XMM-Newton observations of black holes

Black hole astrophysics: Tales of power and destruction
Winchester, United Kingdom, July 18-22 2011

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Contents

- XMM-Newton
- Black holes
  - Birth
  - Galactic black holes
  - Strong Gravitational field
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• XMM-Newton =
X-ray Multi-mirror Mission

• Cornerstone of ESA's Horizon 2000 Science Programme

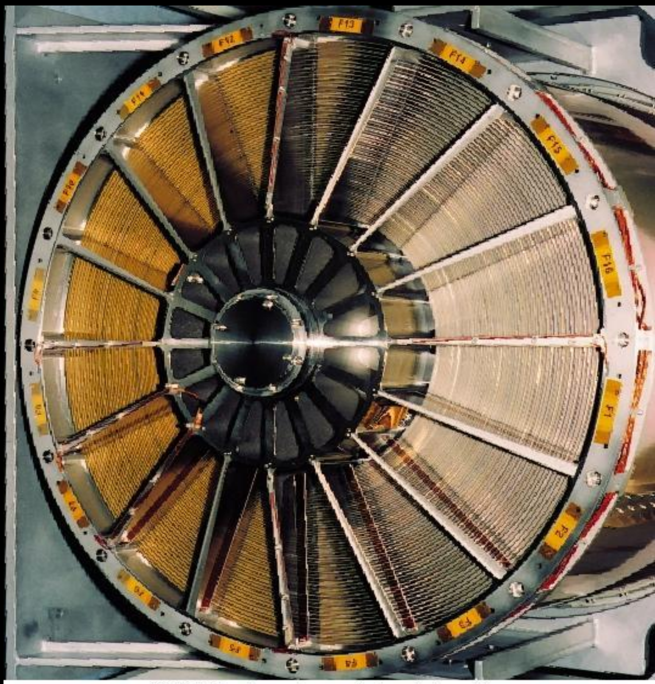
• Launched by an Ariane 5 on 10 December 1999

XMM-Newton preparation

Image courtesy of D. Parker

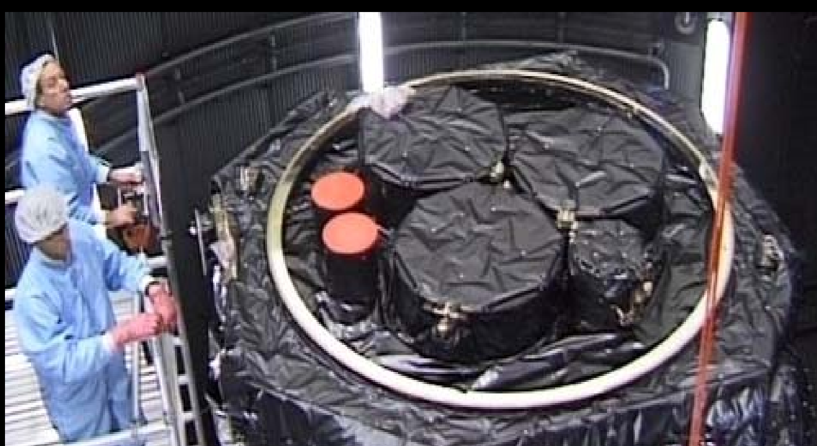
European Space Agency

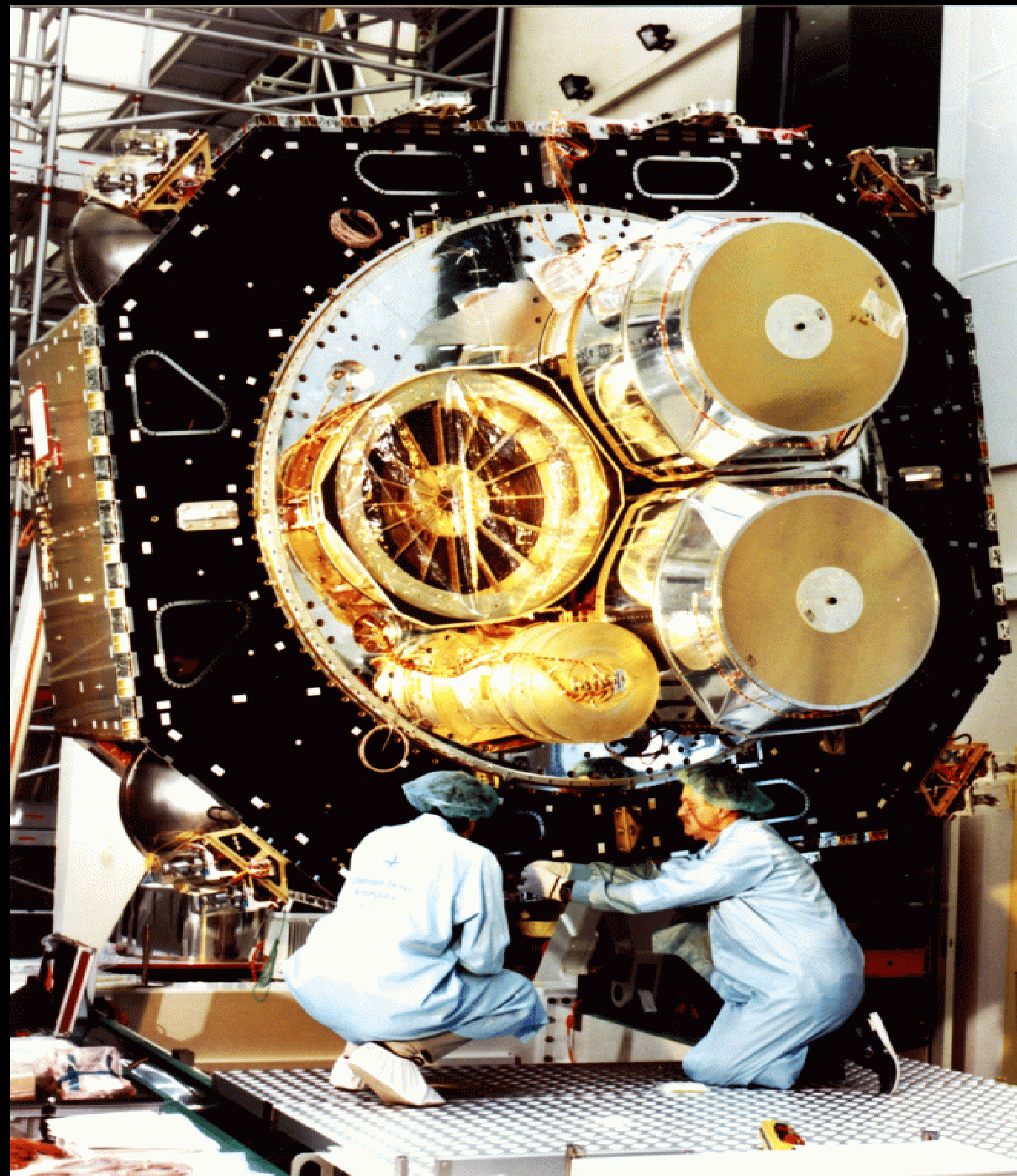
Three mirror modules



XMM-Newton mirrors during integration

Image courtesy of Dornier Satellitensysteme GmbH European Space Agency

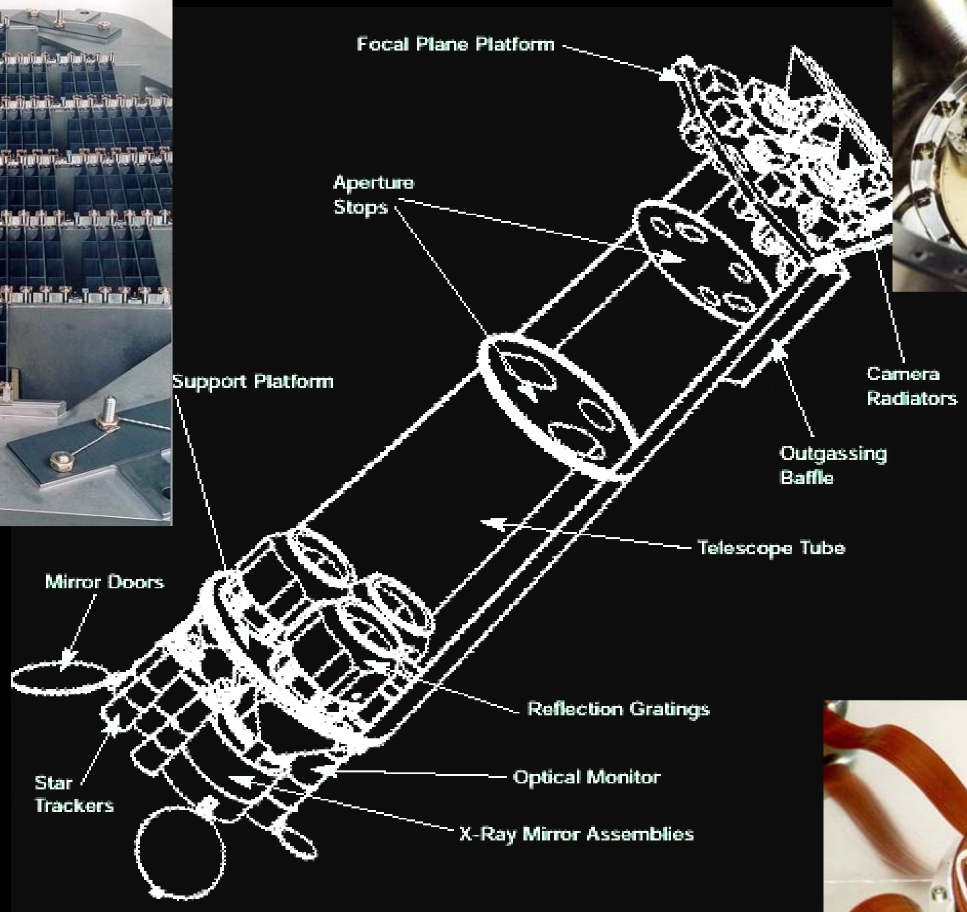


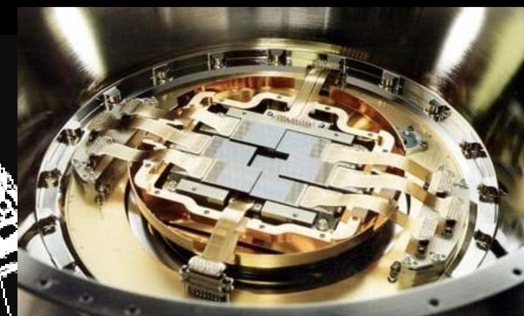


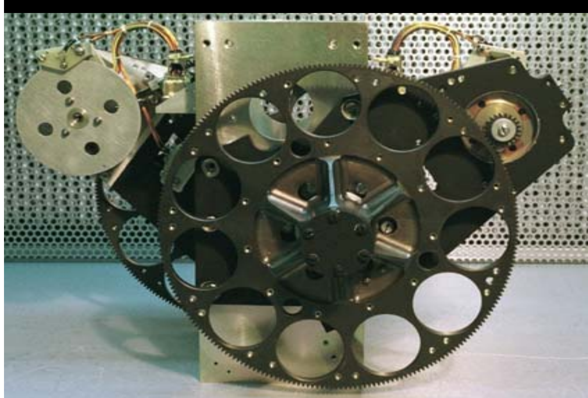
XMM-Newton mirrors during integration

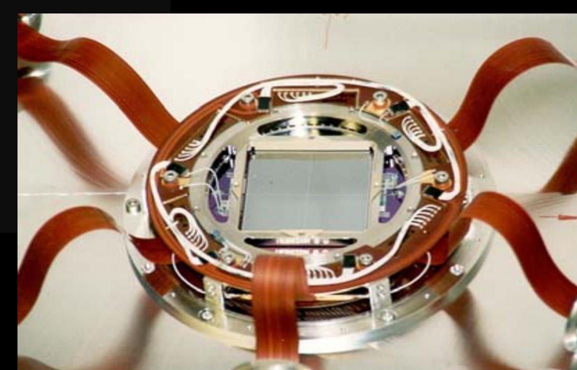
Image courtesy of Dornier Satellitensysteme GmbH European Space Agency

