10 Years Of XMM-Newton: Scientific Achievements And Future Prospects

X-Ray Astronomy 2009

Bologna, September 7-11, 2009

Norbert Schartel

(XMM-Newton Project Scientist)

esa

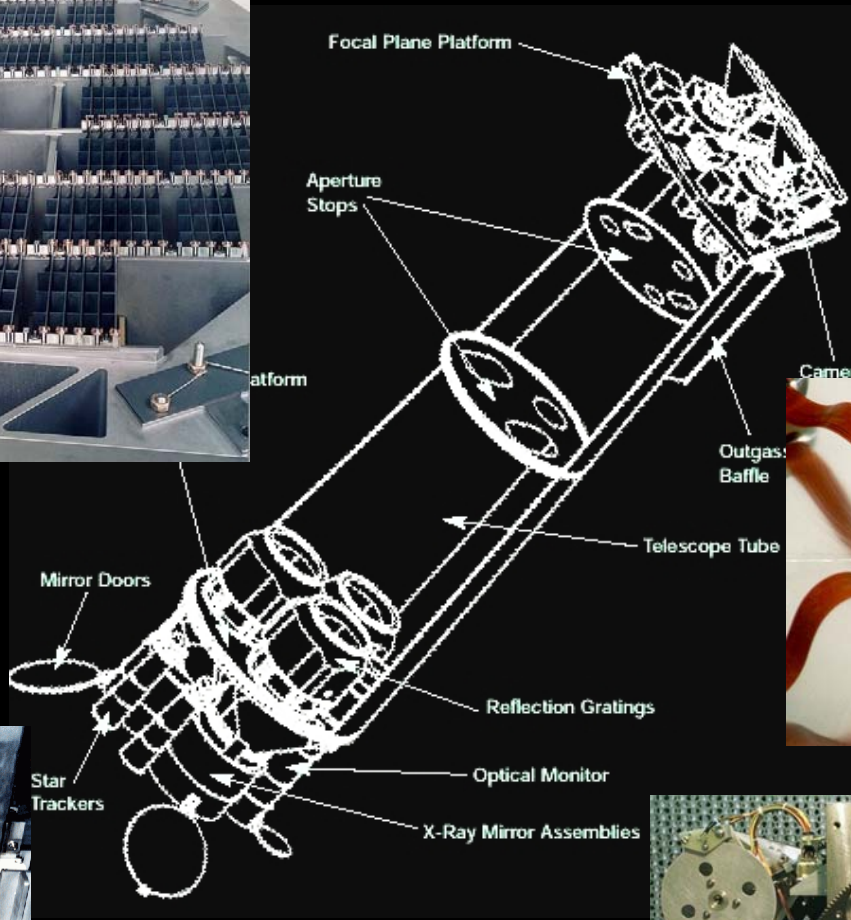
XMM-Newton

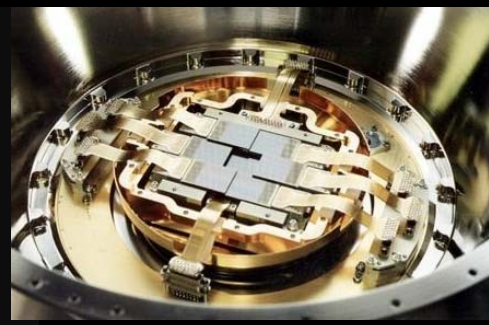
Contents

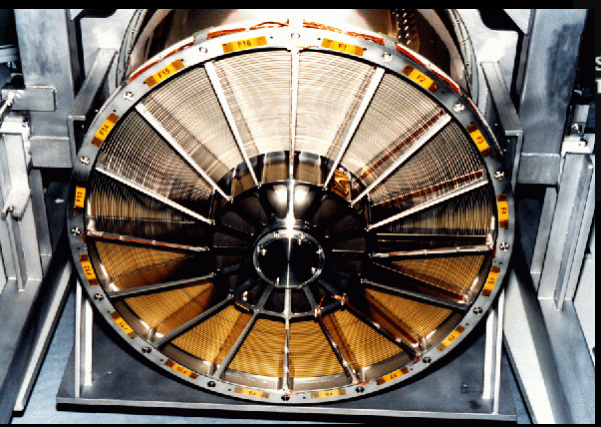
- XMM-Newton
- Scientific Highlights
- What's past is prologue
  - Space-Craft & Instruments
  - Science

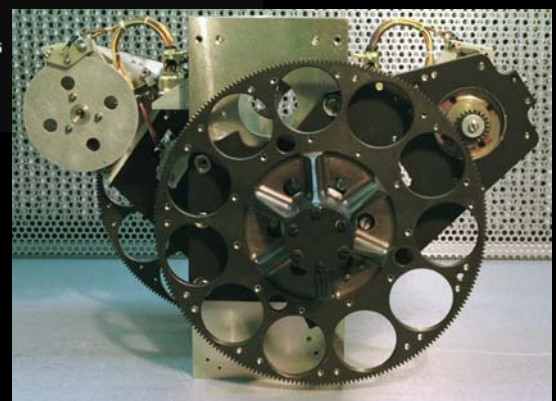
XMM-Newton Launch (10th of December 1999)

Instruments





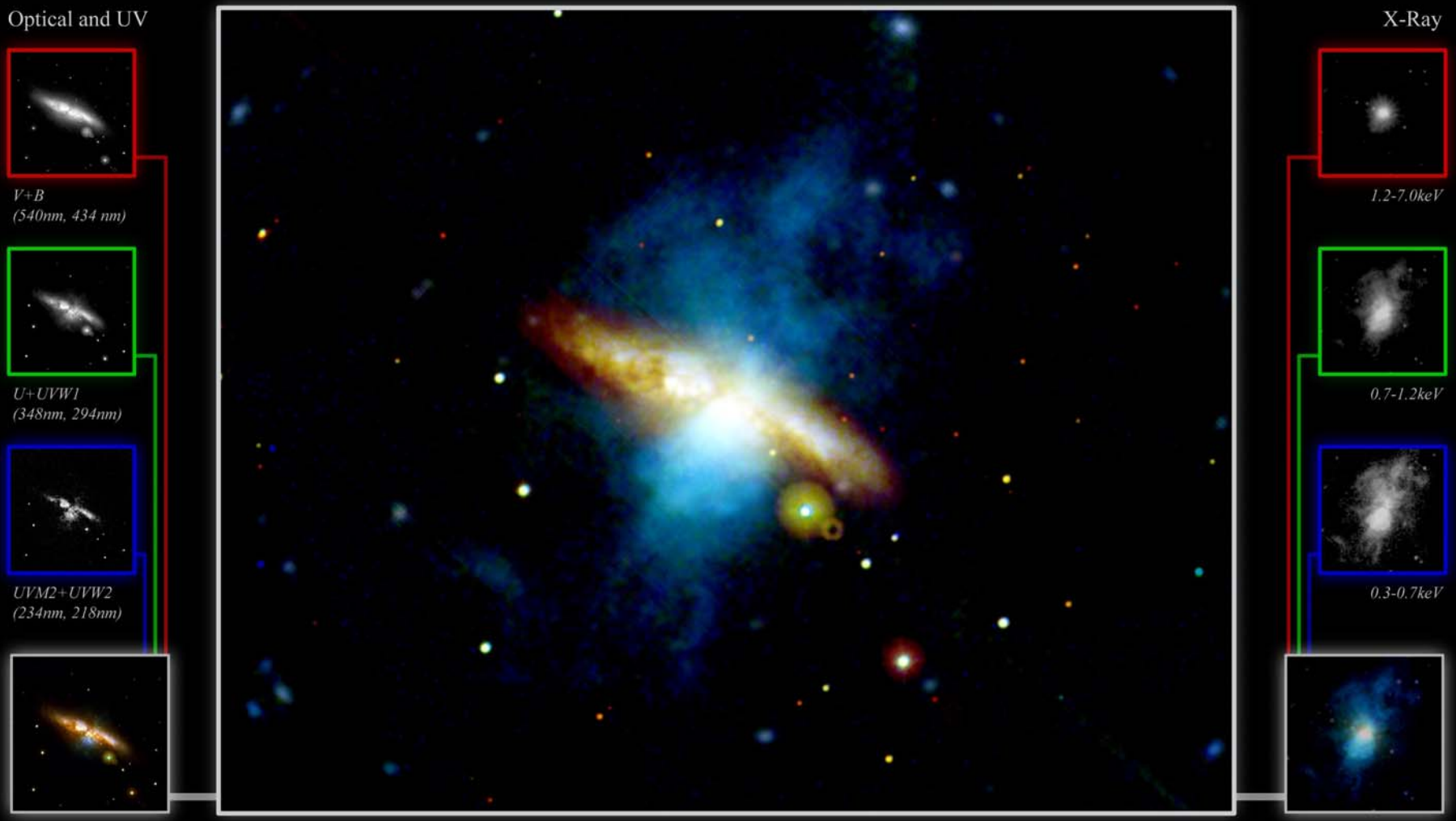




XMM-Newton

- 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)



M E S S I E R 8 2

To celebrate the International Year of Astronomy, and as part of the 100 Hours of Astronomy cornerstone project, the European Space Agency is releasing this magnificent image of the starburst galaxy Messier 82 (M82) obtained with the XMM-Newton observatory. The image shows bright knots in the plane of the galaxy, indicating a region of intense star formation, and emerging plumes of supergalactic winds glowing in X-rays.

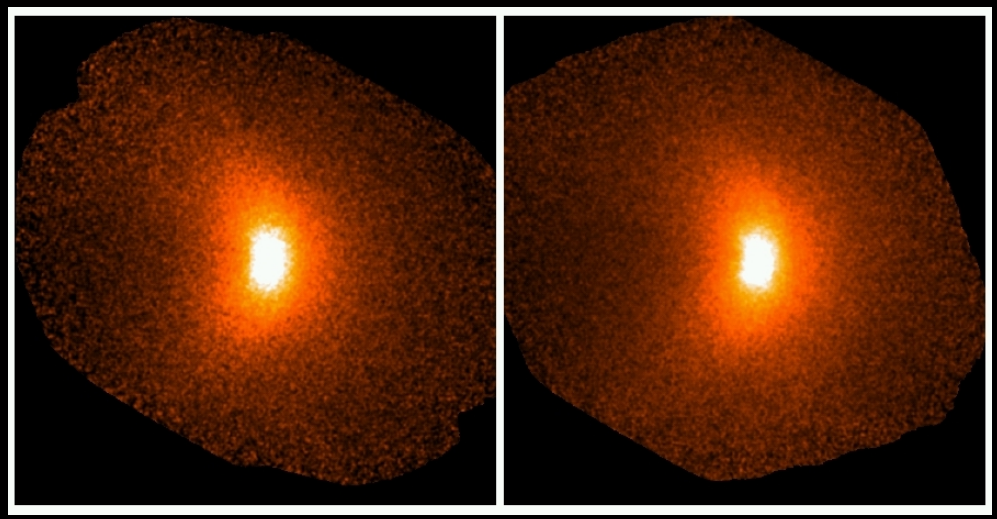
esa

THE UNIVERSE YOURS TO DISCOVER
INTERNATIONAL YEAR OF ASTRONOMY 2009

Image courtesy of Pedro Rodriguez and ESA

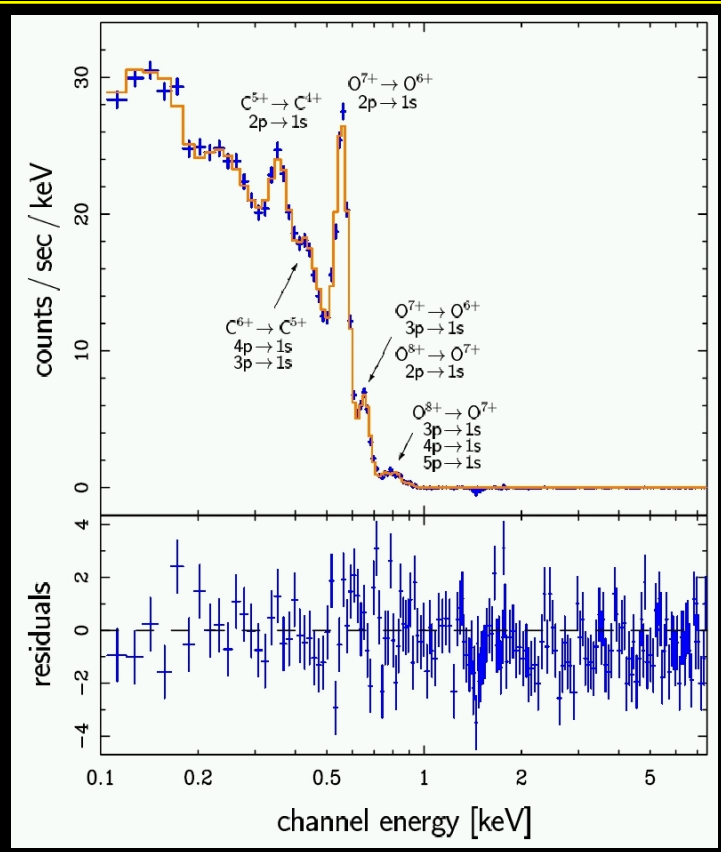
Solar System

C/2000 WM1 (LINEAR)



MOS pn

Dennerl, K, et al., 2003, SPIE 4851, 277



- 17 h of almost uninterrupted observations

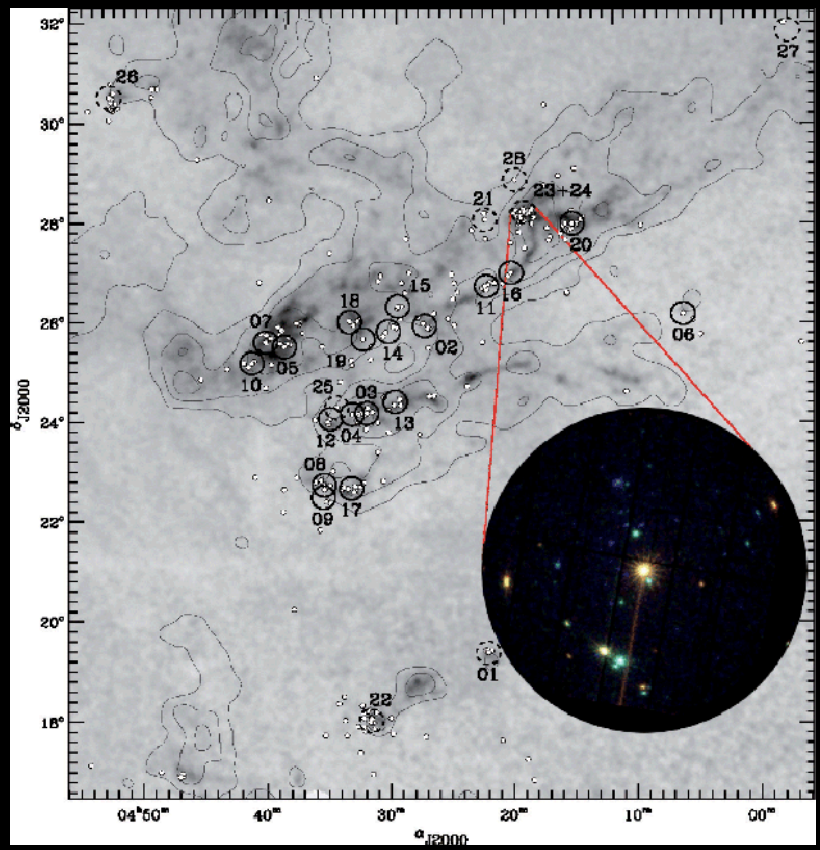
➔ X-ray emission caused by charge exchange reactions between highly charged heavy ions in the solar wind - mainly oxygen and carbon - and cometary gas

Stars

XMM-Newton Extended Survey Of The Taurus Molecular Cloud

- Taurus molecular cloud is a near star formation region
  - Detection of almost all young stars embedded in the cloud as X-ray sources, including many brown dwarfs and protostars

➔ Identification of unusual physical processes not known before in forming stars:
  - ➔ Gas streams falling down onto the forming and young star
  - ➔ Ejection of jets



