The Violent side of the Universe

Highlights from ESA's High-Energy Astronomy Missions

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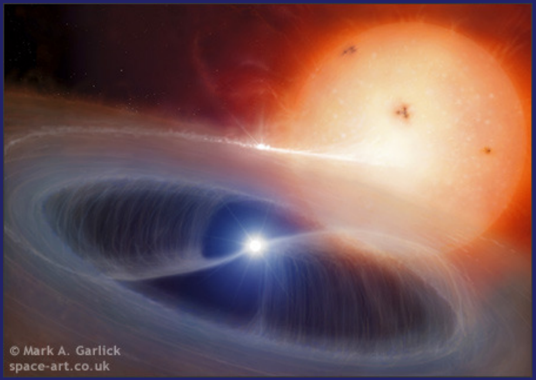
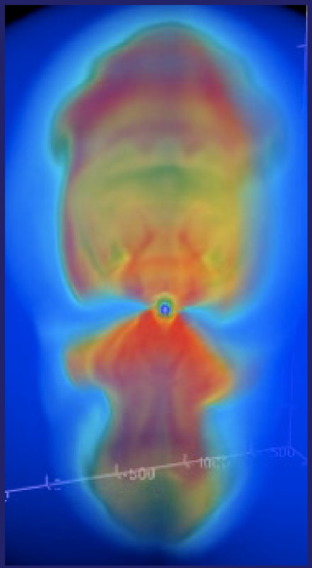
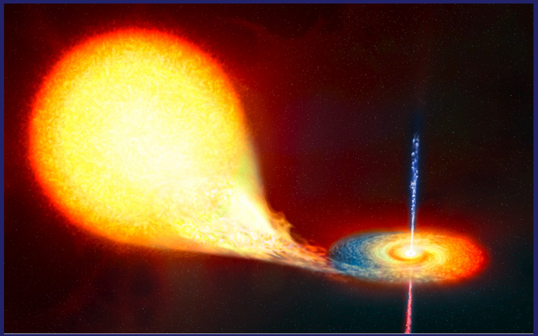
High-Energy Astronomy:
"The unusual suspects"

- Extreme states of matter and space-time:
  - White Dwarfs
  - Neutron Stars
  - Black Holes
- Extreme temperatures and velocities
  - Accretion disks
  - Jets
  - Supernova explosions
  - Gamma-ray bursts
  - Hot gas in Galaxy Clusters
- Tracers of dramatic events
  - Anti-matter annihilation
  - Radioactive glimmer of past supernovae



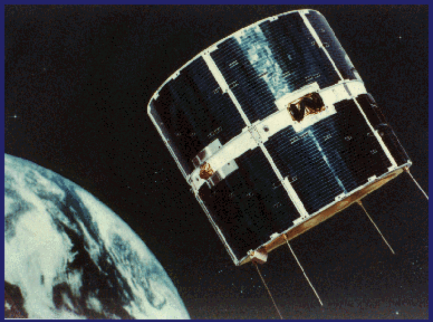




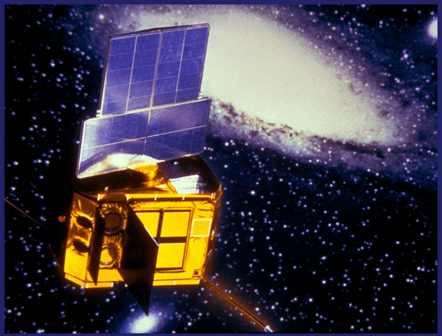
ESA's High-Energy Missions

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

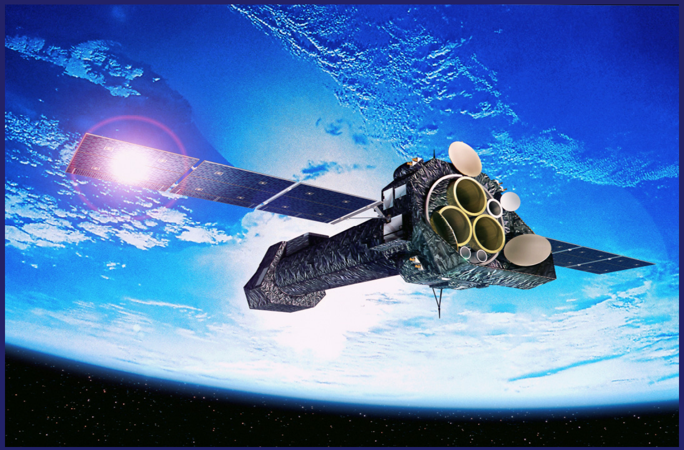
INTEGRAL 2002 ⟶



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

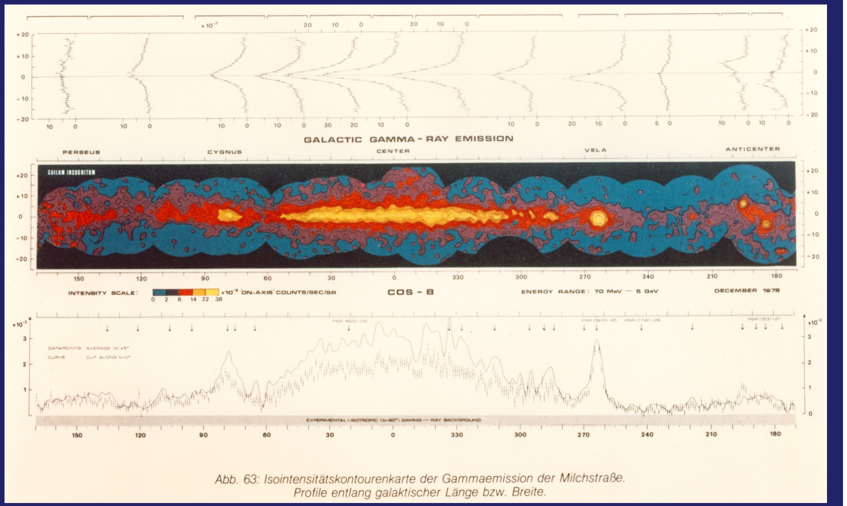
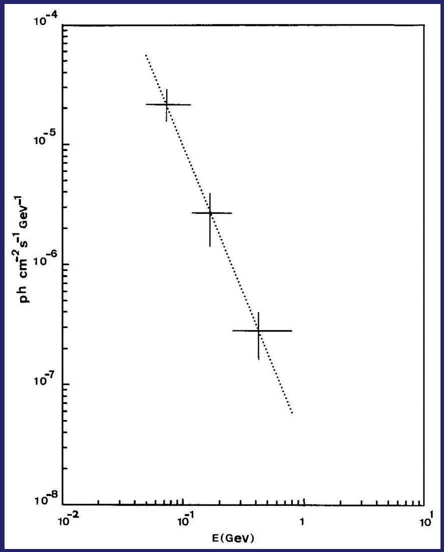


