XMM-Newton – Instuments and Mission

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Former Head, ESA Project Scientist Office

Talk Outline

- Setting the scene: introduction to ESA and its Science Programme.
- An introduction to the **X**-ray **M**ulti-**M**irror mission: XMM-Newton
- The XMM-Newton optics and instruments
- Illustrating the capabilities: selected science highlights from XMM-Newton
- Success factors and the future
- Resources

About Me

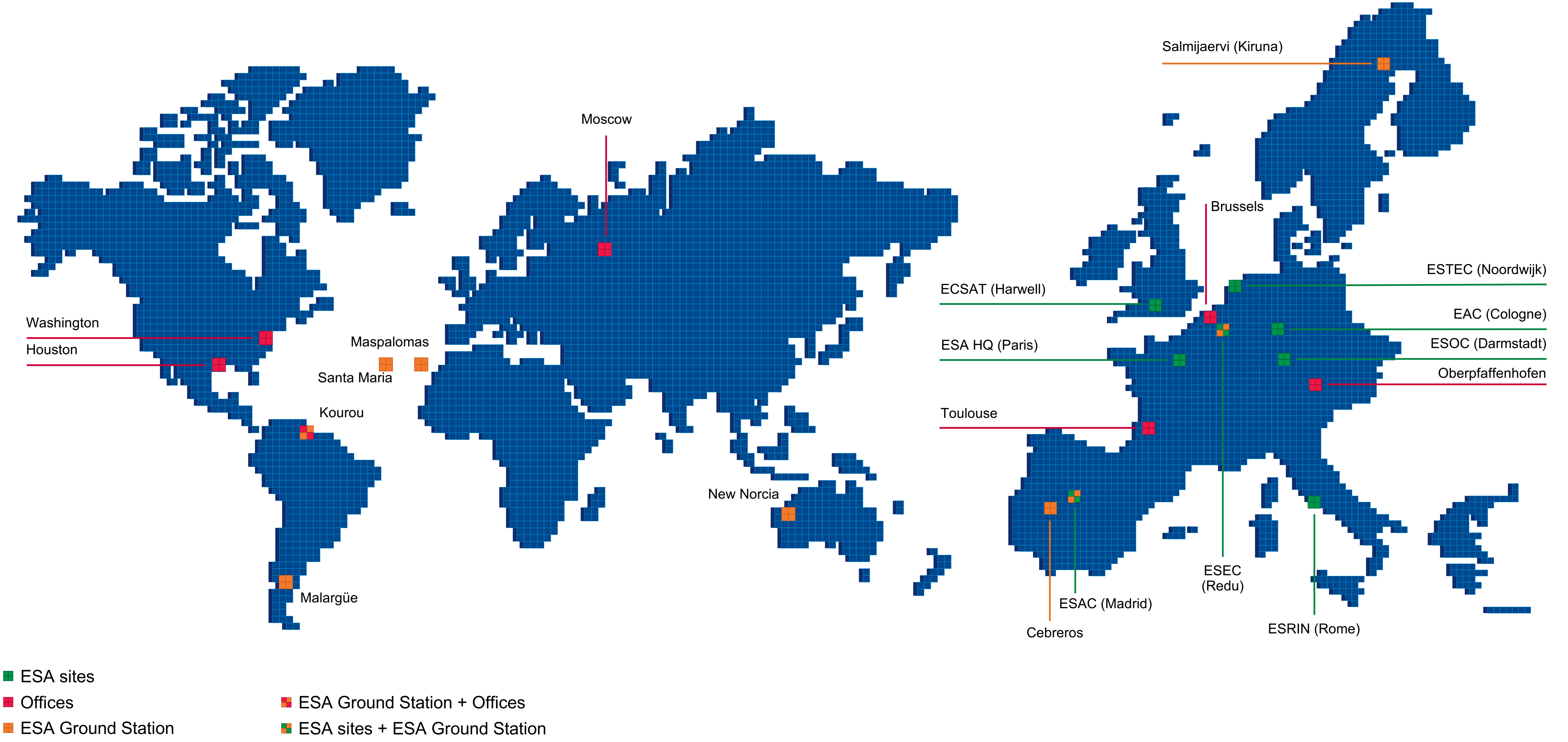
- An X-ray astronomer who studies mainly neutron stars and black holes.
- PhD at MSSL, UK including a year at NASA/GSFC. Then I moved to ESA, working in Germany (ESOC), the Netherlands (ESTEC) and Spain (ESAC).
- At ESAC, I was Head of the Division responsible for the Science Operations of ESA's missions.
- At ESTEC, I was the Head of the ESA Project Scientists team.
- Each science mission has a Project Scientist whose job, broadly speaking, is to maximize the scientific return from their mission, within constraints.

"To provide for and promote, for exclusively peaceful purposes, cooperation among European states in space research and technology and their space applications."

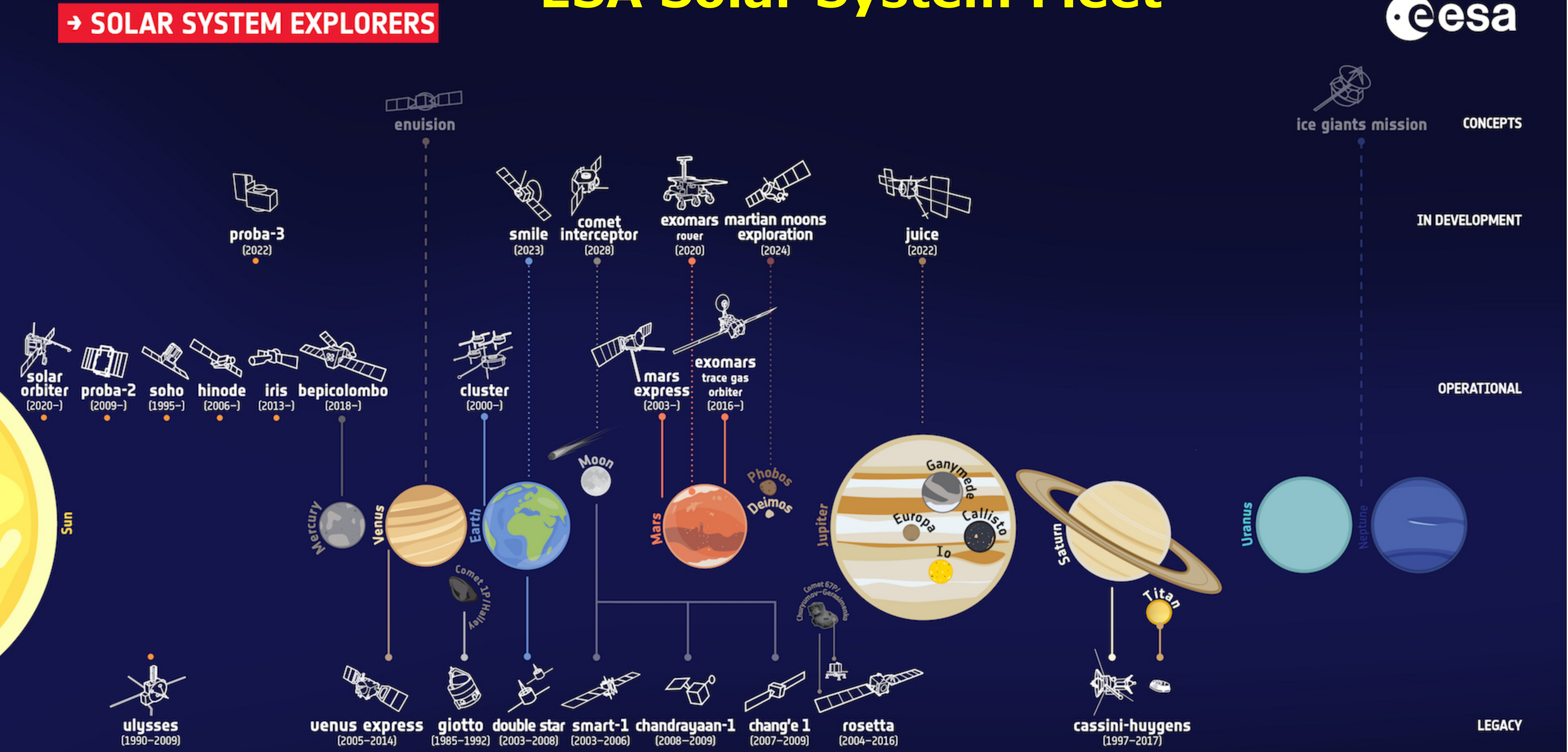
Europe in space

- ESA – Europe’s space agency – combines the resources of its 22 member countries (including many EU countries and Norway, Switzerland and the UK).
- 7 other EU states have Cooperation Agreements with ESA, Slovenia is an Associate Member and Canada takes part in some programmes under a Cooperation Agreement.
- Science is about 15% of ESA (by cost) and Europe has its own telecom, navigation and Earth observation satellites.
- Member States contribute pro-rata to GDP to the Science Programme. Instruments normally nationally funded.
- Europe’s rockets provide guaranteed access to space. Europe’s largest rocket, the Ariane V, has had 82 consecutive launch successes.
- Ariane, Vega and Soyuz rockets are launched from Europe’s space port in French Guyana (near the equator)

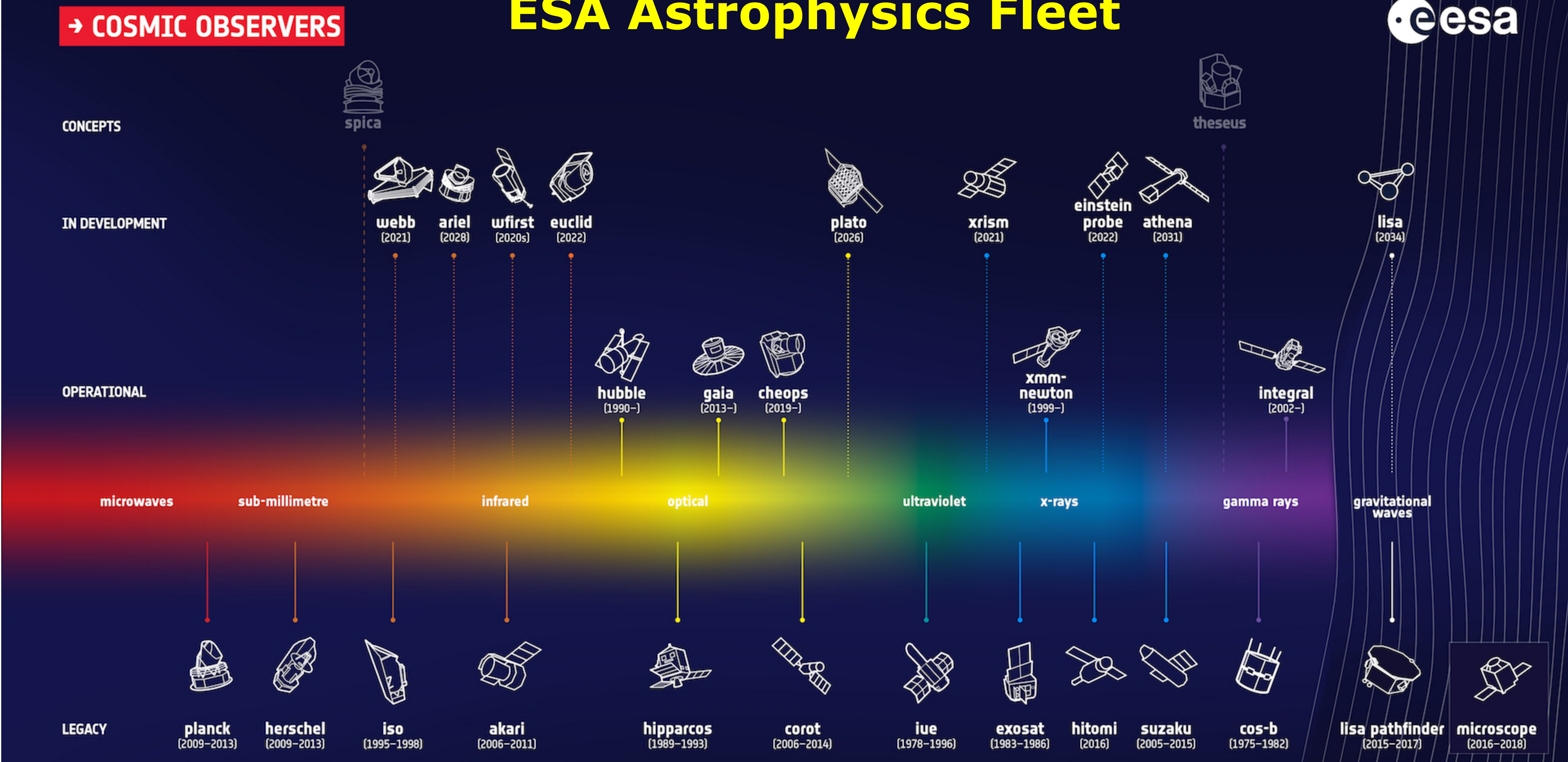
ESA’s Locations

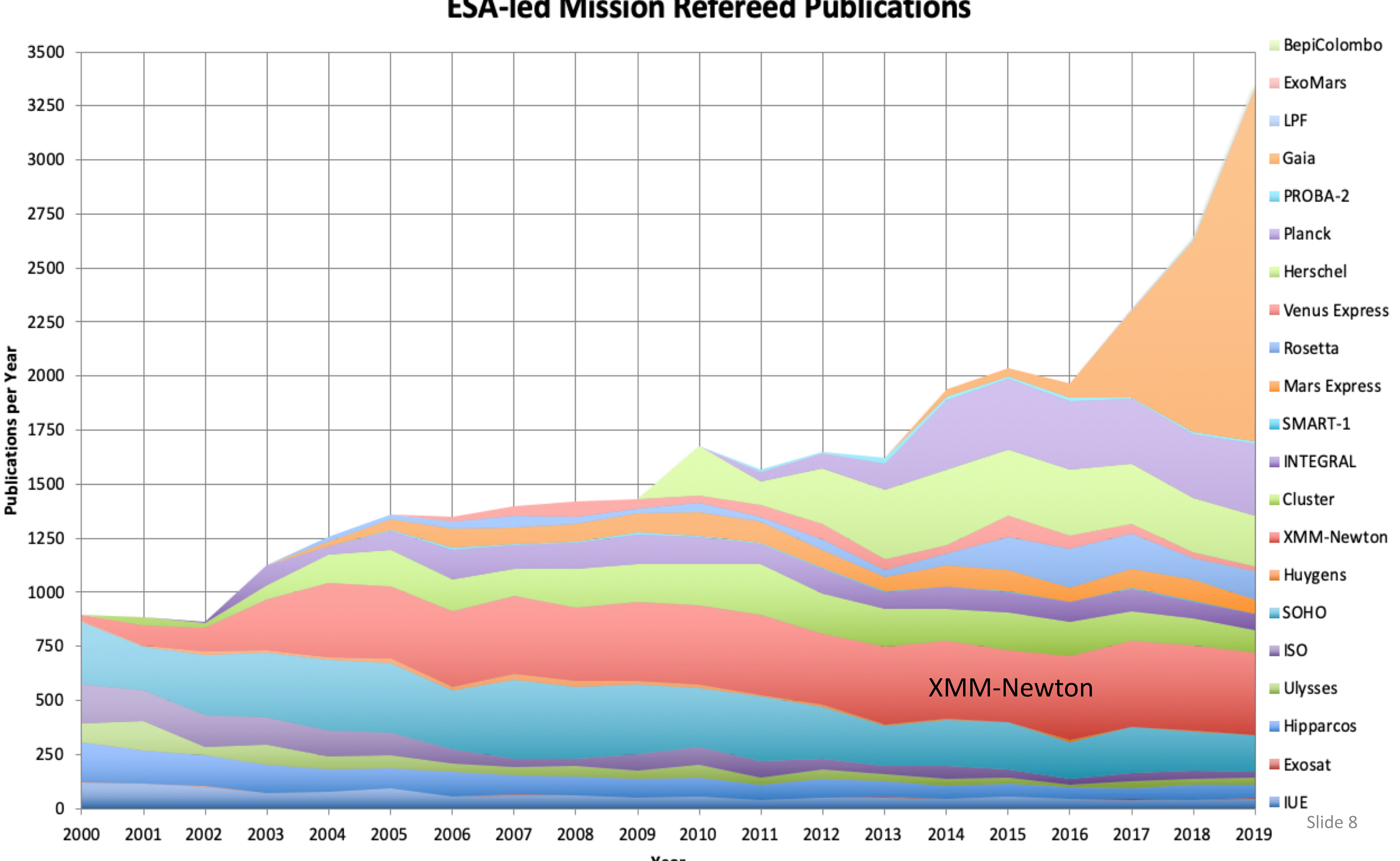


ESA Solar System Fleet



ESA Astrophysics Fleet




ESA-led Mission Refereed Publications
Publications per Year
3500
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
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Year
XMM-Newton
BepiColombo
ExoMars
LPF
Gaia
PROBA-2
Planck
Herschel
Venus Express
Rosetta
Mars Express
SMART-1
INTEGRAL
Cluster
XMM-Newton
Huygens
SOHO
ISO
Ulysses
Hipparcos
Exosat
IUE

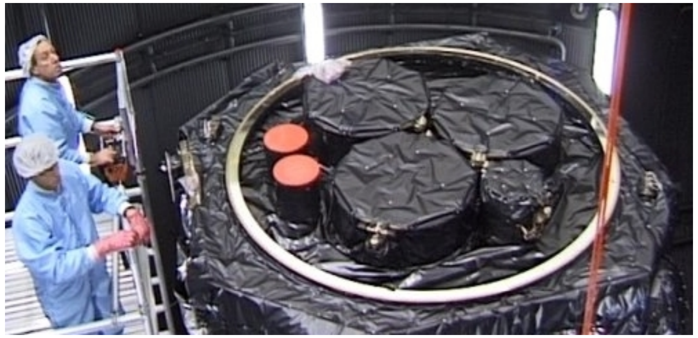
XMM-Newton: An Introduction

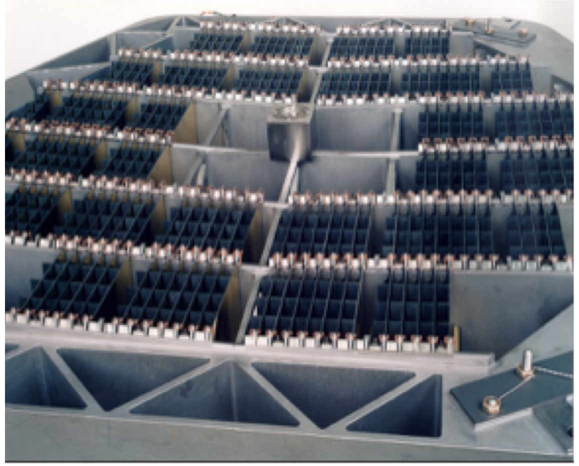
ESA's X-ray observatory

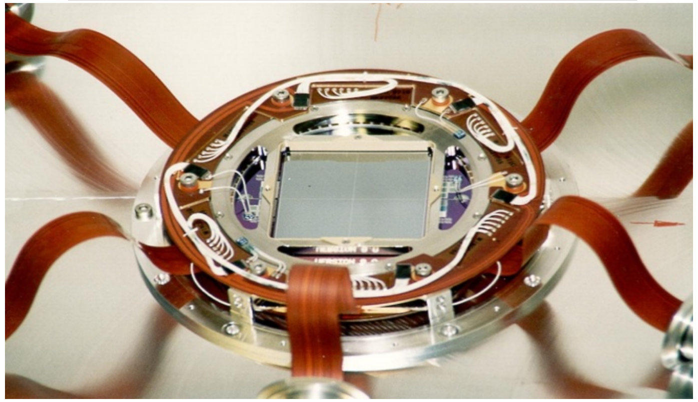
- Launched in 10 December 1999 at 14:32 UTC into a 48-hour eccentric orbit by an Ariane V
- More than 20 years of almost flawless operations
- 3.8 tonne and 11 m in length
- Mission Operations conducted from ESOC (D) and Science Operations from ESAC (ES)
- The US made substantial contributions to two out of the three instruments
- NASA funds the Guest Observer Facility at GSFC, which supports the use of XMM-Newton by the American scientific community. More than a third of the satellite's observing time is awarded to U.S.-based scientists.
- As for other ESA Science Missions, operations are approved to the end of 2022 with the possibility of further extensions

XMM-Newton: An Introduction

Followed EXOSAT (1983) – ESA's first X-ray observatory







Three 15" HEW X-ray mirror modules (4000 cm^2). Six instruments observe simultaneously:

- Two X-ray Reflection Grating Spectrometers (RGS). E/ΔE = 200 to 800. (US contribution)
- Three X-ray CCD cameras (European Photon Image Camera, EPIC (1 pn and 2 MOS). 150 eV energy resolution imaging
- An Optical/UV Monitor (OM) (US contribution)

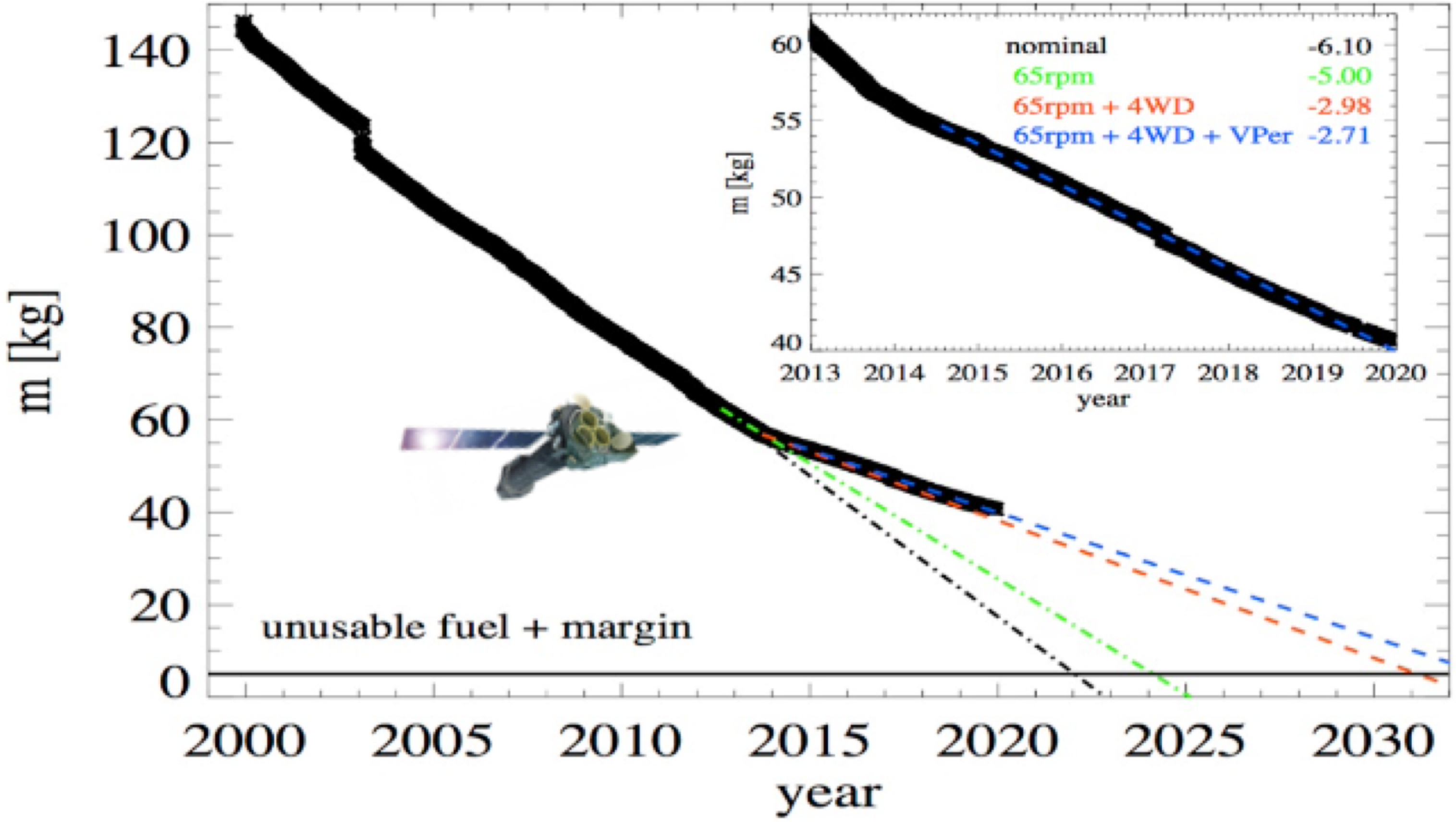
Capabilities are highly complementary to NASA's Chandra observatory (July 1999) which has an effective área of 800 cm^2 and <1" HEW.