Instruments







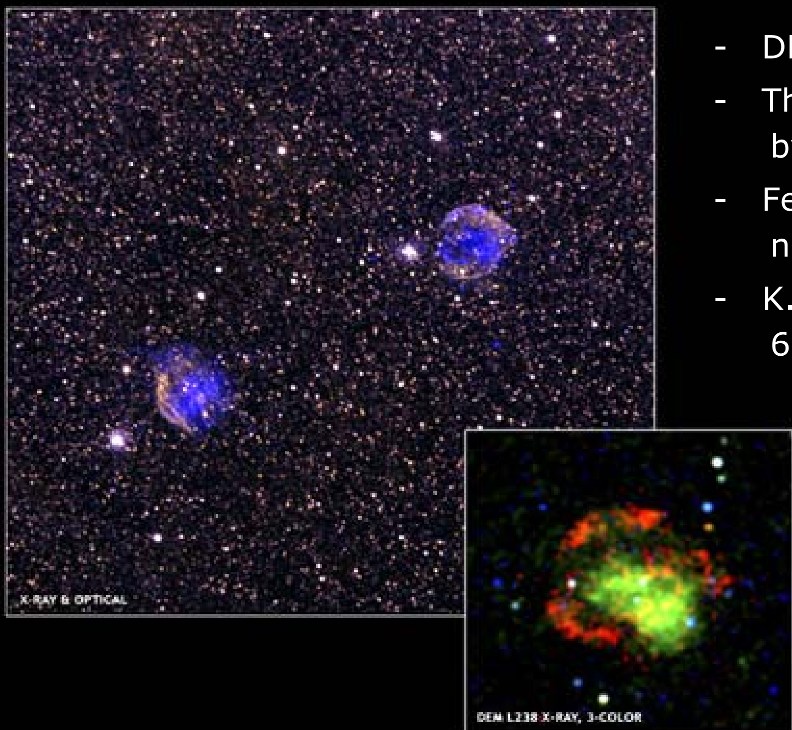


XMM-Newton

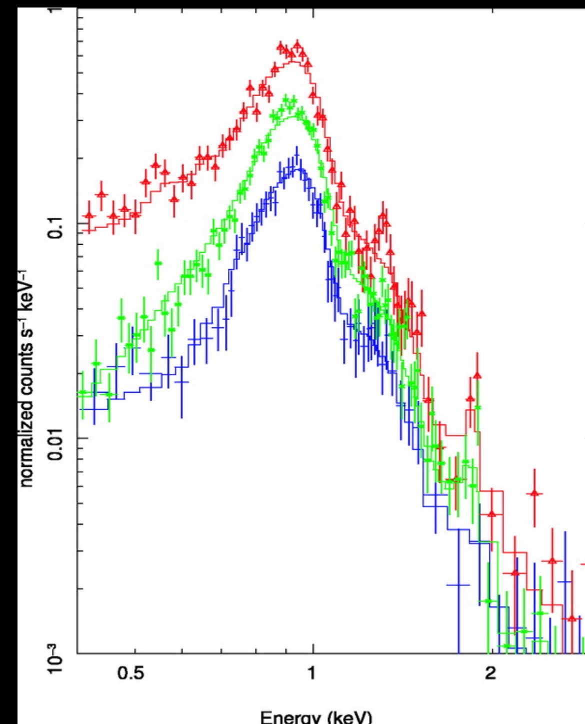
- 3 Mirror Modules / highest effective collecting area ever
- Six simultaneously observing instruments:
    - 3 CCD cameras (one pn and two MOSs)
    - 2 spectrometers (RGS)
    - 1 optical Monitor (OM)

Birth

New Class Of Type 1 SN



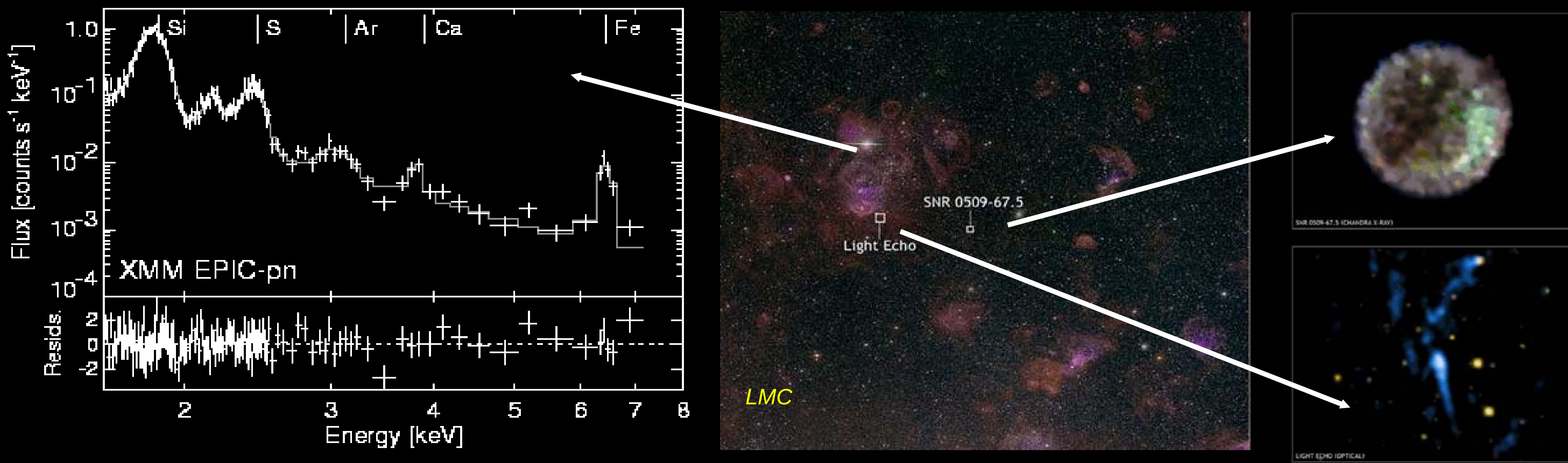
- DEM L238 & DEM L249
- Thermal spectrum dominated by Fe L-shell lines
- Fe over-abundance ➔ Thermo-nuclear Type Ia explosions
- K.J. Borkowski et al. 2007, ApJ 652, 1259



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

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

SNR 0509-67.5: First Test of Detailed Explosion Models



- Badenes et al., 2008, ApJ 680, 1149
- Kosenko et al., 2008, A&A 490, 223

- dynamics and relative ratios of elements (O, Si, S, Fe)
- for the first time: test of detailed explosion models

➔originated ~400 years ago by a delayed detonation type (DDT) explosion (similar to SN 1991T, Type Ia),

➔W_{kin}~ 1.4×10^{51} erg, synthesized 0.97 M_{sun} of 56Ni.

➔excellent agreement with results from light echo

Galactic Black Holes

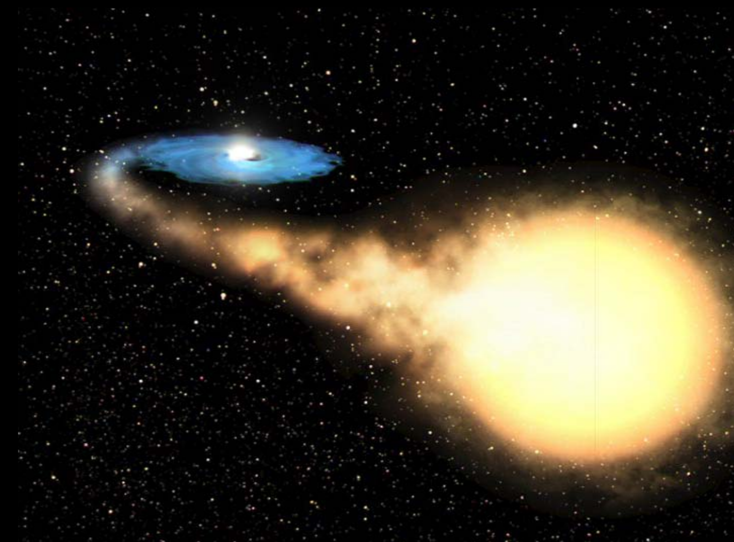
First Black Hole In Globular Star Clusters

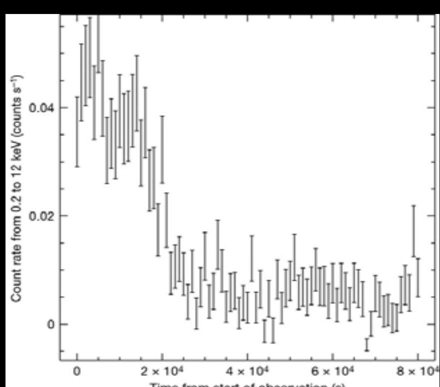
- GCs contain 10^3-10^6 old stars packed within tens of light years

➔ Formation of 10^3 solar mass BH ?

➔Interaction will eject BHs ?

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

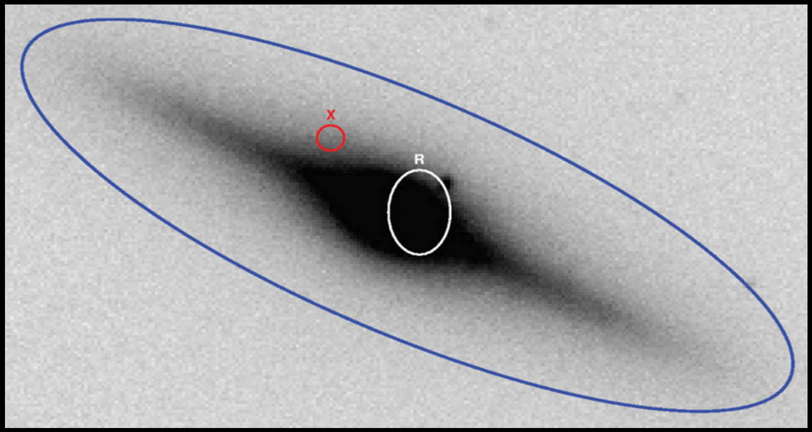


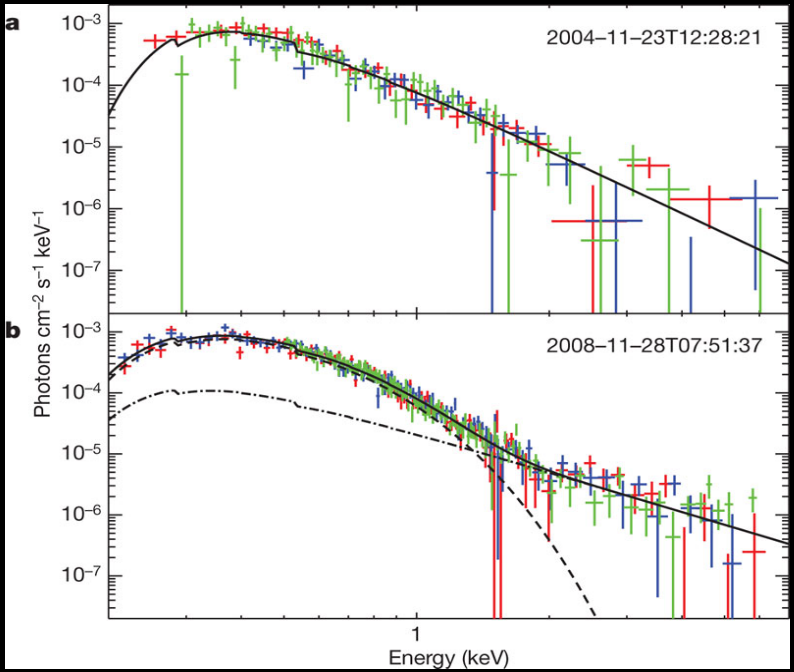


- X-ray source in GC associated with NGC 4472 (in the Virgo cluster)
- X-ray luminosity: 4×10^{39} erg s^{-1}
- Variability excludes composition by several objects