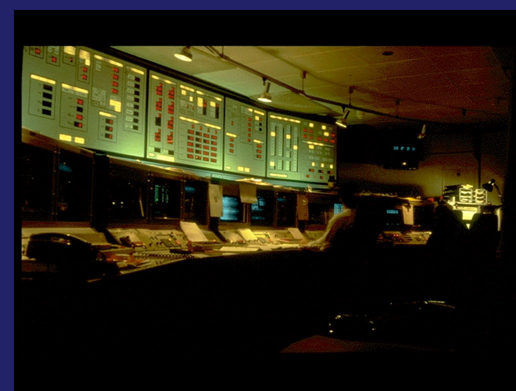
Abb. 63: Isointensitätskontourenkarte der Gammaemission der Milchstraße. Profile entlang galaktischer Länge bzw. Breite.



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

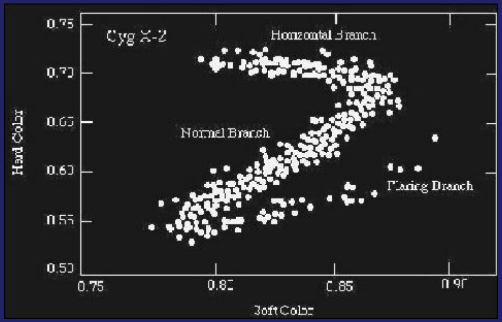
EXOSAT

- 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 ($\Delta E/E = 10\%$)

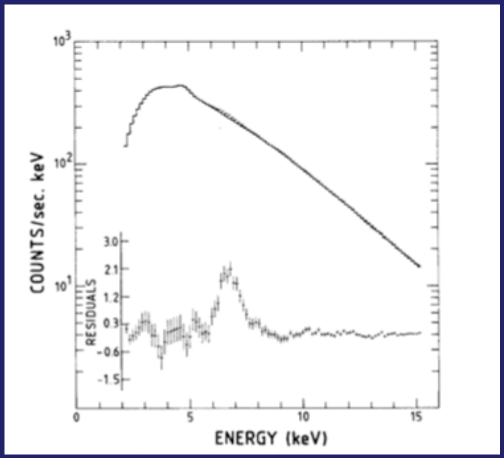


EXOSAT Results

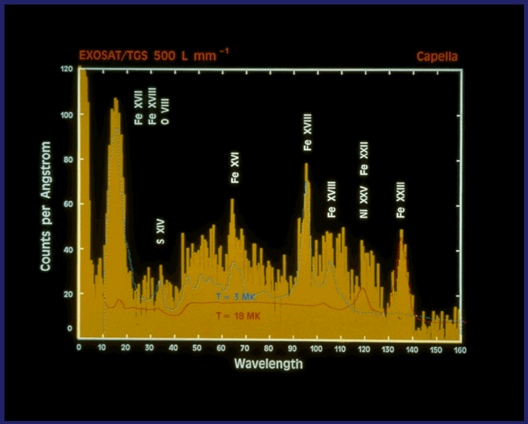
- Quasi-periodic oscillations (QPOs) from LMXB (and other sources), their frequency and intensity dependence on source state.
- Possibly the first broadened iron line from a neutron star X-ray binary (Sco X-1).
- Low-energy (EUV) X-ray spectroscopy with gratings:
  - Line-rich Capella spectrum
  - White dwarf Sirius B

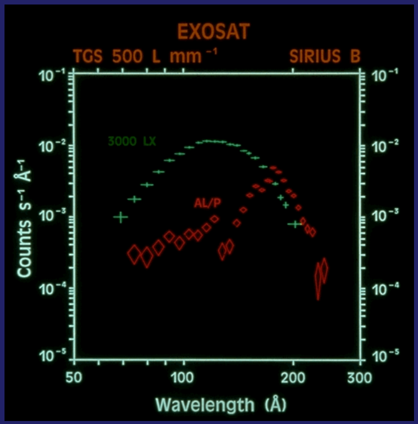


Barr et al. MNRAS (1985)

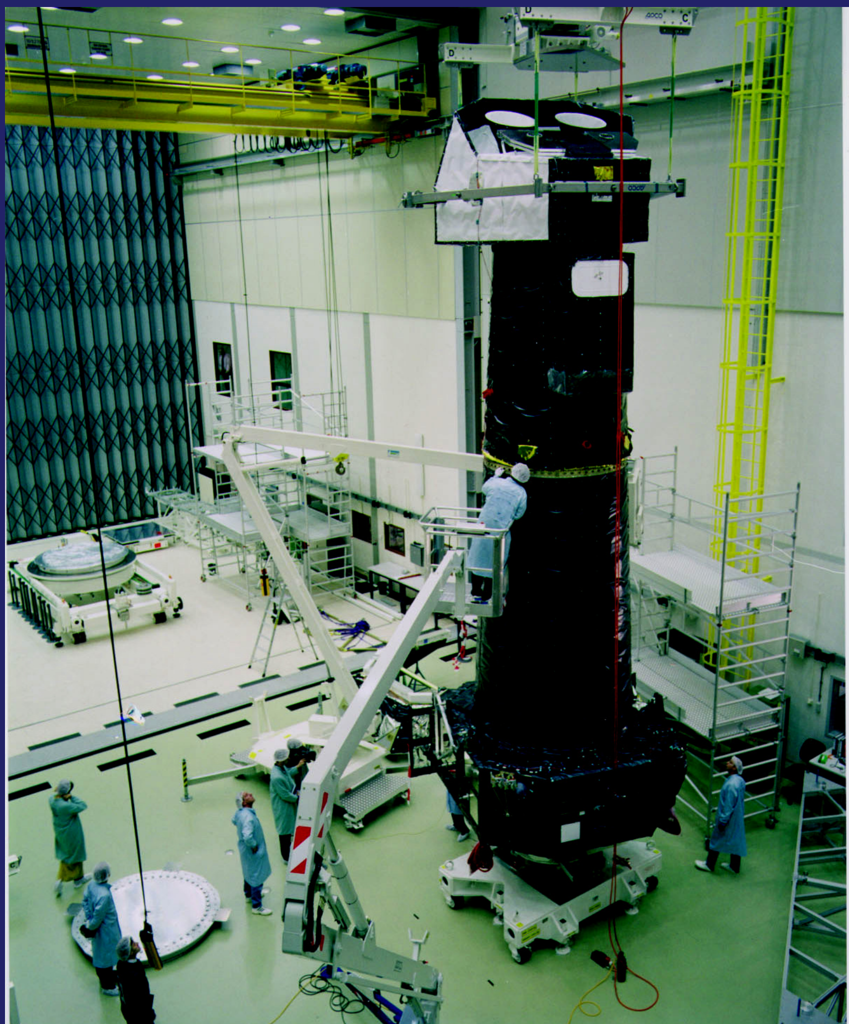


White, Peacock & Taylor (1985)