XMM-Newton: Observing Programme

- The observing programme is defined by the community. No longer any Guaranteed Time. Annual calls for observing time proposals and peer review (Observing Time Allocation Committee, OTAC) with around rotating 70 members.
- Typical oversubscription in time is ~6 from ~500 proposals.
- Two phase proposal submission process
- Around 1500 scientists worldwide participate in each observing call.
- The Science Operations Centre (SOC) at ESAC provides documentation, a helpdesk, scheduling and coordination with other facilities, rapid ToO implementation, improvements to the data analysis software, calibration and the science archive.
- The Users Group play a key role in ensuring that observatory improvements are prioritized and implementation is monitored.

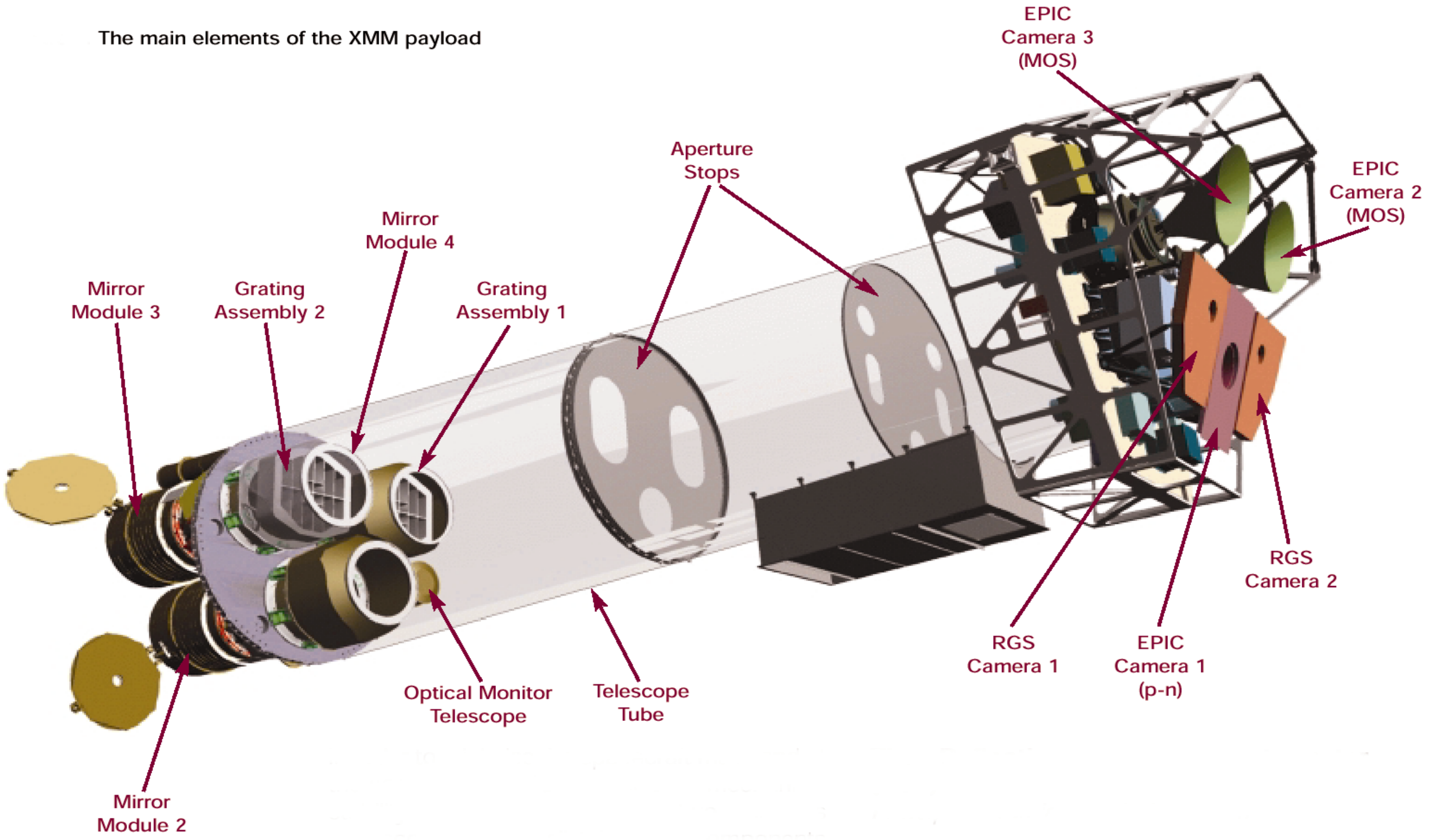
XMM-Newton: Lifetime

- Spacecraft status remains excellent
- All important systems are running on their primary units
- Consumables (fuel) to beyond 2030
- Since 2013 XMM-Newton has been using all 4 reaction wheels (3 reaction wheels before then) which almost halved the fuel consumption



Credit: N. Schartel

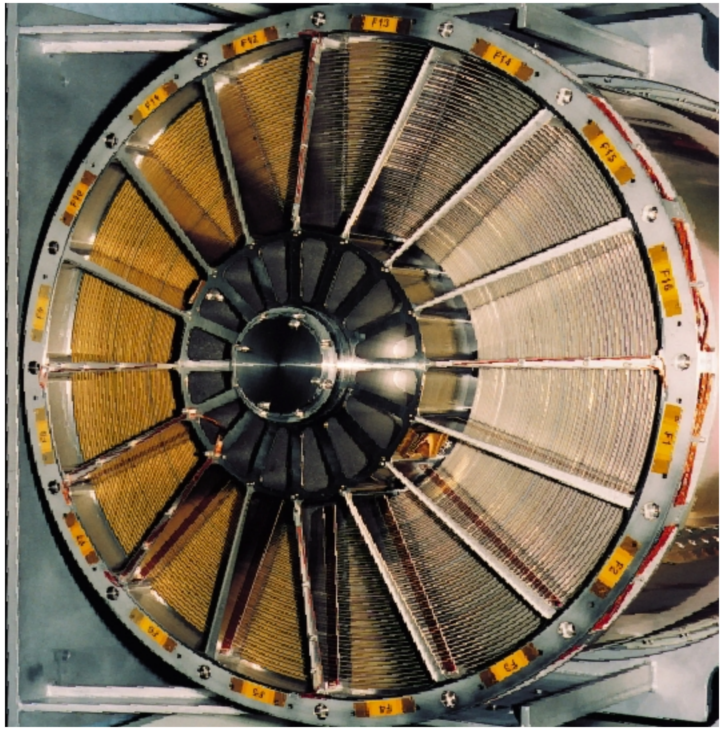
XMM-Newton: An Introduction

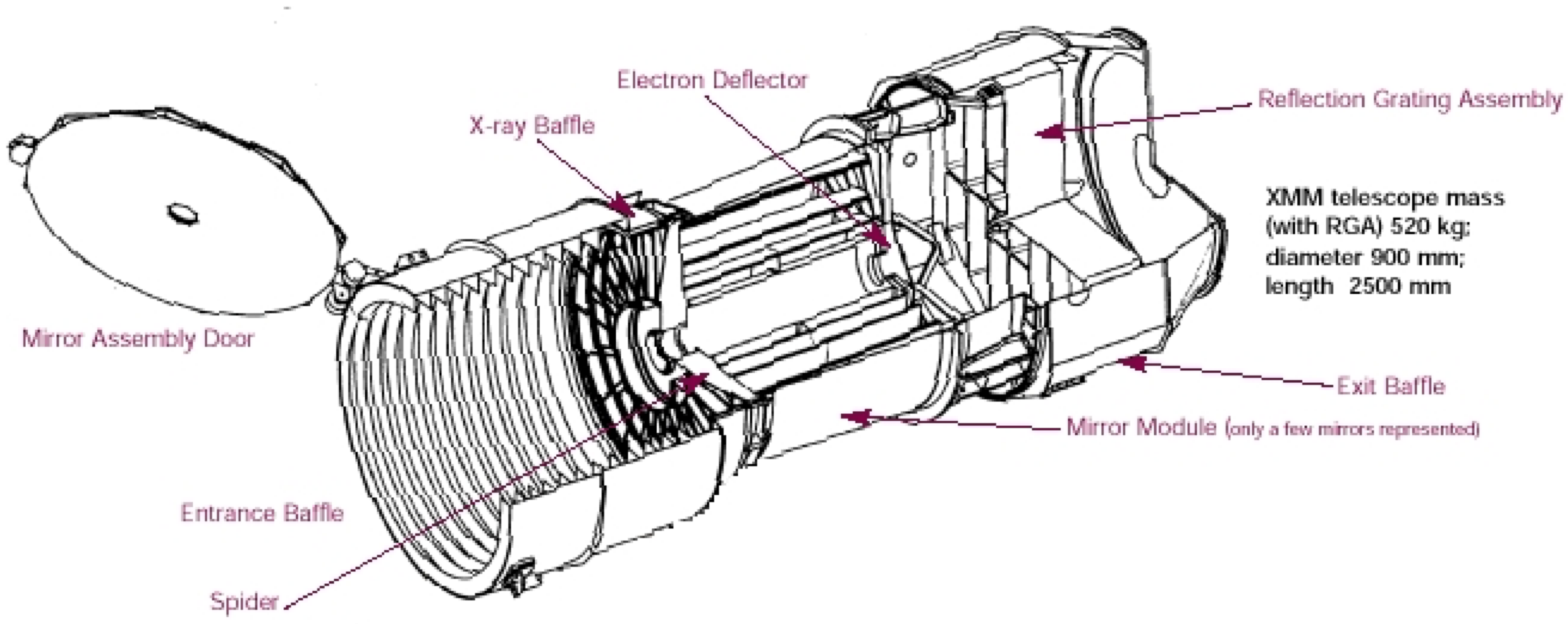


- EPIC:
  - 3 independent CCD-cameras (2 MOS & 1 pn) providing imaging spectroscopy of the same field
  - 3 different light filters for both camera types
  - Different modes to accommodate brightness and timing
- 2 Reflecting Grating Spectrometers (RGS)
  - High-resolution spectroscopy of bright sources in the energy range from 0.3 to 2.1 keV
- Optical Monitor (OM)
  - Extends the spectral coverage of XMM-Newton into the UV and optical
  - Six broadband filters
  - Two grisms, one in the UV and one in the optical

XMM-Newton: Optics

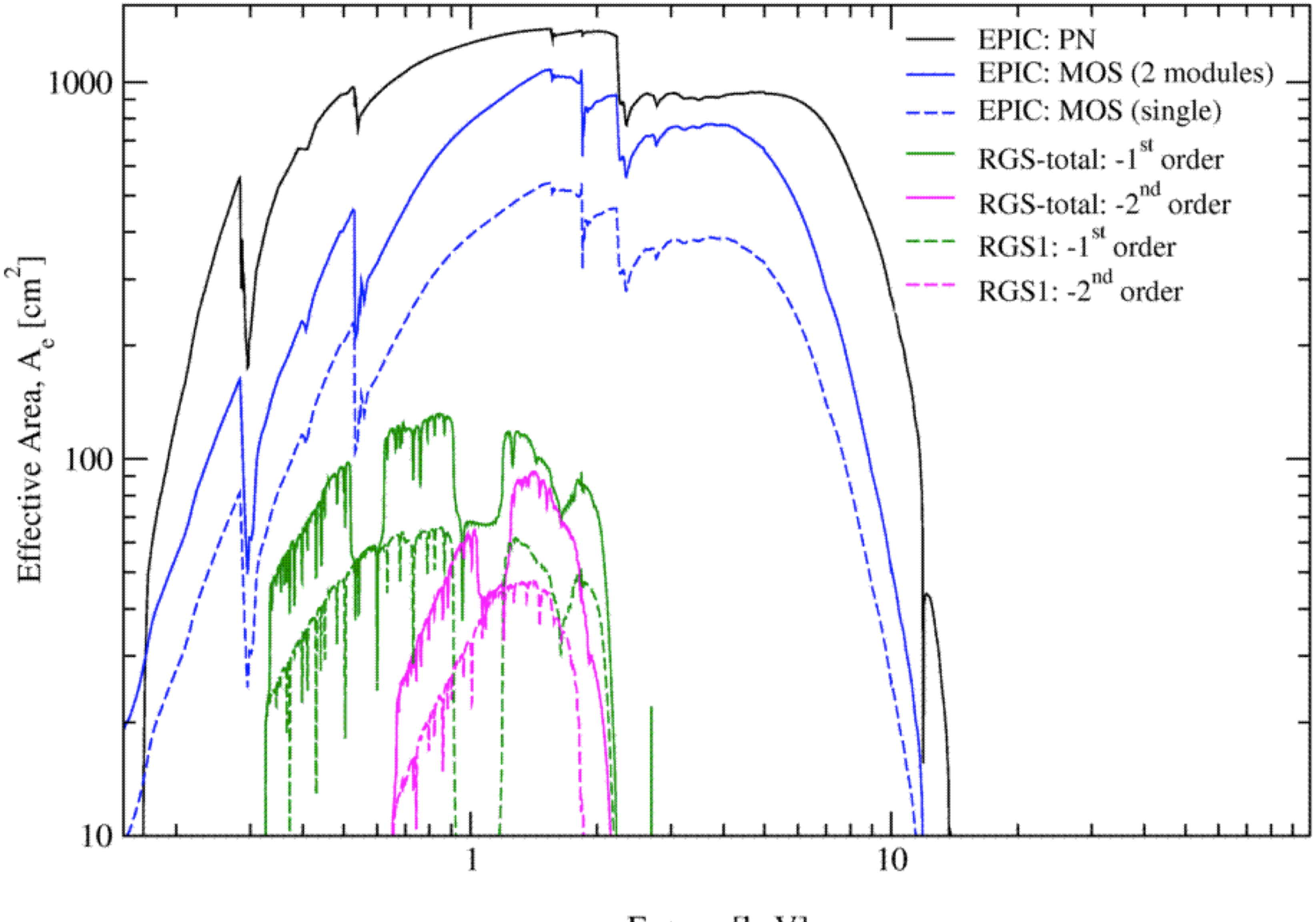
Each of the three X-ray telescopes on board XMM-Newton consists of 58 Wolter I grazing-incidence gold-coated Nickel mirrors. Focal length is 7.5 meters. Outer diameter is 70 cm. Spider with 16 spokes, X-ray and optical baffles, and electron deflector





XMM-Newton: Optics

The X-ray Optics Effective Area

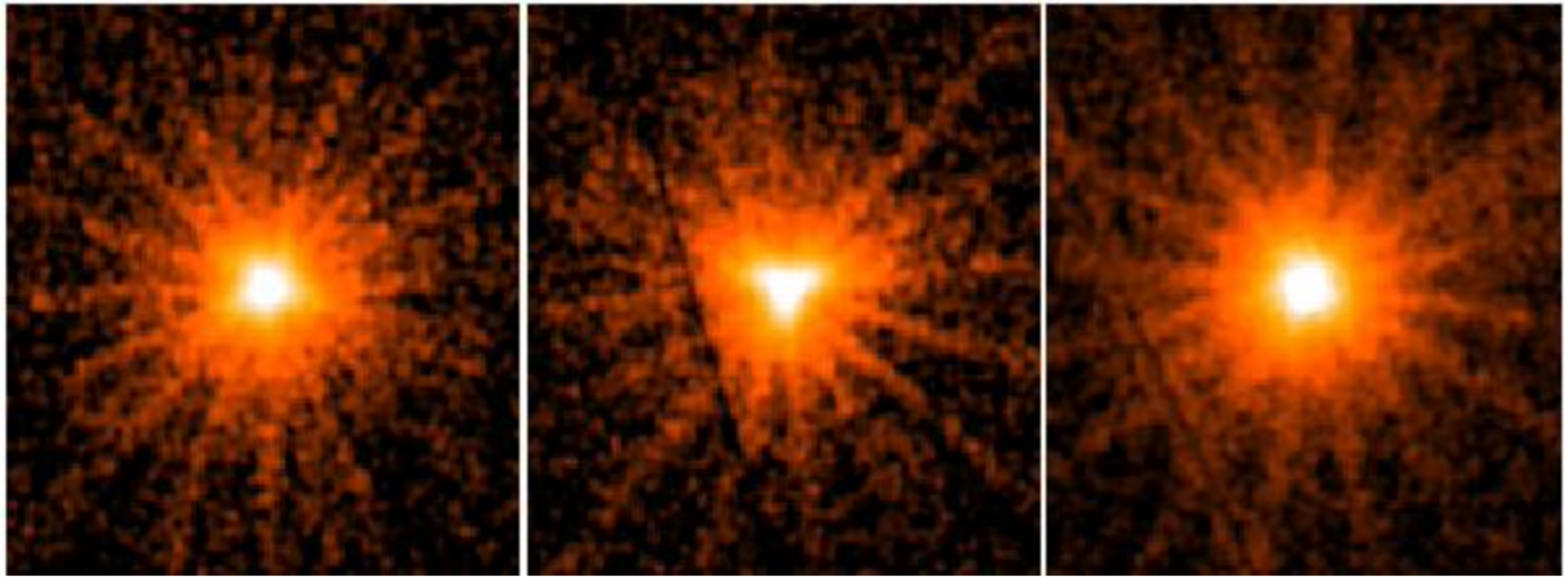


Vignetting at 10’ off-axis:

Area = x 0.4 at 8.0 keV
Area = x 0.6 at 1.5 keV

XMM-Newton: Optics

The X-ray Optics PSF is complex



EPIC MOS1, MOS2 and pn 0.2-10 keV slightly smoothed PSFs of a non-piled up X-ray source. PSF is ~15” HEW, but complex, and mirror unit, position and count rate dependent