➔ 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

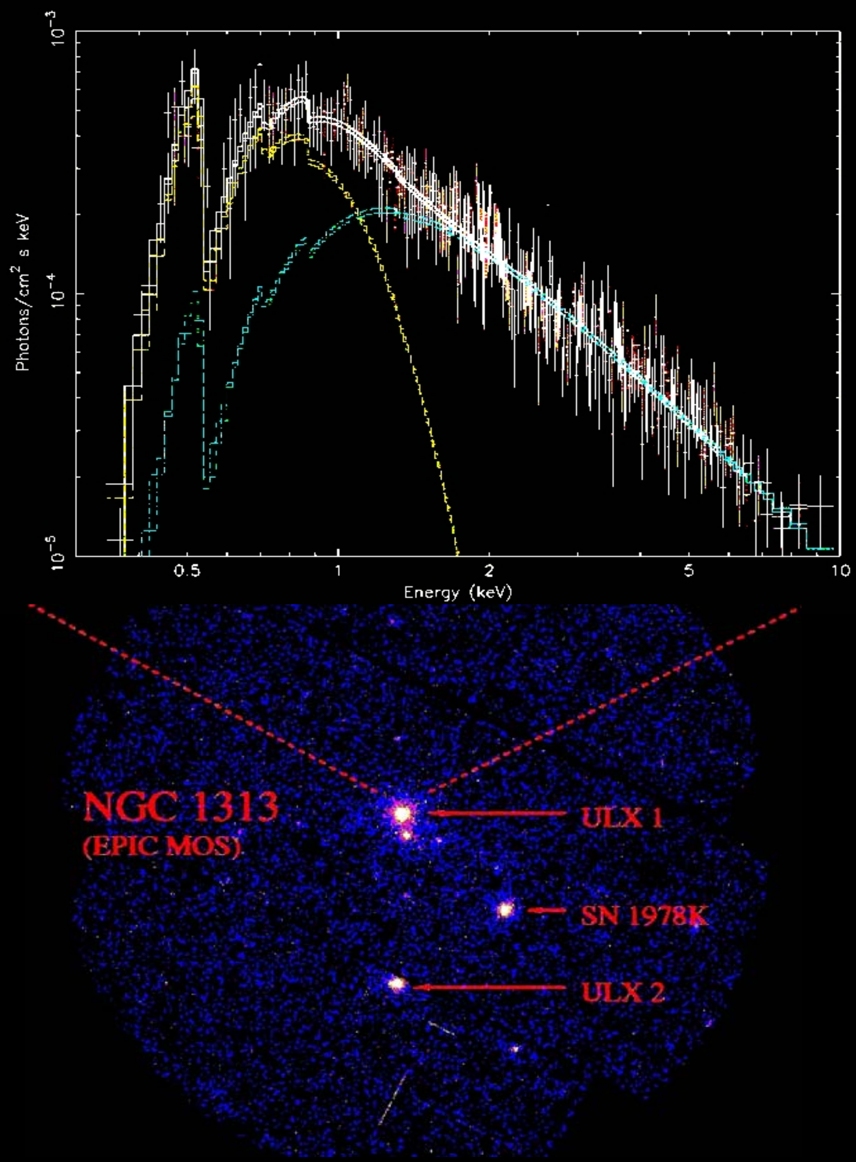
- Variability establishes:

➔ single source

➔ L = 1.1 x 10^{42}erg s^{-1}

➔ m > 500 M_o

Ultraluminous X-Ray Source in NGC 1313



- Cool accretion disk (kT = 150 eV)
- ULX luminosity: 2.0 10^{40} ers/s

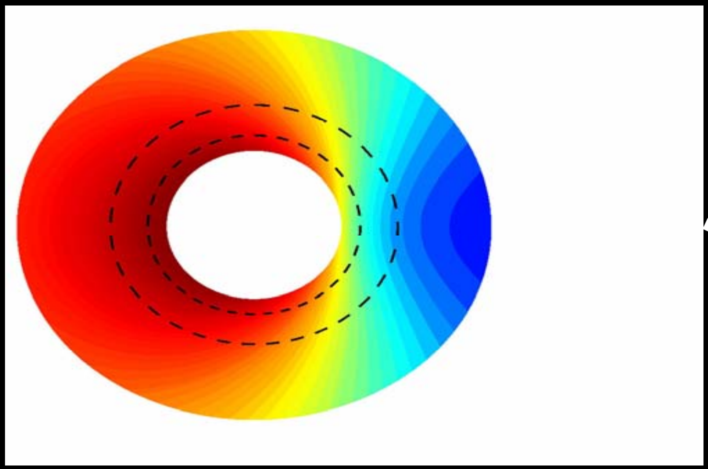
➔ BH mass 100-1000 MO

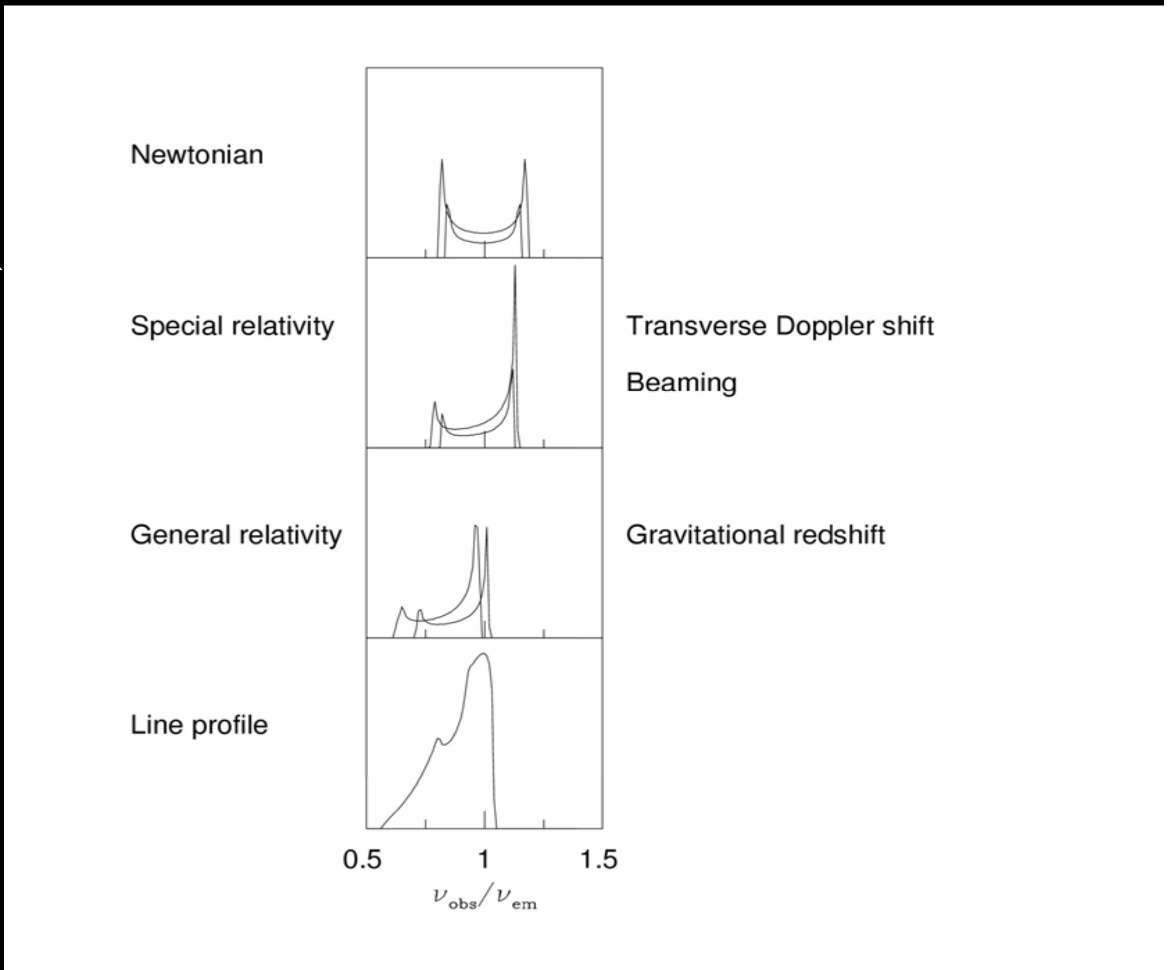
J. M. Miller et al., 2003, ApJ 585, 37

100 - 1000 solar masses

Strong Gravitational Field

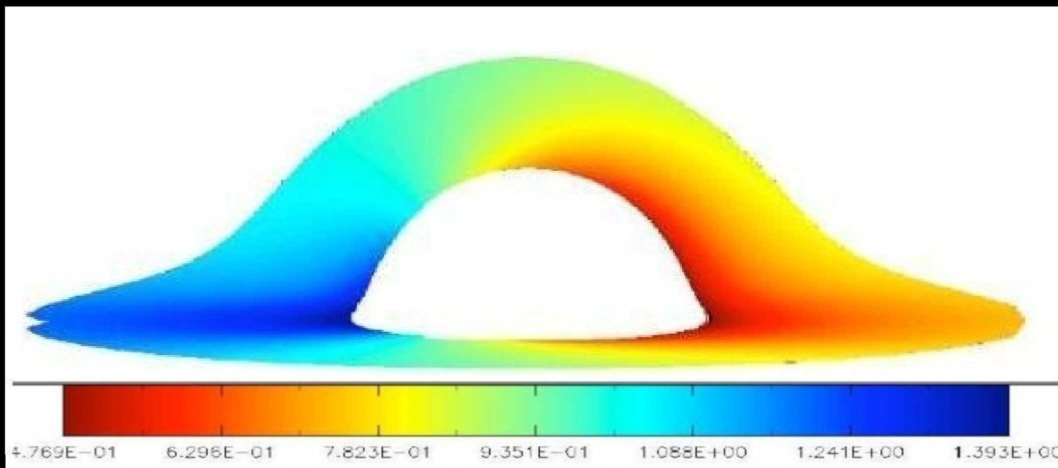
Emission in the Strong Gravitational Field of the Black Hole

