Joint Programs in the Context of Cross Facilities Collaboration in the Multi-Messenger Era

ESA/ESO SCIOPS Workshop 2019

ESAC, ESA, Villanueva de la Cañada, Madrid, Spain, 19-22 November 2019

Norbert Schartel
XMM-Newton Project Scientist, ESA

XMM-Newton

XMM-Newton preparation

Image courtesy of B. Parker

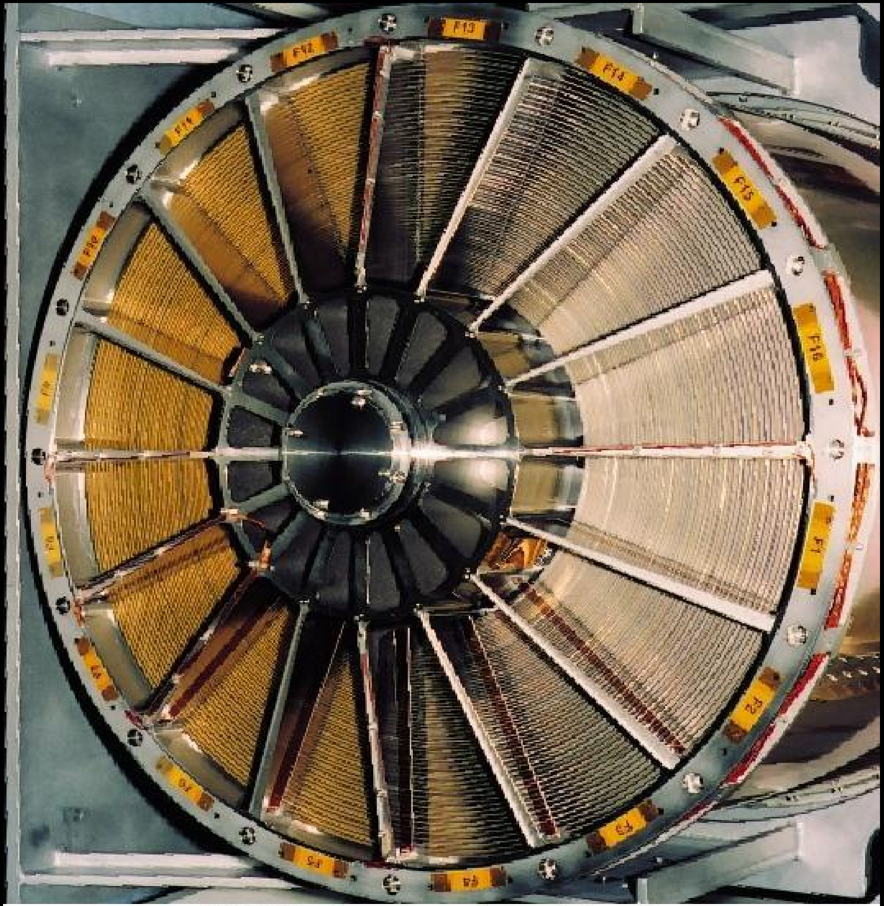
European Space Agency

Mirror Module:

