20th Launch Anniversary of XMM-Newton: Scientific Achievements and Future Perspectives

XMM-Newton 20th Anniversary Goddard Symposium,

NASA Goddard Space Flight Center, Greenbelt, MD, October 21-22, 2019

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XMM-Newton

XMM-Newton preparation

Image courtesy of D. Parker

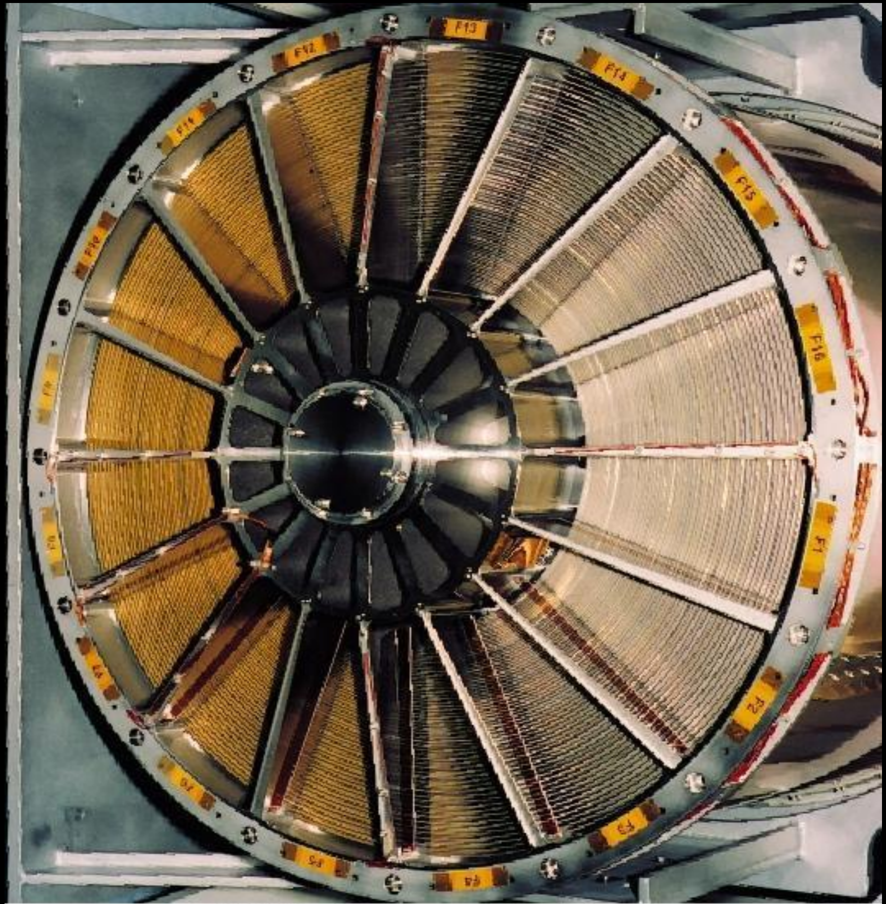
European Space Agency

Mirror Module:

- grazing-incidence Wolter 1 telescopes

- each mirror shell consists of a paraboloid and an associated hyperboloid

- 58 gold-coated nested mirrors

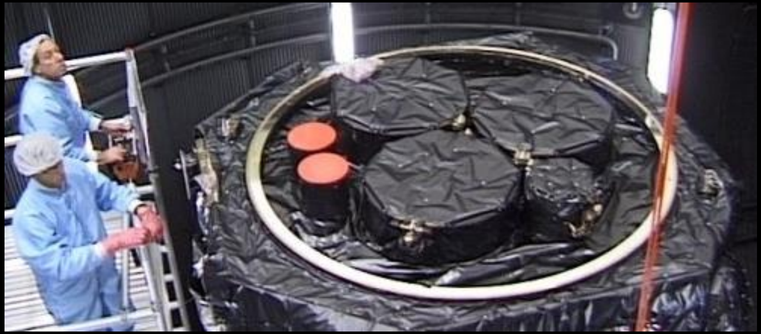


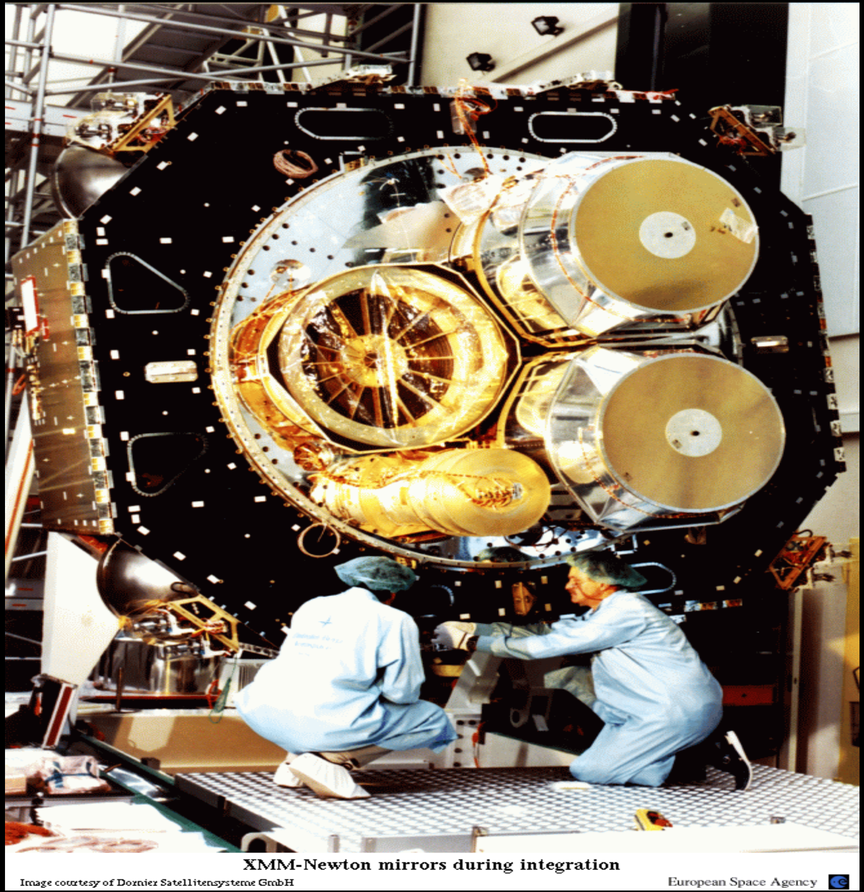
XMM-Newton mirrors during integration

Image courtesy of Dornier Satellitensysteme GmbH

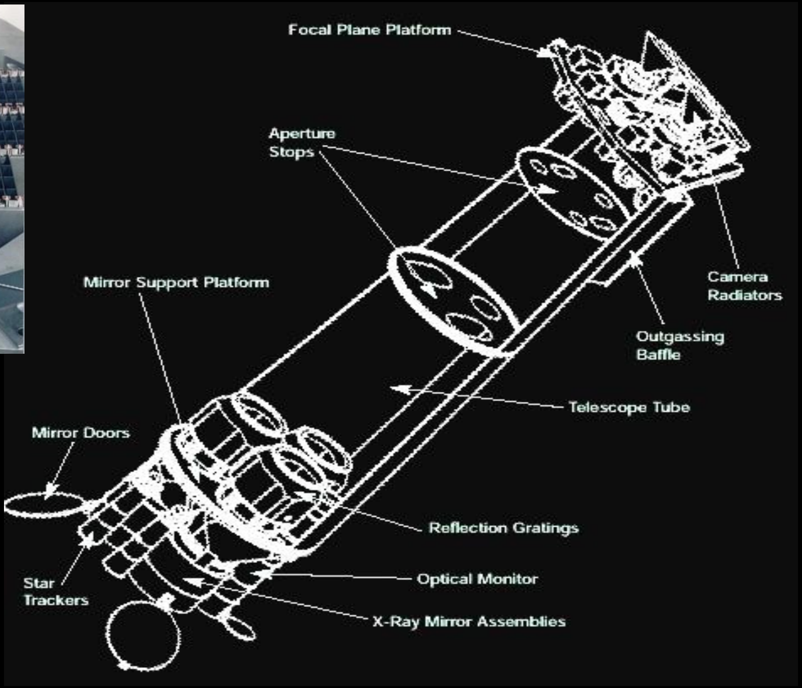
European Space Agency

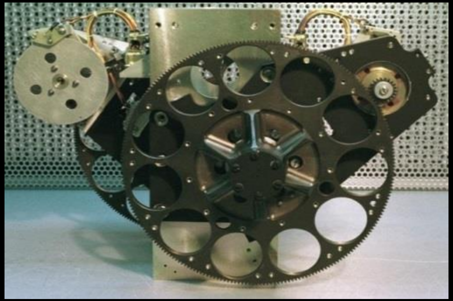
XMM-Newton has three mirror modules

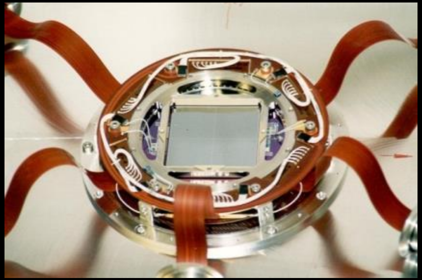




Instruments

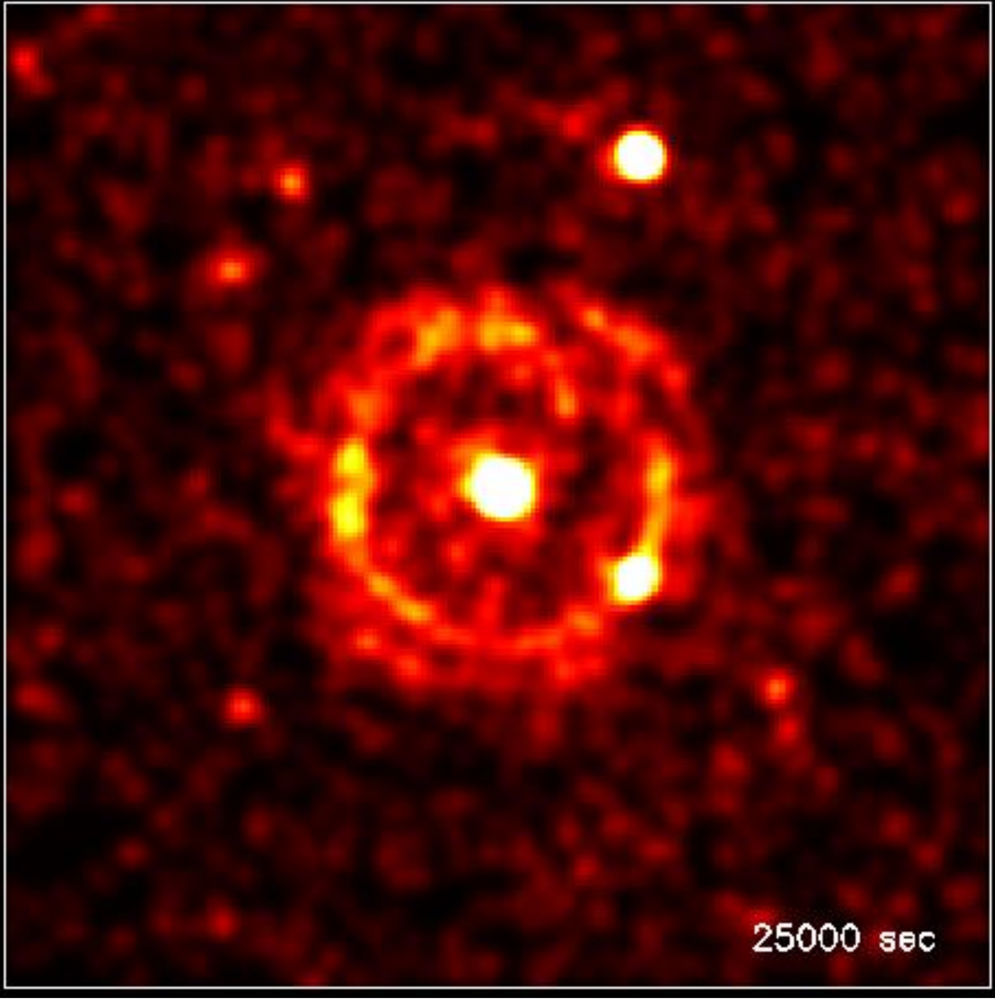






XMM-Newton

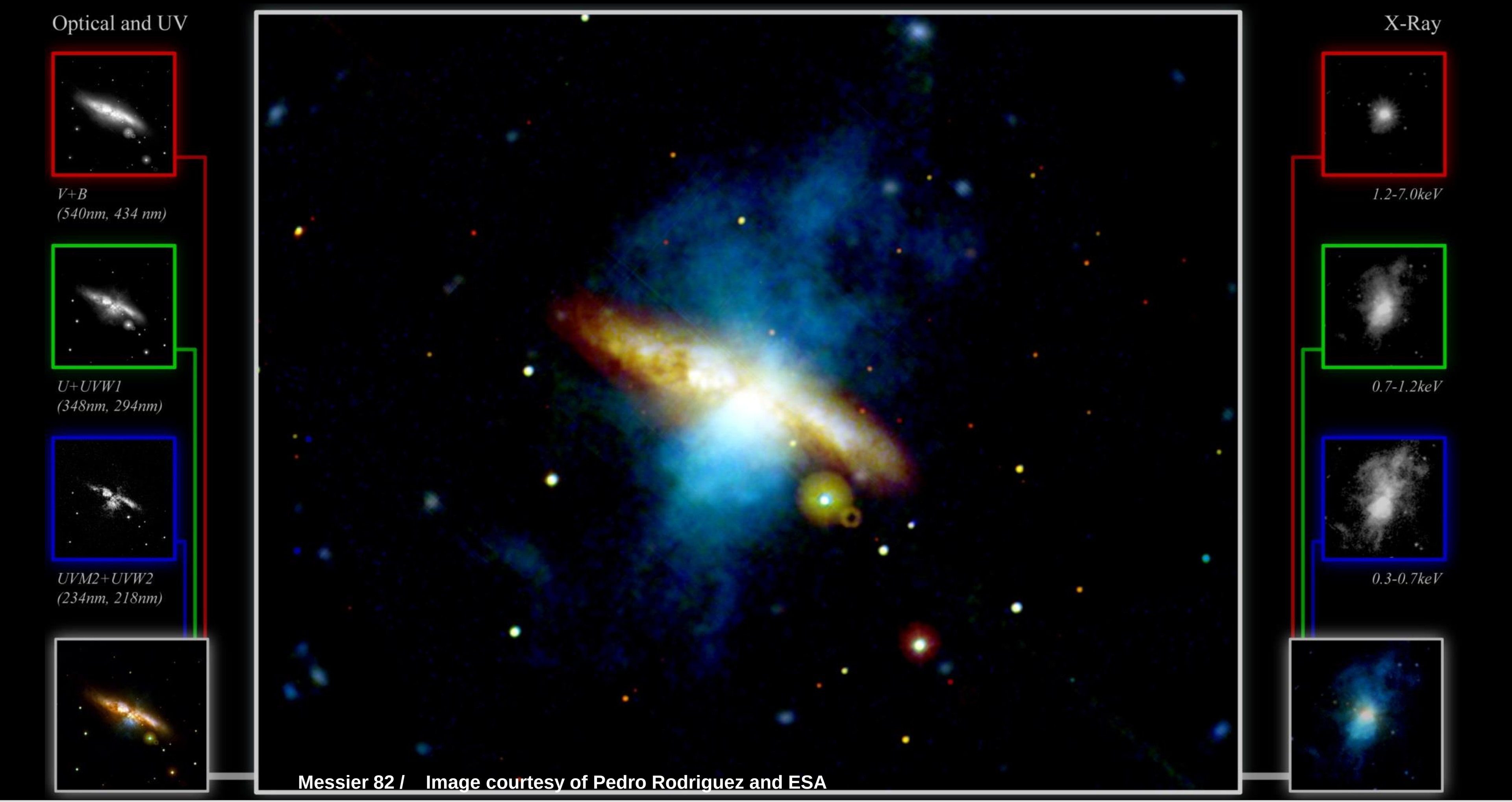
- 3 Mirror Modules / highest effective collecting area ever
- Six simultaneously observing instruments:
    - 3 CCD cameras (one pn and two MOSs)
    - 2 spectrometers (RGS)
    - 1 Optical Monitor (OM)



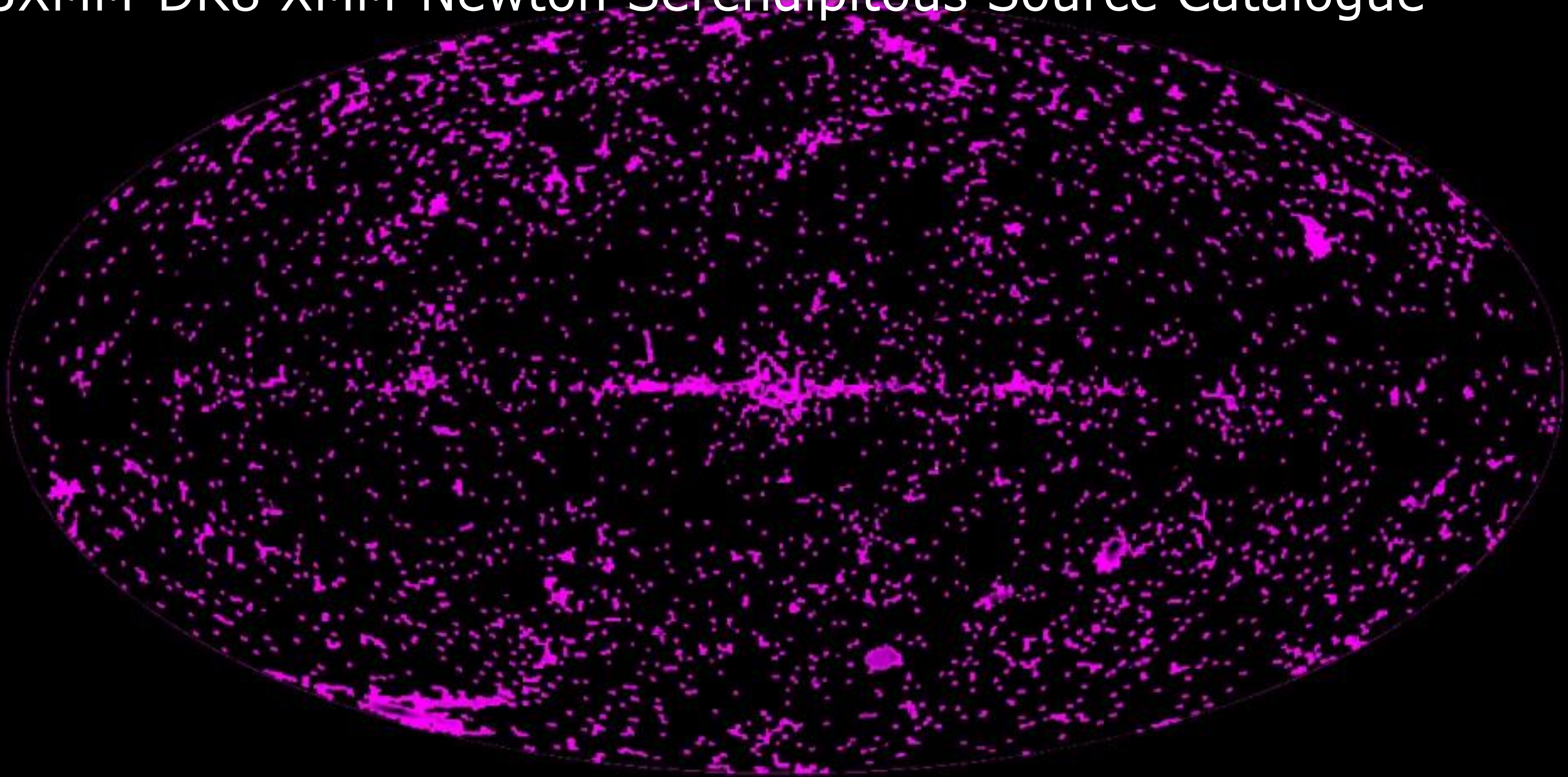
S. Vaughan et al., 2004, ApJ 603, L5

➔ Discovery of an evolving dust-scattered X-ray halo

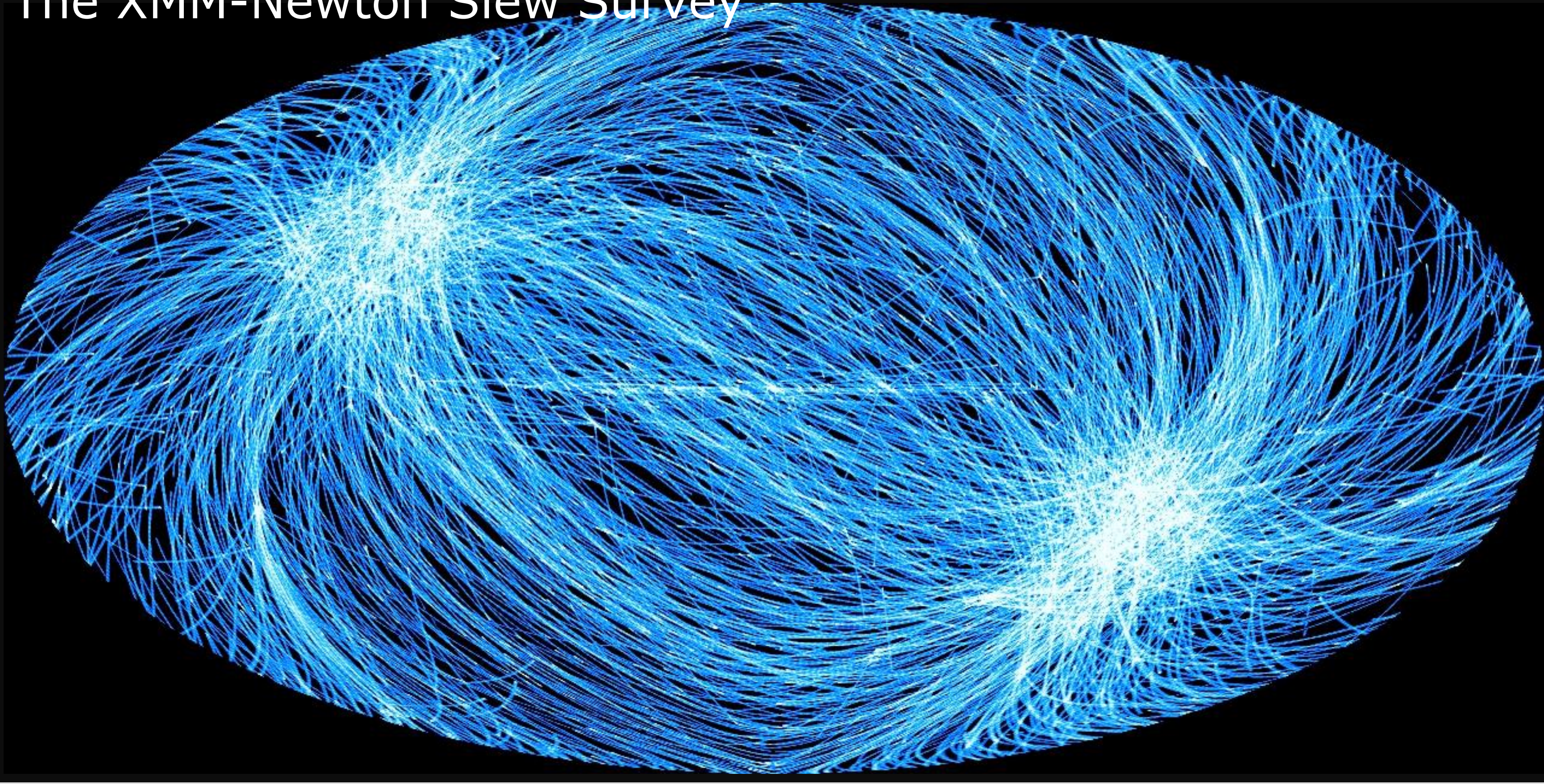
➔ Will allow highly accurate distance determina-tions to the dust


