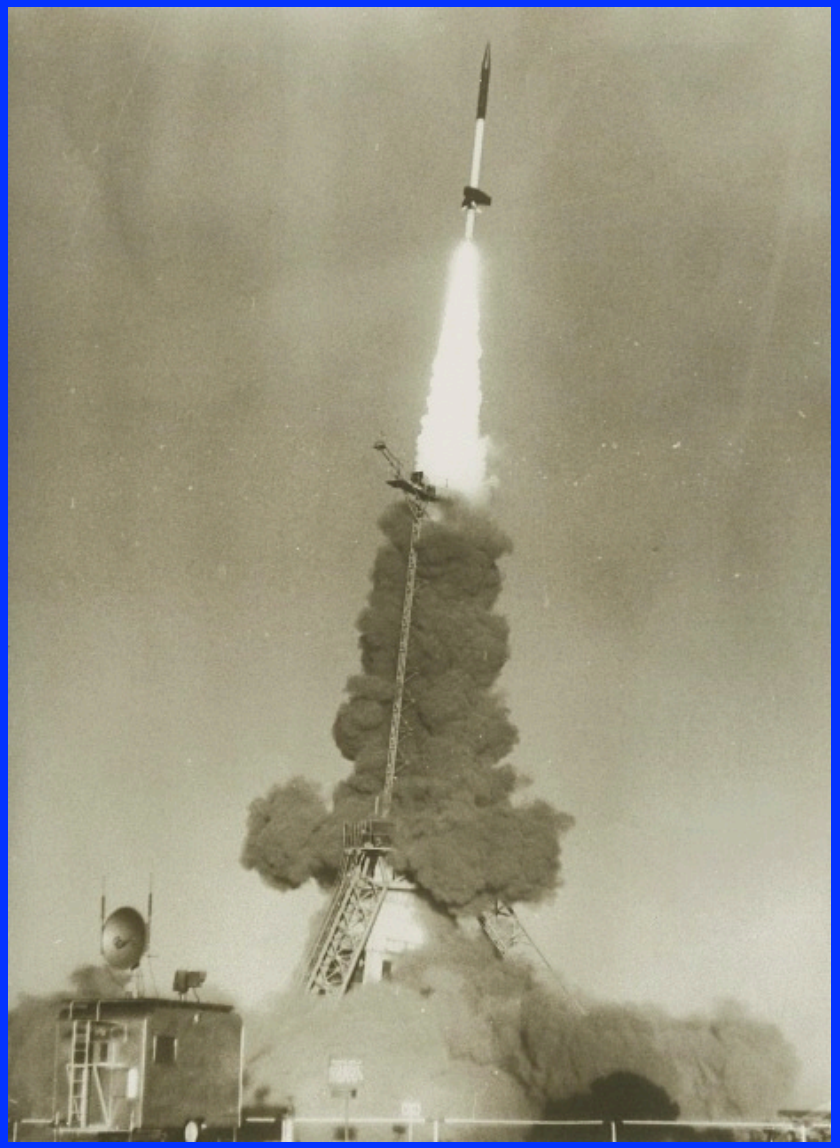
- Dawn of space age 1957
- formation of NASA 1958
- new Space Research Group at Leicester (1960)

1960 Royal Society/DSIR grant to study ‘Solar and Stellar X-radiation’

‘stellar’ source detection seemed an ambitious aim at that time with predicted fluxes a billion times fainter than the Sun

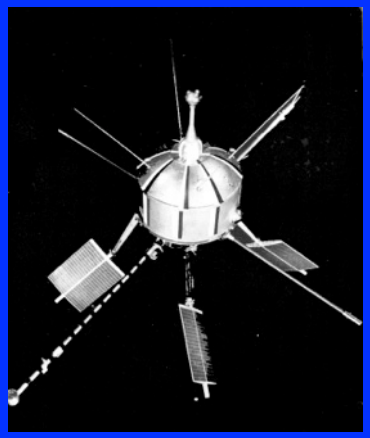
The Skylark research rocket

- first test flight at Woomera in February 1957
- payload of 150 kg to 300 km
- Sun, Moon and star-pointing versions from 1964
- PC on Sun in September 1961 (Sco X-1 also in view !)

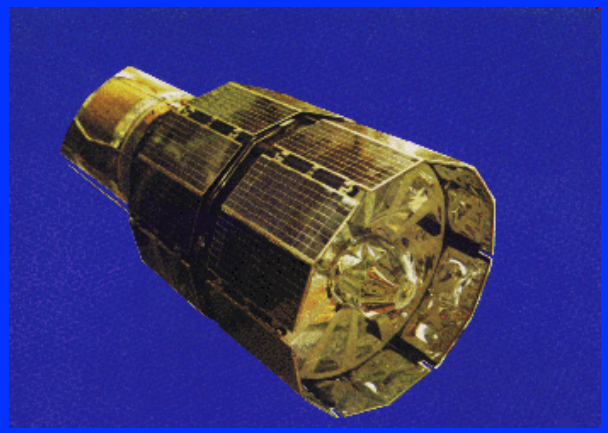


PC = proportional counter

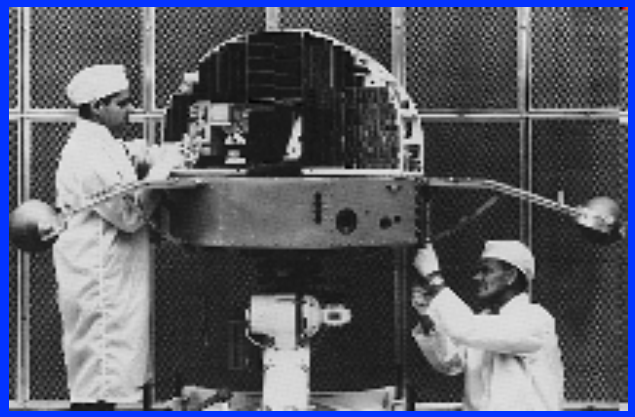
Priority in the 1960s was Solar X-ray studies



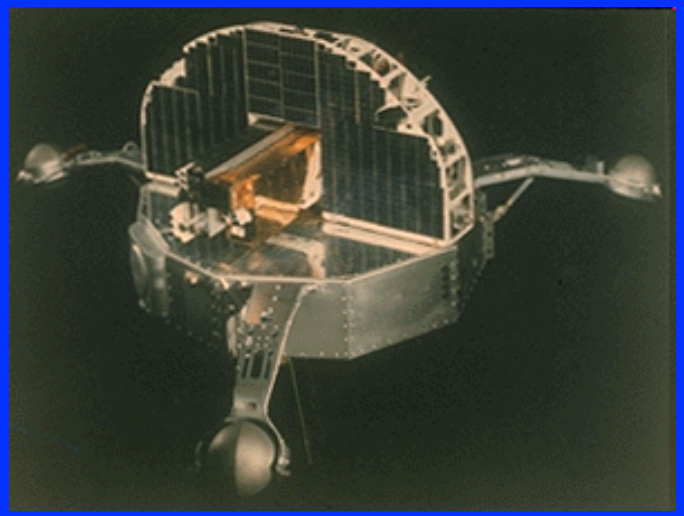
Ariel 1 (April 1962)



ESRO-2 (May 1968)



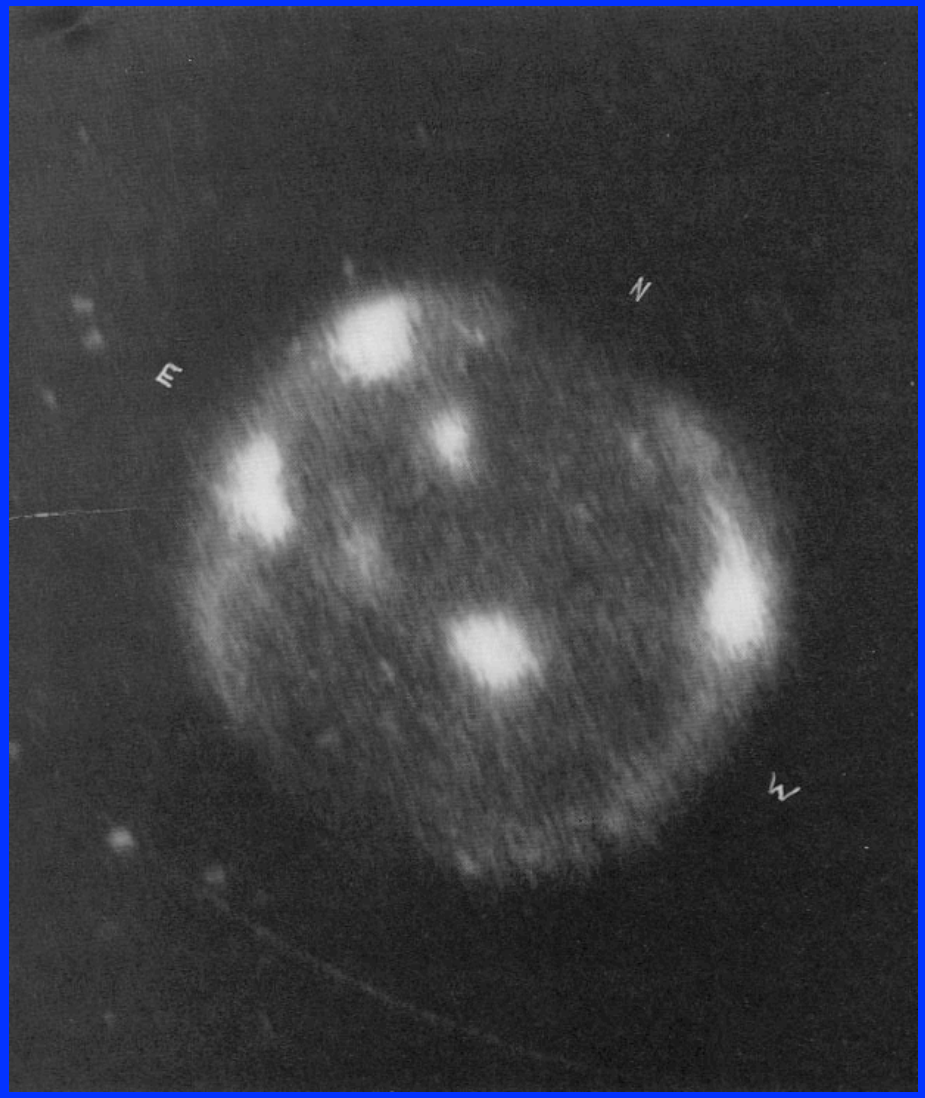
OSO-4 (October 1967)