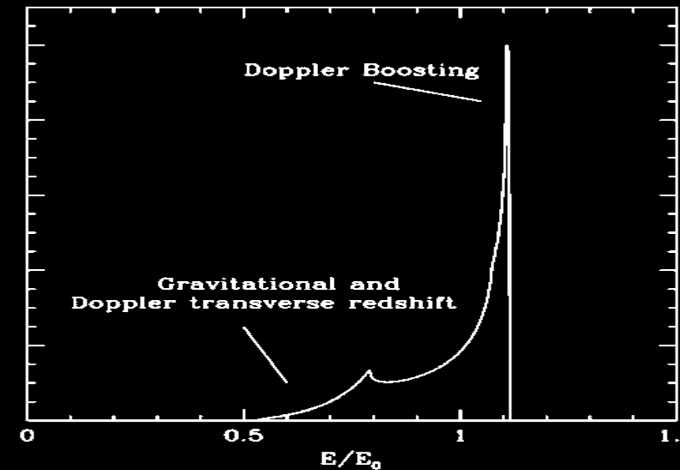


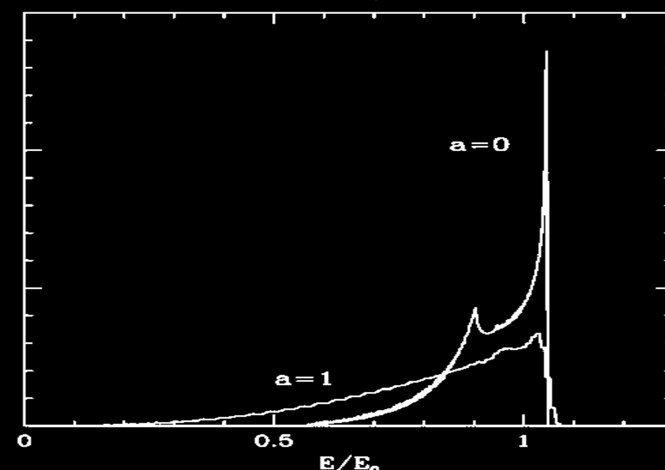


- Fabian et al. (1989); Laor et al (1990); Dovciak et al (2004); K. Beckwith & C. Done, Chris, 2005, MNRAS 359, 1217
- Image courtesy A. Fabian

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

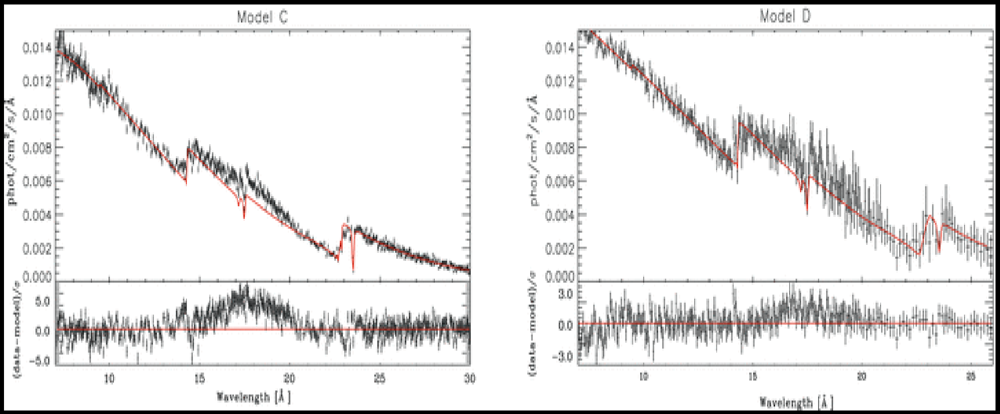






- Image courtesy G. Matt and K. Beckwith
- K. Beckwith & C. Done, Chris, 2005, MNRAS 359, 1217

Broad O VIII Lyα line in the ultracompact X-ray binary 4U 1543-624

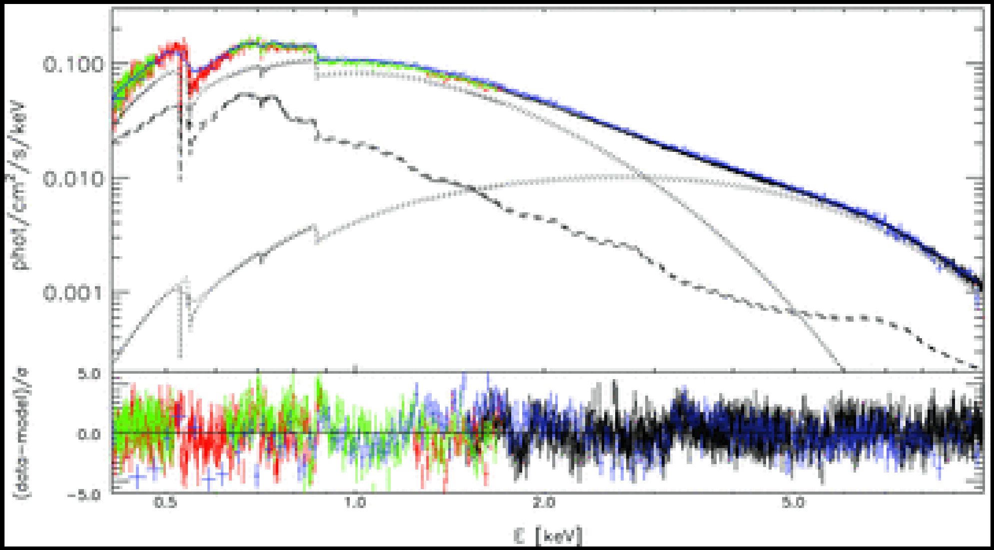


- Discovery of a broad emission feature at ~0.7 keV with the high-resolution spectrographs of the XMM-Newton and Chandra satellites.
- Confirmation of the presence of a weak emission feature at ~6.6 keV

➔ O VIII Lyα and Fe Kα emission caused by X-rays reflected off the accretion disc in the strong gravitational field close to the neutron star

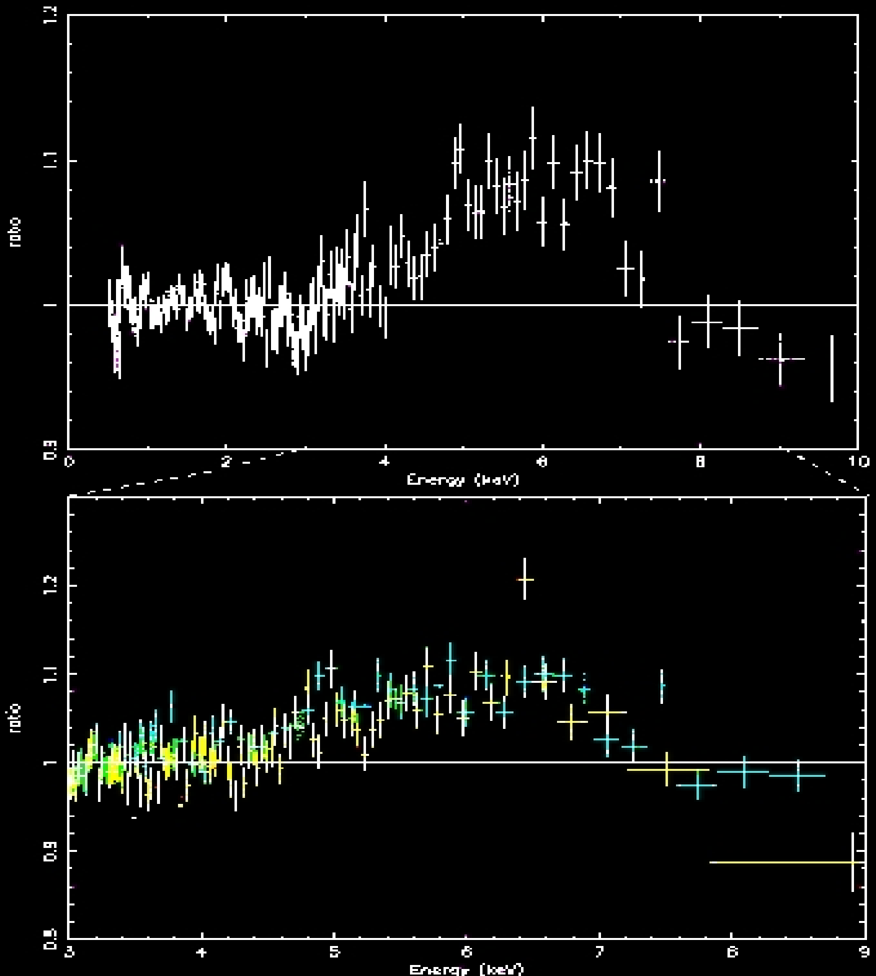
- Ultracompact X-ray binary 4U 1543-624:
  - donor star is a CO or ONe white dwarf
  - transfers oxygen-rich material to the accretor, conceivably a neutron star.

➔ The X-rays reprocessed in the oxygen-rich accretion disc could give a reflection spectrum with O VIII Lyα as the most prominent emission line.



O.K. Madej & P.G. Jonker, 2011, MNRAS 412, L11

XTE J1650-500 in its 2001 Outburst



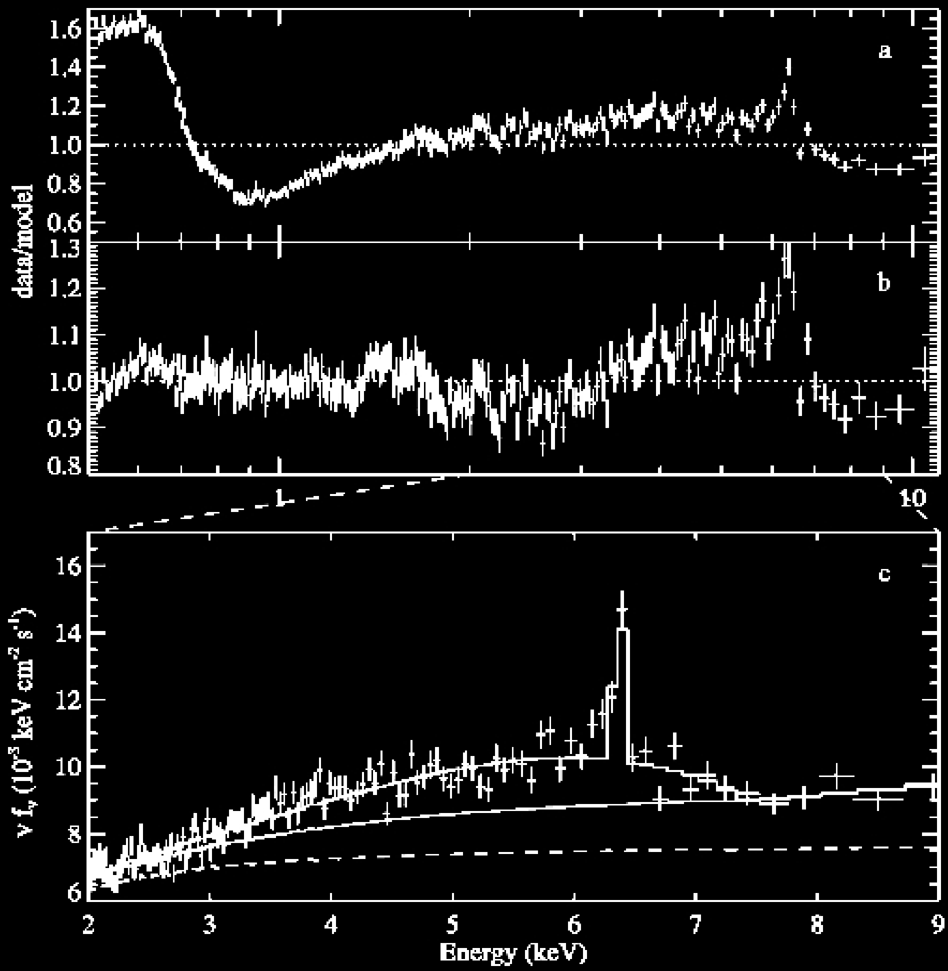
- Broad, skewed Fe Kα emission line suggests the primary in this system may be a Kerr black hole
- Steep disk emissivity profile that is hard to explain in terms of a standard accretion disk model

➔ May be explained by the extraction and dissipation of rotational energy from a black hole with nearly maximal angular momentum