Optical and UV
V+B
(540nm, 434 nm)
U+UVW1
(348nm, 294nm)
UVM2+UVW2
(234nm, 218nm)
X-Ray
1.2-7.0keV
0.7-1.2keV
0.3-0.7keV
Messier 82 / Image courtesy of Pedro Rodriguez and ESA

3XMM-DR8 XMM-Newton Serendipitous Source Catalogue

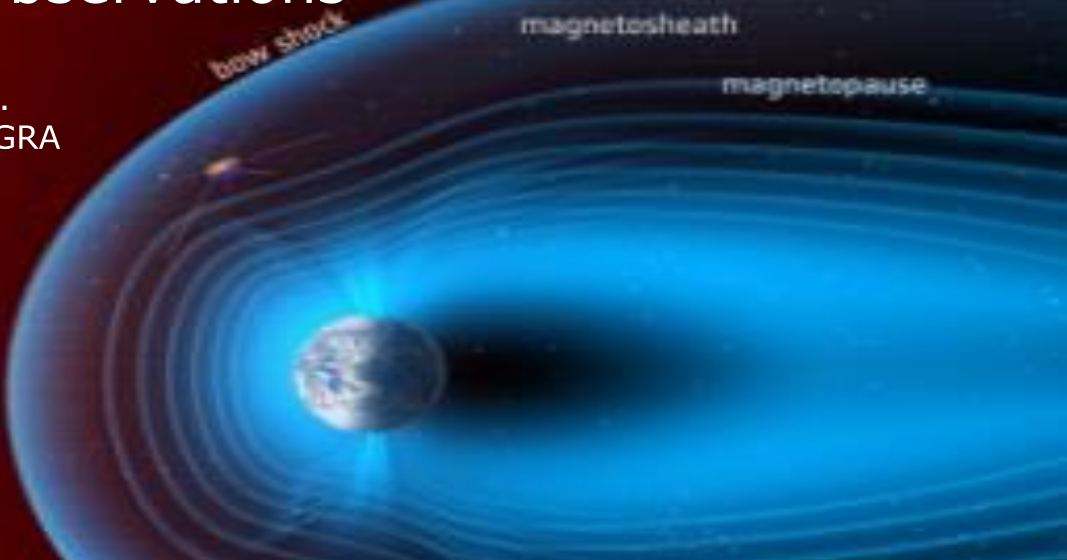


The XMM-Newton Slew Survey



Solar System

Exospheric Neutral Hydrogen Density 10 RE from XMM-Newton X-Ray Observations



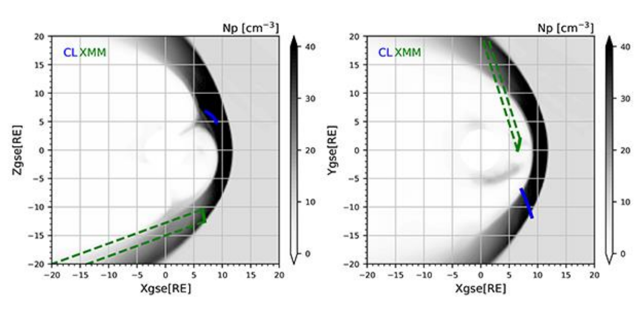
H.K. Connor & J. Carter, 2019 JGRA 124, 1612

XMM-Newton line of sight traversed the dayside of the Earth's magnetosheath and observed strong near-Earth soft X-ray emission

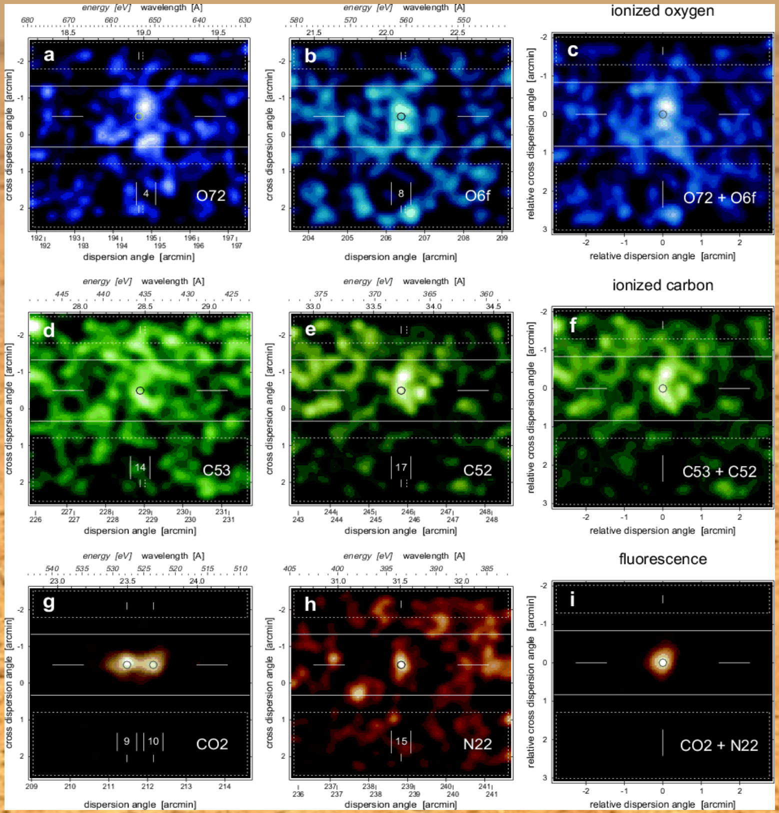
➔ neutral densities

➔ modelled plasma fluxes match well in situ observations of Cluster and Geotail

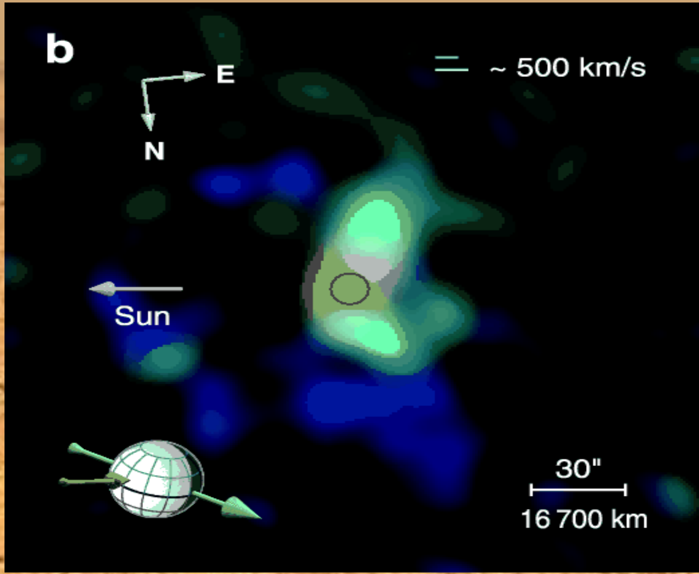
➔ Solar wind-Magnetosphere-Ionosphere Link Explorer



Mars: fluorescent scattering and solar wind charge exchange



K. Dennerl et al., 2006, A&A 451, 709



➔ **fluorescence scattering in upper atmosphere**

- with increasing distance to mars these lines fade

➔ **first detection of charge exchange from an exosphere of another planet**

The independent pulsations of Jupiter's northern and southern X-ray auroras

Jupiter's northern X-ray aurora is concentrated into a hot spot.

The X-ray emission demonstrates that the hot spot is produced by oxygen, sulphur and/or carbon ions that are undergoing charge exchange.

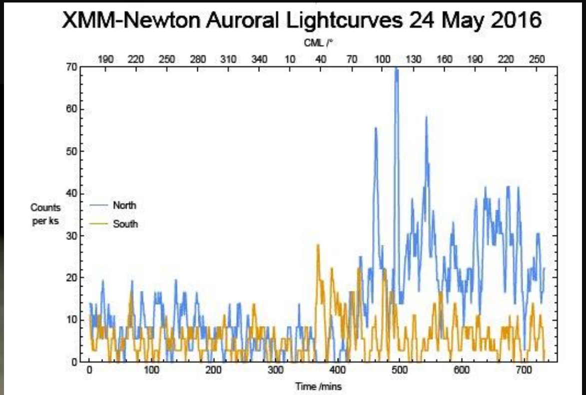
-Observations failed to reveal a similar feature in the south

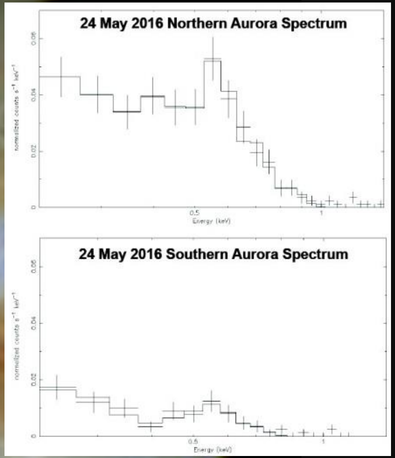
XMM-Newton and Chandra campaigns show that Jupiter's northern and southern spots each exhibit different periodic pulsations and uncorrelated changes in brightness

➔ highly energetic, non-conjugate magnetospheric processes sometimes drive the polar regions of Jupiter's dayside magnetosphere.

in contrast to current models of X-ray generation for Jupiter

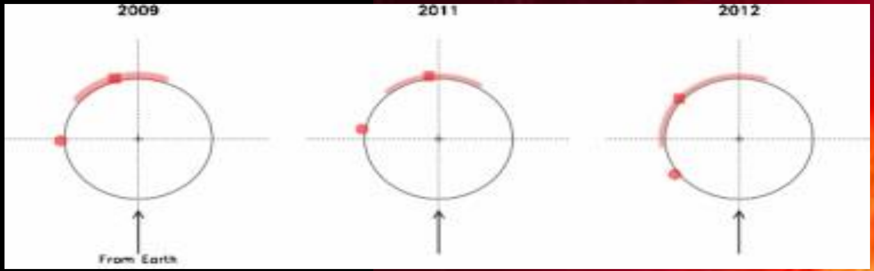
Dunn et al., 2017, Nature Astronomy 1, 758





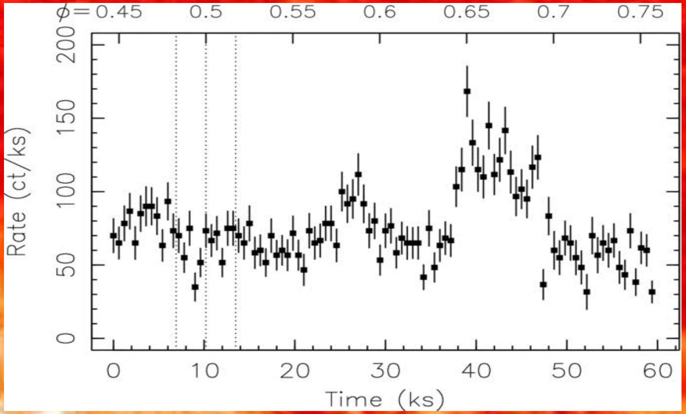
Exoplanets

The Corona of HD 189733 flares in phase with exoplanet's orbit



Planetary phases observed in 2009, 2011, and 2012

L. Pillitteri et al., 2014, ApJ 785, 145



EPIC-pn light curve of HD 189733

HD 189733 has a close-in, transiting, massive exoplanets (hot Jupiter)

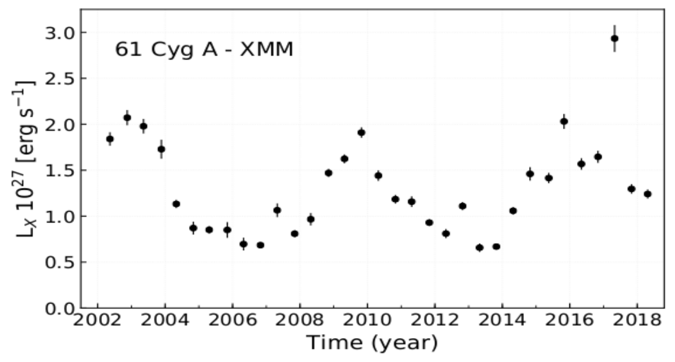
- **➔ Flares in 2009, 2011 and 2013 restricted to a small planetary phase range of Φ = 0.55-0.65**
- **➔ Quiescent spectrum: two temperatures a**
- **➔ During the flares a third component at 0.9 keV**
- **➔ Flaring structure as big as four stellar radii.**
- **➔ Magnetic field in this loop: 40 - 110 G**

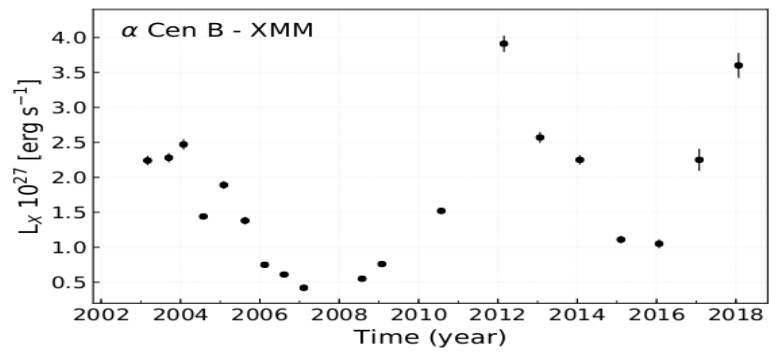
➔ The large length suggests an origin due to magnetic interaction between the star and the close-in planet.

➔ The magnetic field associated with the planet exert a force on the plasma and the coronal loop when the planet passes close to regions of the stellar surface

Stars

Coronal activity cycles in nearby G and K stars





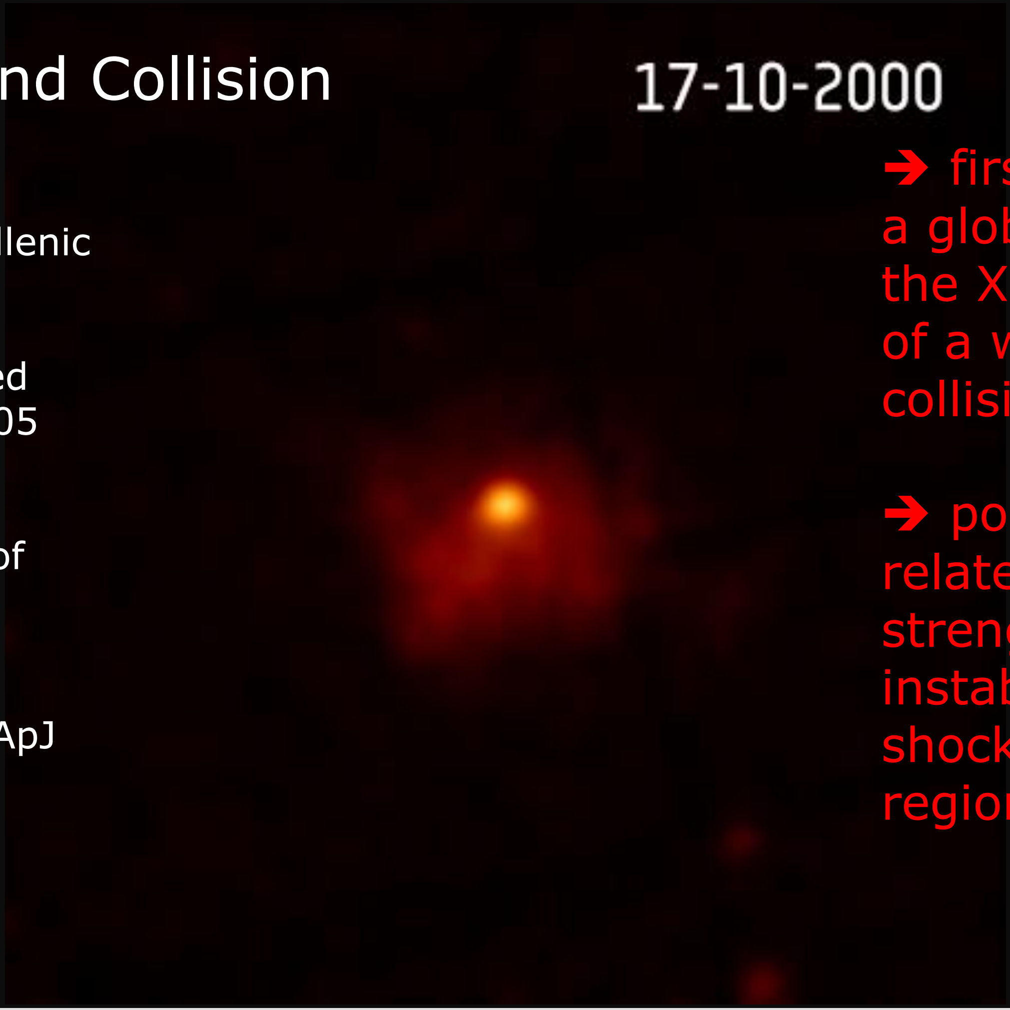
61 Cyg A (K5V) shows a regular coronal activity cycle analog to its 7.3 yr chromospheric cycle. The X-ray brightness variations are with a factor 3 significantly lower than on the Sun.

α Cen B (K1V) data suggest an X-ray cycle with an amplitude of about six to eight and a period of 8 - 9 years.

➔Coronal activity cycles are apparently a common phenomenon in older, slowly rotating G and K stars. The spectral changes of the coronal X-ray emission over the cycles are solar-like in all studied targets.