A&A special feature: 15 papers, 2007, A&A 468; Guedel et al., 2007, A&A 468, 353

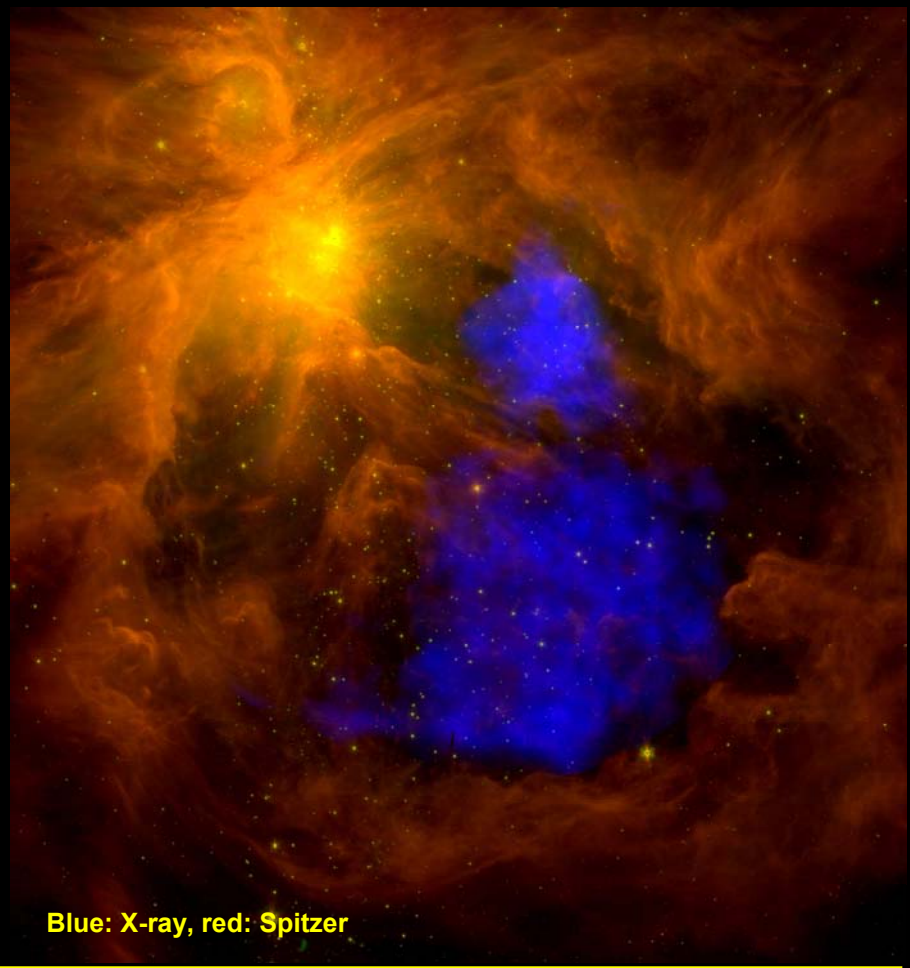
Million-Degree Plasma Pervading The Extended Orion Nebula

- The Orion nebula (near star forming region) is illuminated by a small group of massive stars (the Trapezium).
- XMM-Newton observations reveal a hot plasma with a temperature of 1.7-2.1 10^6 K pervading the southwest extension of the Orion nebula. The plasma flows into the adjacent interstellar medium.

➔ Single hot massive stars contribute to the enrichment of ISM

➔ Suggests that this is a common X-ray outflow phenomenon widespread across our Galaxy

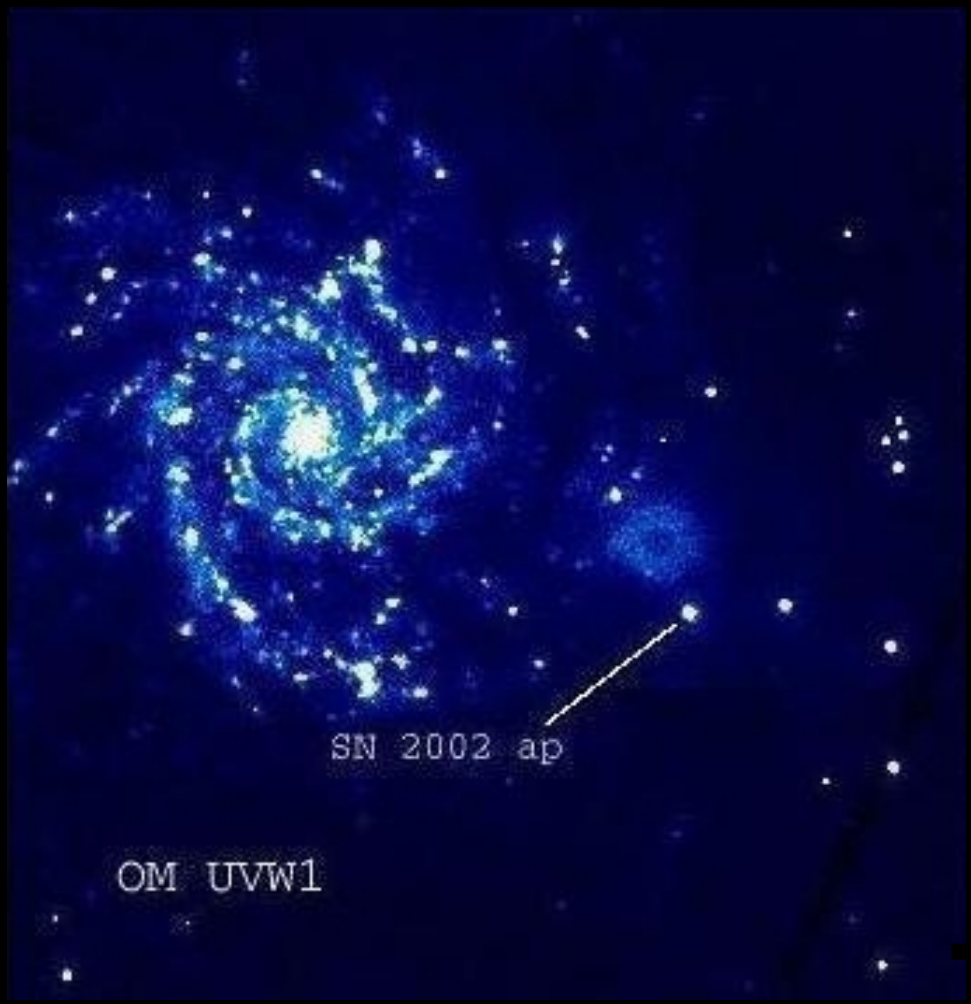
- M. Guedel et al., Science 319, 309, 2008



Blue: X-ray, red: Spitzer

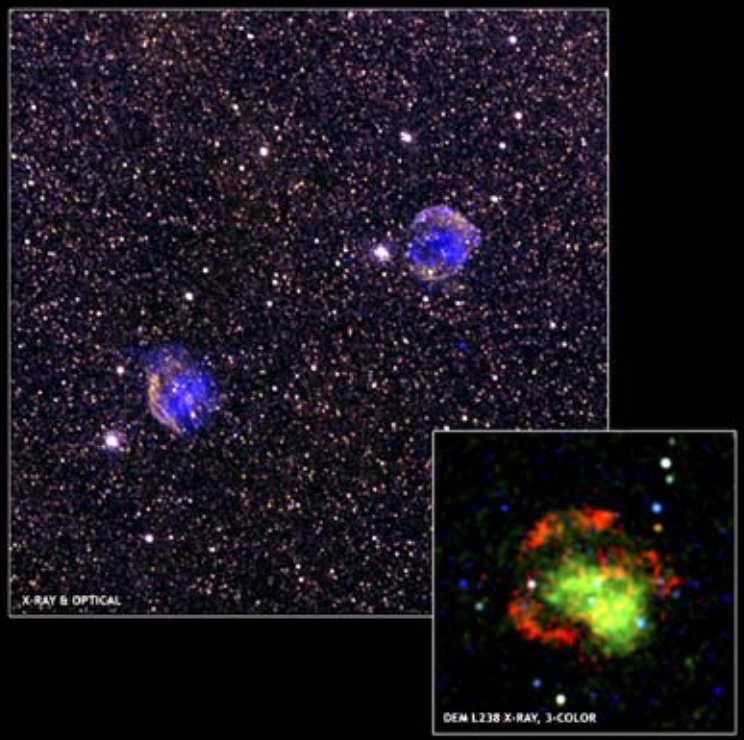
Endpoints Of Stellar Evolution: Supernovae / GRB

Supernova: SN 2002ap

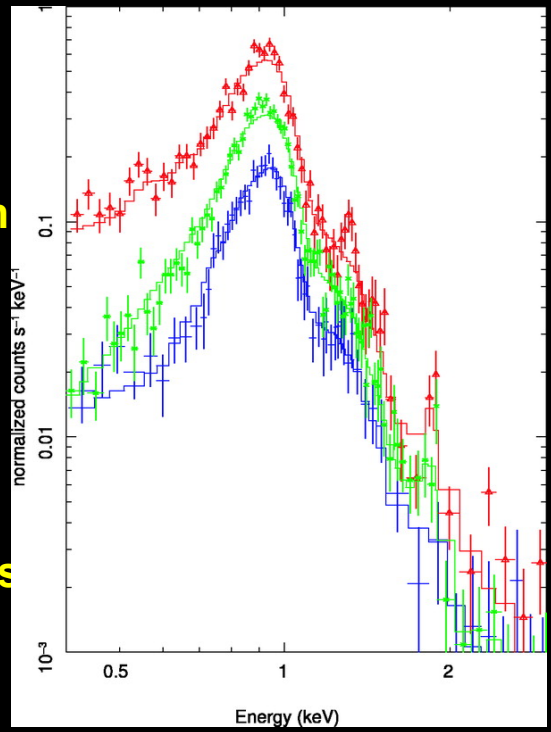


- in M74 (NGC 628)
- SN in general detected in UV, but often not in X-rays
- SN 2002ap detected in X-rays with XMM-Newton
- R. Soria et al., 2002, ApJ 572, L33; F. K. Sutaria et al., 2003, A&A 397, 1011; R. Soria et al., 2004, A&A 413, 107; C.-I. Björnsson & C. Fransson, 2004, ApJ 605, 823; P. Chandra et al., 2004, NuPhS 132, 308
- Image courtesy P. Rodriguez

New Class Of Type 1 SN

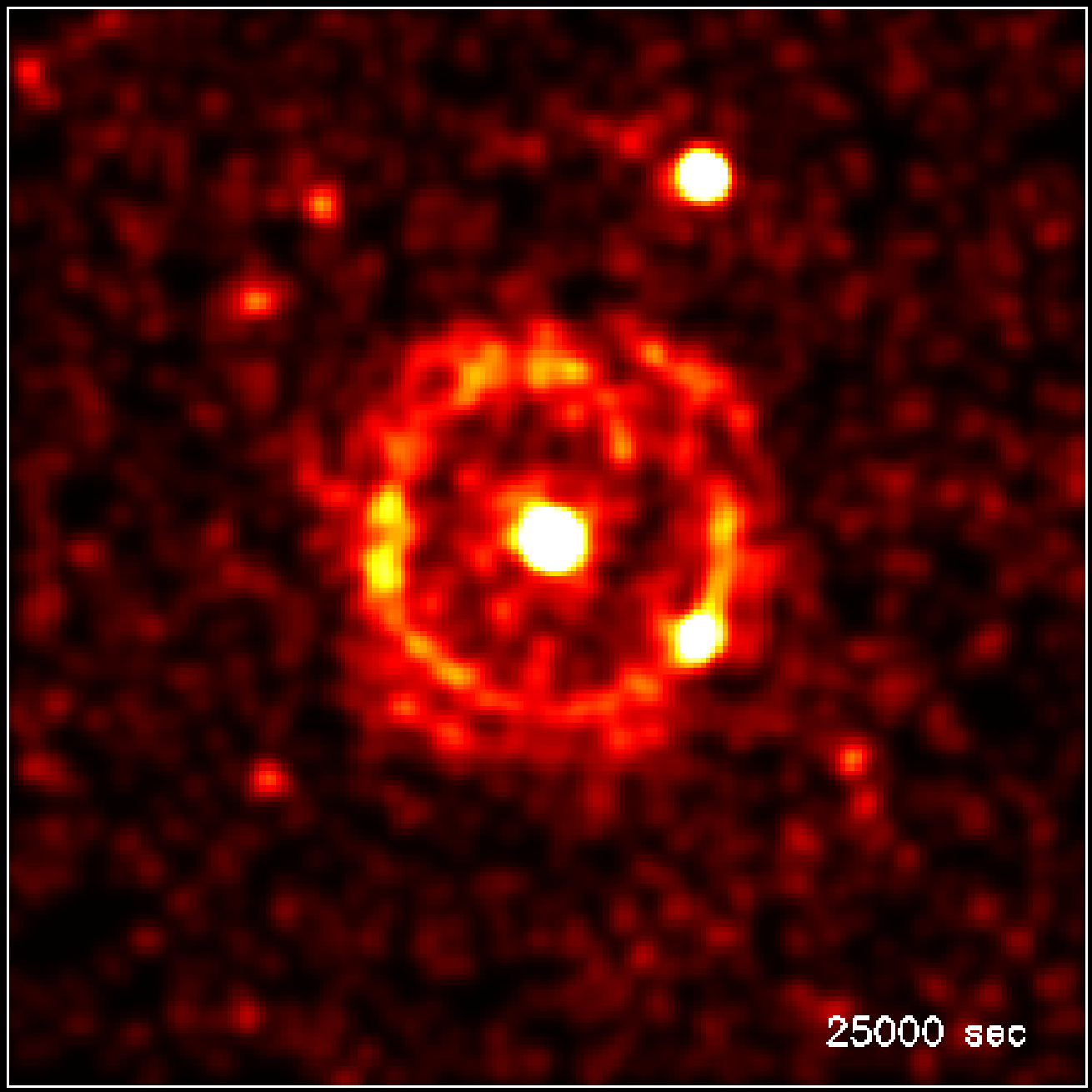


- DEM L238 & DEM L249
- Thermal spectrum dominated by Fe L-shell lines
- Fe over-abundance ➔ Thermo-nuclear Type Ia explosions
- K.J. Borkowski et al. 2007, ApJ 652, 1259



