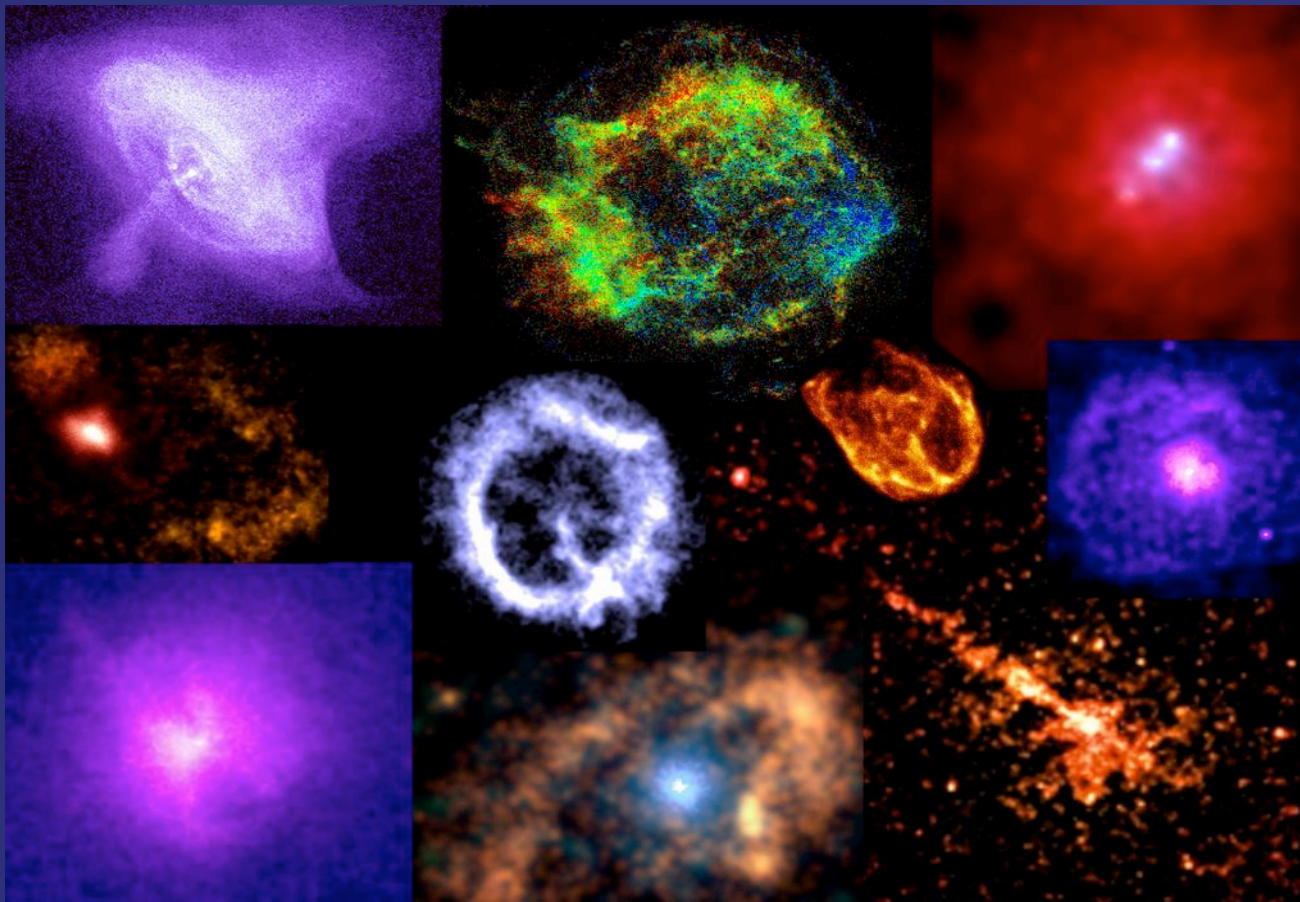
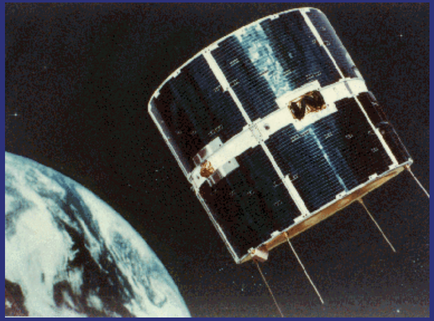
Highlights from ESA's High-Energy Astronomy Missions



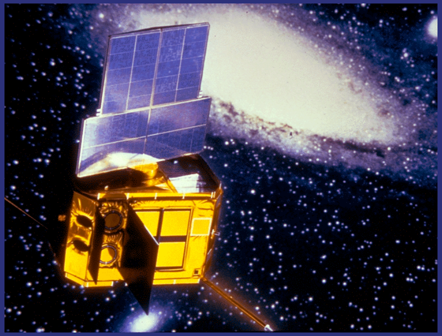
Introduction

- ESA's trailblazers – COS-B and EXOSAT
- ESA's current high-energy missions – Integral and XMM-Newton
- The future – Cosmic Vision

INTEGRAL 2002 ->



COS-B 1975 -1982

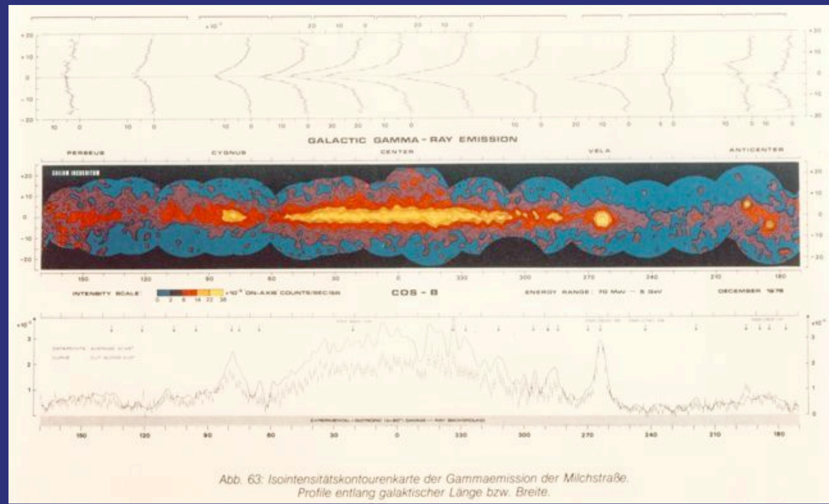


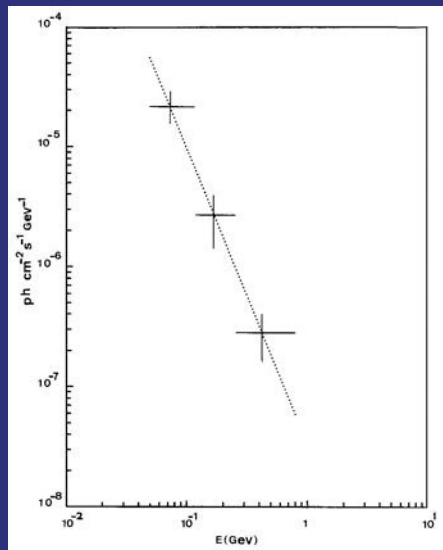
EXOSAT 1983 -1986

XMM-Newton 1999 ->

COS-B

- High-Energy astronomy started in ESA in 1975 with the launch of COS-B which was operated for >6 years.
- A modest 300 kg spacecraft with a single gamma-ray spark chamber and co-aligned X-ray proportional counter.
- Major results were:
  - 2CG catalogue containing around 25 gamma-ray sources
  - First full gamma-ray maps of the galactic plane
  - The first gamma-ray AGN was detected (3C 273)
  - Geminga positioned to 0.25 degrees allowing counterpart searches

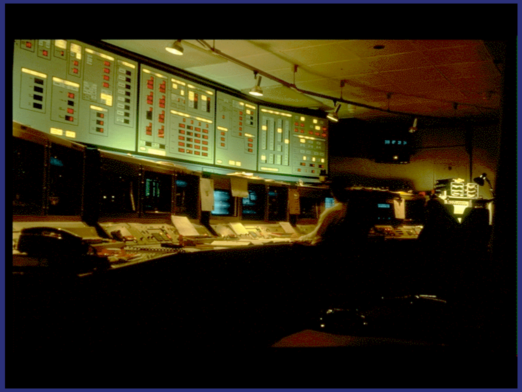




The gamma-ray spectrum of 3C 273 obtained by COS-B (Bignami et al, 1981)