J. Robrade et al. , 2012, A&A, 543, A84, 2016arXiv161206570R (updated plots)

A Changing Wind Collision



HD 5980 is a massive system in Small Magellenic Cloud

- light curve unchanged between 2000 and 2005

- X-ray flux has now increased by a factor of ~2.5

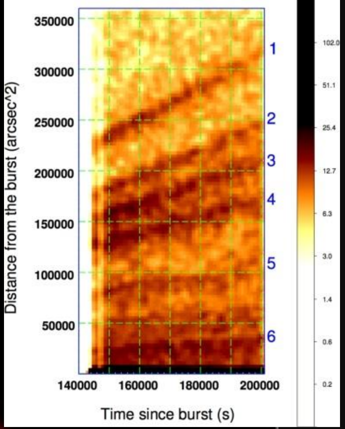
(Y. Nazé et al., 2018, ApJ 853, 164)

→ first detection of a global change in the X-ray emission of a wind–wind collision

→ possibly be related to varying strength of thin-shell instabilities in shocked wind regions

SNs, GRBs & GWs

GRB 160623A Behind the Dust Curtains



XMM-Newton observation ~2 day after the burst GRB 160623A

➔ evidence of six rings

➔ X-ray scattering of the prompt gamma-ray burst emission by dust clouds in our Galaxy

➔ distances of the dust layers with extraordinary precision: 528.1 ± 1.2, 679.2 ± 1.9, 789.0 ± 2.8, 952 ± 5, 1539 ± 20 and 5079 ± 64 pc

(Pintore, F. et al., 2017, MNRAS 472, 1465)

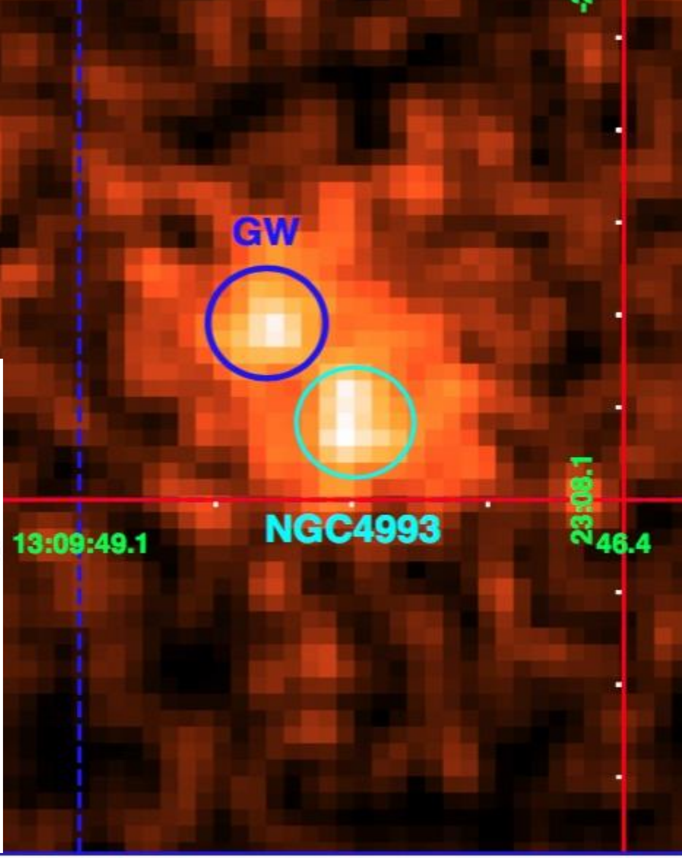
Evidence for a decreasing X-ray afterglow emission of GW170817A and GRB 170817A

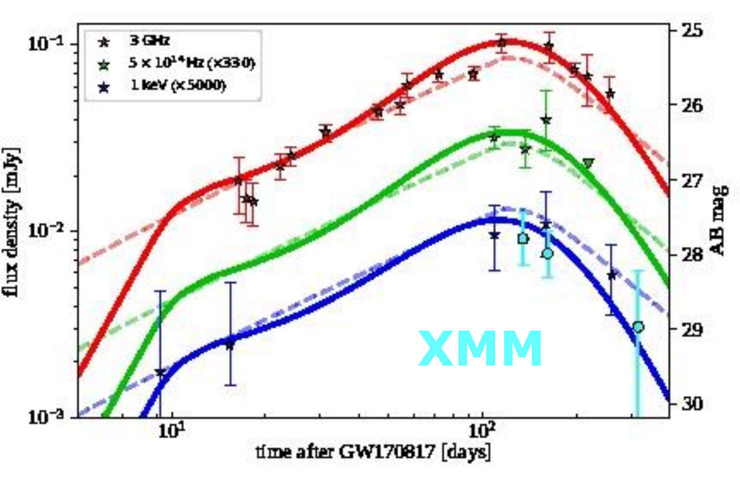
- XMM-Newton observation on the 29th December 2017: 135 day after the event

➔ X-ray light curve started to decrease

➔ i) a structured jet

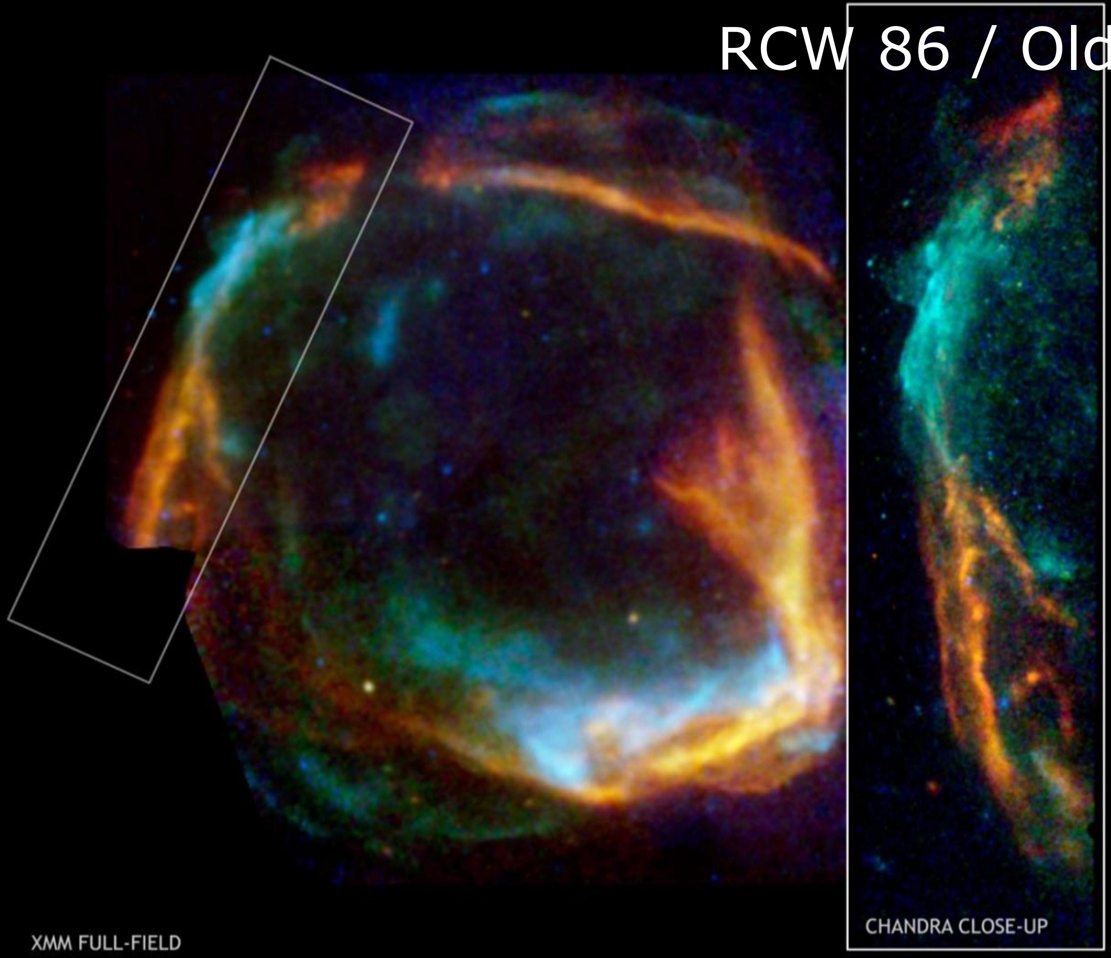
➔ ii) a sotropic fireball





P. D'Avanzo et al., 2018, A&A 613, L1

RCW 86 / Oldest Recorded Supernova



- Along northeastern shell of RCW 86 the dominant X-ray radiation mechanism changes from thermal to synchrotron

• Shock velocity ~2700 km/s

• Magnetic field ~24 μG

→ RCW 86 is the remnant of SN 185 that was observed by Chinese astronomers in 185 (and possibly the Romans)

J. Vink et al, 2006, ApJ 648, L33

Neutron Stars

A strongly truncated inner accretion disc in the Rapid Burster

The neutron star (NS) low-mass X-ray binary (LMXB), the Rapid Burster shows Type II X-ray bursts.

Swift, NuSTAR and XMM-Newton observations during 2015 outburst:

➔ broad Fe K line can modelled using relativistic reflection models

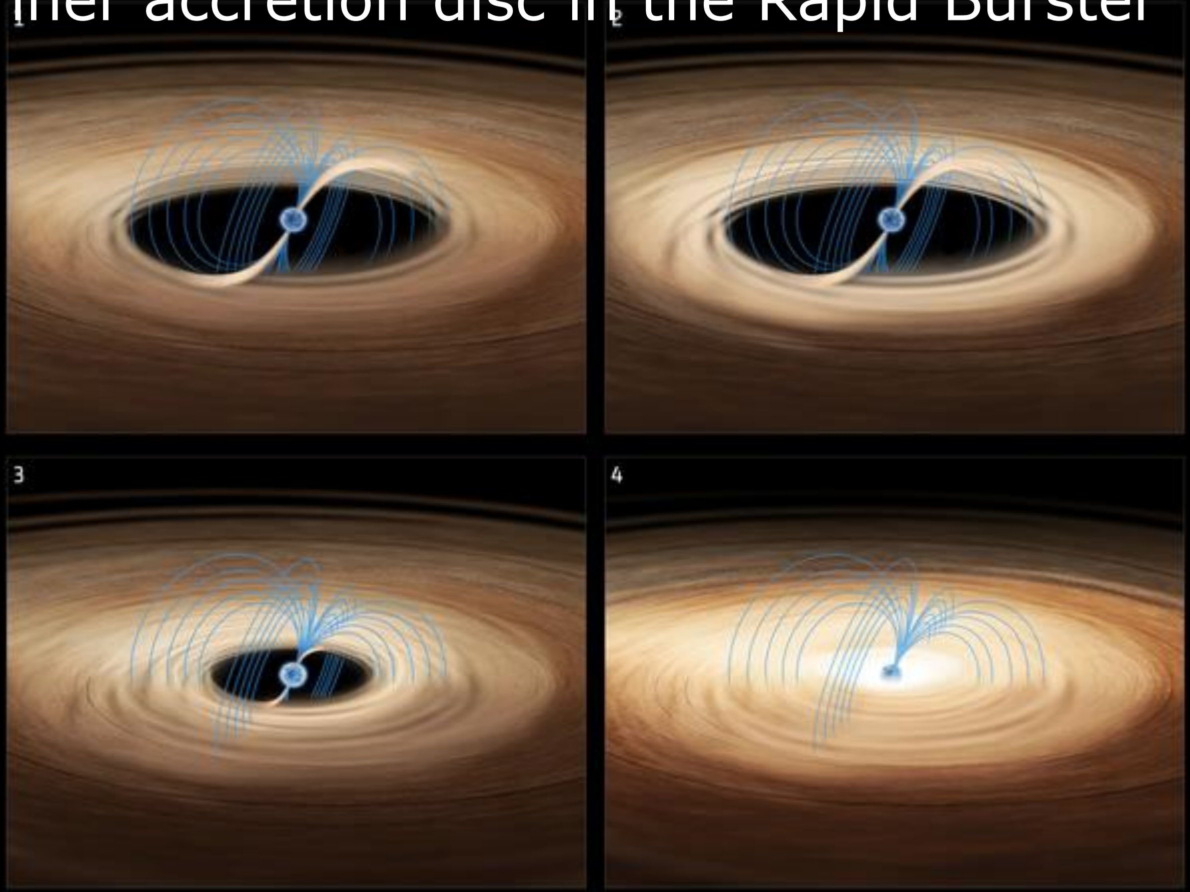
➔ strongly truncated disk at ~41.8 gravitational radii (~87 km),

➔ magnetospheric Type II burst

➔ strongly disfavours instabilities at the innermost orbit

➔ B = 6.2±1.5 × 10^8 G, i.e. larger than typically inferred for NS LMXBs

J. van den Eijnden et al., 2017, MNRAS 466, L98

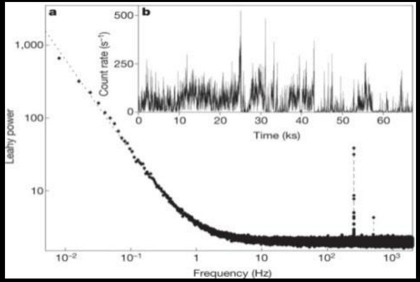


Swings between rotation and accretion power in a binary millisecond pulsar

- first observations of accretion-powered, millisecond X-ray pulsations from a neutron star previously seen as a rotation-powered radio pulsar.
- within a few days after a month-long X-ray outburst, radio pulses were again detected.

➔ evolutionary link between accretion and rotation-powered millisecond pulsar

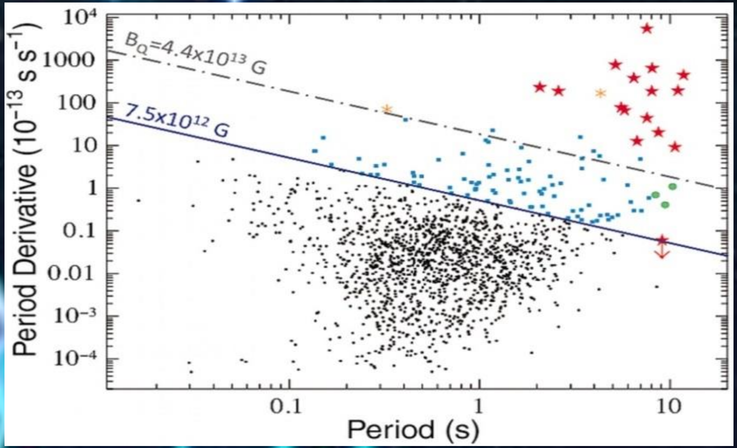
➔ some systems can swing between the two states on very short timescales

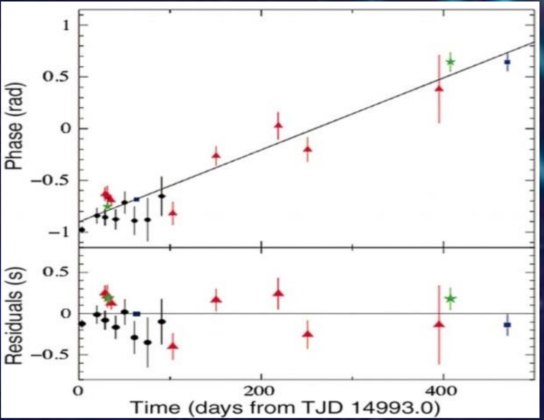


Papitto et al., 2013, Nature 501, 517

A Low-Magnetic-Field Soft Gamma Repeater

- Magnetars: neutron stars with extreme magnetic fields, B ~ 10^{14} to 10^{15} gauss, i.e. the binding energy of an electron exceeds its rest mass
- It was generally assumed that Gamma Ray Burst are a characteristics of Magnetars, which consequently were identified with: Anomalous X-Ray Pulsars and Soft Gamma Repeaters (SGR)



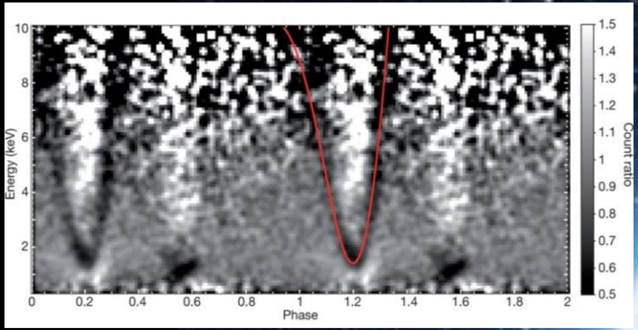


➔ XMM-Newton (& other X-ray observatories) found that SGR 0418+5729 has a magnetic field of < 7.5 × 10^{12} gauss

➔ The emission of a Gamma Ray Burst does not prove a high magnetic field

N. Rea et al., 2010, Science 330, 944

Magnetic multipole field in SGR 0418+5729

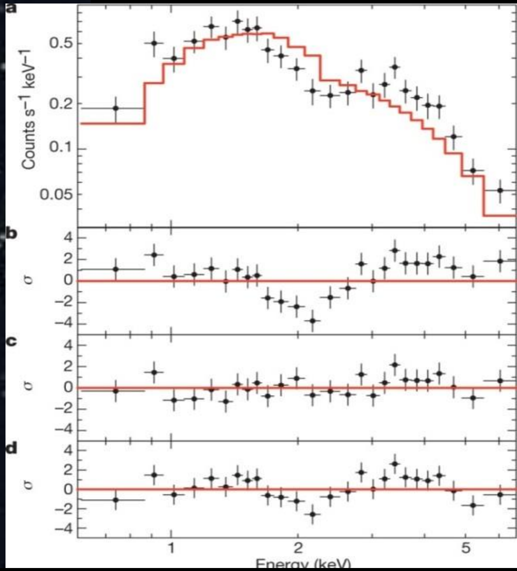


Phase-dependent spectral feature in the EPIC data of SGR 0418+5729.

- Soft-γ-ray repeaters (SGRs) and anomalous X-ray pulsars (AXPs) are neutron stars that sporadically undergo X-ray/γ outbursts
- powered by their magnetic energy
- magnetic fields >> radio pulsars

- **SGR 0418+5729 has a weak dipole magnetic moment of B = 6 × 10 10^{12} G (derived from timing parameters)**
- **A strong field has been proposed in the stellar interior and in multipole components on the surface**
- **X-ray absorption line**
- **which depend strongly on the star's rotational phase**

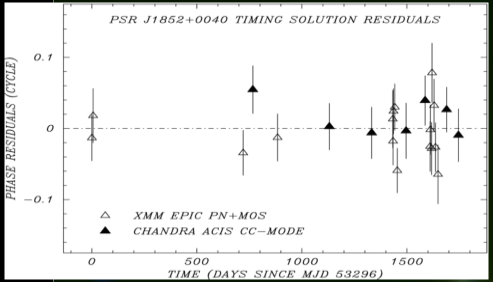
→ proton cyclotron
→ magnetic field from 2 × 10^{14} G to > 10^{15} G



a: spectrum from phase interval 0.15–0.17 and phase-averaged spectrum in red
b: residuals; c: residuals after adding an absorption line

Tiengo et al., 2013, Nature 500, 312

Spin-Down Measurement of PSR J1852+0040



Kesteven 79

Halpern & Gotthelf, 2010, ApJ 709, 436

PSR J1852+0040 is Central Compact Object (CCO)

First measurement of the spin-down rate of a CCO:

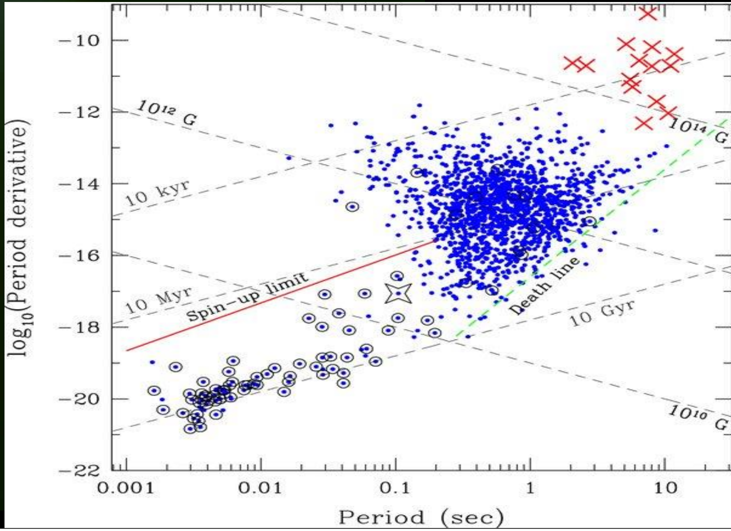
→ dP / dt = (8.68 ± 0.09) × 10^{-18}

→ B_s = 3.1 × 10^{10} G, the smallest ever of a young neutron star and

→ consistent with being a fossil field

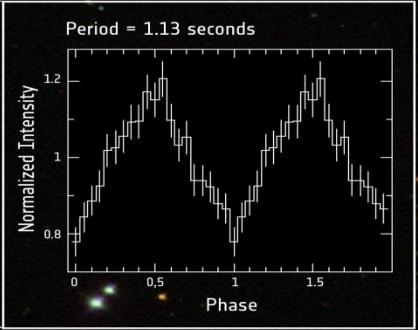
→ strong support for "anti-magnetar"

→ sonsistent with low luminosity and lack of magnetospheric activity or synchrotron nebulae



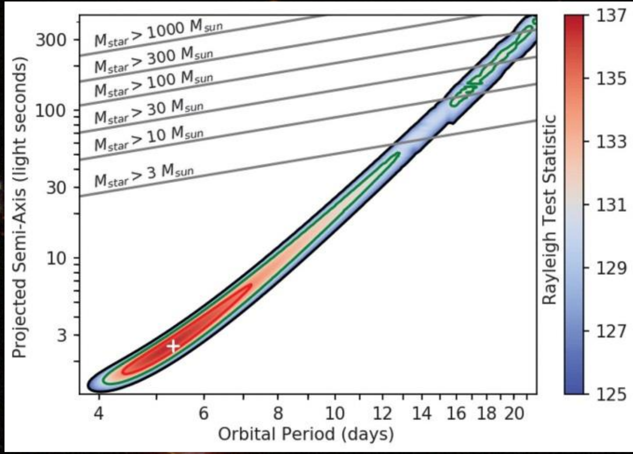
ULX – Intermediate Mass BH

An accreting pulsar with extreme properties drives an ultraluminous X-ray source in NGC 5907



Ultraluminous x-ray sources (ULXs) shine brighter than any x-ray source in our Galaxy.

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



XMM-Newton and NuSTAR observations:

➔ NGC 5907 ULX is a neutron star (NS)
➔ spin period evolves from 1.43 s in 2003 to 1.13 s in 2014.
➔ isotropic peak luminosity of ~1000 × Eddington limit
➔ standard accretion models fail to explain its luminosity, even assuming beamed emission,
➔ strong multipolar magnetic field can describe its properties.
➔ other extreme ULXs might harbour NSs.

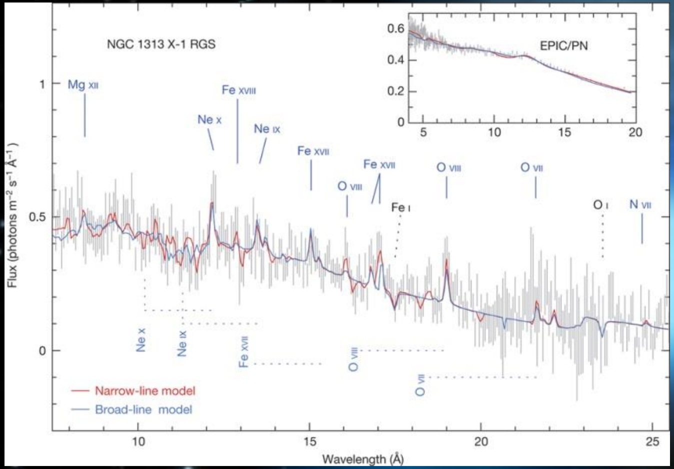
G.L. Israel, 2017, Science 355, 817

Outflows in two Ultraluminous X-ray Sources (ULX)

ULX have X-ray luminosities > 3×10^{39} ergs / s.
Possible explanations are accretion:

(a) onto neutron stars or stellar-mass black holes (BH) in excess of the Eddington limit

(b) onto intermediate-mass BH (10^3–10^5 solar masses)



High-resolution XMM-Newton X-ray spectra of the ULXs NGC 1313 X-1 and NGC 5408 X-1.