OSO-5 (January 1969)

Solar Corona in 1964

- pin-hole camera on sun-pointing Skylark
- active regions & limb brightening



Early cosmic X-ray source studies

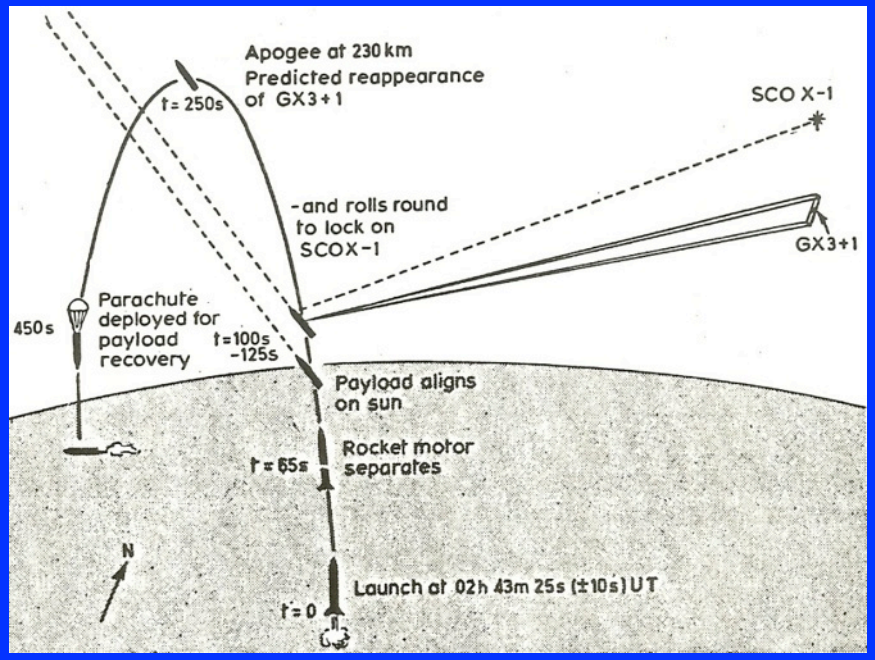
- Sco X-1 discovery in 1962 raised a new challenge, with Skylark from Woomera offering access to the southern sky

- SL 118 (10 April 1967)
  295 cm² PC. FOV 30x30 deg.
  First use of RTD/PSD background reduction
  - Cen X-2 brighter and softer than Sco X-1. Tau X-1 also detected. (Cen X-3 not seen)

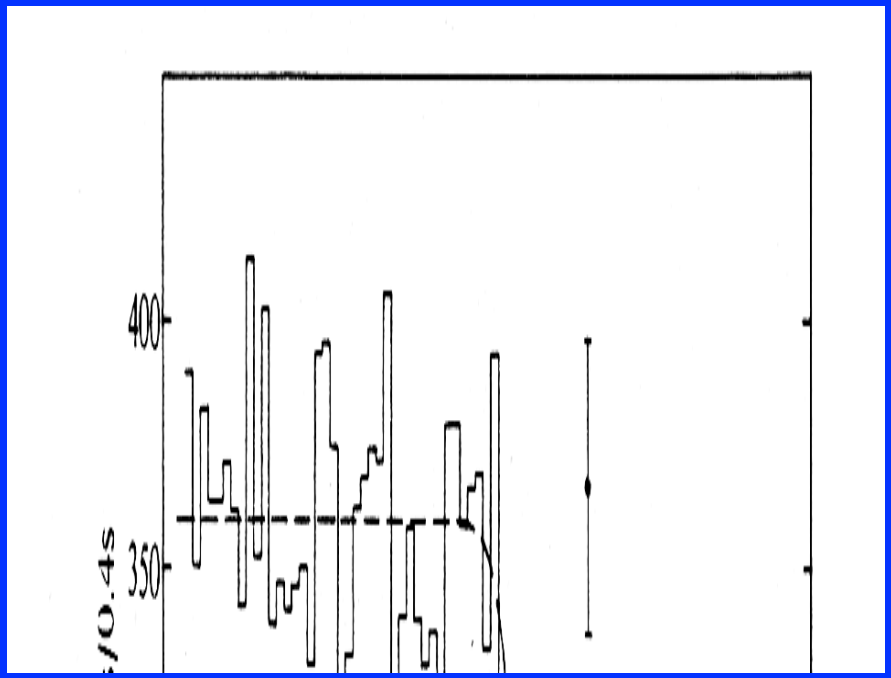
- SL 723 (July 1968) and 724 (April 1969) with largest PCs to date, 2 x 1380 cm²
  - spectra of brightest sources

Lunar occultation to pin down GX 3+1 position

- September/October 1971
- Sun-pointing vehicle, with Sco X-1 detector to fix roll angle
- Launch timing for occultation to occur when rocket at apogee



A sub-arc-sec position for GX 3+1



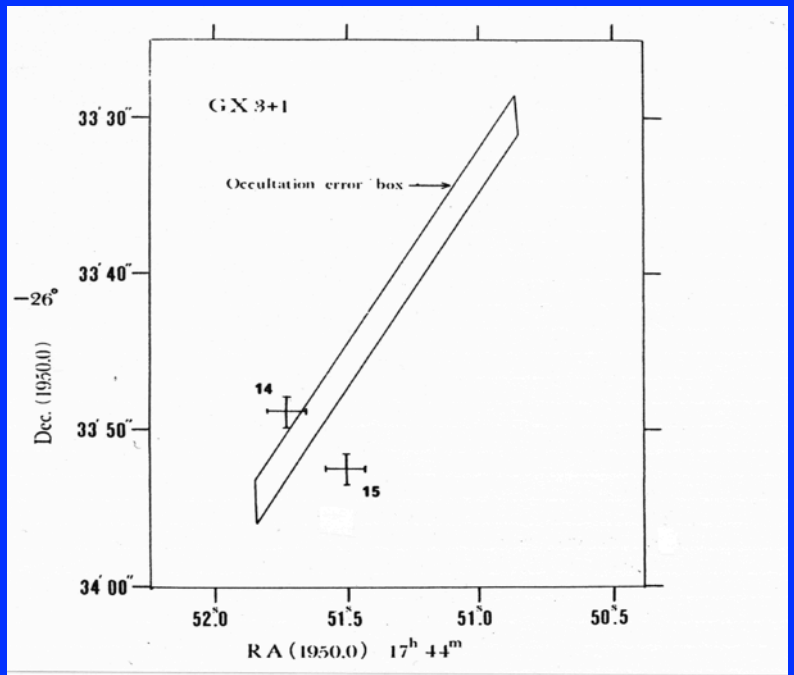


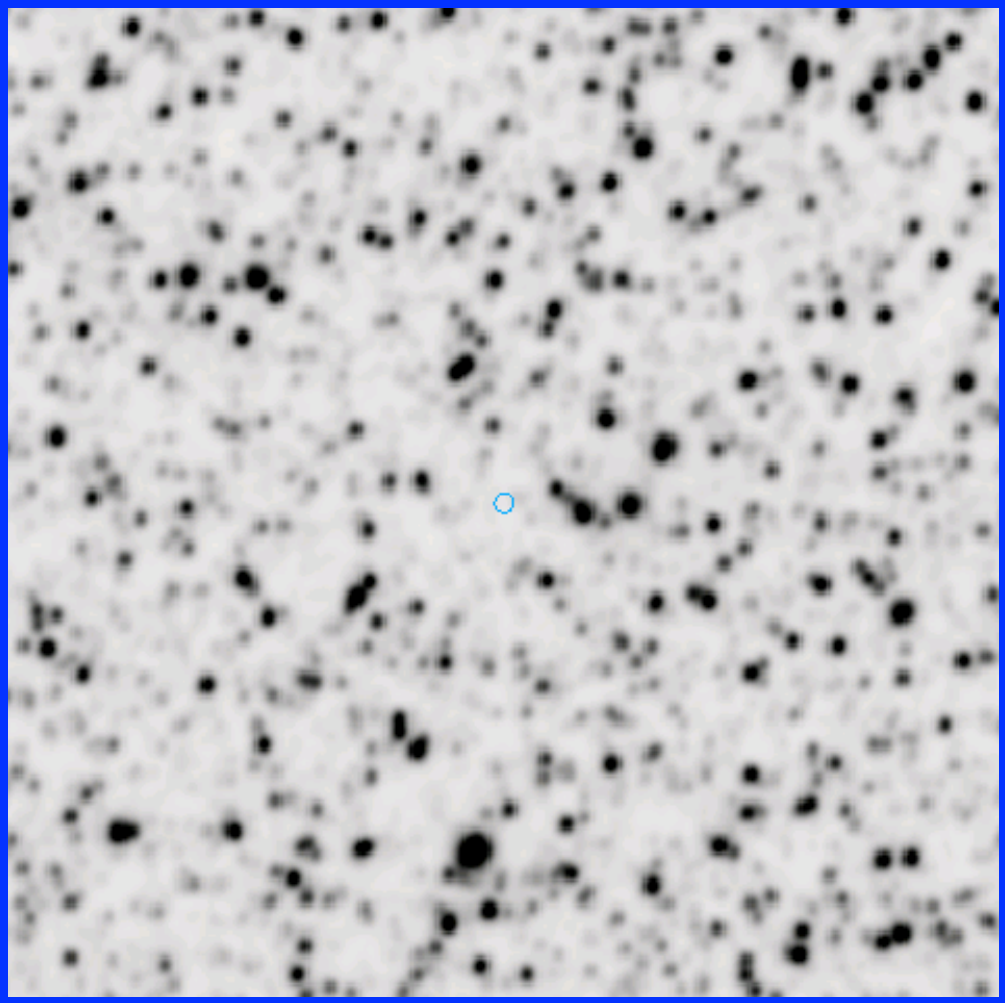
Table 2 Standard Deviations of the Limb Positions