EXOSAT

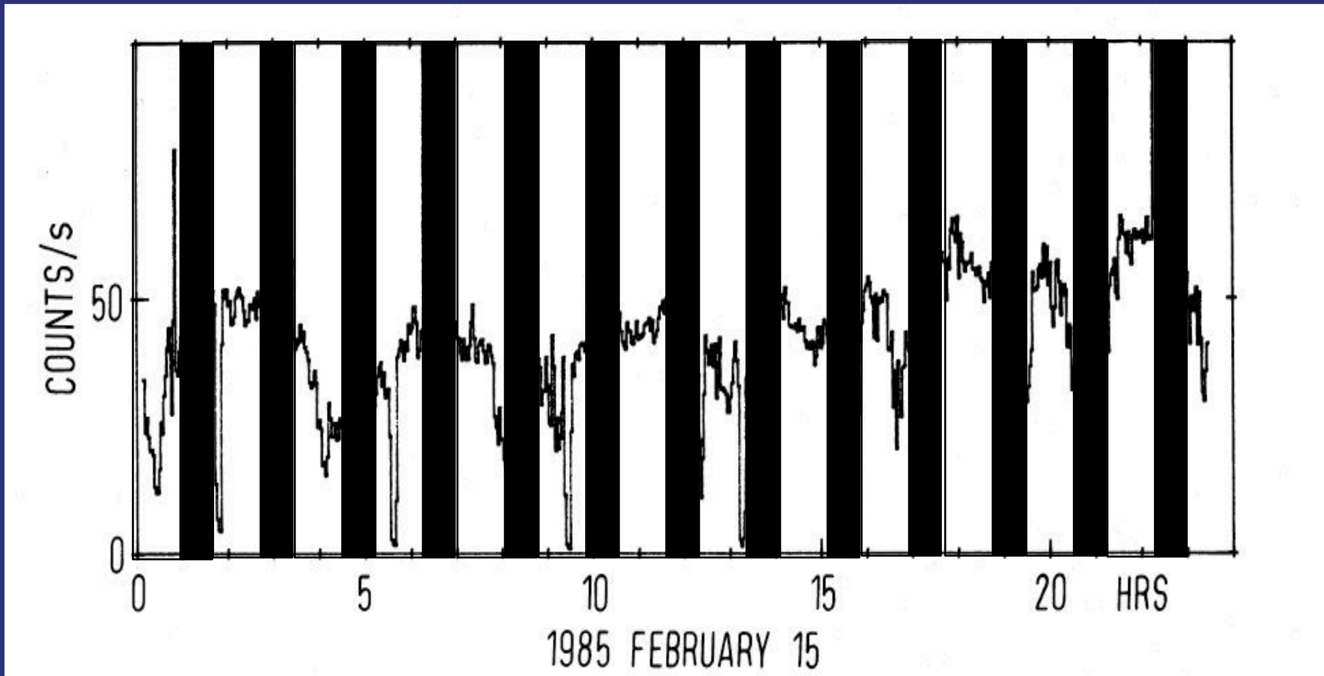
- EXOSAT (1983-1986) was ESA's first X-ray observatory. 1800 observations.
- 500 kg. ESA's first 3-axis stabilized spacecraft with one of the first on-board computers.
- 90-hour highly-eccentric orbit allowed long uninterrupted observations
- Three co-aligned instruments:
  - Two low-energy imaging telescopes with deployable gratings
  - Medium Energy proportional counter array ($\Delta E/E = 20\%$)
  - Gas scintillation proportional counter ($\Delta E/E = 10\%$)



EXOSAT

- A key feature of EXOSAT (and many other of ESA's high-energy missions) was the long un-interrupted observations allowed flares, bursts and other forms of variability to be studied easily for the first time:

EXO 0748-676 lightcurve



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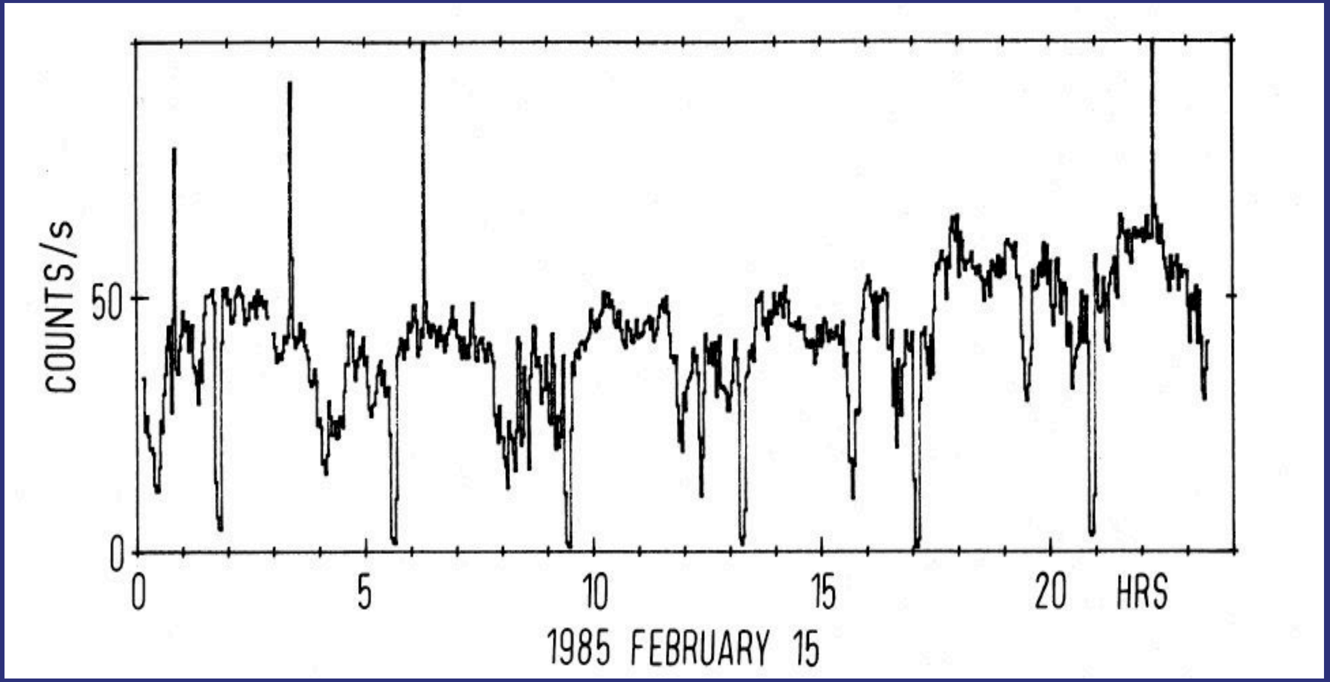
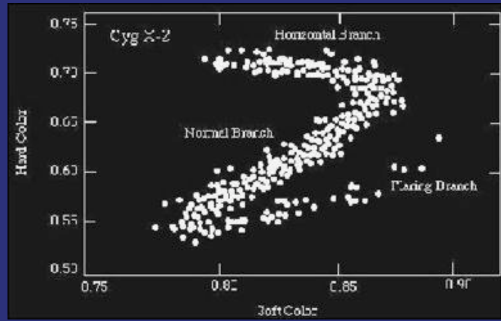
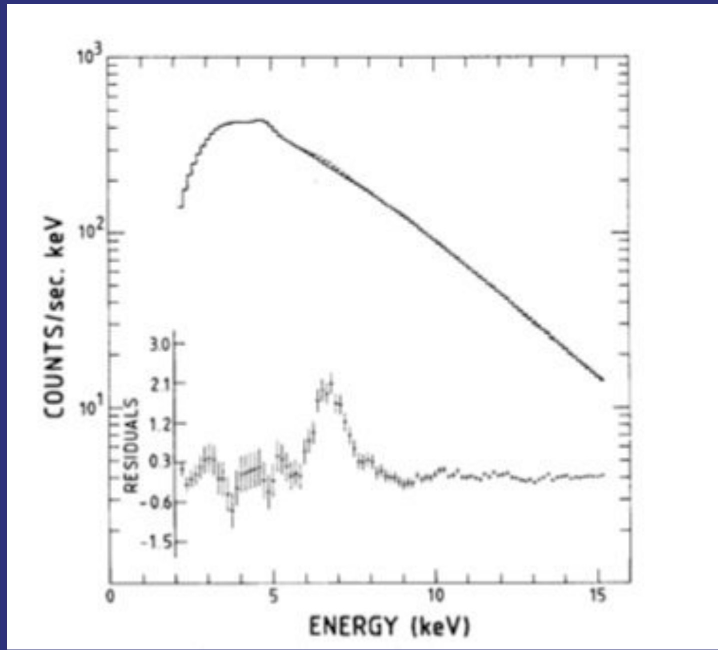


EXOSAT

- EXOSAT made many important discoveries including:
  - Quasi-periodic oscillations (QPOs) from LMXB (and other sources) and investigated how their frequency and intensity depends on source state.
  - The EXOSAT GSPC may have measured the first broadened iron line from a neutron star X-ray binary (Sco X-1).