➔ X-ray absorption lines from highly ionized iron, oxygen and neon

➔ Blueshift velocity ~ 0.2 c

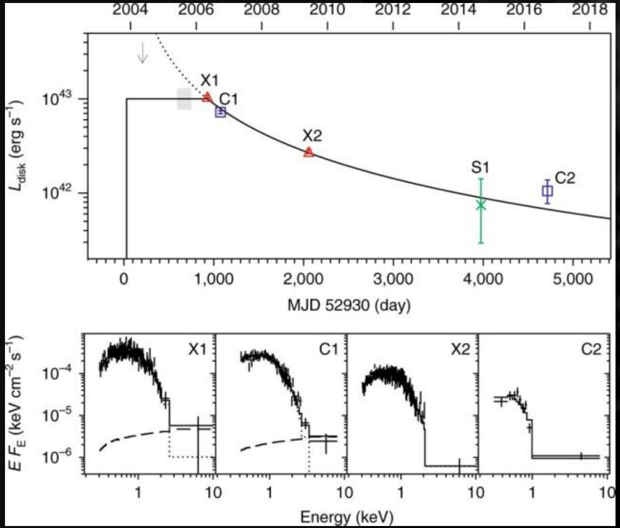
➔ The absorption lines occur in a fast-outflowing gas, as predicted by models of hyper-accreting stellar-mass BH

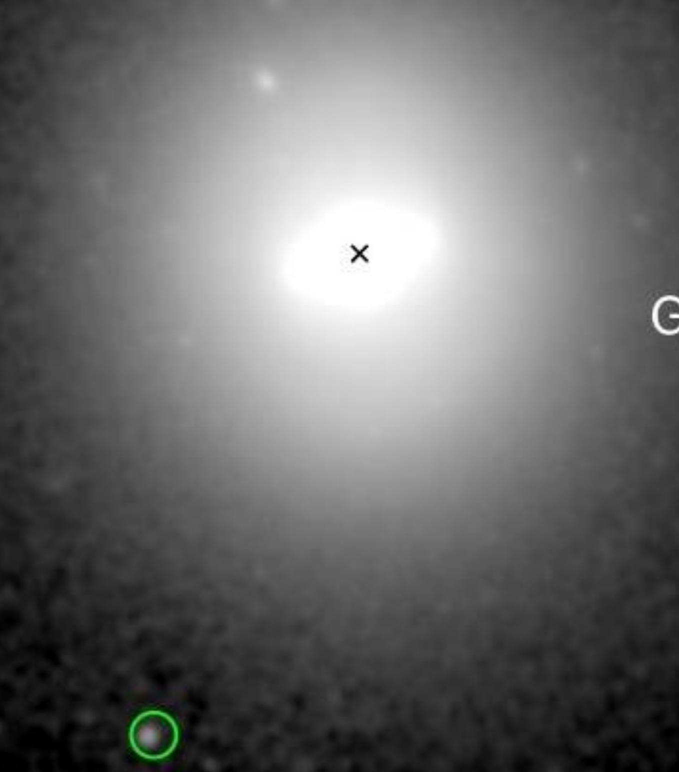
C. Pinto, et al., 2016, Nature 533, 64

Tidal Disruption Events

A tidal disruption event rom an intermediate-mass black hole in an off-centre star cluster

- luminous X-ray outburst from a massive star cluster
- luminosity peaked at 10^{43} erg/s and decayed systematically over 10 years

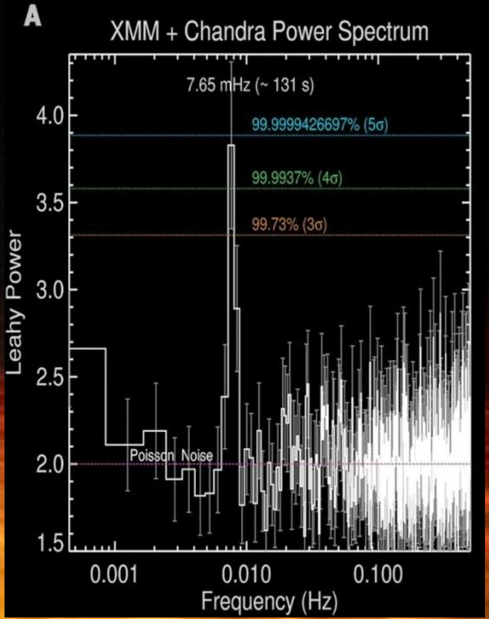




→ **thermal-state signature**
→ **very high luminosities**
→ **ultrasoft X-ray spectra**
→ **characteristic power-law evolution of the light curve**
→ **provides strong evidence that the source contains an intermediate-mass black hole**

Lin et al, 2018 Nature Astronomy 2, 656

Quasi-Periodic Oscillations after a Star is Disrupted by a Massive Black Hole



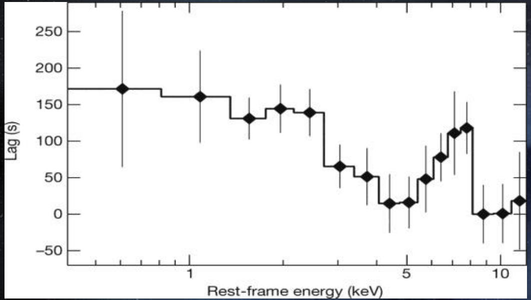
- tidal forces close to black holes can rip apart stars that come too close to them.
- stellar debris spirals toward the black hole

➔ stable 131-second x-ray quasi-periodic oscillation from the tidal disruption event ASASSN-14li

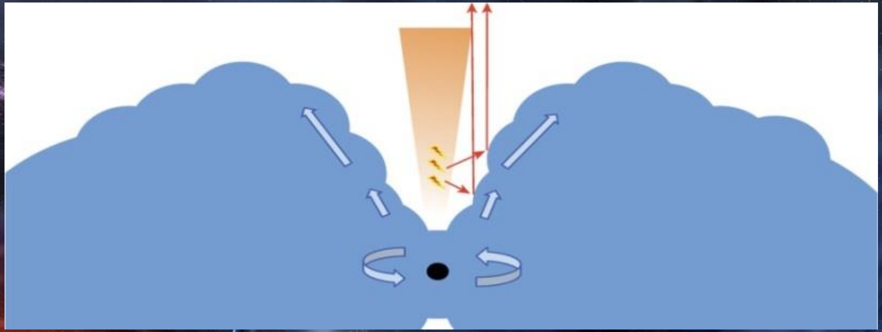
➔ periodicity originates from close to the event horizon and that the black hole is rapidly spinning

D. R. Pasham, et al., 2019, Science 363, 531

Relativistic Reverberation in the Accretion Flow of a Tidal Disruption event



The emission from ~4–5 keV and 8–13 keV (continuum) vary first, and the iron line from ~7–8 keV responds ~100 s later.



Swift J1644+57 is a super-Eddington accreting source, with a thick disk (blue) and a relativistic radio jet (orange). The blue arrows represent the dynamics in the disk: the accretion flow rotates around the central black hole and the walls of the funnel are outflowing at ~0.1c–0.5c.

Swift J1644+57 tidal disruption event

- relativistic jet pointed in line of sight

Kara et al., 2016, Nature 535, 388

➔ Reverberation arising from gravitationally redshifted iron Kα photons reflected off the inner accretion flow

➔ Accretion rate of 100 times the Eddington limit

➔ X-rays do not arise from the relativistic jet

Flows of X-ray gas reveal the disruption of a star by a massive black hole

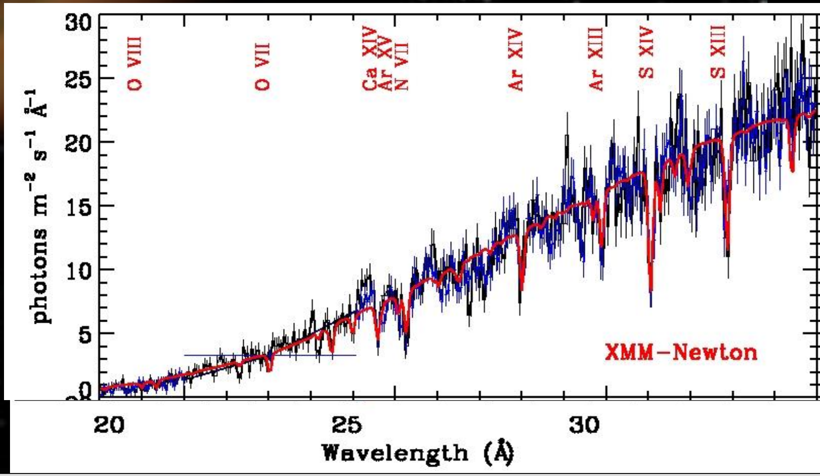
J.M. Miller et al., 2015, Nature 526, 542

- tidal disruption event ASASSN-14li
- detection of blue-shifted absorption lines of highly ionized atoms
- variability indicates that the gas is close to the black hole
- narrow line widths indicate a low volume filling factor
- outflow speeds are below the escape speed from the radius set by variability

➔ rotating wind from the inner region of a nascent accretion disk, or

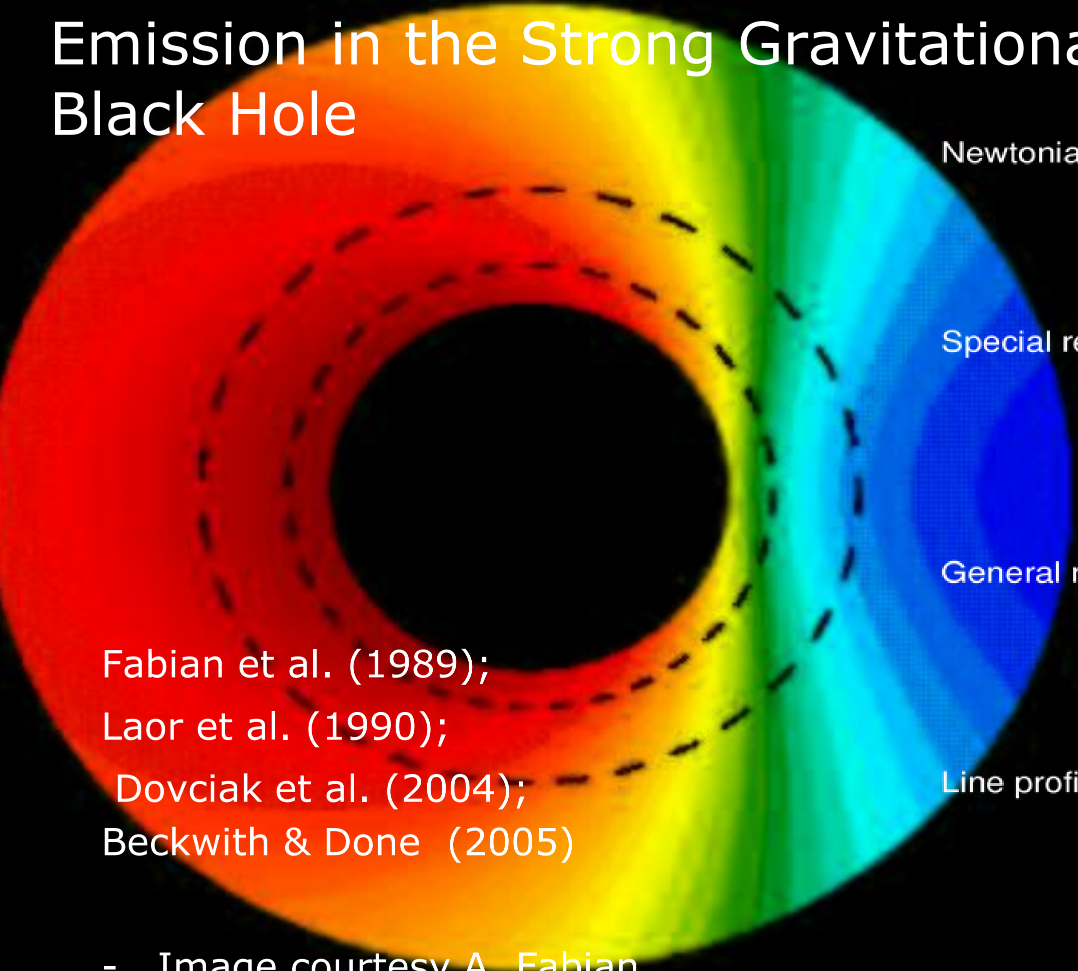
➔ a filament of disrupted stellar gas near to the apocenter of an elliptical orbit

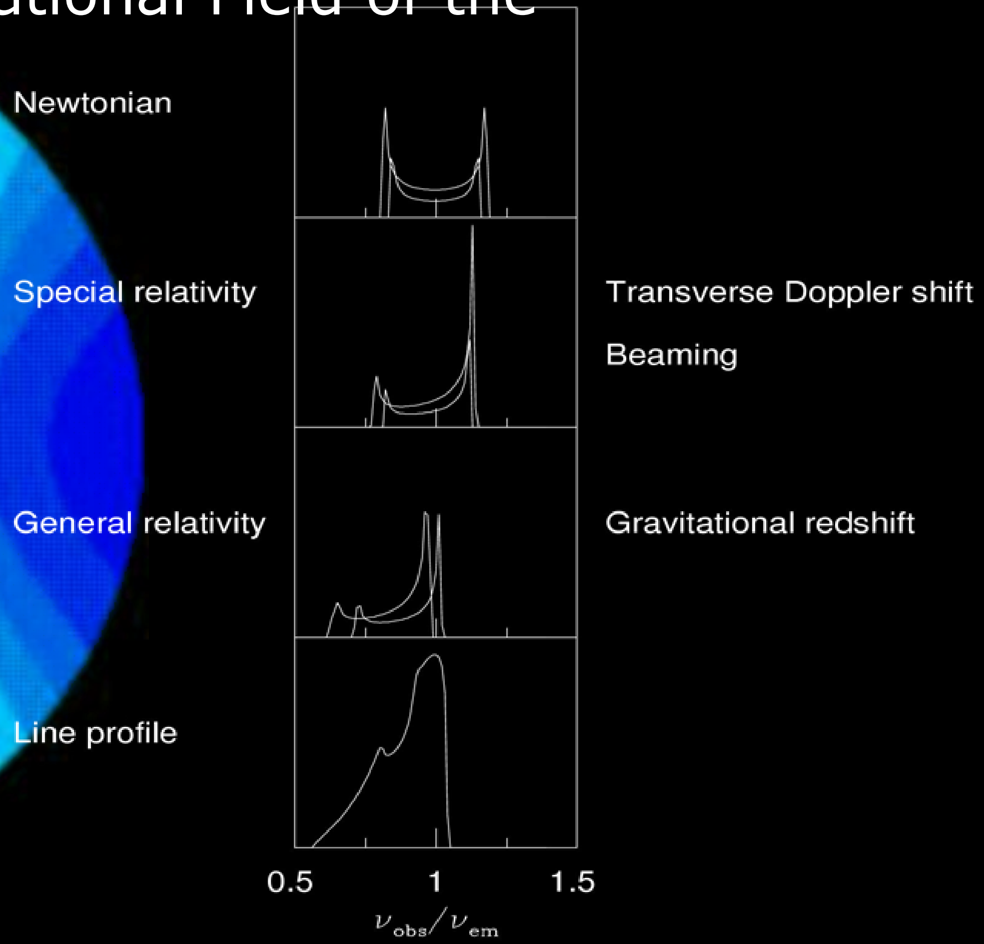
The high-resolution (RGS1 & RGS2) X-ray spectra of ASASSN-14li reveal blue-shifted absorption lines.



Black Holes / General Relativity

Emission in the Strong Gravitational Field of the Black Hole

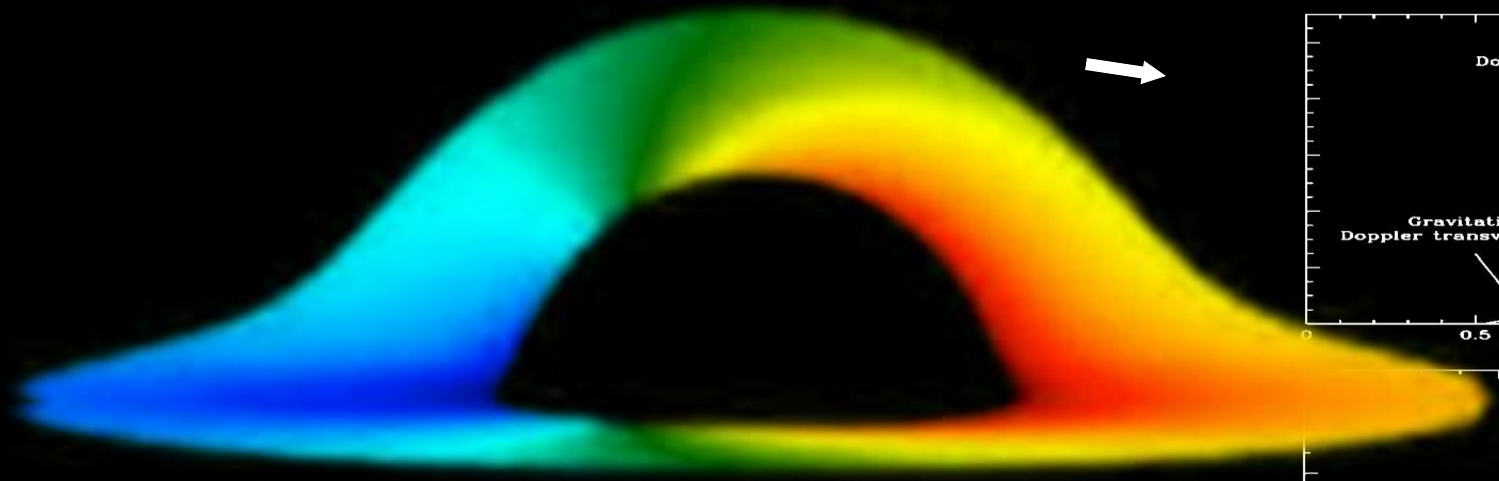


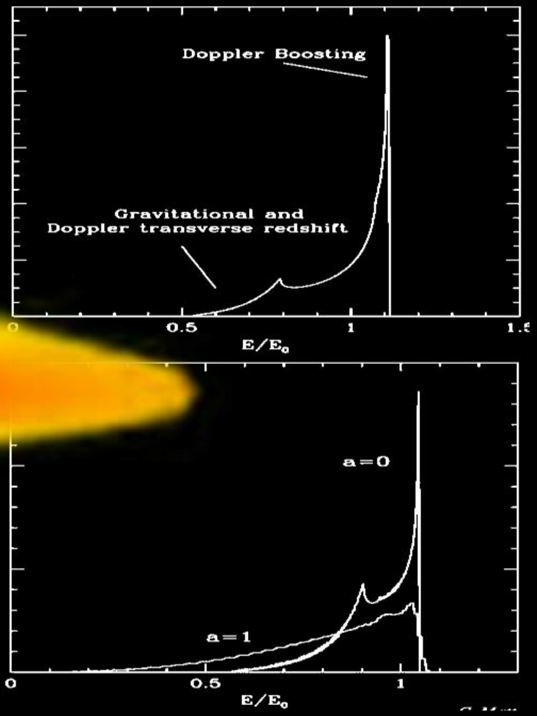


Fabian et al. (1989);
Laor et al. (1990);
Dovciak et al. (2004);
Beckwith & Done (2005)

- Image courtesy A. Fabian

Emission in the Strong Gravitational Field of the (Kerr) Black Hole

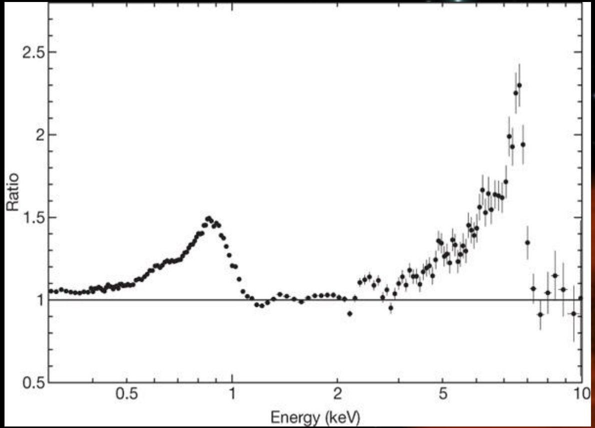


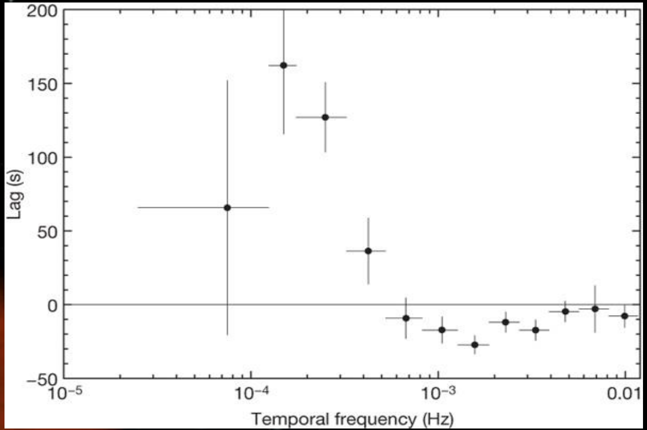


- Image courtesy G. Matt and K. Beckwith

K. Beckwith & C. Done,
2005, MNRAS 359, 1217

Broad line emission from iron K- and L shell transitions in the active galaxy 1H 0707-495





Broad Iron K & L emission lines :

- Line ratio (photons) 1:20
- Emitted between 1.3 and 400 r_g
- Emissivity index 4
- BH spin rate a > 0.98

➔ Frequency-dependent lags between the 1 - 4 kev band flux and the 0.1 – 1 keV band flux

➔ Negative lag for v > 6 x 10^{-4} Hz

➔ Power law changes before refection

A.C. Fabian, 2009, Nature 459, 540

A rapidly spinning supermassive black hole at the center of NGC1365

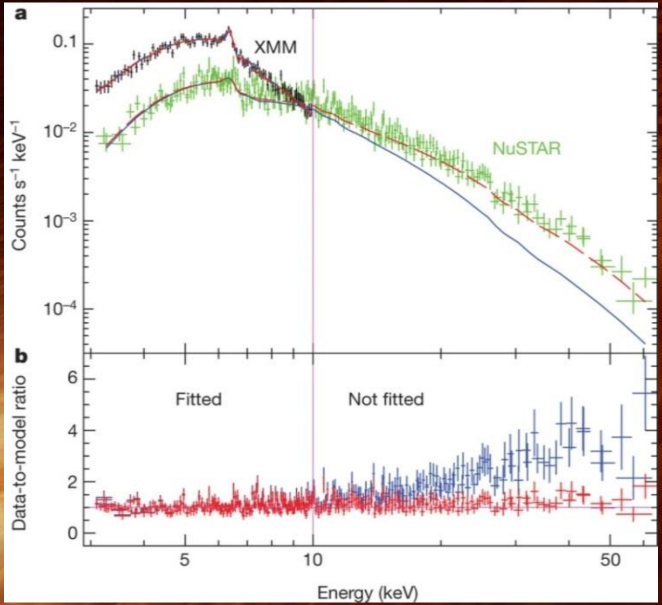
Simultaneous observation of NGC 1365 by XMM-Newton and NuSTAR:

➔ relativistic disk features through broadened Fe-line emission and an associated Compton scattering excess of 10-30 keV

➔ temporal and spectral analyses allows to disentangle continuum changes due to time-variable absorption from reflection, which arises from a region within 2.5 gravitational radii of the rapidly spinning black hole.