- grazing-incidence Wolter 1 telescopes

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

- 58 gold-coated nested mirrors

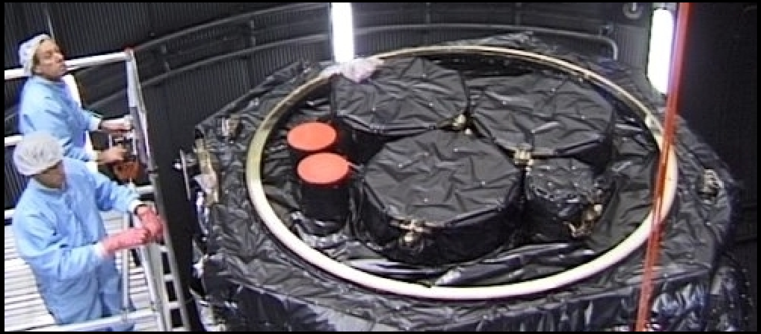


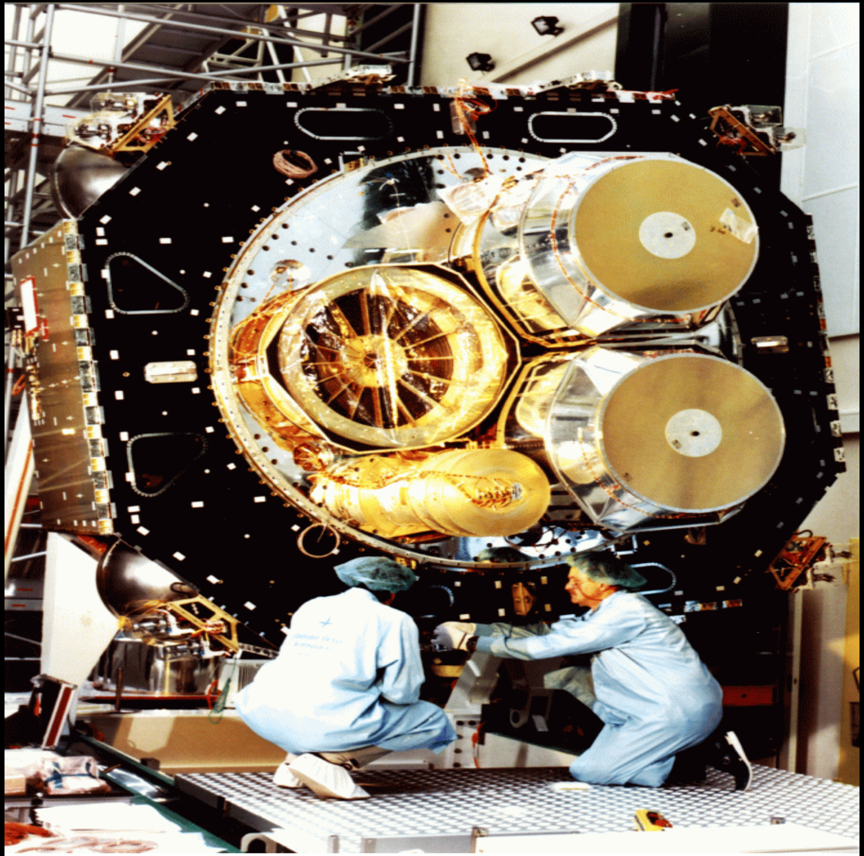
XMM-Newton mirrors during integration

Image courtesy of Dornier Satellitensysteme GmbH

European Space Agency

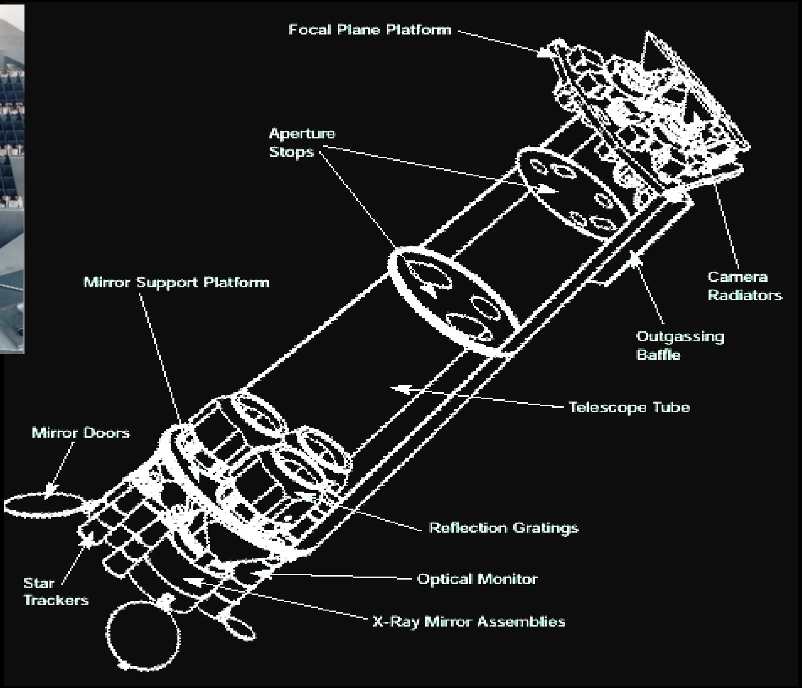
XMM-Newton has three mirror modules

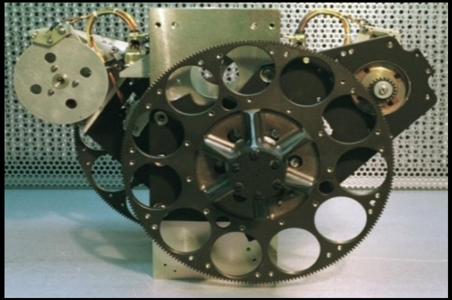


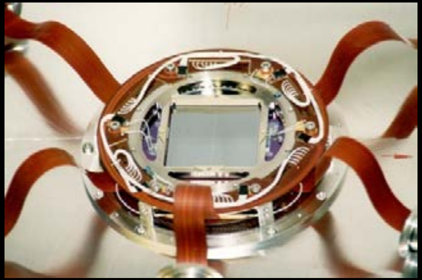


XMM-Newton mirrors during integration

Instruments

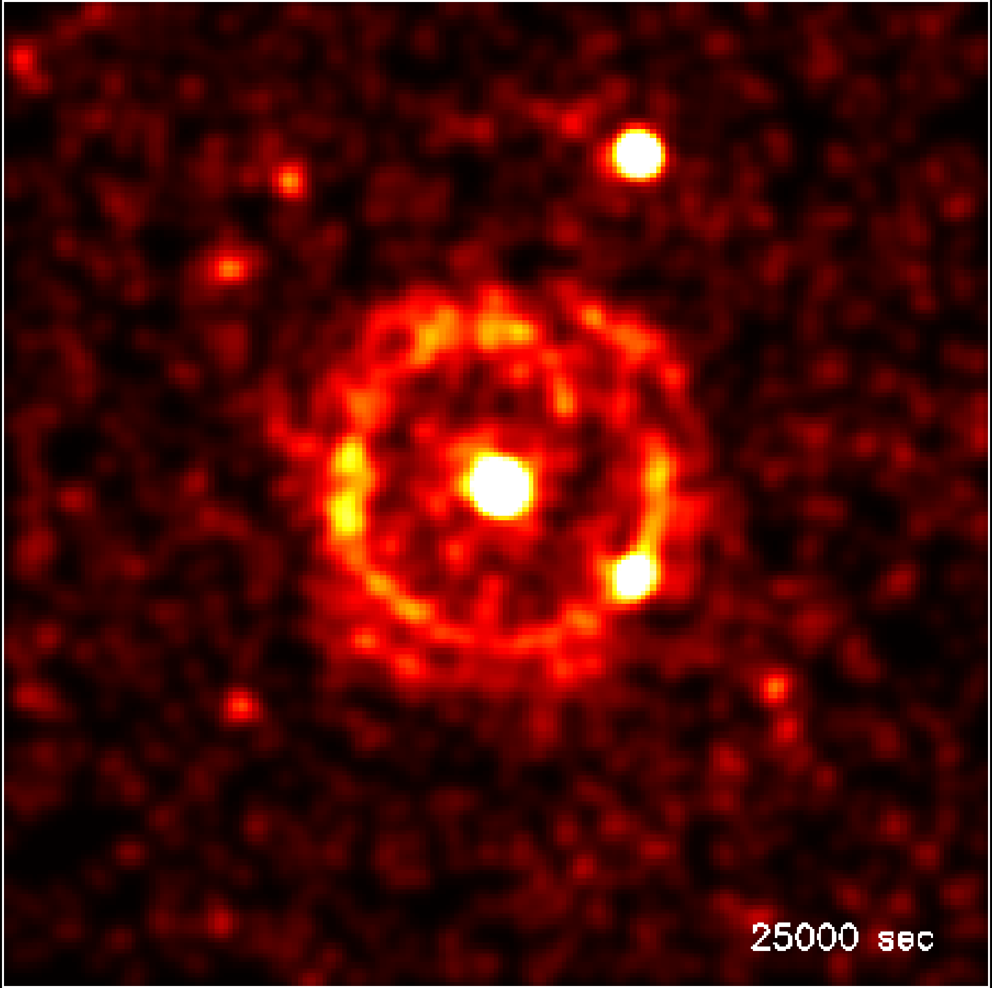






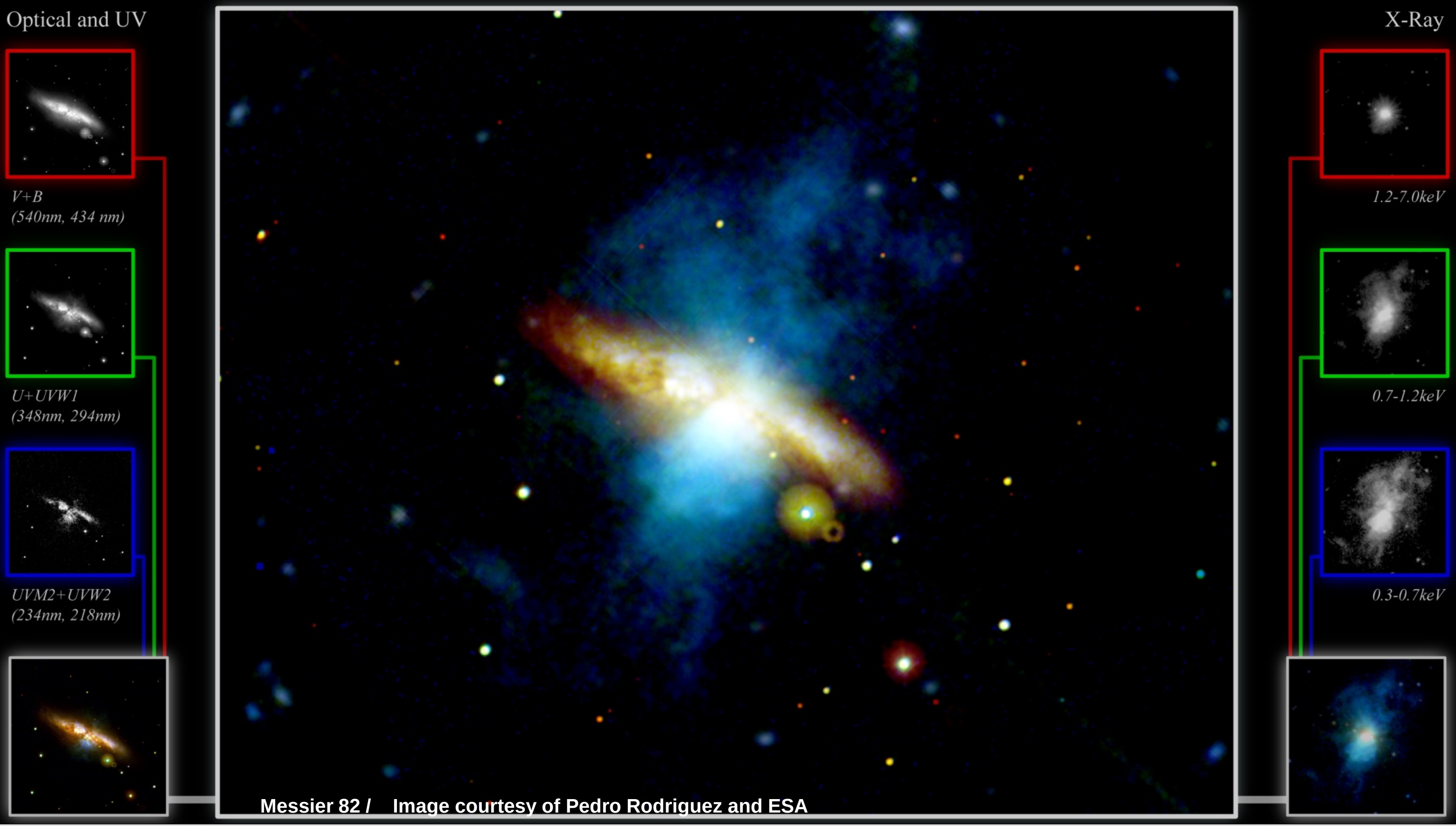
XMM-Newton

- 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

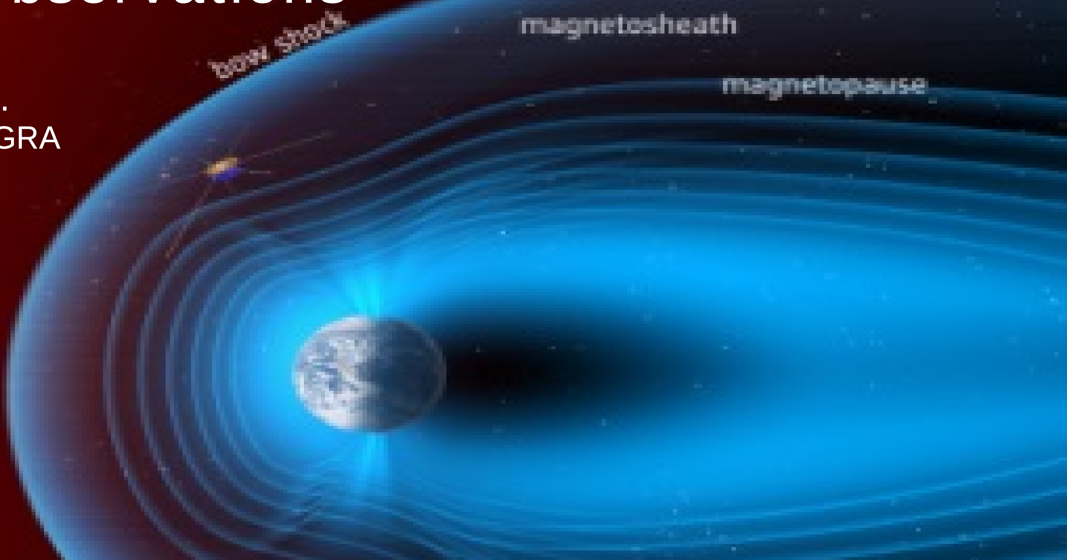
- ➔ Discovery of an evolving dust-scattered X-ray halo
- ➔ Will allow highly accurate distance determina-tions to the dust