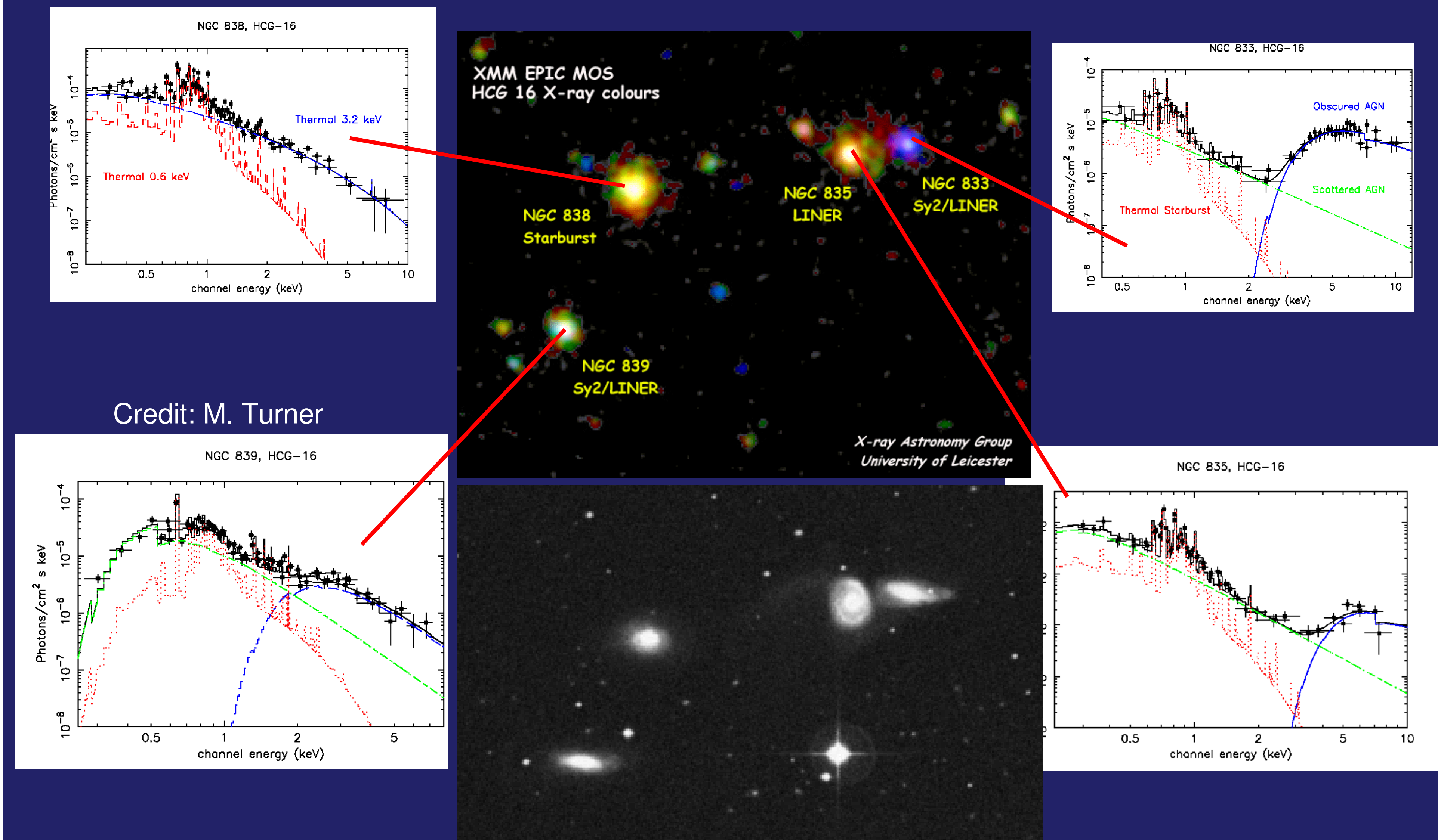


XMM-Newton



- 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.