➔ Absorption-dominated models that do not include relativistic disk reflection can be ruled out both statistically and on physical grounds.

Risaliti G., et al., 2013, Nature 494



a: XMM-Newton and NuSTAR spectral data and models. The two models contain a relativistic reflection component plus variable partial covering (red), and a double partial covering (blue). Both models have been fitted to the data below 10 keV. The models strongly deviate at higher energies. b, Data-to-model ratio for the double partial covering (blue) and relativistic reflection plus variable absorber (red) models.

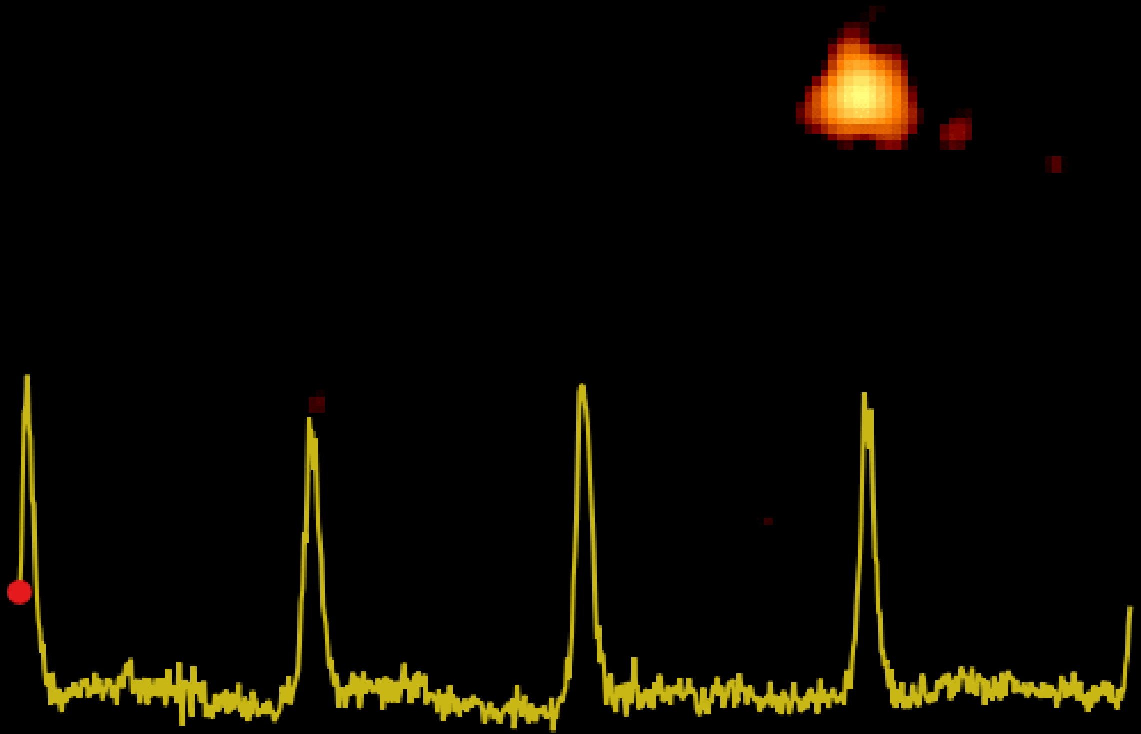
Nine-hour X-ray quasi-periodic eruptions from a low-mass black hole galactic nucleus

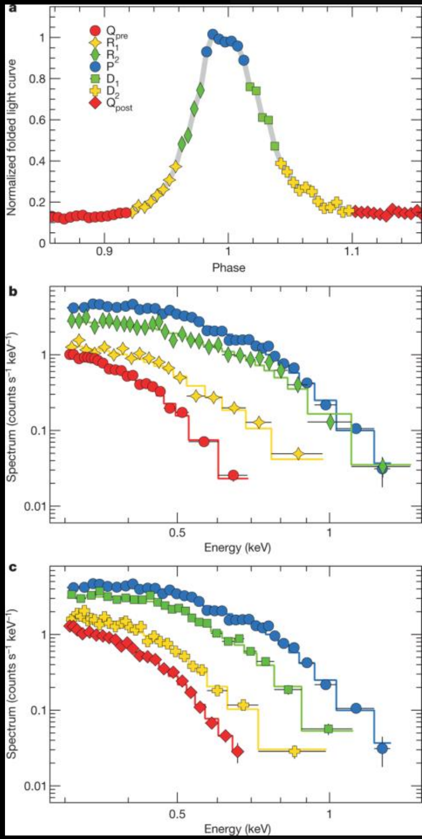
Seyfert 2 galaxy GSN 069

$z = 0.0189$

$M_{BH} \approx 2\times10^6 M_\odot$

Miniutti et al., 2019, Nature 573, 381





European Space Agency

Supermassive Black Holes Outflows and Winds

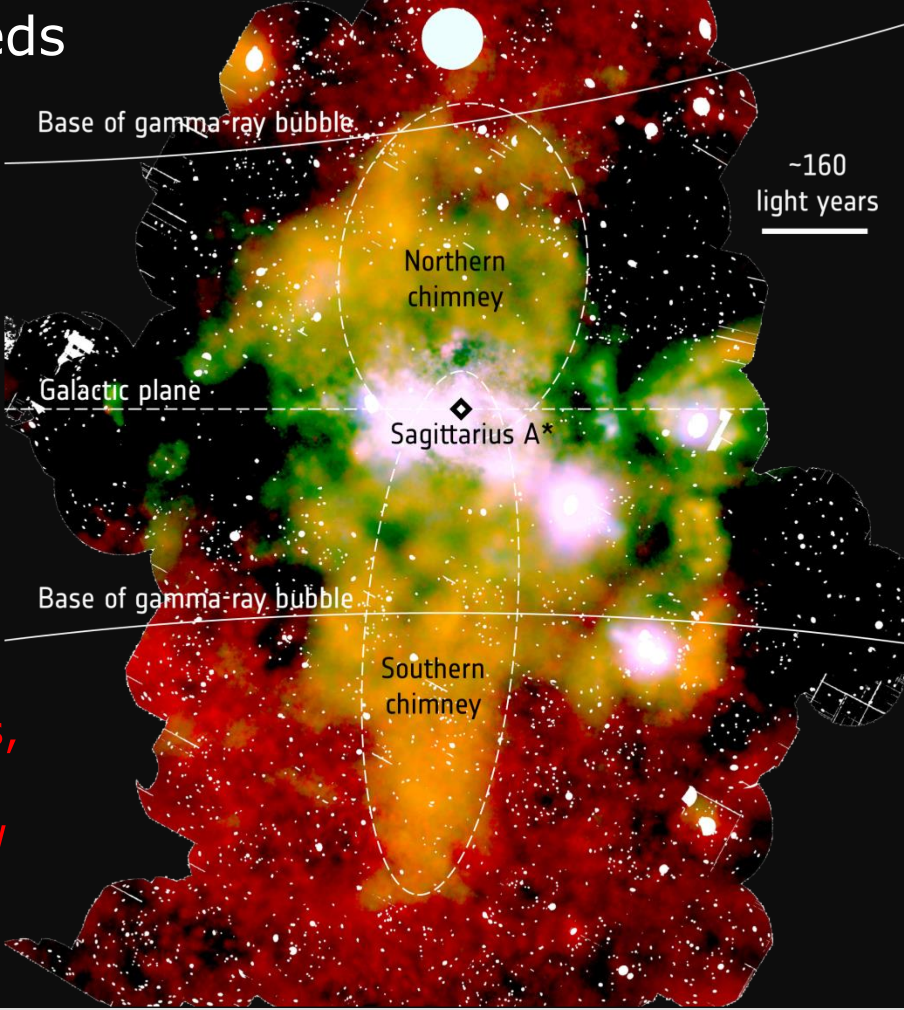
An X-ray chimney extending hundreds of parsecs above and below the Galactic Centre

- γ-ray observations revealed the `Fermi bubble' implying relativistic particles populating huge cavities on both sides of the Galactic plane
- ROSAT X-ray maps show that the edges of these cavities are bright in X-rays

➔ XMM-Newton finds prominent X-ray structures connecting the Galactic Centre to the Fermi bubbles.

➔ channels through which energy and mass, injected by episodic events at the Galactic Centre, are transported from the central few parsecs to the Fermi bubbles

G. Ponti et al., 2019 Nature567, 347

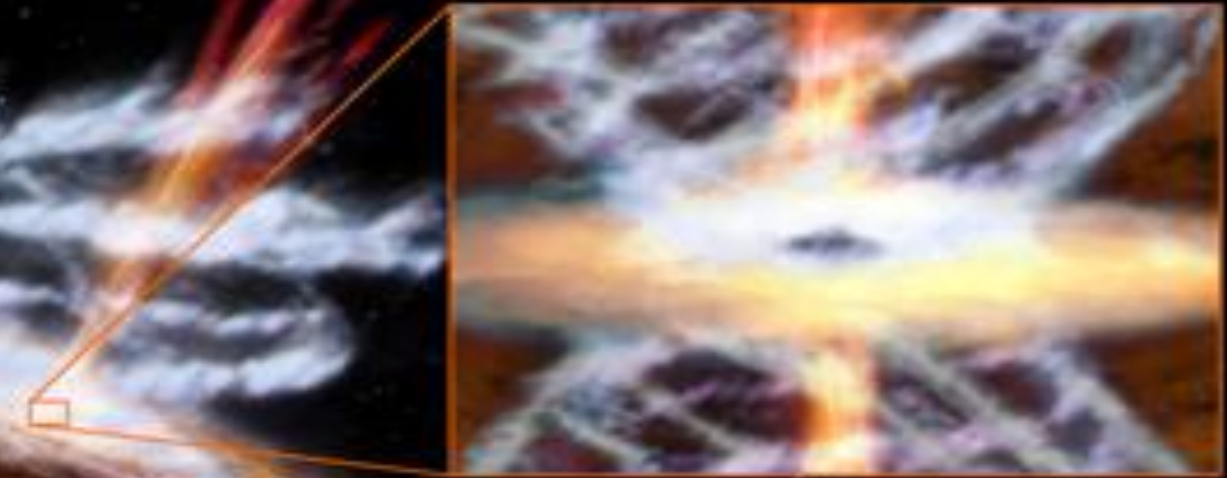


Ultra-fast Outflows in Radio-quiet Active Galactic Nuclei

F. Tombesi et al., 2012, MNRAS 422, L1

F. Tombesi, et al., 2011, ApJ 742, 44

F. Tombesi, et al., 2010, A&A 521, 57



Ultra-fast outflows (UFOs) are detected through blueshifted Fe XXV/XXVI K-shell transitions.

- 42 local radio-quiet AGNs

➔ >35% are showing UFOs

➔ v ~ 0.03c -0.3c, mean ~0.14c

➔ Ionization parameter is very high

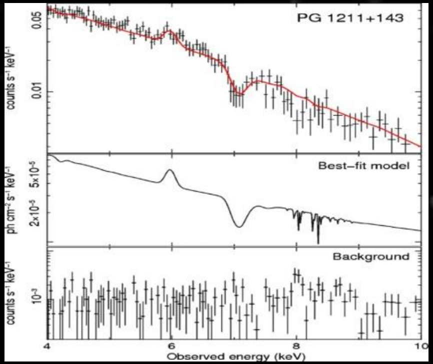
➔ Column densities are N_H~10^{22}-10^{24} cm^{-2}

➔ Location: ~10^2-10^4 r_s from the central black hole

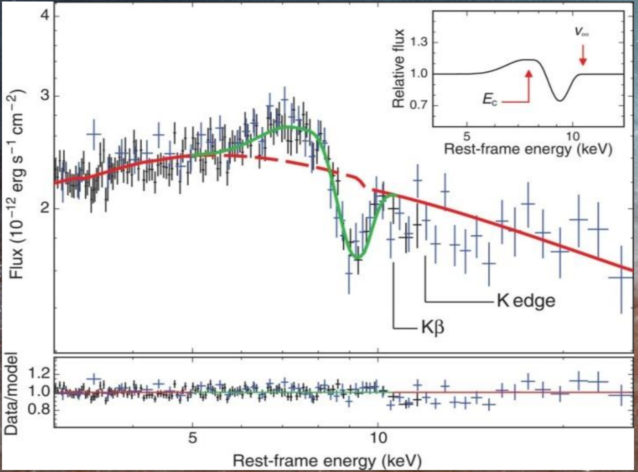
➔ Outflow rates: ~0.01-1 Mo y^{-1} / 5-10% of the accretion rates

➔ mechanical power ~42.6-44.6 erg s^{-1}

➔ significant contribution to the AGN cosmological feedback



Black hole feedback in the luminous quasar PDS 456



XMM-Newton pn (black) and NuSTAR (blue) data are shown. The green curve shows a model where the emission and absorption residuals characterizing the Fe-K band are described through a self-consistent 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} ergs/s

➔ Enough to provide the feedback required by models of black hole and host galaxy coevolution.

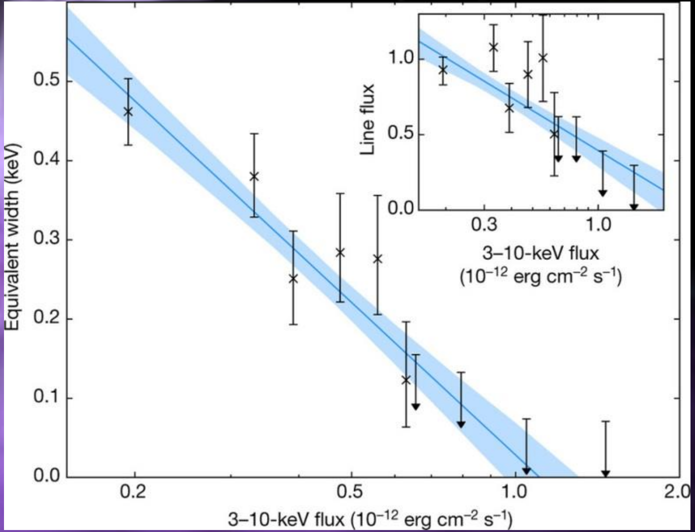
E. Nardini, et al., 2015, Science 347, 860

The response of relativistic outflowing gas to the inner accretion disk of a black hole

Gas outflows from AGNs release huge quantities of energy into the interstellar medium, potentially moderating the growth of their host galaxy.

XMM-Newton observations of the narrow line Seyfert-1 galaxy IRAS 13224-3809:
➔ extreme ultrafast gas flow in the X-ray spectrum
➔ 0.236 ± 0.006 times the speed of light (71,000 km/s)
➔ absorption is strongly anti-correlated with the emission of X-ray

➔ X-ray emission from within a few gravitational radii of the black hole is ionizing the disk wind hundreds of gravitational radii further away as the X-ray flux rises.



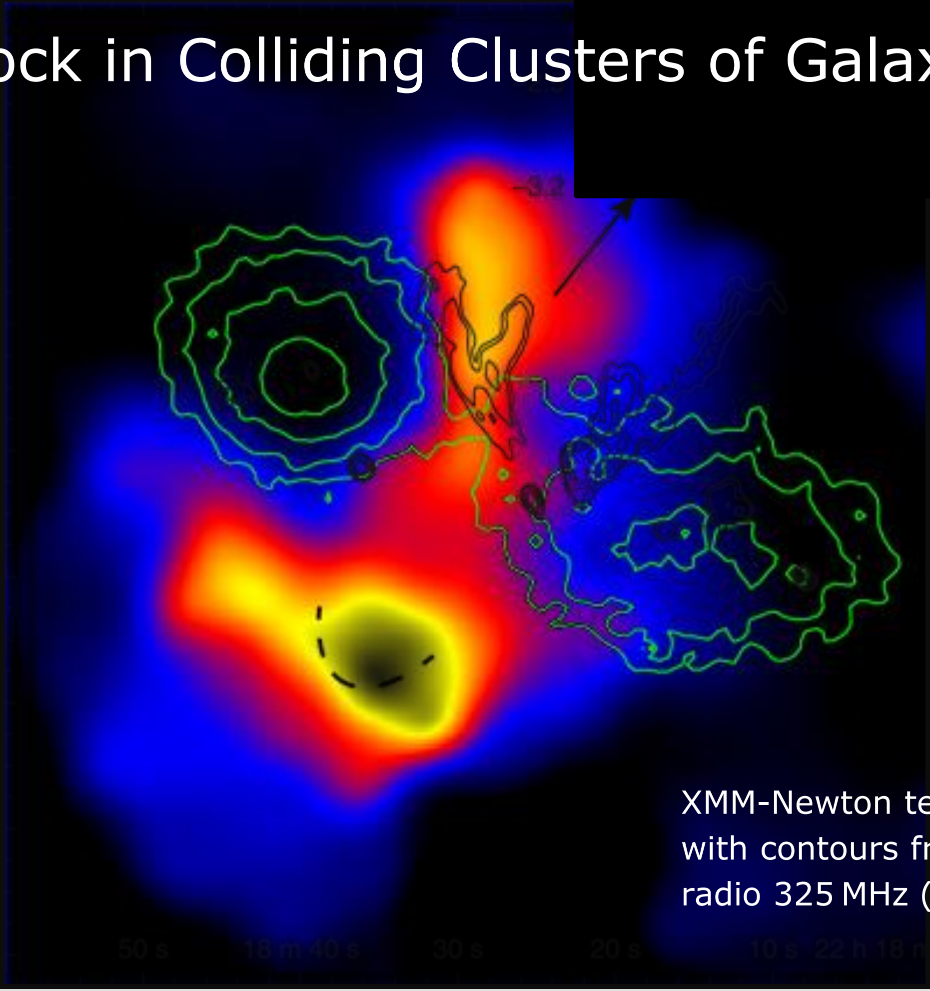
M. L. Parker, et al., 2017
Nature 543, 83

Clusters of Galaxies

Pre-Merger Shock in Colliding Clusters of Galaxies

1E 2216.0-0401 and 1E 2215.7-0404 are observed at an early phase of major merger.

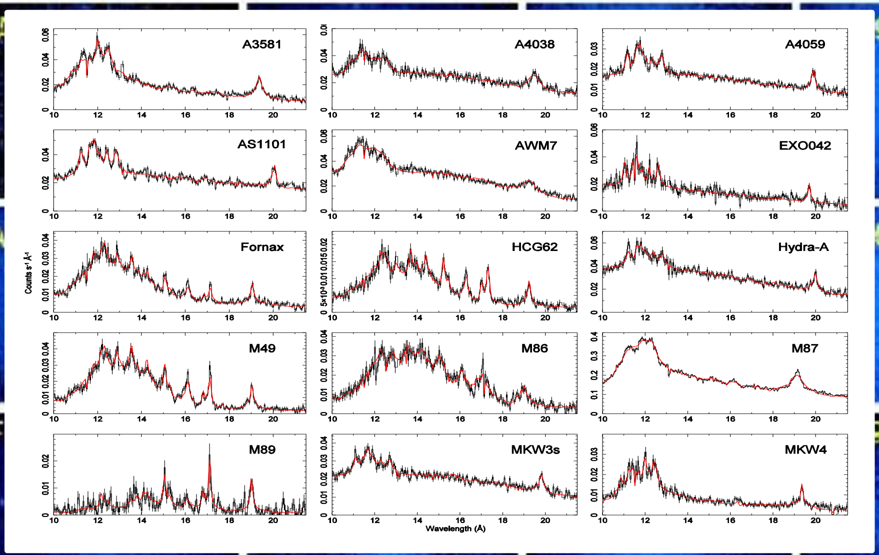
➔ Contrary to all the known merger shocks, the new shock propagates outward along the equatorial plane of the merger.



L. Gu et al., 2019, Nature Astronomy

XMM-Newton temperature map overlapped with contours from the X-ray (green) and radio 325 MHz (white) images.