Experiment	Timing and rocket position	Lunar ephemeris	Combined error
Leicester	0.2″	0.3″	0.4″
MSSL	3.4″	0.3″	3.4″

but no optical counterpart found

due to heavy dust obscuration in GC region

Update on GX 3+1 region: WISE IR image (3.4 μm)



Satellite era

Ariel 5 & Einstein Observatory

X-ray astronomy moves into orbit

- UHURU satellite, developed by the AS&E group, launched by NASA in 1970
  - extended exposures from minutes to months and years
  - improved detection sensitivity
  - ability to monitor transient or variable nature of many sources
- UHURU – many major discoveries and catalogued several hundred sources, including X-ray binaries and galaxy clusters

- *UK-led Ariel 5 followed into a similar low equatorial orbit 4 years later – was there anything left to discover?*

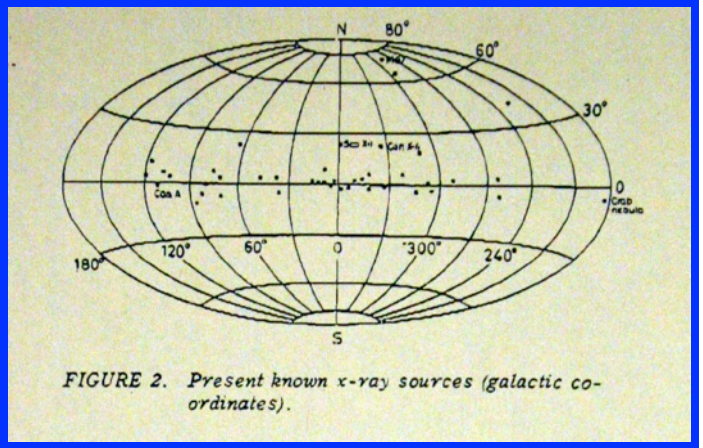


FIGURE 2. *Present known x-ray sources (galactic co-ordinates).*

By the end of the 1960s: ~33 secure sources of which 1 extragalactic (M87)

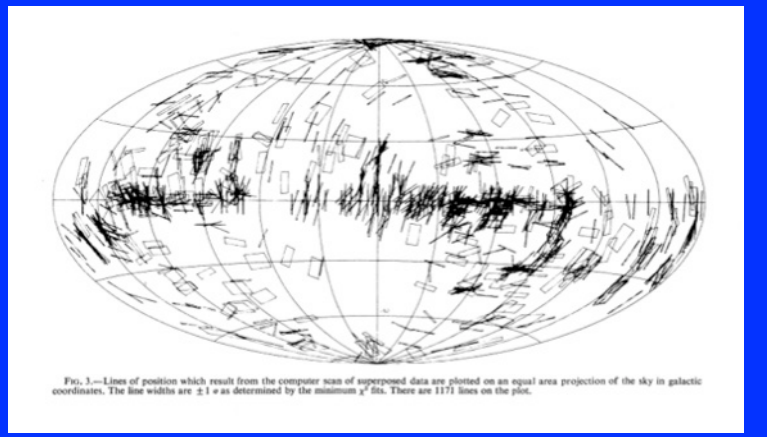


FIG. 3.—Lines of position which result from the computer scan of superposed data are plotted on an equal area projection of the sky in galactic coordinates. The line widths are $\pm 1\,\sigma$ as determined by the minimum χ^2 fits. There are 1171 lines on the plot.

First Uhuru catalogue

Ariel 5 satellite

UK – US collaboration

Scout B-1 launch 15 October 1974

- 129 kg S/C into equatorial 500 km LEO
  10 rpm spin with axis control by gas jets, later by magnetorquer
- operated for 5.5 years to re-entry in March 1980

A. Rotation modulation collimator (UCL/MSSL)

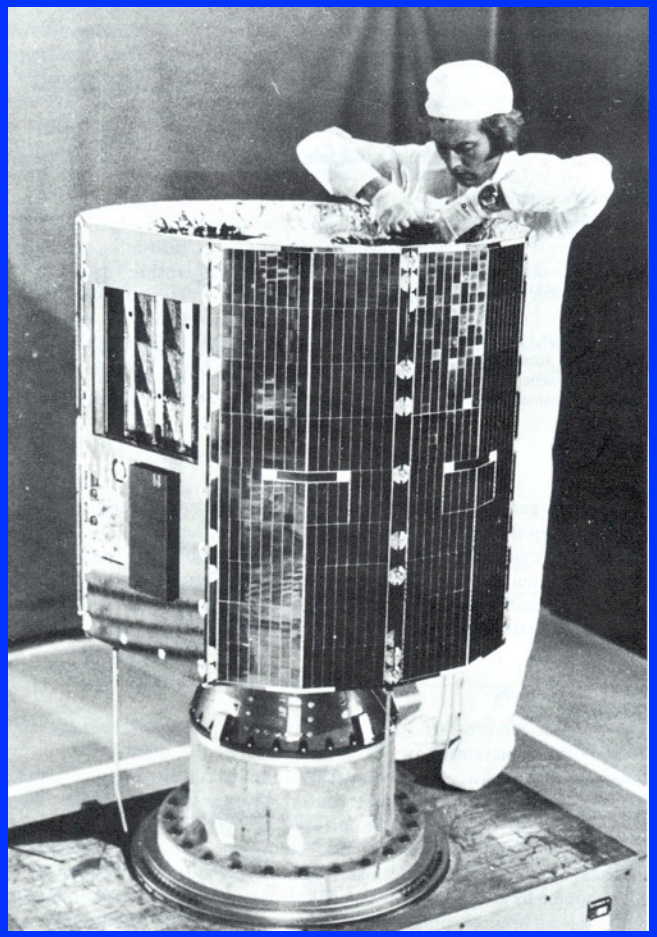
B. Sky survey Instrument (Leicester)

C. Proportional counter spectrometer (UCL/MSSL)

D. Bragg Polarimeter (Leicester)

F. Hard X-ray scintillation counter (Imperial)

G. All sky monitor (Goddard)



Ariel 5 Sky Survey Instrument (SSI)

PC of 145 cm² (LE) and 290 cm² (HE)
0.75 x 10.5 ^{0} FOV, inclined at 65 ^{0} to spin plane

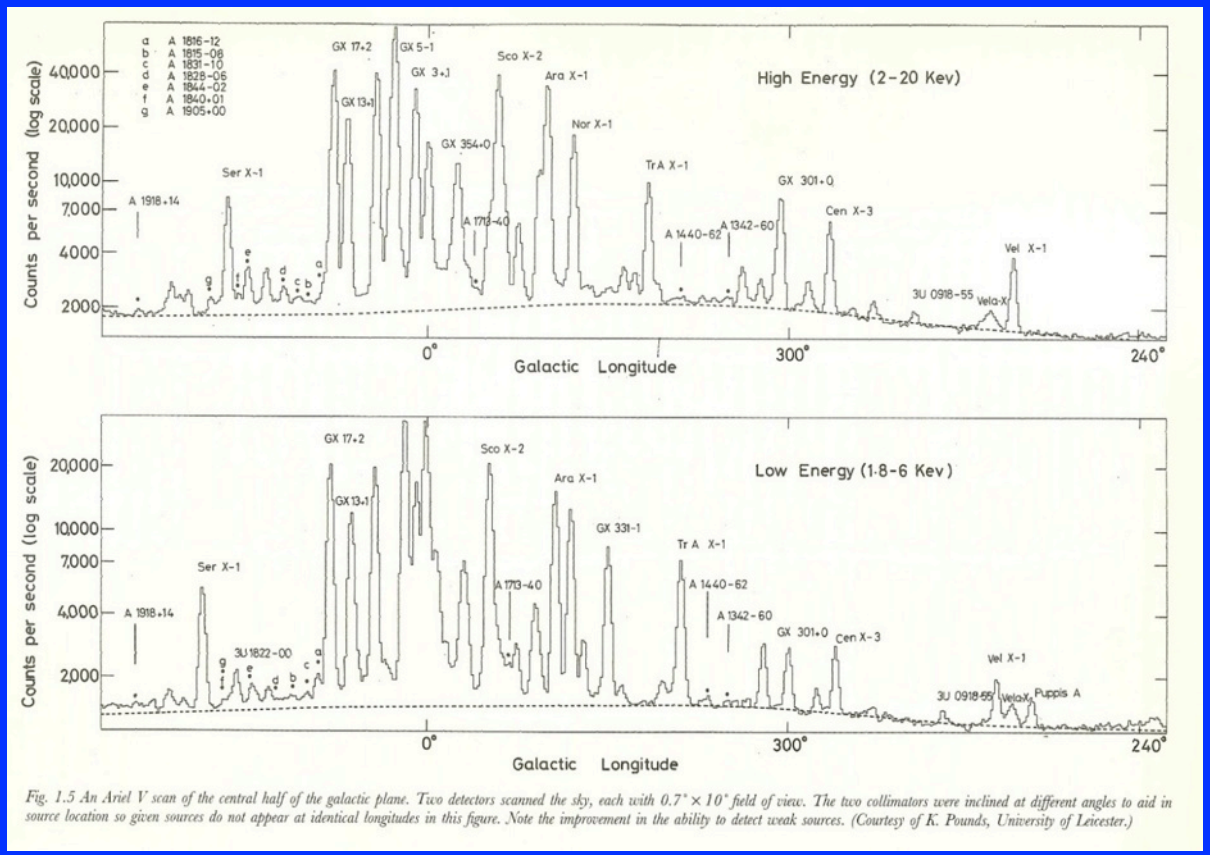


Fig. 1.5 An Ariel V scan of the central half of the galactic plane. Two detectors scanned the sky, each with 0.7° × 10° field of view. The two collimators were inclined at different angles to aid in source location so given sources do not appear at identical longitudes in this figure. Note the improvement in the ability to detect weak sources. (Courtesy of K. Pounds, University of Leicester.)