XMM-Newton: Instrument Characteristics

The overall instrument characteristics

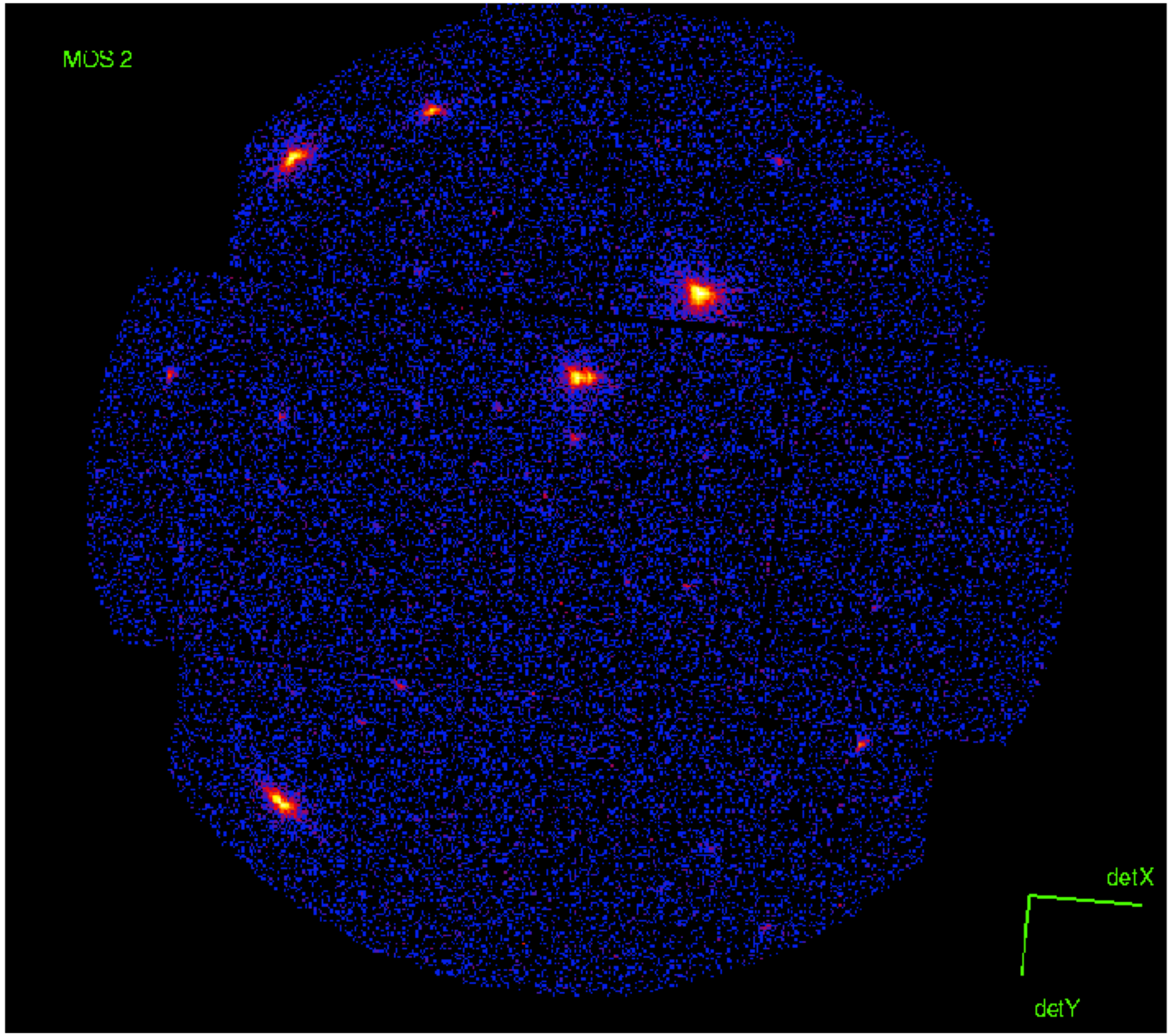
Instrument	EPIC MOS	EPIC pn	RGS	OM
Bandpass	0.15-12 keV	0.15-12 keV	0.35-2.5 keV (1)	180-600 nm
Orbital target vis. (2)	5-135 ks	5-135 ks	5-135 ks	5-145 ks
Sensitivity (3)	$\sim 10^{-14}$ (4)	$\sim 10^{-14}$ (4)	$\sim 8 \times 10^{-5}$ (5)	20.7 mag (6)
Field of view (FOV)	30' (7)	30' (7)	~5'	17'
PSF (*FWHM/HEW*) (8)	5”/14”	6”/15”	N/A	1.4”-2.0”
Pixel size	40 μm (1.1”)	150 μm (4.1”)	81 μm (9×10^{-3} Å) (9)	0.476513” (10)
Timing resolution (11)	1.75 ms	0.03 ms	0.6 s	0.5 s
Spectral resolution (12)	~70 eV	~80 eV	0.04/0.025 Å (13)	180 (14)

(3) After 10 ksec in erg cm^{-2} s^{-1}

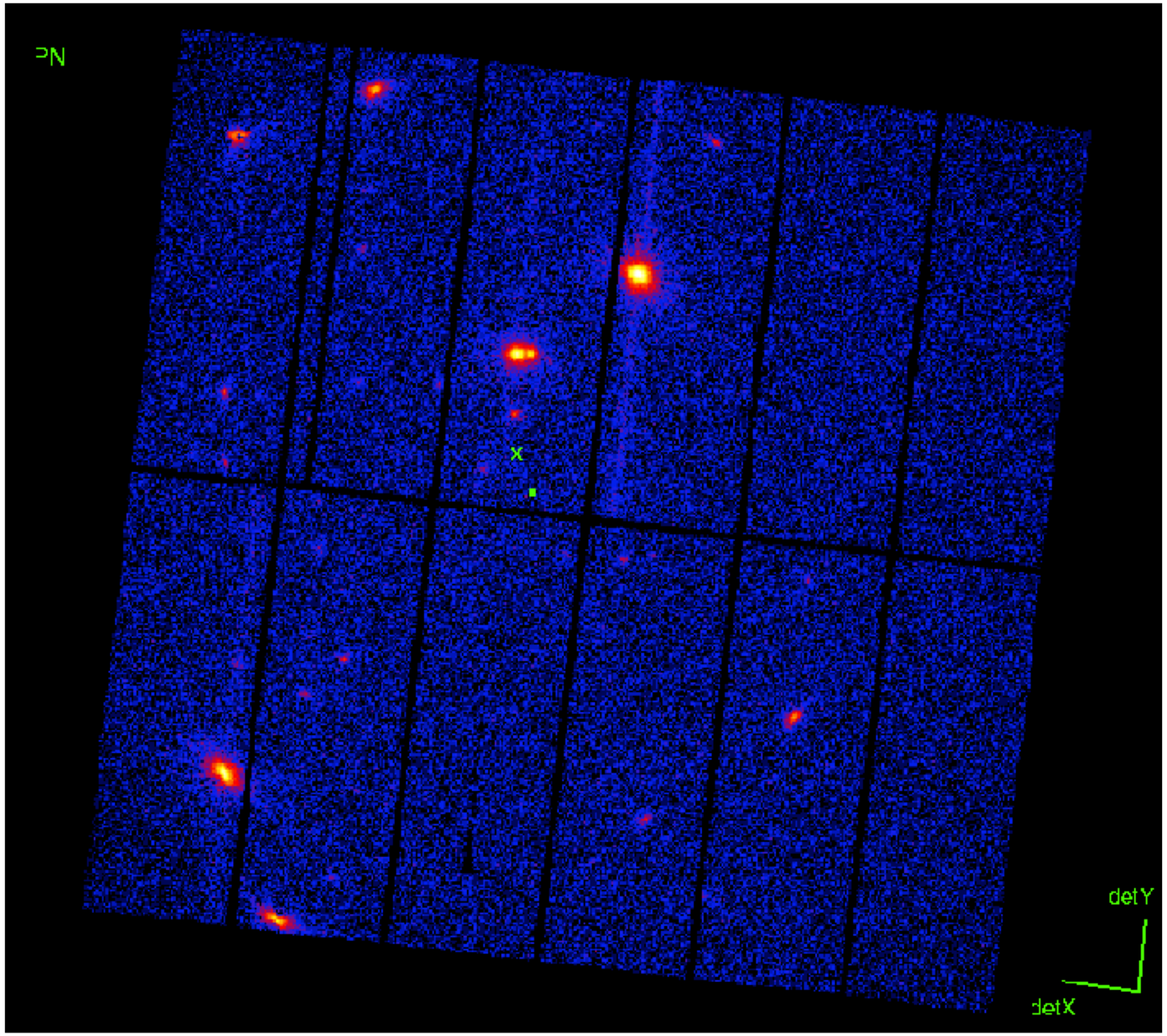
(12) At 1 keV. EPIC ~150 eV at 6.4 keV

XMM-Newton: EPIC Images

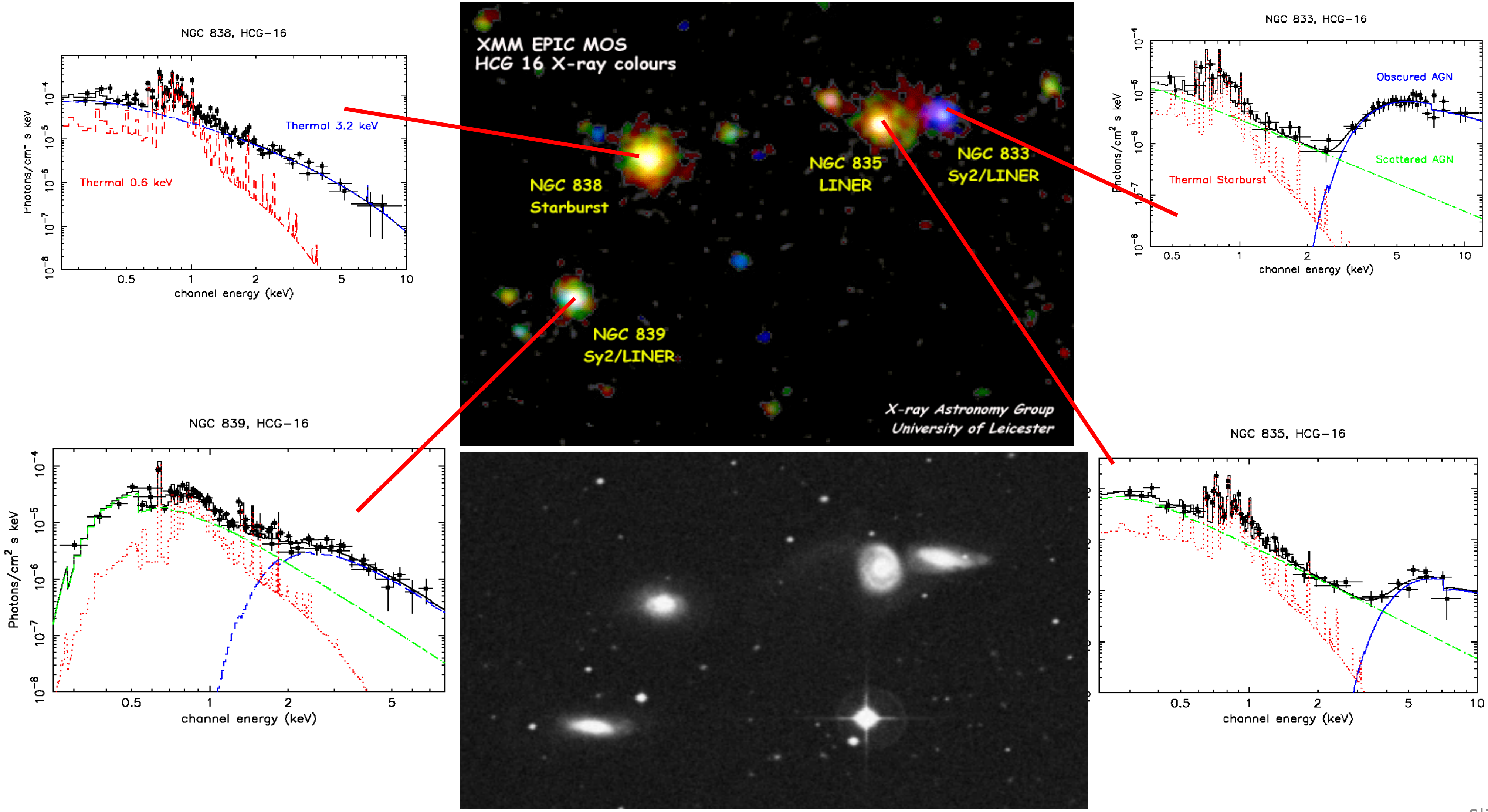
7 Front illuminated CCDs each 10.9’ x 10.9’



12 Back illuminatedCCDs each 13.6’ x 4.4’



XMM-Newton: Imaging Spectroscopy



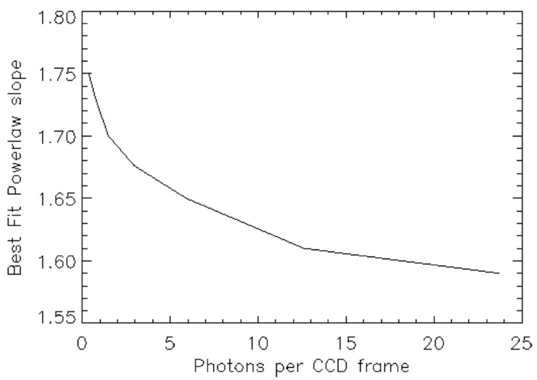
XMM-Newton: Pile-up

Pile-up occurs when a source is so bright that there is a significant possibility that two or more X-ray photons deposit charge packets in a single pixel during one read-out cycle.

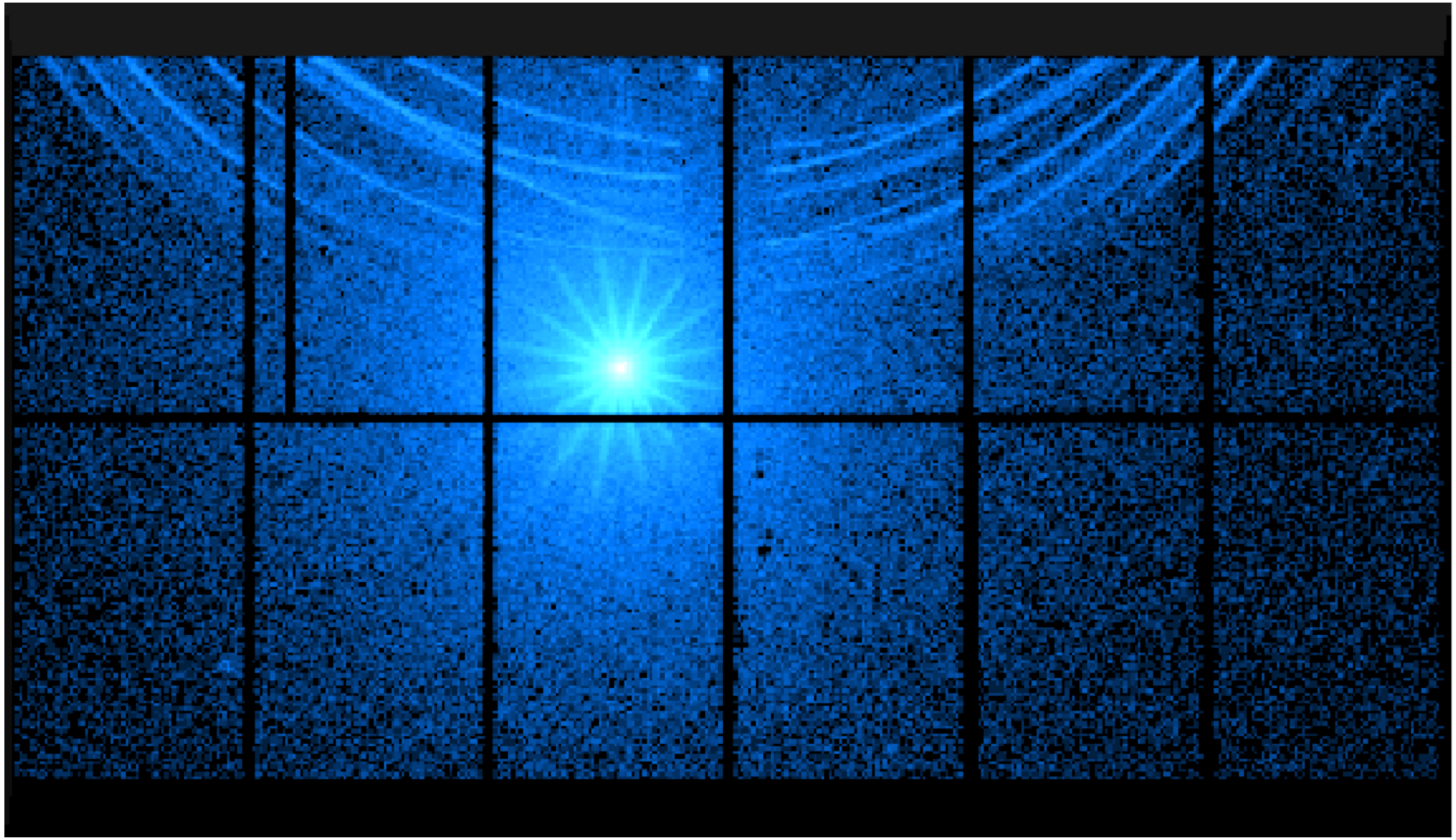
- In such a case these events are recognized as one single event having the sum of their energies. This will result in a hardening of the spectrum as piled-up soft events are shifted in the spectrum to higher energies, unless the sum of the energies is higher than the threshold for event rejection onboard.
- In addition, pile-up leads to a more or less pronounced depression of counts in the central part of a bright source, resulting in flux loss.
- Choice of EPIC modes is important. Tools to evaluate pile-up available.

An example of the effects of pileup of an absorbed 1 keV thermal plasma on the MOS full window mode with different input fluxes in units of 0.15-10 keV 10^{-12} erg cm^{-2} s^{-1}

Input flux [1]	Output count rate [s^{-1}]	Counts per MOS frame	N_H [10^{20} cm^{-2}]	kT [keV]	Norm./ expect
4.05	1.08	0.22	3.0	0.967	1
13.4	3.56	0.71	3.05	0.972	1
40.5	10.5	2.1	3.2	0.979	0.98
134	33.3	6.65	3.5	1.010	0.95
405	85.4	17.1	4.1	1.022	0.80

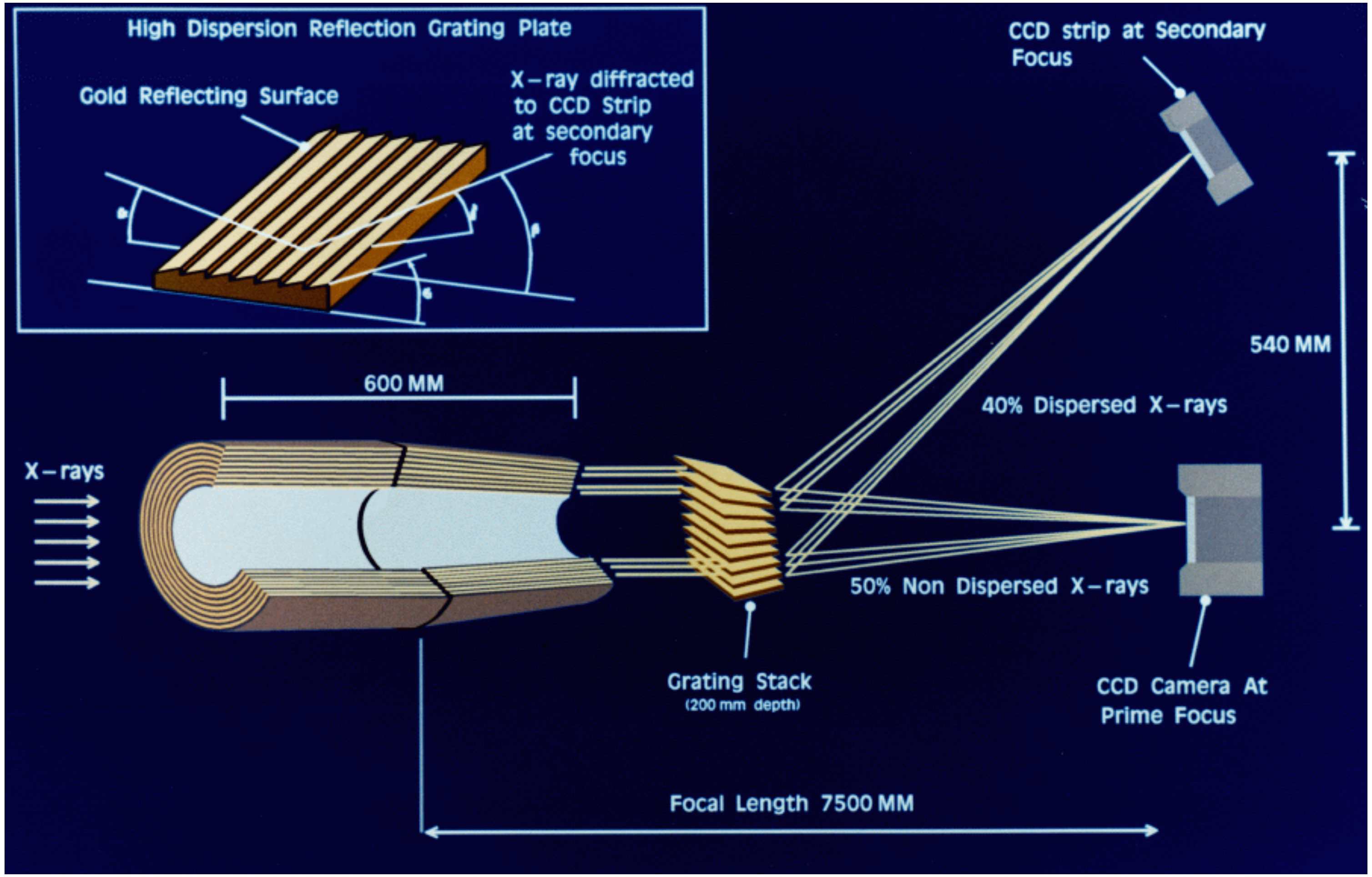


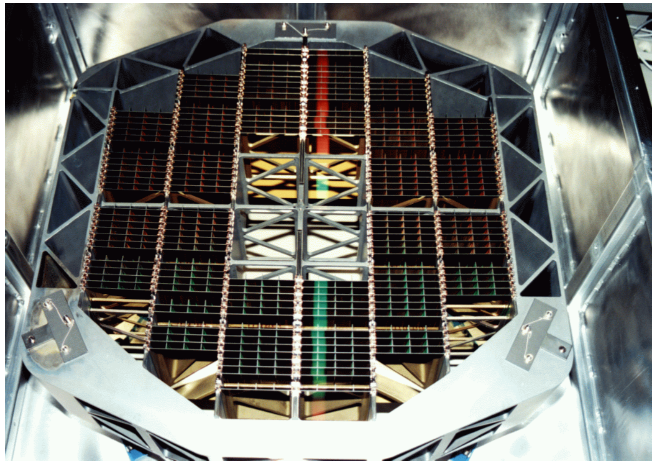
XMM-Newton: Straylight

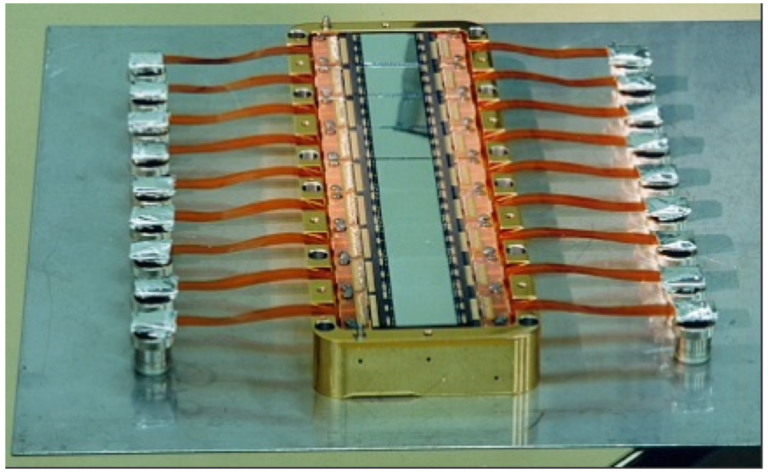


Straylight: EPIC pn image of GRS 1758-258 demonstrating the complex PSF and the effects of straylight.
In the upper part of the image, sharp arcs appear that are caused by single mirror reflections of photons from GX 5-1 which is $\sim 40'$ off-axis to the north and outside the FOV.