Messier 82 / Image courtesy of Pedro Rodriguez and ESA

Some Scientific Highlights

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



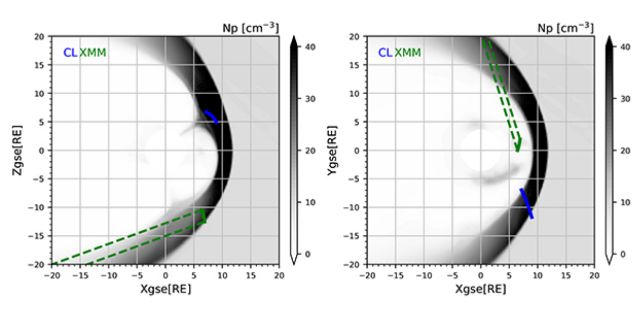
H.K. Connor & J. Carter, 2019 JGRA 124, 1612

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

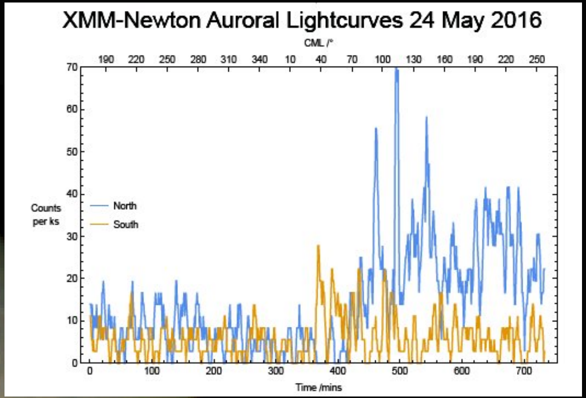
➔ neutral densities

➔ modelled plasma fluxes match well in situ observations of <u>Cluster and Geotail</u>

➔ Solar wind-Magnetosphere-Ionosphere Link Explorer



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.

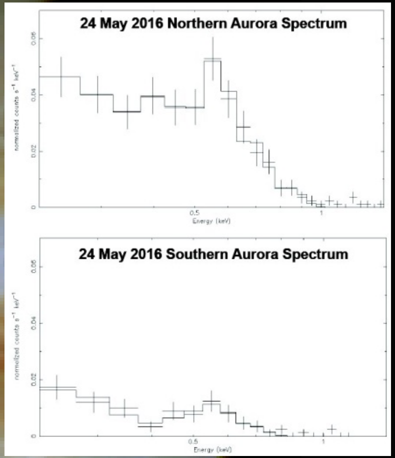
-Observations failed to reveal a similar feature in the south

<u>**XMM-Newton, Chandra and JUNO**</u> 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.

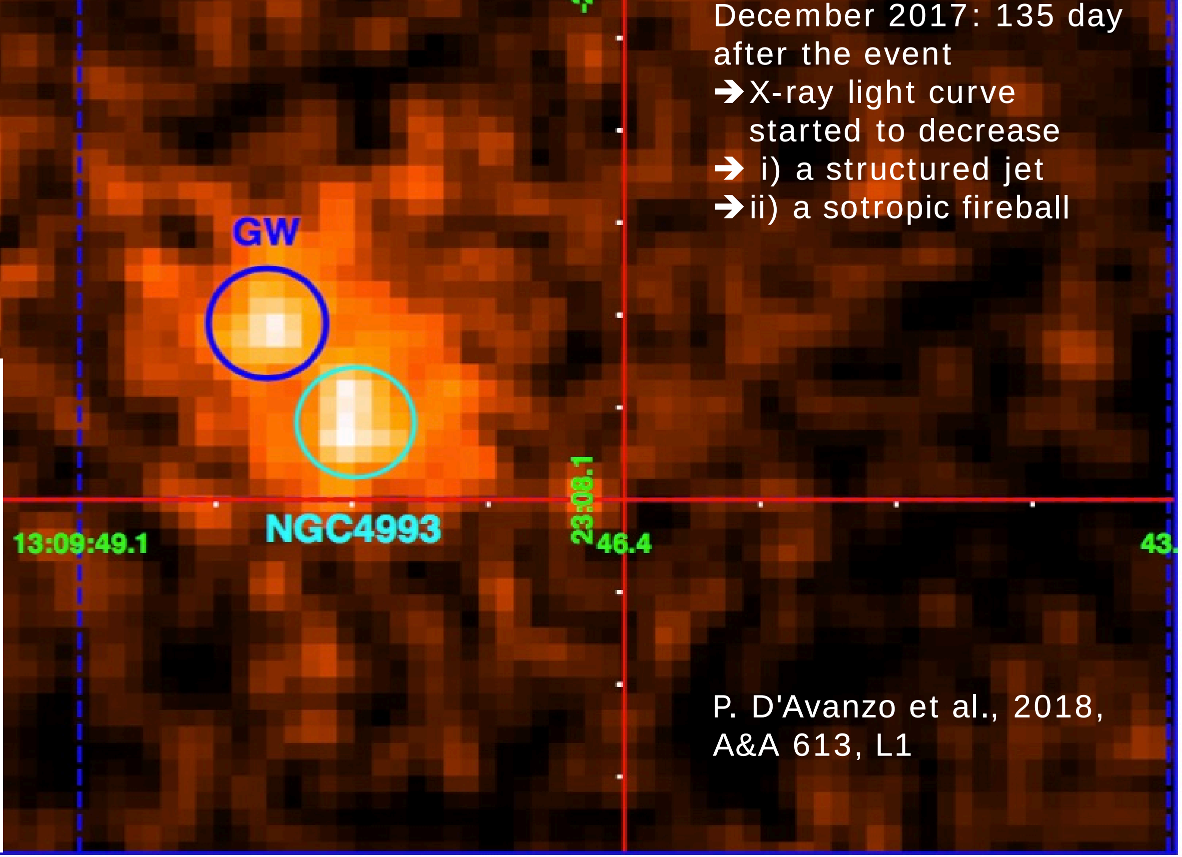
in contrast to current models of X-ray generation for Jupiter

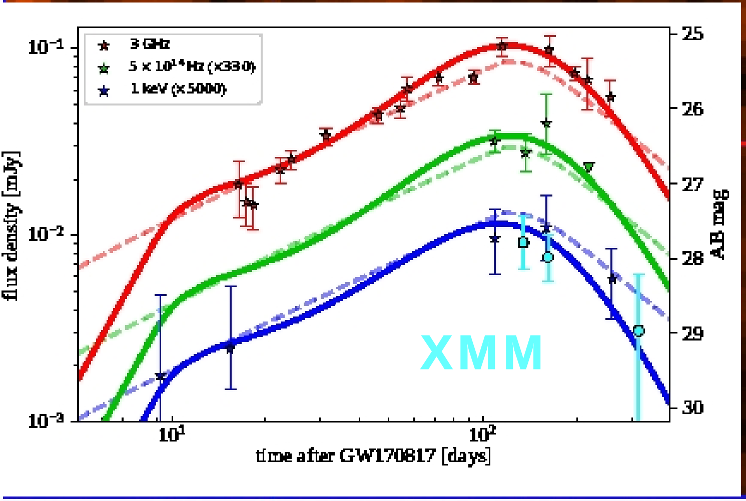
Dunn et al., 2017, Nature Astronomy 1, 758



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

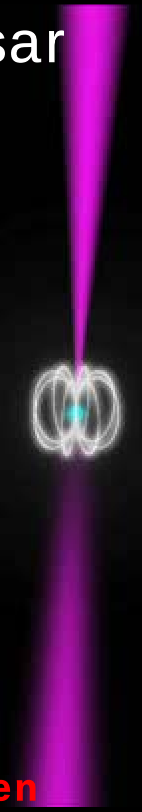
- XMM-Newton observation on the 29th December 2017: 135 day after the event
➔X-ray light curve started to decrease
➔ i) a structured jet
➔ii) a sotropic fireball





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

Swings between rotation and accretion power in a binary millisecond pulsar

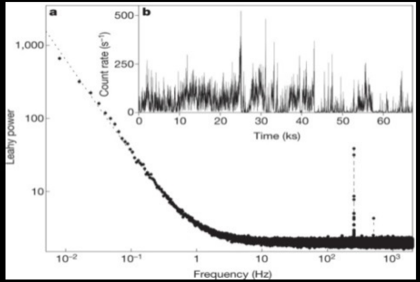


- **first observations of accretion-powered, millisecond X-ray pulsations from a neutron star previously seen as a rotation-powered radio pulsar.**
- **within a few days after a month-long X-ray outburst, <u>radio</u> pulses were again detected.**