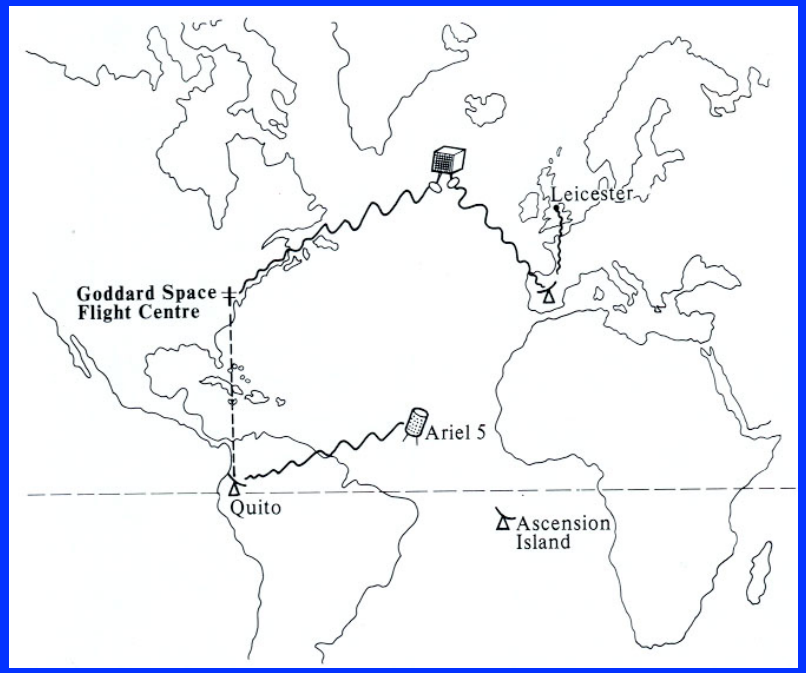
scanning instrument
new survey of the sky

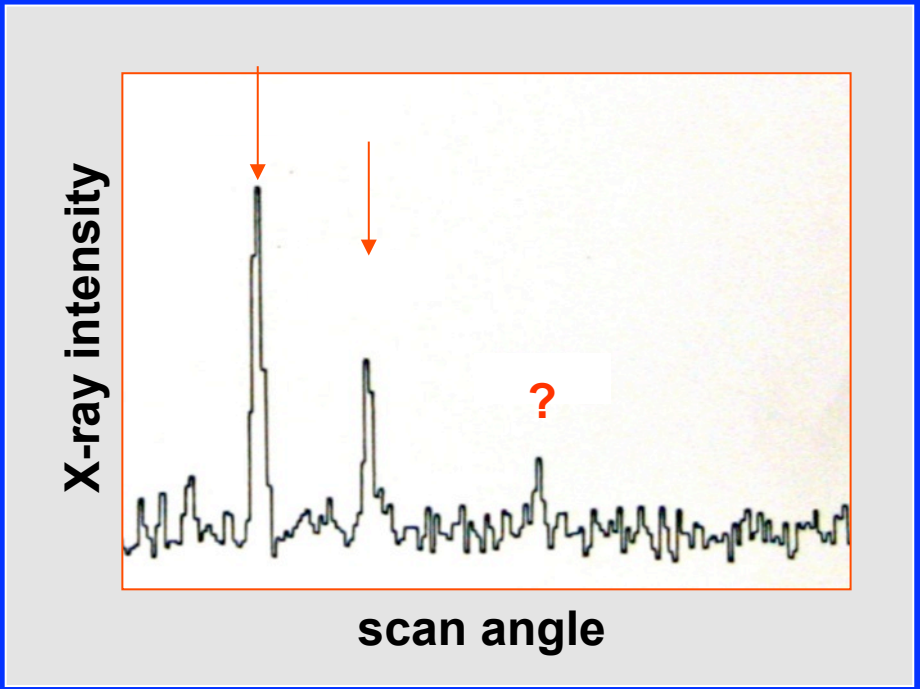
extensive monitoring
of the Galactic plane

search for transients
and other variables

- quasi real-time
  data delivery to
  Leicester

Ariel 5 SSI data





- 6 quick-look orbits data in near real-time
- SSI data stored in 1024 (16 bit) words over each orbit
  - 30 kB per day [~40 tweets]
- data reduction on PDP-8 computer on to strip chart, labelled with known X-ray sources and candidate objects
- quick-look data examined by eye every day to search for transients etc.

Martin Turner in the Ariel 5 Data Terminal Room @ Leicester, circa 1975

- PDP-8 computer was programmed using paper tape
  … but we did have a pen plotter
- Our PDP-8 machine was eventually largest installation in UK

X-ray transient discovery

letters to nature

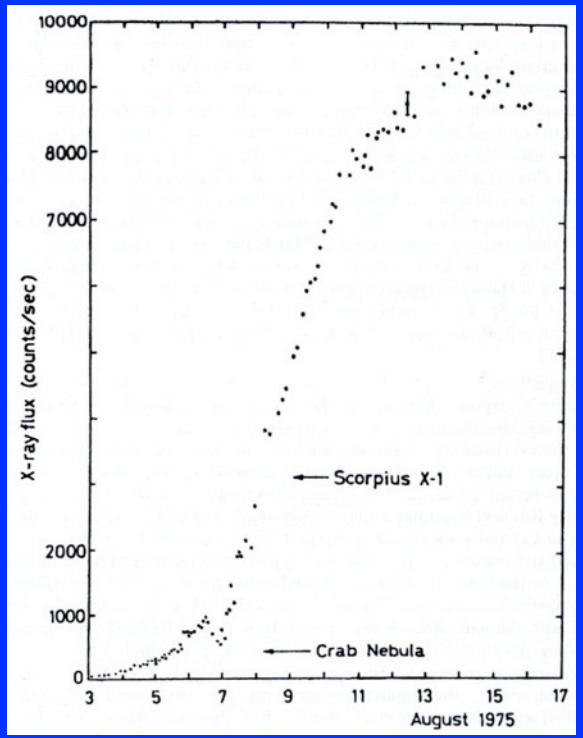
Nature **257**, 656 - 657 (23 October 1975); doi:10.1038/257656a0

Discovery of powerful transient X-ray source A0620—00 with Ariel V Sky Survey Experiment

MARTIN ELVIS, C. G. PAGE, K. A. POUNDS, M. J. RICKETTS & M. J. L. TURNER

X-ray Astronomy Group, Department of Physics, University of Leicester, Leicester, UK

ON August 3 a faint new X-ray source was discovered (at 15 Ariel counts s^{-1}) near the boundary of the Monoceros and Orion constellations and 6° from the galactic plane, during routine monitoring of the Milky Way with the Ariel V Sky Survey Experiment (SSE). During the following week, the source—designated A0620—00—increased rapidly in intensity to become the brightest in the sky (at 2–18 keV). The X-ray light curve from continued observation with the SSE to August 16 is shown in Fig. 1. The ordinate is in Ariel counts s^{-1} and for comparison, the corresponding count rates for the Crab Nebula and Sco X-1 are 400 s^{-1} and 3,200 s^{-1}, respectively. The precursor peak on August 6 is real and is qualitatively similar to the feature seen[1] in the rise to maximum intensity of the earlier Ariel transient A1524—62. Subsequent observations of A0620—00 with the Ariel V experiments pointing along the spin axis of the spacecraft have shown the intensity to have remained very high at least until August 27.



A0620-00

- brightest ever cosmic X-ray source after 2 weeks
- European Astronomy Society meeting 3 days after discovery – in Leicester
- attracted alarming headlines

Great balls of fire!

THE earth is under bombardment from outer space.

An enormous ball of fiery gas, bigger and hotter than the sun, is firing off fusilades of X-rays.

But the head of the team of scientisets from Leicester University who discovered it said: "We don't think that it's anything to do with little green men."

Harmful

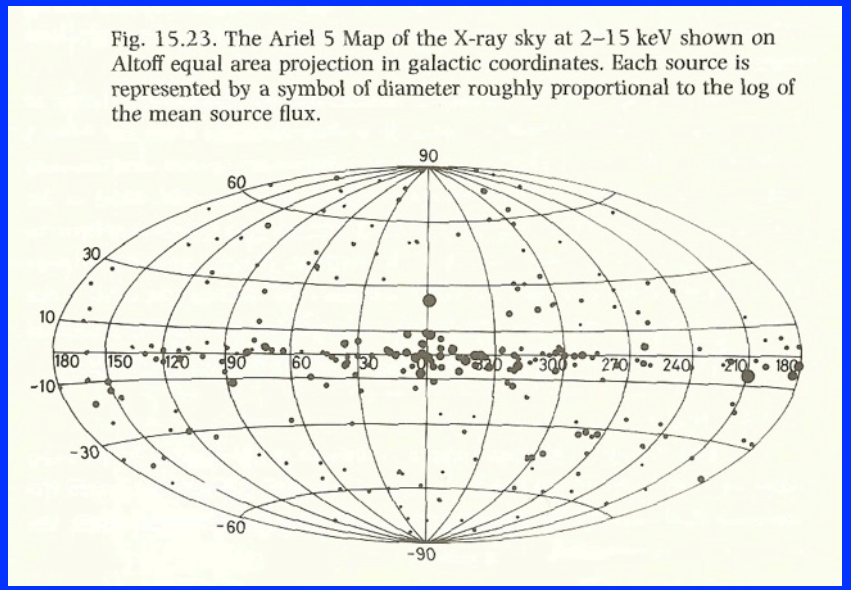
Prof Ken Pounds added: "As far as we're concerned, this thing has a natural explanation."