XMM-Newton: Reflection Grating Spectrometer





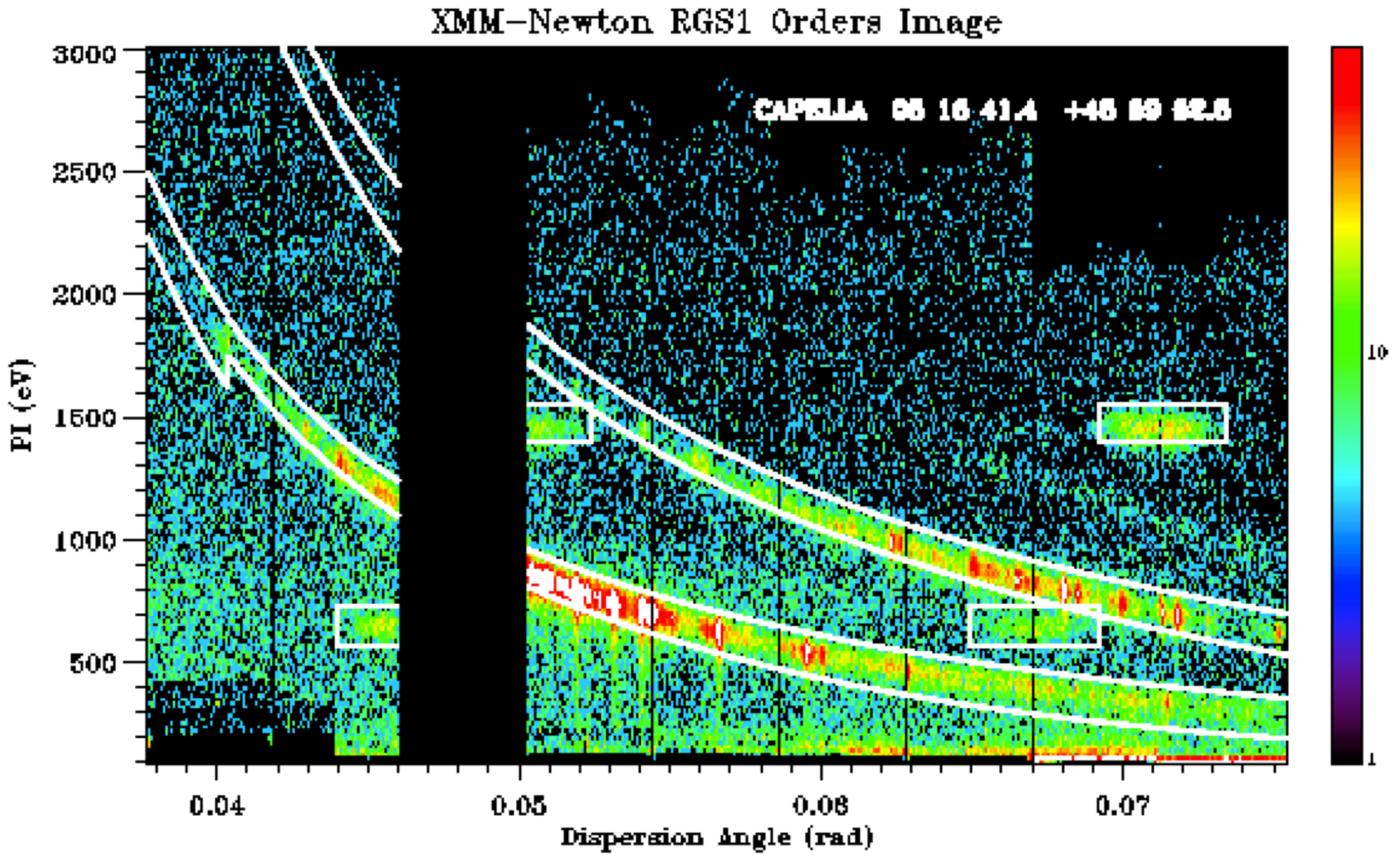


9 CCDs for readout

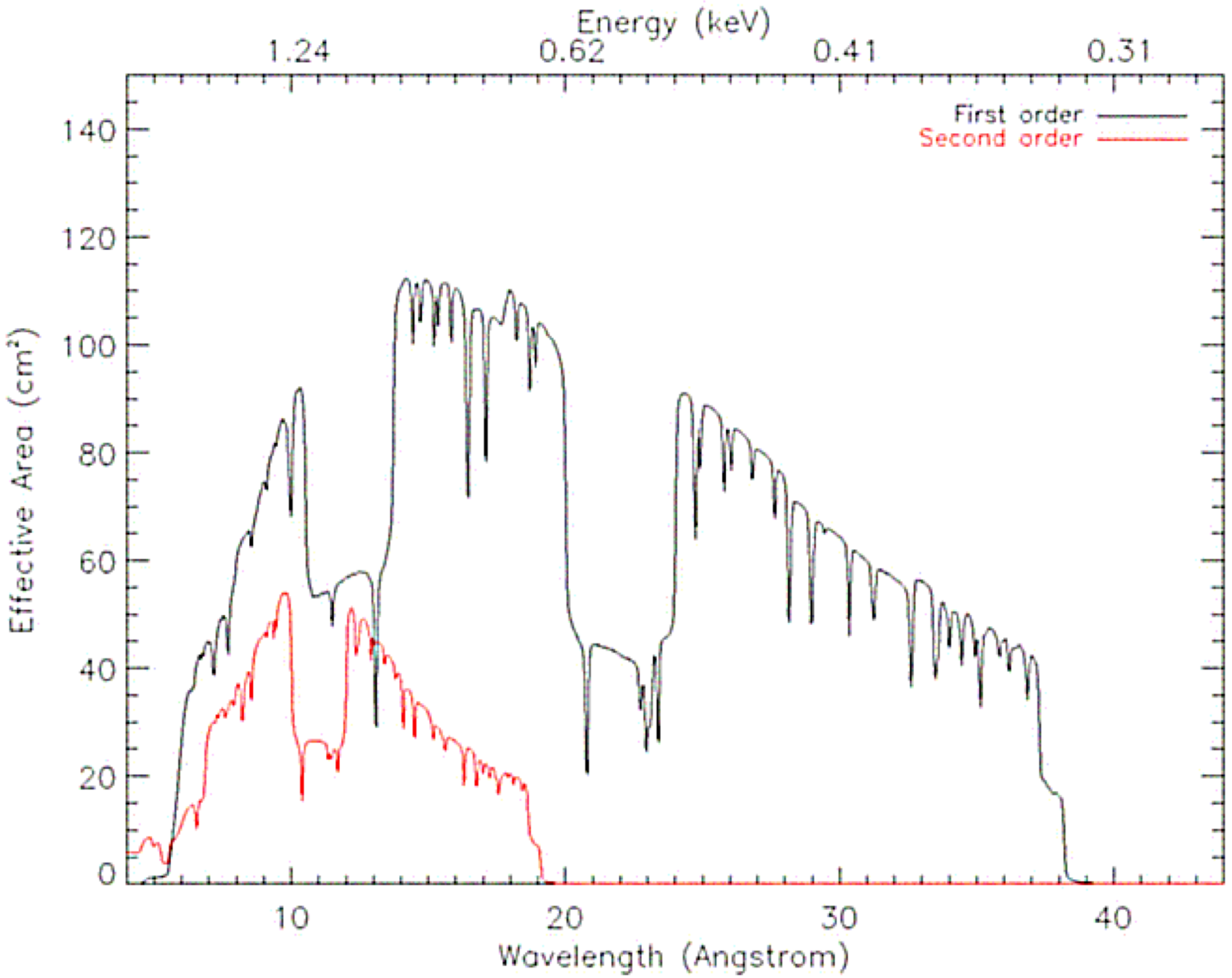
XMM-Newton: Reflection Grating Spectrometer

		RGS1			RGS2		
		10 Å	15 Å	35 Å	10 Å	15 Å	35 Å
Effective area (cm^2)	1st order	51	61	21	53	68	25
	2nd order	29	15	-	31	19	-
Resolution ($km\ s^{-1}$)	1st order	1700	1200	600	1900	1400	700
	2nd order	1000	700	-	1200	800	-
Wavelength range	1st order	5 - 38 Å (0.35 - 2.5 keV)					
	2nd order	5 - 20 Å (0.62 - 2.5 keV)					
Wavelength accuracy	1st order	$\pm$5 mÅ			$\pm$6 mÅ		
	2nd order	$\pm$5 mÅ			$\pm$6 mÅ		
Bin size [3x3 $(27\mu)^2$ pixels]		2.5 arcsec (cross dispersion direction)					
	7 - 14 mÅ (dispersion direction, first order)						

XMM-Newton: Reflection Grating Spectrometer



XMM-Newton: Reflection Grating Spectrometer



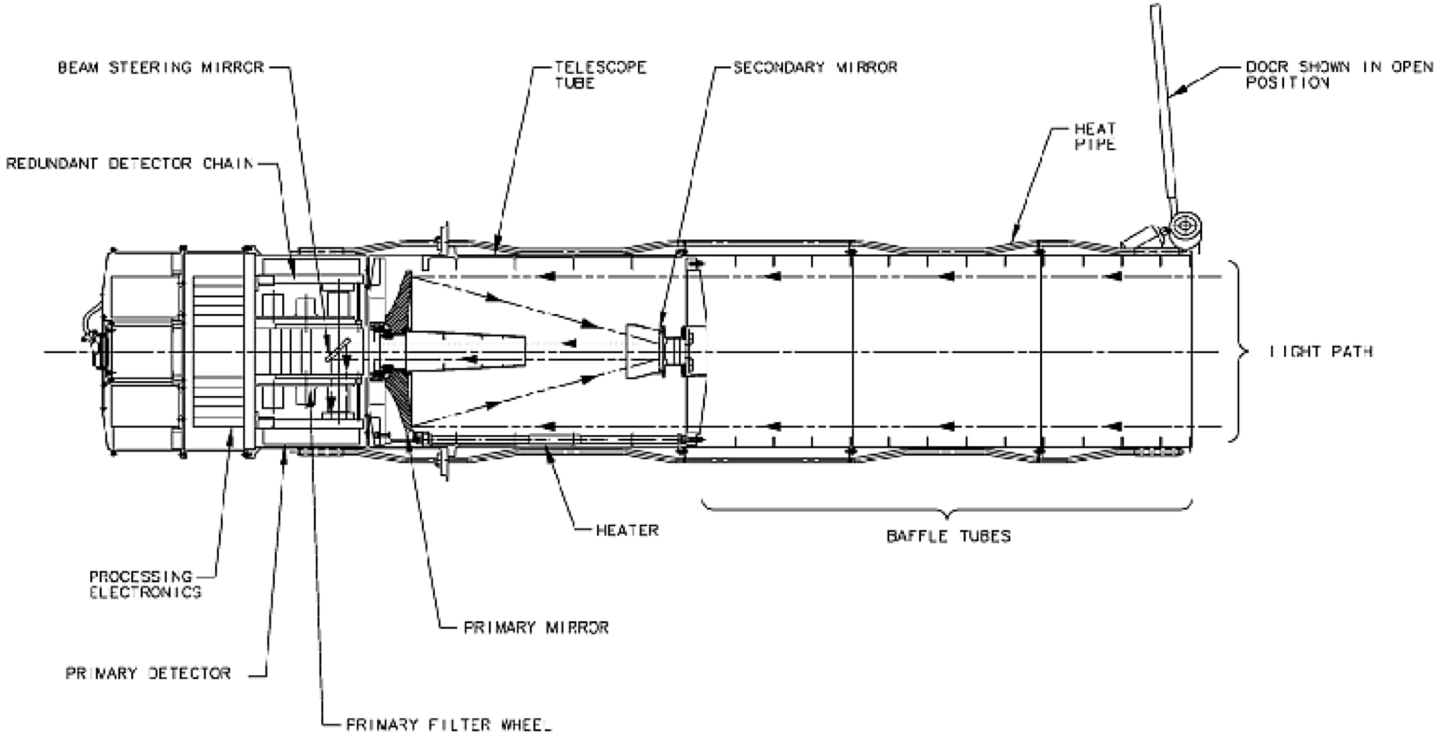
RGS1 and 2 Summed Effective Area

CCD4 on RGS2 failed after the first week of operations

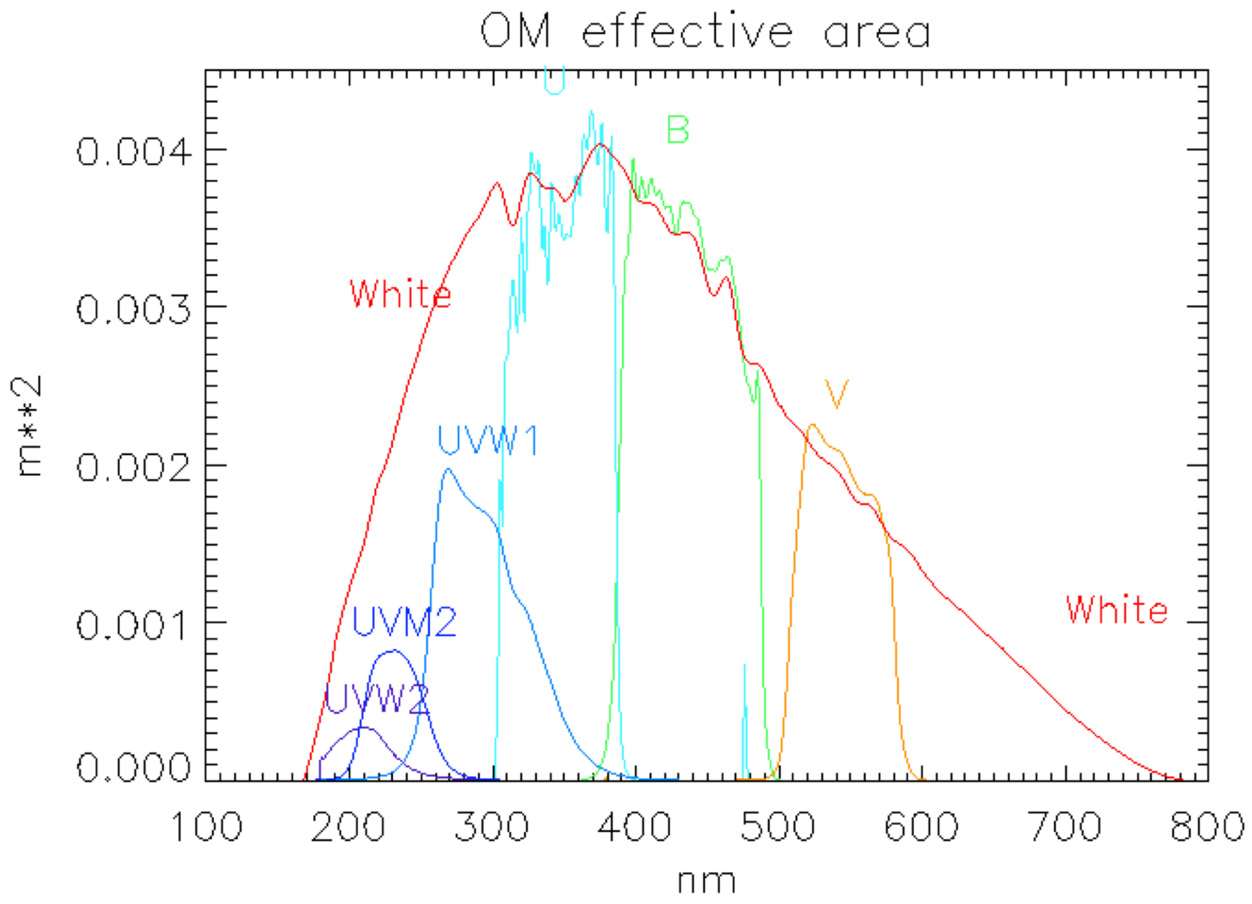
CCD7 of RGS1 failed in Sep 2000

XMM-Newton: Optical Monitor

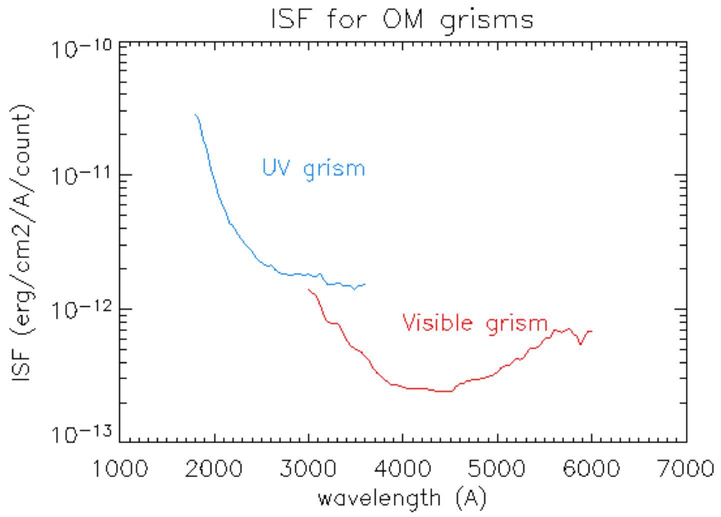
The OM telescope consists of modified Ritchey Chrétien optics. From the primary mirror, incoming light is reflected onto a secondary from where it is reflected onto a rotatable flat mirror located behind the primary. This can direct the beam onto one of two detector assemblies operated in cold redundancy. Spectral resolution is achieved using narrow-band filters and two grisms mounted on a rotating filter wheel. Each OM detector consists of two micro-channel plate (MCP) intensifiers (~10^5) feeding an oversampled 256 x 256 usable pixel CCD. The FWHM is 1-2"



XMM-Newton: Optical Monitor



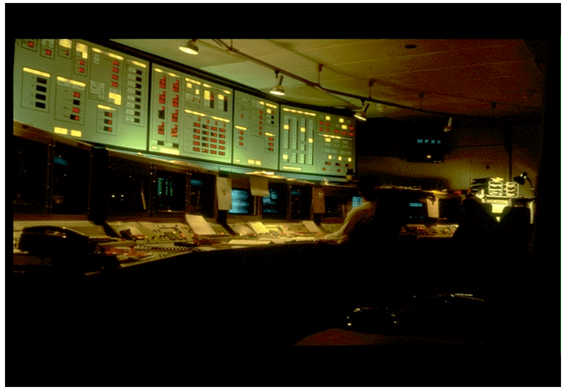
Throughput curves for the various OM filters folded with the detector sensitivity



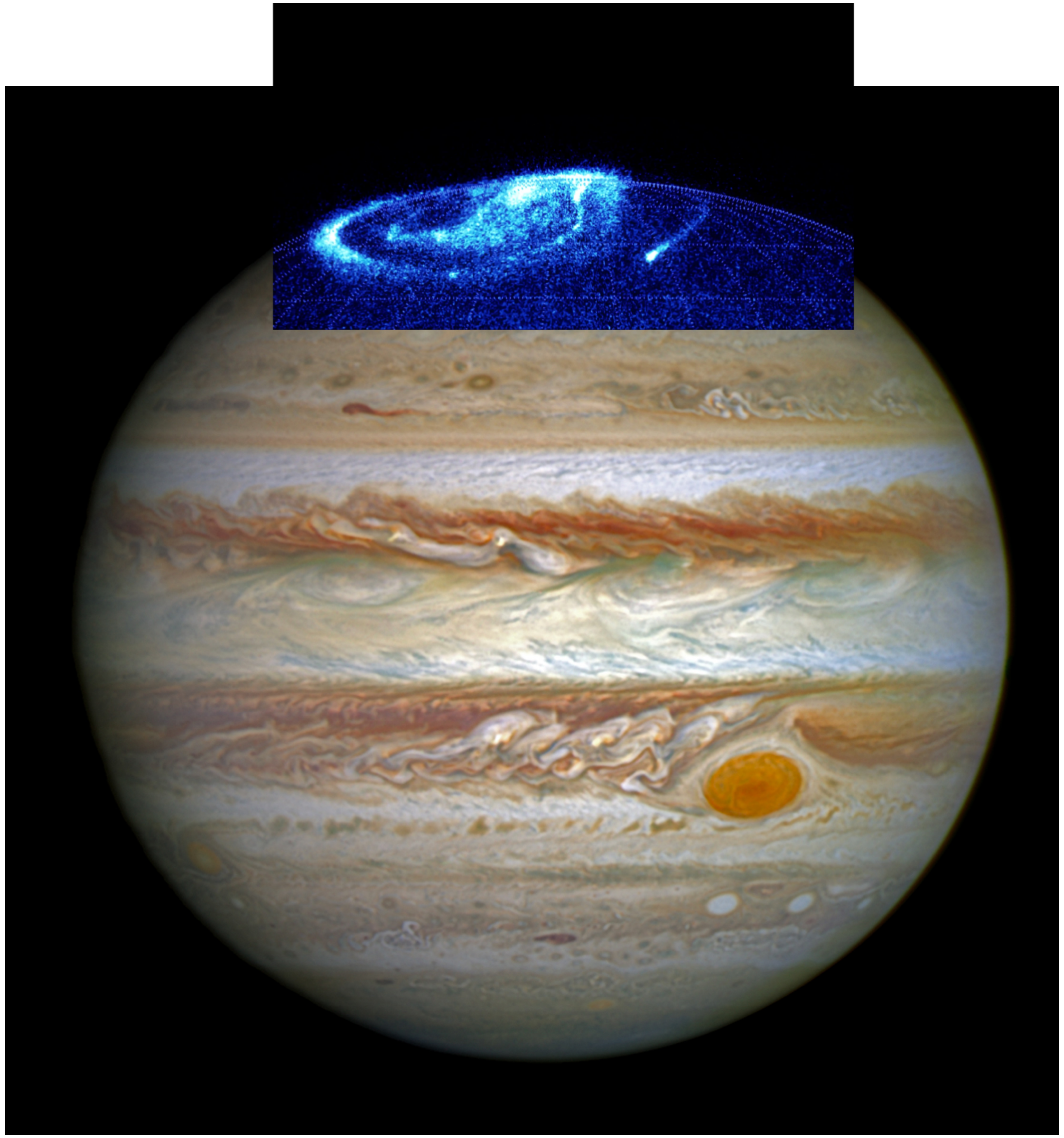
The Inverse Sensitivity Function (ISF) for the two grisms gives the transformation from count rate in an extracted spectrum to physical flux units as a function of wavelength.

