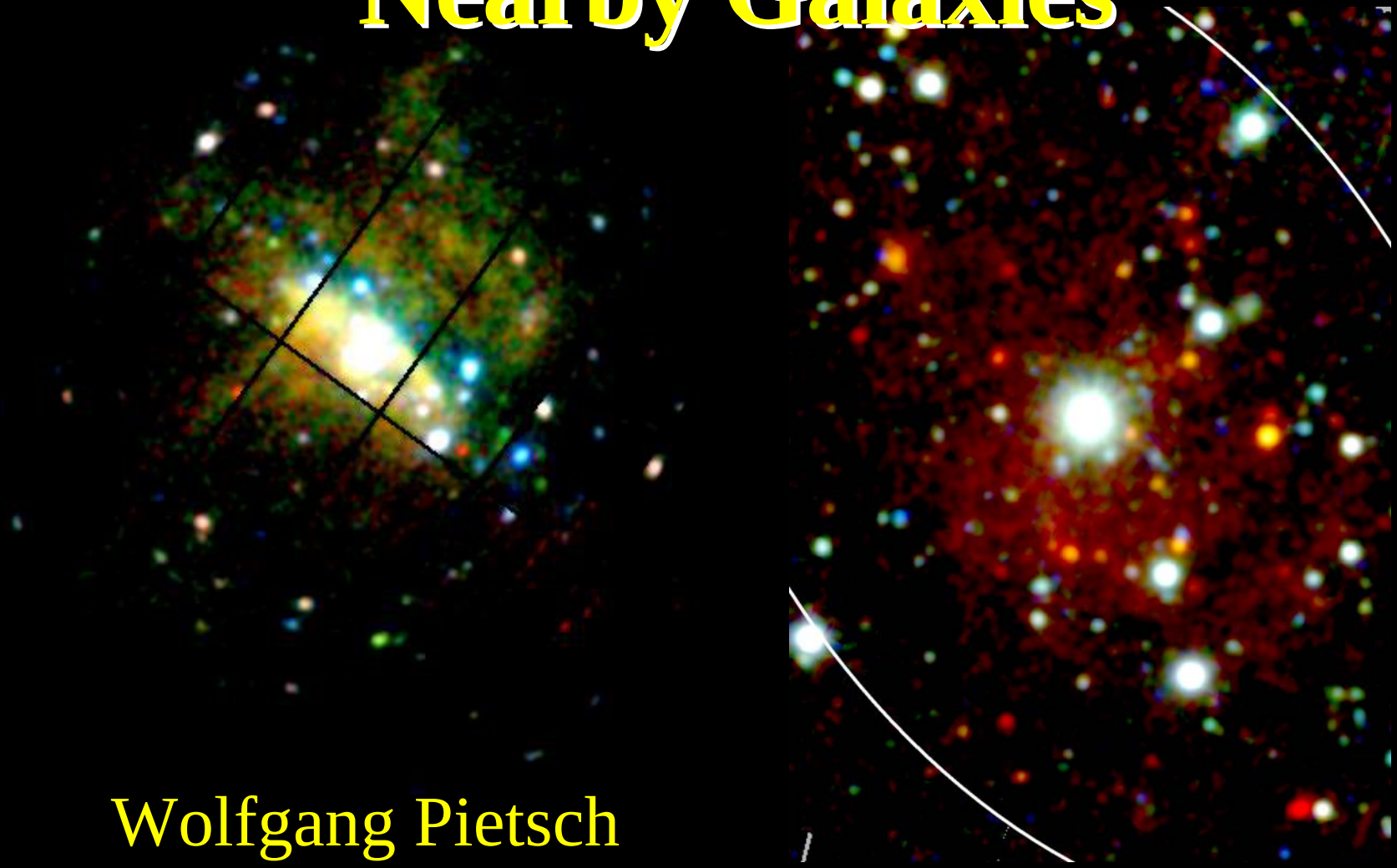
X-ray Observations of Nearby Galaxies



Wolfgang Pietsch

Max Planck Institut für extraterrestrische Physik

XMM-Newton EPIC view of the starburst galaxy NGC 253

Wolfgang Pietsch

Max Planck Institut für extraterrestrische Physik

In collaboration with:

D. Breitschwerdt, M.J. Freyberg, F. Haberl, A. Vogler,

T.P. Roberts, M. Sako , A.M. Read,

M. Ehle, G. Trinchieri,

and XMM-Newton Cal/PV collaboration

First papers:

XMM-Newton observations of NGC 253: Resolving the emission components in the disk and nuclear area (Pietsch et al. 2001, A&A 365, L174)