➔ 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 rapidly spinning supermassive black hole at the center of NGC1365

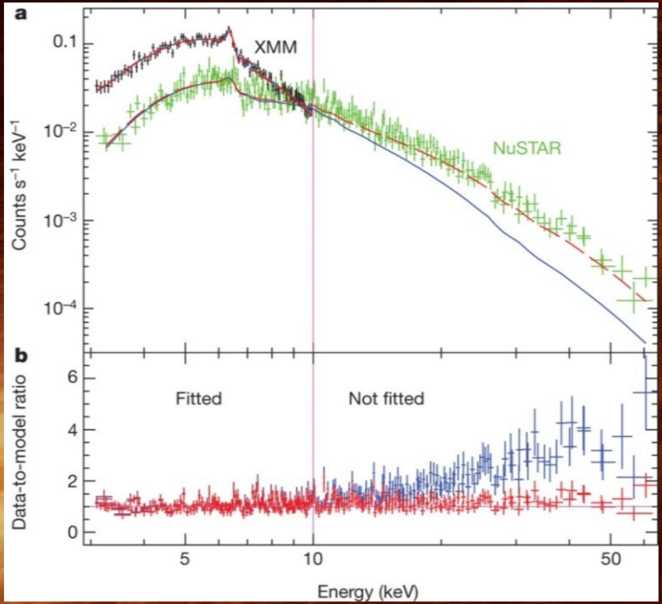
Simultaneous observation of NGC 1365 by <u>XMM-Newton and NuSTAR</u>:

➔ 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.

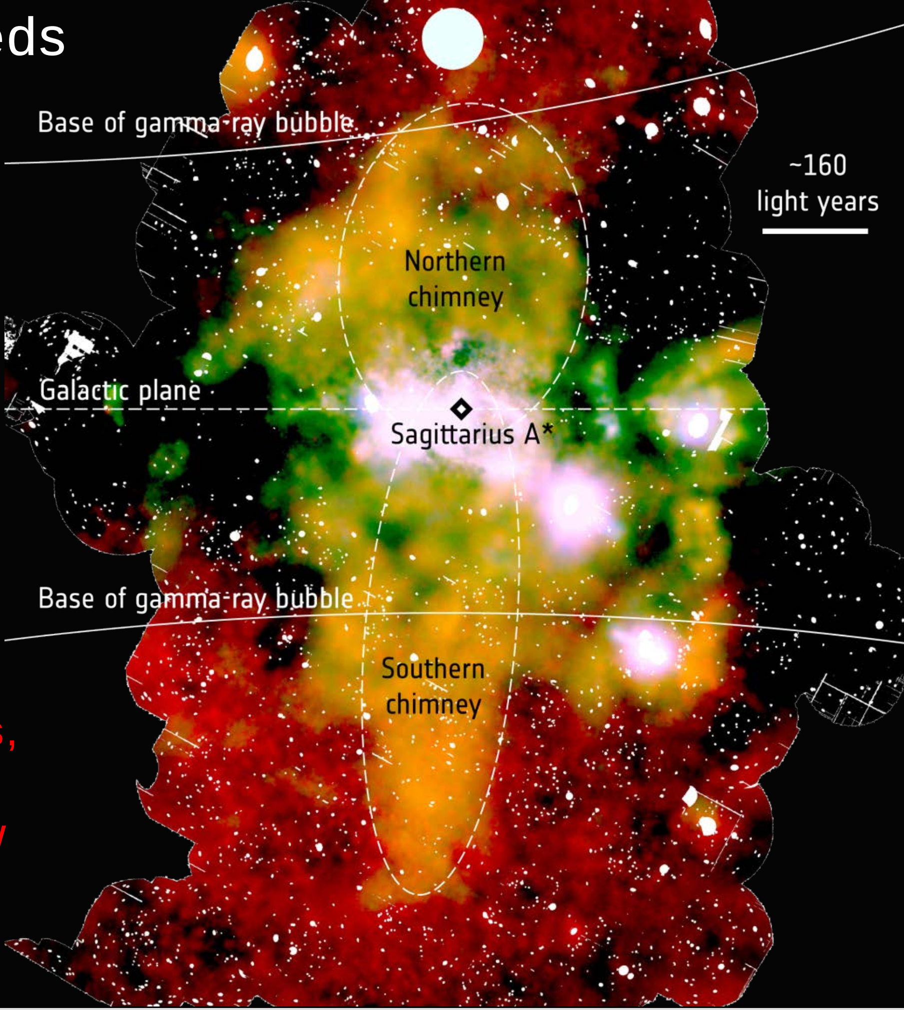
An X-ray chimney extending hundreds of parsecs above and below the Galactic Centre

- 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

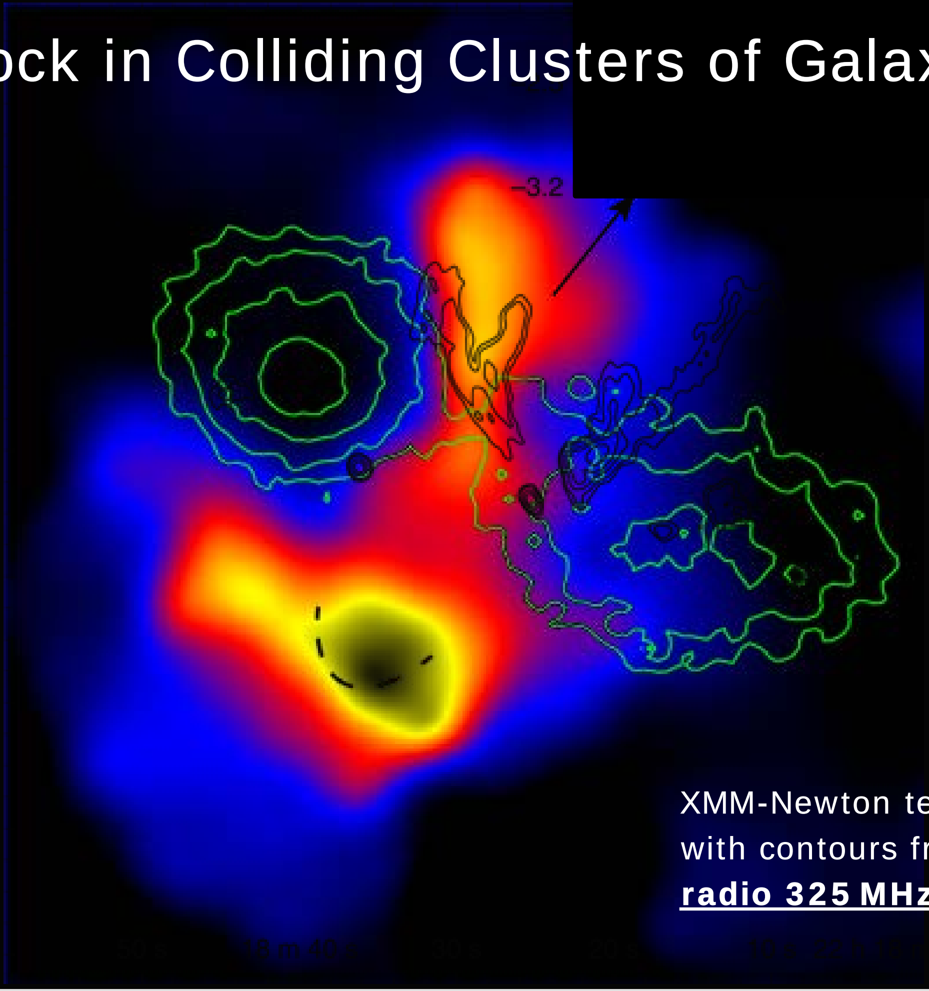
G. Ponti et al., 2019 Nature567, 347



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.