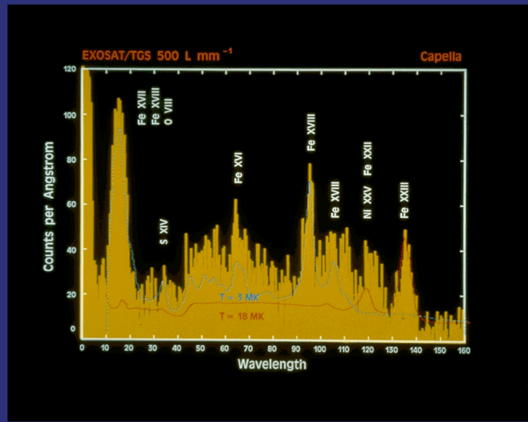


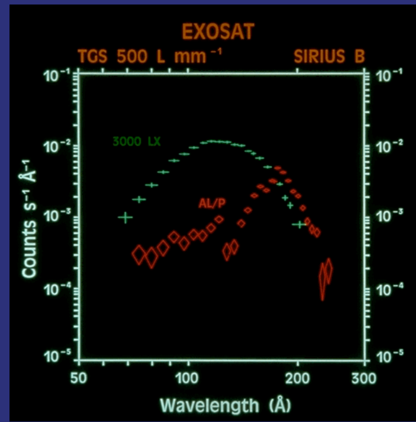


White, Peacock & Taylor (1985)

EXOSAT

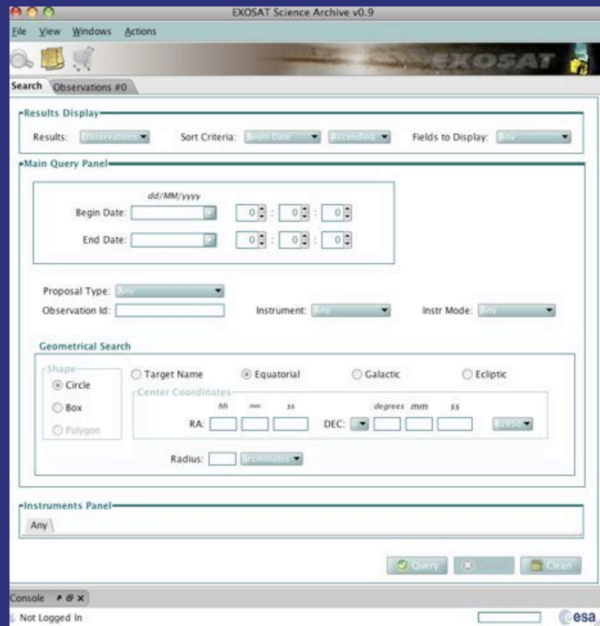
- The EXOSAT gratings opened up the field of low-energy (EUV) X-ray spectroscopy:
    - Line-rich Capella spectrum
    - White dwarf Sirius B



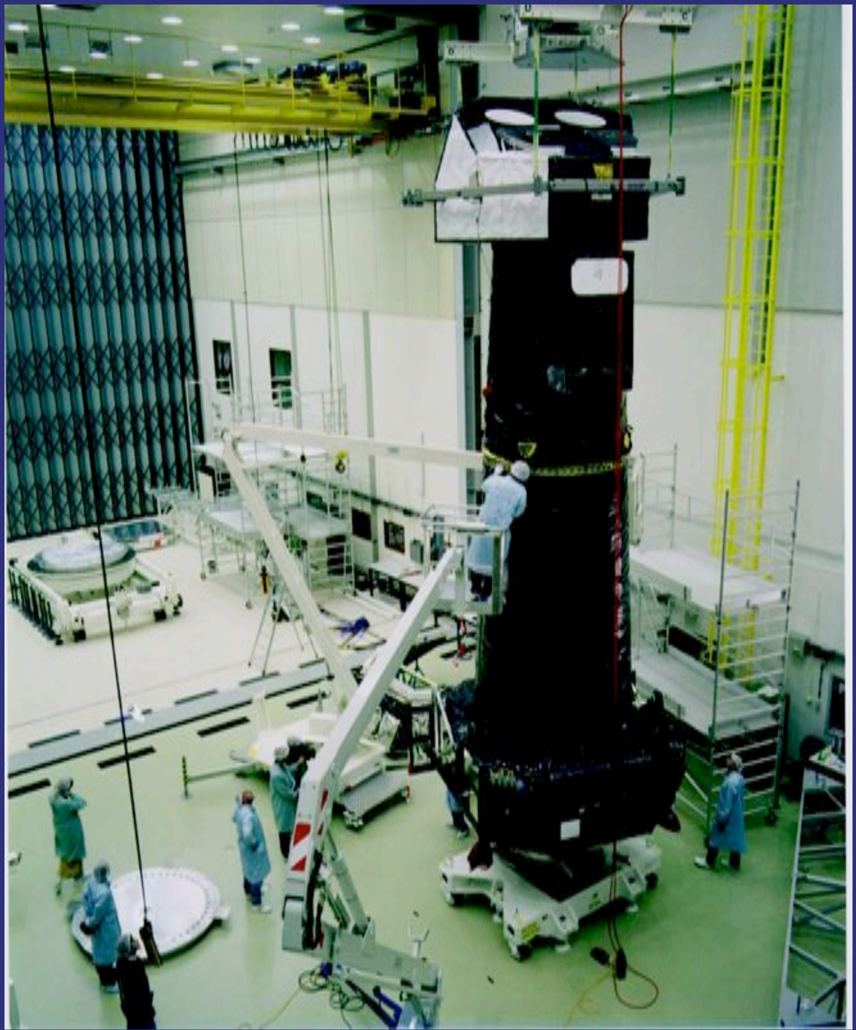


- Finally, after more than 20 years EXOSAT raw data and products are being put into an ESA archive by the team at ESAC. Download latest JAVA version:

  http://exsa.esac.esa.int/exsa/exsa.jnlp

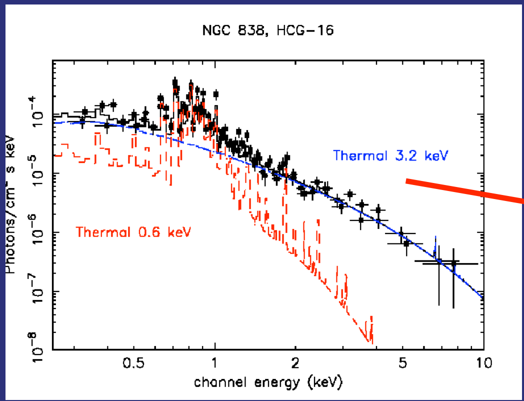


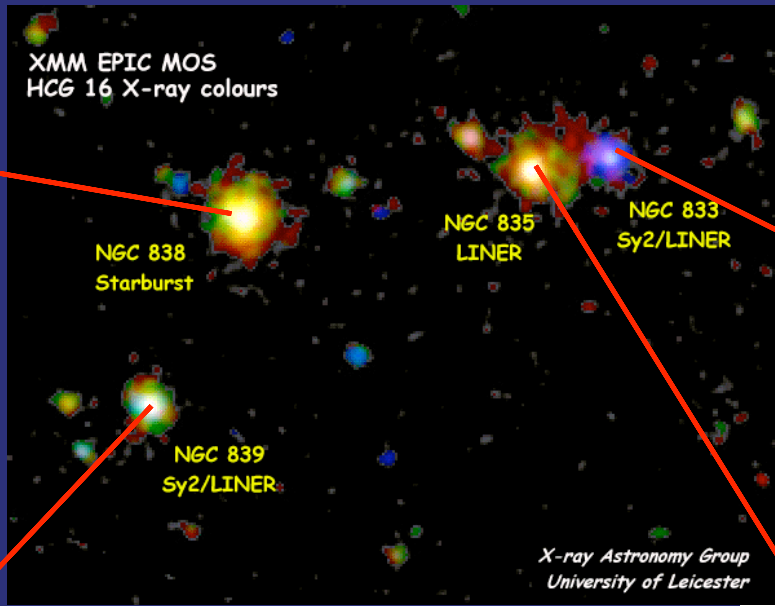
XMM-Newton

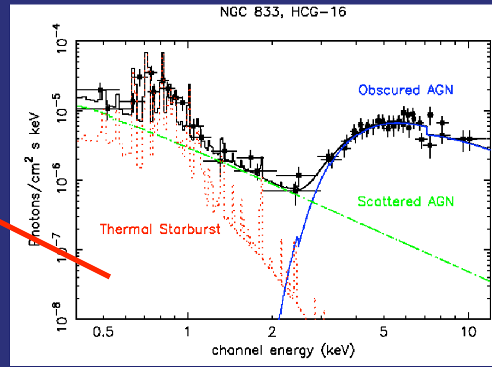


- ESA's second X-ray astronomy observatory. Launched Dec 1999
- 2000 users worldwide. 300 refereed papers per year. Observing programme continues to be a factor 7 over-subscribed.
- Mass: 3 tonnes and height of 10 m, 7.5 m focal length
- 48 hour eccentric orbit.
- Three co-aligned instruments: 3 Imaging cameras, and 2 gratings behind large area optics. Optical/ UV monitor.