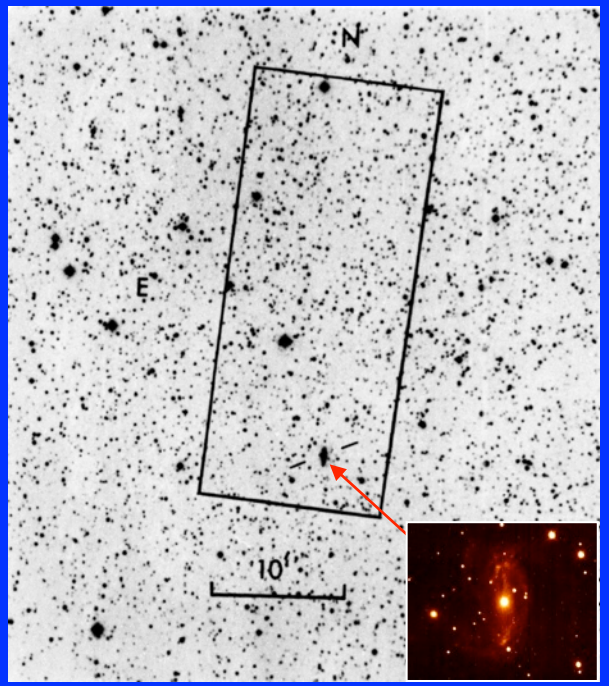
Earth is protected from the harmful effects of X-rays by the atmosphere. But the bombardment could affect short-wave radio reception.

Prof. Pounds said his team did not know if the ball was moving. But it is so far away that it would take at least 500 years to reach us, even if it travelled at the speed of light.

Ariel 5 SSI sky survey legacies

- Ariel 5 SSI catalogued almost 300 cosmic X-ray sources in its 5+ years of operations
- Confirmation of Seyfert galaxies as luminous X-ray sources





Seyfert MCG-8-11-11

Fundamental properties of the brightest Galactic X-ray sources remained elusive

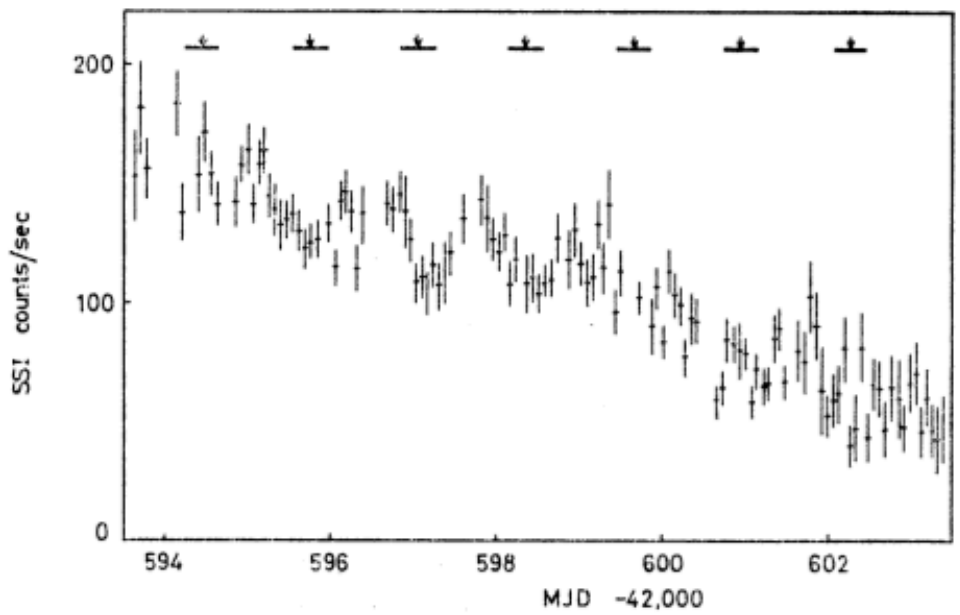


FIG. 1. *The SSI light curve of Aql X-1 between 1975 June 30 and July 9. The points are corrected fluxes in the SSI HE (2–18 keV) system; error bars are ±1 σ. The arrows show the predicted 1·3-day flux minima from the full analysis of the data.*

Aql X-1: claimed 1.3 day period

correct period is 0.79d
also probable msec pulsar

First detection of Fe line in Perseus cluster

Mitchell+ 1976
Ariel 5 Expt C

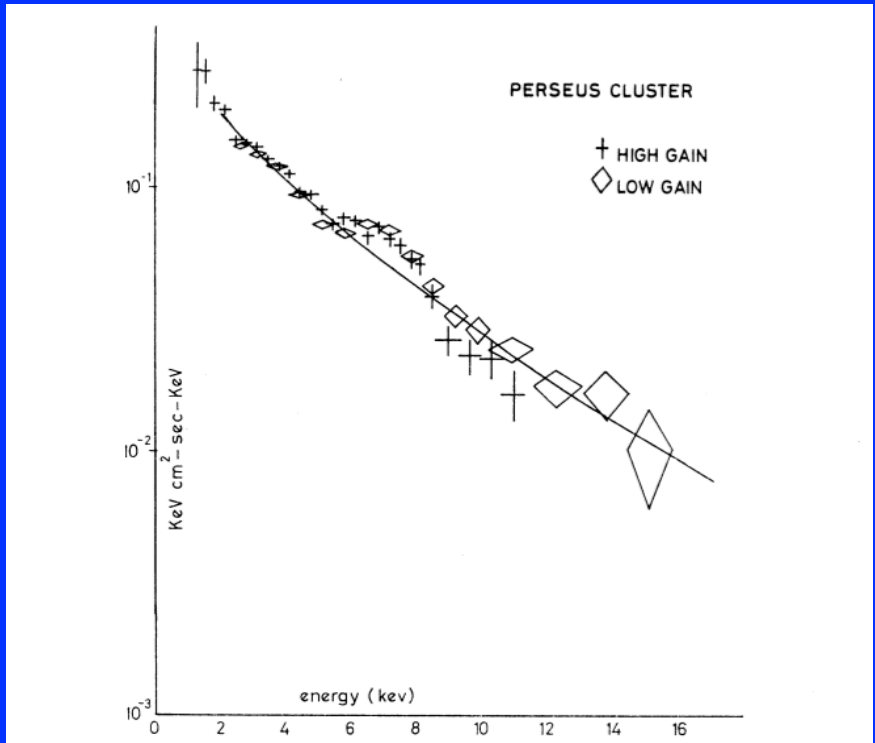
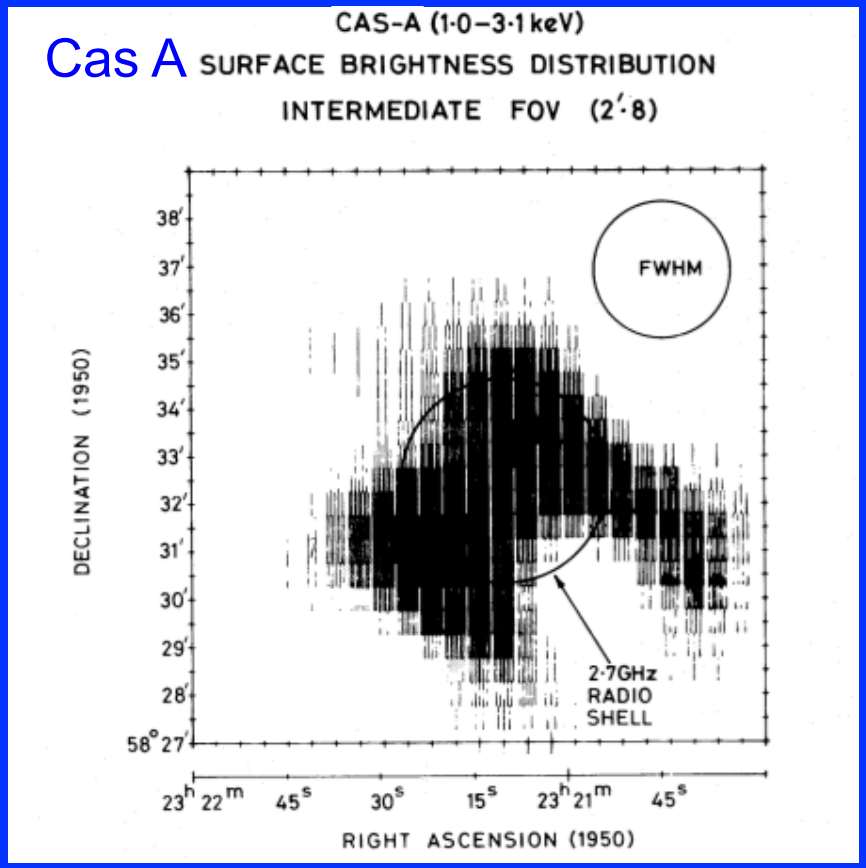


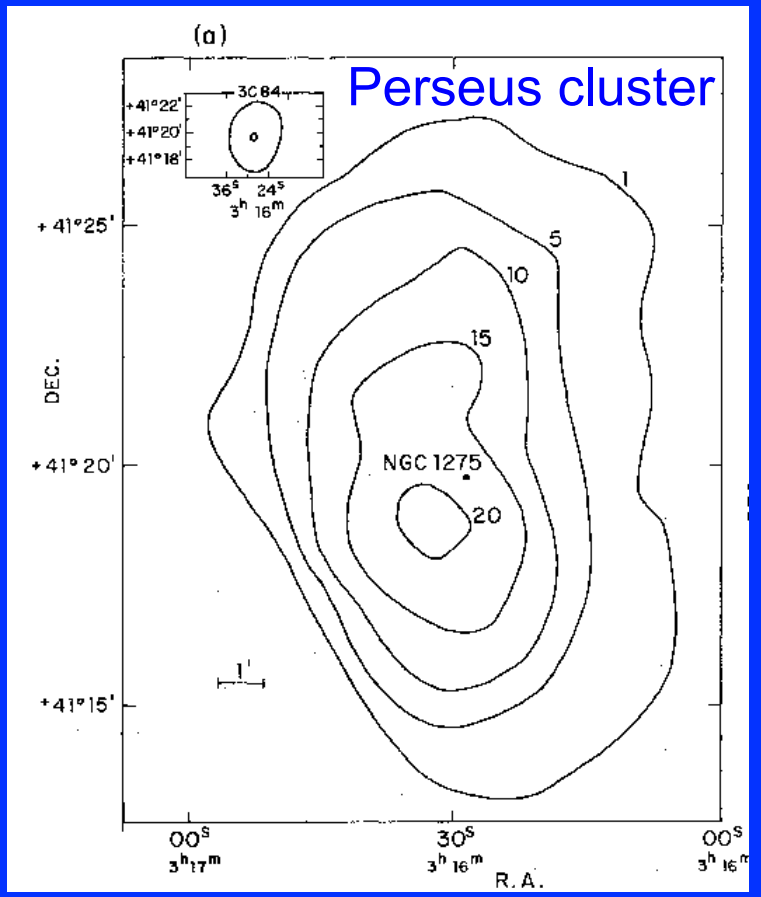
FIG. 1. *The Ariel 5 X-ray spectrum of the Perseus Cluster in the energy range 1·3–16 keV. The two detector gain modes are selected by ground command. The solid line represents the computed continuous spectrum from a Gull & Northover adiabatic gas sphere with central temperature (T(o)) 32 keV and* $T_\infty = -4$ *keV. The emission feature at around 7 keV is visible in both gain modes.*