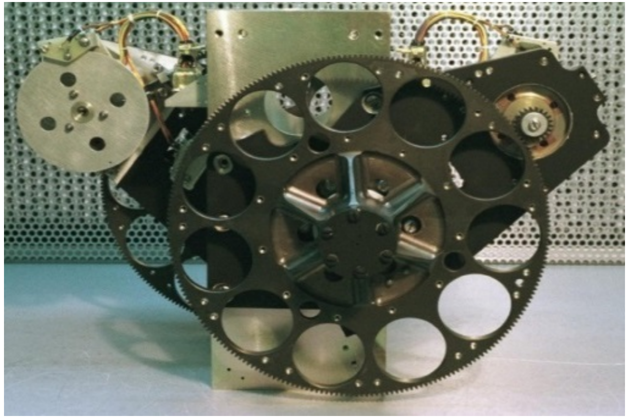
Some History

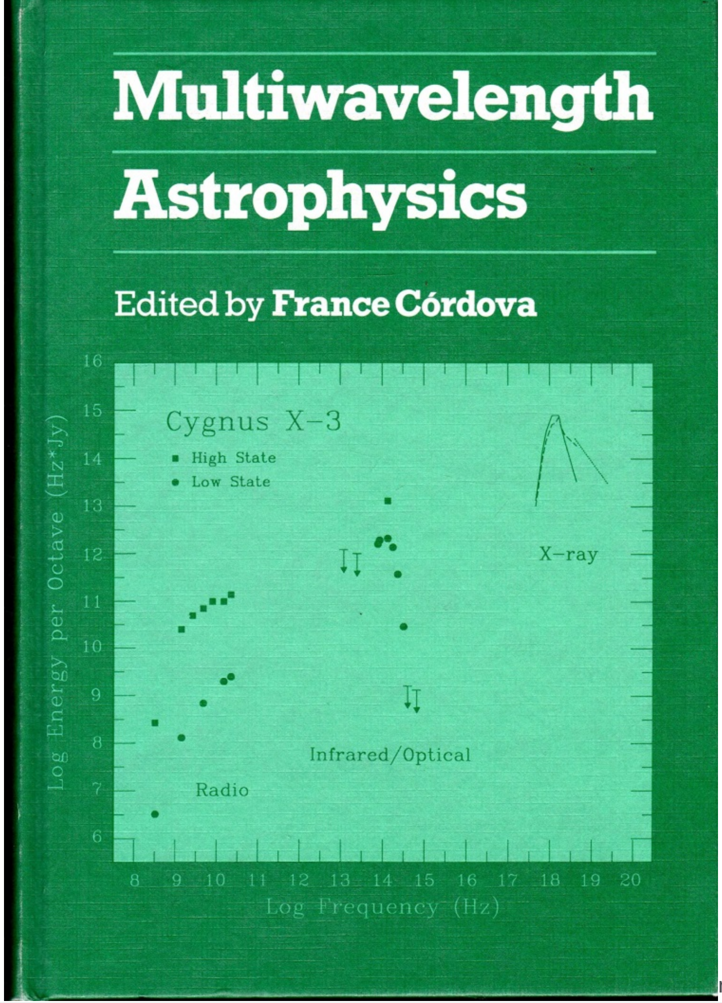
Deep Roots in Multiwavelength

Mid-1980s proposal for a space-based platform to extend AXAF (Chandra) to optical wavelength

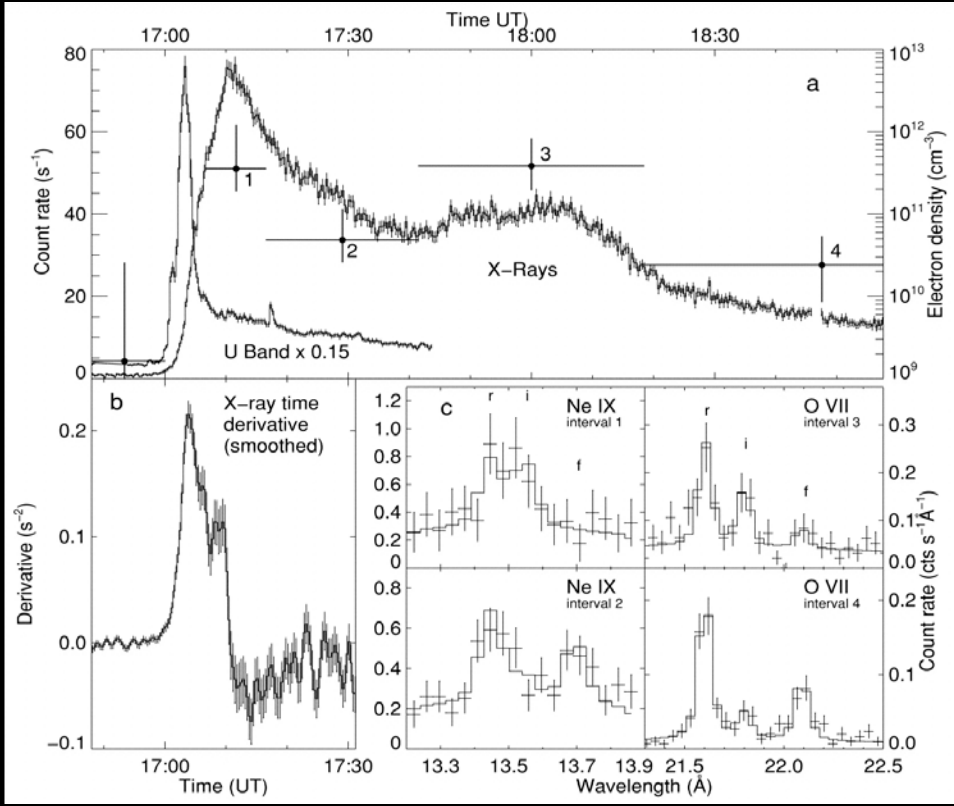
1983 proposal to XMM-Newton for OM

1987 First Workshop on Multiwavelength Astrophysics





Flare density variations and continual chromospheric evaporation in Proxima Centauri



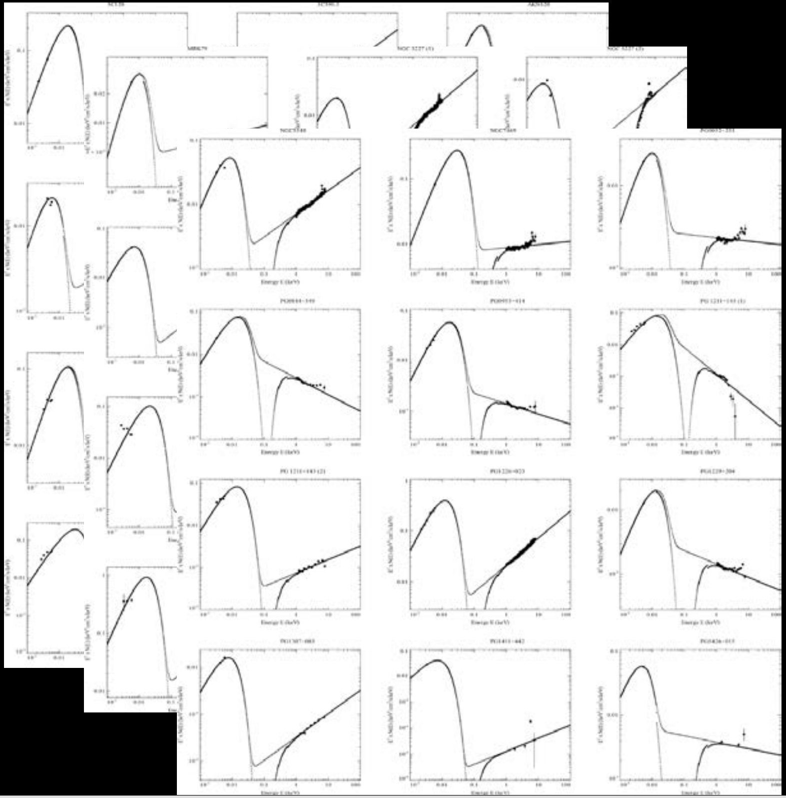
- Proxima Centauri (dM 5.5e dwarf) is nearest star to the Sun
- XMM-Newton observed the weakest X-ray flares on a magnetically active star ever.
- Correlated X-ray and optical variability strongly supports coronal energy and mass supply by a continuous sequence of rapid explosive energy releases.
- Variable emission-line fluxes in the He-like triplets of O VII and Ne IX allow to determine density variations, implying densities between 2×10^{10} and 4×10^{11} cm^{-3}

➔ Estimates of the mass and the volume of the line-emitting plasma.