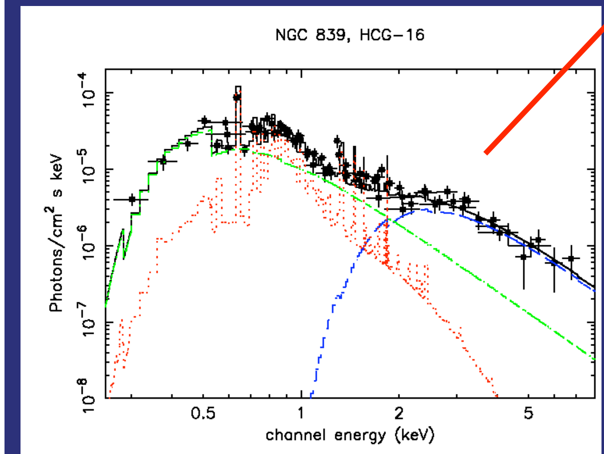
Imaging Spectroscopy

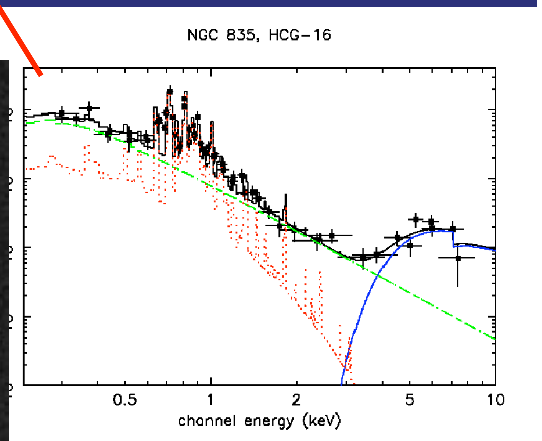






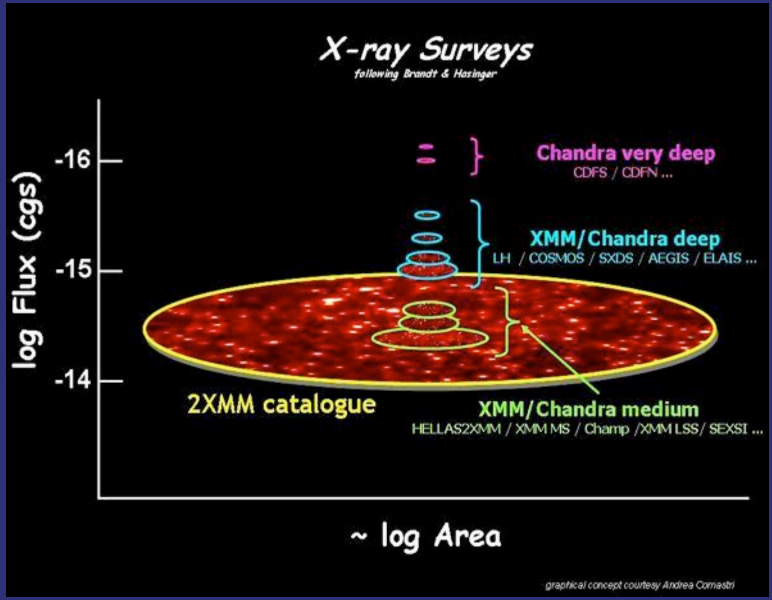
Credit: M. Turner



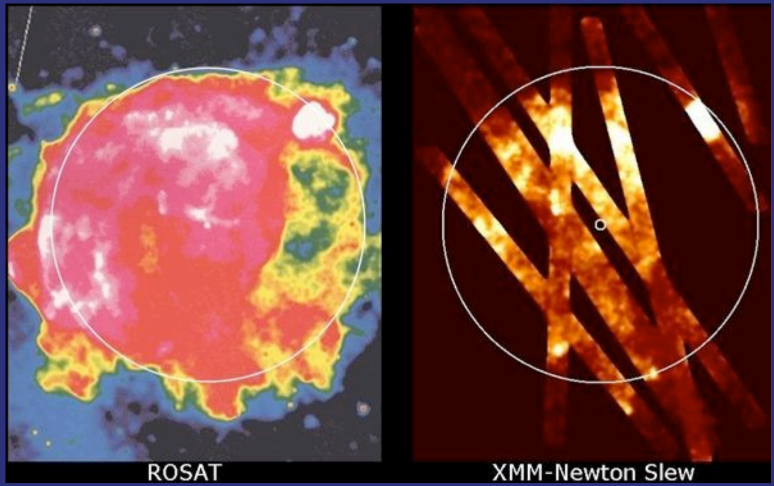


XMM-Newton Source Catalogues

- 2XMMi catalogue: serendipitous sources detected in EPIC is the largest X-ray catalogue ever:
  - 289,000 sources
  - 221,000 individual sources
  - source products: spectra, light curves
- X-ray Slew catalogue (D2):
  - 7686 sources detected
- SUSS catalogue of UV sources:
  - 753,000 sources
  - 620,000 individual sources
- Discoveries using XMM-Newton almost too many to mention!

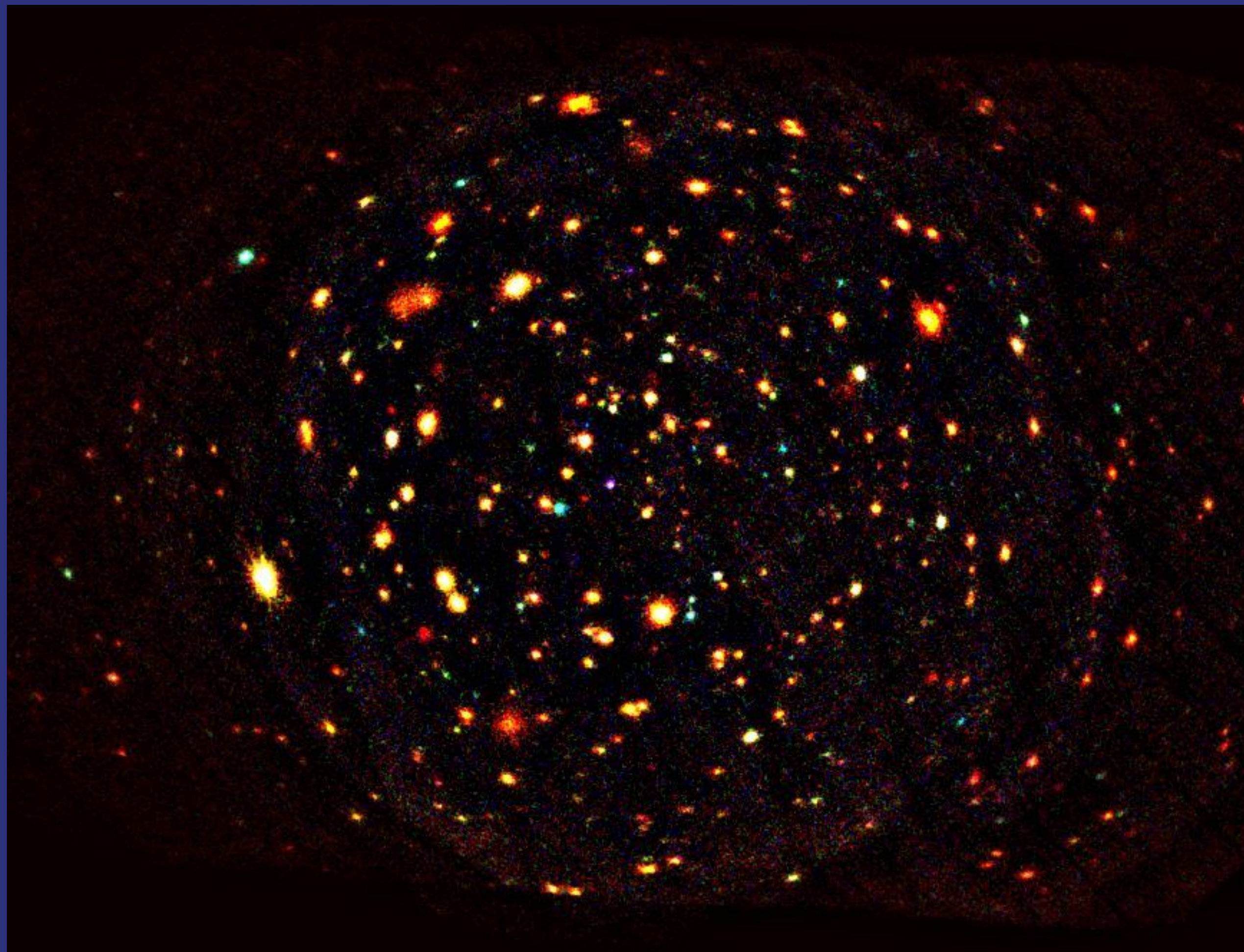


Brandt & Hasinger (2005)