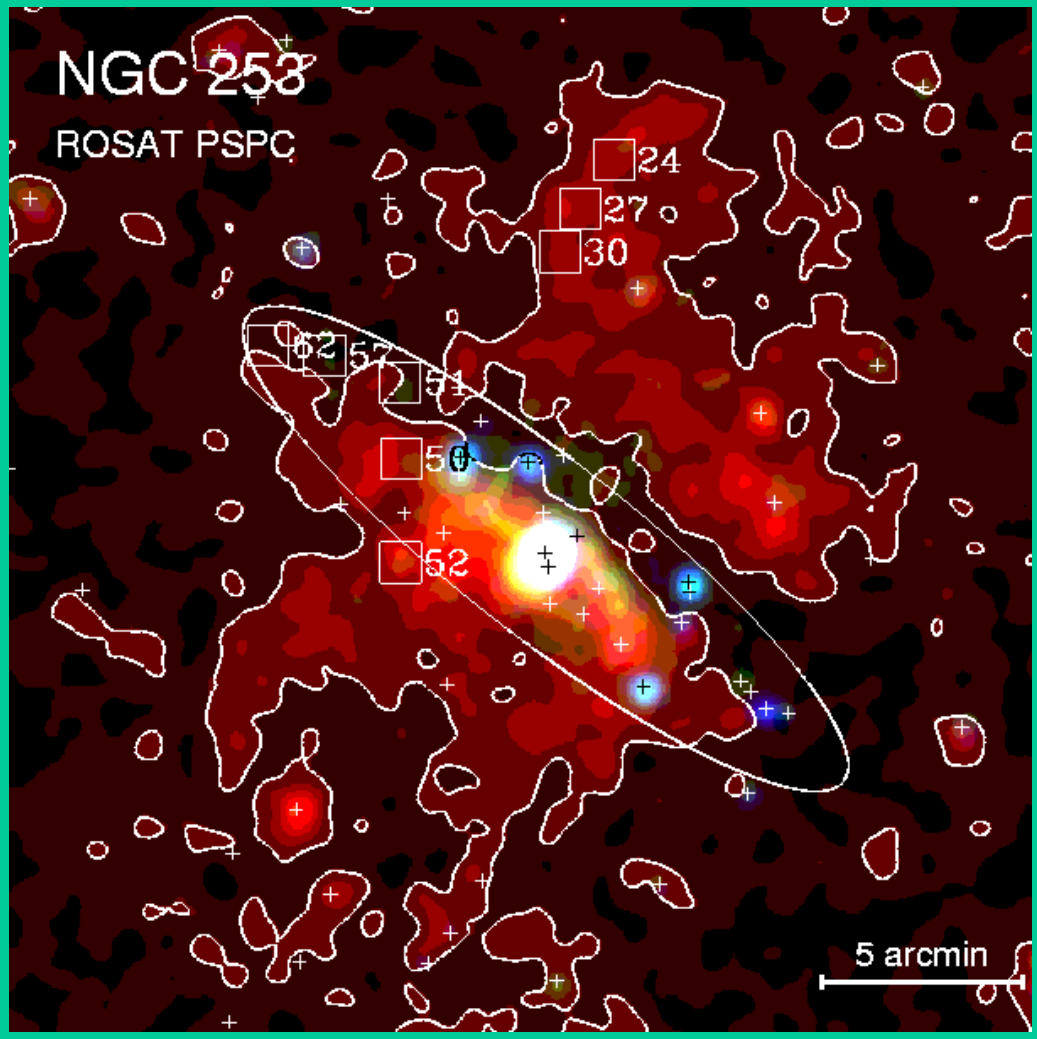
RX J004717.4-251811: The first eclipsing X-ray binary outside the local group (Pietsch, Haberl, Vogler 2003, A&A 402, 457)

ROSAT observations of NGC 253

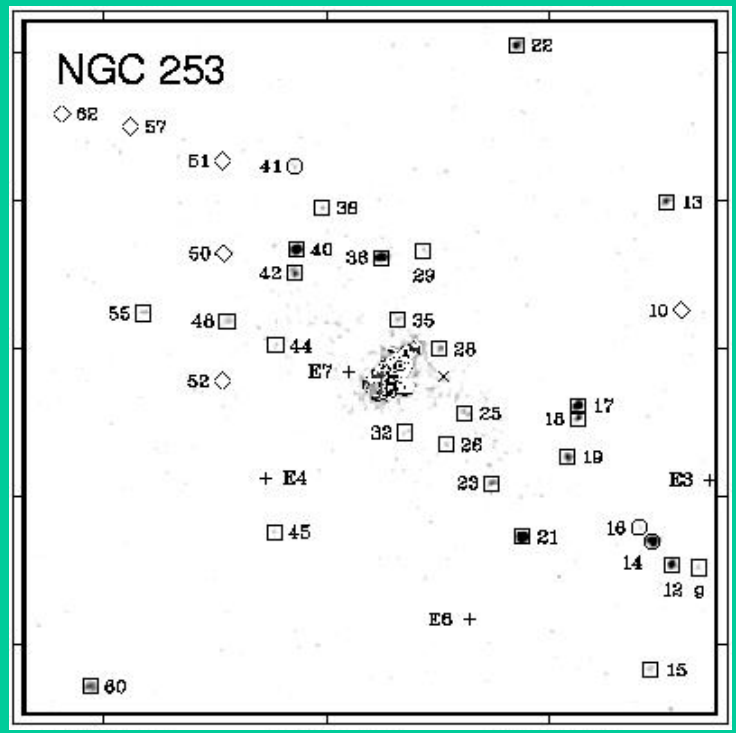
PSPC colour image:

0.1-0.4 keV **0.5-0.9 keV** **0.9-2.0 keV**

Vogler & Pietsch 1999, A&A 342, 101
Pietsch et al. 2000, A&A 360, 24

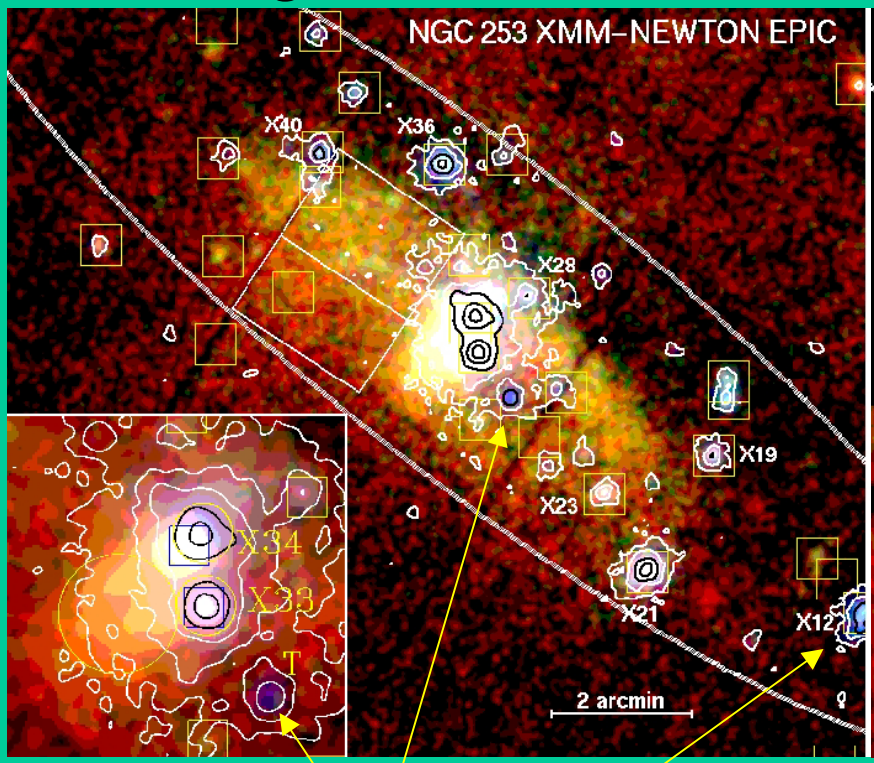