Copernicus X-ray images

OAO-3: US mission with UK collaboration



Cas A

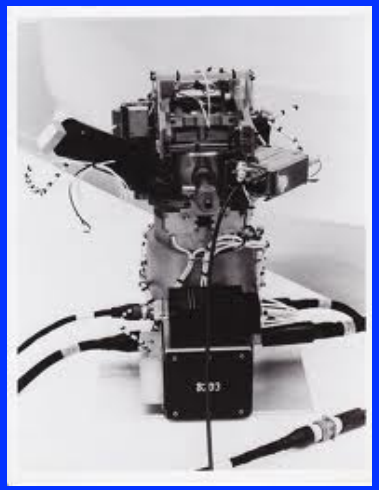


Charles, Culhane & Fabian 1977

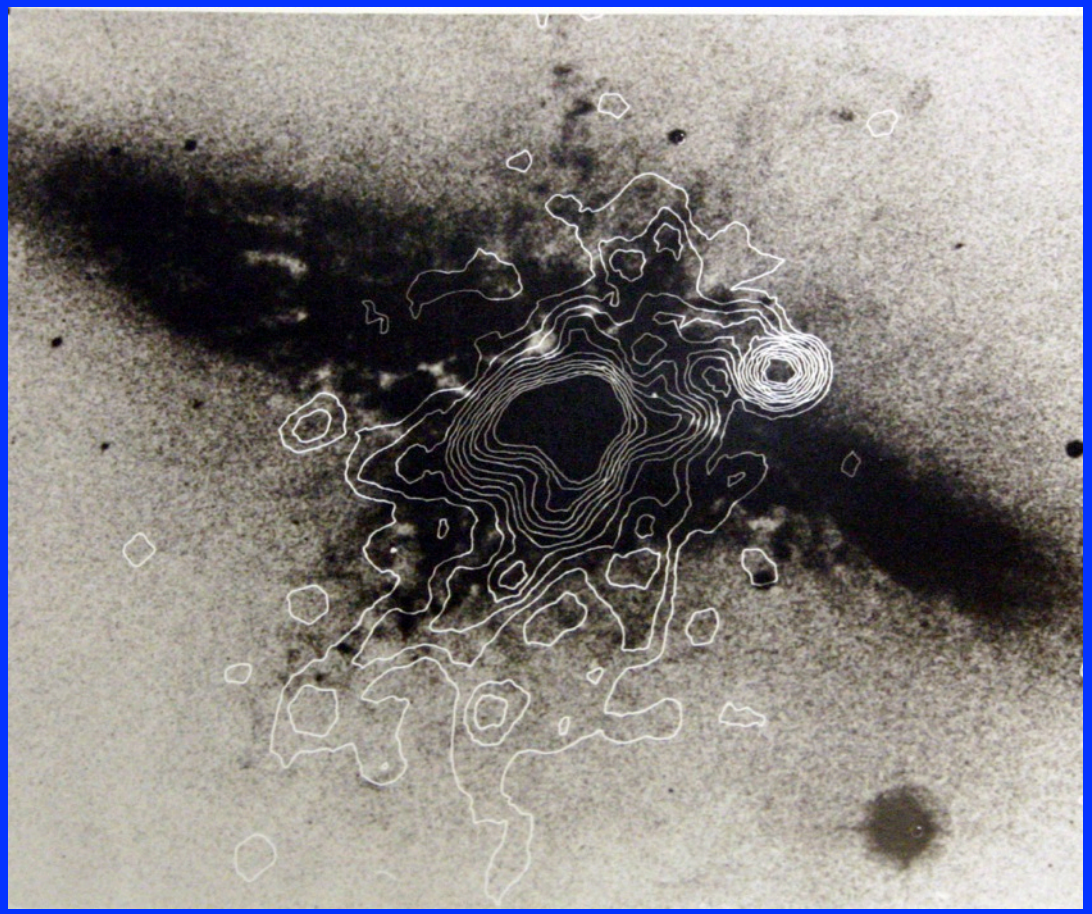
Wolff + 1976

Einstein Observatory

- NASA's Einstein Observatory launched in 1979
- Arcsecond imaging for the first time
- Focal plane instruments: IPC and HRI
- Leicester played a role in the development of the HRI
  - provided opportunities for Leicester postgrads and postdocs to visit CfA