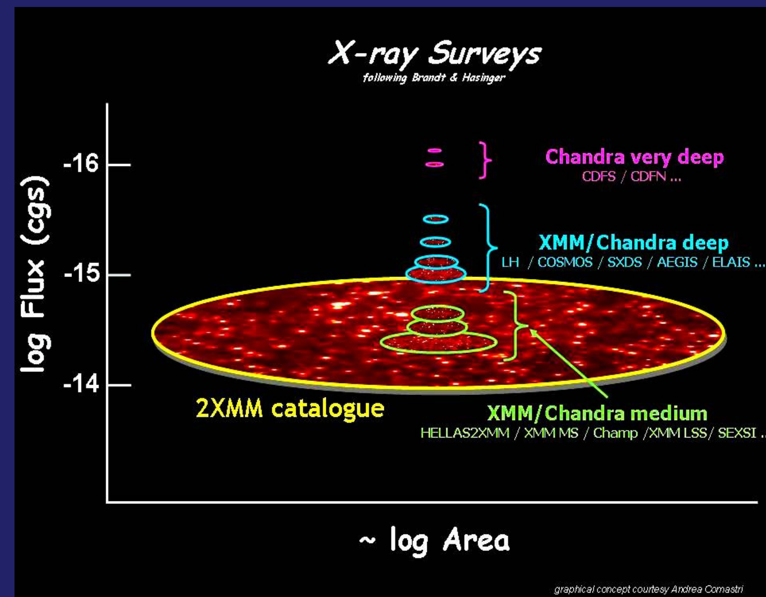
Imaging Spectroscopy



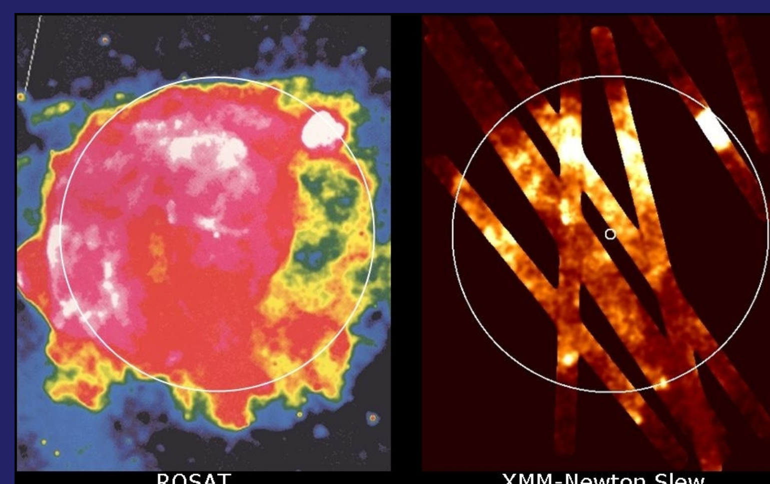
Credit: M. Turner

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!

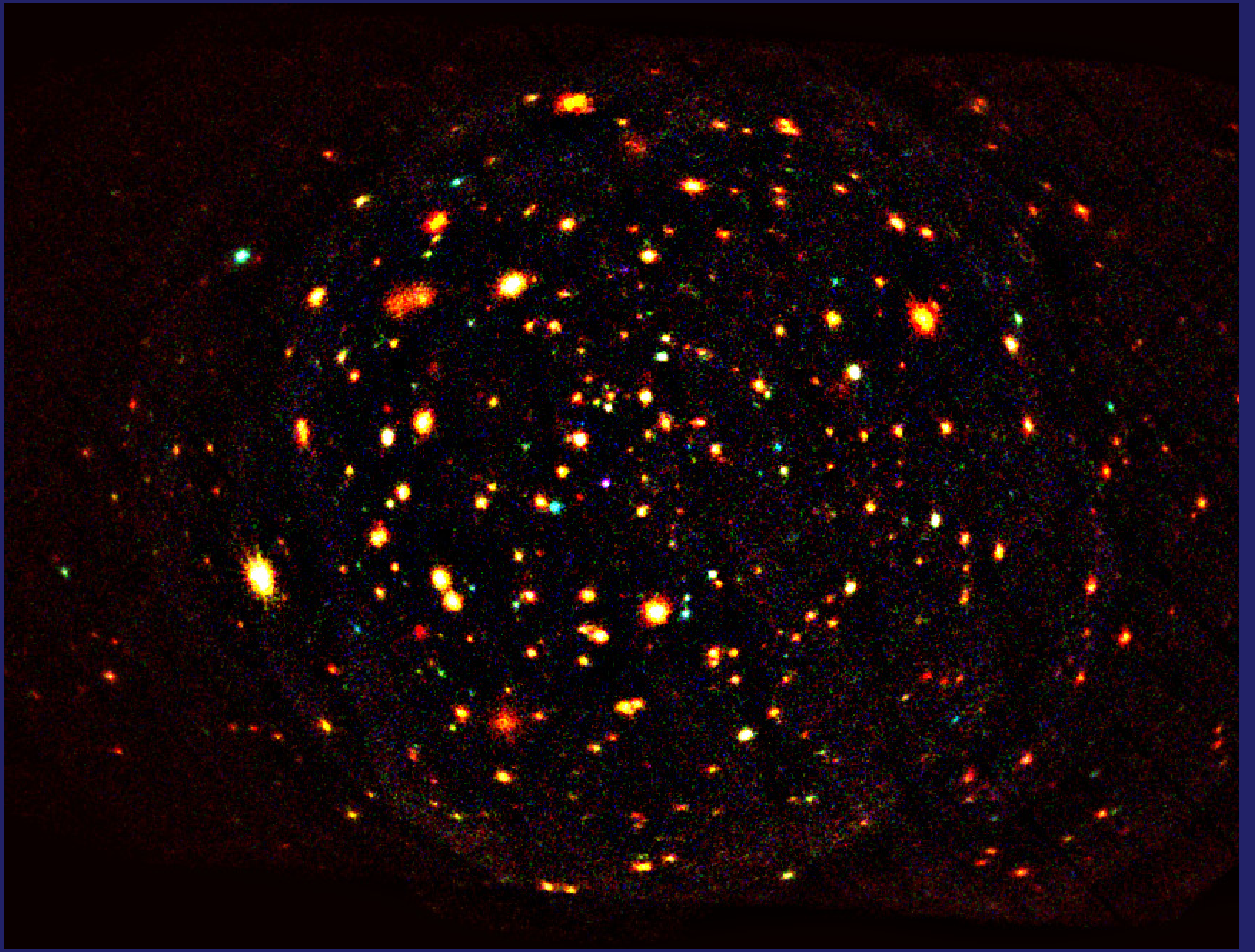


Brandt & Hasinger (2005)