Lockman Hole Deep Image

- Deep (1 Ms) image of a low-column part of the extragalactic sky
- Many hundreds of AGN and clusters of galaxies
- At least 23 papers on this data!
- Continued deep observations with XMM-Newton to approach the confusion limit >5 keV



Hasinger et al. (2001)

esa SCIENCE

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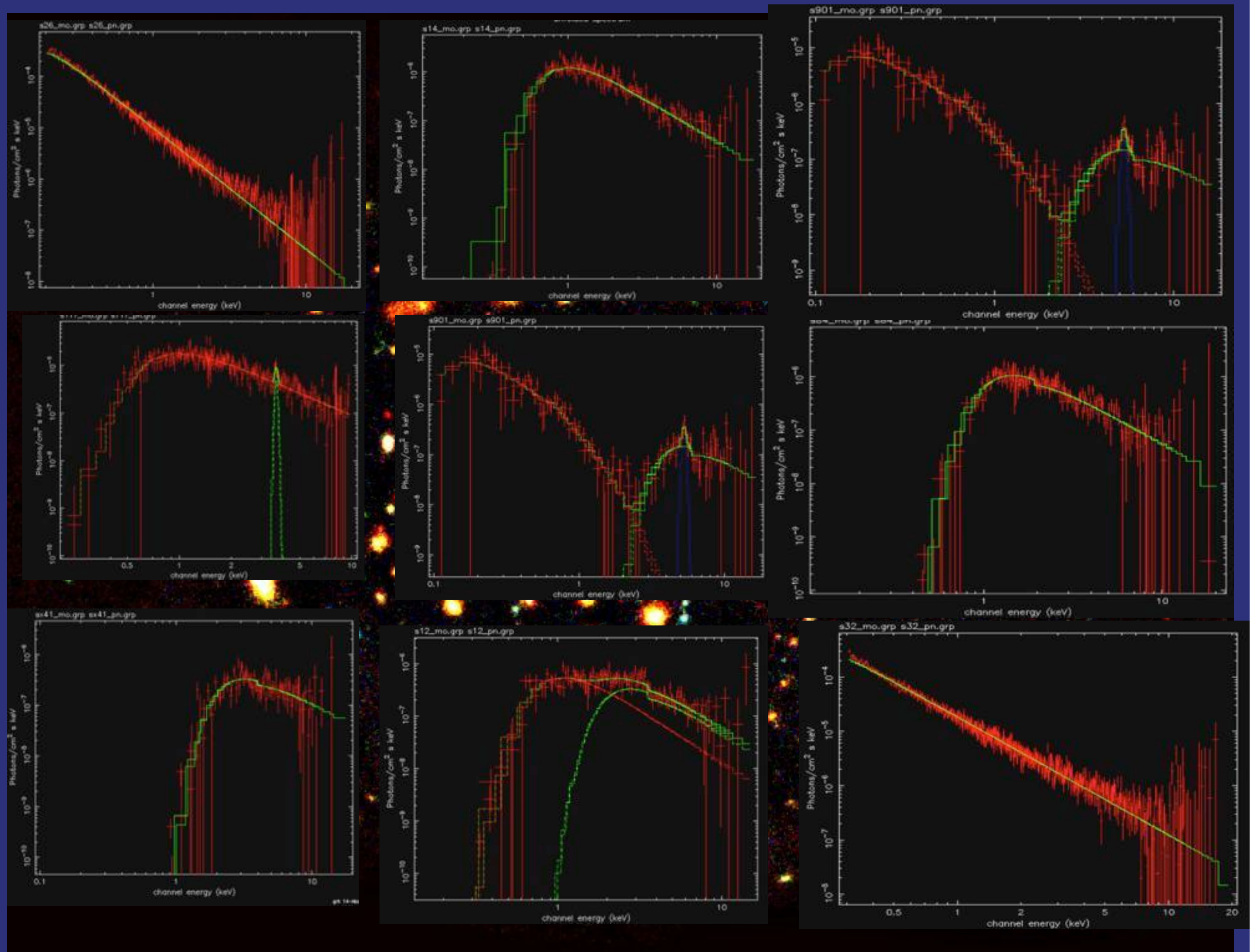
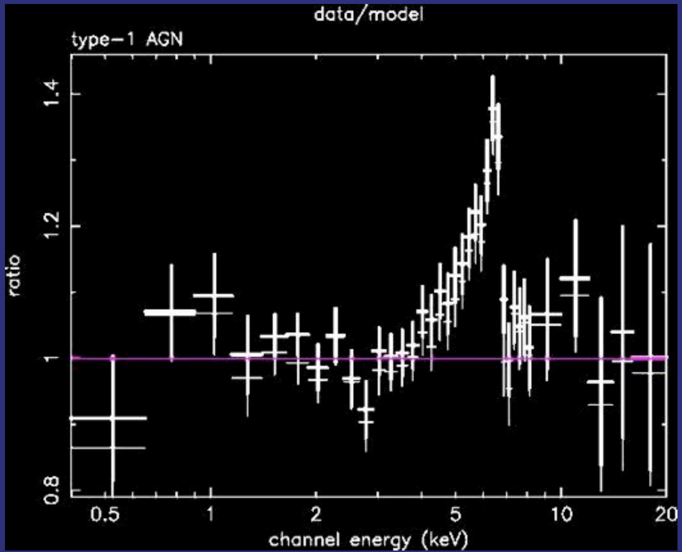
- Many hundreds of AGN and clusters of galaxies
- At least 23 papers on this data!
- Continued deep observations with XMM-Newton to approach the confusion limit >5 keV
- XMM-Newton provides spectra of the brightest objects – the key to understanding the nature of the objects

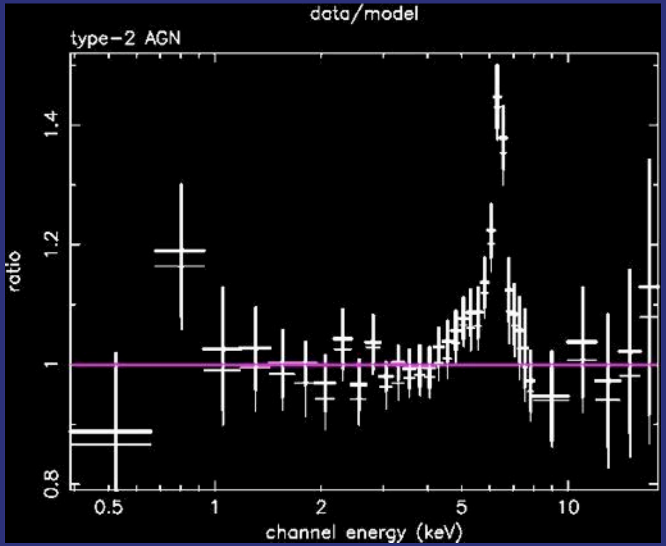


Hasinger et al. (2001)