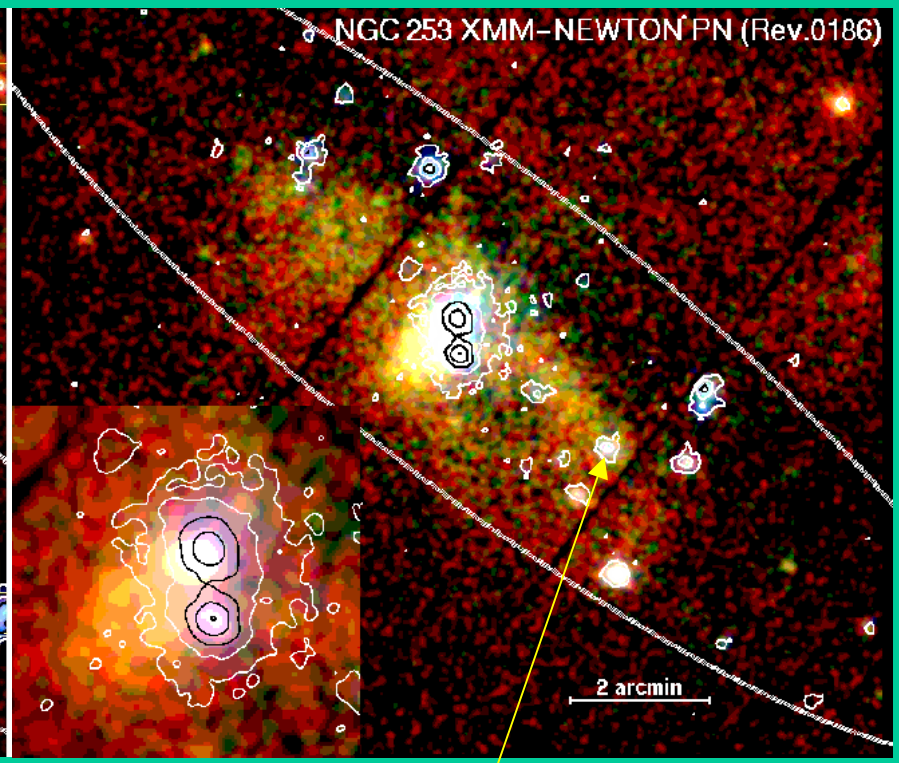
HRI image



XMM-Newton observations of NGC 253 transients in outburst I

Colour images: 0.2-0.5 keV 0.5-0.9 keV 0.9-2.0 keV contours 2-10 keV