RGS Cluster Sample: Constraints on Turbulence



RGS spectral fits for the (1.7′+1.7′) region with the 7 -25 Å spatial broadening profile

- 44 cluster of galaxies with RGS spectra

➔ 50% show upper limits on turbulence less than 500 km/s

➔several spectra have upper limits consistent with strong turbulence (>1000 km/s)

➔ upper limits are larger than the Mach numbers required to balance cooling

➔ suggests that dissipation of turbulence may prevent cooling

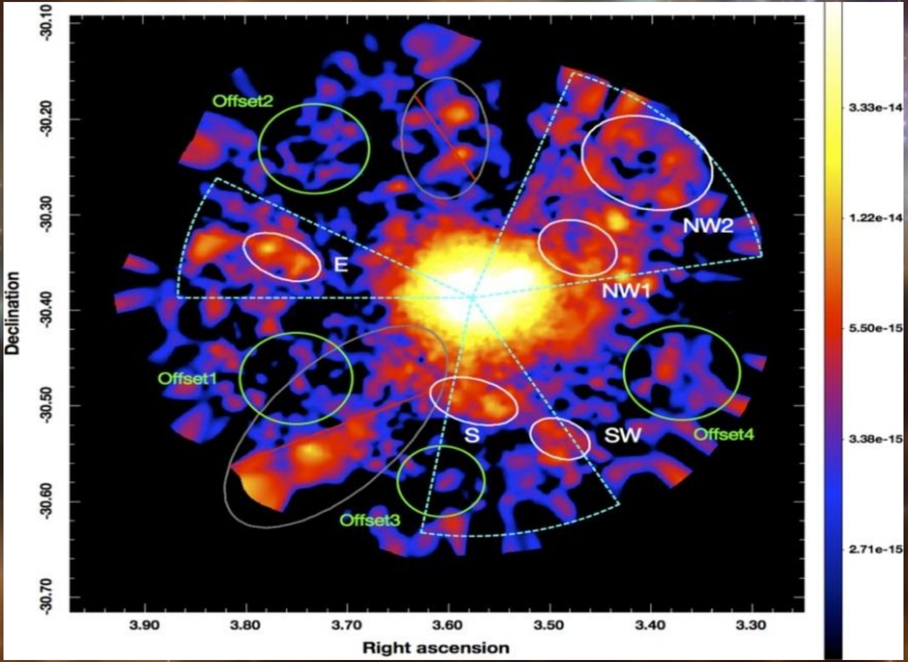
C. Pinto et al., 2015, A&A 575, 38

Warm–hot baryons comprise 5–10% of filaments in the cosmic web

XMM-Newton observations of filamentary gas structures (T=10^7 K) associated with Abell 2744.

- ➔ **hot gas structures are coherent over scales of 8 Mpc**
- ➔ **the filaments coincide with over-densities of galaxies and dark matter, with 5–10% of their mass in baryonic gas**
- ➔ **gas has been heated up by the cluster's gravitational pull and is now feeding its core**
- ➔ **large fraction of the missing baryons reside in the filaments of the cosmic web**

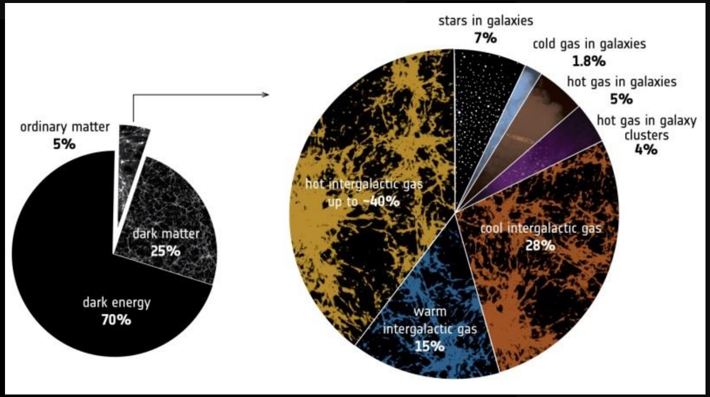
D. Eckert, et al., 2015, Nature 528, 105



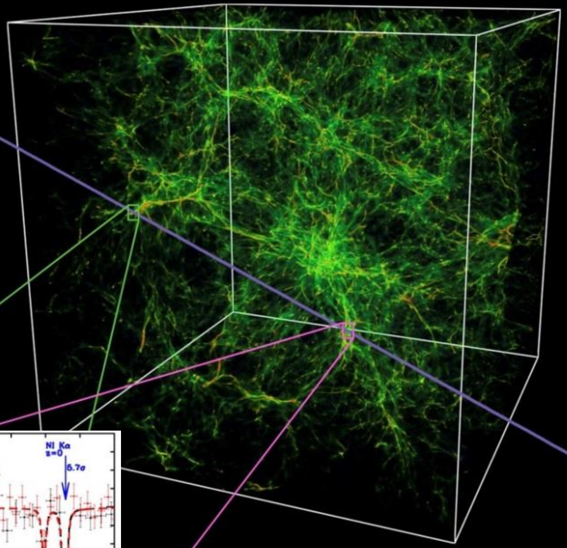
XMM-Newton/EPIC surface-brightness image of the galaxy cluster Abell 2744 in the 0.5–2 keV band (bar at right; units are erg s^{-1} cm^{-2} $arcmin^{-2}$), right ascension and declination are in degrees.

Cosmology

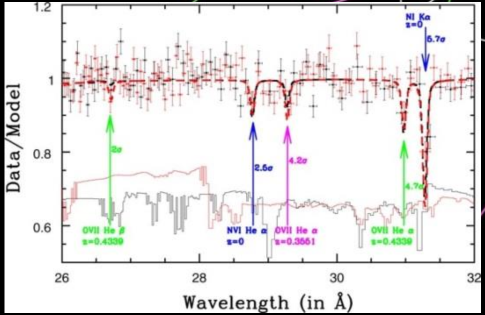
Observations of the missing baryons in the warm–hot intergalactic medium



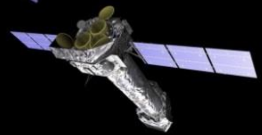
-- observed number of baryons in the local universe falls short (30-40%) of the total baryons predicted by Big-Bang Nucleosynthesis
-- from $z \approx 2$ onwards the baryons condense into a filamentary web and undergo shocks heat up to $T \approx 10^5$–10^7 K



- 1.5 Ms XMM-Newton RGS spectrum on the X-ray brightest blazar 1ES 1553+113, with $z > 0.4$
  - two absorbers of highly ionized oxygen (O vii)
  - no associated cold absorption
  - associated galaxy overdensities

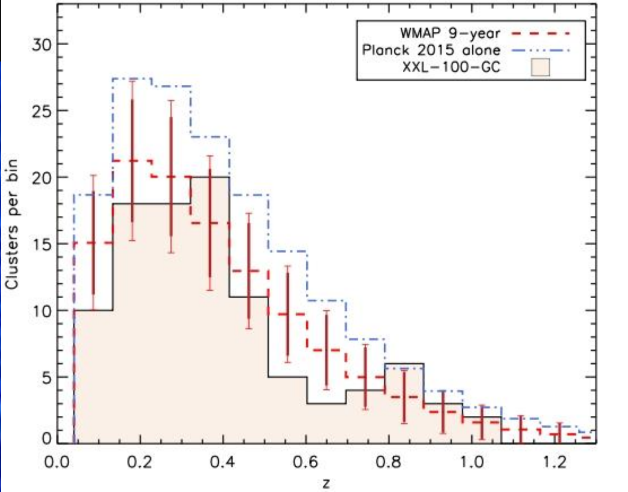


Nicastro et al., 2018, Nature 558, 406



The XXL Survey of the X-Ray Sky

Pierre, M. et al., 2016, A&A 592, 1
Pacaud, F. et al., 2016, A&A 592, 2



- Two extragalactic regions of 25 deg^2

→ A&A special feature : First results

→ 13 papers by a consortium

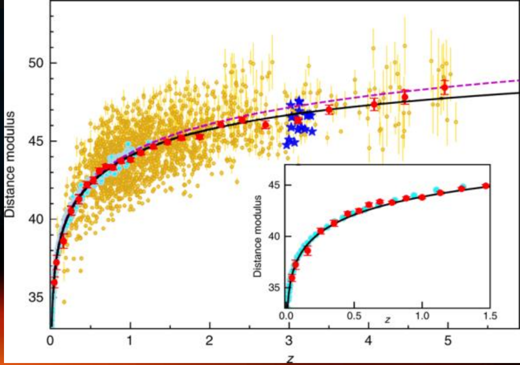
→ ~450 clusters and ~25 000 AGNs

→ No evolution of luminosity function of clusters out to z ~ 1.

→ Sky density of brightest clusters is slightly below the predictions from the WMAP9 model, and significantly below the prediction from the Planck 2015 cosmology.

→ Possible explanations: cluster mass calibration, cosmological model, rest mass of neutrinos

Cosmological Constraints from the Hubble Diagram of Quasars at High Redshifts

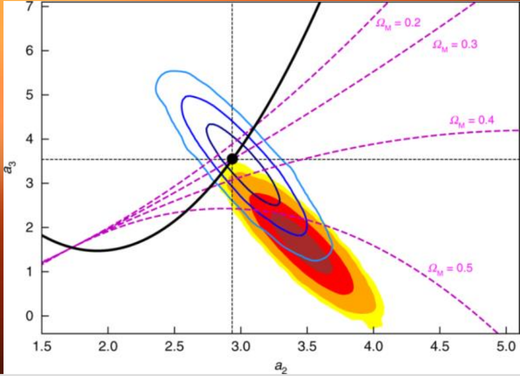


- distances based on the X-ray and ultraviolet emission of the quasars
- $z < 1.4$ agreement with supernovae and concordance ΛCDM model

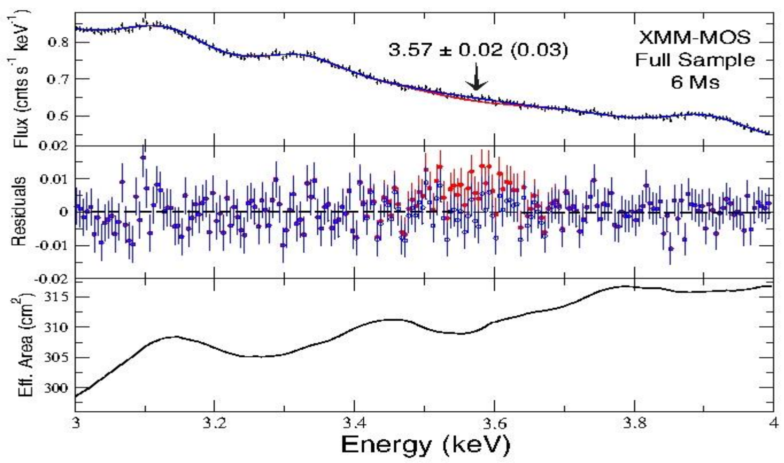
➔ **$z > 1.4$ derivations of ~4σ**

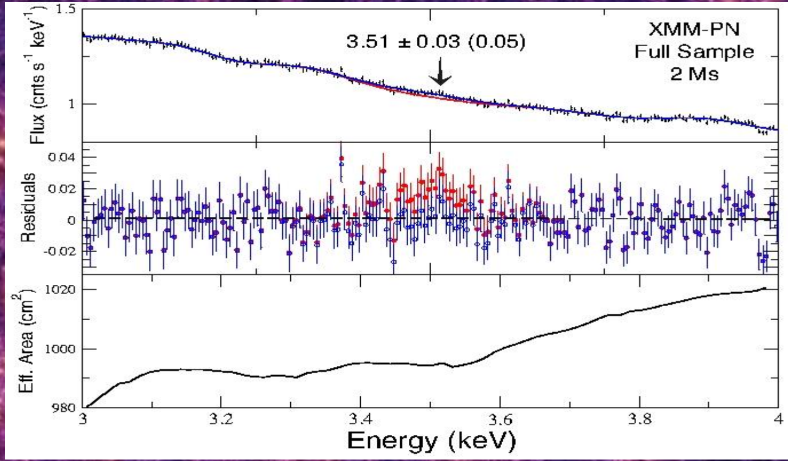
➔ **does dark energy density increasing with time?**

G. Risaliti & E. Lusso, 2019, Nature Astronomy 3, 272



Detection of An Unidentified Emission Line in the Stacked X-ray spectrum of Galaxy Clusters





➔ **weak unidentified emission line at E=3.56keV in the stacked XMM spectrum of 73 galaxy clusters spanning**

➔ **no atomic transitions**

E. Bulbul et al., 2014, ApJ 789, 13
A. Boyarsky, et al., 2014, PhRvL 113, 1301

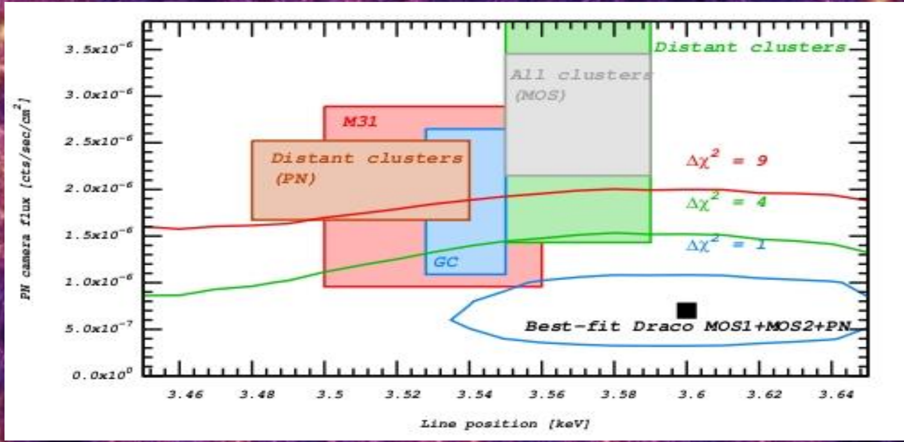
➔ **an intriguing possibility is the decay of sterile neutrino, <u>a long-sought dark matter particle candidate</u>**

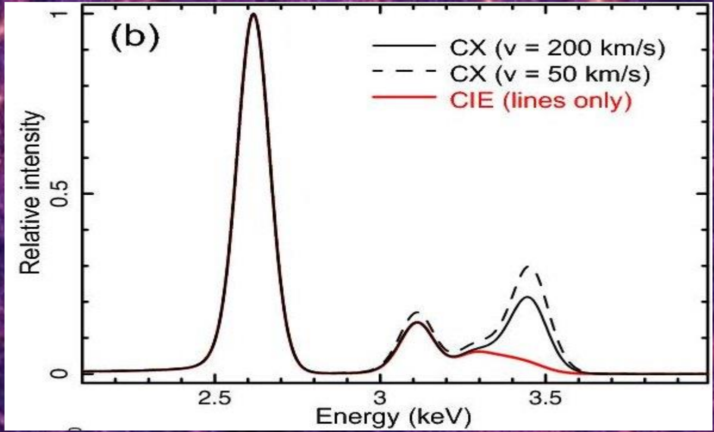
➔ **assuming that all dark matter is in sterile neutrinos with m = 2E = 7.1 keV the detection corresponds to a neutrino decay mixing angle $\sin^2(2\theta)=7 \times 10^{-11}$**

➔ **<u>below previous upper limits</u>**

Detection of An Unidentified Emission Line in the Stacked X-ray spectrum of Galaxy Clusters

Bulbul et al. (2014, ApJ 789, 13) and Boyarsky, et al. (PhRvL 113, 1301) are the most cited astrophysical papers in 2014 after the Planck results and SDSS





Searching for decaying dark matter in deep XMM-Newton observation of the Draco dwarf spheroidal

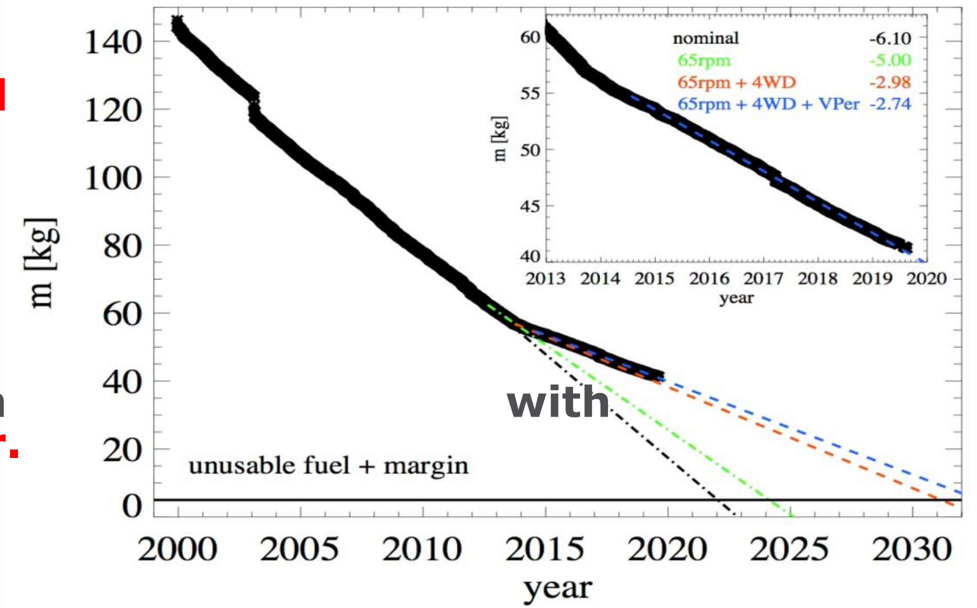
O. Ruchayskiy et al. 2016, MNRAS 460, 1390;
T. Jeltema & S. Profumo, 2016, MNRAS 458, 3592

STATUS

STATUS OF SPACECRAFT

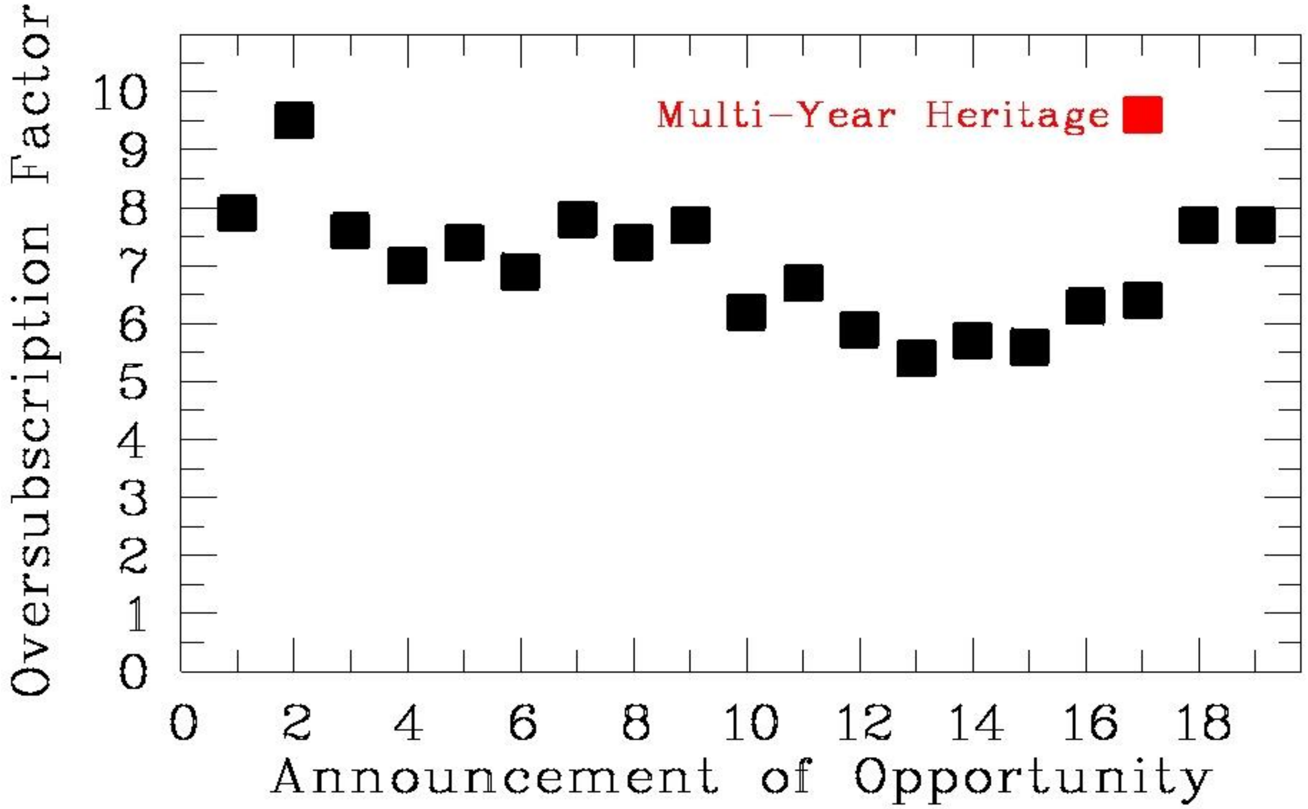
- **Spacecraft status is very good**
- **All important systems are running on their primary unit, i.e. full redundancy still available.**
- **Currently 42 kg of fuel remain with usage of around 3 kg per year.**

➔ ~2031



- **The solar array is generating around 1790 W and between 800-1350W are used.**
- **All other systems susceptible to wear are in good condition**