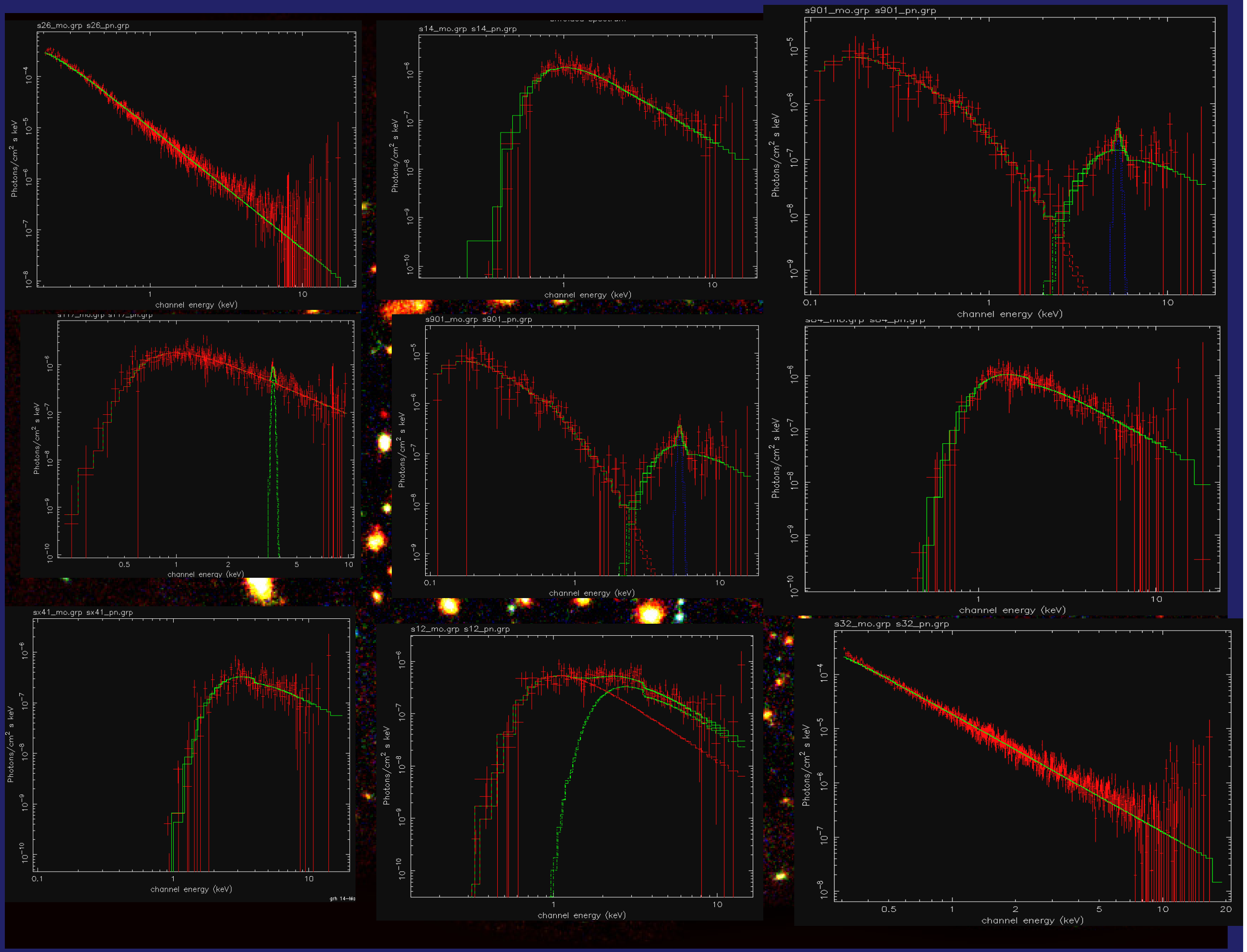
Lockman Hole Deep Image

- Deep (1 Ms) image of a non-obscured part of the extragalactic sky
- Many hundreds of AGN and clusters of galaxies
- Continued deep observations with XMM-Newton to approach the confusion limit >5 keV



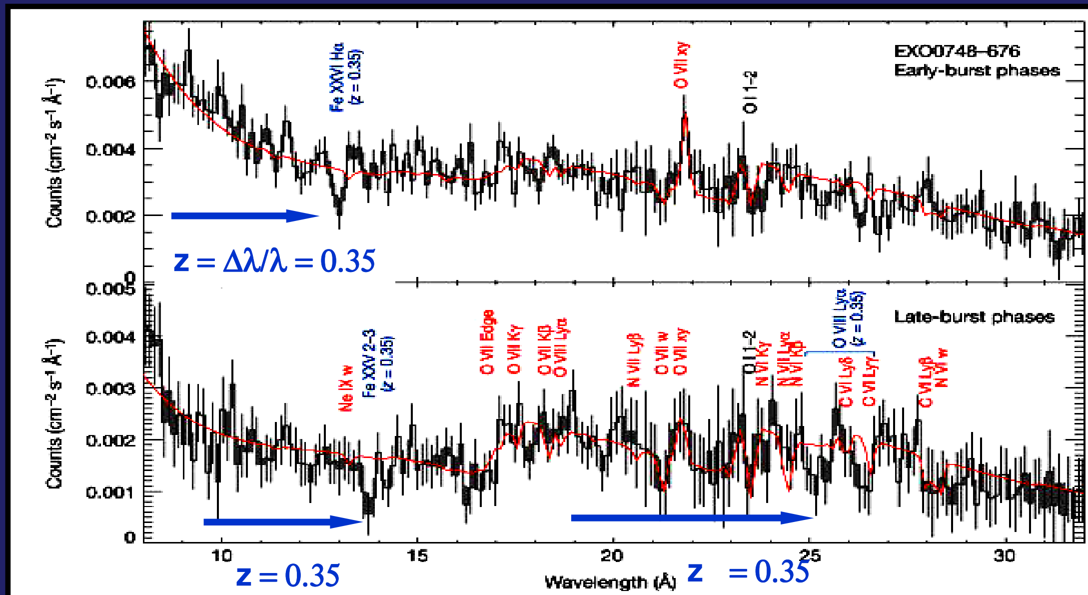
Lockman Hole Deep Image

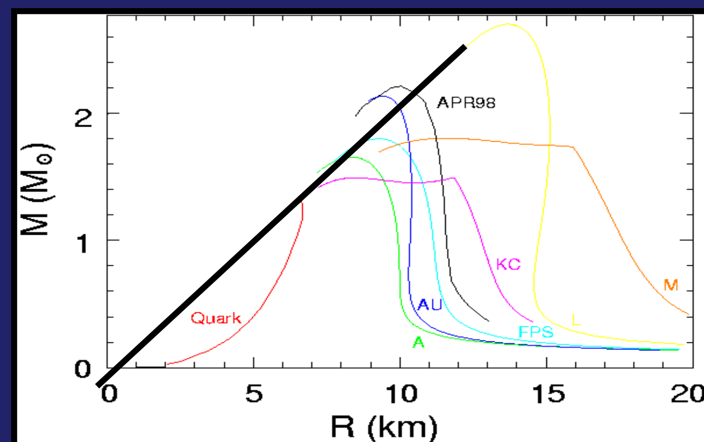
- XMM-Newton provides spectra of the brightest objects – the key to understanding the nature of the objects
- Allows the accretion history of the Universe to be studied as a function of cosmic time