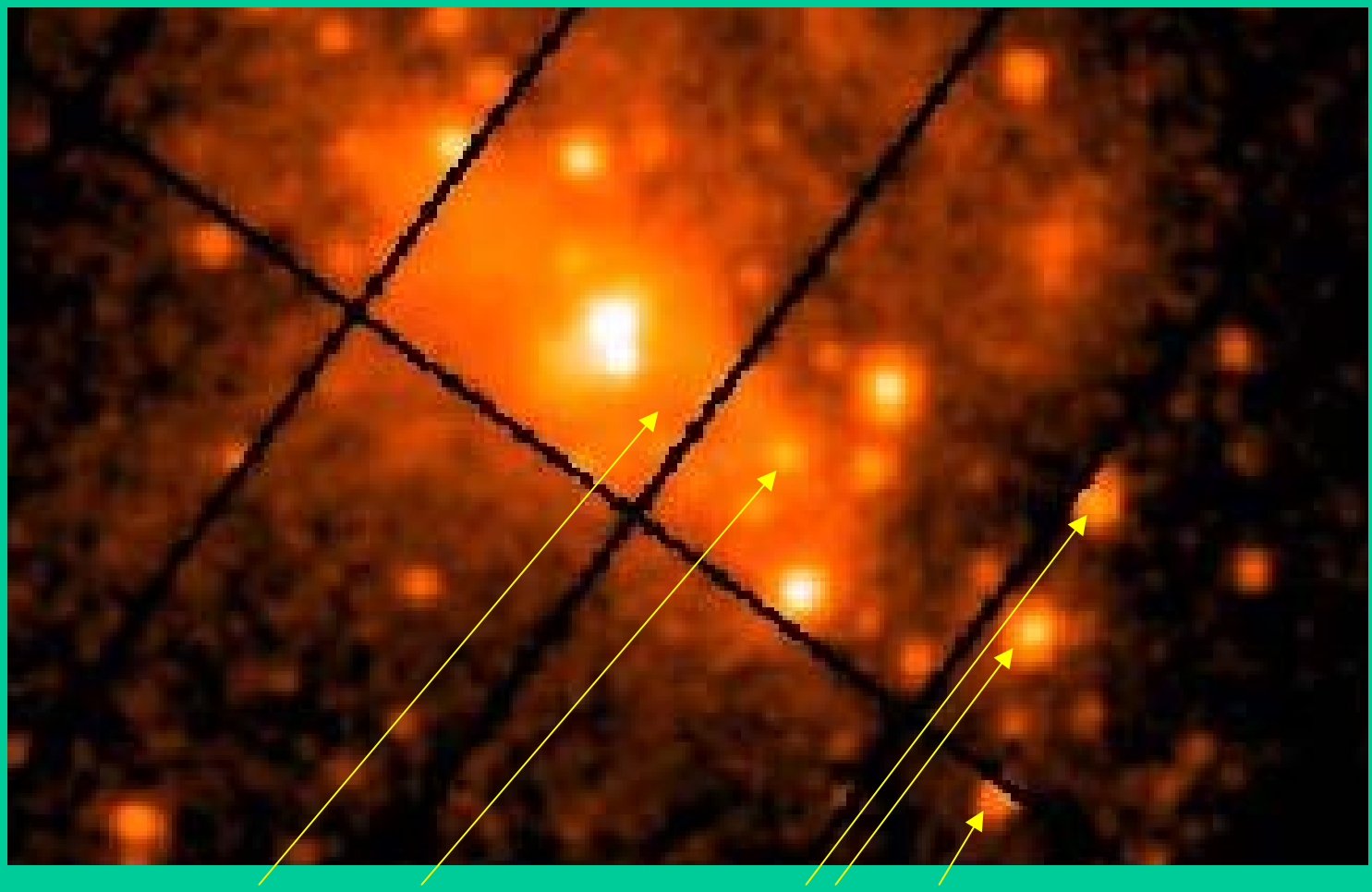




PV Jul 2000

SSC GT Dec 2000

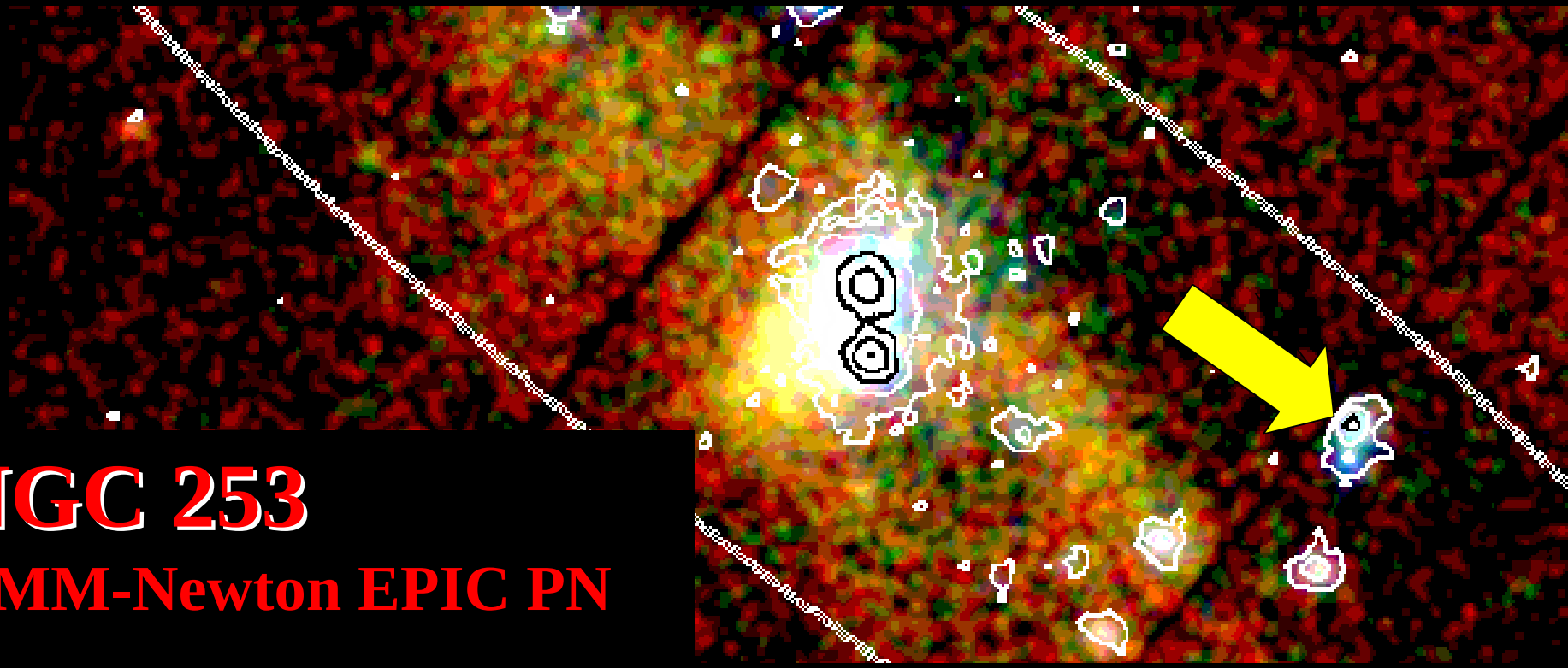
XMM-Newton observations of NGC 253 transients in outburst II