➔ Importance of chromospheric evaporation in active stellar coronae

M. Güdel, et al., 2002, ApJ 580, L73

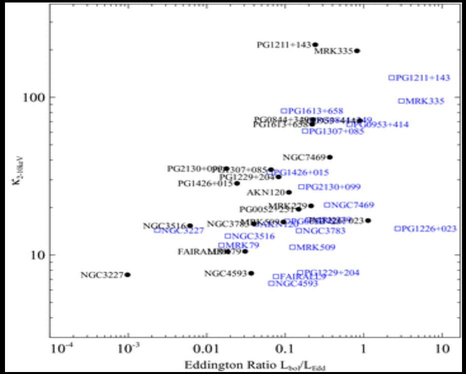
Simultaneous X-ray/optical/UV spectral energy distributions of AGNs

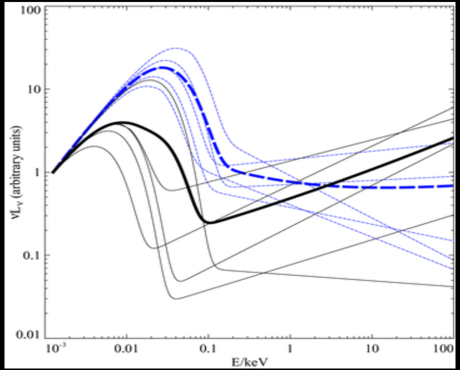


R. V. Vasudevan & A.C. Fabian, 2009, MNRAS 392, 1124

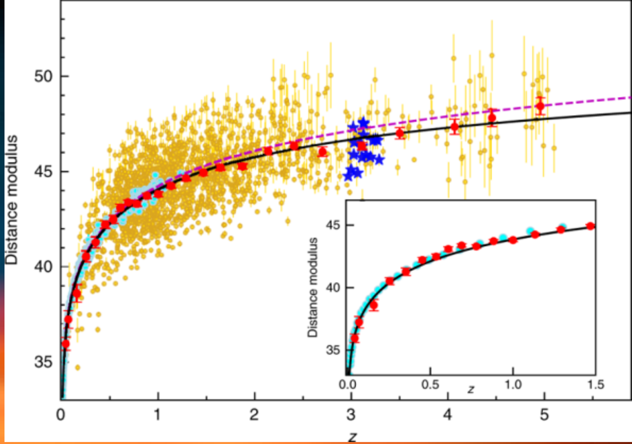
- Contemporaneous optical, ultraviolet (UV) and X-ray observations from the XMM-Newton European Photon Imaging Camera (EPIC-pn) and Optical Monitor (OM)

➔ For the first time, simultaneous spectral energy distributions (SEDs) for the majority of the Peterson et al. reverberation mapped sample of active galactic nuclei (AGN).





Cosmological Constraints from the Hubble Diagram of Quasars at High Redshifts

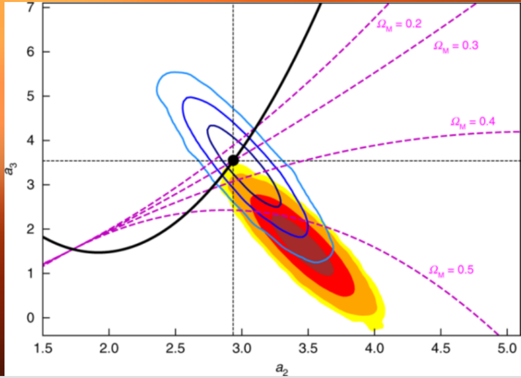


- distances based on the X-ray and ultraviolet emission of the quasars
- $z < 1.4$ agreement with supernovae and concordance ΛCDM model

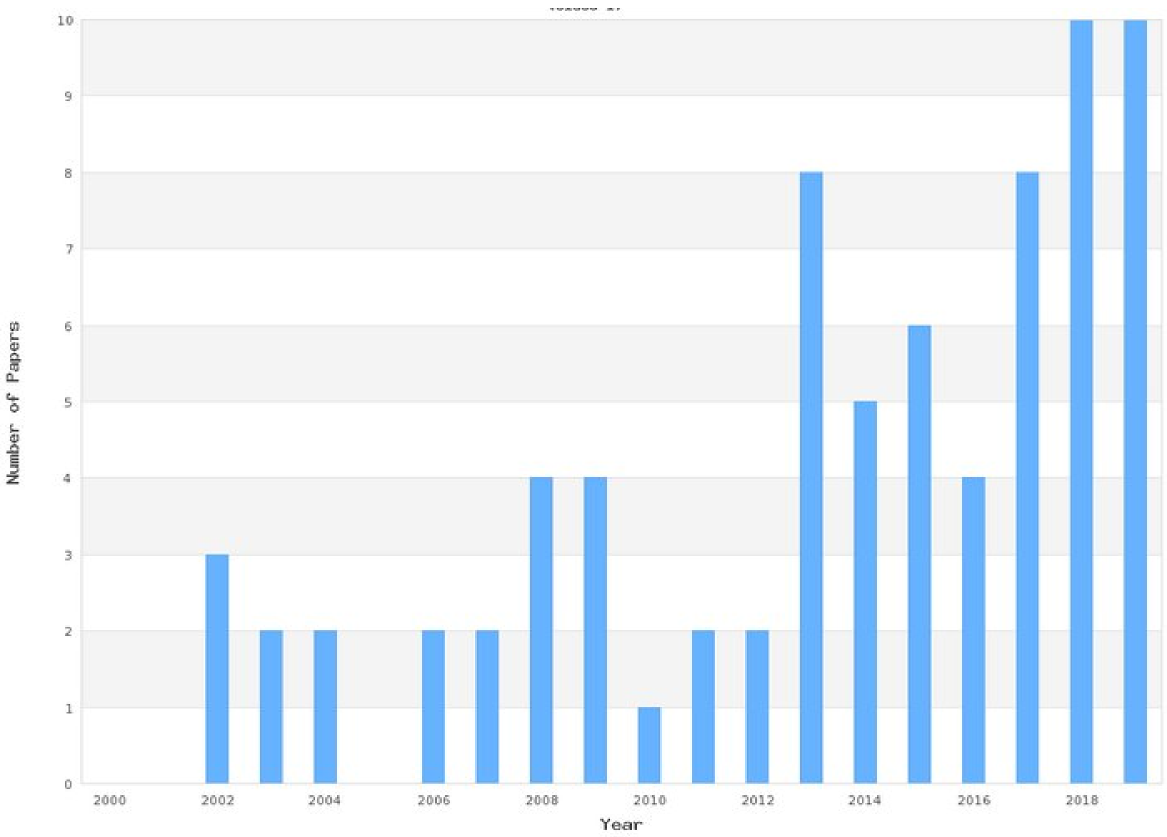
➔ **$z > 1.4$ derivations of ~4σ**

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

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



Highest Profile Journals



Multiwavelenght Science: SZ / Planck

Multiwavelenght Science:
SZ / Planck

SZ-X-ray for clusters of galaxies

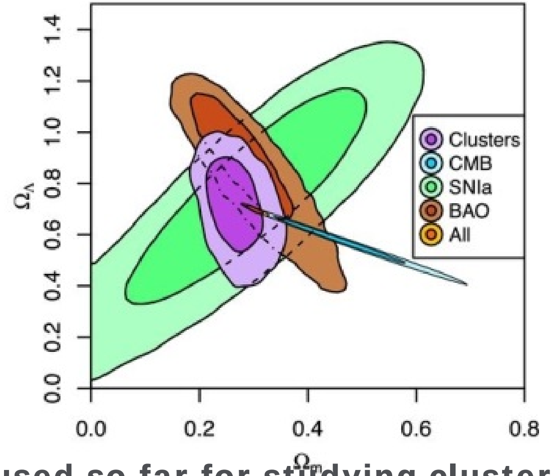
Most of the XMM-Newton observed clusters of galaxies were compared with the Planck observations