XMM-Newton's Predecessor - EXOSAT

- EXOSAT (1983-1986) was ESA's first X-ray observatory. Made 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%). Non-imaging
  - Gas scintillation proportional counter ($\Delta E/E$ ~10%). Non-imaging

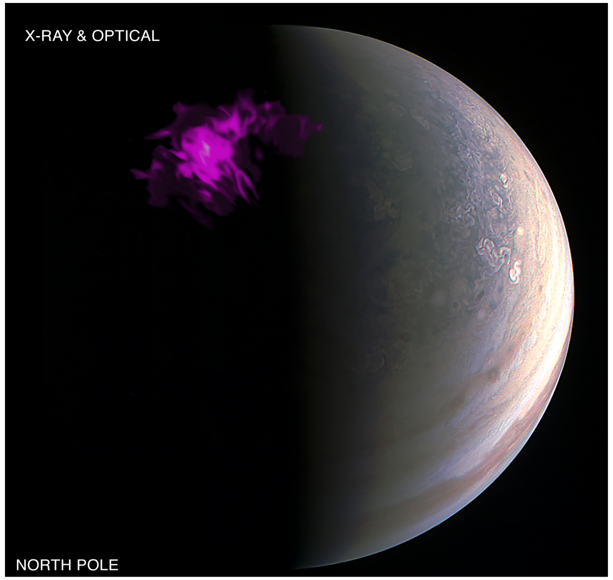


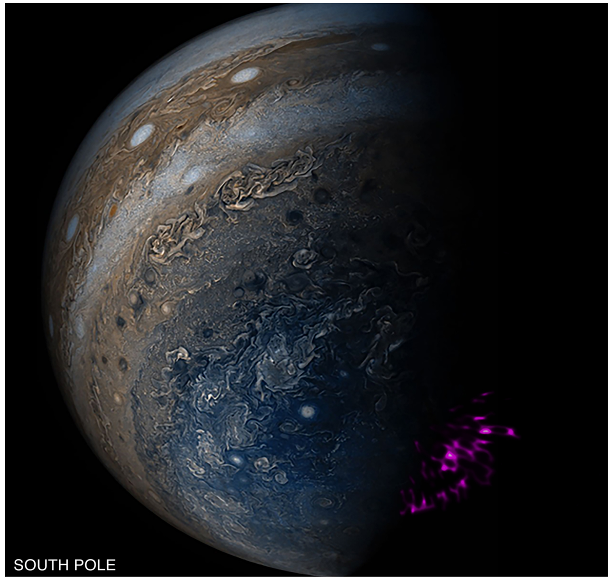
XMM-Newton: Science Highlights



HST STIS UV on 19 May 2016 + WFC3-UVIS composite from OPAL programme / NASA, ESA, J. Nichols

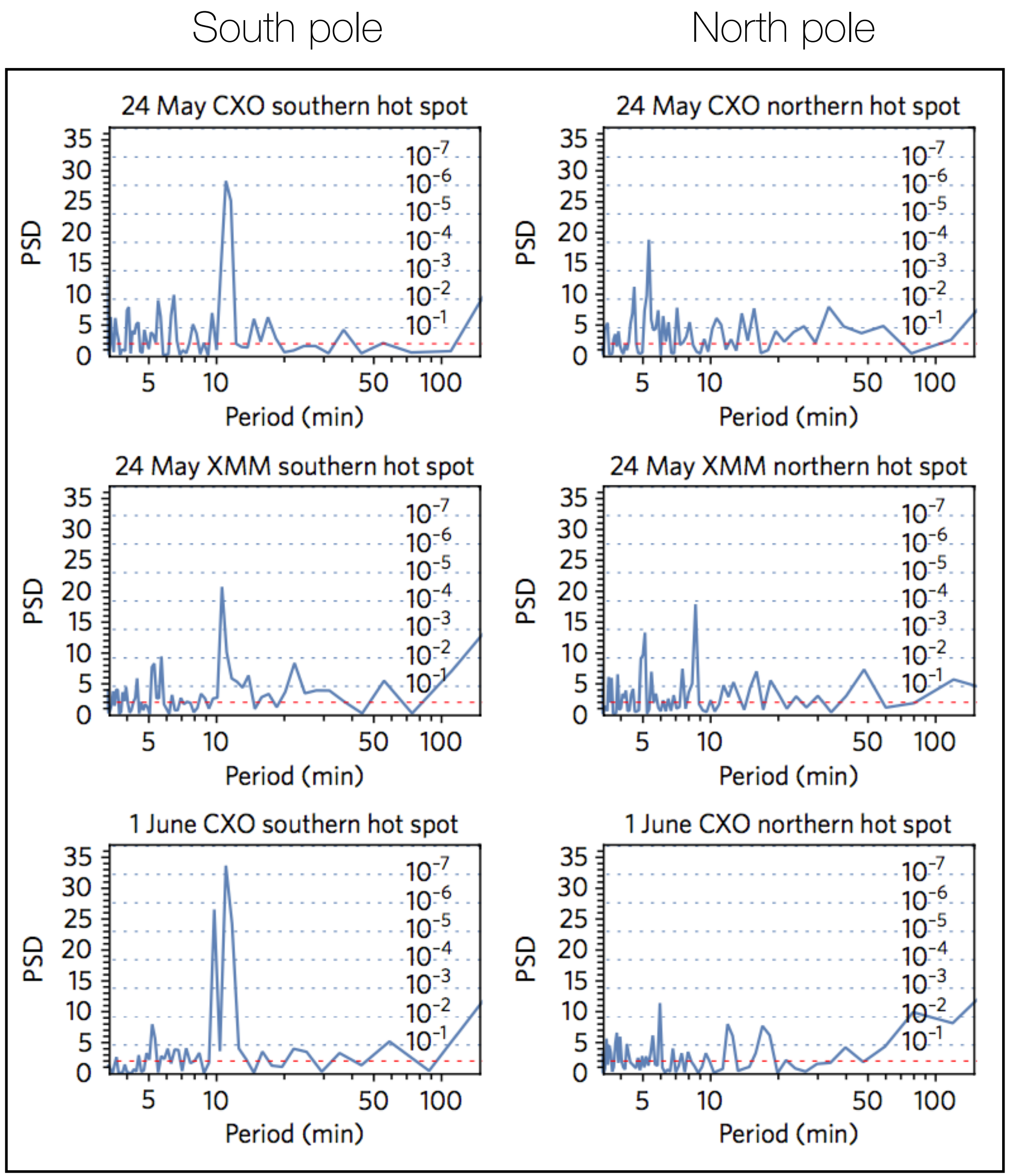
XMM-Newton and *Chandra* observations revealed X-ray 'hot spots' at both poles





X-ray: Chandra, NASA/CXC/UCL/W. Dunn et al.
Optical N: Juno, NASA/JPL-Caltech/SwRI/MSSS
Optical S: Juno, NASA/JPL-Caltech/SwRI/MSSS/Gerald Eichstadt/Seán Doran

XMM-Newton: Science Highlights



Dunn et al. 2017, Nature Astronomy

The X-ray emission from the Earth's North and South aurorae is correlated

For Jupiter, XMM-Newton Found:

- South pole: 11 minute periodic pulsations
- North pole: erratic period and intensity variations, uncorrelated with South pole

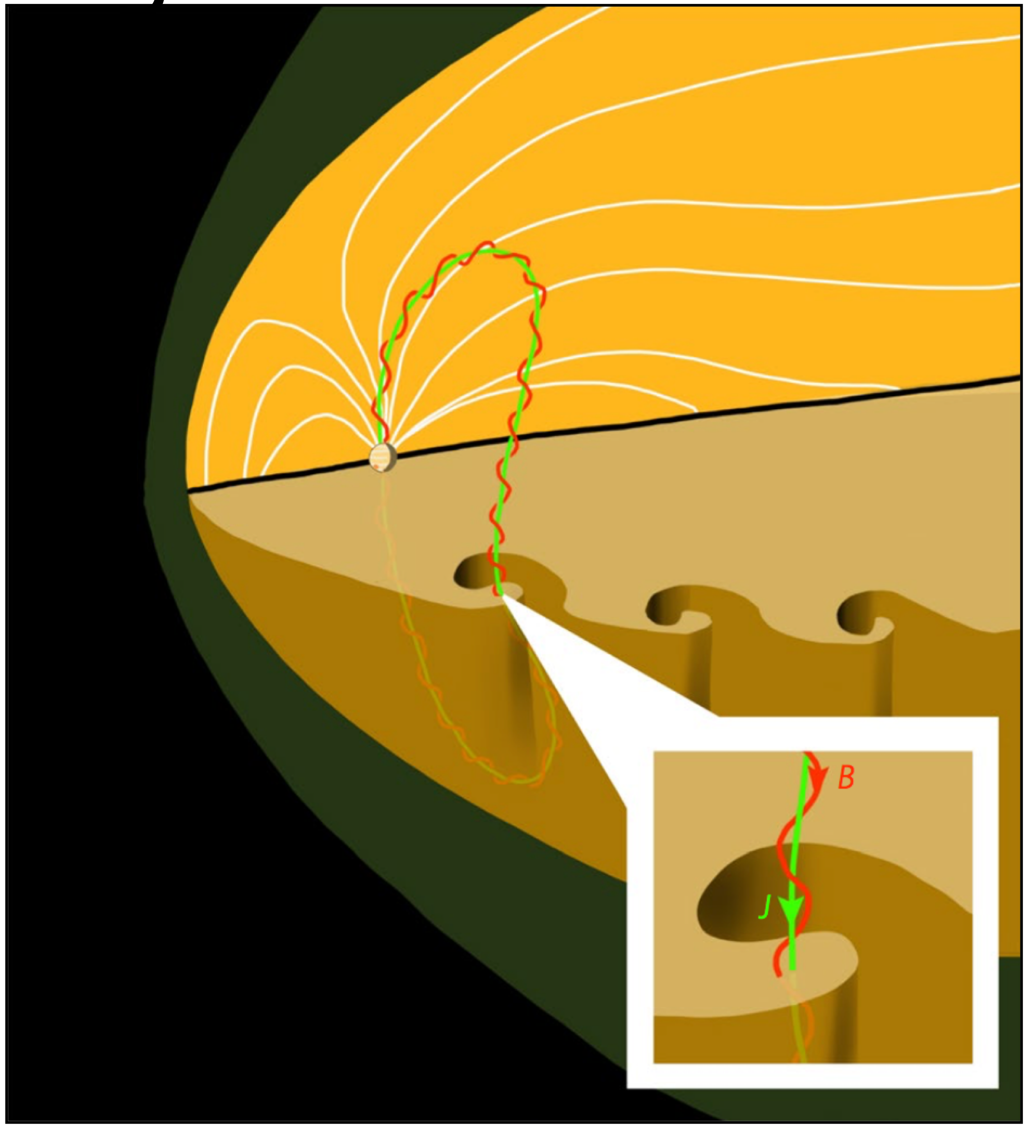
XMM-Newton: Science Highlights

X-ray emission from Jupiter's aurorae

Dunn et al. 2017, Nature Astronomy

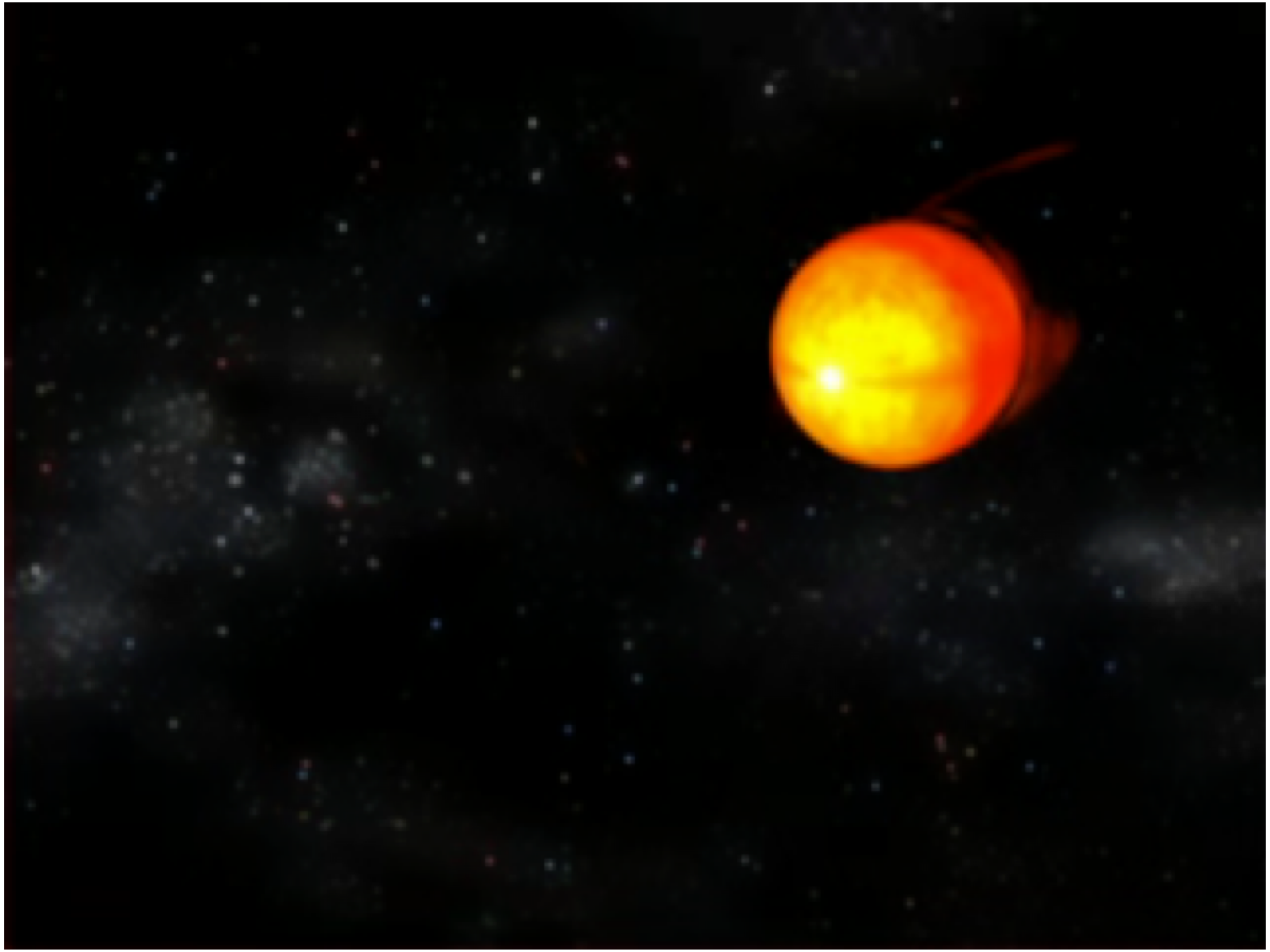
Mechanism:

- Particle acceleration starts at Jupiter's magnetopause, ~60–90 R_J and is accelerated down field lines until it impacts with the atmosphere
- The difference in behaviour between the two poles may be related to different viewing geometries - we could see more of the northern than the southern aurora.
- For the northern aurora we may be seeing regions where the magnetic field attaches to >1 location, with different travel times. Produces erratic behaviour.
- For the south we may be seeing a region where the magnetic field connects to only one location



With thanks to Mark McCaughrean

Neutron stars



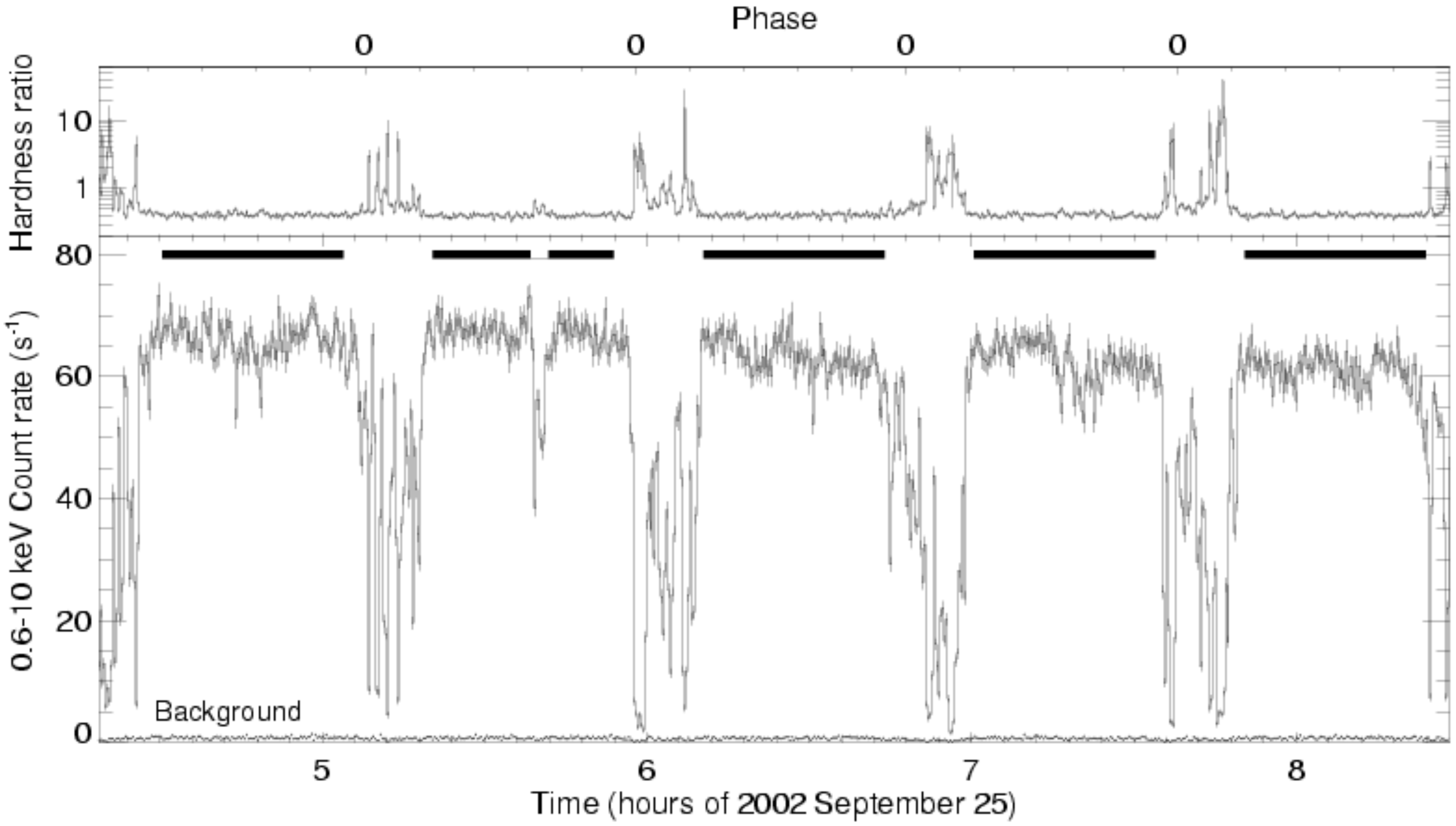
A simulation of material accreting from a ”normal star” onto a neutron star

As we learn more and more about how stars evolve, this enables us to better understand how whole galaxies evolve

XMM-Newton: Science Highlights

Understanding the spectral changes during X-ray dips

XB 1916-053



XMM-Newton: Science Highlights

Understanding the spectral changes during X-ray dips

In the 'EXOSAT' era:

Persistent spectrum is modified by an increase in N_H of an atomic absorbing component with less than solar abundances and by electron scattering (energy independent)

In the 'ASCA/BeppoSAX/RXTE' era:

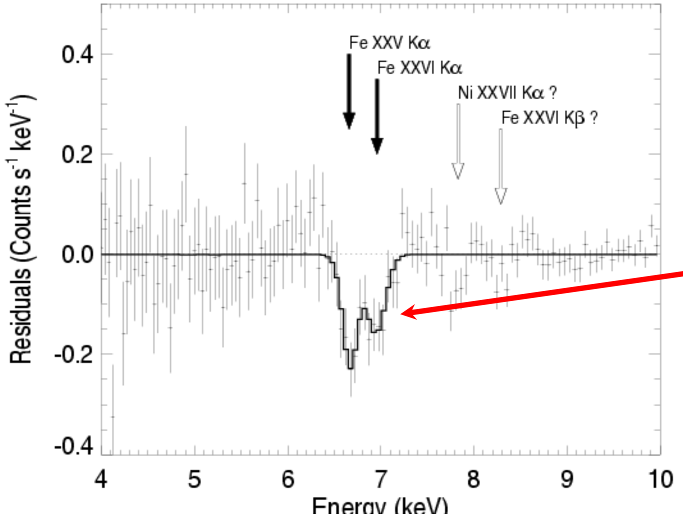
Progressive covering (e.g., Church et al. 1997). The X-ray emission originates from a point-like blackbody with a power-law from an extended corona. Partial and progressive covering of the extended component by a neutral absorber. The absorption of the point-like component is allowed to vary independently from that of the extended component.