AO2 June 19/20, 2003

EPIC PN colour image:
0.2-0.5 keV 0.5-1.0 keV 1.0-2.0 keV

RX J004717.4-251811: The first eclipsing XRB outside the Local Group



NGC 253

XMM-Newton EPIC PN

Wolfgang Pietsch, Frank Haberl, Andreas Vogler

Max Planck Institut für extraterrestrische Physik

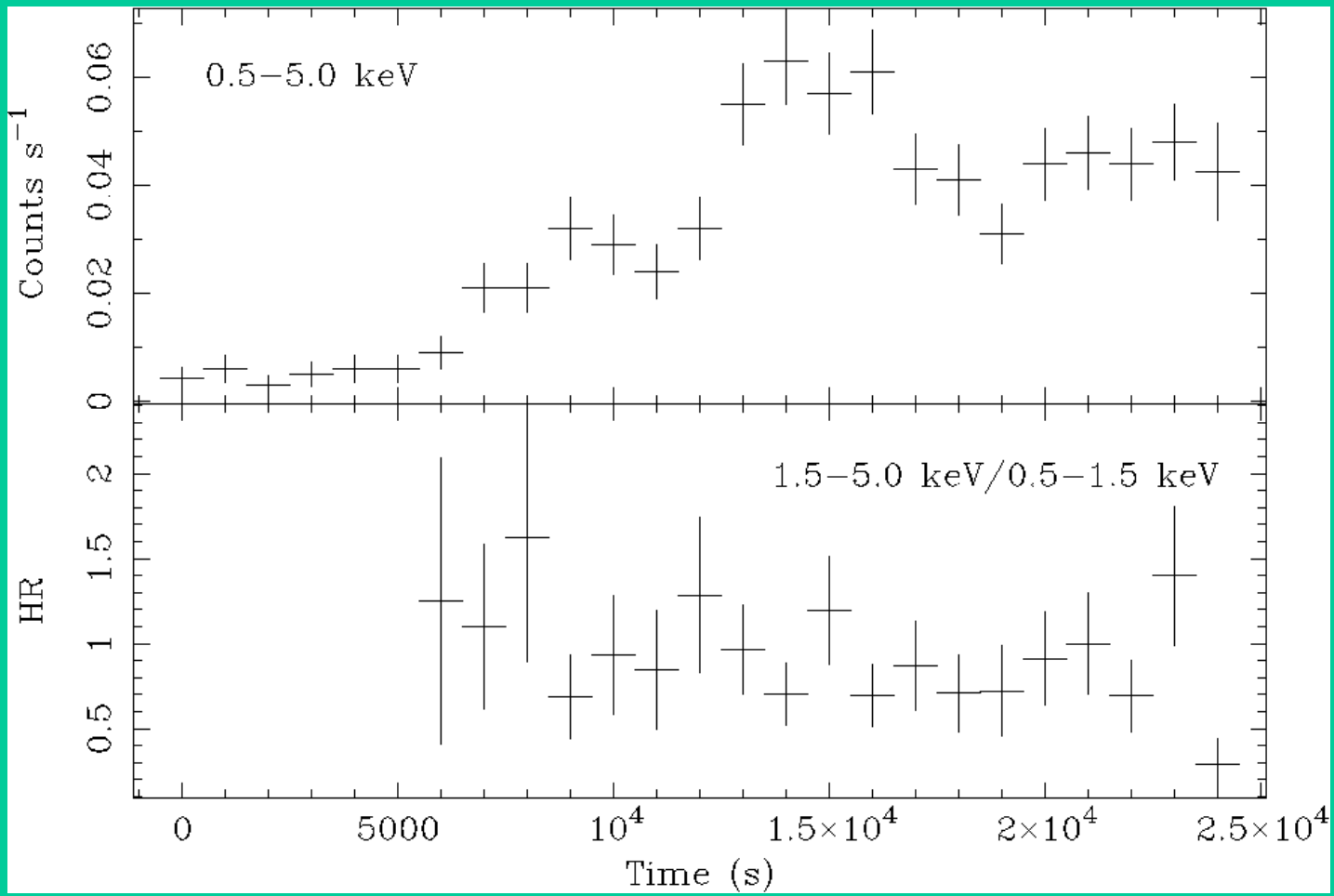
A&A 402, 457 (2003)

Eclipsing X-ray binaries (XRBs)

- **Luminous XRBs among first X-ray sources detected and optically identified (Milky Way, SMC, LMC)**
- **Eclipses for orbital variability**
  Pulsations for rotation of compact object
  
  neutron star masses
- **Long term variability (precession of accretion disk or free precession of neutron star?)**
- **Flares**

Examples:	Cen X-3	Her X-1	LMC X-4	SMC X-1
pulsation	4.84 s	1.24 s	0.71 s	13.5 s
orbital period	2.1d	1.7 d	1.4 d	3.9 d
eclipse duration	0.183	0.137	0.144	0.147
long term	?	35 d	30 d	35-60 d
flares	no	no	yes	no

XMM-Newton EPIC PN light curve and hardness ratio: December 13/14, 2000



Egress from low to high state at MJD 51892.146 (6)

X-ray observations of RX J004717.4-251811 (NGC 253 X17)