Lockman Hole Deep Image

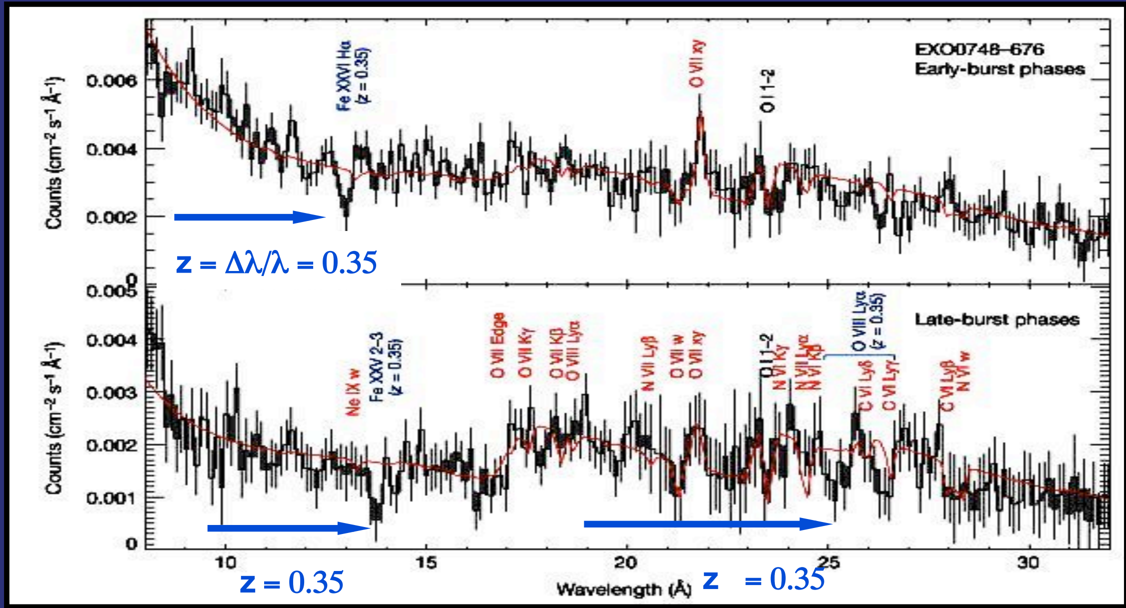
- Stacked spectra of the Lockman Hole AGN reveal a broadened asymmetric iron line.
- Summed spectra from 53 Type 1 AGN and 41 Type 2 (Streblyanska et al. 2005)
- Allows the accretion history of the Universe to be studied as a function of cosmic time

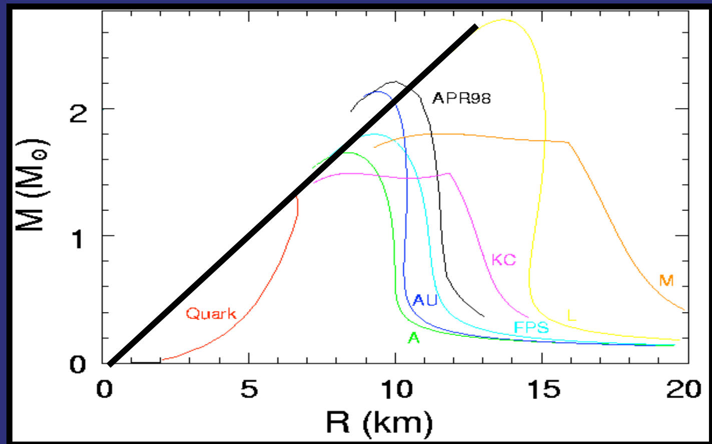




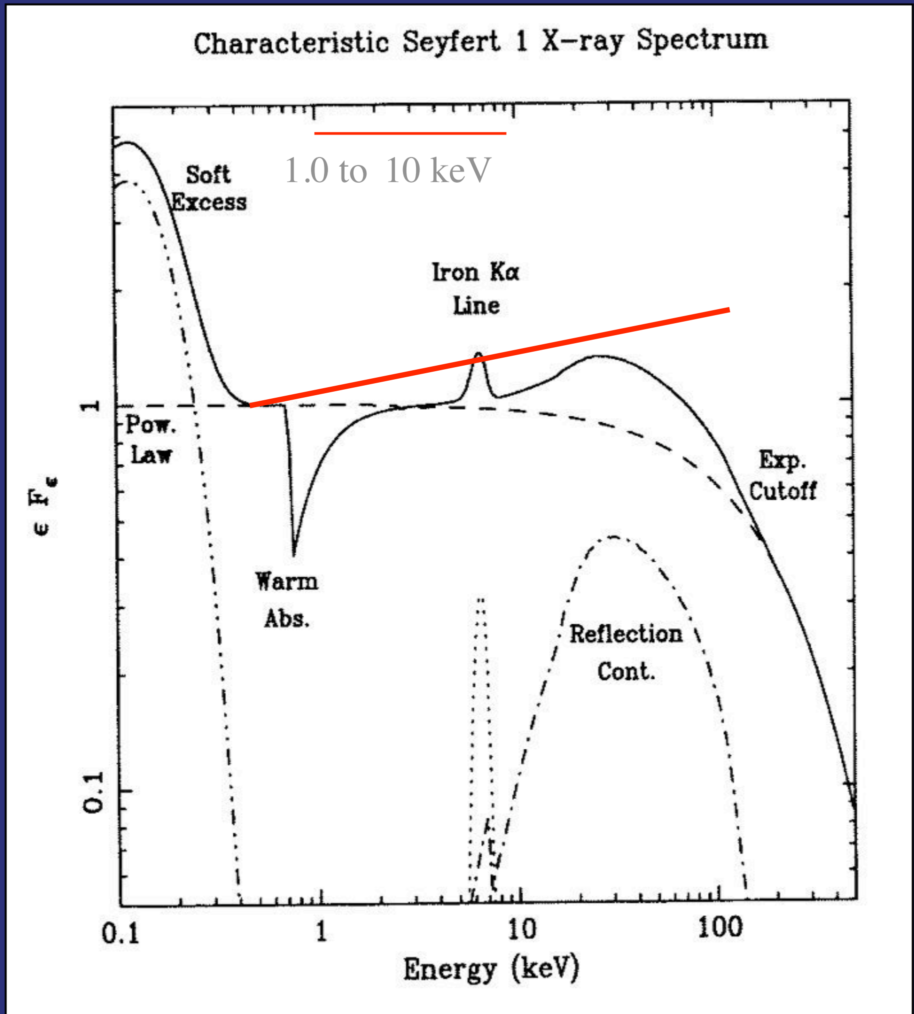
EXO 0748-676: Grating Spectra

- XMM-Newton has detected the gravitational redshift on the surface of a neutron star.
- Constrains M/R for a neutron star leading to constraints on the nature of the EOS of matter under extreme conditions
- Provides a challenge for the next generation of X-ray observatories!





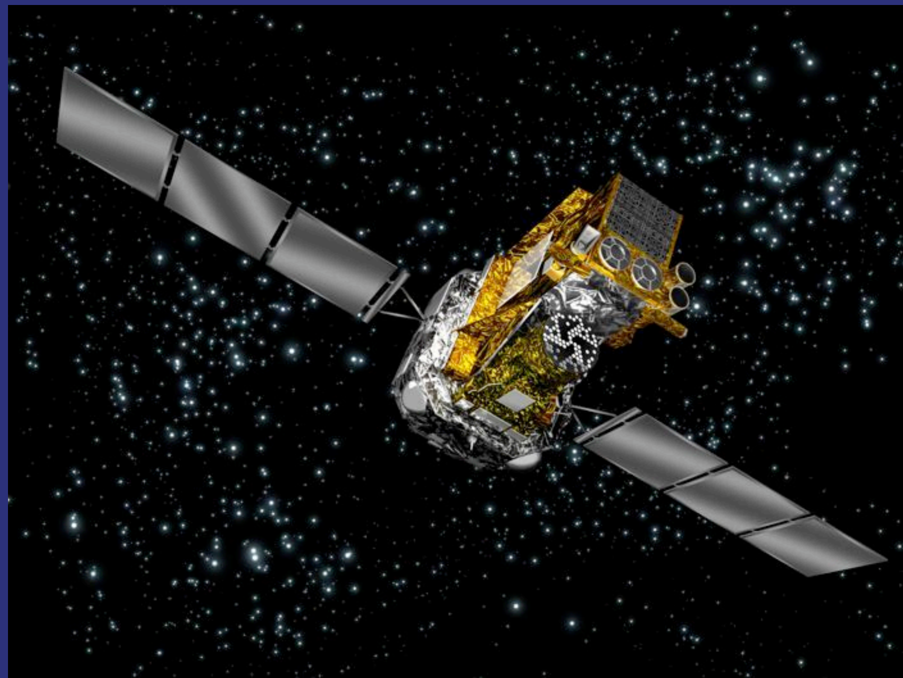
Energy Coverage is Important Too!



- Observing in the 1-10 keV energy range (classical X-ray astronomy) then you obtain the canonical AGN Power-law spectrum with a photon index of 1.7.
- Energy range was the great strength of BeppoSAX (0.1 – 300 keV) and is one of the important advantages of Integral (3 – 10,000 keV).