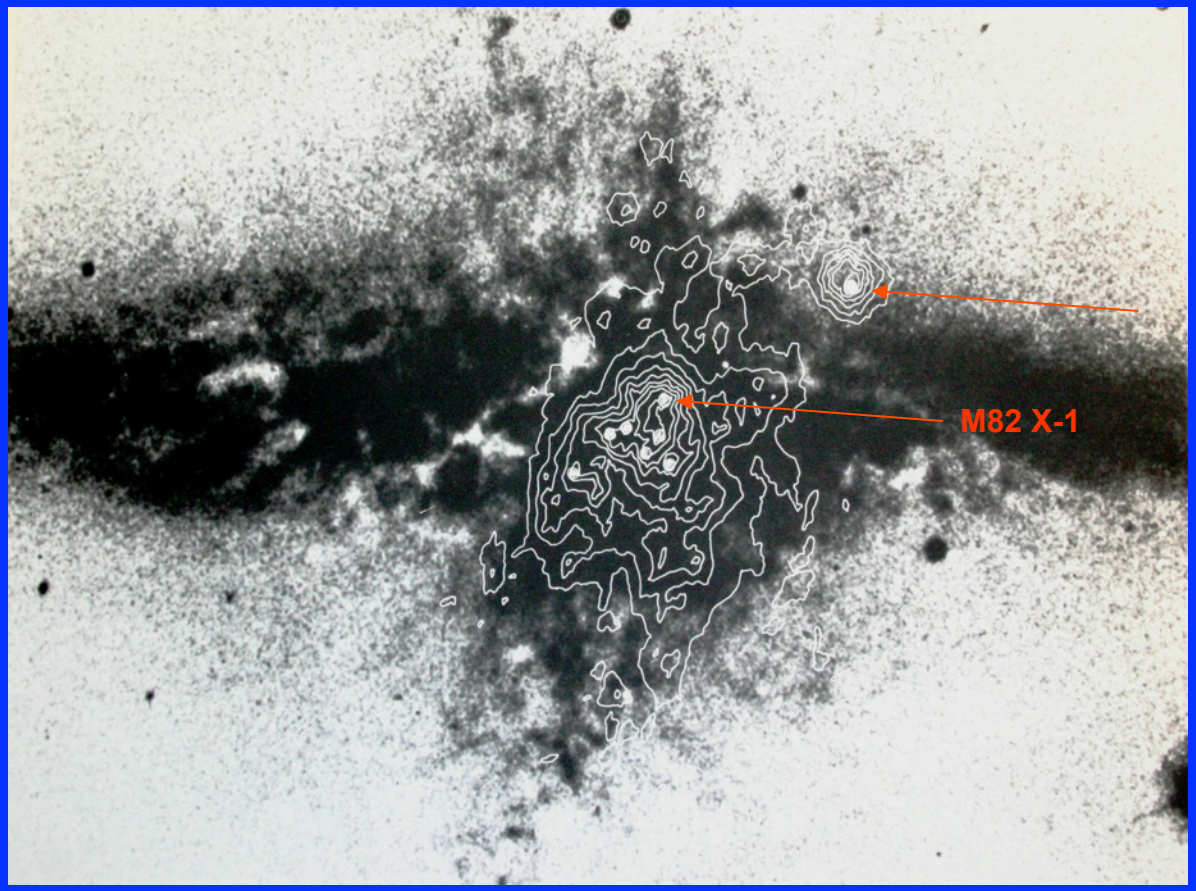
M82 studies with Einstein HRI



Watson, Stanger & Griffiths 1981

M82: extended emission from Einstein HRI

first definitive evidence of hot gas halos in starburst galaxies



ULX populations in starburst galaxies

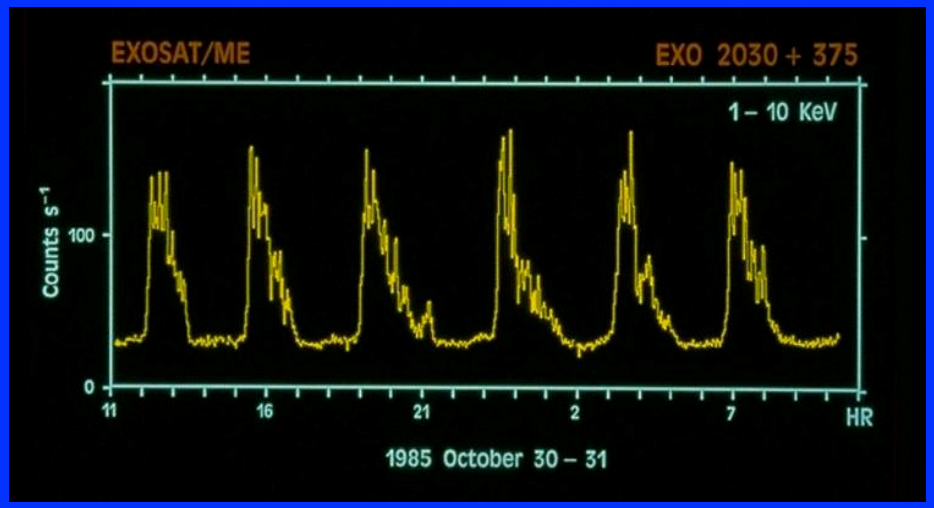
Satellite era

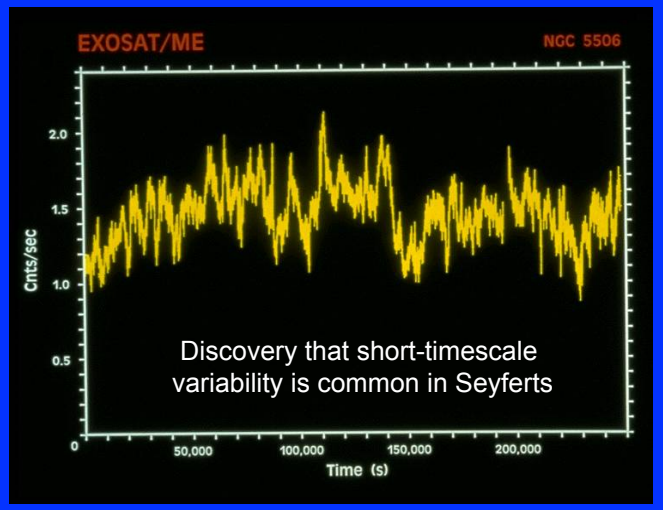
EXOSAT & Ginga

EXOSAT (1983-86)

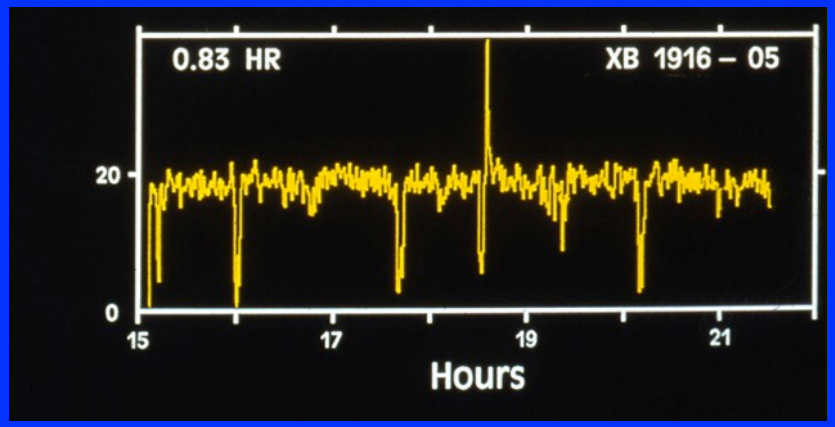
- ESA's first X-ray mission
- ME detector array from Leicester/MSSL
  - provided some of the best hard X-ray observations of the sky observations ever obtained with non-imaging instruments
- soft X-ray imaging with EXOSAT CMA
- first X-ray satellite in deep space orbit
  - real-time operations and continuous monitoring
  - first dedicated guest observer facility

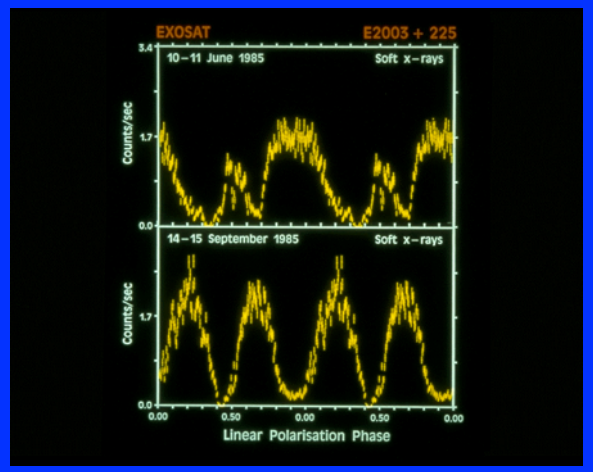
EXOSAT





Long-term monitoring of Galactic and extragalactic sources with EXOSAT ME

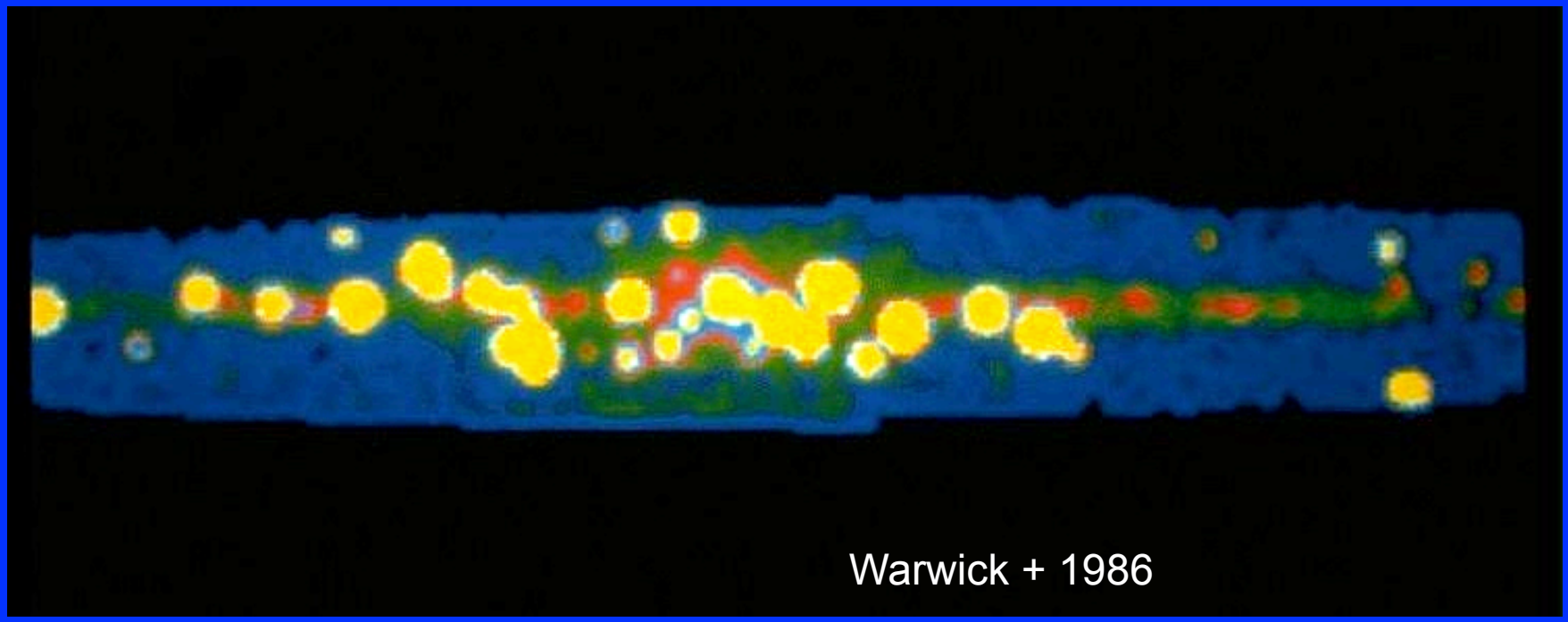




"Dippers" - X-ray signature of LMXB at last

orbital/spin modulation of mCVs

EXOSAT

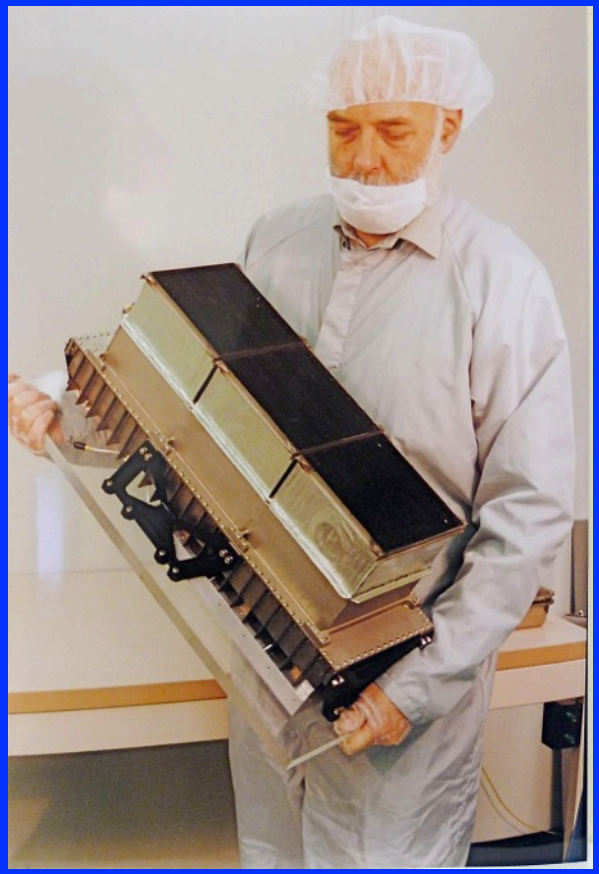


EXOSAT ME mapping of the Galactic plane: discovery of the X-ray Galactic Ridge - made possible by the narrow FOV of the EXOSAT ME collimators