➔ Explosions with energies of 3×10^{50} ergs

➔ New class of SN Ia, more massive and young (100 Myr old) progenitors



GRB 031203

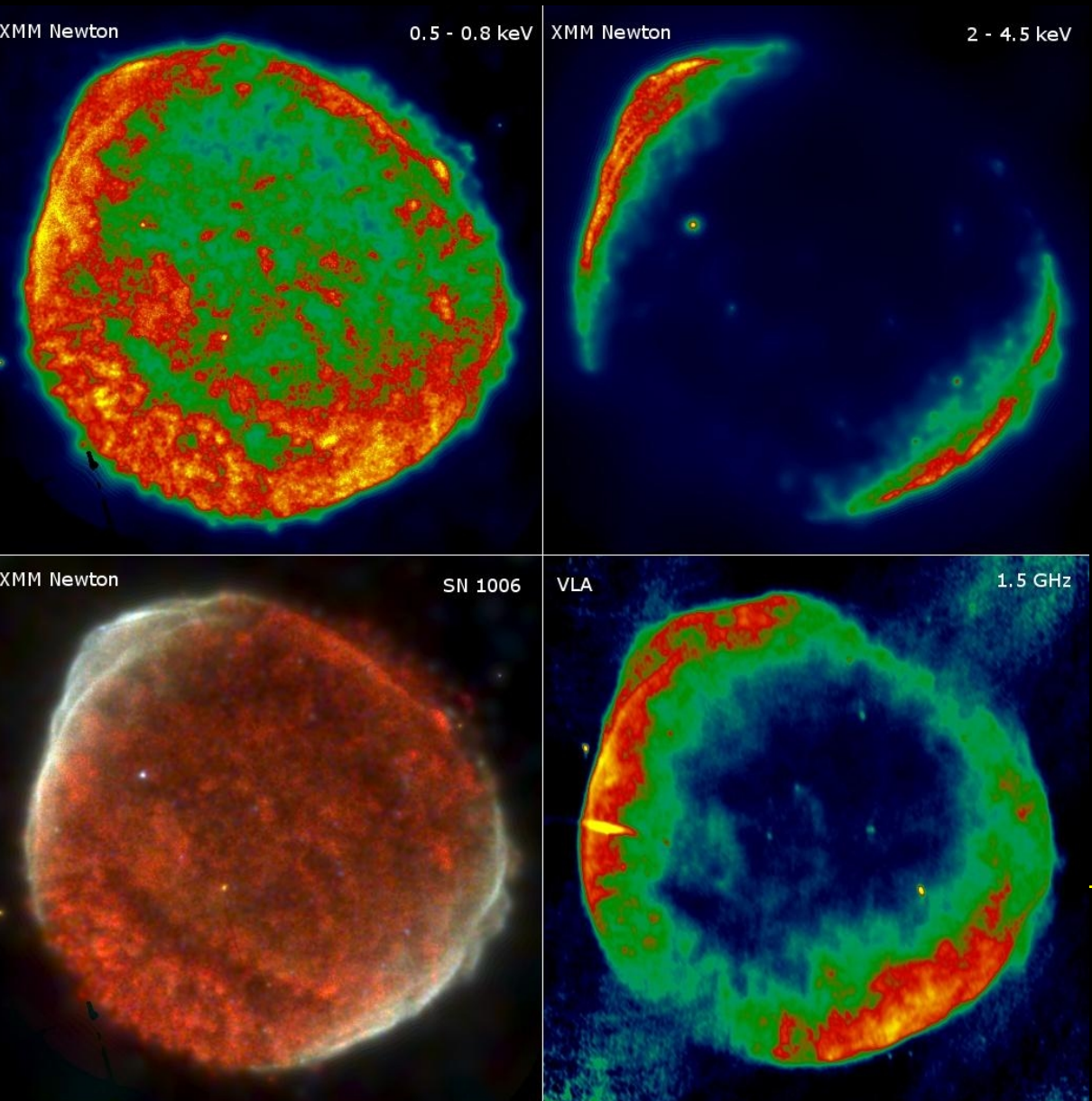
- S. Vaughan et al., 2004, ApJ 603, L5

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

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

Supernova Remnants

SN 1006: Variations Of Cosmic-ray Acceleration

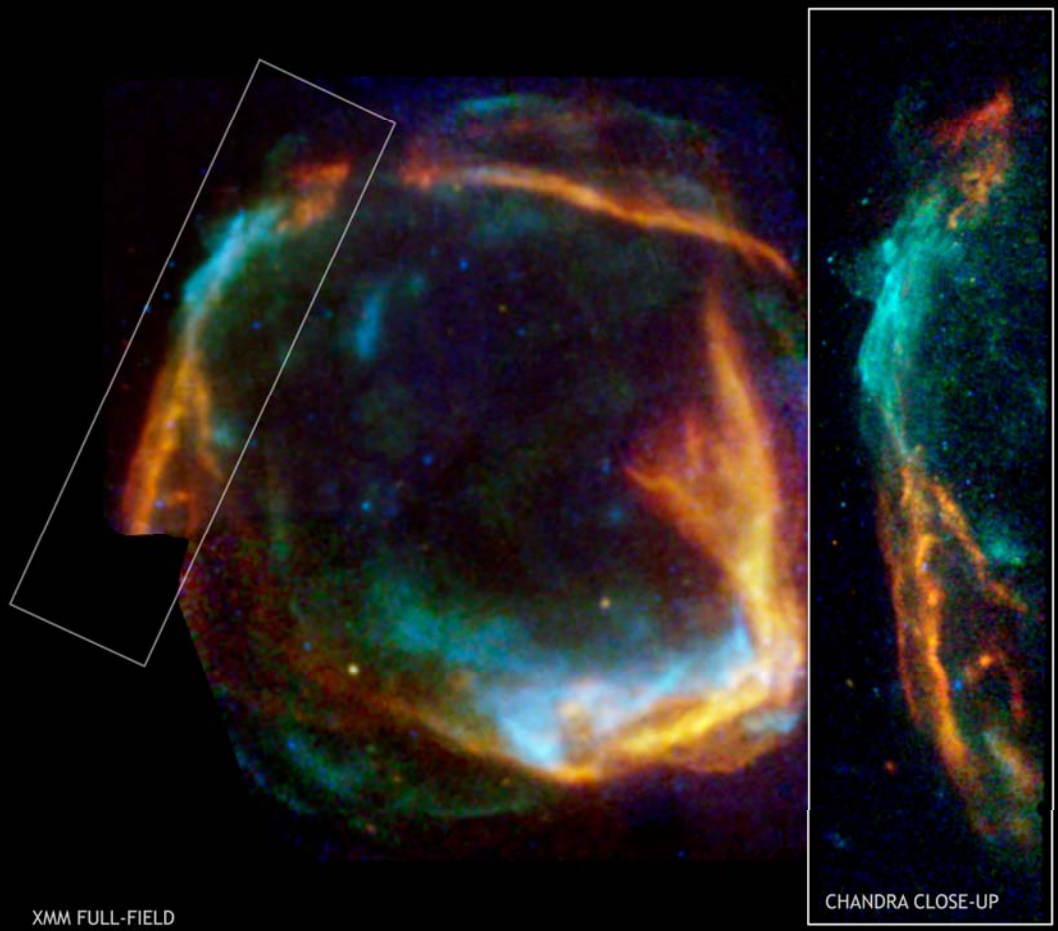


- R. Rothenflug et al., 2004, A&A 425, 121
- Prototype of shell supernova remnants
- Non-thermal synchrotron emission

➔ The magnetic field is amplified where acceleration is efficient

➔Relation to the TeV emission

RCW 86 / Oldest Recorded Supernova



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

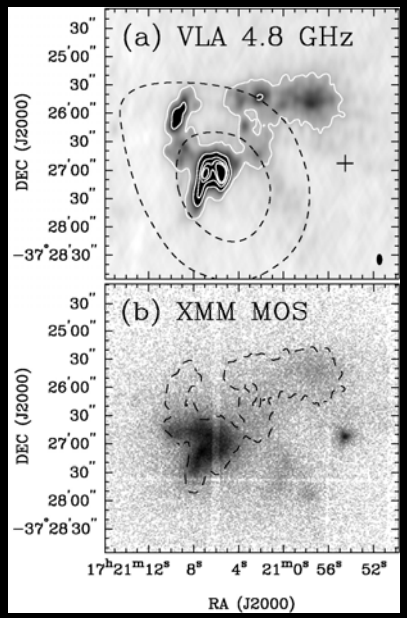
➔ Shock velocity ~2700 km/s

➔ Magnetic field ~24 μG

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

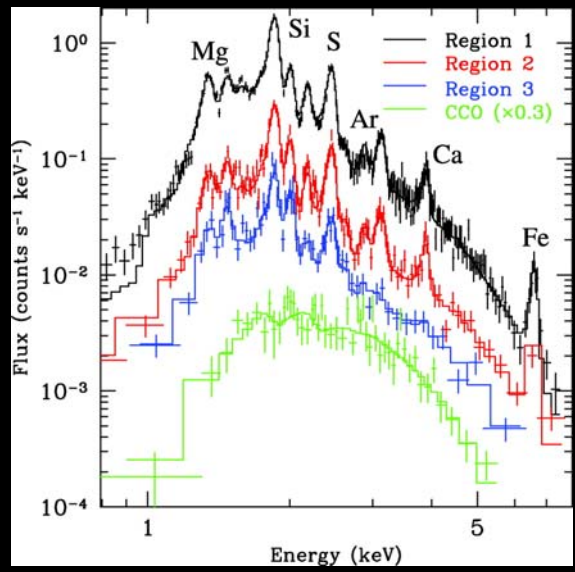
J. Vink et al, 2006, ApJ 648, L33

(Re-)Discovery Of G350.1-0.3: A Young, Luminous Supernova Remnant And Its Neutron Star



•Radio images of 'G350.1-0.3' shows irregular knot: classified as probable background galaxy

Gaensler, B. M., et al., 2008, ApJ 680, L37



• XMM-Newton spectra:

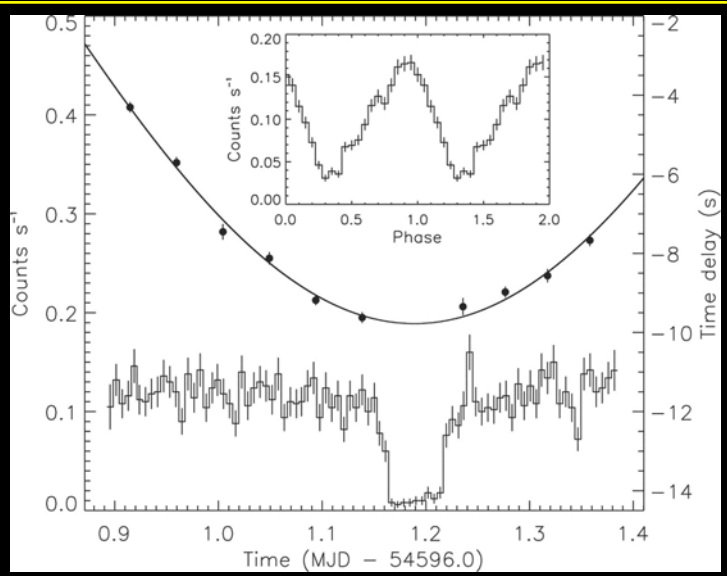
➔G350.1-0.3 is a young, luminous supernova remnant, for which H I and 12CO data indicate a distance of 4.5 kpc

➔ Diameter implies an age of only ~900 years

➔ Unresolved X-ray source is most probably a neutron star associated with G350.1-0.3 (central compact object)

White Dwarfs

RXJ 10648.0-4418: An Ultramassive, Fast-Spinning White Dwarf



- XMM-Newton observation of the eclipse of RXJ 10648.0-4418

➔ Accurate determination of period, time delay of X-ray pulses

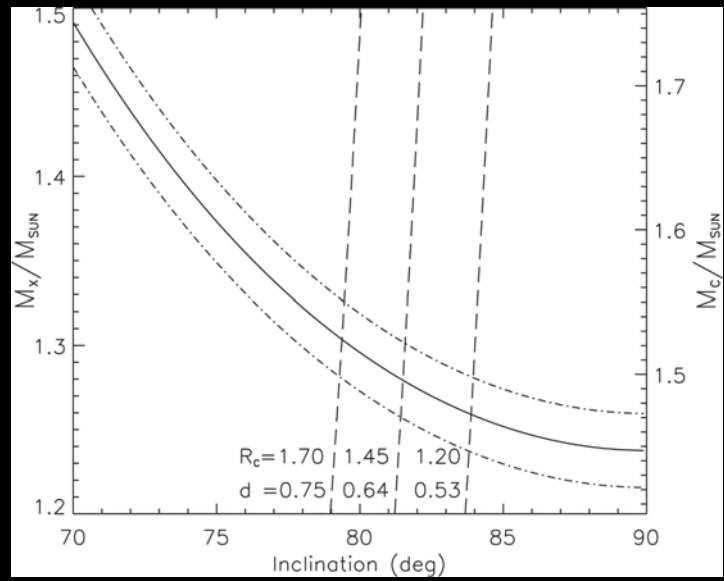
- Mereghetti et al., 2009, Science 325, 1222