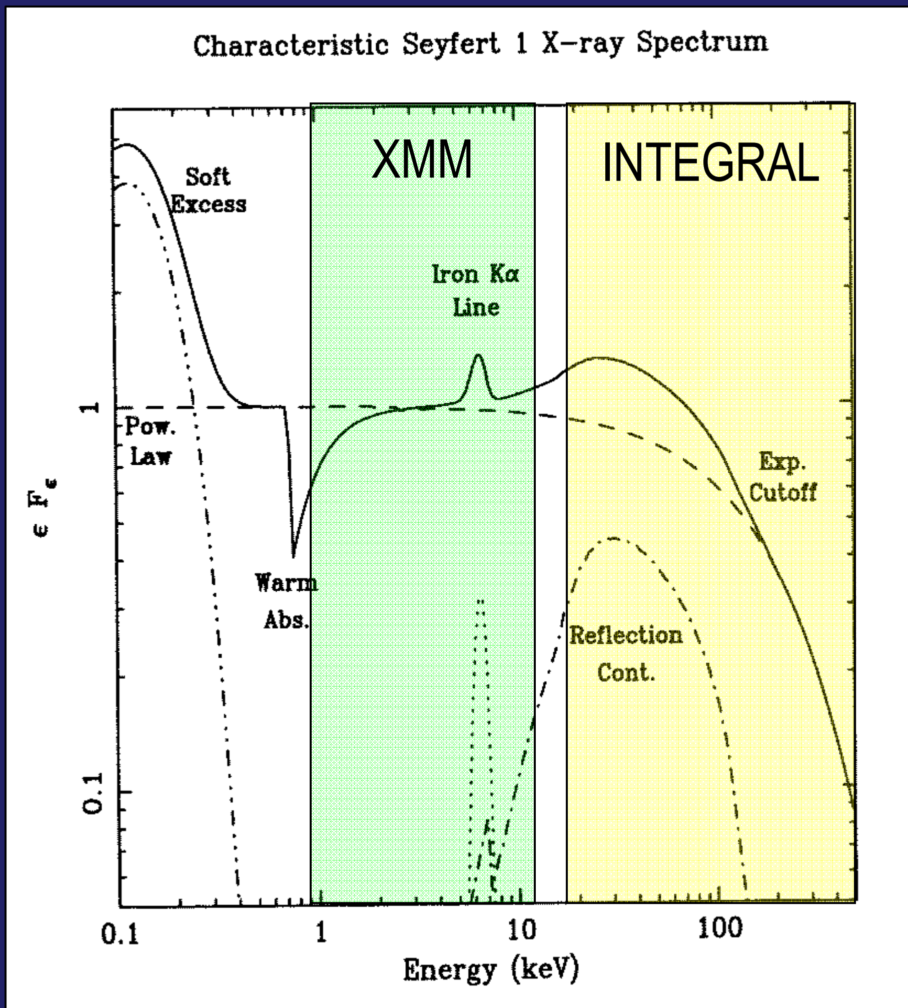
EXO 0748-676: Grating Spectra

- XMM-Newton has detected the gravitational redshift on the surface of a neutron star.
- Constrains mass-radius relation for a neutron star leading to constraints on the nature of matter under extreme conditions. Impossible to get this in the laboratory!
- Provides a challenge for the next generation of X-ray observatories!





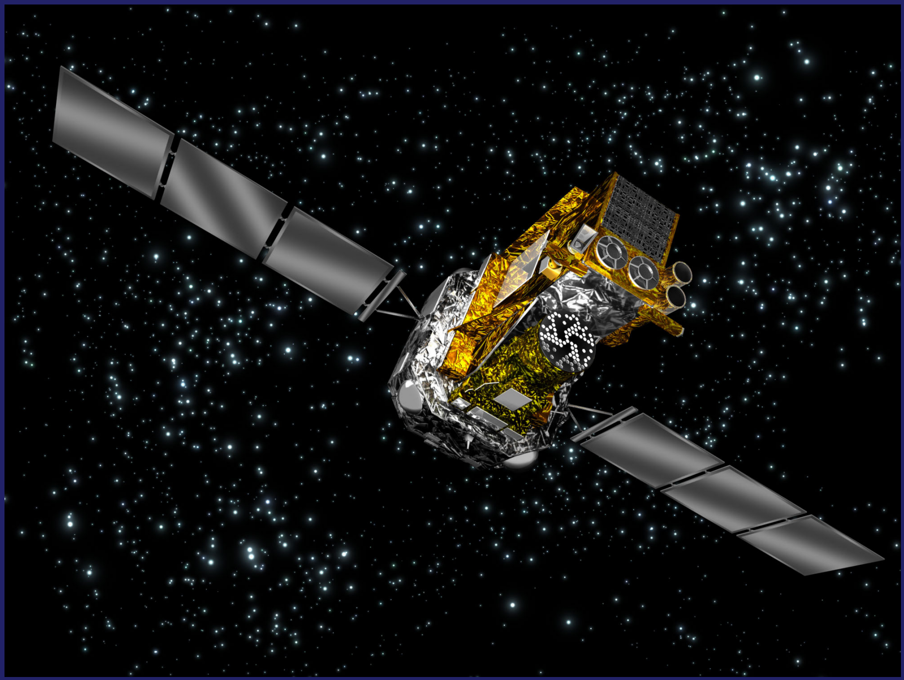
Energy Range is Important!



- Observing in the 1-10 keV energy range (classical X-ray astronomy) alone can give a limited picture.
- 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).