J. M. Miller, et al. 2002, ApJ 570, L69

5 –15 solar masses

MCG-6-30-15: Extraction of Energy from the Spinning Black Hole



- \`Deep minimum' state
- Difficult to understand in any pure accretion disc model

➔ Extraction and dissipation of rotational energy from a spinning black hole

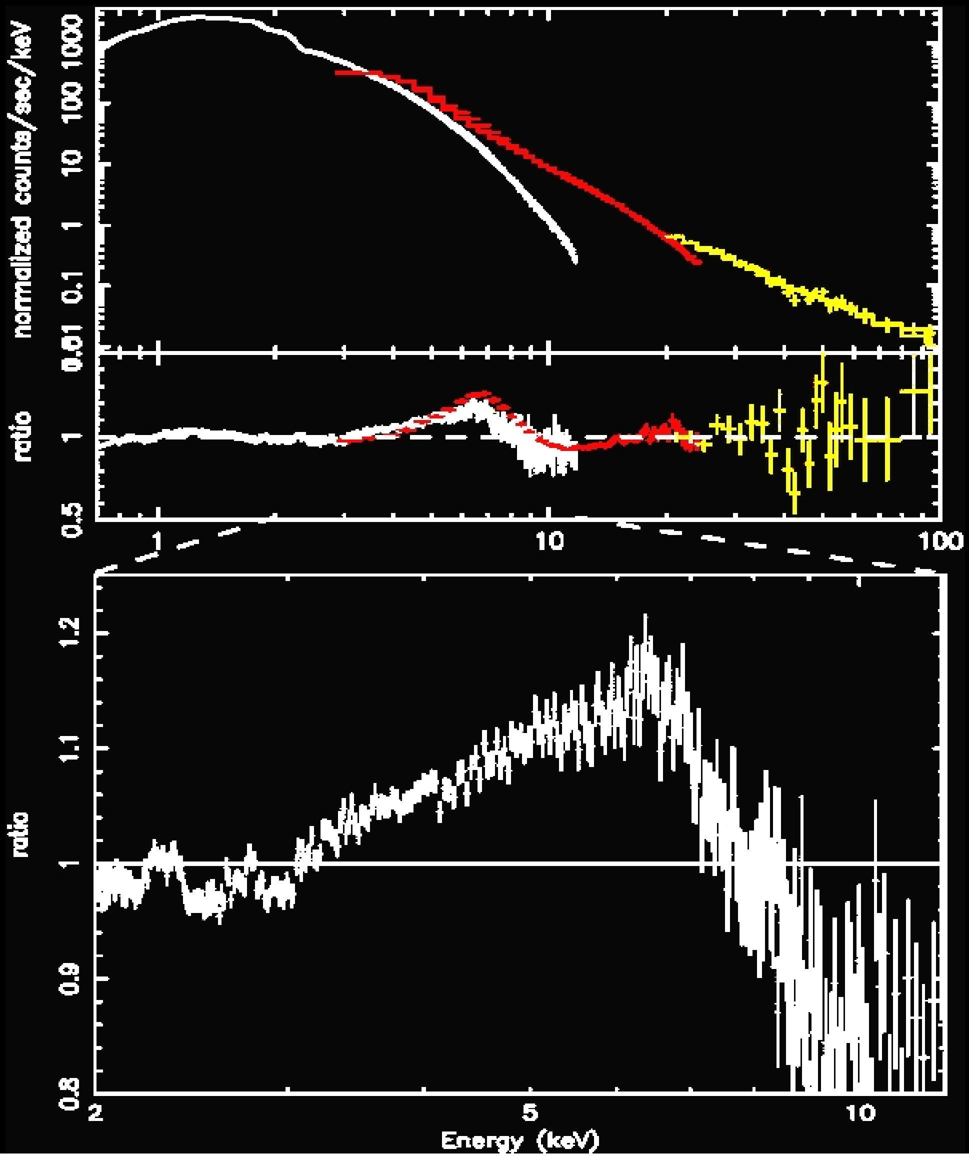
J. Wilms et al., 2001, MNRAS 328, L27

10^6–10^8 solar masses

Black Holes

Determination of the angular momentum ...

Outburst of the Galactic Black Hole GX 339-4

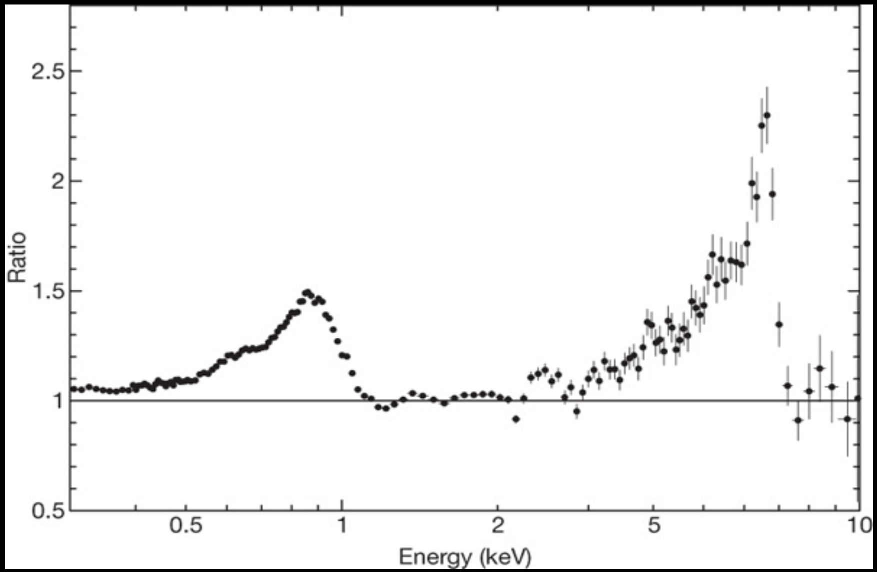


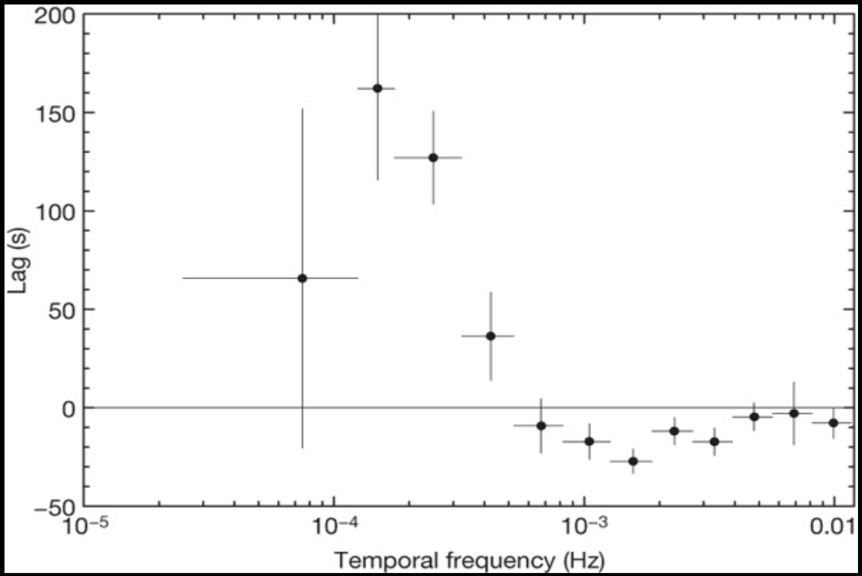
- Extremely skewed, relativistic Fe Kα emission line and ionized disk reflection spectrum
- Inner disk radius is not compatible with a Schwarzschild black hole

➔ Black hole with a>0.8-0.9 (where rg=GM/C² and a=cJ/GM²)

J.M Miller et at., 2004, ApJ 606, L131

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

Black Holes

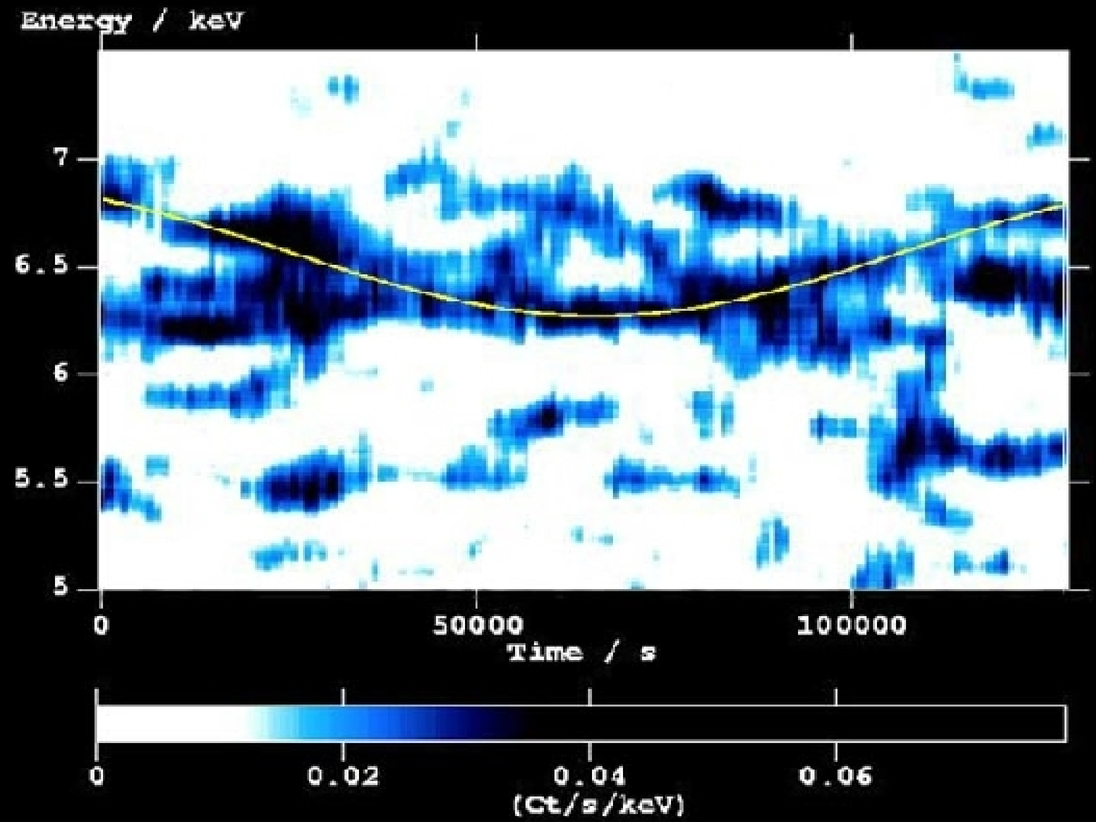
… first steps in the time-energy plane …

Orbital Motion Close to the Central Black Hole of Mrk 766

- Energy-time plane of EPIC pn data in the 4-8 keV band
- Fe Kα emission shows a variation of photon energy with time con-sistent with sinusoidal variation