➔ RXJ 10648.0-4418 is white dwarf

➔ Dynamical constrain of mass M > 1.2 M_o

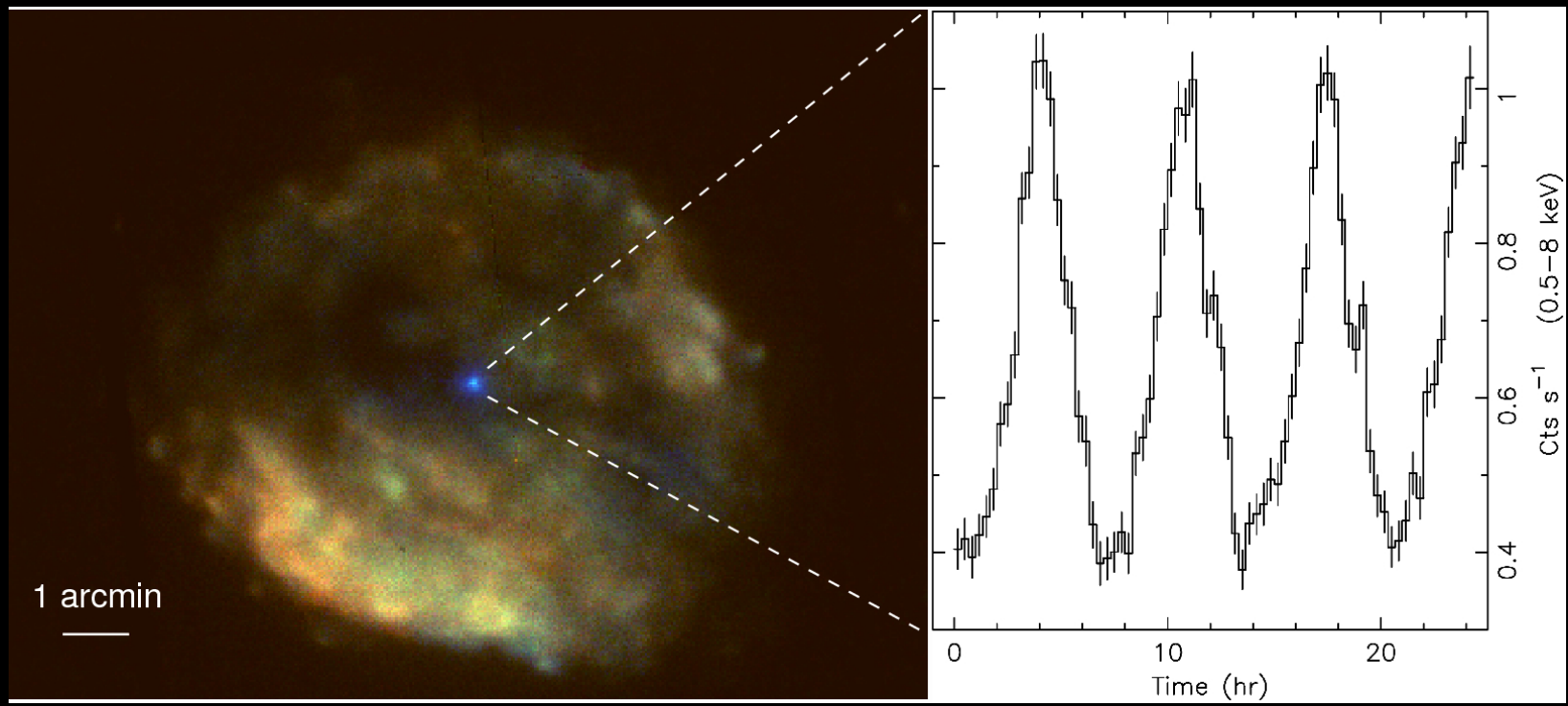
➔ Chandrasekhar limit ➔ SN Ia

➔ Equation of state



Neutron Stars

RCW 103



- Strong periodic modulation at 6.67+/-0.03 hours

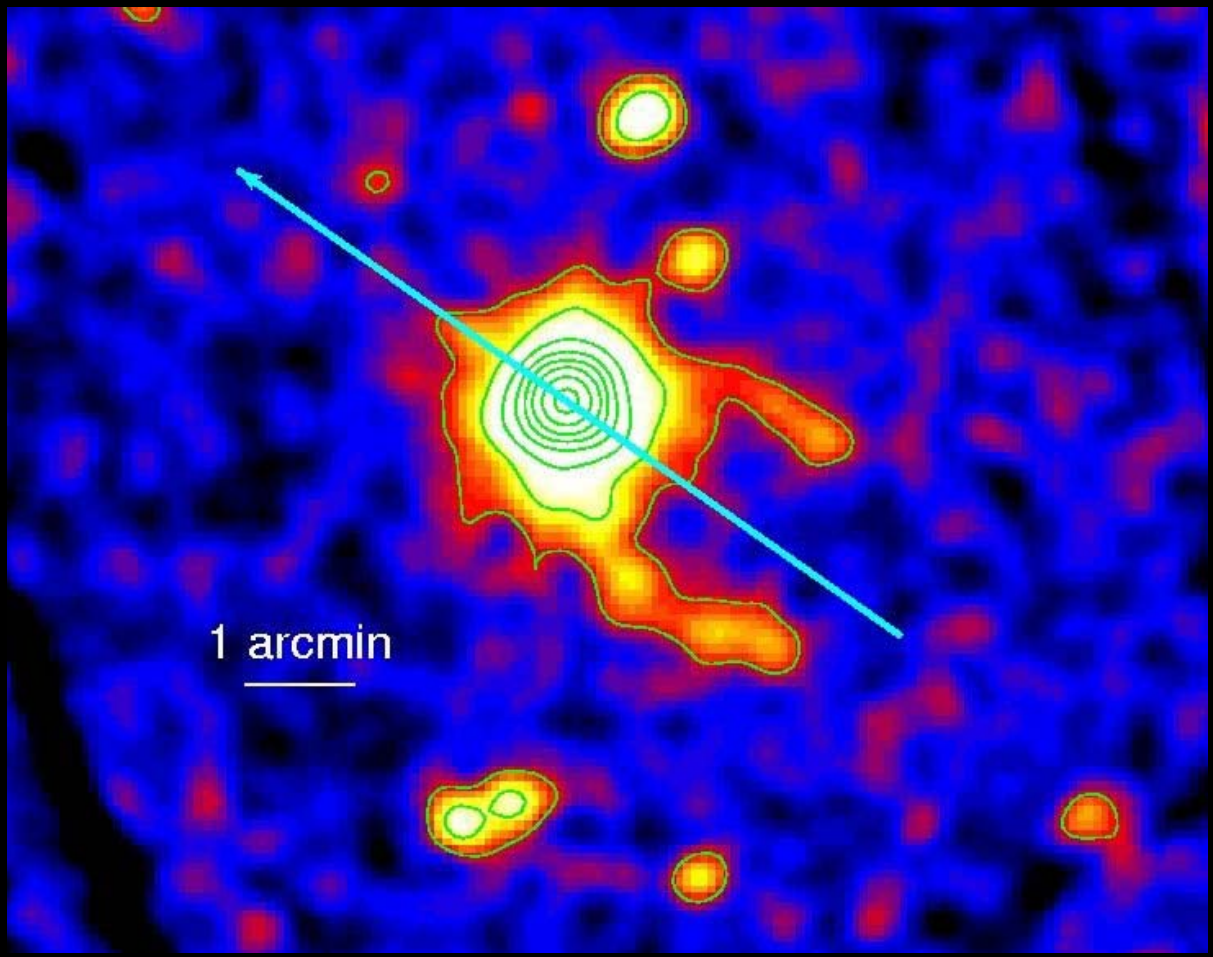
De Luca et al., Science 313, 814

- 2000-year-old supernova remnant RCW 103

→X-ray binary or peculiar magnetar

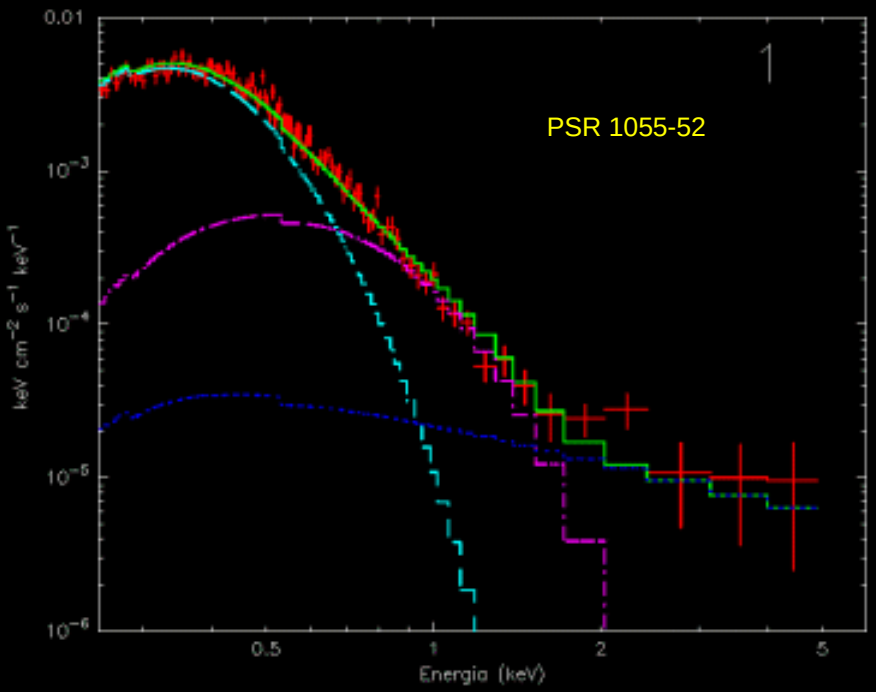
→ Both scenarios require nonstandard assumptions

Geminga's Tails: A Pulsar Bow Shock Probing The Interstellar Medium



- P. A. Caraveo et al., 2003, Science 301, 1345
- Tails aligned with the object's super-sonic motion
- Electron-synchrotron emission in the bow shock between the pulsar wind and the surrounding medium
- ➔Gauge the pulsar electron injection energy and the shock magnetic field

Polar Caps Of The Three Musketeers

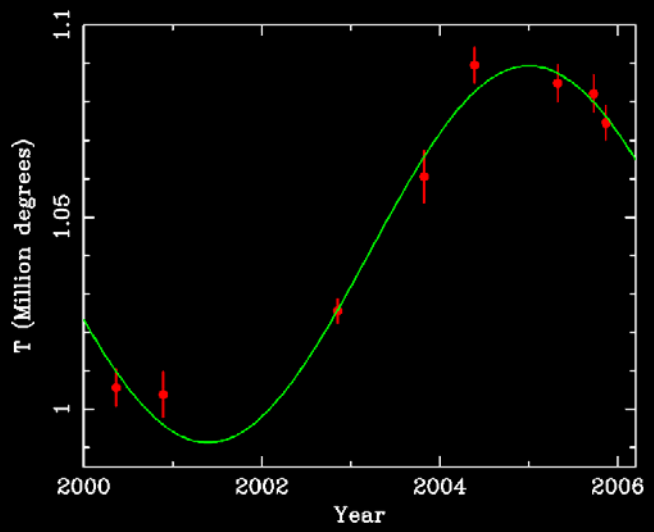


- P. A. Caraveo, et al., 2004, Science 305, 376
- A. De Luca, 2005, 2005, ApJ 623, 1051

- Three isolated neutron stars: Geminga, PSR B0656+14, PSR B1055-52
- Phase-resolved spectroscopy: two blackbody components + power-law
- Hotter bb coming from a smaller portion of the star surface (a ``hot spot'')

➔ Complex models of neutron star magnetic field configuration and surface temperature distribution are required

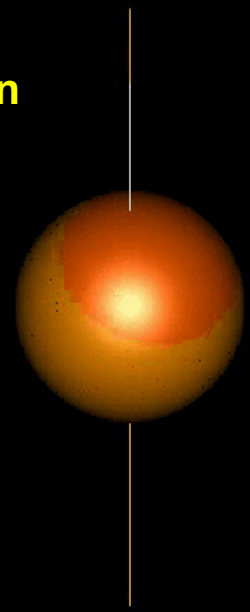
Isolated Neutron Star RX J0720.4-3125



➔ Precession of the neutron star

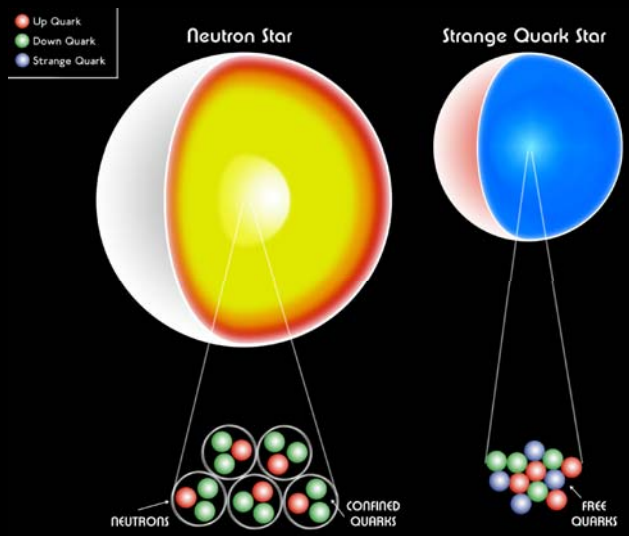
➔ Two hot spots of different temperature and size, probably not located exactly in antipodal positions

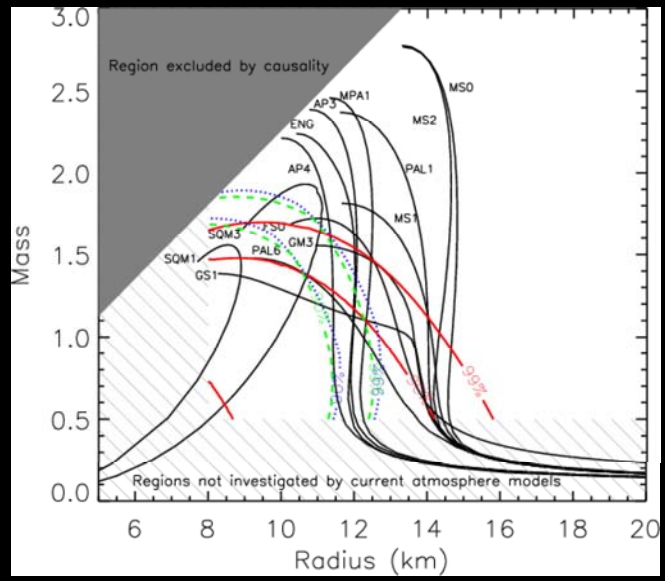
- F. Haberl et al., 2006 A&A in press / astro-ph-0603724



- XMM-Newton spectra over 4.5 years
- Sinusoidal variations in:
  - inferred blackbody temperature
  - size of the emitting area
  - depth of the absorption line
  - period of 7.1 +/- 0.5 years

Constraining The Equation Of State Of Supra-Nuclear Dense Matter





- Quiescent X-ray binaries in globular clusters: ω Cen, M13, NGC 2808
- N. Webb & D. Barret, Didier, 2007, ApJ 671, 727

- Distance to globular clusters is well known
- X-ray spectra are from a hydrogen atmosphere.:

➔ Radii to be from 8 km and masses up to 2.4 M_{solar}.

➔Equations of state: normal nucleonic matter and one possible strange quark matter mode

Black Holes

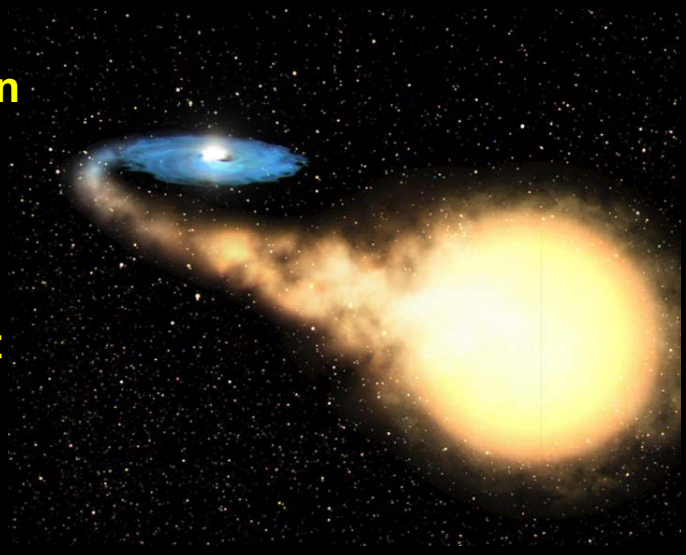
First Black Hole In Globular Star Clusters

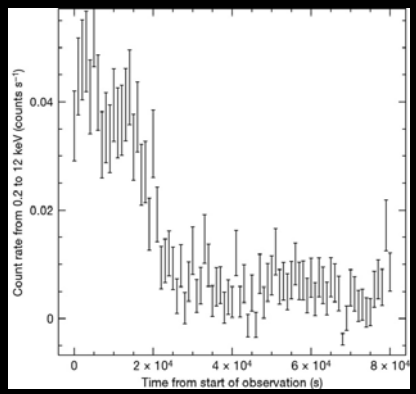
- GCs contain 10^3-10^6 old stars packed within tens of light years

➔ Formation of 10^3 solar mass BH ?

➔Interaction will eject BHs ?

T.J. Maccarone et al., 2007, Nature 445, 183

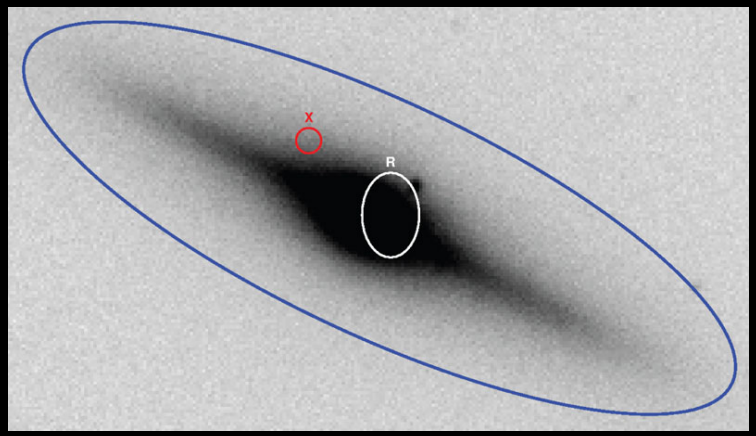




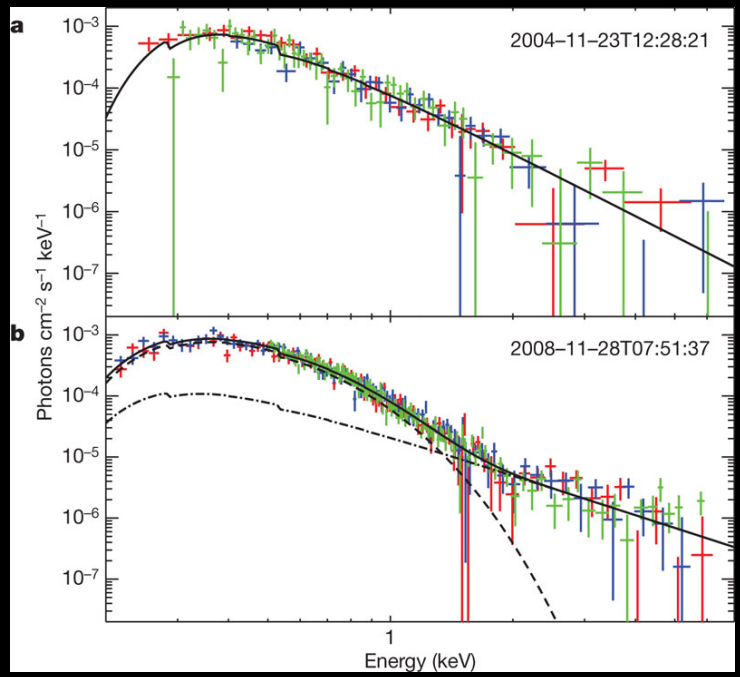
- X-ray source in GC associated with NGC 4472 (in the Virgo cluster)
- X-ray luminosity: 4×10^{39} erg s^{-1}
- Variability excludes composition by several objects

➔ Black hole (15-30 or 400 solar masses)

An Intermediate-Mass Black Hole In ESO 243-49



- 2XMM J011028.1-460421 identified in 2XMM Serendipitous Source catalogue
- Located in the edge-on spiral galaxy ESO 243-49 ➔ distance
- S. A. Farrell, et al., 2009, Nature 460, 73