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

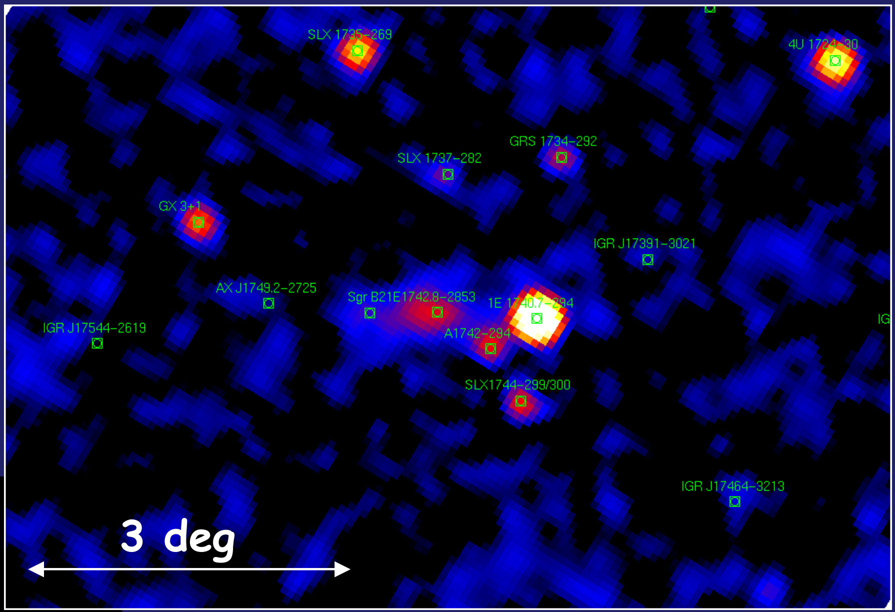
INTEGRAL



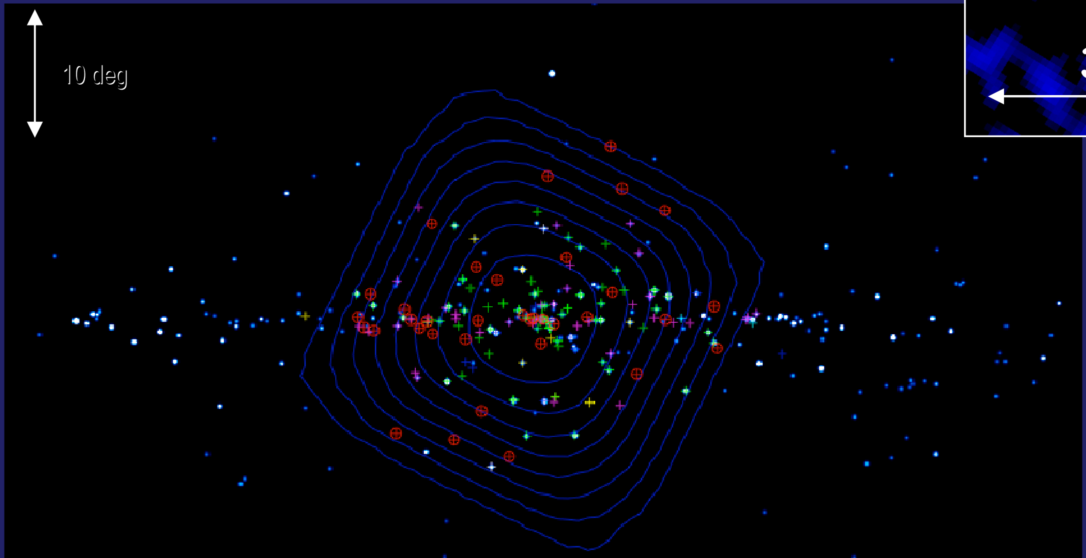
- INTEGRAL, ESA's gamma-ray observatory, has been operating since 2002 October.
- ESA led mission in collaboration with Russia (Proton) and the United States.
- 3 keV to 10 MeV energy coverage
- Highly eccentric 72 hour orbit.
- Mass: 4 tonnes, 5 m high, 16 m span solar panels
- Two Gamma-ray instruments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



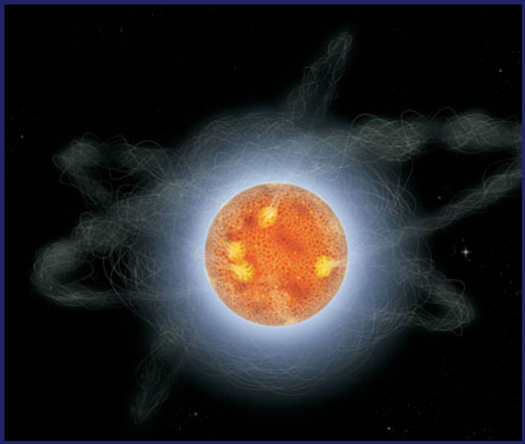
Galactic Centre, 17-50 keV, Δ T = 3 days



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

Exploring new ground

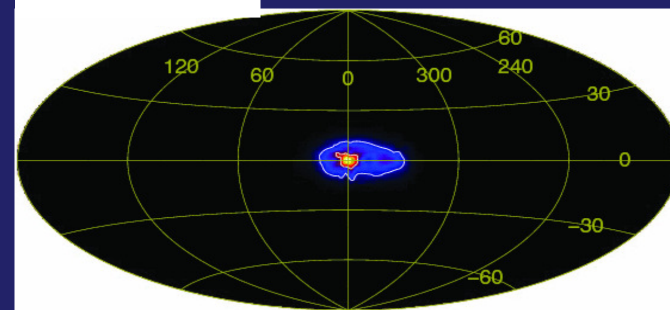
- With its unique properties INTEGRAL has found new classes of X-ray binary sources - heavily absorbed systems and the rapidly varying Supergiant Fast X-ray Transients.
- Further out in the universe, INTEGRAL has demonstrated a lack of heavily absorbed AGN, expected to explain the high-energy background.
- “Magnetars”, neutron stars with extreme magnetic fields; were found to have an unexpected strong emission far above the classical X-ray range.
- There are signs of a new class of fainter gamma-ray bursts, coming from the local universe.



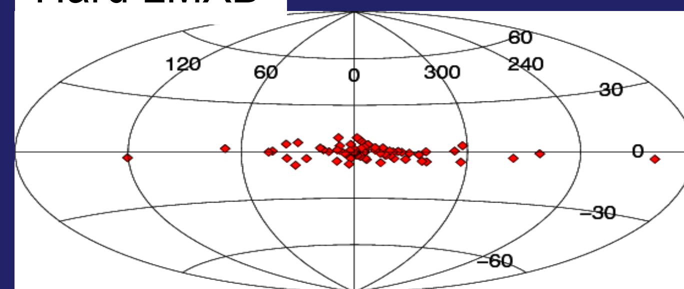
Antimatter at the Centre

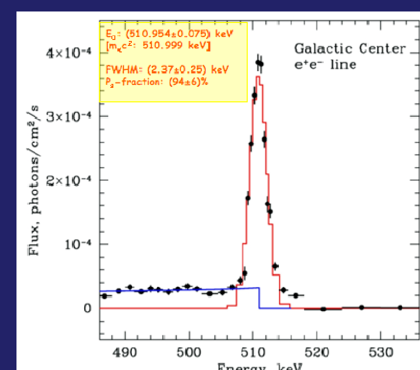
- INTEGRAL's spectrometer, SPI, has observed an asymmetry in the 511 keV diffuse emission from the inner regions of the galaxy
- Half, of possibly all, anti-matter could be produced by hard (>20 keV) LMXB systems which show a similar asymmetry.
- Reduces (or eliminates) need for more exotic explanations involving e.g., dark matter