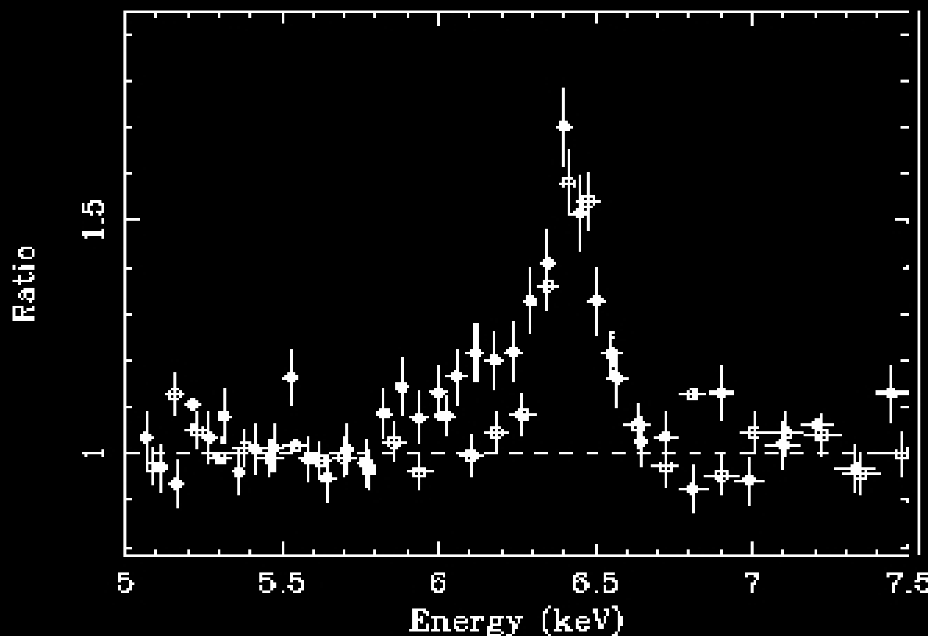
➔ Orbit has a period ~165 ks and a line-of-sight velocity ~13,500 km/s

- $4.9\times10^5 < M_{BH} < 4.5\times10^7$

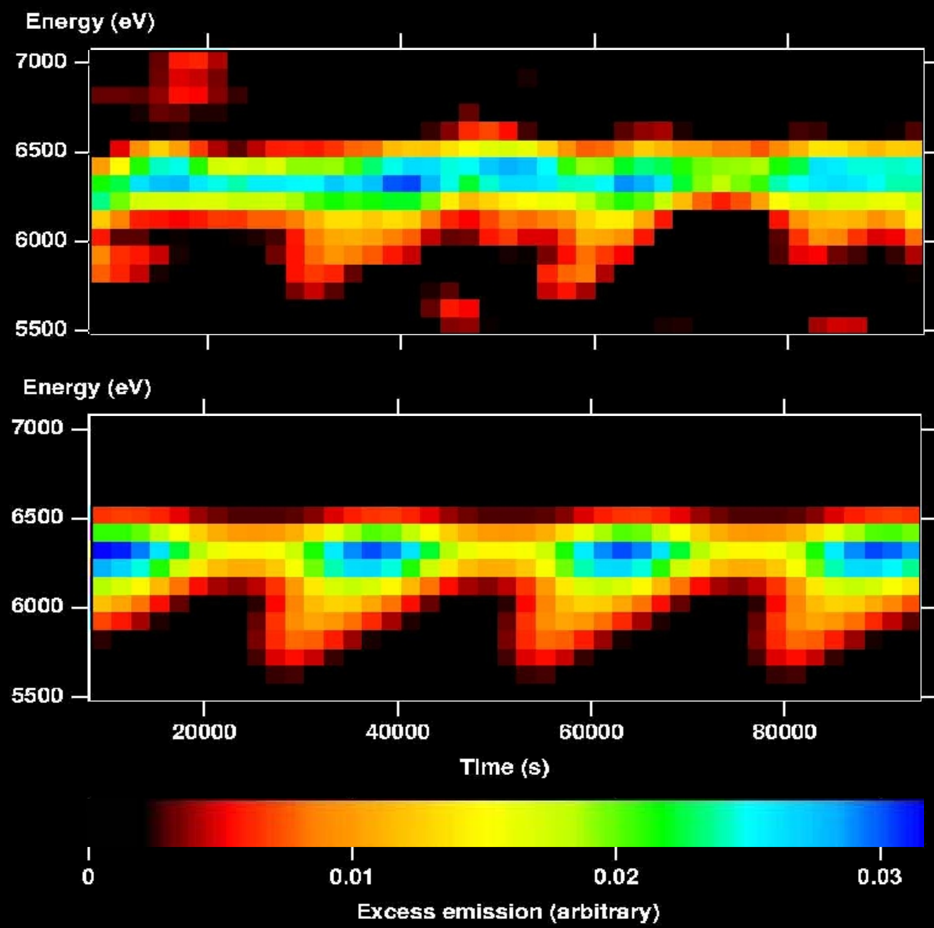


T. J. Turner, et al., 2006, A&A 445, 59

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) × $10^7 M_o$

Black Holes

… feedback to the theory …

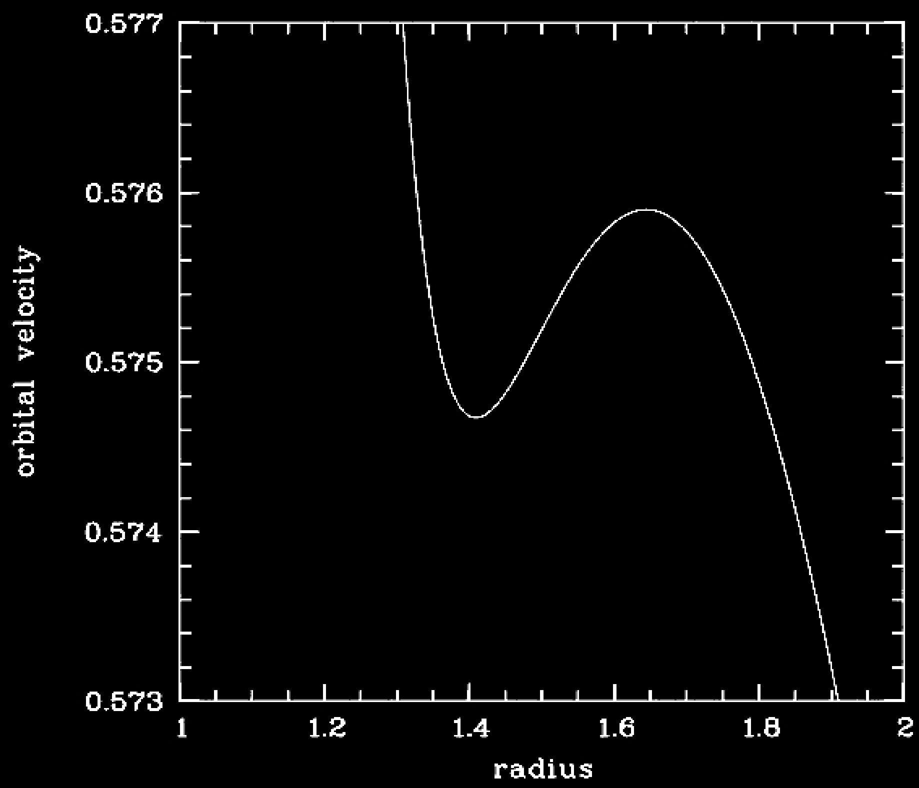
Micro-quasars / Galactic Center BH

- GRO J1655-40, XTE J1550-564 and GRS 1915+105 show twin high frequency quasi-periodic oscillations with a ratio of 3:2 and/or 3:1
- Resonance between vertical and radial epicyclic oscillations and Kepler orbits

➔ New topological structure

➔ a = 0.99616

➔ Galactic Center BH: M = (3.28±0.13) $10^6 M_\odot$

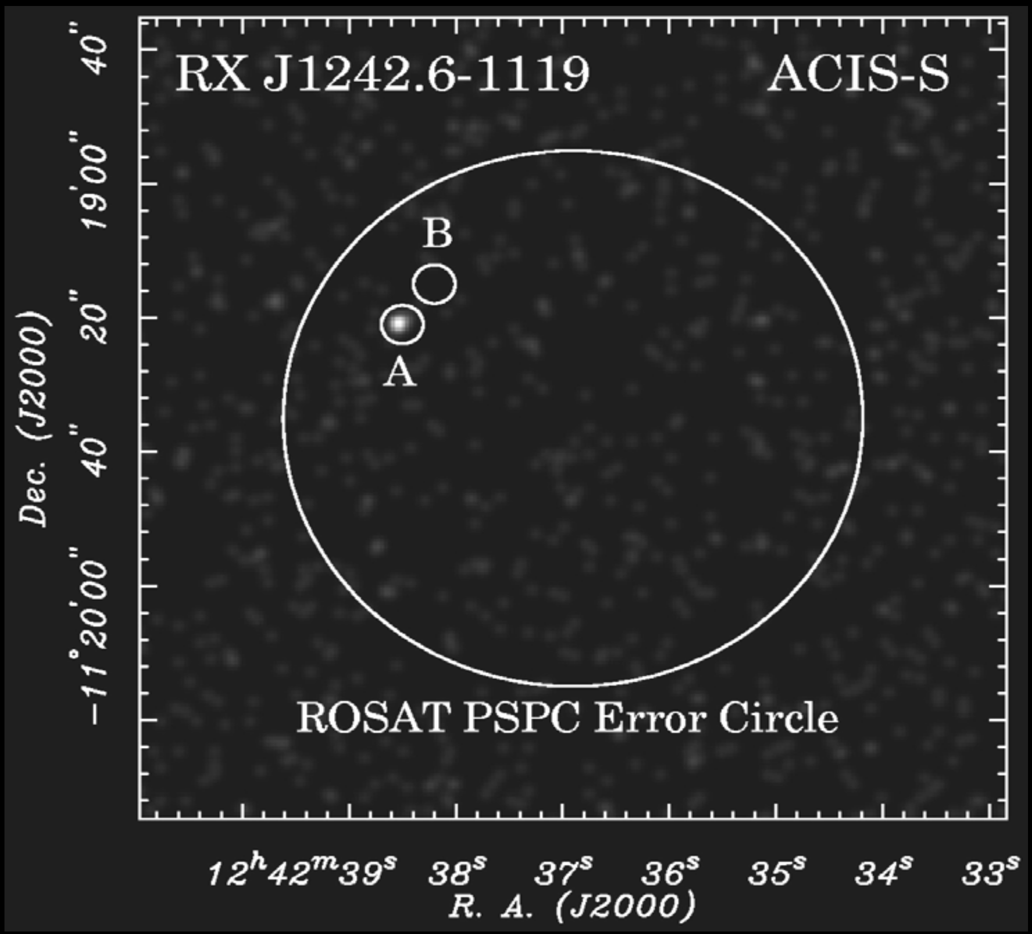


B. Aschenbach, 2004, A&A 425, 1075

SMB / AGNs

... various aspects ...