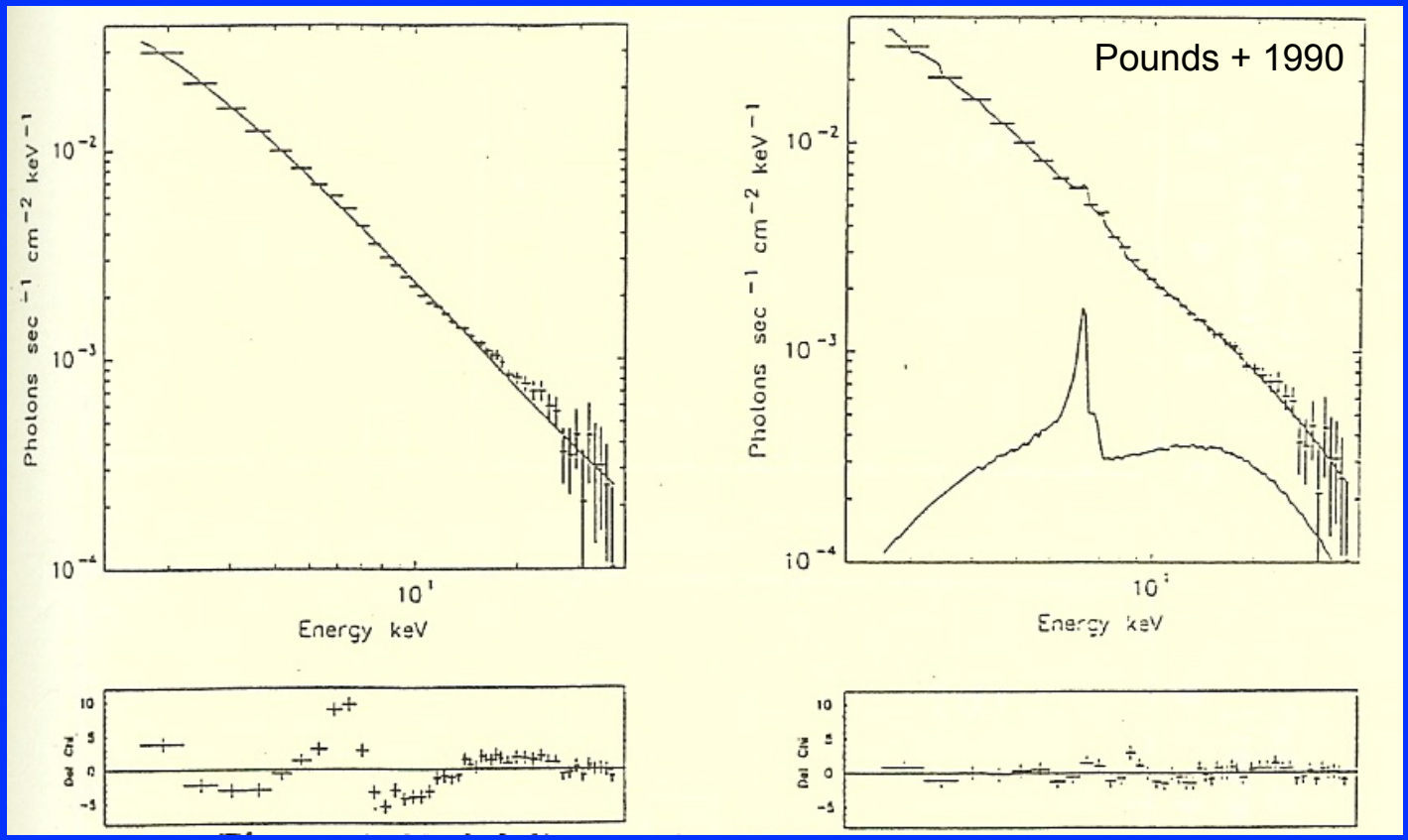
Ginga (1987-91)

Japanese mission + UK

- 4000 cm² LAC developed by a joint Leicester-Japan team
- powerful instrument for timing and broadband spectra



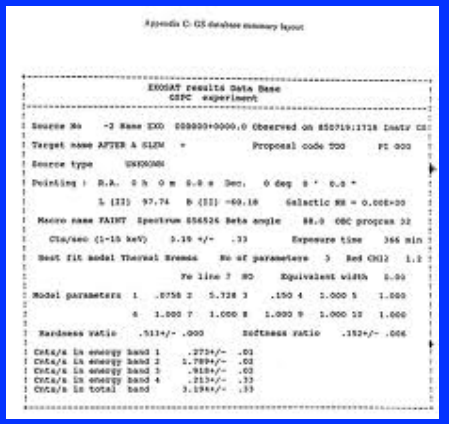
GINGA



Discovery of ‘reflection’ in AGN using stacked spectra from 10 Seyfert observations, hints that Fe K lines were broad

EXOSAT Legacies

- EXOSAT Results Database: online data archive released 1989
  - processed “science quality” data products
  - database system to provide infrastructure and access / manipulation tools
  - online access via “SPAN” (Space Physics Analysis Network – built on DECnet)
  - cross-correlation databases
- transferred to GSFC in 1990
  - foundations of NASA’s HEASARC
- Provided key model for future projects
- Encapsulated many ideas of the Virtual Observatory



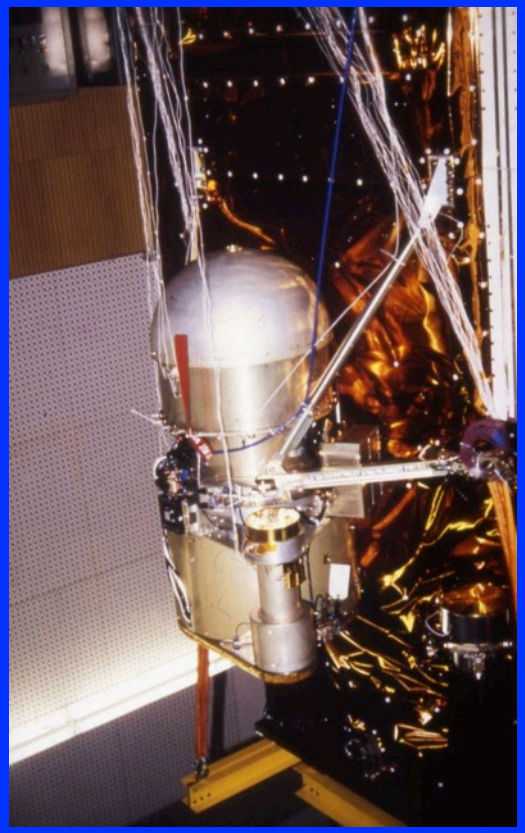
- EXOSAT team: an excellent training ground
  - Lorella Angellini, Paul Barr, Lucio Chiappetti, Thierry Courvoisier, Paolo Giommi, Manfred Gottwald, Frank Haberl, Julian Osborne, Arvind Parmar, Andy Pollock, Luigi Stella, Gianpiero Tagliaferri, Michiel van der Klis (+ Nick White of course)

Satellite era

ROSAT, XMM-Newton & Swift

ROSAT (1990-97)

German mission
UK & US collaboration



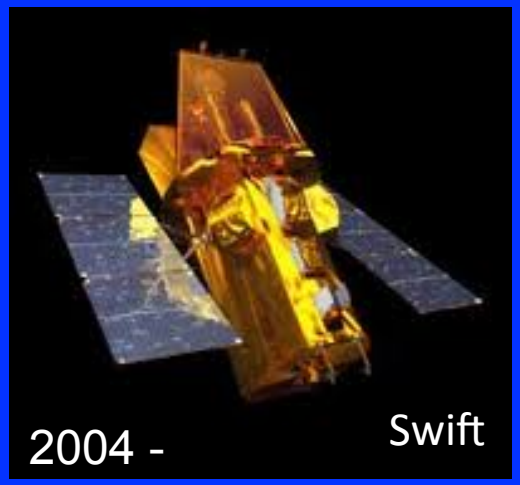
5 UK groups contributed to the ROSAT WFC: Leicester, MSSL, Birmingham, Imperial College, RAL

WFC carried out the first sky survey at extreme UV wavelengths during 1990/91

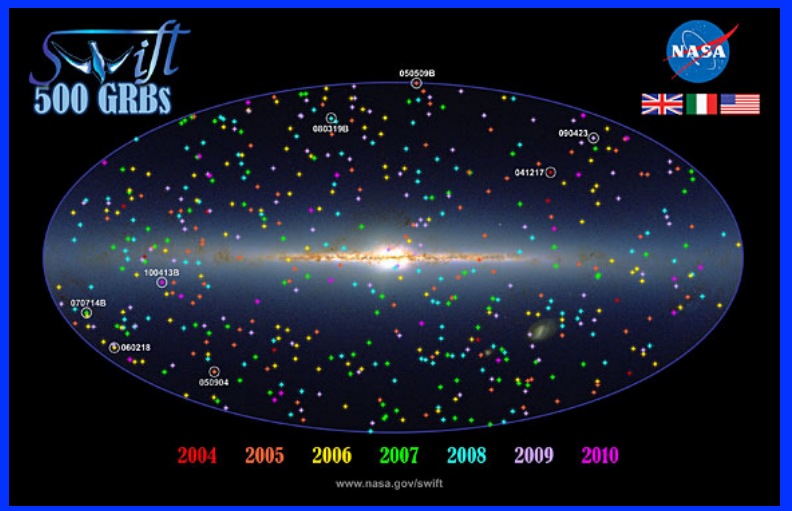
Current missions

Leicester, MSSL, Birmingham: EPIC, OM, RGS + SSC

XMM First Light Press Conference

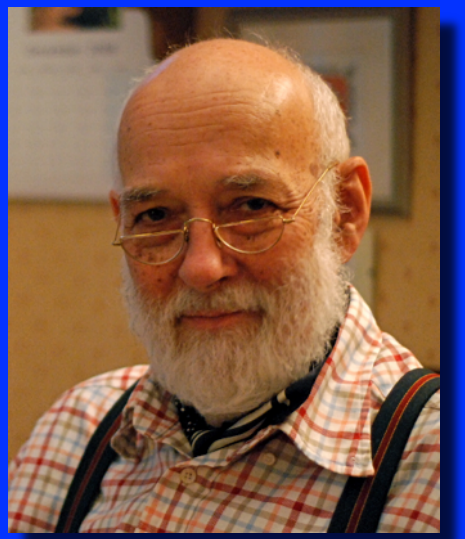


Leicester, MSSL: XRT, UVOT + data centre



500 GRB milestone passed in 2010

Real credit due to …



Is the pioneering spirit still with us?

end