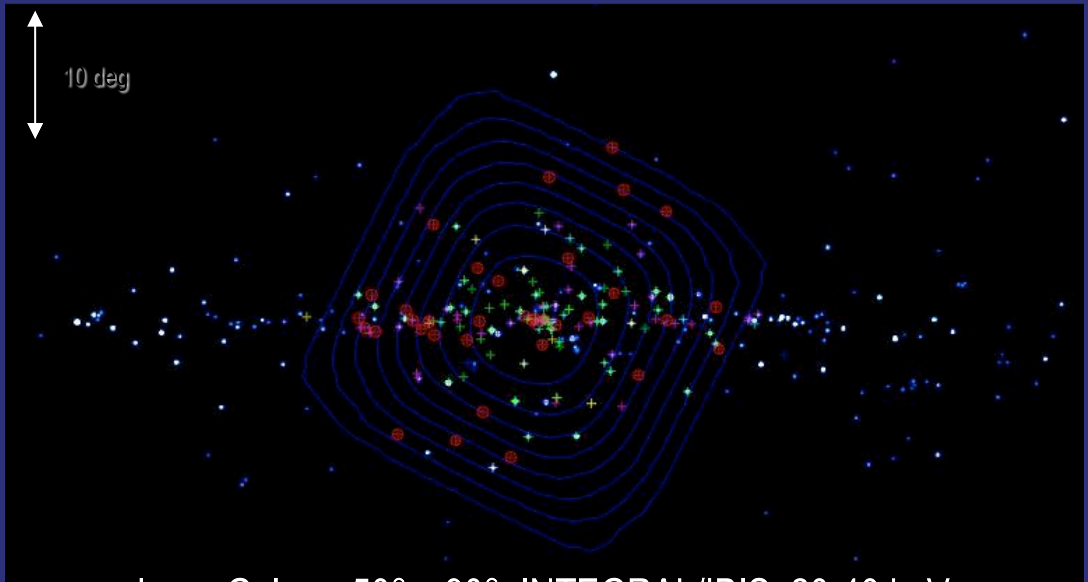
INTEGRAL

- INTEGRAL, ESA's gamma-ray observatory, has been operating since 2002 October.
- ESA led mission in collaboration with Russia (Proton) and the United States.
- 3 keV to 10 MeV energy coverage
- Highly eccentric 72 hour orbit.
- Mass: 4 tonnes, 5 m high, 16 m span solar panels
- Two Gamma-ray instruments (coded masks) provide imaging spectroscopy of the >15 keV sky. Concurrent X-ray and optical monitoring.

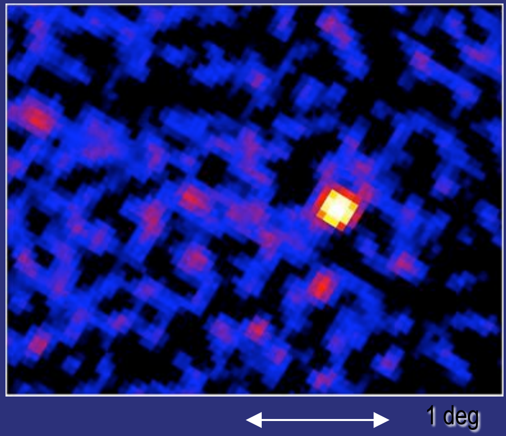


INTEGRAL

- INTEGRAL's key feature is probably the large FOVs of its instruments – allows many sources to be studied in a single exposure



Inner Galaxy, 50° x 90°, INTEGRAL/IBIS, 20-40 keV

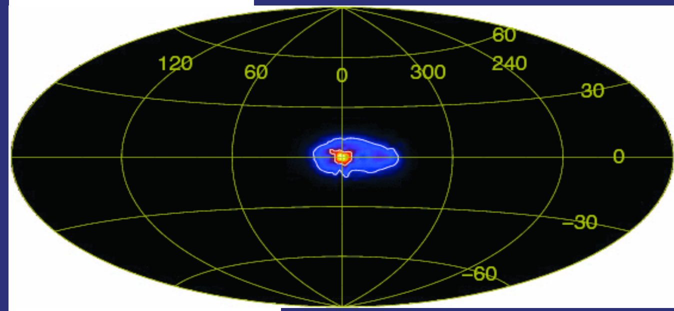


Galactic Centre, 20-60 keV, ΔT = 3 days

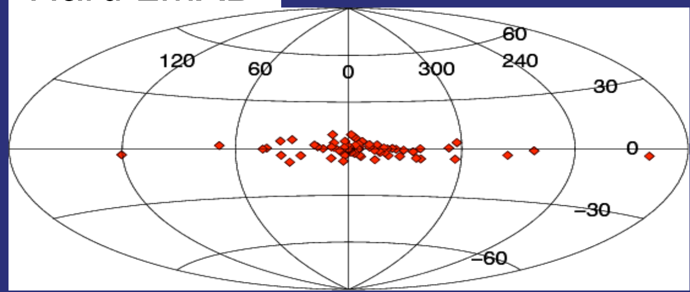
INTEGRAL Science

- INTEGRAL has many science highlights so far: discovery of a new class of obscured HMXB and a local faint GRB population, insights into the outburst mechanisms of super-giant fast X-ray transients and so on.
- INTEGRAL's spectrometer, SPI, has observed an asymmetry in the 511 keV diffuse emission from the inner regions of the galaxy
- Half, of possibly all, anti-matter could be produced by hard (>20 keV) LMXB systems which show a similar asymmetry.
- Reduces (or eliminates) need for more exotic explanations involving e.g., dark matter

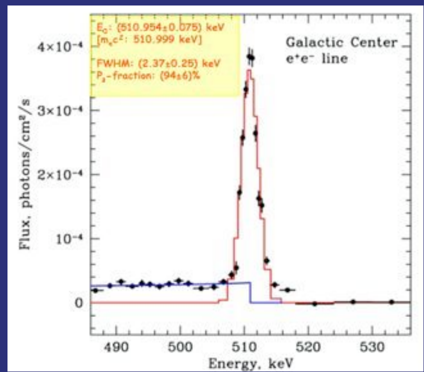
511 keV



Hard LMXB

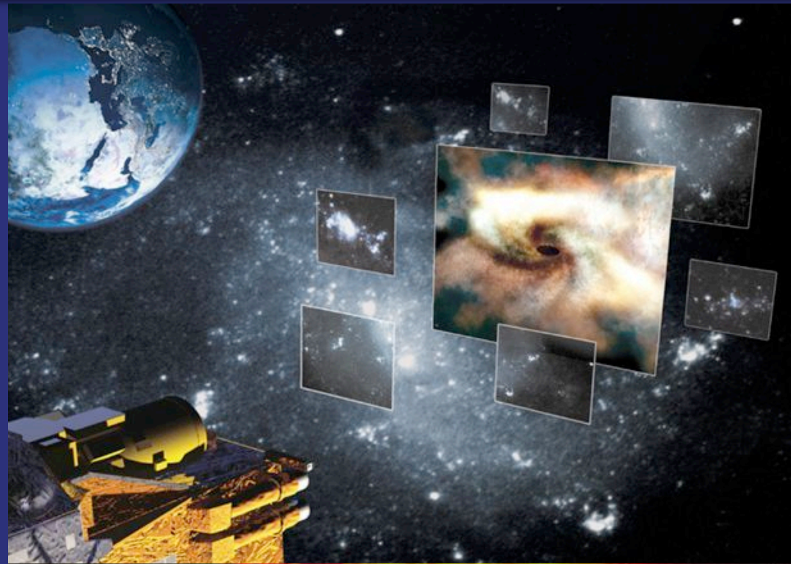


Weidenspointner et al., Nature (2008)



High-Energy Astronomy: The Future

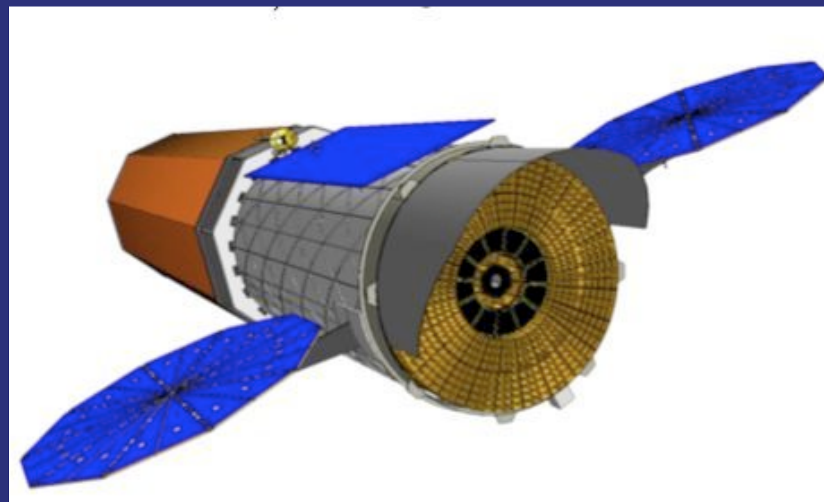
- XMM-Newton and INTEGRAL have sufficient consumables to last until ~2018 and are funded until the end of 2012.
- Both missions are producing first class science and their observing programmes are heavily over-subscribed. No shortage of ideas!
- Given continued good technical status, then these missions provide a superb return on investment. If the funds can be found, then continued operations should be a high priority.