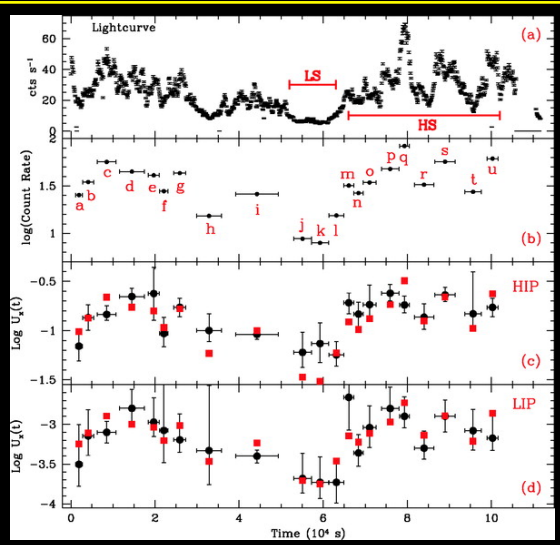


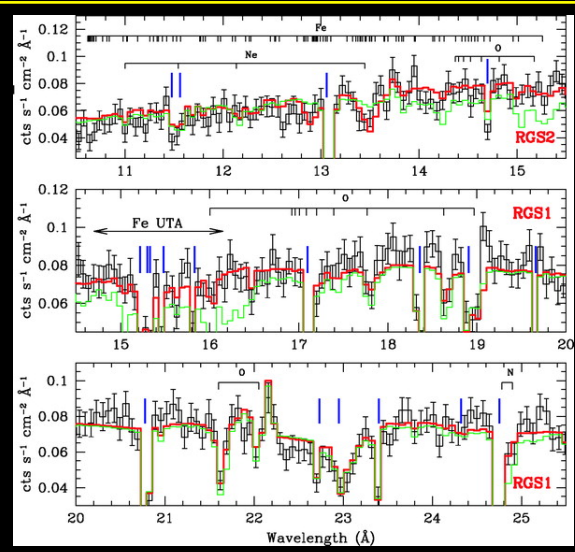
➔ Variability establishes single source

➔ L = 1.1 x 10^{42}erg s^{-1} ➔ m > 500 M_o

Active Galactic Nuclei

Compact, Conical, Accretion-Disk Warm Absorber Of The Seyfert 1 Galaxy NGC 4051





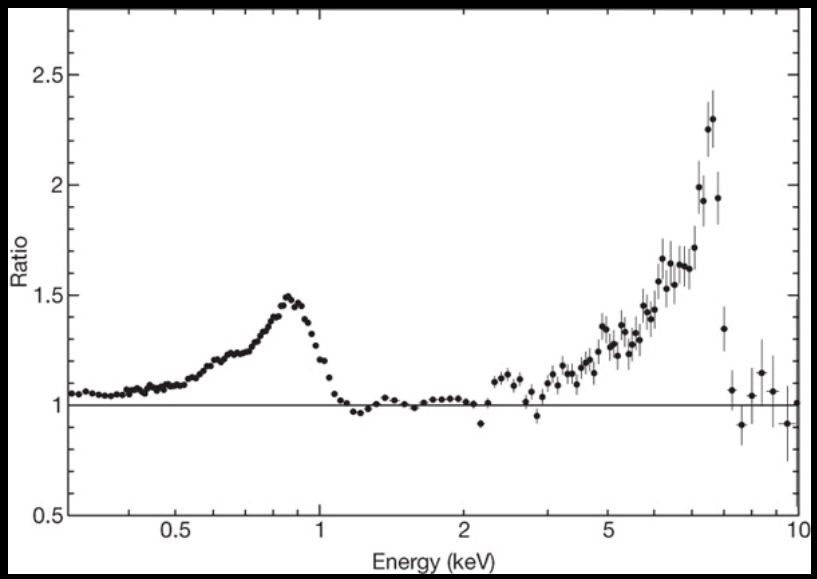
- Absorber consists of two different ionization components, with a difference of ~100 in ionization parameter and ~5 in column density
- Distances 0.5-1.0 lt-days (2200RS-4400RS) and <3.5 lt-days (<15,800 RS) from the continuum source

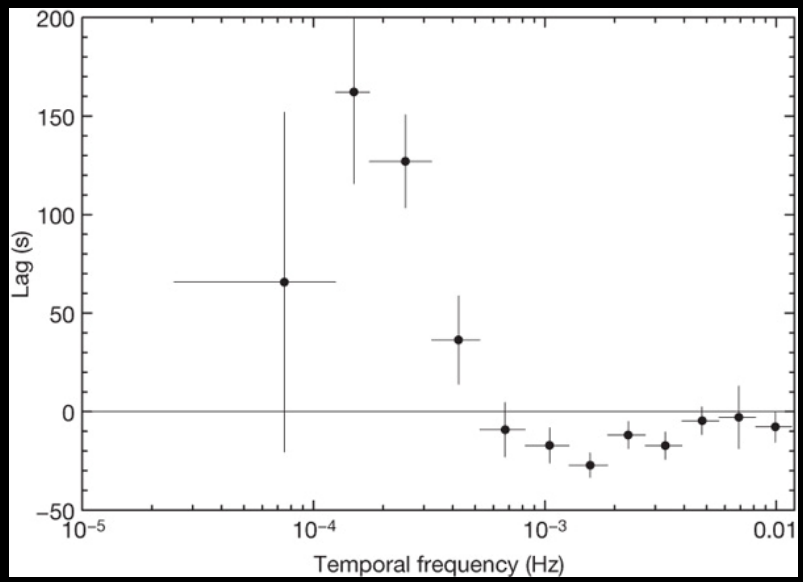
➔ Suggests strongly accretion-disk origin for the warm absorber wind

➔ Mass outflow rate from wind is 2%-5% of the mass accretion rate

- Krongold et al., 2007, ApJ 659, 1022

Broad Line Emission From Iron K- And L Shell Transitions In 1H 0707-495





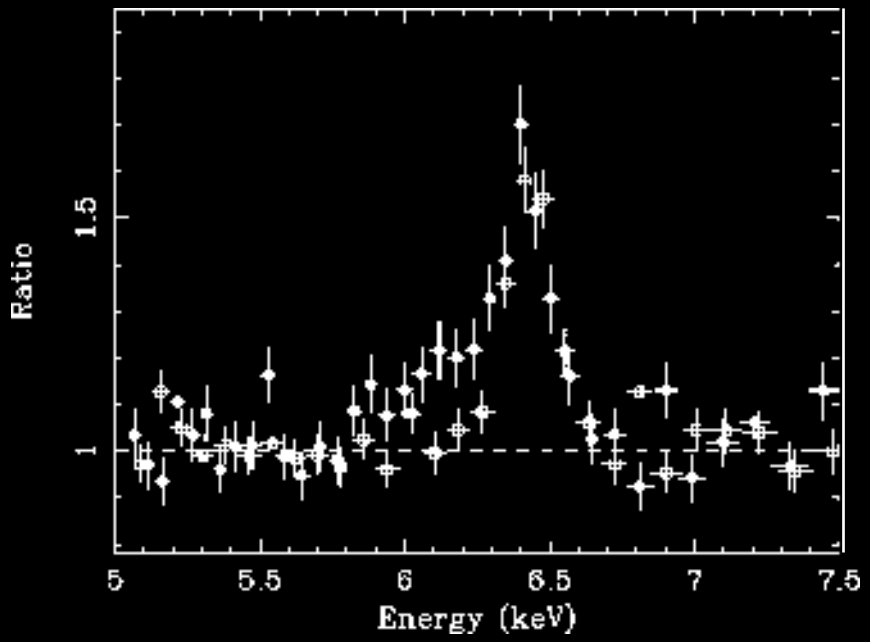
- **Narrow line Seyfert 1**

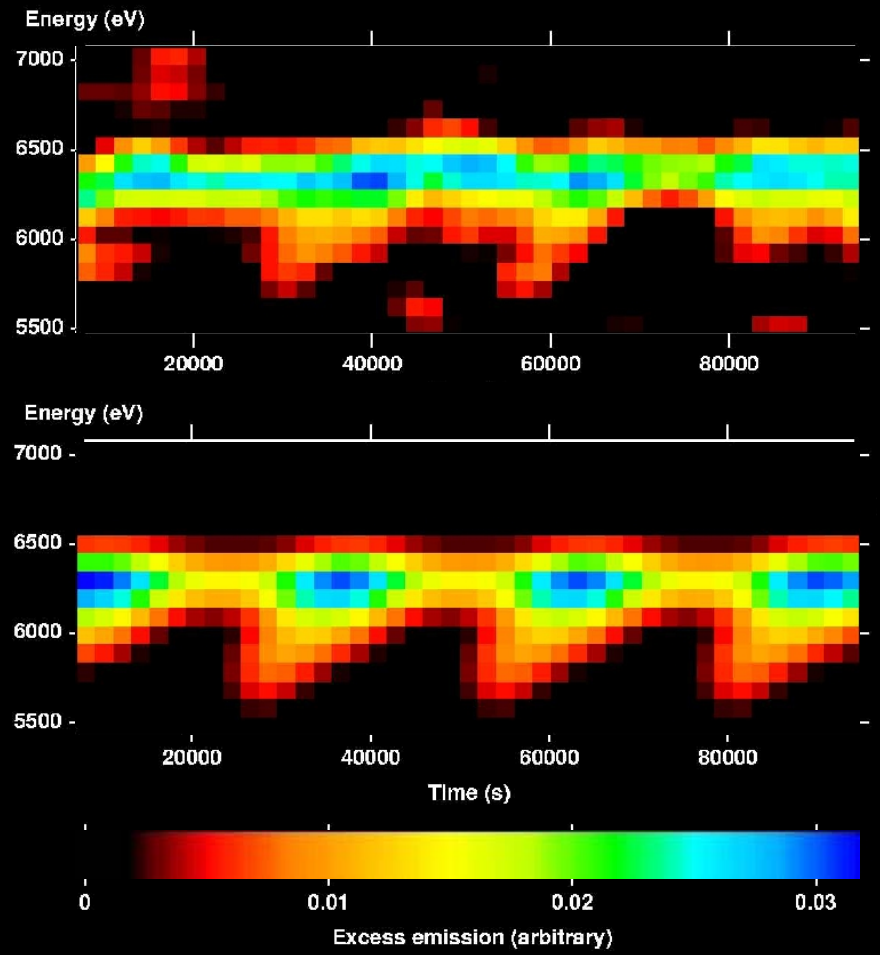
➔ **Broad lines from iron K- and L shell characterized by:**
  - line ration (photons) 1:20
  - 1.3 – 400 r_g
  - emissivity index 4
  - a > 0.98

➔ **Frequency-dependent lags between the 0.3-1-keV and 1-4-kev band**
  - ➔ Negative lag for f> 6 x 10-4 Hz
  - ➔ Power law changes before refection

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

Flux And Energy Modulation Of Iron Emission In NGC 3516



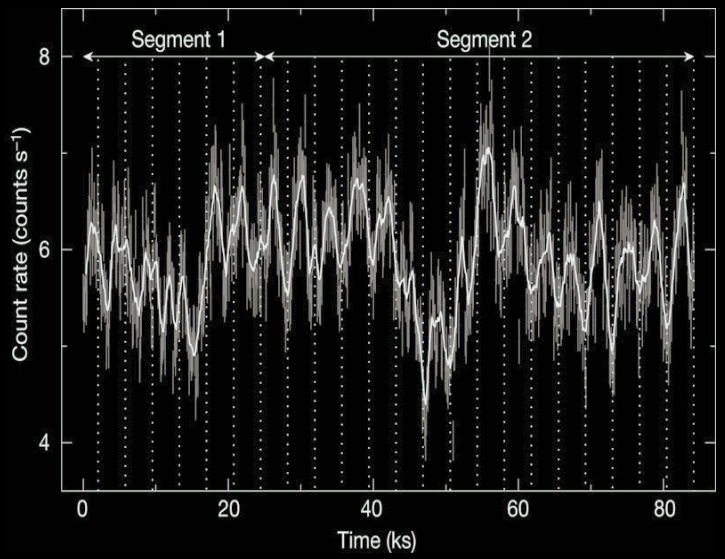


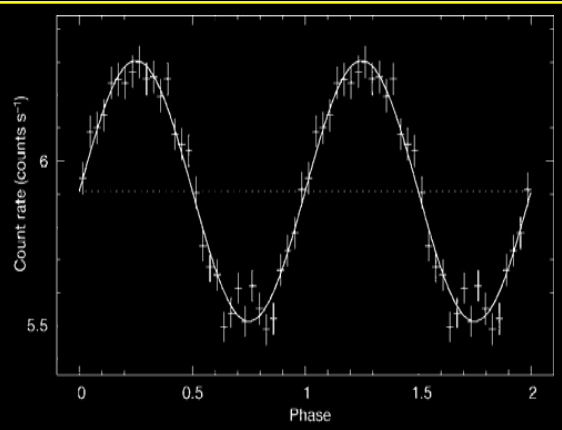
- K. Iwasawa, G. Miniutti, A.C. Fabian, 2004, MNRAS 355, 1073

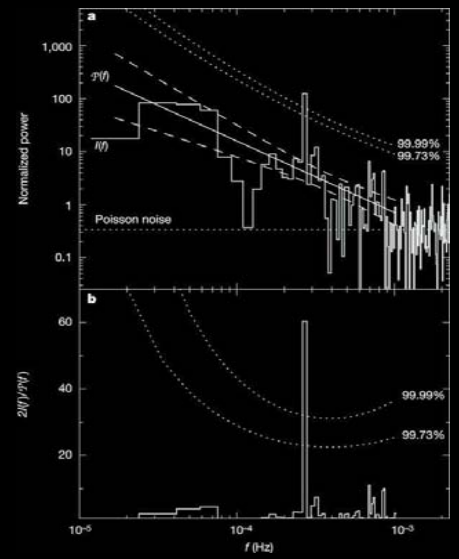
➔ "Co-rotating" flare at a (3.5-8) r_{Sch}

- Mass of the BH: (1-5) × $10^7 M_o$

First QPO From An AGN







• Gierlinski et al., 2008, Nature 455, 369

- Since 20 years QPO in X-ray binaries, but no one in AGNs (13y)
- RE J1034+396 nearby (z=0.043) narrow-line Seyfert 1
- Black hole mass: 6.3 x 10^5 to 3.6 x 10^7 M_{sun}

➔ XMM-Newton detection of a ~ 1 hour quasi periodic oscillation (QPO)

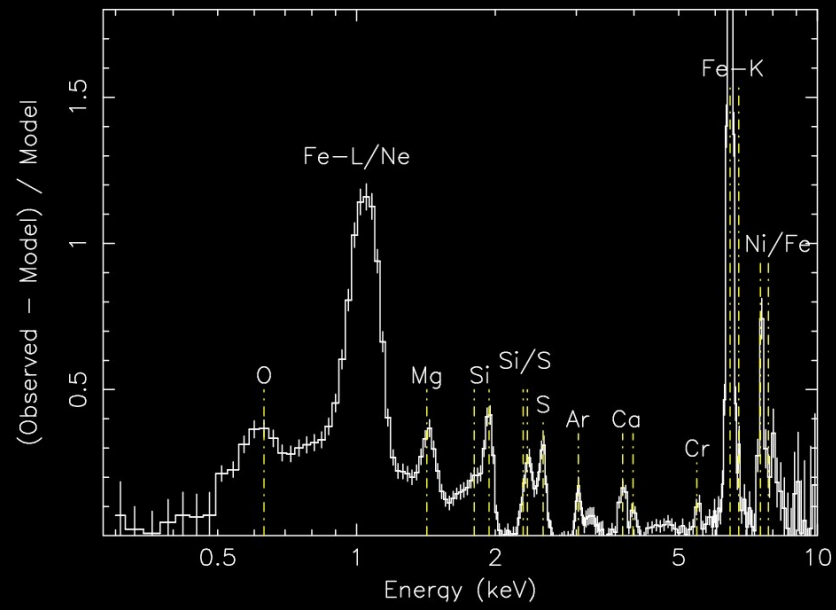
➔ Important cornerstone for generalization of accretion process into BHs