XMM-Newton: Science Highlights

Understanding the spectral changes during X-ray dips

In the ‘XMM-Newton’ era:

XMM-Newton is able to simultaneously study the changes in the X-ray continuum and lines (particularly Fe k at 6.4-6.7 keV) during dips.
Demonstrated that the continuum and line changes can be modeled by a highly ionized absorber.

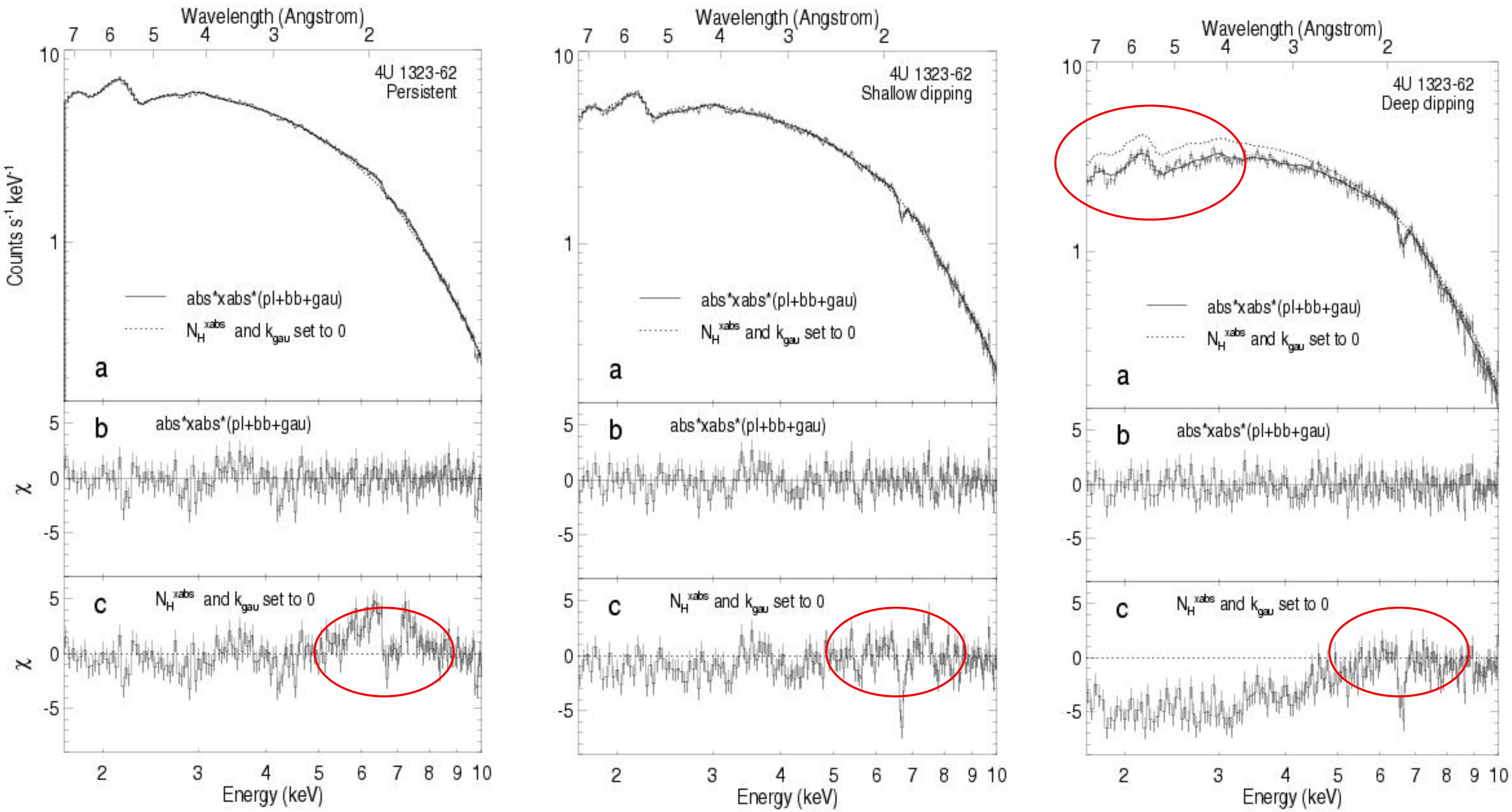


Absorption features in the spectrum of XB 1916-053

Boirin et al. (2004)

XMM-Newton: Science Highlights

With thanks to Maria Diaz Trigo and Laurence Boirin



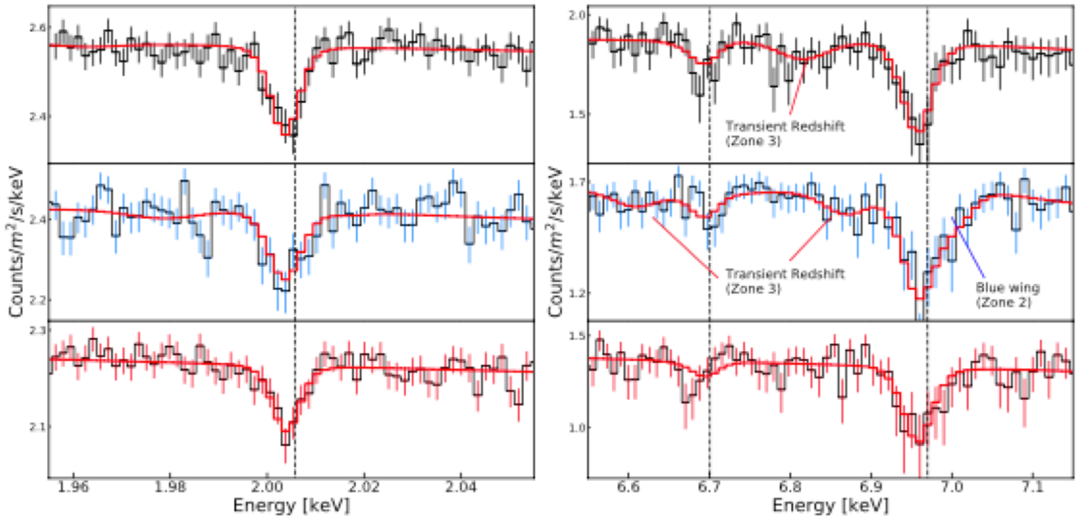
$Log(\xi)$ = 4.0 erg cm s^{-1}
N_H^{xabs}= 3.5 10^{22} cm^{-2}

3.7 erg cm s^{-1}
5.0 10^{22} cm^{-2}

3.3 erg cm s^{-1}
17 10^{22} cm^{-2}

~~XMM-Newton~~ Chandra: Science Highlights

- Trueba et al. had 300 ksec of Chandra/HETG observations of the 50 minute (compact) dipping source XB 1916-053
- They find that during non-dipping intervals the bulk of the absorption originates in a disk atmosphere that is redshifted by $v \simeq 220 - 290$ km s^{-1} ($r \sim 1200$ GM/c)
- This shift is present in the strongest, most highly ionized lines (Si XIV and Fe XXVI), with a significance of 5σ
- Absorption lines observed during dipping events (associated with the outer disk) instead display no velocity shifts suggesting that the redshift is intrinsic to an inner disk atmosphere and not systematic motion

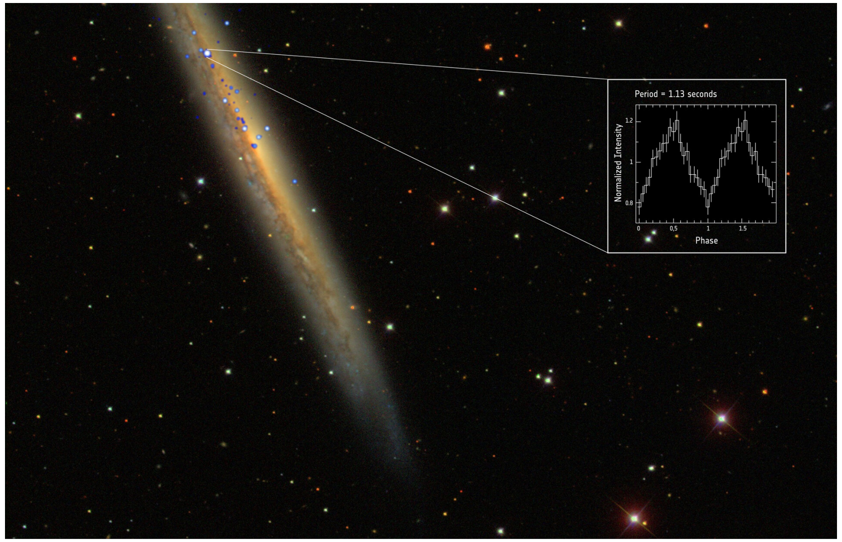


HETG spectra from 3 observations, with the Si XIV region (MEG) and Fe K band (HEG) in the left and right panels. Black dotted vertical lines plot the rest energies for Si XIVα, Fe XXVα, and Fe XXVIα. The bulk of Si XIV and Fe XXVI absorption displays consistent redshifts between 230 to 290 km s^{-1}

Trueba et al. 2020 ApJ

XMM-Newton: Science Highlights

The ULX in NGC 5907 is not a black hole!

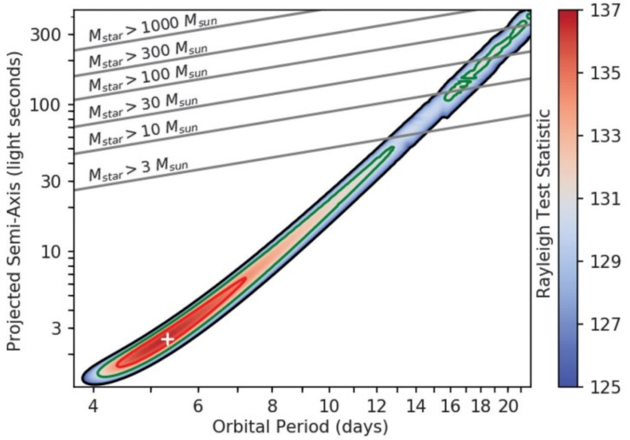


Ultra-luminous x-ray sources (ULXs) are observed in off-nucleus locations and have L_x > few 10^{39} erg s^{-1} – the Eddington luminosity of a 10 $M_\odot$ black hole

ULXs are usually modelled as stellar-mass black holes (BHs) accreting at very high rates or intermediate-mass BHs.

XMM-Newton and NuSTAR observations revealed that:

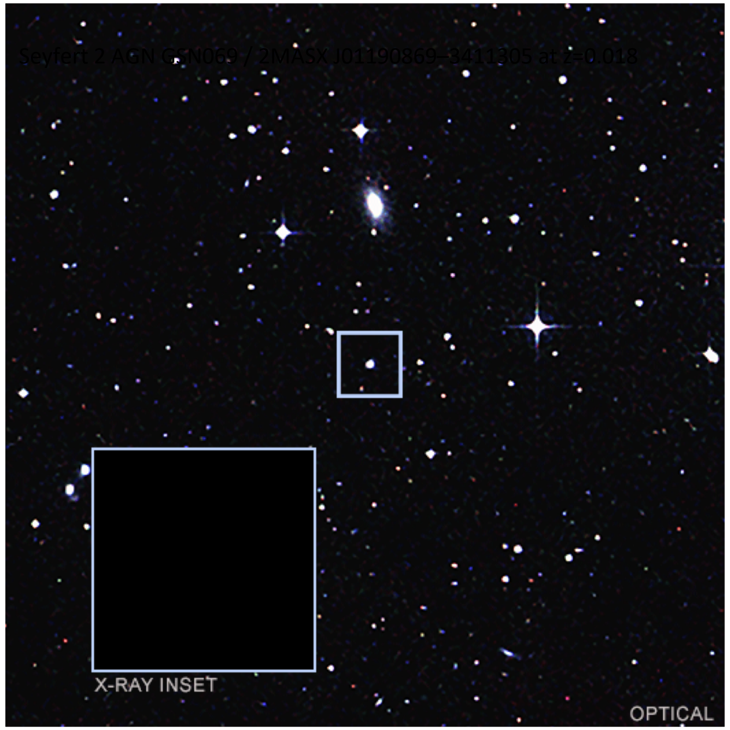
- The X-ray emission from ULX NGC 5907 is pulsed. The spin period evolved from 1.43 s in 2003 to 1.13 s in 2014 implying a spin-up timescale ~40 years. So a neutron star!
- Isotropic peak luminosity is ~1000 × Eddington limit for a neutron star
- Most likely orbital period around 5.3 days
- Standard accretion models fail to explain its luminosity, even assuming beamed emission
- Accretion through a strong multipolar magnetic field can describe its properties.

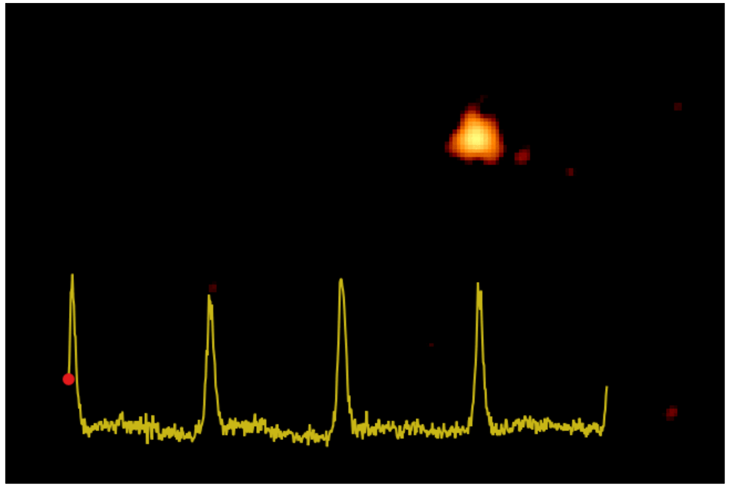


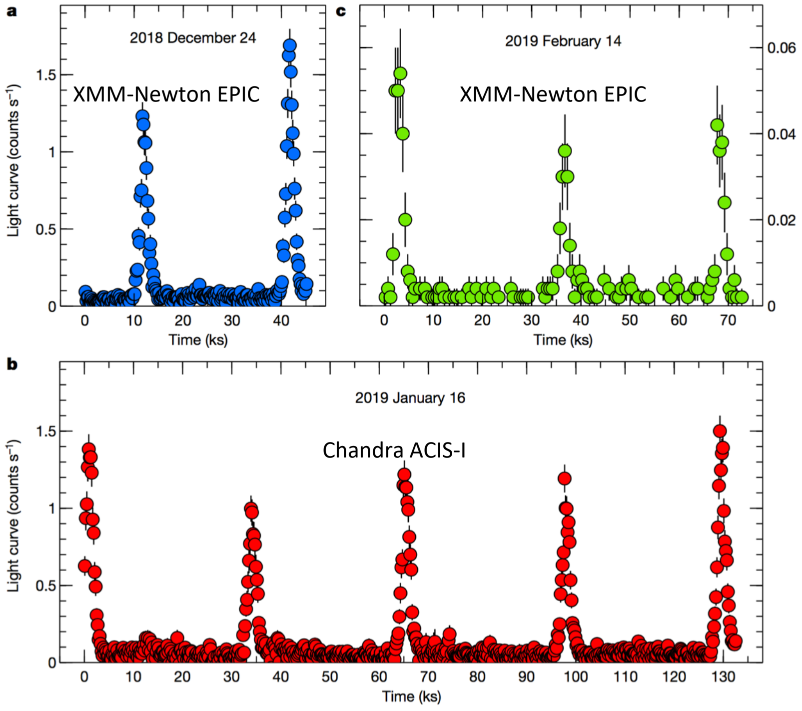
Orbital Period Constraints from NuSTAR

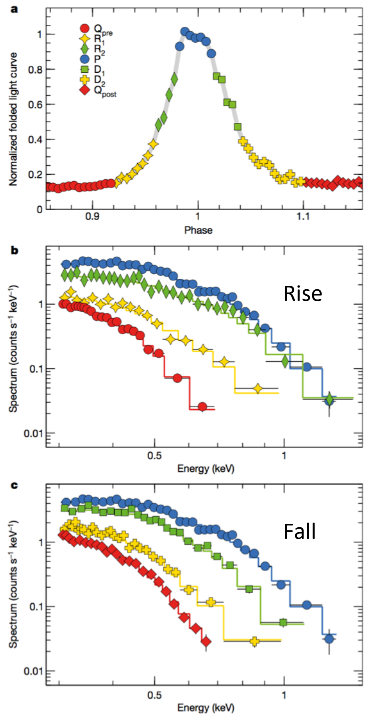
G.L. Israel, 2017, Science 355, 817

XMM-Newton: Science Highlights









Quasi-periodic eruptions from a low-mass black hole galactic nucleus

- Unexpected ~9 hour eruptions from a 4 x 10^5 M⊙ black hole in the Seyfert 2 galaxy GSN 069
- Soft x-ray emission from the accretion disk
- During eruptions flux increases by a factor ~20
- Due to instability in the accretion flow, or orbiting disrupted star
- Similar (slower) events in more massive AGN?