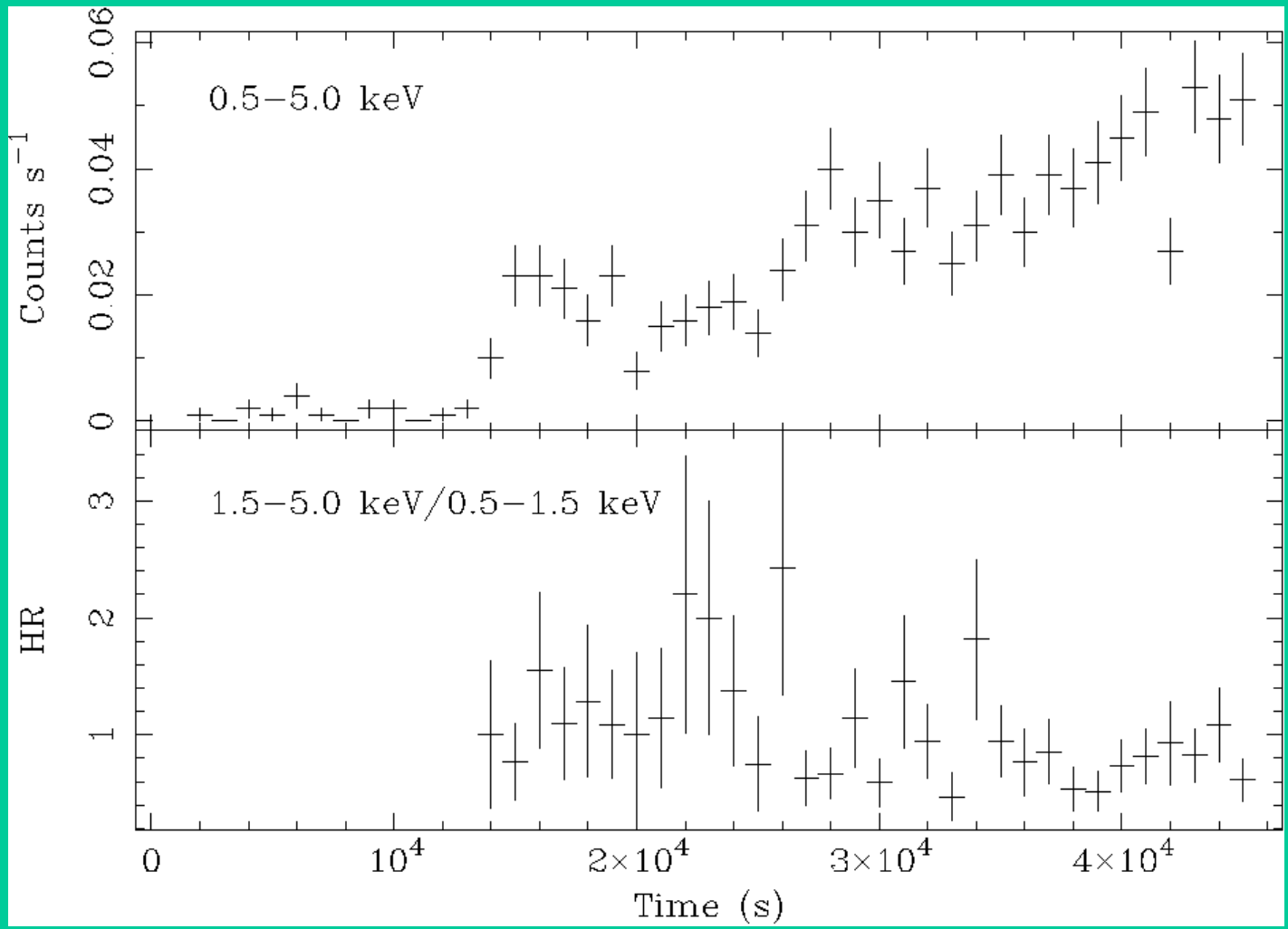
Observatory	Obs. id.	Obs. dates	L.t. (ks)	R_e ($''$)	Count rate (ct ks^{-1})	HR	L_X^{**} (10^{37} erg s^{-1})	Comment
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
XMM-Newton	0125960101	2000-06-03	39.0	10.0	7.0 ± 0.4	0.51 ± 0.05	2.6 ± 0.2	
XMM-Newton	0125960201	2000-06-04	14.0	10.0	7.2 ± 0.7	0.38 ± 0.05	2.7 ± 0.3	
XMM-Newton	0110900101	2000-12-13/14	30.7	10.0	4.3 ± 0.7	0.50 ± 0.15	1.4 ± 0.2	low state
					41.8 ± 1.7	0.86 ± 0.07	14.0 ± 0.6	high state
Chandra	969	1999-12-16	14.2	3.5	54.8 ± 2.0	0.74 ± 0.06	20.1 ± 0.7	
Chandra	790	1999-12-27	44.1	5.0	1.4 ± 0.4	0.27 ± 0.18	0.7 ± 0.2	low state
					28.7 ± 0.9	0.91 ± 0.06	14.6 ± 0.5	high state
Chandra	383	2001-08-16	2.2	3.5	4.6 ± 1.5	0.43 ± 0.30	1.6 ± 0.5	
ROSAT	600088h-0	1991-12-08/10	3.1	6.0	3.4 ± 1.1		22 ± 7	
ROSAT	600088h-1	1992-06-05/07	24.9	6.0	0.9 ± 0.2		6 ± 1	
ROSAT	600714h	1995-01-03/07	10.9	6.0	4.0 ± 0.6		26 ± 4	
ROSAT	600714h-1	1995-06-13/17	14.0	6.0	0.3 ± 0.2		2 ± 1	
		1995-07-05/07	5.9	6.0	0.3 ± 0.2		2 ± 1	
ROSAT	601111h	1997-12-20/27	16.8	6.0	1.1 ± 0.3		7 ± 2	
Einstein	583/2083	1979-07-05/08	27.4	11.5	$1.5 \pm 0.3^{*}$		18 ± 4	