Cluster Of Galaxies

Origin Of Elements In Galaxy Clusters

Sersic 159-03

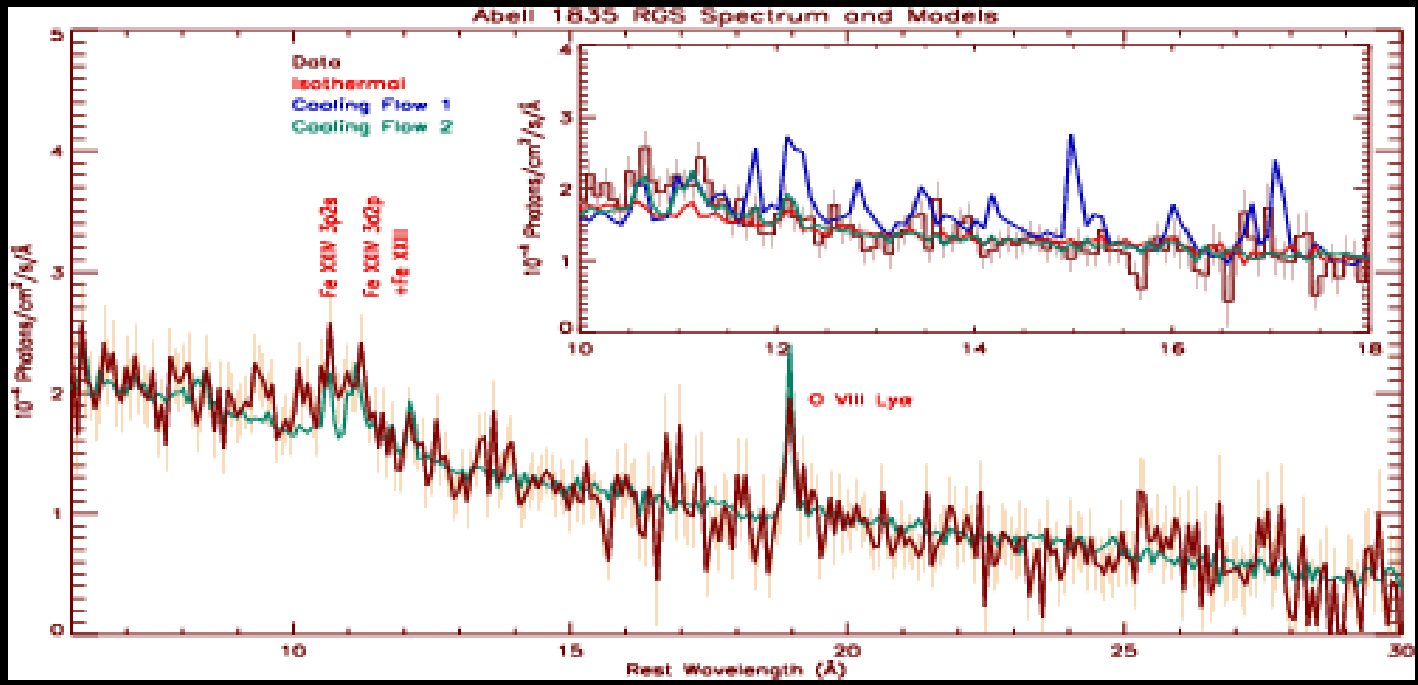
2A 0335+096



N. Werner, et al. , 2006, A&A 446, 475; J. de Plaa, et al. 2006, A&A 452, 397 & 2007, A&A 465, 345

- Abundances ➔
  - 30% of the supernovae in these clusters were exploding white dwarfs (Type Ia')
  - 70% were collapsing stars at the end of their lives (core collapse)

Cooling Flows In Clusters Of Galaxies: Abell 1835, Abell 1795, Sérsic 159-03



- **Strong cooling flow missing for low temperatures**

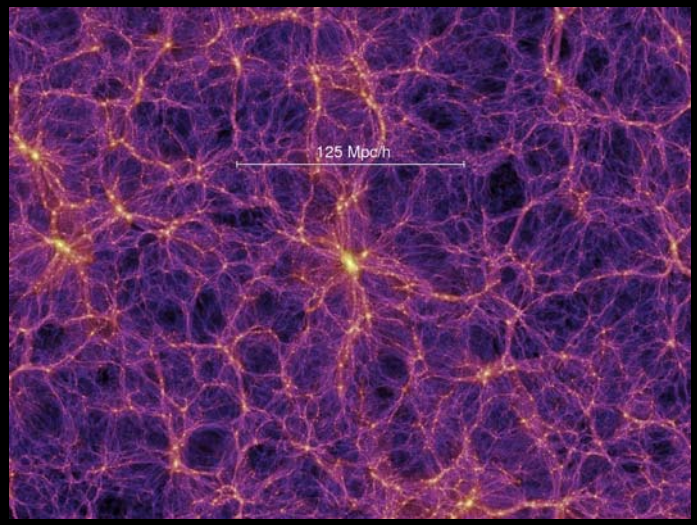
➔ Heating ➔ AGN feedback

- J.R. Peterson, et al., 2001, A&A 365, L104
- T. Tamura, et al., 2001, A&A 365, L87
- J.S. Kaastra, et al., 2001, A&A 365, L99

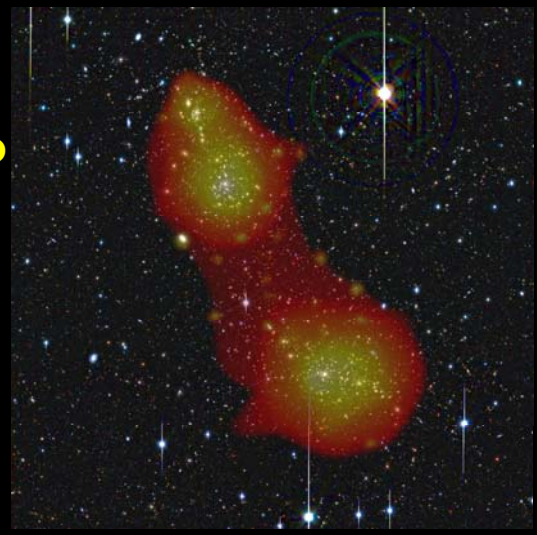
Cosmology And Early Universe

- ….WHIMs …
- ……Dark matter and
- .. Dark energy

Detection Of Hot Gas In The filament Connecting Two Clusters Of galaxies



• About 50% of the baryons in the local Universe are expected to resides in filaments connecting clusters of galaxies in form of low density gas with temperatures of $10^5<T<10^7$ K.



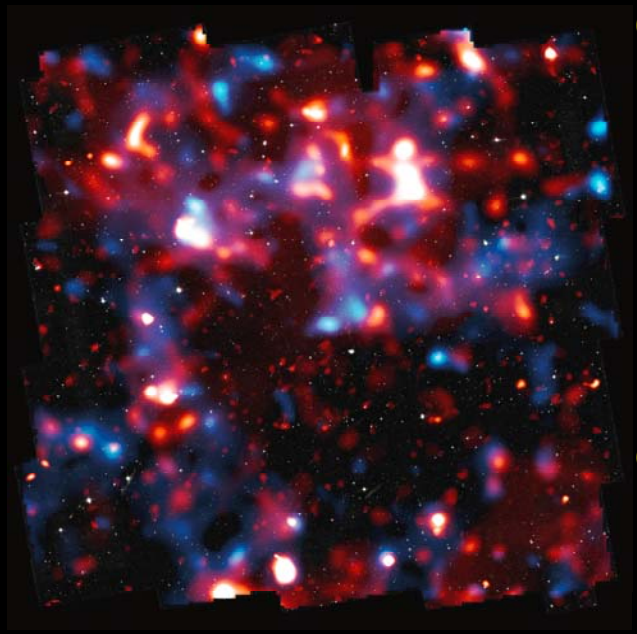
• Filament connecting the clusters of galaxies A 222 and A 223 (z = 0.21) has been previously detected using weak lensing data

➔ Detection of the filament in the soft-band X-rays with a 5σ with kT = 0.91±0.25 keV

➔ Baryon over-density of $\rho/\langle\rho C\rangle \approx 150$, which is consistent with expectations for the densest and hottest parts of the warm-hot intergalactic medium

Werner et al., 2008, A&A 482, 29

Dark Matter Maps Reveal Cosmic Scaffolding



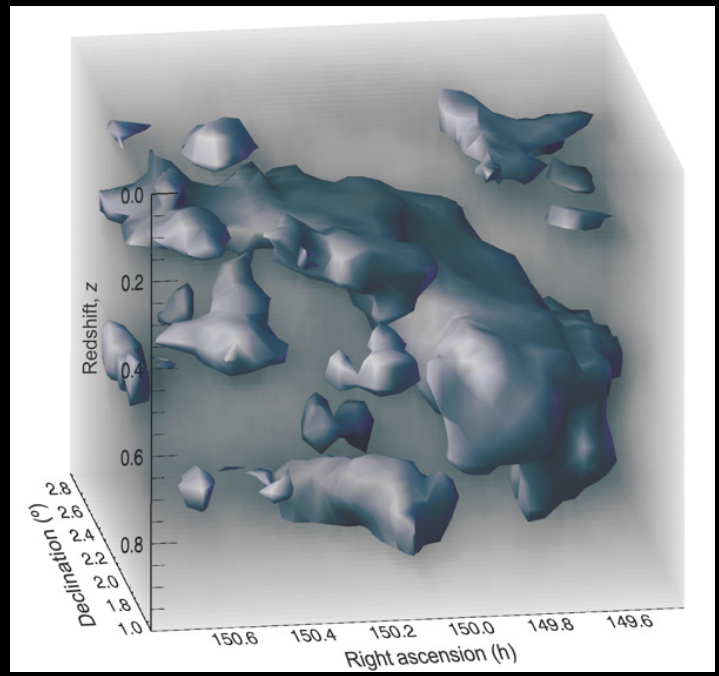
COSMOS Field:
- 1.637 degree^2
- 1000 h (HST)
- 400 h (XMM)

Matter:
- 1/6 baryonic (hot and cold)
- 5/6 dark

Gravitational lensing: total amount of matter (hot and cold)

Optical & infrared: cold baryonic matter

XMM-Newton: hot matter (red in picture)

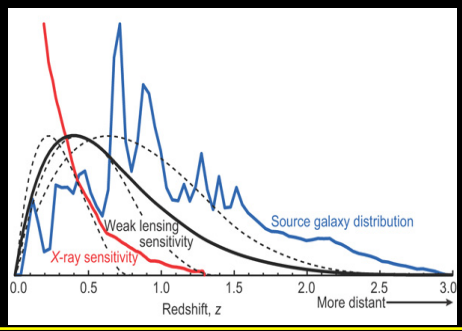


➔ Maps of the large-scale distribution of dark matter, resolved in both angle and depth.

➔Loose network of filaments, growing over time, which intersect in massive structures at the locations of clusters of galaxies

➔ Consistent with predictions of gravitationally induced structure formation

R. Massey et al., 2007, Nature 445, 286



XMMXCS J2215.9-1738

- Massive galaxy cluster at z=1.45
- The redshift of XMMXCS J2215.9-1738 is the highest currently known for a spectroscopically confirmed cluster of galaxies

- Stanford et al., 2006 ApJ 646, L13

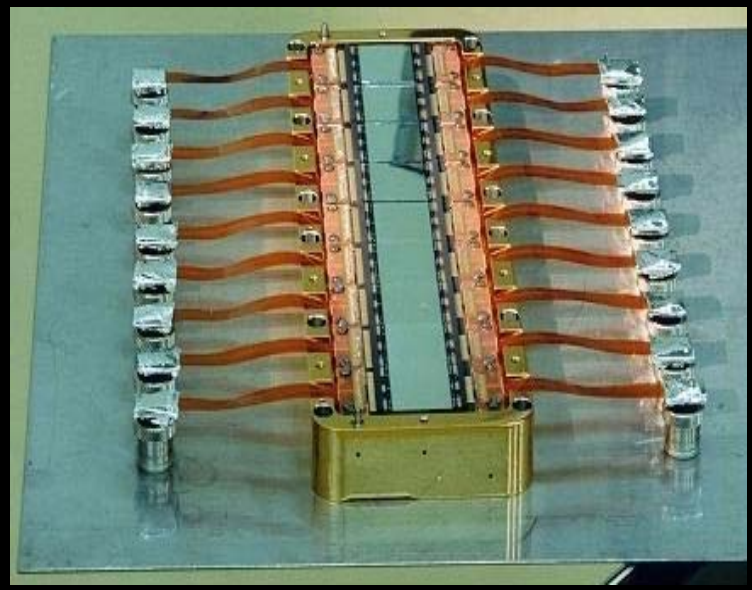
What's past is prologue[1]

[1] W. Shakespeare, 1623, The Tempest, Act 2, Scene 1

Status Of The Spacecraft

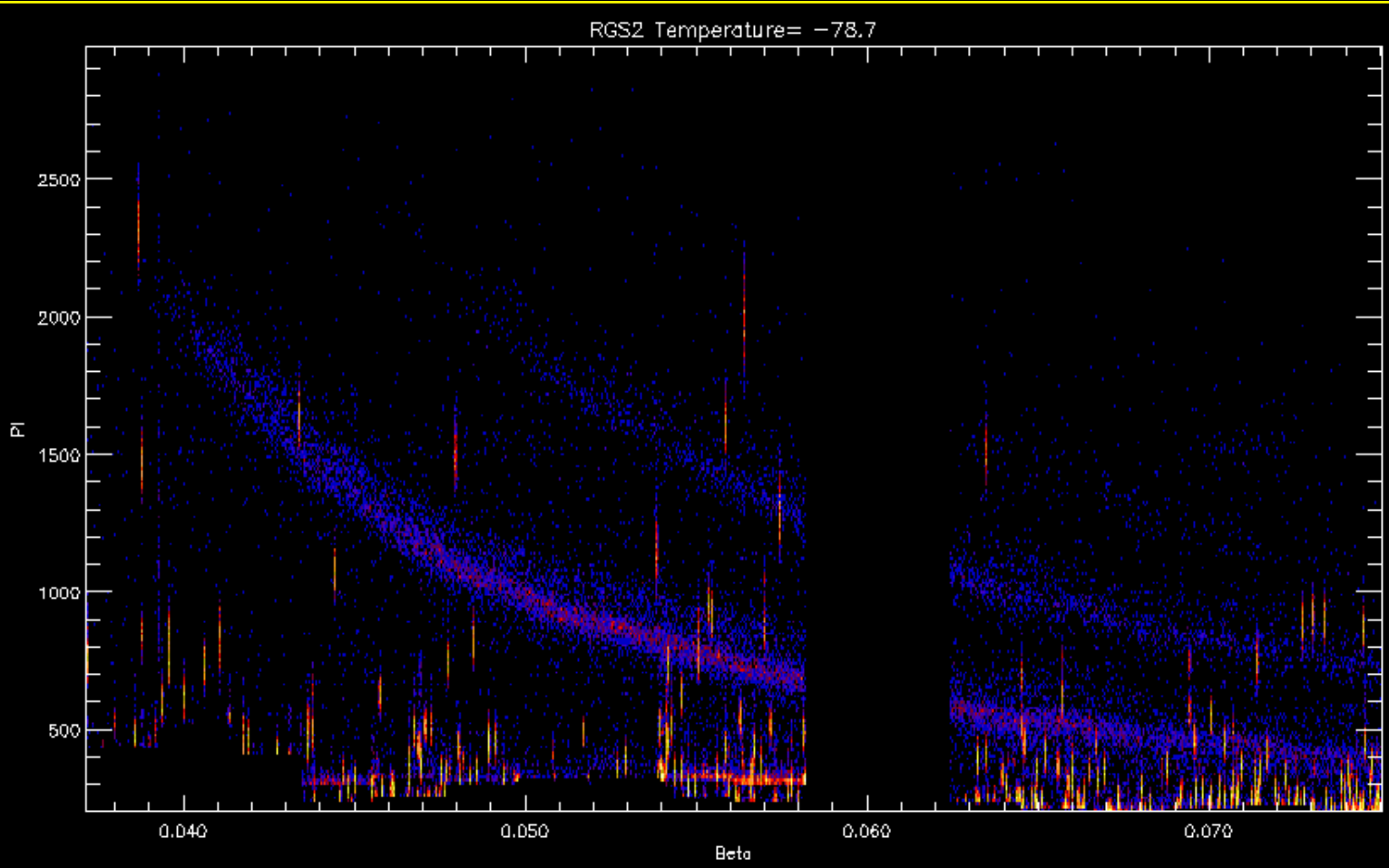
- Spacecraft status is very good
- In May 2007 Mission Extended Operations Review concluded that XMM-Newton can operate at least up to 2018
- All systems are running on their primary unit, i.e. full redundancy still available
- At end of 2009 August, 79.1 kg of fuel remain with usage of around 6 kg per year
- The solar array is generating around 1950 W and between 800-1200 W are used.
- All other consumable are fine, too
- On November 2007, the SPC approved operations until end of 2012. Further extensions will be reviewed in 2 years time