Oversubscription of Announcements of Opportunity



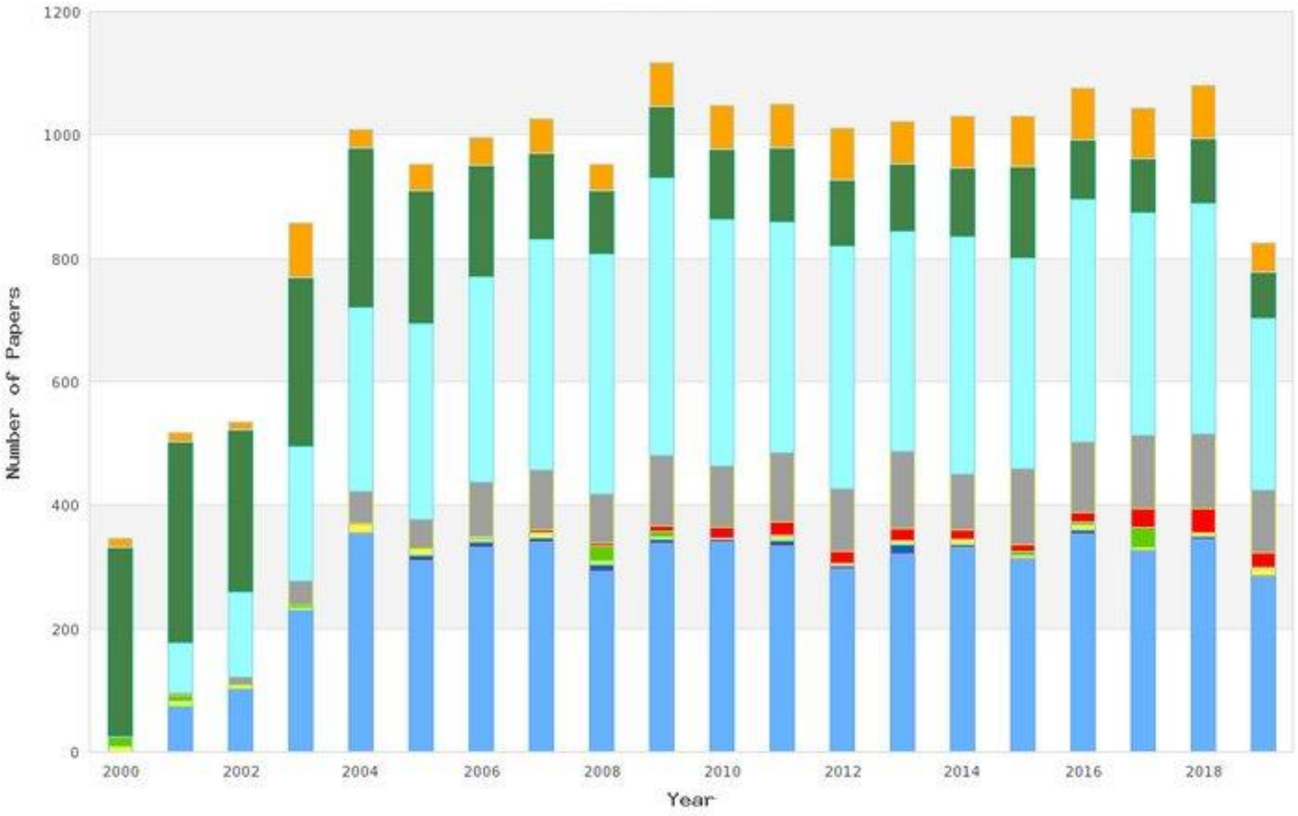
Publications I

XMM in Name
Mentions XMM
XMM & Citation

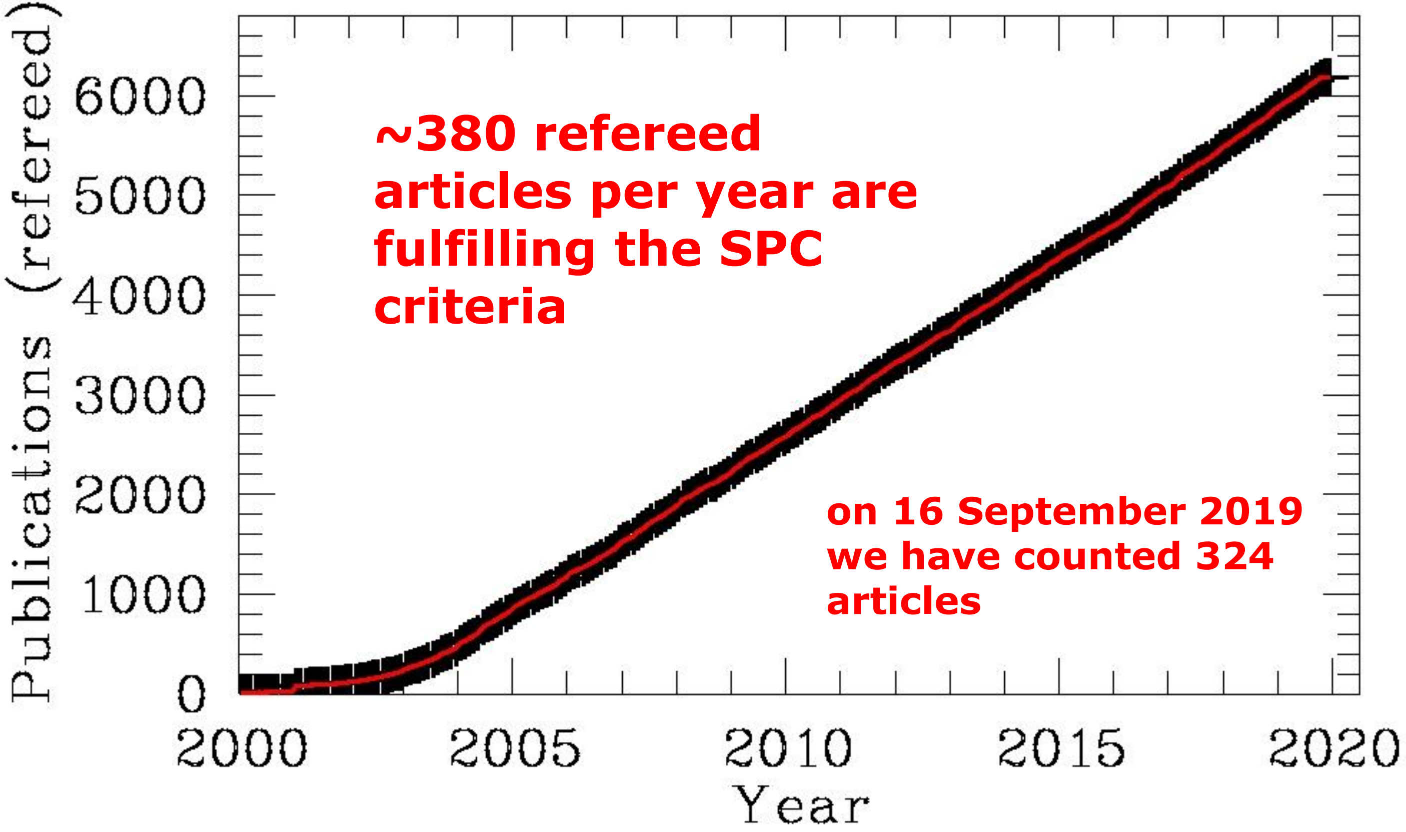
Uses Others

--- SPC ---

Uses Products
Describes
Predicts
Catalogue
Uses Data



Publications II



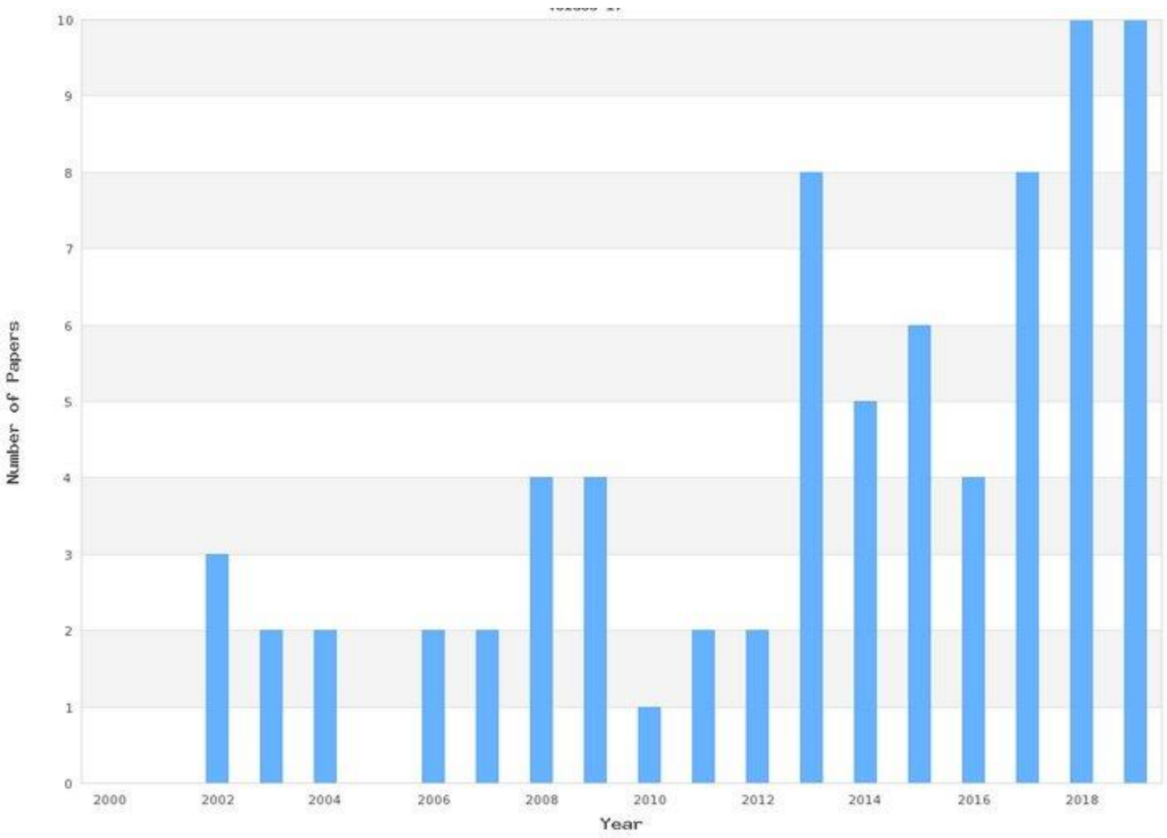
Citations

Analysis of XMM-Newton papers (2 June 2018, L Valencic, GSFC, NASA)

XMM-Newton articles from	Top 1% (most cited) astrophysical papers:	Top 10% (most cited) astrophysical papers:
1 year ago:	9.7%	39.5%
2 years ago:	5.0%	36.0%
5 years ago:	4.3%	34.7%

~10% of XMM-Newton papers are within the top 1% of all astrophysical papers

Highest Profile Journals



"XMM-Newton the next Decade" Workshop

- **May 2016, ESAC with 148 Participants**
- **Presentations:**

  http://www.cosmos.esa.int/web/xmm-newton/2016-workshop

“XMM-Newton the next Decade” Workshop

1. Many scientific opportunities will be opened up by joint (and follow-up) observations associated with **new space missions and ground facilities**, e.g., Transiting Exoplanet Survey Satellite (TESS), eROSITA, JWST, Euclid and the Cherenkov Telescope Array (CTA).
2. Target of Opportunity (TOO) observations are expected to play an increasingly important future role.
3. MYHP were introduced in AO-17 allowing the allocation for up to 6 Ms observing time.

On Multi-Year Heritage Programmes:

Recommendation 2016-06-08/04: At a recent Workshop: “XMM-Newton: The Next Decade“, it was clear that there was widespread support at this stage of the mission, for consideration of a new type of observing proposal. This would encourage visionary programmes which would not otherwise be likely to emerge because of the time constraints within allocation cycles, and also a perception that they would be unlikely to succeed in competition with other more standard proposals. The details of the scope and implementation of this new category of proposal would be discussed further within the UG and with the new OTAC chairperson, with a view to offering it in cycle AO-17.

EVOLUITON OF SCIENTIFIC STRATEGY

Scientific Strategy:

2006: TOO time budget expanded

2007: Workshop XMM-NEWTON THE NEXT DECADE

2007: Users' Group supports large programs

2008: 1st observation of a very large program

2010: ~25% of A&B observing time to large programs

2010: Planck Clusters

2012: ~45% of A&B observing time to large programs

2013: 1.5 Ms simultaneous with NuSTAR

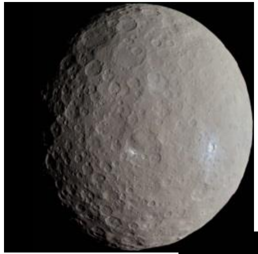
2016: up to 3.0 Ms simultaneous with NuSTAR

2016: Workshop XMM-NEWTON THE NEXT DECADE (May 2016)

2017 Legacy Programs (~6 Ms over 3 years)

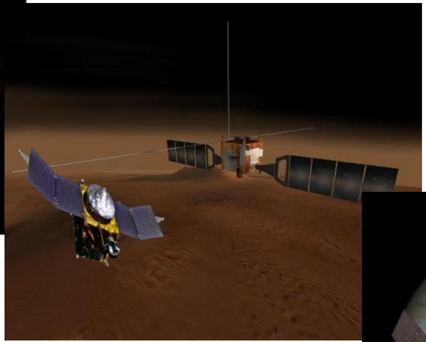
SCIENTIFIC POTENTIAL

Our Solar System

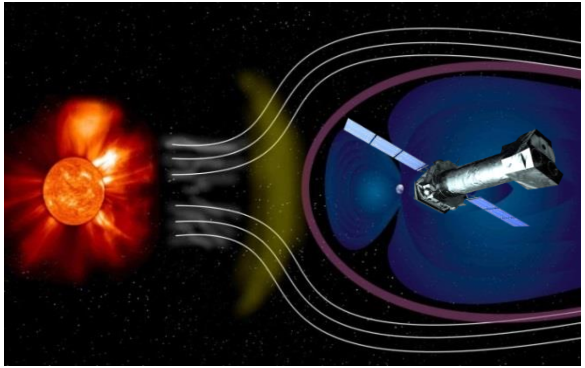


Ceres:
- charge exchange induced X-rays from water vapor
- outgassing from dwarf planets

Mars:
- fluorescent scattering of solar X-rays
- solar wind charge exchange in exosphere
- in situ MAVEN, ExoMars



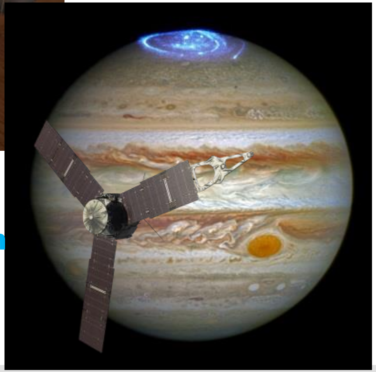
Solar wind Magneto-sphere Ionosphere Link Explorer (SMILE):
- launch 2023
- images solar wind charge exchange X-ray emission produced in the Earth's magneto-sheath
- XMM-Newton had shown the existence of this emission (Carter et al. A&A 2008 & 2011)



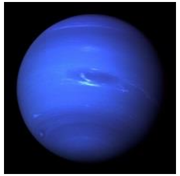
Unparalleled opportunity of associating the X-ray images and in-situ plasma measurements returned by SMILE with the measurements from XMM-Newton observations

Comets:
- laboratory for charge exchange induced X-ray (SNR, clusters of galaxies)
- heavy ion content of the solar wind (<u>solar maximum in 2024</u>, outside ecliptic plan)

Jupiter:
- aurorae
- charge exchange emission
- "disk" controlled by the Sun
- in situ JUNO (→ 2022)



X-ray detection of Uranus and Neptune would explore new scientific territory, with the potential of new discoveries (like for Jupiter and Saturn)



Understanding planetary systems: their formation, and their host stars

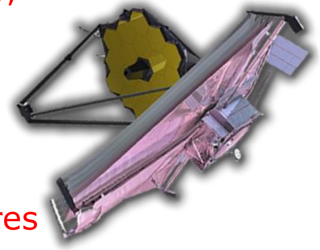
NASA's Transiting Exoplanet Survey Satellite (TESS) mission has started to monitor 200,000 nearby stars to discover new transiting exoplanets. → comprehensive study of magnetic activity in late-type stars

- Our understanding of the star-planet interaction will progress through monitoring programmes of selected systems through planetary orbital phases.

- New hot-Jupiters with evaporating atmospheres (e.g. Salz et al., 2015, A&A, 576, 42) will certainly be key targets for studies of exoplanetary mass loss in the next years.

XMM-Newton is uniquely suited to such studies as it provides simultaneous measurements in the X-ray and optical/UV regimes and has highest effective area.

JWST will perform detailed spectroscopic follow-up of transiting exoplanets to examine their atmospheres. To really understand the chemistry, we will need to monitor the host star X-ray flares



The X-ray luminosity of the host star is of fundamental importance to understand planets habitability

TRAPPIST-1 (Wheatley et al., 2017, MNRAS 465, L74) & Proxima Centrauri b (Ribas et al., 2016, A&A 596, 111)

Accretion onto Galactic Compact Objects

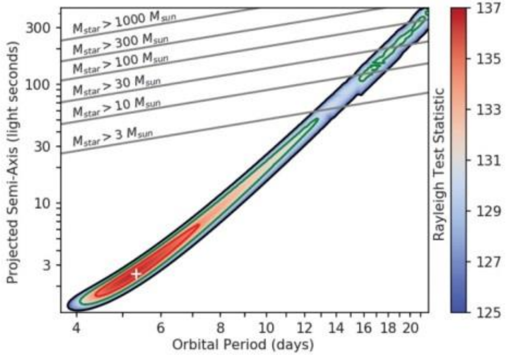
With its high throughput and fast timing capability, XMM-Newton has a central role in the study of Galactic Compact Objects.

- Transitional Millisecond pulsars (MSP) are of the highest scientific importance given that they are the “missing link” for the understanding of the evolution of the whole source class.
- Ultraluminous X-ray Pulsars (ULXP):
  - Search for new ULXP
  - high resolution spectra to study in detail the winds which provide insights into the physical processes.

Such potentially breakthrough studies require XMM-Newton imaging or RGS observations which combines both high throughput with high spectral resolution.

XMM-Newton’s impressive track record:

- **low magnetic field magnetar & cyclotron (Tiengo et al., 2013 Nature, 500, 312)**
- **Transitional MSP (Papitto et al., 2013, Nature 501, 517)**
- **ULX showing wind tracing hyper-accretion (Pinto et al, 2016, Nature 533, 64)**
- **Neutron star is compact source in ULX (Israel et al., 2017, Science 355, 817)**

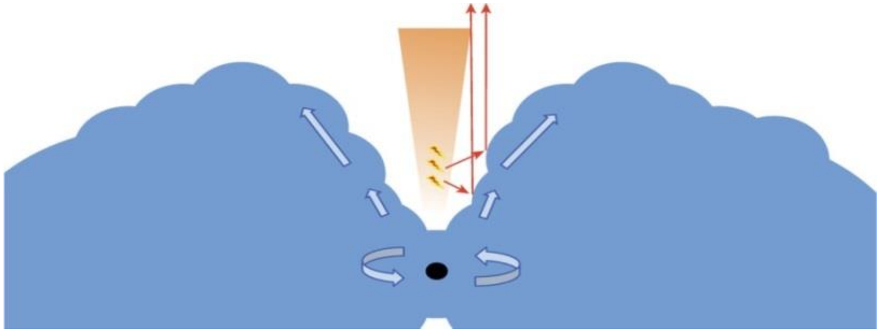


(Israel, 2017, Science 355, 817)

Active Galactic Nuclei (AGN)

Ultra-deep X-ray reverberation observations of AGNs have a massive untapped potential: geometry of the X-ray remitting corona, returning radiation, jet & wind launching, quasi-periodic-oscillation, disk structure, innermost stable orbit.

XMM-Newton has the required effective area to perform such studies (preferably with simultaneous NuSTAR observations)



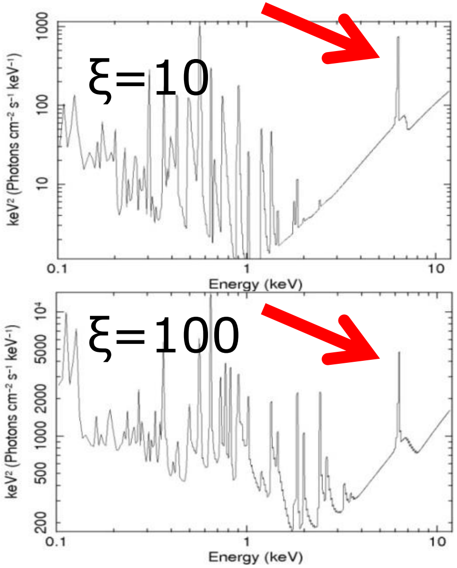
Kara et al., 2016, Nature 535, 388

Large multi-wavelengths monitoring campaigns of AGNs allow to study the physics of the outer disk e.g. the launching of outflows and winds.

XMM Newton is the preferred X-ray facility due to its high throughput and high spectral resolution capacity

Iron Line Studies: A Continuing Success

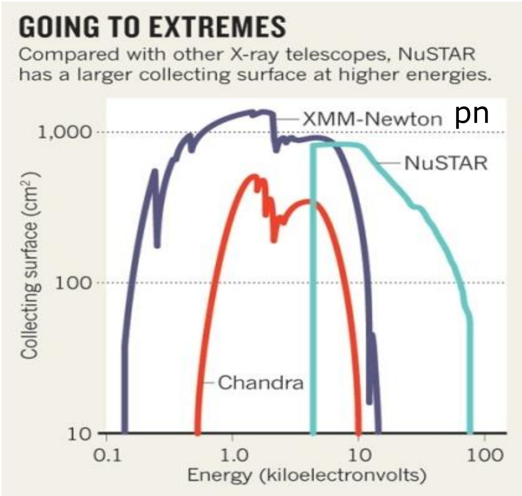
Why is iron so interesting?
- isolated emission line
e.g. reflection spectrum



+ high ionization parameter
+ high abundance

- **XMM-Newton has the required high effective area in combination with the ability to make long uninterrupted observations.**
- **In addition, simultaneous observations with NuSTAR enable an accurate determination of the underlying continuum,- something that cannot be easily achieved by any other combination of satellites, especially for weak sources.**
- **25% of XMM-Newton high priority time (priority A and B) in AO-17 is being observed simultaneously with NuSTAR**

NuSTAR (Nuclear Spectroscopic Telescope Array, NASA

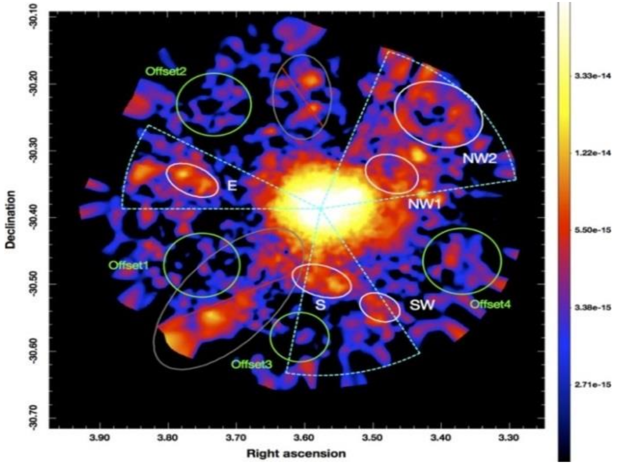


Galaxies and Clusters of Galaxies

Key questions of galaxy and clusters of galaxies:

- the origin of hot haloes around galaxies,
- shocks in the intra-cluster medium
- structure formation in the outskirts of clusters
- spatially resolved metallicity
- finding high redshift clusters (z>1.2)
- their evolution with cosmic time.