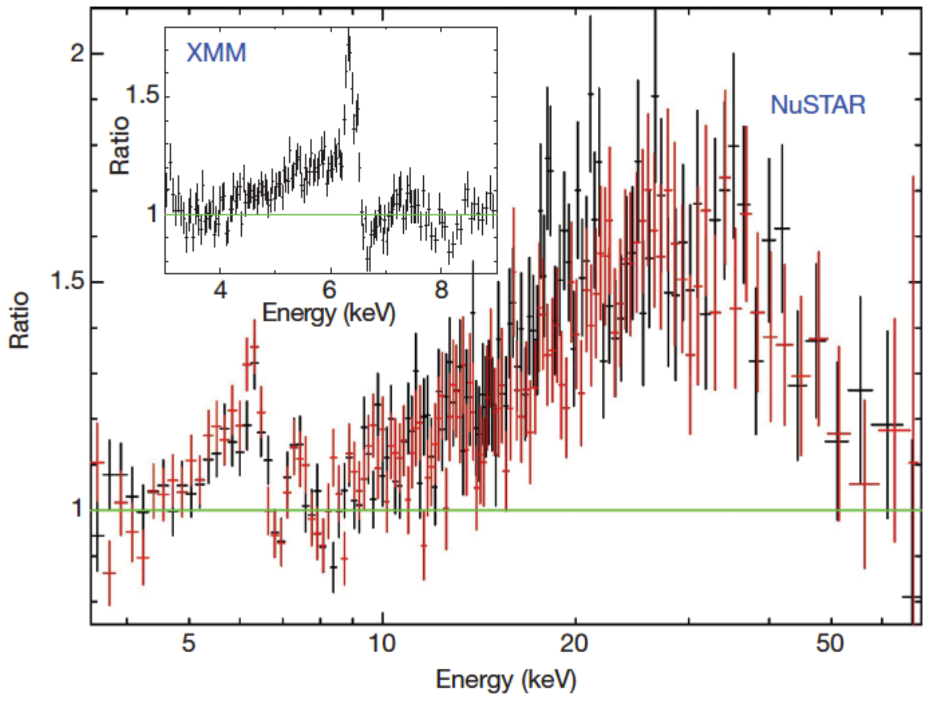
Artist's impression of an active galactic nucleus: ESA, NASA, AVO Project, P Padovani

Miniutti et al. 2020, Nature Astronomy

XMM-Newton: Science Highlights

Rapidly spinning black holes in AGN and the importance of reflection

Relativistic and other effects in extreme gravity can broaden narrow emission features so that they become ”continuum like”



NGC 1365

XMM-Newton: Science Highlights

Rapidly spinning black holes in AGN and the importance of relativistic reflection

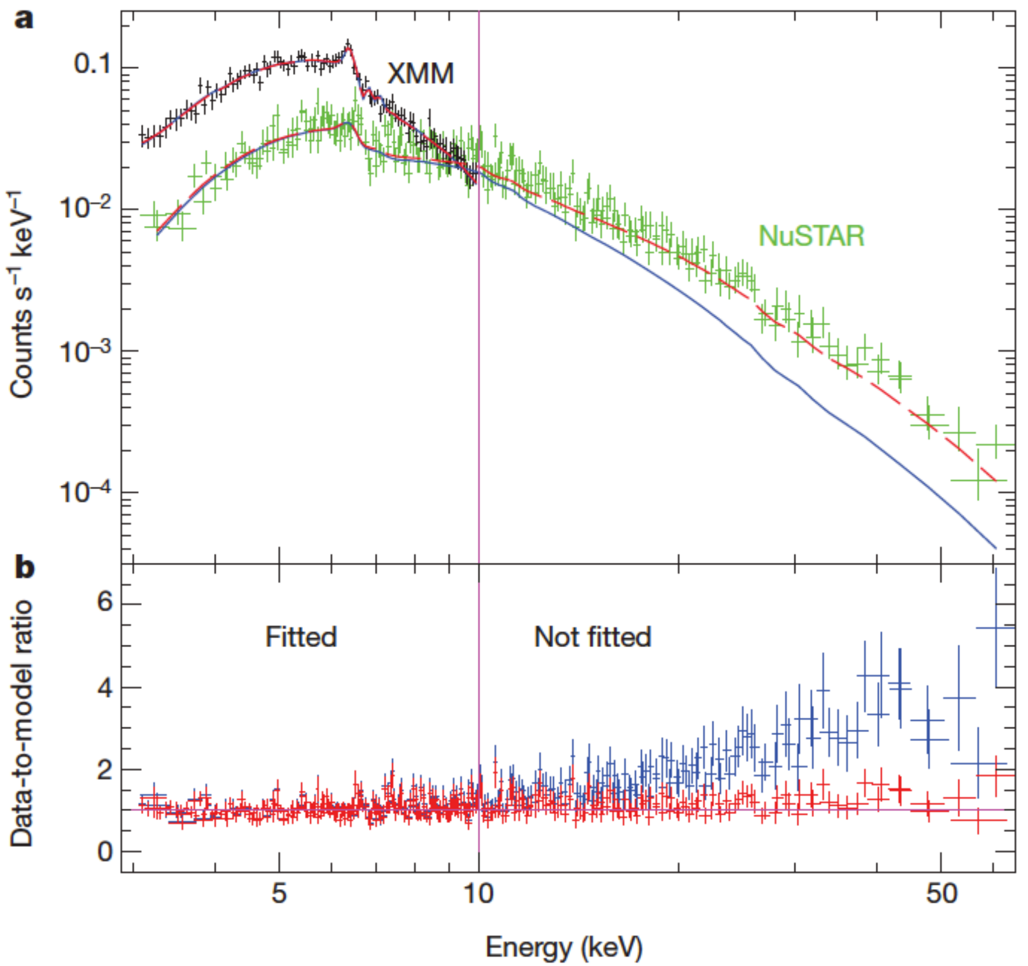
Is the broadening due to:

- Relativistic reflection from a rapidly rotating inner accretion disk and a variable partially covering absorber.
- Multiple, partially covering absorbers, with no relativistic reflection.

XMM-Newton data alone could not distinguish between the two models for NGC 1365.

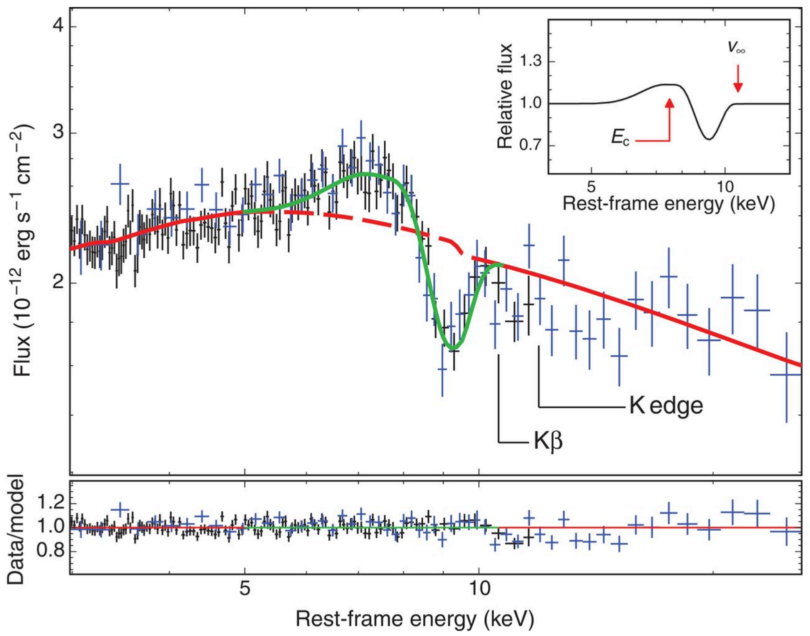
The black hole spin parameter is >0.84 (90% conf.)

Risaliti et al. Nature (2013)



XMM-Newton and NuSTAR spectra with the two models described left. The model with relativistic reflection (red line) fits both data sets well, while the partially covered absorbers (blue line) cannot reproduce the NuSTAR data

XMM-Newton: Science Highlights



XMM-Newton EPIC EPIC data are shown in black and NuSTAR data are shown in blue.

The green curve shows a model where the emission and absorption residuals around the Fe-K band are described by a P-Cygni profile from a spherically symmetric outflow.

- XMM-Newton and NuSTAR simultaneously observed PDS 456 on four occasions in 2013
- The emission and absorption residuals of the Fe-K band are described through a self-consistent P-Cygni profile
  - Nearly spherical symmetric outflow of highly ionized gas
  - This wind is expelled at relativistic speeds from the inner accretion disk
  - The outflow’s kinetic power >10^{46} erg s^{-1}
  - Enough to provide the feedback required by models of black hole and host galaxy coevolution.

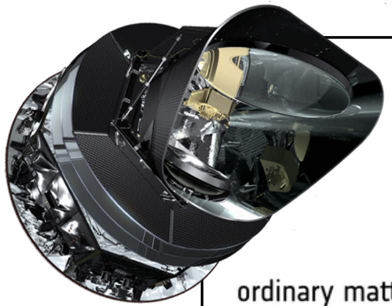
Nardini, et al., 2015, Science 347, 860

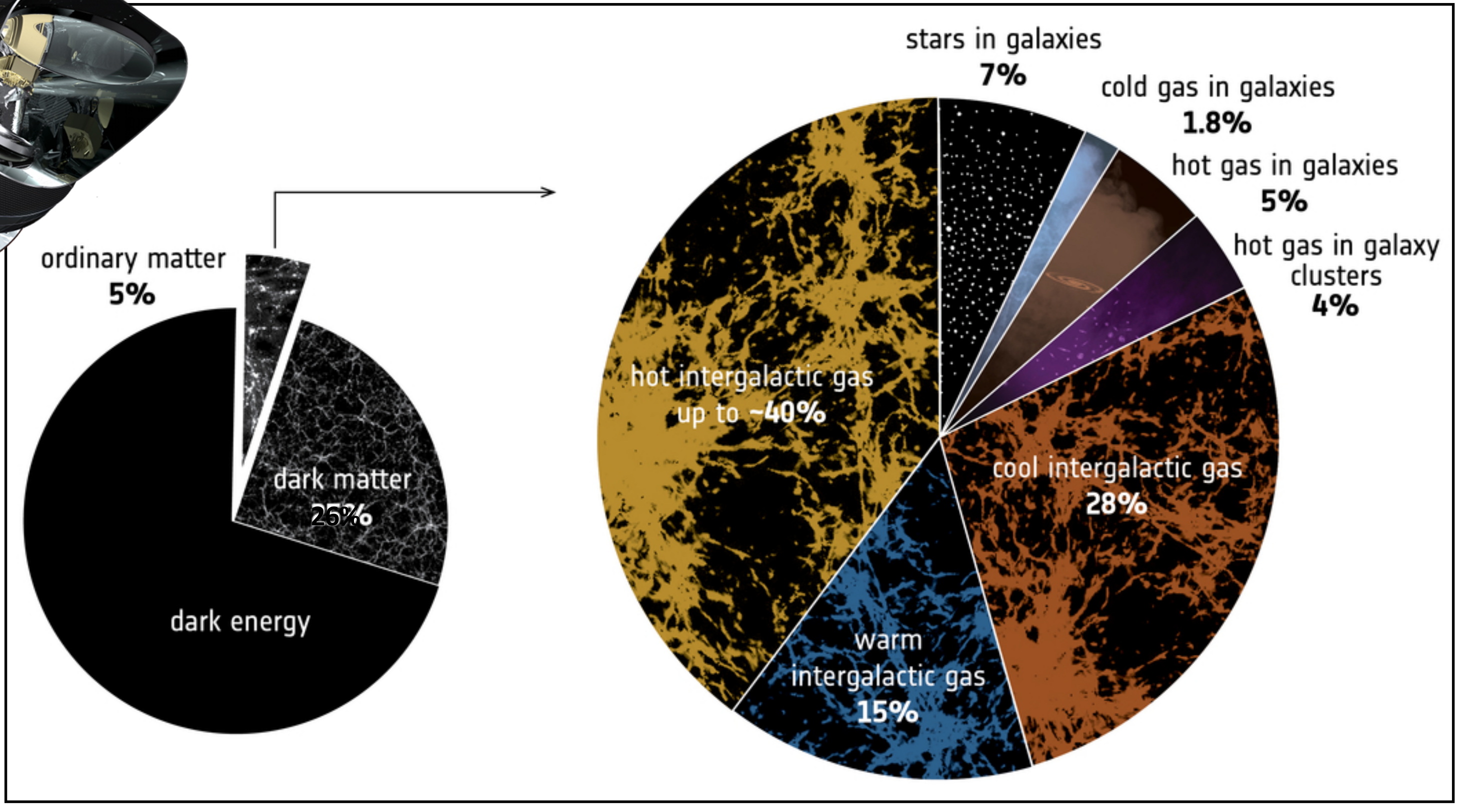
With thanks to Norbert Schartel

XMM-Newton: Science Highlights

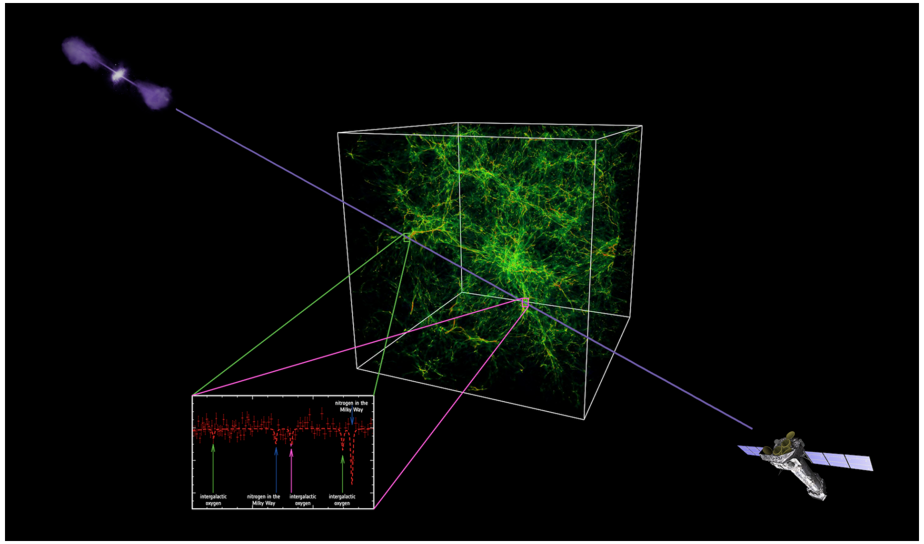
The hunt for the missing baryons

Planck DR3
July 2018



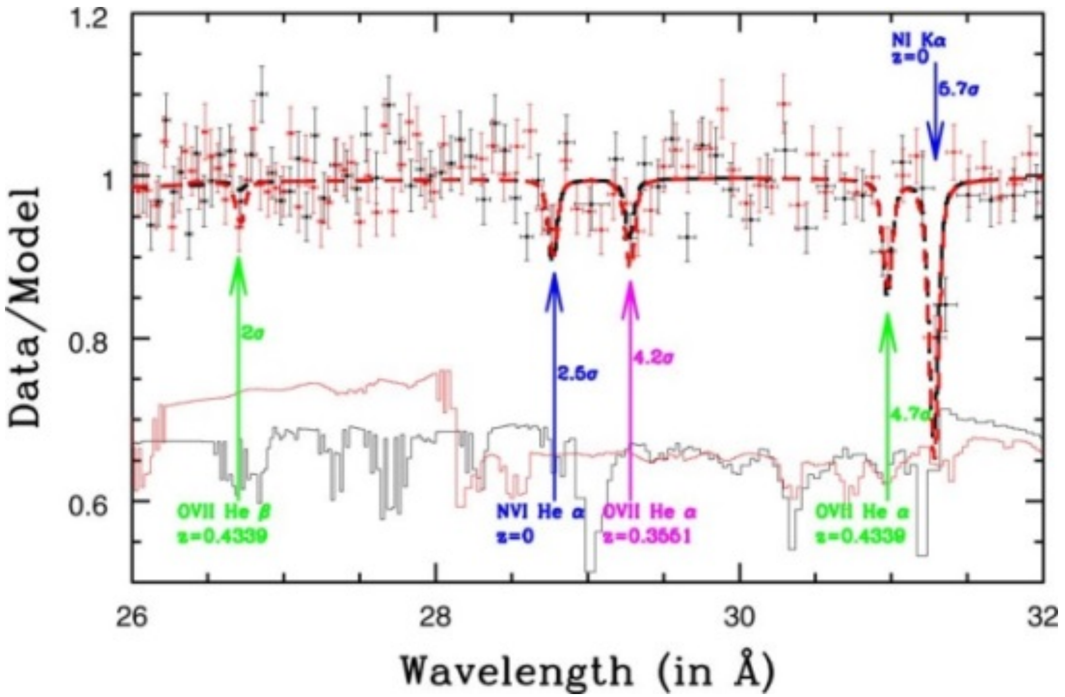


XMM-Newton: Science Highlights



Observations of the missing baryons in the warm–hot intergalactic medium

- Observed number of baryons in the local universe falls short (30-40%) of the total baryons predicted by big bang nucleosynthesis
- From $z \approx 2$ the baryons condense into a filamentary web and undergo shock heating up to $T \approx 10^5$–10^7 K



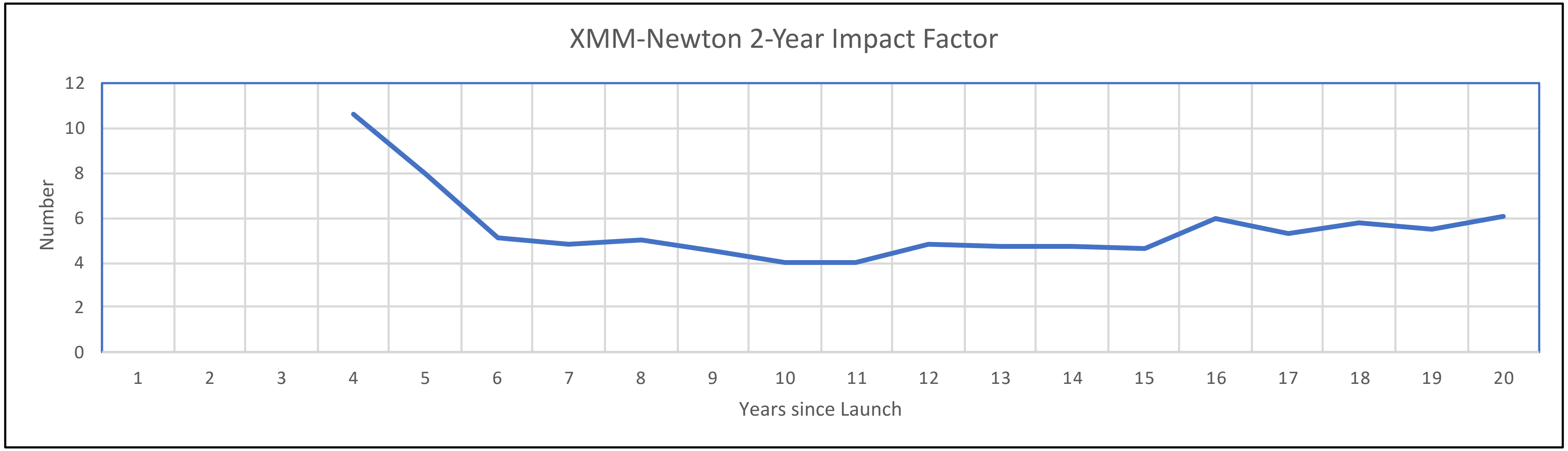
Nicastro et al., 2018

- 1.5 Msec (25 days!) XMM-Newton RGS spectrum of the quasar 1ES 1553+113, at $z \lesssim 0.48$
- Two absorbers of highly ionized oxygen (O vii) detected at intermediate redshifts.
- No variability or cold absorption so features unlikely to be associated with the quasar

XMM-Newton: Measuring Success

How do we measure the success of a scientific mission?

- There is no single metric that can be reliably used to quantify success. Probably the simplest and most informative is the total number of refereed publications – earlier VG
- However, this does not necessarily say much about the "impact" or legacy of the mission, or its public impact
- To supplement the number of publications other metrics are used:
  - Number of Citations – **213,000**
  - Number of influential papers (deemed to be those with >100 citations) – **416**
  - The number of unique author names – **16,600**
  - h- and m- indices – **160**, **7.6**



Most missions start with a high impact factor which declines rapidly for the first few years, followed by a slower decline. XMM-Newton is highly unusual in that the impact factor continues to rise after ~20 years

XMM-Newton: Success Factors

1. The Spacecraft, instruments and Ground Segment:

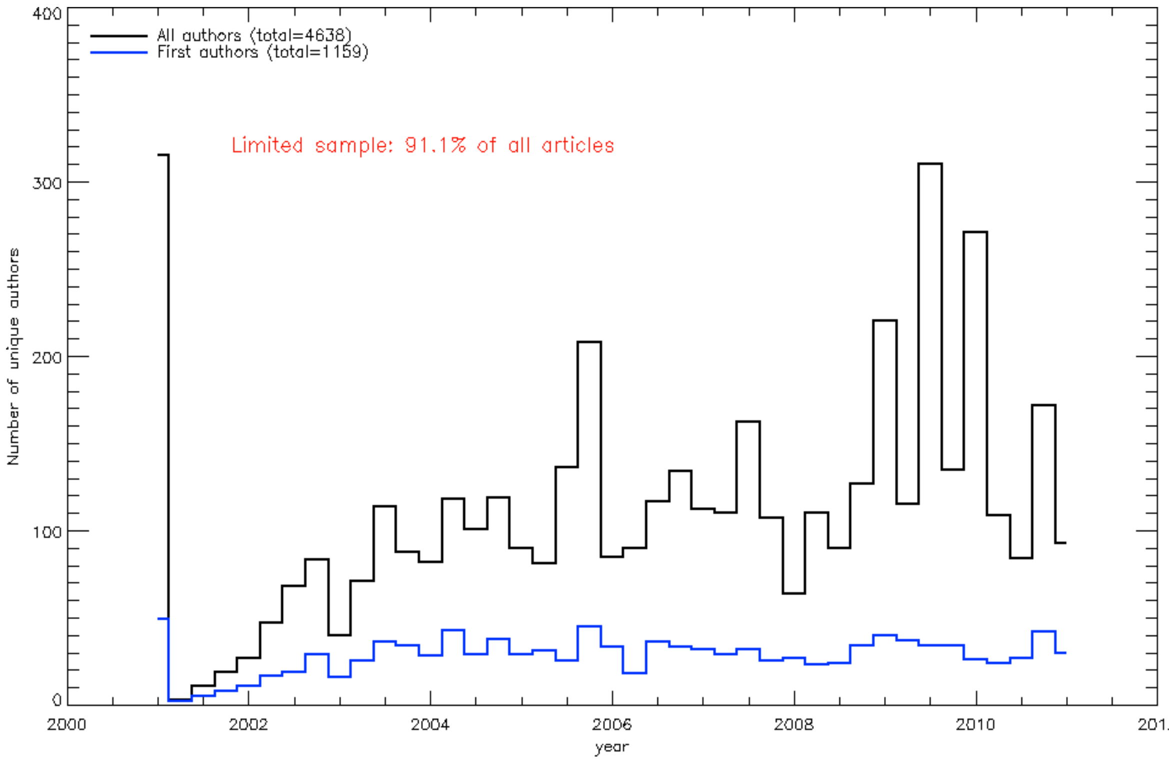
It is almost self-evident that:

- The spacecraft has worked reliably for >20 years.
- The instrumentation is still providing competitive measurements after >20 years operations. Tribute to the foresight and skills of the instrument consortia
- The Science Operations Centre at ESAC and instrument teams have ensured efficient scheduling, and that the calibrations and data analysis software are updated to reflect the latest information
- The Missions Operations Centre at ESOC have ensured that the mission is run in a highly efficient manner, ensuring the longest possible lifetime. They also played a key role in saving the mission in 2008

XMM-Newton: Success Factors

2) The Large and Highly Productive Community

- 400 PhD thesis recorded that use XMM-Newton data, or report on hardware developments, calibration etc
- The black curve shows the date when for the first time an author appeared on an XMM-Newton paper (numbers binned quarterly).
- The blue line shows the same for first authorship.
- It is remarkable that after so many years in operation, the mission continues to attract ~400 new publishing scientists a year (~120 as first authors).