Reflection Grating Spectrometers

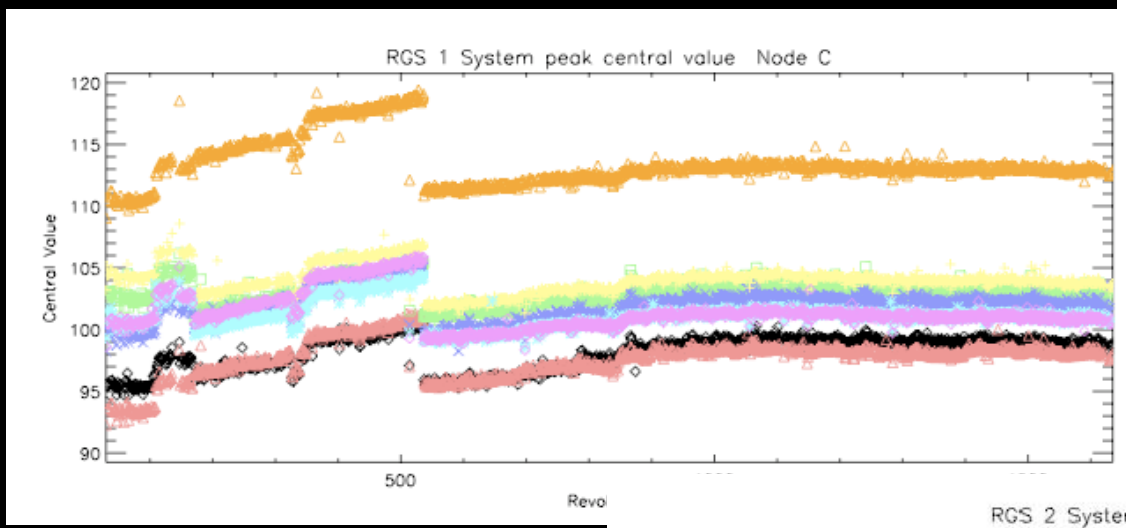


- 2 CCDs were lost early in the mission (full wavelength coverage due to redundancy between RGS1 and RGS2)
- RGS 2 single readout mode since August 2007 to avoid ADC errors (no impacts for large majority of sources)
- Reduction in EPIC MOS and RGS operating T in 2002 resulted in far fewer hot pixels

Reflection Grating Spectrometers



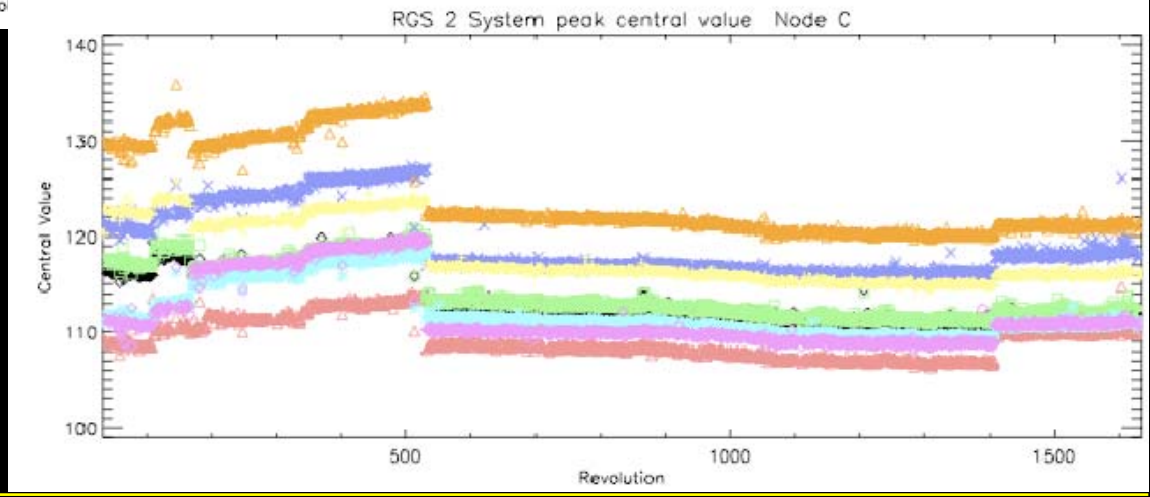
RGS Offset Evolution



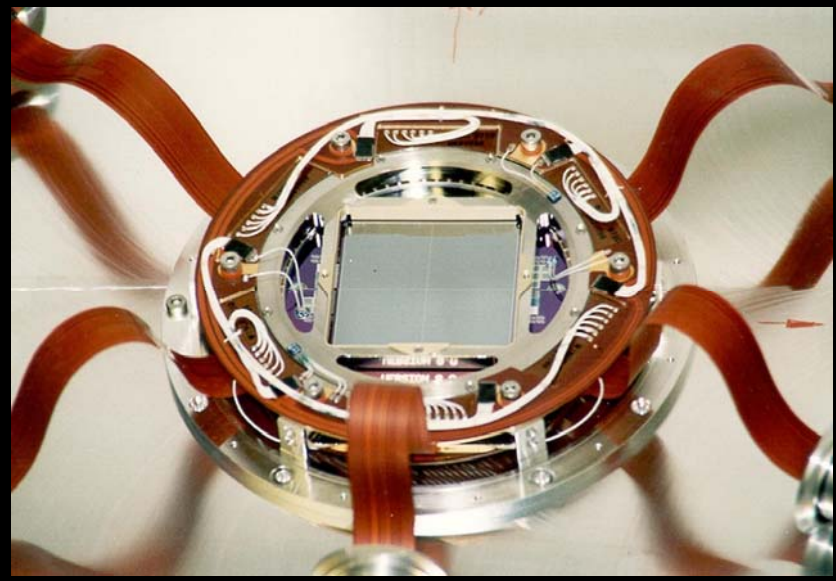
Offsets pretty smooth after "cooling" in rev 532

Almost no sensitiv-eness to solar flares.

Only change in last period due to R1-CCD 2 new operational voltages from rev 1400 on

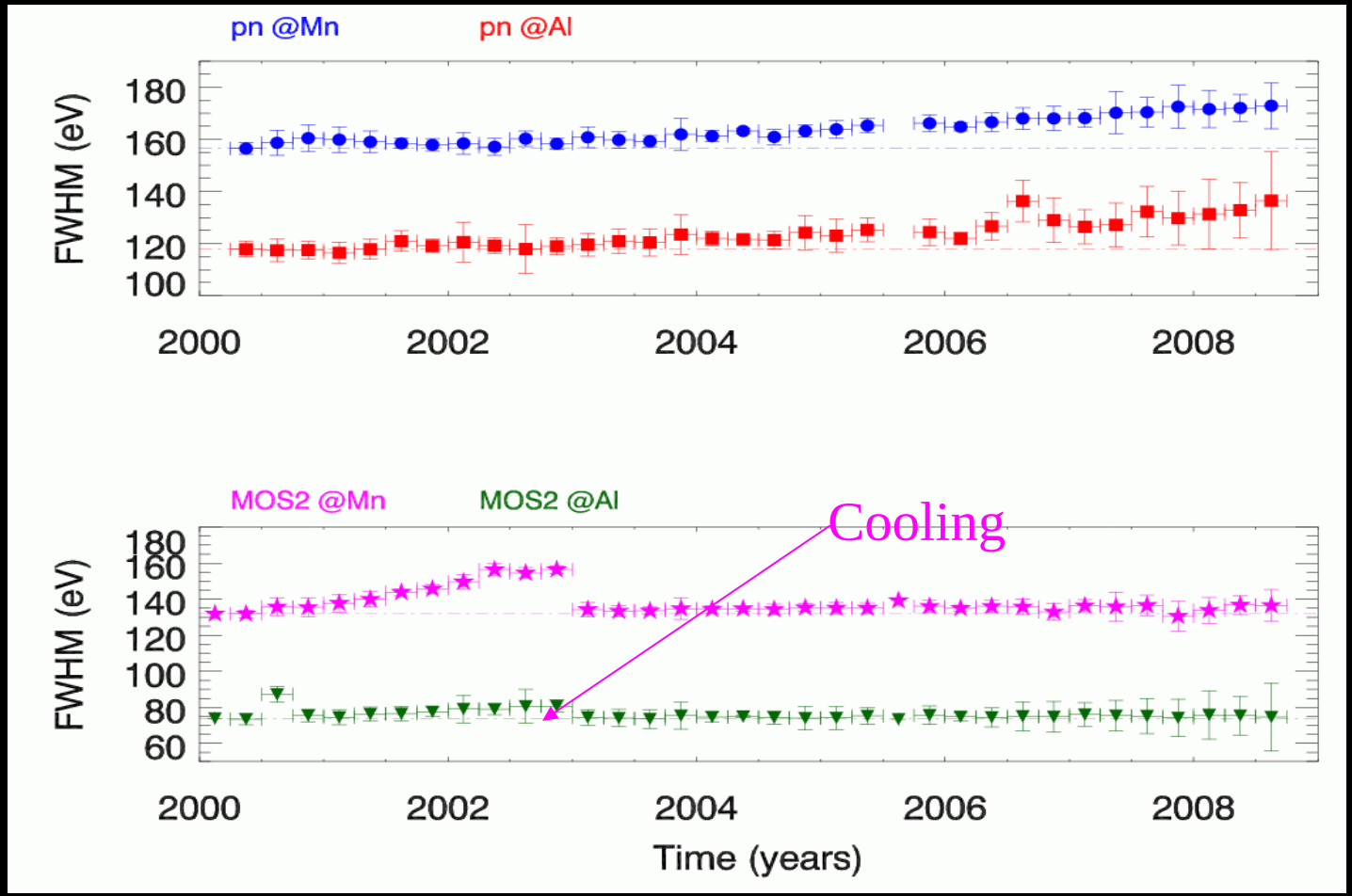


EPIC Cameras



- The Nov 2002 reduction in EPIC MOS (and RGS) operating T resulted in far fewer hot pixels, and decreased energy resolution degradation rates.
- 4 micrometeoroid impact events in 9 yrs have resulted in the loss of 1 in 14 of the MOS CCDs – a 5% reduction in the EPIC area.
- No effects of contamination visible

EPIC Resolution



Extrapolation in 2015:

190 eV

150 eV

76-77 eV

139 eV

Users

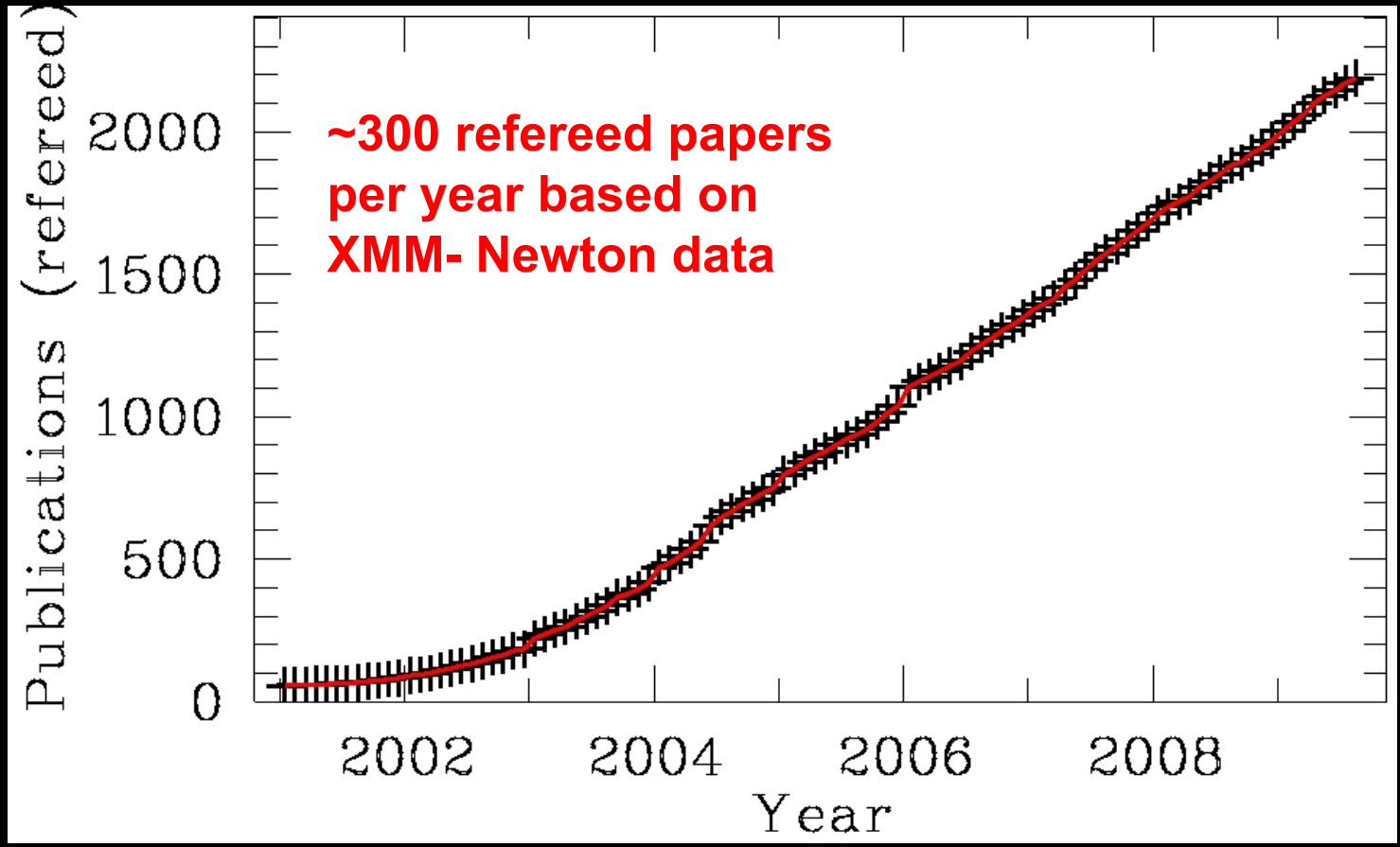
- **Users:**
  - Large Community: 1500 - 2000 scientists
  - All scientific topics are addressed
    - from comets and planets up to the most distant quasars
  - Most of the users are “external” to the XMM-Newton project, e.g. they do not belong to instrument institutes nor the Survey Science Center)

➔ **Observatory type mission:**
  - Annual call for observing time proposals
  - Peer review process (OTAC)
  - Support for users: from definition of observation details, enhancement, scheduling/coordination, TOO request evaluation and TOO implementation … help-desk, …analysis…to … (SAS) … calibration … archiving … SAS workshops, documentation, conferences and public outreach

Requests And Users

- **Announcement of Opportunity (AO8):**
  - 555 valid proposals were submitted
  - **Oversubscription 7.4**
  - 397 different principal investigators
  - 1430 individual scientists from 25 countries
  - 10 proposals joint XMM/Chandra
  - 5 proposals joint XMM/VLT
- **Observing Time Allocation Committee: OTAC**
  - 66 scientists (rotation every 2 AOs)
  - Chaired by Prof. B. McBreen
- **Archive: XSA**
  - 2700 external registered uses
  - 120 external users per month (typical value)
  - 3300 data sets (ODF and PPS) per month (typical value)
- **Analysis Software: SAS:**
  - Version 8.0 (July 2008 – June 2009)
  - ~2000 downloads
  - ~1500 scientists have access to SAS 8.0 (not counting downloads with only one user)
- **Ph.D.:**
  - > 85