Huge Drop in the X-Ray Luminosity of the Nonactive Galaxy RX J1242.6-1119A

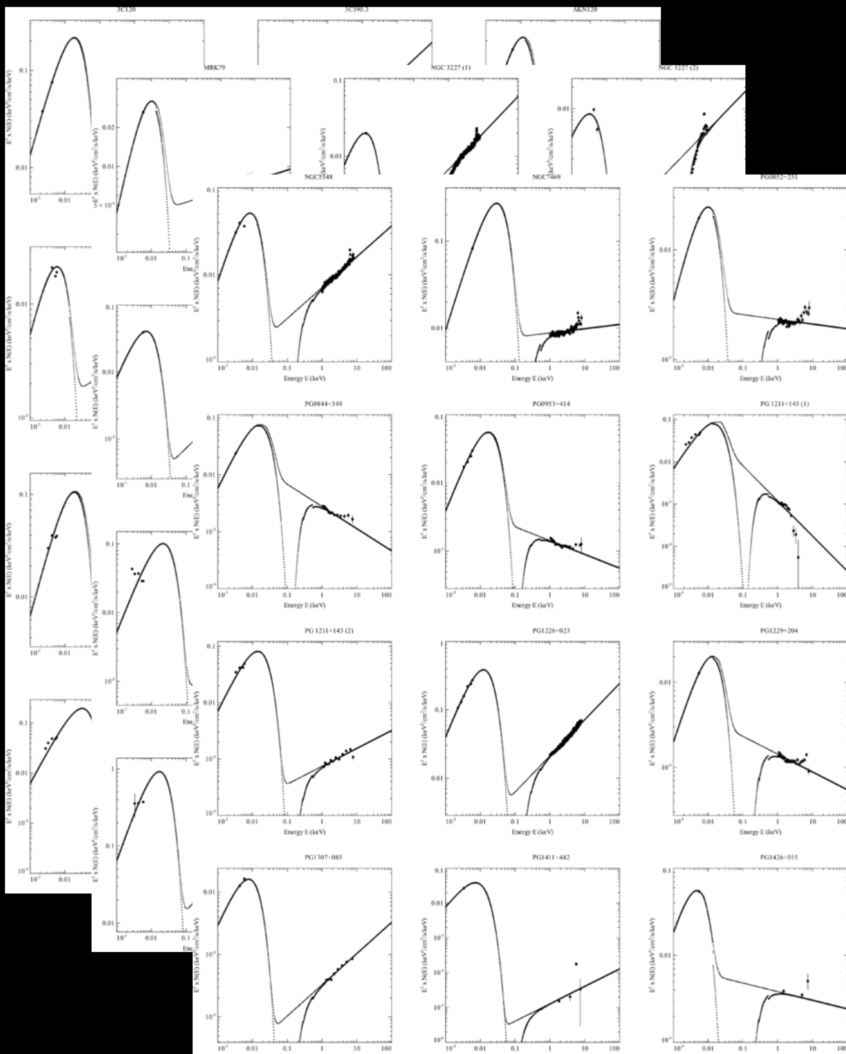


- ROSAT, Chandra and XMM-Newton
- ~200 drop in X-ray luminosity

➔ (Partial or complete) tidal disruption of stars captured by the black holes

S. Komossa et al., 2004, ApJ 603. L17

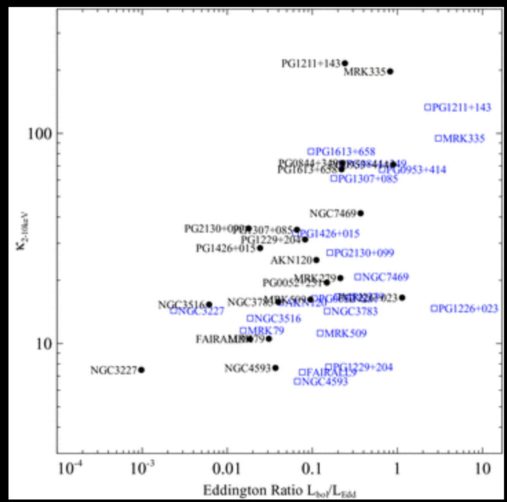
Simultaneous X-ray/optical/UV spectral energy distributions of AGNs

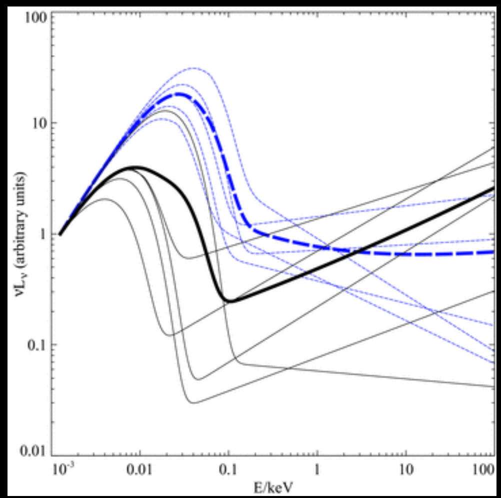


R. V. Vasudevan & A.C. Fabian, 2009, MNRAS 392, 1124

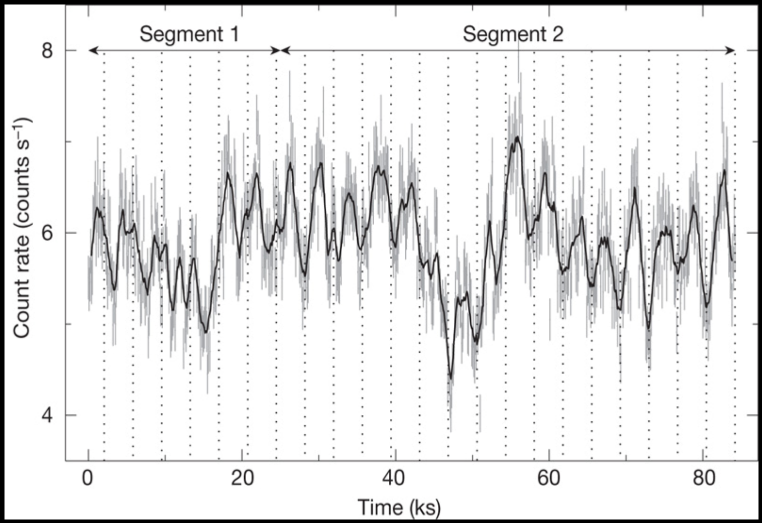
- Contemporaneous optical, ultraviolet (UV) and X-ray observations from the XMM-Newton European Photon Imaging Camera (EPIC-pn) and Optical Monitor (OM)

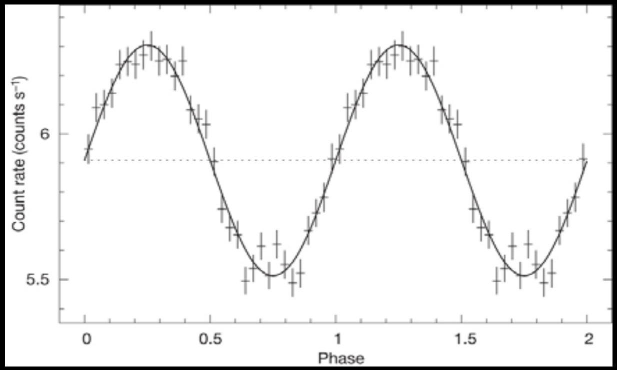
➔ For the first time, simultaneous spectral energy distributions (SEDs) for the majority of the Peterson et al. reverberation mapped sample of active galactic nuclei (AGN).



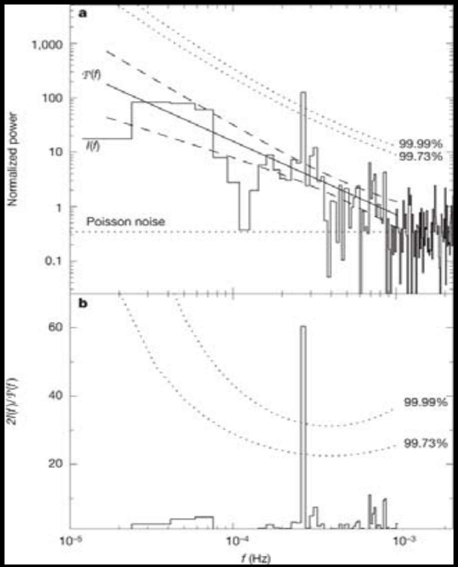


First QPO from an AGN





Gierlinski et al., 2008,
Nature 455, 369

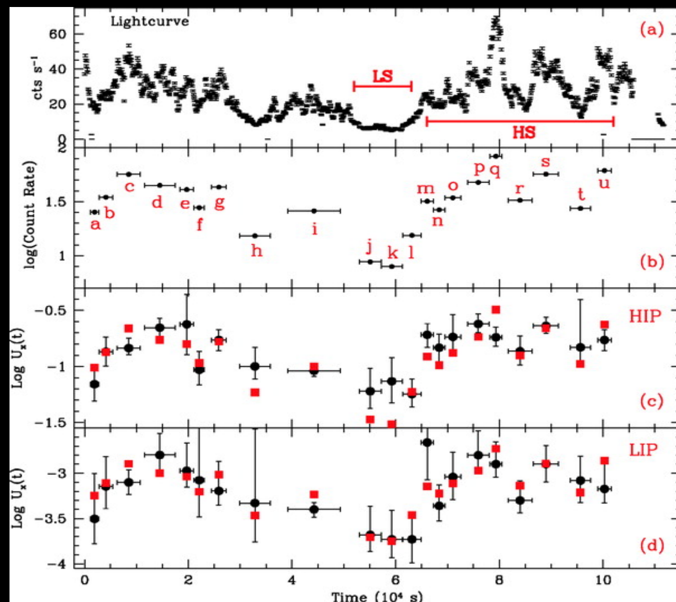


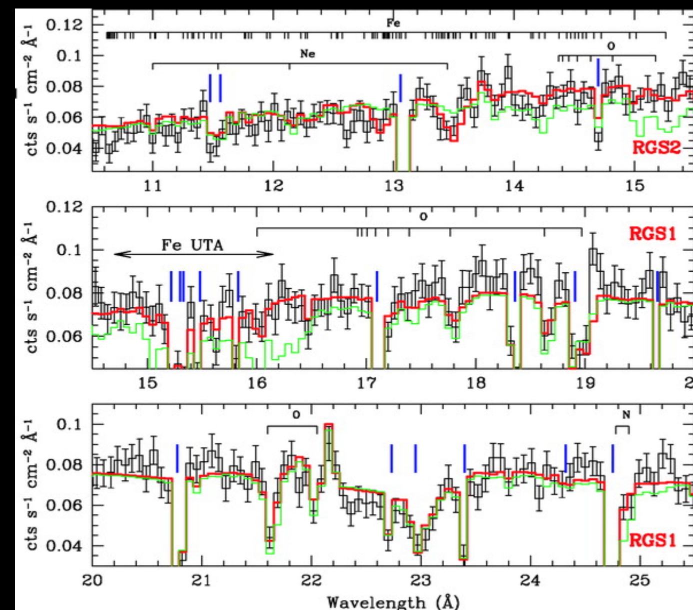
- Since 20 years QPO in X-ray binaries, but never found for AGNs (13y)
- RE J1034+396 nearby (z=0.043) narrow-line Seyfert 1
- Black hole mass: 6.3 x 10^5 to 3.6 x 10^7 M_{sun}