511 keV



Hard LMXB

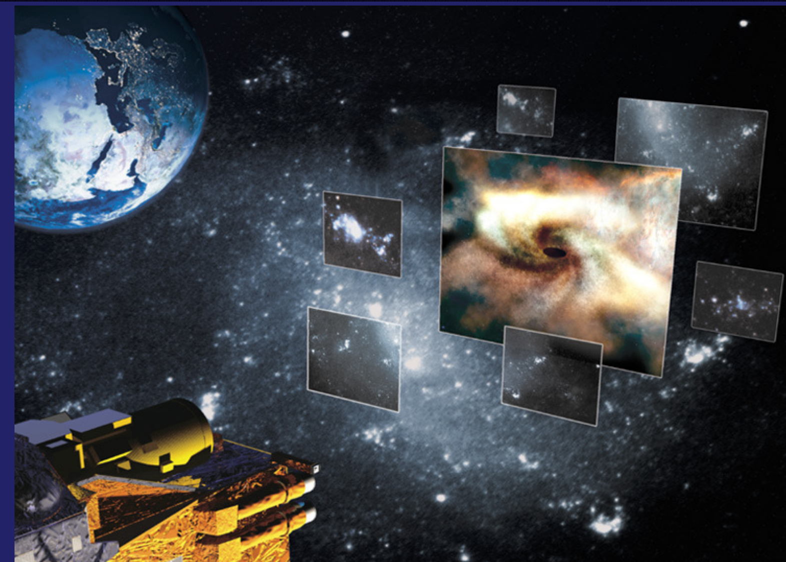




Weidenspointner et al., Nature (2008)

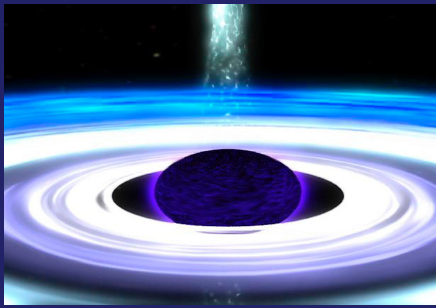
The years to come

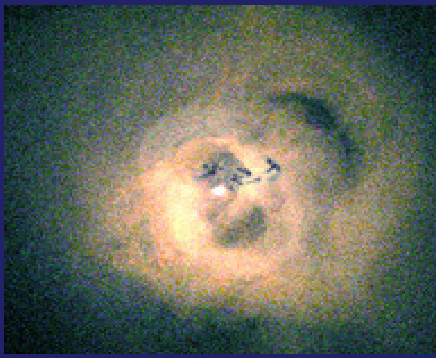
- XMM-Newton and INTEGRAL have sufficient consumables to last until ~2018 and are funded until the end of 2012.
- Both missions are producing first class science and their observing programmes are heavily over-subscribed. No shortage of ideas!
- Given continued good technical status, then these missions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

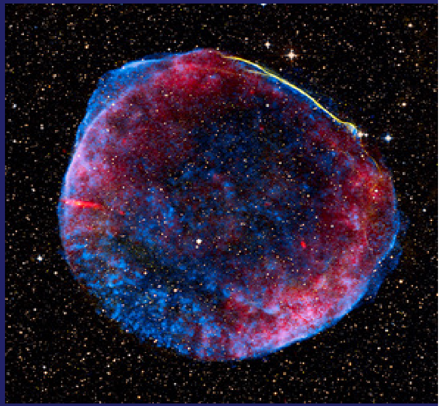


Some Questions to Pursue

- Black Holes and Matter under Extreme Conditions:
  - How do super-massive Black Holes grow and evolve?
  - Does matter close to a Black Hole still follow 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 habitable planets?
  - How are particles accelerated to extreme energies?



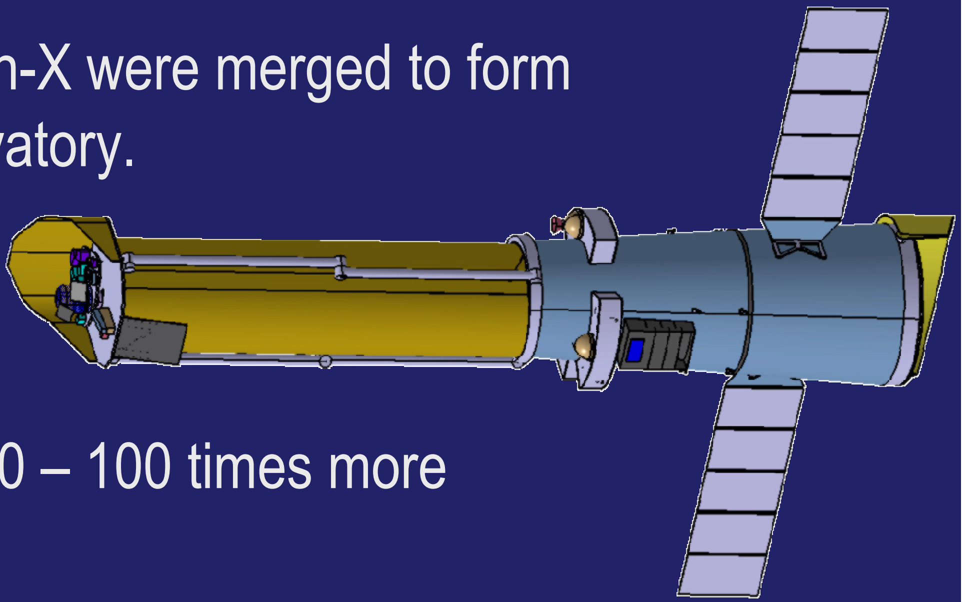




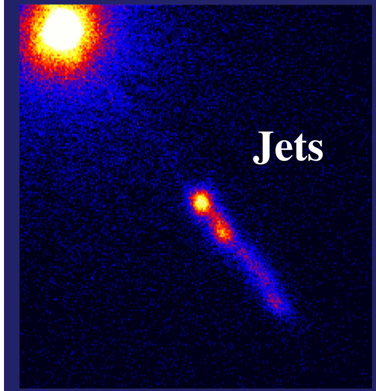
ESA SCIENCE

A Vision of 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.
- The XEUS X-ray observatory concept was one of three large mission concepts selected for an assessment study within the Cosmic Vision framework.
- 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.



Summary



- High-energy astronomy presents us with a, dramatic, violent, ever-changing universe.
- Observing from space allows to study physics under circumstances far beyond our experimental possibilities.
- ESA has contributed for more than 30 years with its high-energy satellites and continues to do so with XMM-Newton and INTEGRAL.
- To shoulder the growing complexity and cost for a factor 10-100 improved performance, the next generation observatory will be a global endeavor. IXO is the natural step in ESA, JAXA and NASA's study of the high-energy universe.