Publications



Citations

Analysis of XMM-Newton papers (1 July 2008, L. Valencic, GSFC, NASA)

XMM-Newton Papers from:	Top 1% Astro-physical Papers:	Top 10% Astro-physical Papers:
1 year ago:	8.3%	45%
2 year ago:	5.6%	41%
3 year ago:	3.7%	31%
4 year ago:	0.7%	29%
5 year ago:	2.4%	33%
6 year ago	9.2%	37%

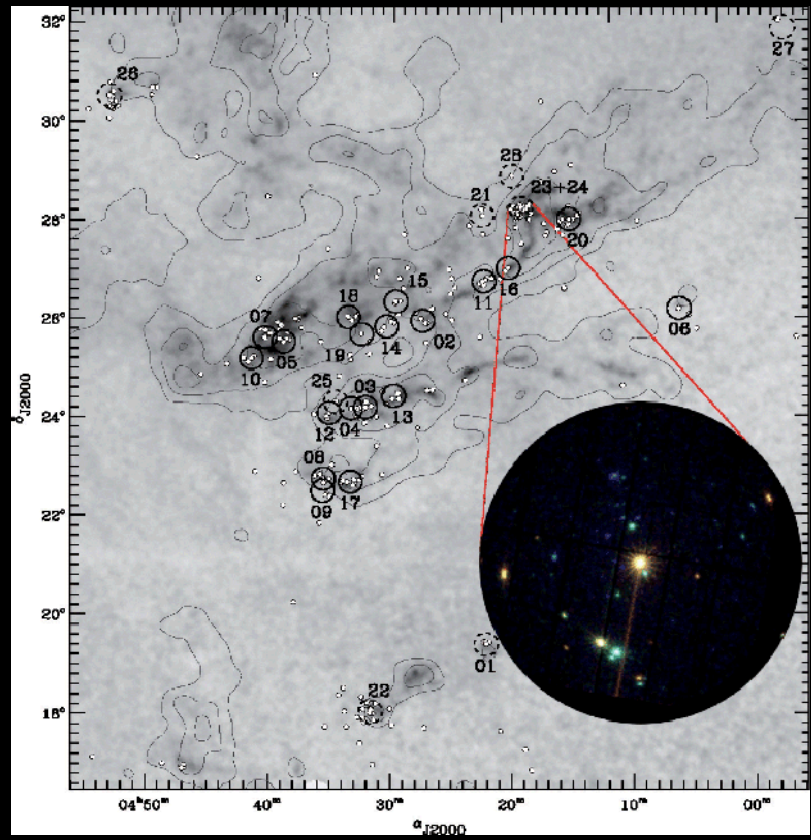
"XMM-Newton: The Next Decade"

- **Workshop at ESAC from 4th - 6th June 2007**
- **125 participants (more than twice the expected number)**

➔ **Astronomical Notes (regular issue 2/ 2008): 26 invited lectures where the authors outline many exciting and innovative research programs**

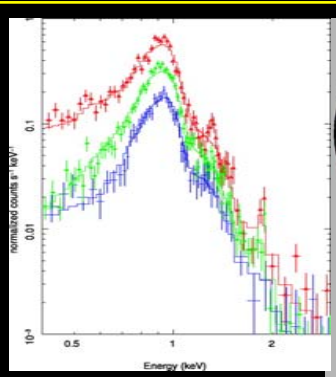
Understanding Formation Of Stars And Planets

- **Combination of Herschel and XMM-Newton observation of proto-stars and forming young stellar systems:**
  - Unique insights into the accretion and outflow processes
  - The relationship between the two
  - The role played by magnetic fields
- **Combining ALMA and XMM-Newton results will provide complementary views on the effects of stellar radiation on proto-planetary disks.**



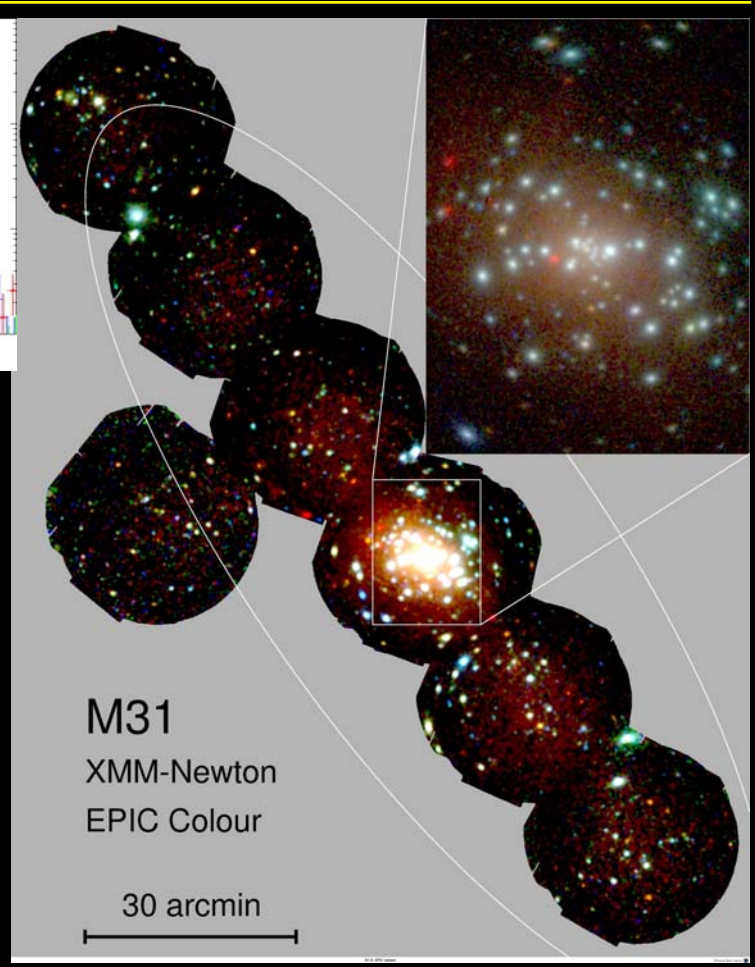
New Classes Of Rare Galactic Objects

- **Discovery of a new class of type Ia supernova in 2007 illustrates the importance of complete samples of rare galactic objects**

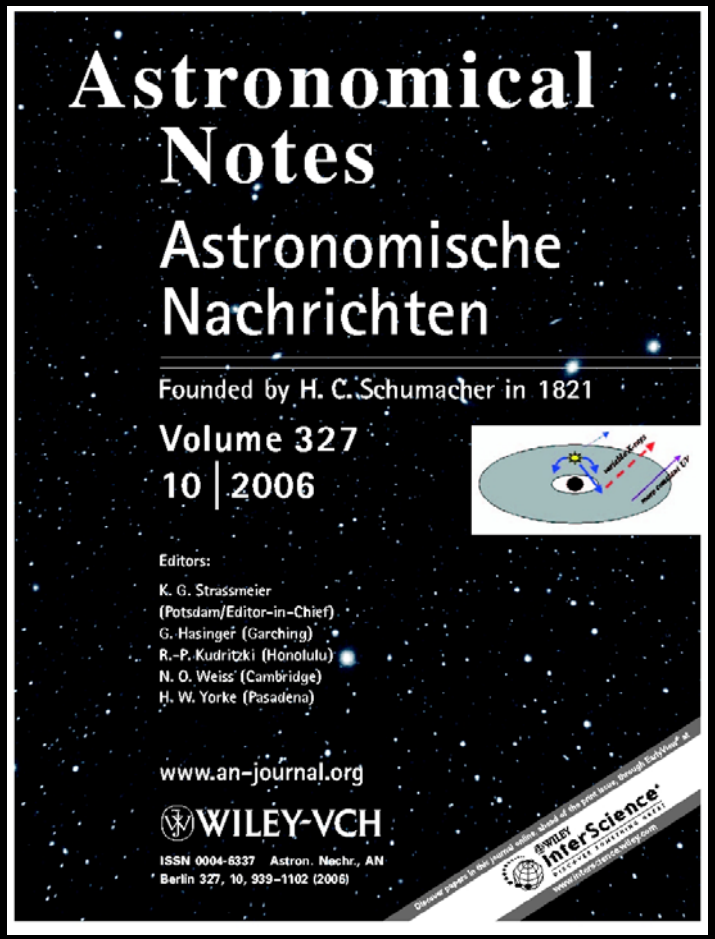


➔ **Best established through careful mapping of nearby galaxies**

➔ **XMM-Newton is uniquely suited to this task, as the other current (Chandra, Swift and Suzaku) or planned missions lack the required spatial resolution, effective area, or large field of view.**



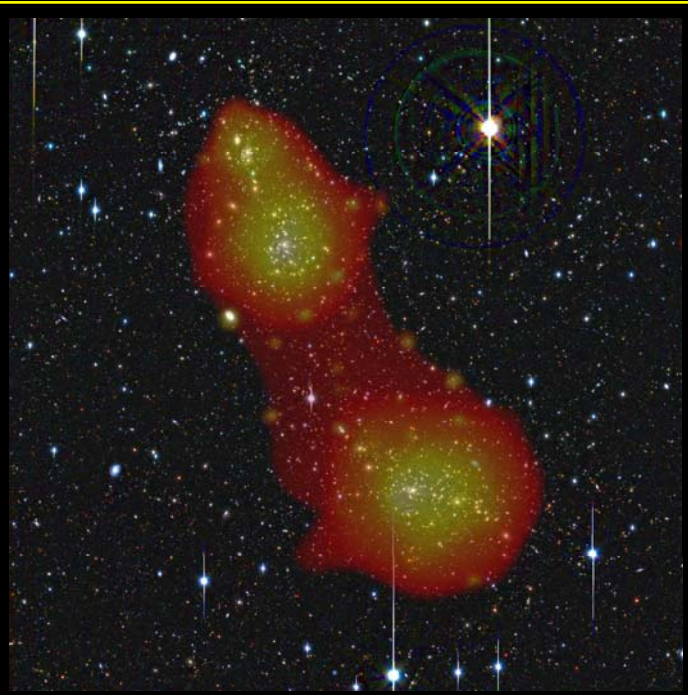
Relativistically Broadened Iron Lines



- The October 2006 issue of Astronomical Notes was entirely devoted to relativistically broadened iron lines emitted in the vicinity of black holes, where strong gravitational fields affect the physics of line production and their variability:

➔ Unique ability of XMM-Newton to generate long, uninterrupted, high signal-to-noise time series which are essential for this type of study

WHIM



- XMM-Newton has made the first detection of the warm-hot intergalactic medium (WHIM) between Abell 222/223

➔ Observations of other cluster pairs will be crucial this medium to be better characterised and to investigate whether it contains the “missing” baryons in the local Universe

➔ Since the spectral features imprinted by the WHIM are very faint the high throughput of XMM-Newton will be essential to secure the required high-quality spectra.

➔ The WHIM acts also as a tracer of large-scale structures in the Universe and will undoubtedly be a prime target for future X-ray missions XMM-Newton will thus serve as a precursor and pathfinder for such missions.

Ultra-Deep Field

- XMM-Newton 3 Msec ultra-deep field:

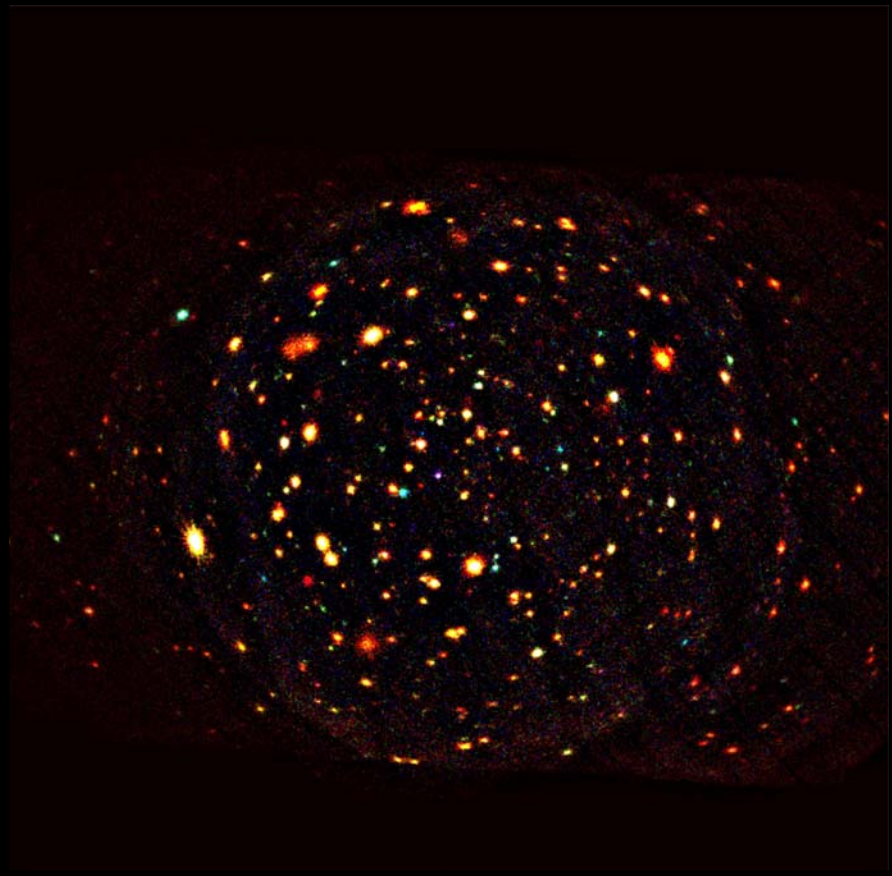
➔ The most sensitive view of the hard X-ray sky ever

➔ Many new Compton-thick AGN at the epoch of their peak activity,

➔ Investigates the role of accreting super-massive black holes in galaxy evolution

➔ Targets an unexplored discovery space

➔ Pathfinder for future X-ray missions.



Dark Matter, Structure Formation And Dark Energy

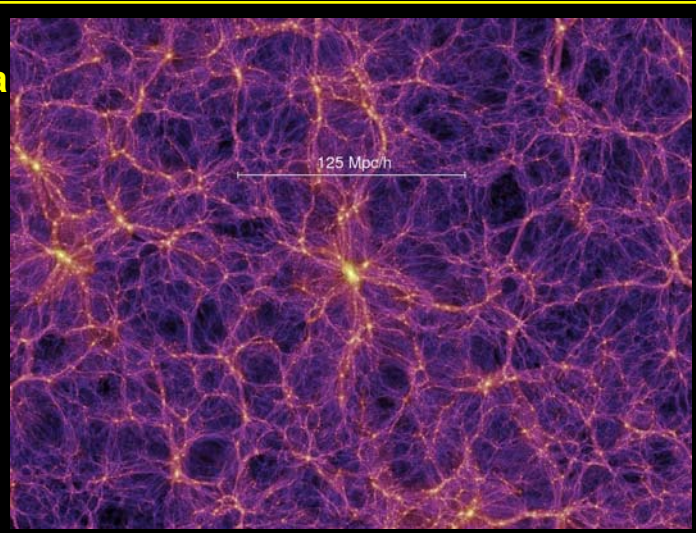
- XMM-Newton, Planck, ALMA and South Pole Sunyaev-Zel'dovich experiment data will allow a major step in our understanding of dark matter, structure formation, and dark energy.

- Planck will increase by a factor >50 the number of massive clusters known at intermediate red-shifts, providing a powerful tool for precision cosmology.

➔ XMM-Newton observations are crucial in exploiting this sample and setting new constraints on the dark energy equation of state and its evolution with cosmic time

➔ Independent measurements of distances are crucial for testing the consistency of the ΛCDM cosmological model

➔ Combined data-set will allow precise calibration of the mass/Sunyaev-Zel'dovich relation, thereby providing completely independent constraints on cosmological parameters



Call Is Open!

- **Due date for proposals is the 9th of October 2009 (12:00 UT):**

http://xmm.esac.esa.int/