130 observations of Planck detected clusters

Physics: hot gas

X-ray emission ~ (electron density)^2

SZ ~ electron density



Mantz et al., 2015, MNRAS 446, 2005

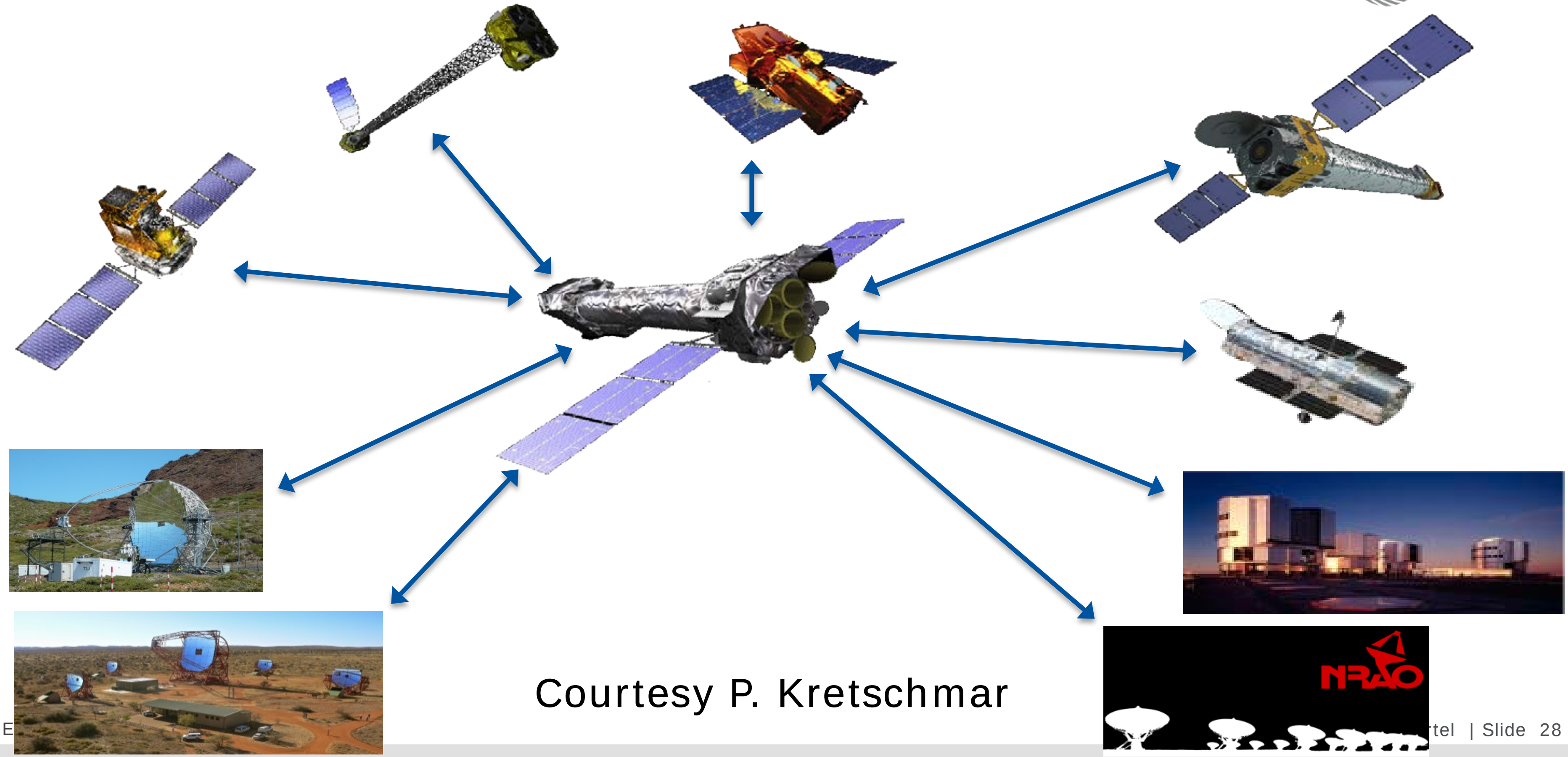
Most used so far for studying cluster selection for cosmological studies

Cluster physics based on X-ray and SZ starts to build up.

Supported by higher spatial resolution of next generation SZ-telescopes

Clusters are stable and therefore almost no requests for joint programs

Joint Programs



Courtesy P. Kretschmar

Joint Programs of Large Observatories

- **NASA connects all (its) Large Observatories over joint programs**

Large Observatories

- **Chandra**
- **XMM-Newton**
- **HST / JWST**
- **Spitzer**

- **NRAO**

Joint Programs of Large Observatories

Connecting all Large Observatories over joint programs:

NASA + European + International

Large Observatories	European	International
-		**CTA**
- **Chandra**		
-	**XMM-Newton**	
- **HST / JWST**	**ESO VLT(I)**	
- **Spitzer**	*(Herschel)*	
		ALMA
- **NRAO**	**Euro Radio**	**SKA**

Joint Programs

Connecting all Large Observatories + (some) medium size missions

Large Observatories	European	International
-		CTA **HESS & MAGIC**
-	**Integral**	
- **Chandra**	**Swift (no exchange)**	
- **XMM-Newton**		
- **HST / JWST**	**ESO VLT(I)**	
- **Spitzer**	*(Herschel)*	
		ALMA
- **NRAO**	**Euro Radio**	SKA

AO 18

Statistics on Joint observations (255 observations in 100 proposals)

	Nr. of Prop.	Nr. of obs	Time/Orbits
Chandra	13 (11)	30	1213.0
HST	19 (13)	46	108.0
VLT	6	22	80.0
Swift	15	33	826.0
NuSTAR	57 (69)	144	9730.0
INTEGRAL	0 (9)	0	None
MAGIC	0 (13)	0	None
HESS	0 (6)	0	None
NRAO	6 (0)	18	47.6

Statistics on Joint observations (296 observations in 104 proposals)

	Nr. of Prop.	Nr. of obs	Time/Orbits
Chandra	11	11	535.0
HST	31	81	219.0
VLT	10	33	58.0
Swift	10	14	430.0
NuSTAR	47	170	15484.0
INTEGRAL	1	1	45.0
MAGIC	0 (12)	0	None
HESS	2	3	33.0
NRAO	9 (3)	16	78.5

Joint Observations

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Mission	Observations	Time
NuSTAR	385 observations,	22253.5 ks
Chandra	123 observations,	7446.3 ks
INTEGRAL	122 observations,	4873.6 ks
HST	115 observations,	5962.5 ks
VLT	94 observations,	3140.7 ks
Ground	82 observations,	3984.8 ks
RXTE	78 observations,	3079.6 ks
Swift	55 observations,	2889.9 ks
VLA	38 observations,	1622.6 ks
BeppoSAX	31 observations,	1671.8 ks
VLBA	31 observations,	1462.5 ks
Radio	28 observations,	1409.0 ks
Suzaku	23 observations,	1371.1 ks
ATCA	15 observations,	779.1 ks
HESS	13 observations,	359.8 ks
Kepler	13 observations,	954.3 ks
GMRT	12 observations,	359.2 ks
FUSE	10 observations,	523.0 ks
WEBT	10 observations,	264.3 ks
Effelsberg	9 observations,	234.1 ks
JUNO	9 observations,	648.5 ks
NICER	9 observations,	548.4 ks
Herschel	7 observations,	168.1 ks
MAGIC	7 observations,	228.8 ks
VLBI	6 observations,	264.2 ks
ESO	5 observations,	192.5 ks
CANGAROO	4 observations,	139.0 ks
LCOGT	4 observations,	479.2 ks
Mars Express	4 observations,	386.8 ks
SAAO	4 observations,	104.5 ks
TNG	4 observations,	114.5 ks
VLTI-Gravity	4 observations,	140.8 ks
Astrosat	4 observations,	249.6 ks
EAVN	4 observations,	140.8 ks
GMVA	4 observations,	140.8 ks
VERITAS	4 observations,	140.8 ks
AGILE	4 observations,	63.0 ks
Parkes	3 observations,	188.2 ks
Galex	3 observations,	151.5 ks
HMXT	3 observations,	152.2 ks
Calar Alto	2 observations,	61.4 ks
Cassini	2 observations,	102.4 ks
GLAST	2 observations,	85.1 ks
MeerKAT	2 observations,	68.0 ks
La Palma	2 observations,	51.9 ks
IRTF	2 observations,	240.3 ks
SPRINT-A	2 observations,	90.2 ks
FACT	2 observations,	136.0 ks
Atrosat	2 observations,	41.9 ks
Copernicus	2 observations,	64.0 ks
Keck	2 observations,	102.4 ks
ALMA	1 observations,	32.0 ks
Dawn	1 observations,	73.6 ks
EVN	1 observations,	15.0 ks
JVLA	1 observations,	52.5 ks
REM	1 observations,	90.0 ks
Spitzer	1 observations,	34.0 ks
WSRT	1 observations,	26.0 ks
MAVEN	1 observations,	100.8 ks
AMI LA (Radio)	1 observations,	50.0 ks
EHT	1 observations,	25.5 ks
IR	1 observations,	141.4 ks
LOFAR	1 observations,	26.0 ks
Lowell	1 observations,	26.0 ks

Total number of observations: 1418

Total observing time (ks): 71020.3

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Total observing time (ks): 71020.3

“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.

SCIENTIFIC POTENTIAL

Understanding planetary systems: their formation, and their host stars

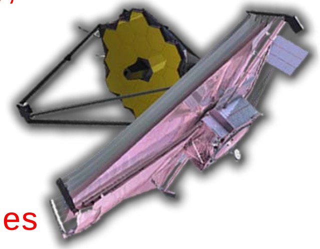
NASA's Transiting Exoplanet Survey Satellite (TESS) mission has started to monitor 200,000 nearby stars to discover new transiting exoplanets. → comprehensive study of magnetic activity in late-type stars

- 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

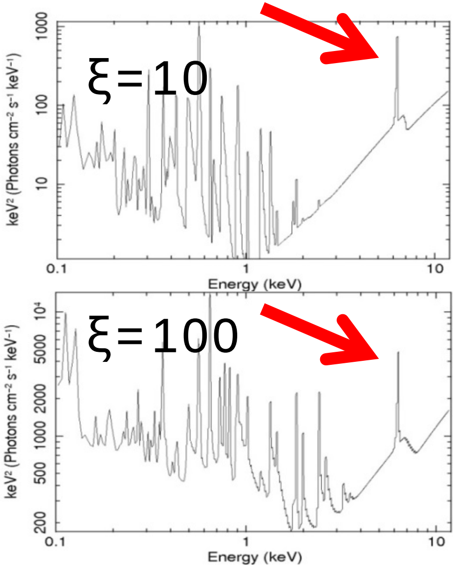


The X-ray luminosity of the host star is of fundamental importanct to understand planets habitability