High-Energy Astronomy: The Future

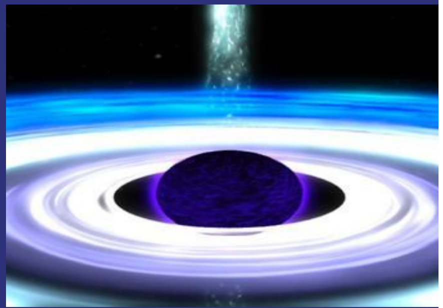
- There have been 16 years between the launches of ESA's two X-ray missions and 27 years between ESA's two gamma-ray missions.
- Europe's vision for the future of space science is Cosmic Vision. The XEUS X-ray observatory concept was one of three large mission concepts selected for an assessment study.
- In July 2008, XEUS and NASA's Con-X were merged to form IXO – the International X-ray Observatory.
- This next generation observatory is the global (ESA/JAXA/NASA) successor to XMM-Newton, *Chandra*, Suzaku and Integral etc. 10 – 100 times more capable than existing missions.

IXO

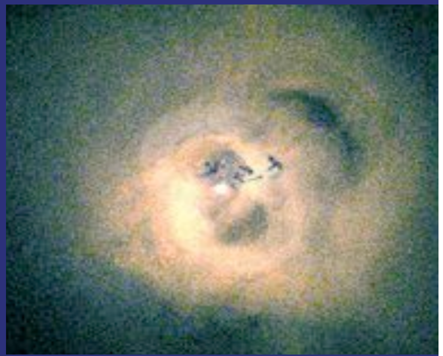


High-Energy Astronomy: The Future

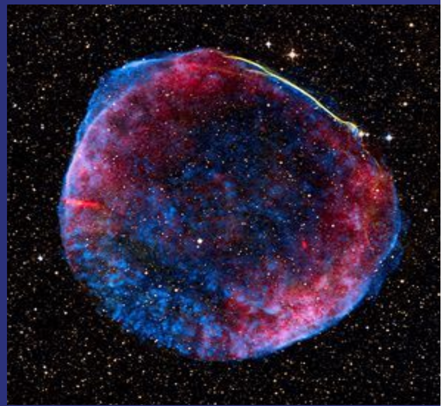
- Black Holes and Matter under Extreme Conditions:
  - How do super-massive Black Holes grow and evolve?
  - Does matter orbiting close to a Black Hole event horizon follow the predictions of General Relativity?
  - What is the Equation of State of matter in Neutron Stars?



- Galaxy Formation, Galaxy Clusters and Cosmic Feedback:
  - How does Cosmic Feedback work and influence galaxy formation?
  - How does galaxy cluster evolution constrain the nature of Dark Matter and Dark Energy?
  - Where are the missing baryons in the nearby Universe?

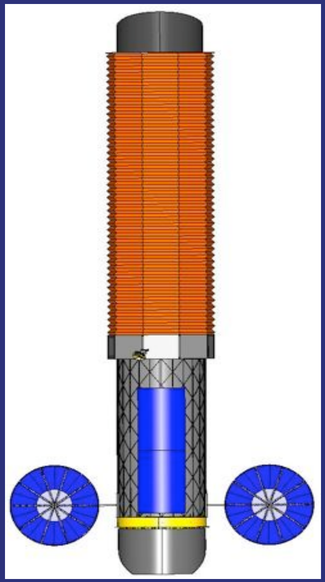
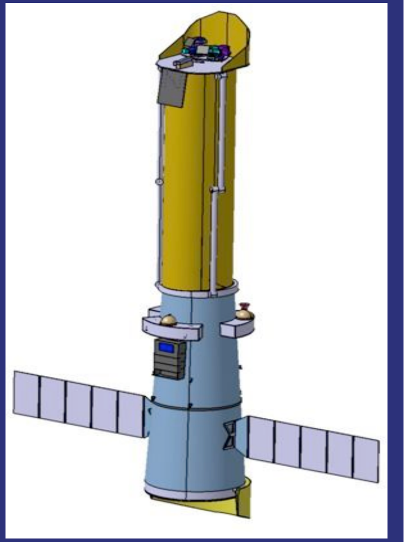
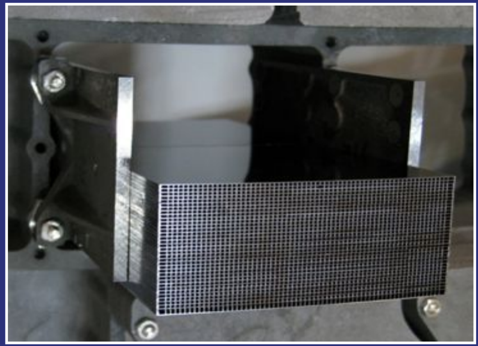
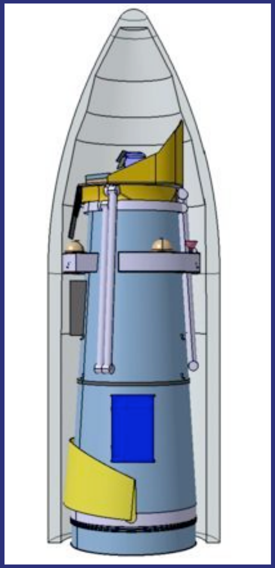


- Lifecycles of Matter and Energy:
  - When and how were the elements created and dispersed?
  - How do high energy processes affect planetary formation and habitability?
  - How do magnetic fields shape stellar exteriors and the surrounding environment?
  - How are particles accelerated to extreme energies producing shocks, jets and cosmic rays?

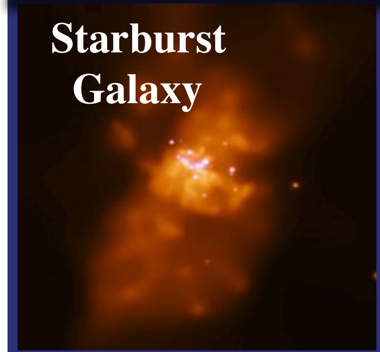


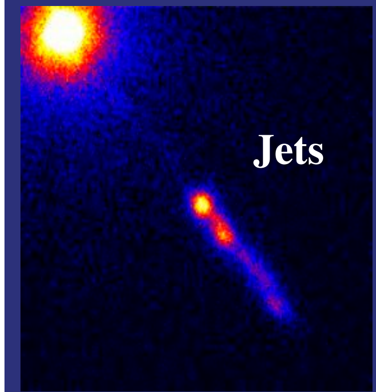
High-Energy Astronomy: The Future

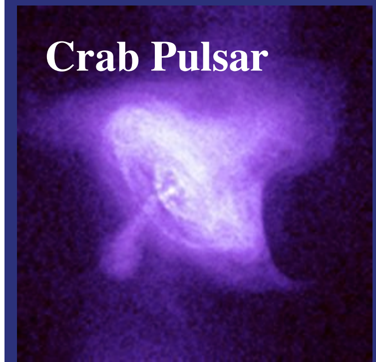
- 6.3 tonne spacecraft with an Ariane 5 or Atlas 551 launch into orbit around the Earth-Sun L2 point.
- 20 m focal length X-ray optic providing an area of 3 m^2 at 1.25 keV with 5” HED spatial resolution. Extendable optical bench.
- Optics is the key technology: concept compatible with US slumped glass and ESA silicon pore optics technologies. Selected as late as possible. Multi-coating extends energy response to 40 keV.
- Model payload includes imaging X-ray cameras, a high-spectral resolution imaging calorimeter, gratings, a high time resolution spectrometer and an X-ray polarimeter.
- Two independent studies by NASA and ESA both show that the concept is **feasible** (and mass limited) with very similar overall designs.
- If selected, IXO could be launched as early as 2020.

Summary







- ESA was one of the pioneers of high-energy astronomy with the COS-B and EXOSAT satellites launched in 1975 and 1983.
- With XMM-Newton and INTEGRAL, Europe has (after 40 years!) established shared leadership in the field of high-energy astronomy – a vital component of ESA's Science Programme.
- Each generation of missions has added new capabilities resulting in wonderful discoveries. But this is at the expense of complexity and cost.
- The successor to XMM-Newton and INTEGRAL will be a global endeavor. With its factor 10-100 improved performance, IXO is the natural step in ESA, JAXA and NASA's study of the high-energy Universe.