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

➔ Provides fundamental length-scale of SMBH system

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





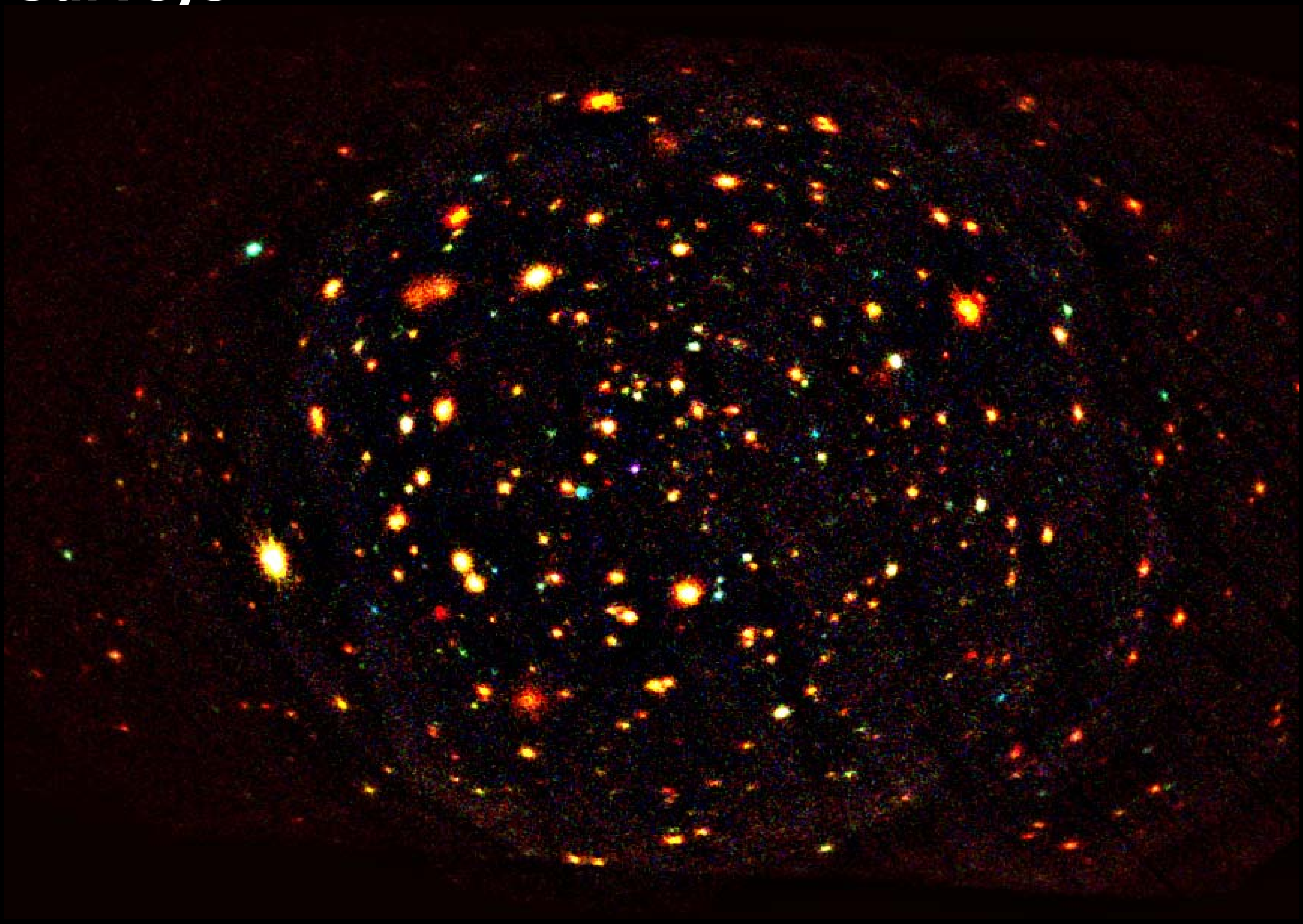
- Absorber consists of two different ionization components, with a difference of ~100 in ionization parameter and ~5 in column density
- Distances 0.5-1.0 lt-days (2200RS-4400RS) and <3.5 lt-days (<15,800 RS) from the continuum source

➔ 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

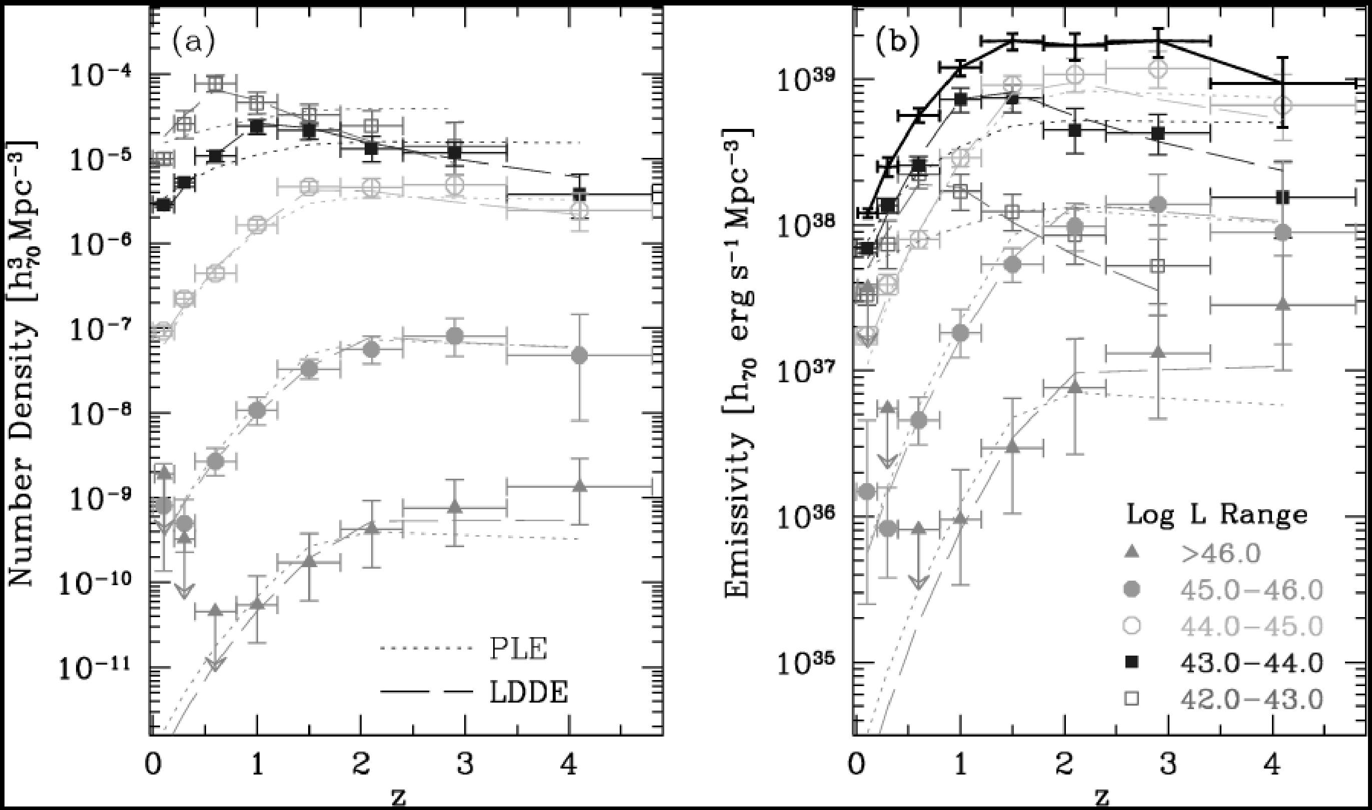
Cosmology and Early Universe: Deep Fields and large Surveys



XMM-Newton Lockman Hole 800 ks

G. Hasinger

Luminosity-dependent evolution of soft X-ray selected AGN



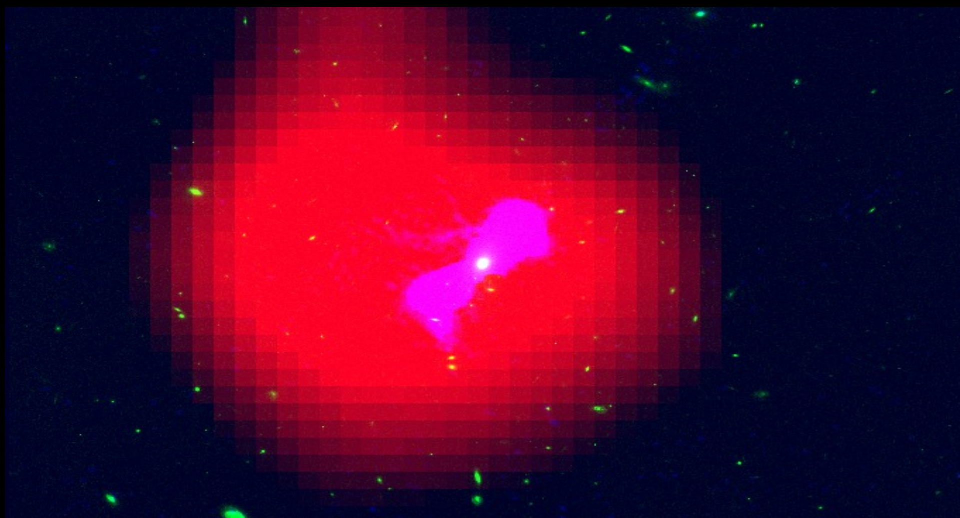
G. Hasinger, T. Miyaji & M. Schmidt, M., 2005, A&A 441, 417

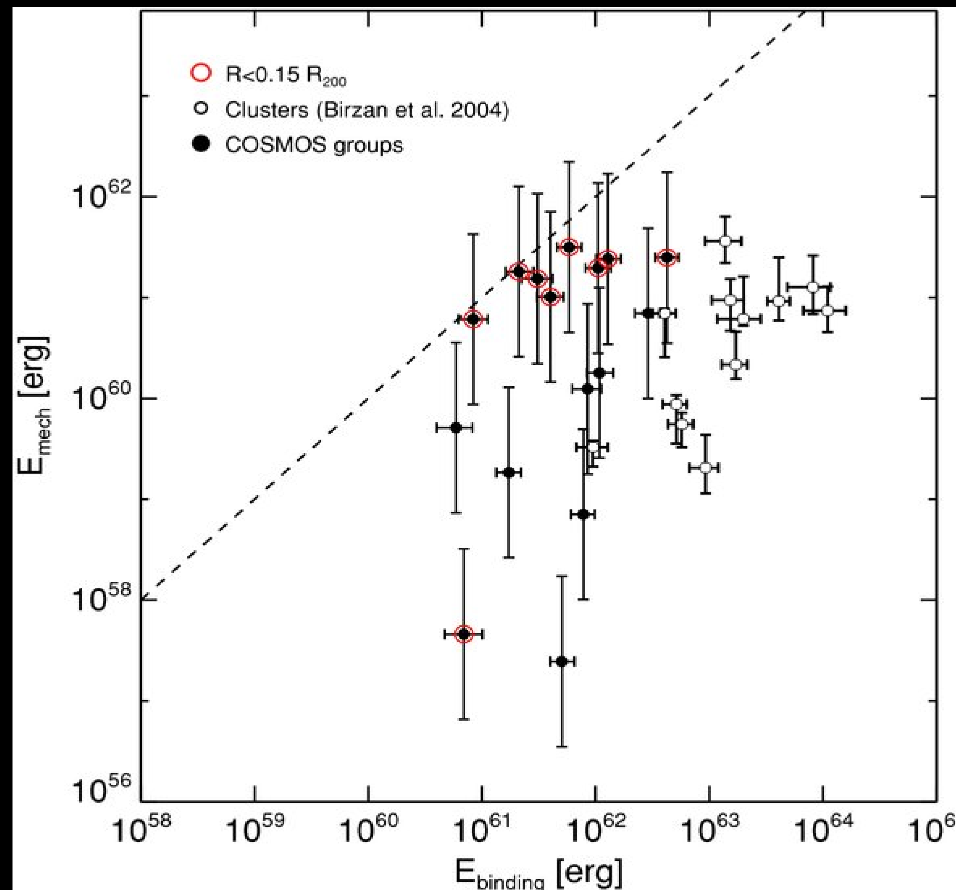
- total of ~1000 AGN from a variety of ROSAT, XMM-Newton and Chandra surveys

➔ First time reliable space densities for low-luminosity (Seyfert-type) X-ray sources at cosmological redshifts.

➔ The evolutionary behaviour of AGN shows a strong dependence on X-ray luminosity: while the space density of high-luminosity AGN reaches a peak around z~2, the space density of low-luminosity AGNs peaks at redshifts below z=1. This confirms previous ROSAT findings of a luminosity-dependent density evolution.

Radio Galaxy Feedback in X-ray-selected Groups





Giodini, et al., 2010, ApJ 714, 218

- Comparison of the mechanical energy released by radio galaxies with the host groups' gravitational binding energy

➔ Radio galaxies produce sufficient energy to unbind a significant fraction of the intra-group medium (negligible in massive galaxy clusters)

- Reproduce the breaking of self-similarity in the scaling relation between entropy and temperature for galaxy groups.