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

Iron Line Studies: A Continuing Success

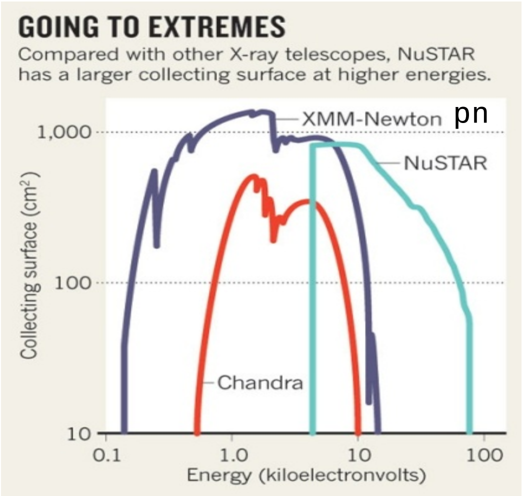
Why is iron so interesting?
- isolated emission line
e.g. reflection spectrum



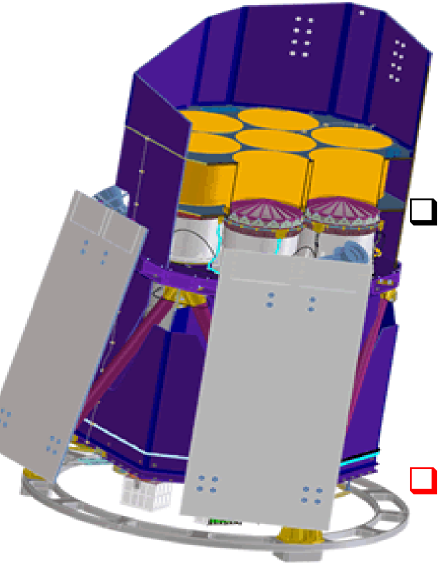
+ high ionization parameter
+ high abundance

- ❑ **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



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

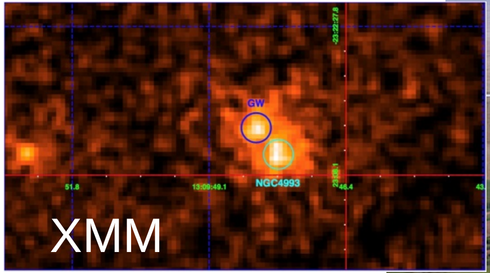
- There is a huge potential for XMM-Newton follow-up of new and transient sources while eROSITA continues scanning
- Observations with XMM-Newton will be importantl in providing a physical interpretation and understanding of these detections e.g. temperature of hot clusters of galaxies
- XMM-Newton’s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

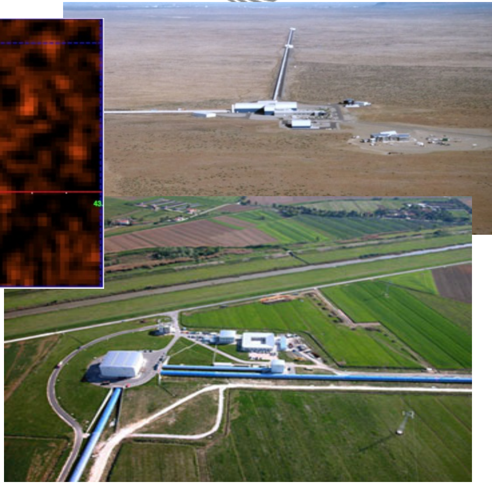
The Search for Electromagnetic Counterparts of Gravitational Wave Events

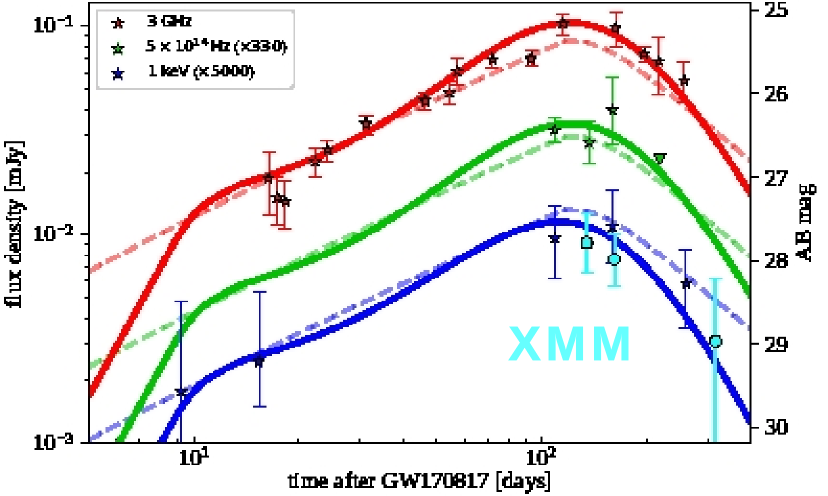
The GW interferometers Virgo and LIGO will restart observation in 2019, with 2020 reserved for a major upgrade, followed by operations from 2021 onwards.

➔ increasing sensitivity

➔ decreasing positional error







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

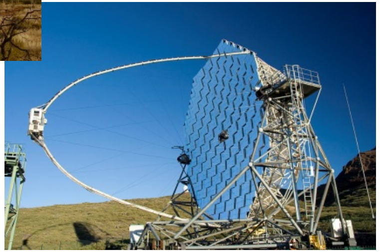
➔ only XMM-Newton and Chandra can attain the required sensitivity

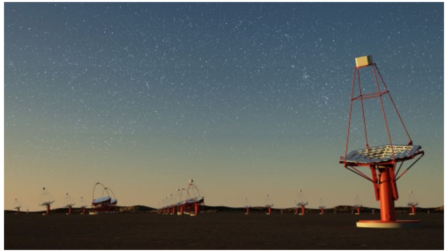
➔ increasing sensitivity of the GW observatories implies that (most) future GW events will be even fainter

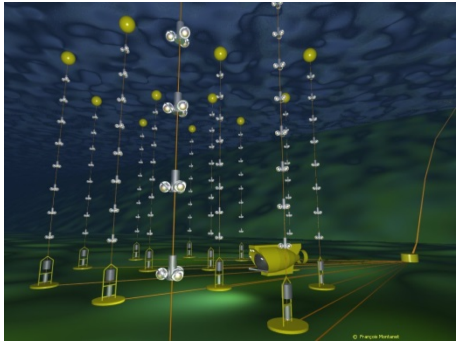
➔ Rapid XMM-Newton follow-up observations could permit searches for **hyper-massive NS shortly after merger**.

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



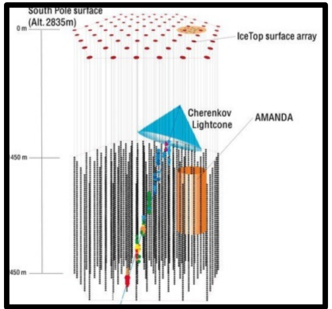




A BL-Lac-type AGN was recently discovered as source of high energy cosmic neutrinos.

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.



Some Thoughts for Discussion

Quo vadis?

- Neil Gehrels, PI of Swift, (passed away)
  - Swift was renamed to Neil Gehrels Swift Observatory
  - “95% of the knowledge we have about GRB is based on the observation of the three brightest GRBs”

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  - Swift was renamed to Neil Gehrels Swift Observatory
  - “95% of the knowledge we have about GRB is based on the observation of the three brightest GRBs.

- Very generally astrophysics sources:
  - Physics from very very few brightest sources
  - Huge amount of weak contributes basically nothing to the physics understanding
  - however,

    evolution, universe, H0, m of light

How much of our knowledge about stars comes from the Sun?

Compton Gamma Ray Observatory with BATSE versus BeppoSAX?

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  - Kilonova / short GRB
    - extremely well knowing from theory
    - well constraint by short GRB
    - however, weak sources

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- What do we know about physics of GWE:
  - BH – NS
    - theory: yes
    - observations from SMBH, but also one intermediary BH
    - no observation form stellar mass BH
    - very likely much weaker than Kilonova / short GRB

Quo vadis?

- What do we know about physics of GWE:
  - BH - BH
    - theory (of EM emission)?
    - however, first paper are coming ..
    - ignored by observers?
    - much, much weaker
    - and very short
    - New Physics
    - Holy grail

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- What do want to see for BH - BH
  - spectrum, with as much large observatories as possible
  - we have to be very quick

- We need instantaneously extremely good positions
- 15 arcmin: XMM-Newton goes immediately
- 7 arcmin: Chandra goes
- .... if possible ... arcsec

- theory: yes
- observations from SMBH, but also one intermediary BH

Quo vadis?

- Three nearby bright GW with a arcsec-position-error per year have the potential to bring much more physics that 1000 weaker GWs per year with a degree-error size position

- Improving the position is much more important than going to more sensitivity

- If necessary add GW-observatories in Australia, Argentina, Russia, South-Africa .. Chile / ESO ..