With thanks to Jan-Uwe Ness

XMM-Newton: Success Factors

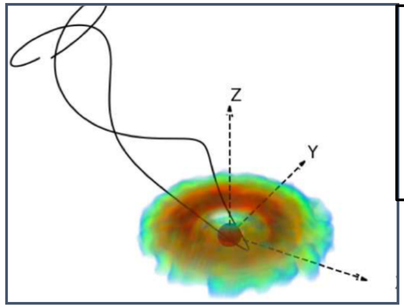
2. The Large and Highly Productive Community:

- There were 1100 unique author names for the 780 EXOSAT publications – a measure of the size of the community using the mission (maybe 30% overestimate)
- With XMM-Newton, the community has grown by a factor of 15 to 16,600 unique names. This is the largest of any ESA-led mission.
- 58% of first authors are located at institutes in the ESA member states – the rest are worldwide including 24% in the US.
- 1500 scientists involved in each call for observing proposals

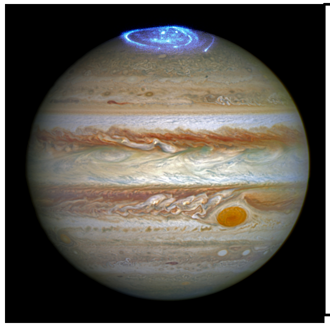
This is a classic "chicken and egg" situation – is the size of the community the result of having such a successful mission – or is the mission the result of the large and productive community?

XMM-Newton: Success Factors

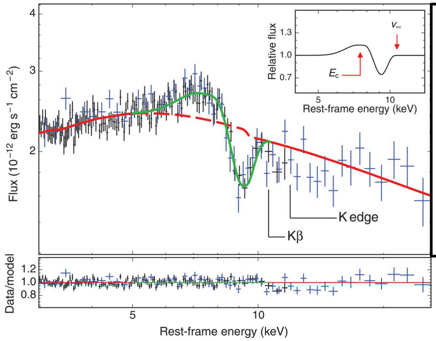
3. **The results often come from joint observations with other facilities**



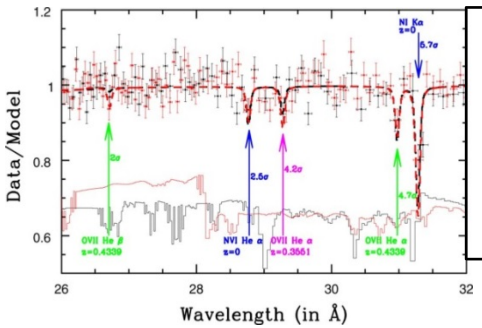
Radiation Belts: INTEGRAL and XMM-Newton



Jupiter's Aurorae: Chandra, Juno, HST and XMM-Newton

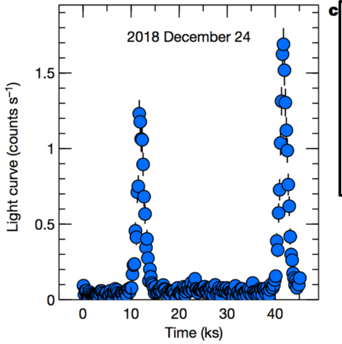


PDS 456 Relativistic Wind: XMM-Newton and NuSTAR

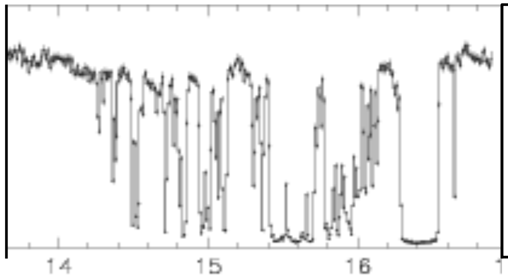


Missing Baryons: XMM-Newton (but major contribution by Chandra)

NGC 5907 ULX Pulsations: XMM-Newton and NuSTAR

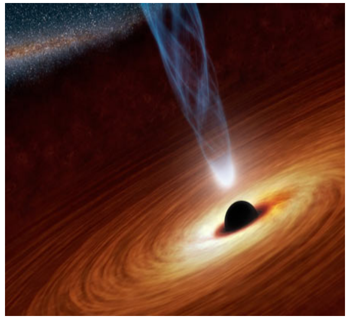


GSN 069 Outbursts: XMM-Newton and Chandra



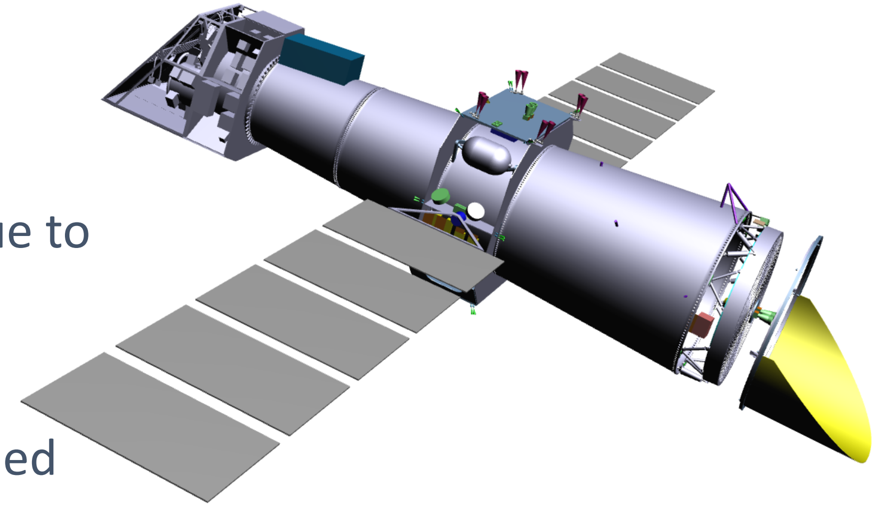
Dipping Sources: XMM-Newton and Chandra (with ASCA, BeppoSAX, RXTE)

M31: XMM-Newton and Herschel



NGC 1365 Relativistic Reflection: XMM-Newton and NuSTAR

The Future: Athena



Athena CDF spacecraft design

- Subject to no unexpected failures, XMM-Newton operations can continue to the early 2030s (limited by on-board fuel)
- ESA plans to launch its successor mission – Athena – in the early 2030's
- Mission is under study (Phase B1) with adoption ("final approval") planned for mid-2022. Strong US participation in the mission: X-IFU.

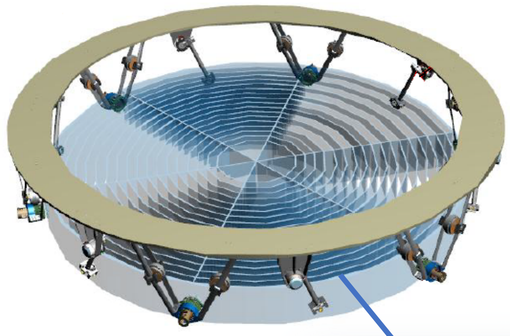
Athena will have:

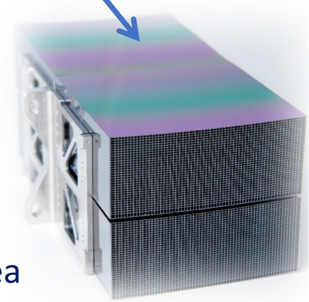
- **Single telescope** using Silicon Pore Optics (SPO) technology, 12 m focal length, 5" Half Energy Width (HEW), area: ≥1.4 m^2 at 1 keV, 0.25 m^2 at 6 keV.

Two instruments (work individually):

- **WFI** (Active Pixel Sensor Si detector): wide-field (40'x40') spectral-imaging, CCD-like energy resolution (≤170 eV at 6 keV)
- **X-IFU** (cryogenic imaging spectrometer): 2.5 eV energy resolution, 5' diameter effective field-of-view, ~5" pixel size

Takes the X-ray spectroscopy heritage of XMM-Newton to the next level!





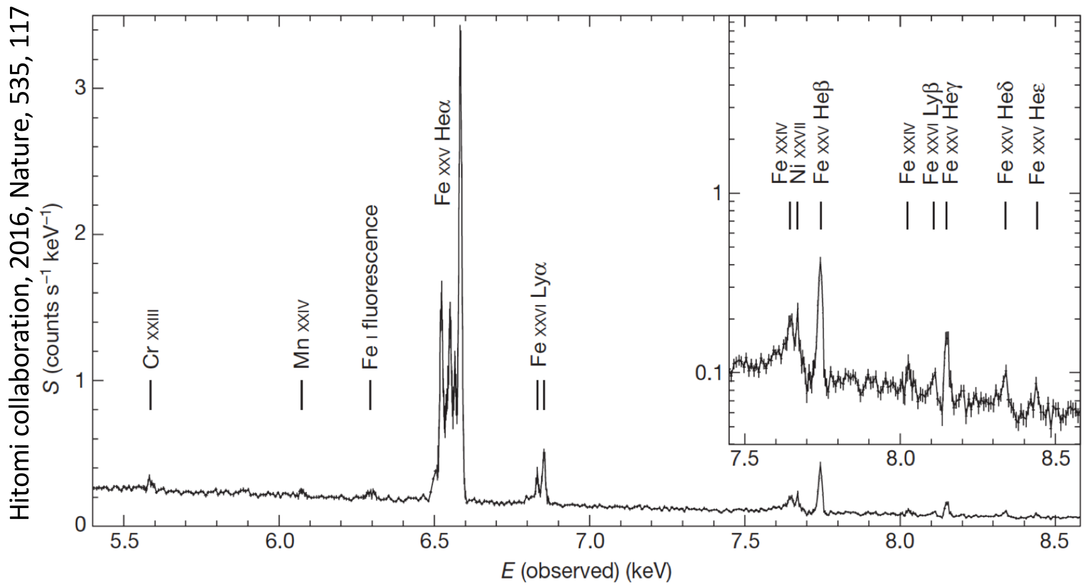
Athena mirror will consist of 678 Mirror Modules (MMs):
100,000 mirror plates
300 m^2 polished and coated area

With thanks to Matteo Guainazzi

The Future: Athena

Will Athena have the same 3 success factors?

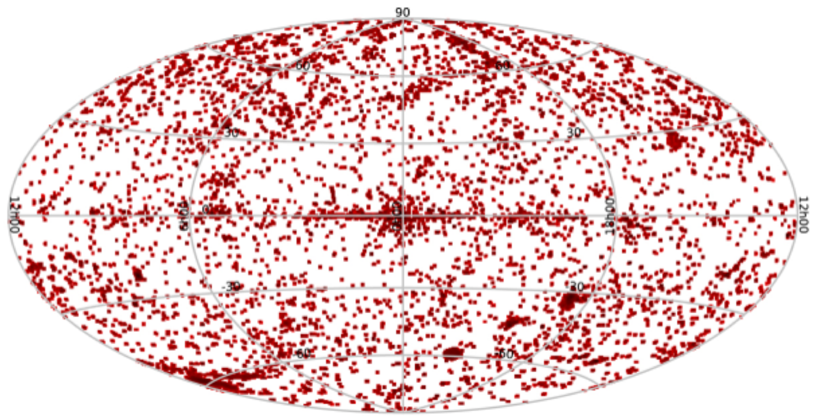
1. Superb instruments, optics, spacecraft and ground segment. Most likely, Athena will have two incredibly challenging and state-of-the-art instruments. ESA knows how to build spacecraft and the community (including US and Japan) their part of the ground segment and instruments
2. The large and highly productive community to exploit the results: Yes, with the expected lifetimes of XMM-Newton and Chandra nearly overlapping with Athena and results from eRosita and XRISM the community is likely to be even stronger.
3. Opportunities for collaboration and joint observations. Yes, will probably become even more important with new facilities such as SKA, E-ELT, CTA, the Rubin Obs and LISA etc. The field of multi-messenger astronomy will continue expand.

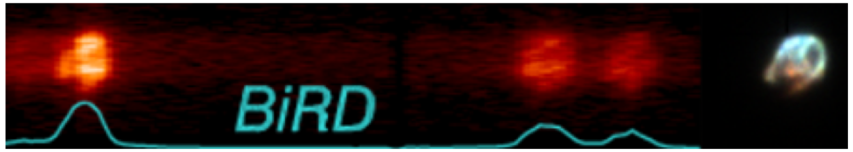


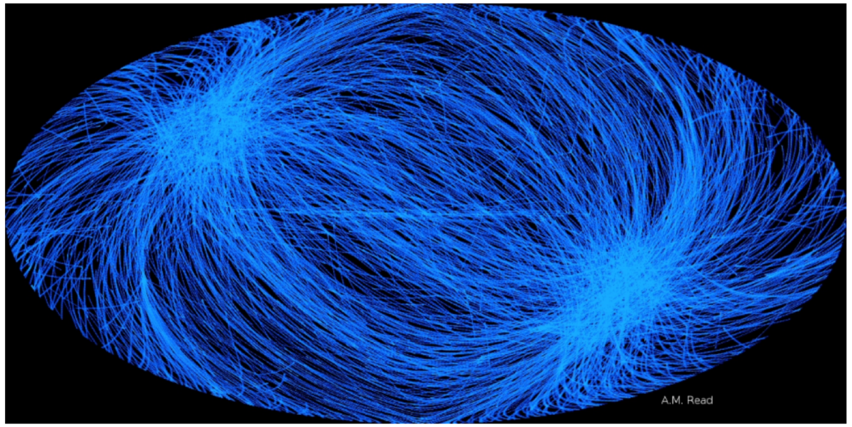
XMM-Newton: Catalogues

XMM-Newton Catalogues include:

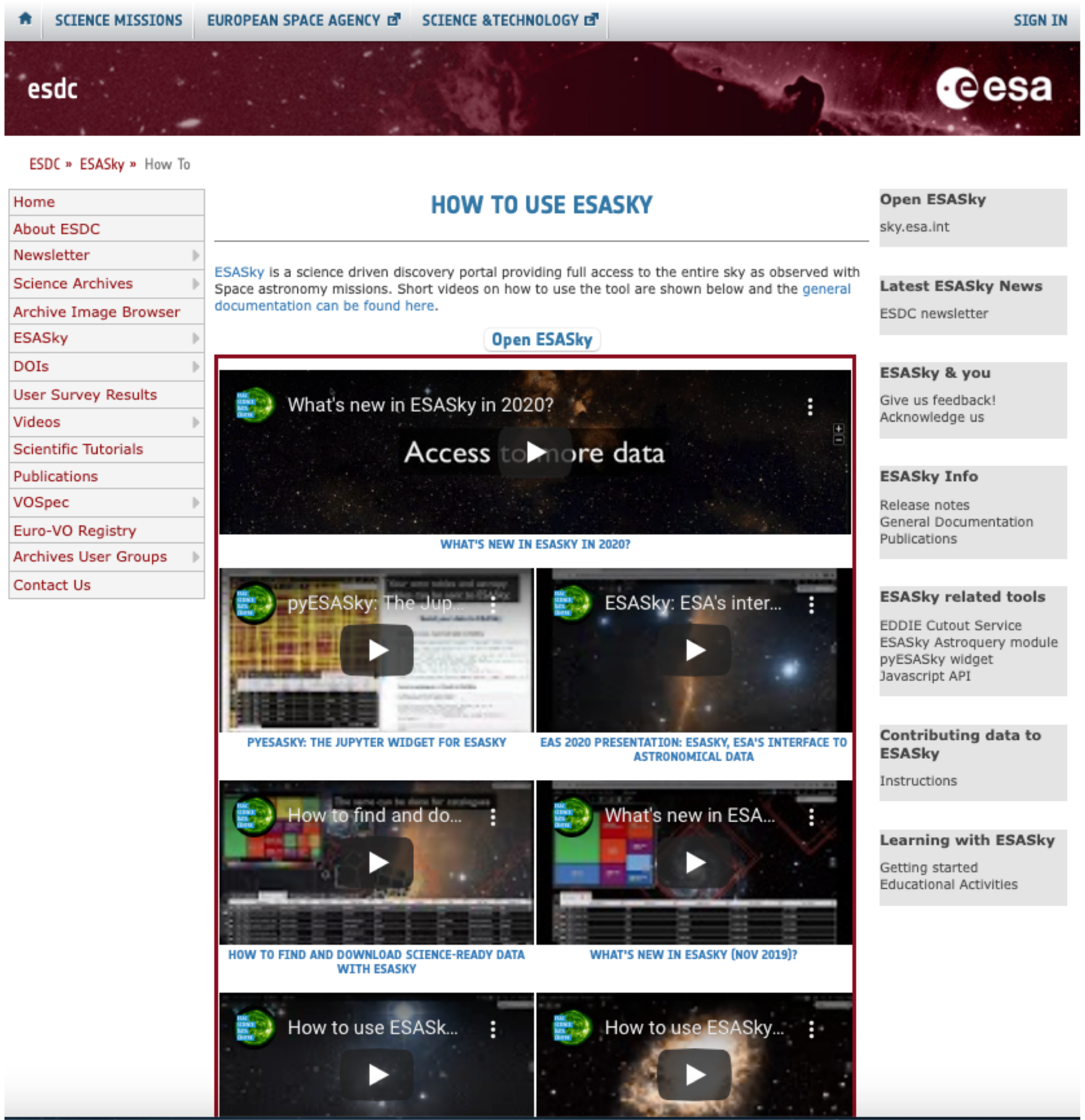
- XMM-Newton Serendipitous Source catalogue (4XMM-DR10). 850,000 detections of 575,000 unique sources. 1192 sq deg.
  - stacked exposure
  - Multi-object coverage
  - SEDs
- BiRD (Browsing Interface for RGS data)
- OM serendipitous UV source Catalogue – 8.9 million detections of 5.9 million sources
- Spectral fit Catalogue
- Slew Survey Catalogue. Covers 84% of sky with 72,000 sources

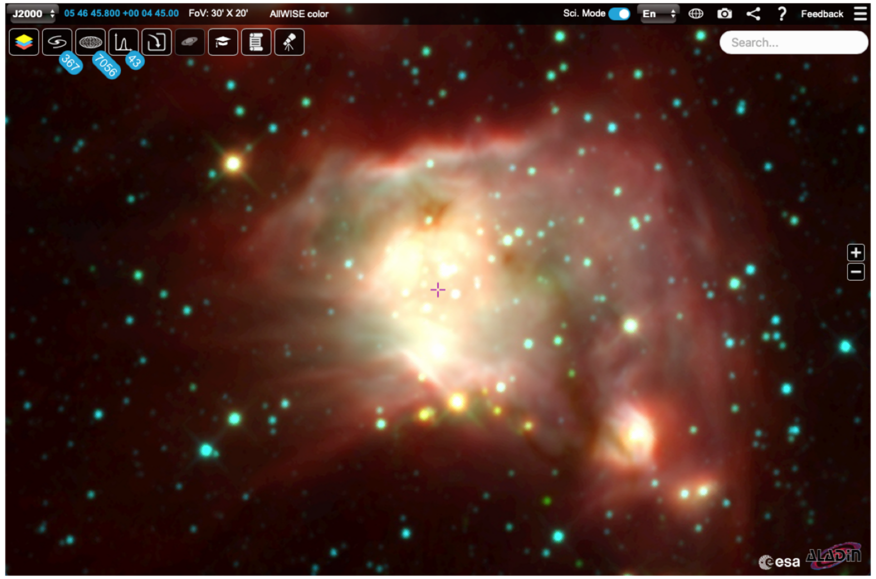






ESA Sky - sky.esa.int





ESASky is a science driven discovery portal providing full access to the entire sky as observed with Space astronomy missions.

More Information

General information on the Science Progamme’s missions, news, Announcements of Opportunity, jobs etc: cosmos.esa.int

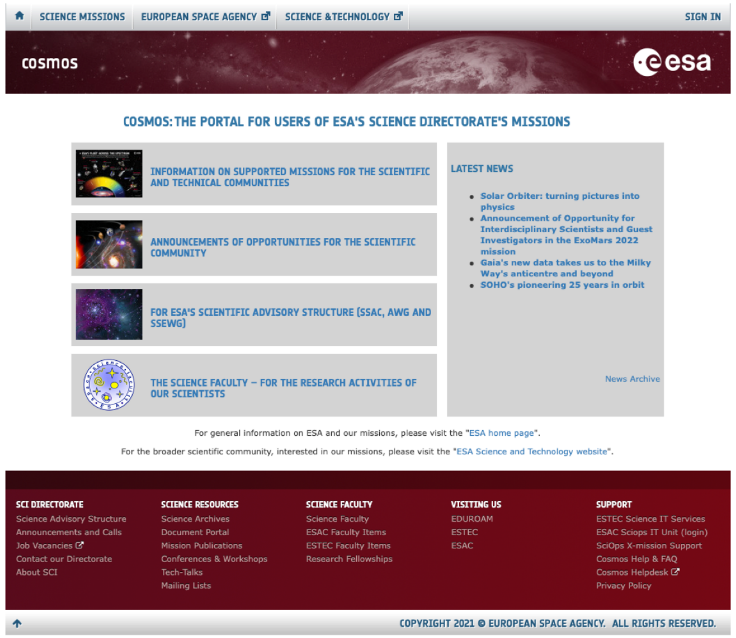
Information for users of XMM-Newton: www.cosmos.esa.int/web/xmm-newton

XMM-Newton Users Handbook: xmm-tools.cosmos.esa.int/external/xmm_user_support/documentation/uhb/index.html

XMM-Newton Science Analysis System (SAS) Users Guide: xmm-tools.cosmos.esa.int/external/xmm_user_support/documentation/sas_usg/USG/

Cross Mission Calibration through the International Astrophysical Consortium for High Energy Calibration (IACHEC): iachec.org

ESA Sky: sky.esa.int



Thank you!