XMM-Newton is a sensitive instrument for the detection of weak extended sources.



XMM-Newton/EPIC surface-brightness image of the galaxy cluster Abell 2744 in the 0.5–2 keV band (bar at right; units are erg s^{-1} cm^{-2} $arcmin^{-2}$).

D. Eckert, et al., 2015, Nature 528, 105

Several of the new, high-spatial-resolution Sunyaev-Zeldo'vich (SZ) imagers e.g. MUSTANG2 and NIKA2 or ALMA, will have spatial resolutions similar to that of XMM-Newton.

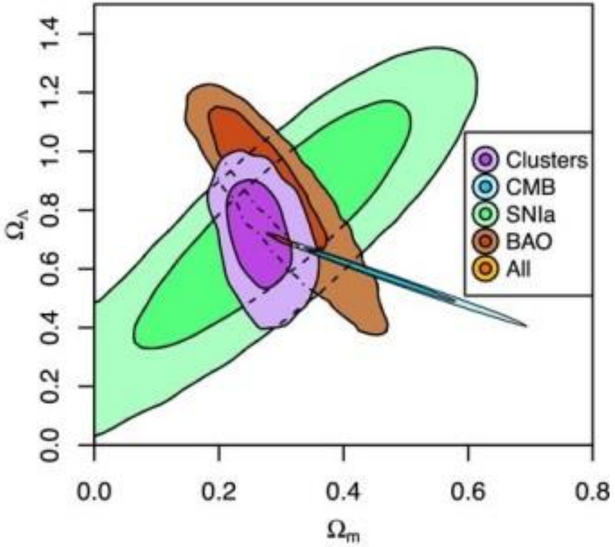
➔ XMM-Newton has the a combination of spatial resolution, hard energy response, and collecting area, which is ideal to study in detail the features detected with SZ imagers

➔ information on the 3D structure (e.g., clumpiness)

➔ follow-up observations of new, deeper SZ surveys

Tests of cosmological models & Cosmology I

The tightest constraints on the cosmological parameters are only obtained by combining results based on super-novae, cosmic microwave background and clusters of galaxies

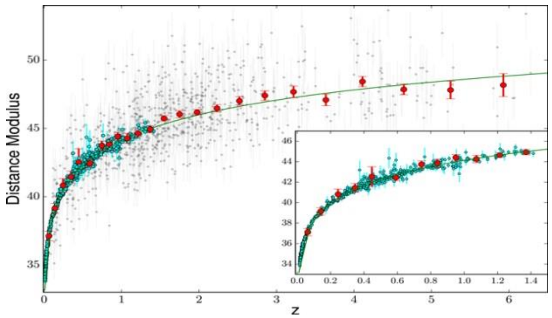


Mantz et al., 2015, MNRAS 446, 2005

XMM-Newton observations are crucial to precisely determine the cluster structure due to its low intrinsic background, spatial resolution and high effective area.

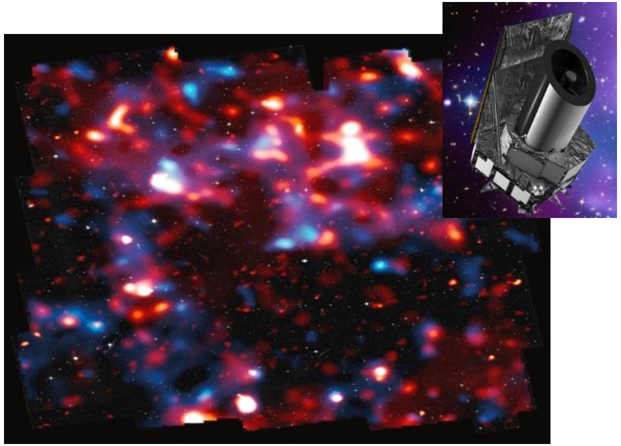
The combination and follow-up of future samples defined in X-rays (eROSITA), Sunyaev-Zel'dovich (South Pole Telescope) , radio (LOFAR & ALMA) and optical/infrared (DES, LSST, Euclid) with strong and weak lensing measurements will improve the sample definition and bias understanding, leading to significantly tighter constraints on the cosmological parameters.

Tests of cosmological models & Cosmology II



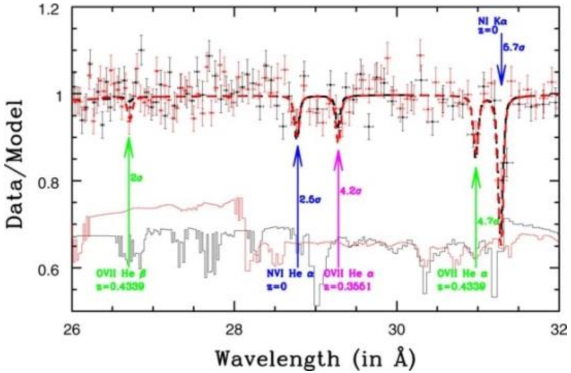
Hubble Diagram for the quasar sample (grey points) and super-novae (cyan) (Risaliti & Lusso, 2019, Nature Astronomy 3, 272)

Large X-ray quasar samples offer an important opportunity of determine cosmological parameters in the redshift range z=2.0-4.0, using SEDs (alpha ox).



R. Massey et al., 2007, Nature 445, 286
Dark Matter mass distribution derived from HST observations

A future large area, medium-deep X-ray extragalactic survey would dramatically advance our understanding of the distribution of dark matter versus cold and hot baryonic matter and its evolution.

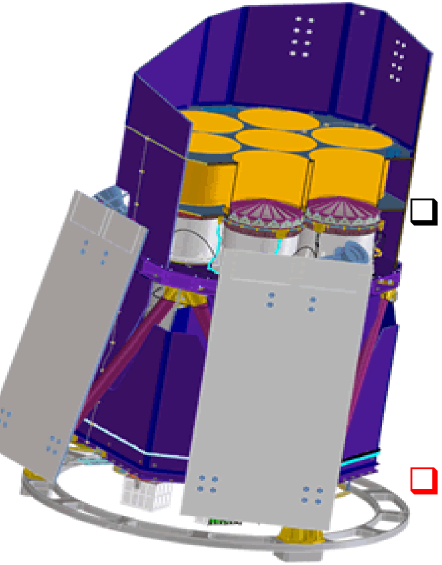


Nicastro et al., 2018, Nature 558, 406

Further RGS observations of Warm-Hot Intergalactic Medium (WHIM) would provide an estimate of their

Distribution leading to optimization of Athena's programme

Exciting New Possibilities: eROSITA



- **eROSITA is the primary instrument on-board the Russian led "Spectrum-Roentgen-Gamma" satellite**
- **Four years (8 scans) all-sky survey in the 0.5 to 10 keV energy range**

The main scientific goals are:

i. **50-100 thousand galaxy clusters and groups**
ii. **All obscured accreting Black Holes in nearby galaxies and up to 3 million new, distant AGN**
iii. **Extending Galactic X-ray source populations**

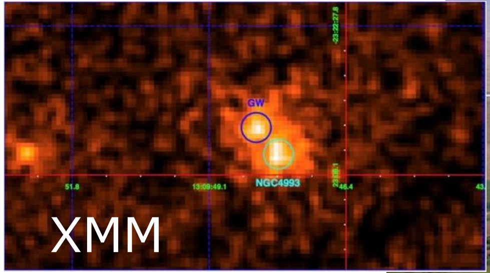
- **There is a huge potential for XMM-Newton follow-up of new and transient sources while eROSITA continues scanning**
- **Observations with XMM-Newton will be importantlin providing a physical interpretation and understanding of these detections e.g. temperature of hot clusters of galaxies**
- **XMM-Newton's high effective area, high spatial resolution and its ability to make long uninterrupted observations, make it ideal for follow-up observations.**

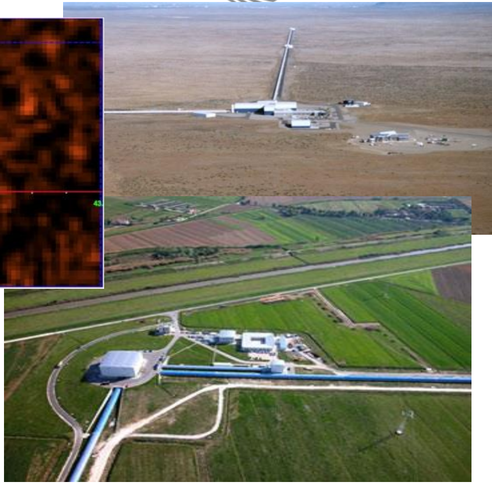
The Search for Electromagnetic Counterparts of Gravitational Wave Events

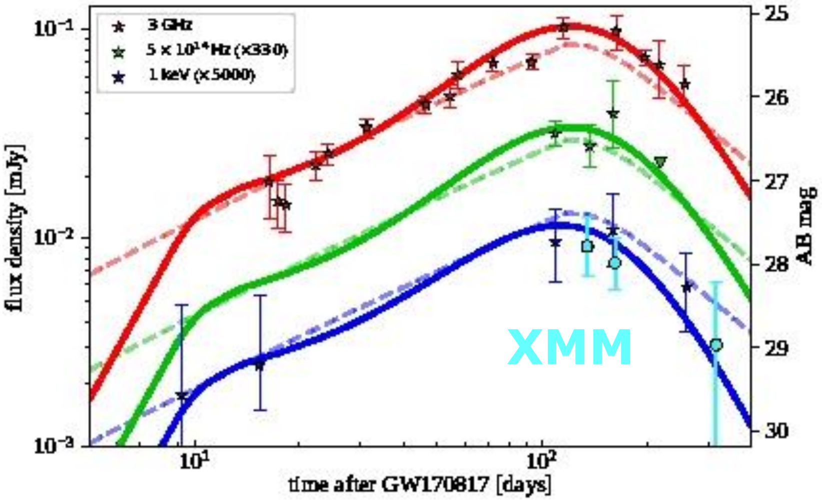
The GW interferometers Virgo and LIGO will restart observation in 2019, with 2020 reserved for a major upgrade, followed by operations from 2021 onwards.

➔ **increasing sensitivity**

➔ **decreasing positional error**







GW 170817 impressively demonstrated the importance of X-ray observations in order to understand the burst/jet-emission:

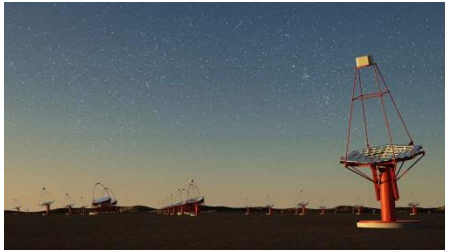
➔ **only XMM-Newton and Chandra can attain the required sensitivity**

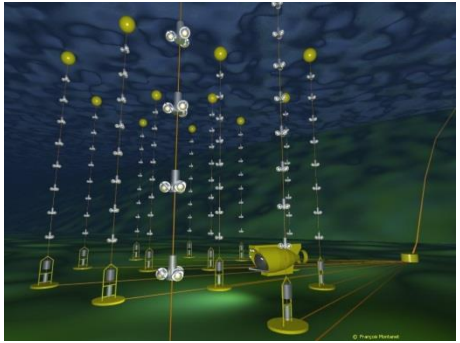
➔ **increasing sensitivity of the GW observatories implies that (most) future GW events will be even fainter**

➔ **Rapid XMM-Newton follow-up observations could permit searches for hyper-massive NS shortly after merger.**

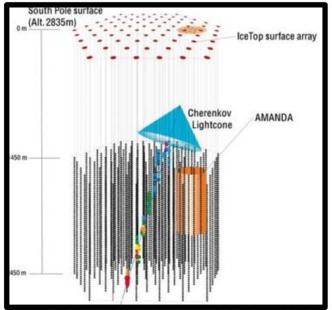
New Sources Emitting at the Highest Energies and New Facilities for finding Transients

New Gamma-ray sources from H.E.S.S., MAGIC, VERITAS and later CTA (from 2022) in the GeV to TeV energy range





A BL-Lac-type AGN was recently discovered as source of high energy cosmic neutrinos.



XMM-Newton is of central importance in the identification and interpretation of new sources detected at γ-ray energies.

As BL-Lacs are rare but strong X-ray emitters, XMM-Newton is clearly the facility of choice for future searches, due to its high sensitivity in combination with a large field of view.

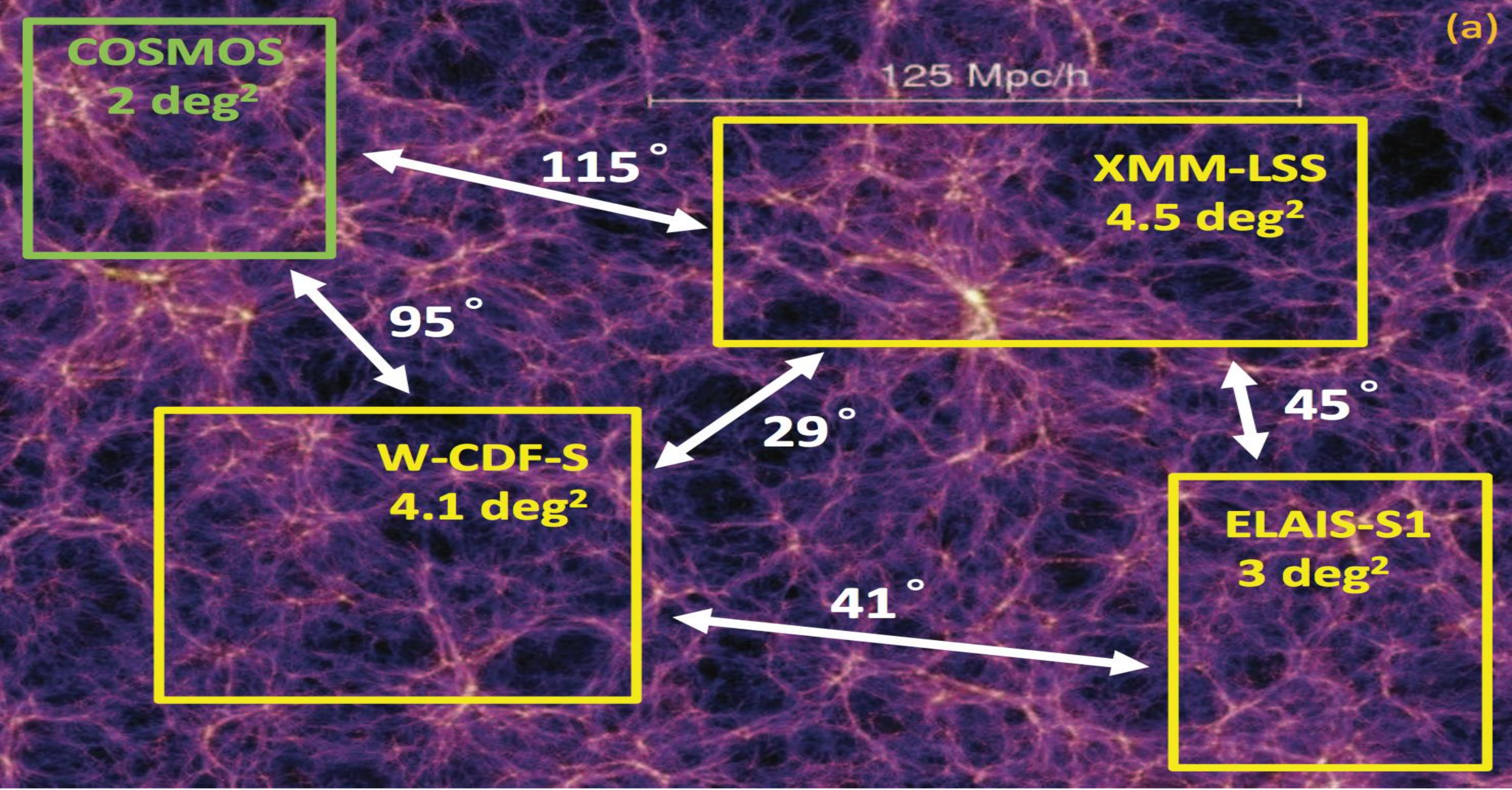
Two Successful Multi-Year Heritage Proposals awarded in AO-17

Completing and Ensuring Major Impact from the XMM-SERVS Survey

We propose to complete our 12 deg^2 survey at 50 ks depth of three legacy sky regions: the SERVS areas of W-CDF-S, ELAIS-S1, and XMM-LSS. XMM-LSS won a 1.3 Ms AO-15 allocation. W-CDF-S and ELAIS-S1 coverage is now integrally required so that XMM-SERVS can dramatically advance studies of SMBH growth across the full range of cosmic environments, links between SMBH accretion and host-galaxy properties, groups/clusters at z = 0.1-2, proto-clusters, and other topics.

Witnessing the culmination of structure formation in the Universe

This is a Heritage program to study the ultimate products of structure formation in mass and time: a large, unbiased, signal-to-noise limited sample of galaxy clusters detected by Planck via their Sunyaev-Zel'dovich effect. Completing the high-fidelity XMM coverage of this sample has extraordinary legacy value


(a)
125 Mpc/h
COSMOS
2 deg²
XMM-LSS
4.5 deg²
W-CDF-S
4.1 deg²
ELAIS-S1
3 deg²
115 °
95 °
29 °
45 °
41 °

xmm20anniversary.esa.int

European Space Agency

HEAD Meeting

Special session on

XMM-Newton

Monterey, CA, USA

17-21 March 2019

X-ray Astronomy

Special lecture about

XMM-Newton mission

Bologna, Italy

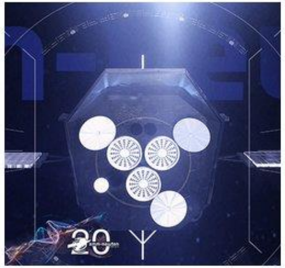
8-13 September 2019

"Astrophysics of hot plasma in extended X-ray sources"

XMM-Newton Workshop

ESAC, Madrid, Spain

12-14 June 2019



Celebration Event: 20 years from launch

ESAC, Madrid, Spain

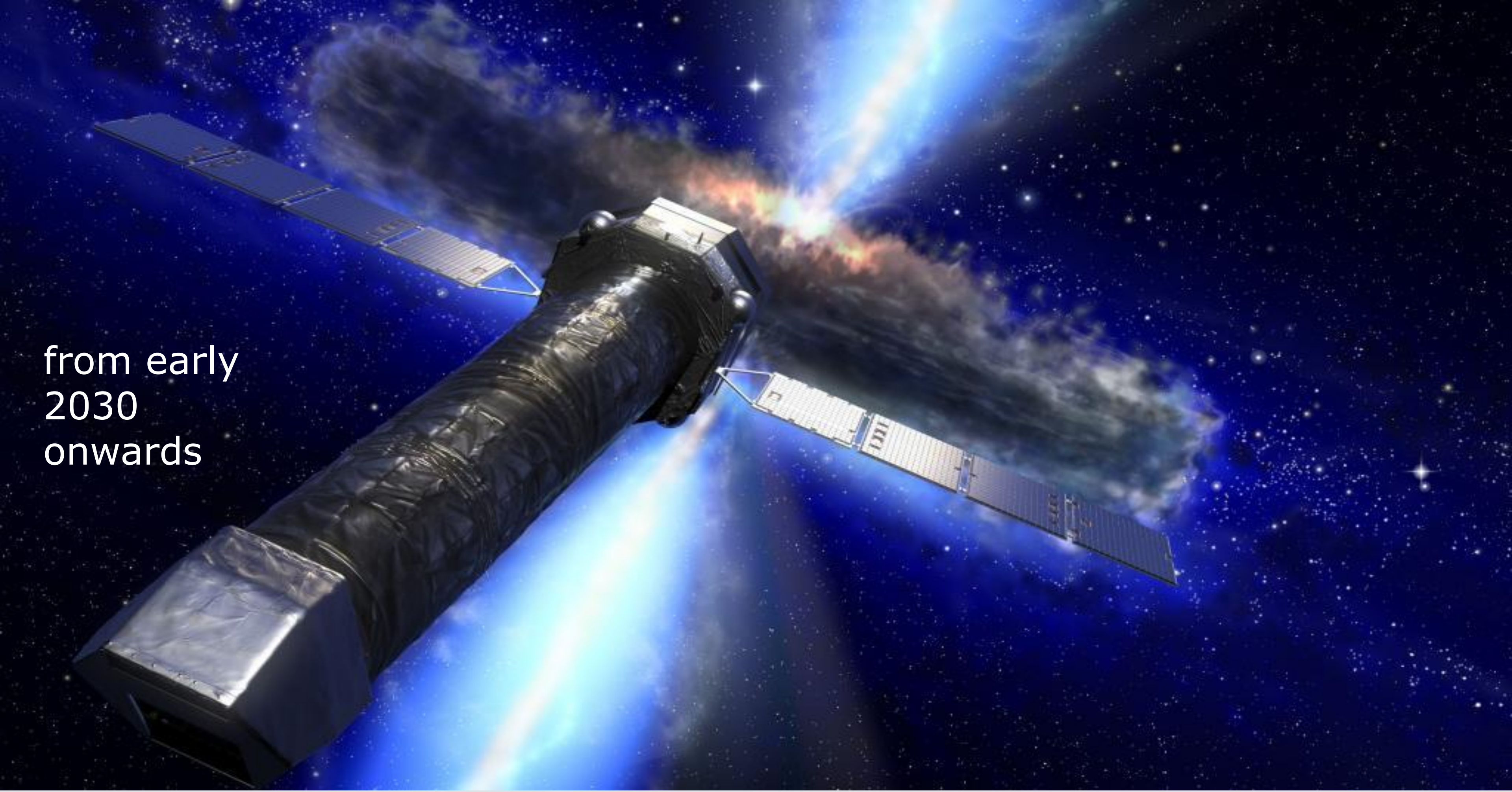
10 December 2019

The X-ray Universe

ESLAB, ESTEC, The Netherlands

25-29 May 2020

If you are organising an event related to XMM-Newton or where XMM-Newton can contribute, please contact us



from early 2030 onwards