Notes and references:

* : according to Fabbiano & Trinchieri (1984)

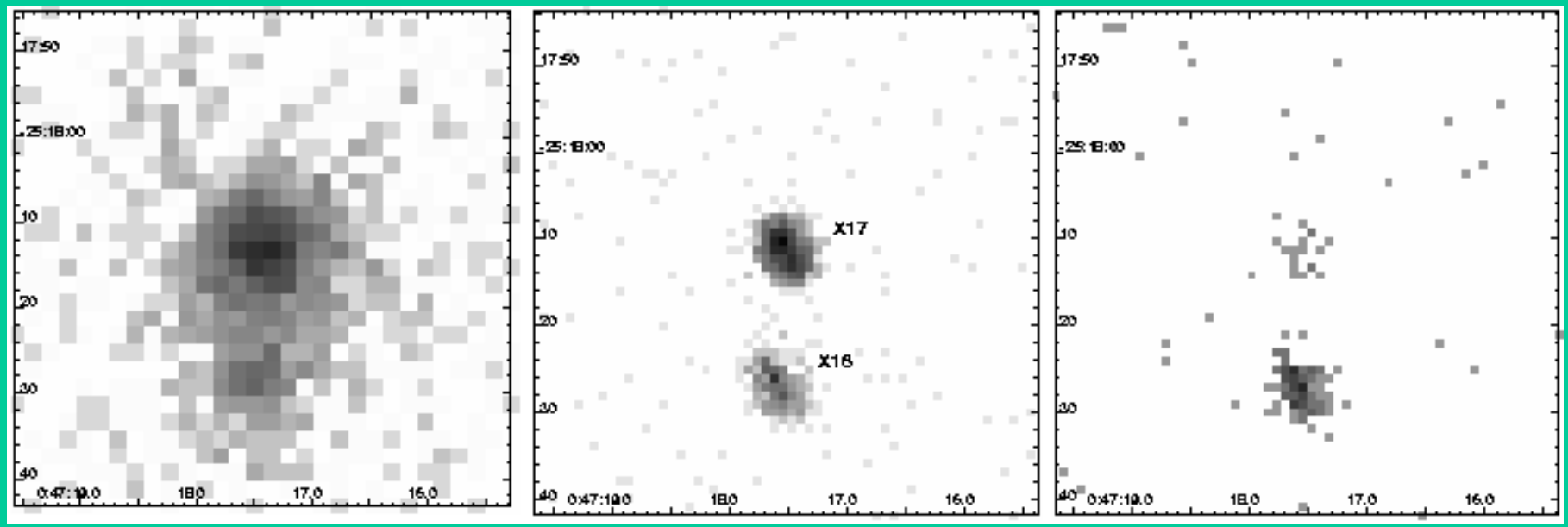
**: 0.5–2.4 keV absorption corrected luminosity assuming an absorbed power law spectrum ($N_H = 1.9 \times 10^{21}$ cm^{-2}, photon index $\Gamma = 1.7$) and a distance of NGC 253 of 2.58 Mpc (Puche et al. 1991) which we use throughout the paper

Chandra ACIS S light curve and hardness ratio: December 27, 1999



Egress from low to high state at MJD 51539.276 (6)

Images of RX J004717.4-251811 region
logarithmically scaled



XMM-Newton
EPIC PN
Dec 13/14, 2000
high state

Chandra
ACIS S
Dec 27, 1999
high state

Chandra
ACIS S
Dec 27, 1999
low state

RX J004717.4-251811: orbital period determination

- Two eclipse egresses, about one year apart
  p = 352.870 (12) d / n ; n = 1,2,3,...
- Restriction of all XMM-Newton and Chandra observations => 123 possible periods < 10 d

Allowed orbital periods of RX J004717.4-251811 (NGC 253 X17)

Period (d)	Error* (10^{-6} d)	Ecl. dur. (**)	Obs. 383 (***)	Comment (****)
1.470243	10	0.15		B
2.484902	10	0.13		B
2.778391	10	0.13	E	B
3.207928	10	0.14		
4.969849	20	0.13	E	B
6.190937	20	0.14		B, E-
7.671308	20	0.15		E-

Notes:

* : determined to achieve longest possible eclipse duration

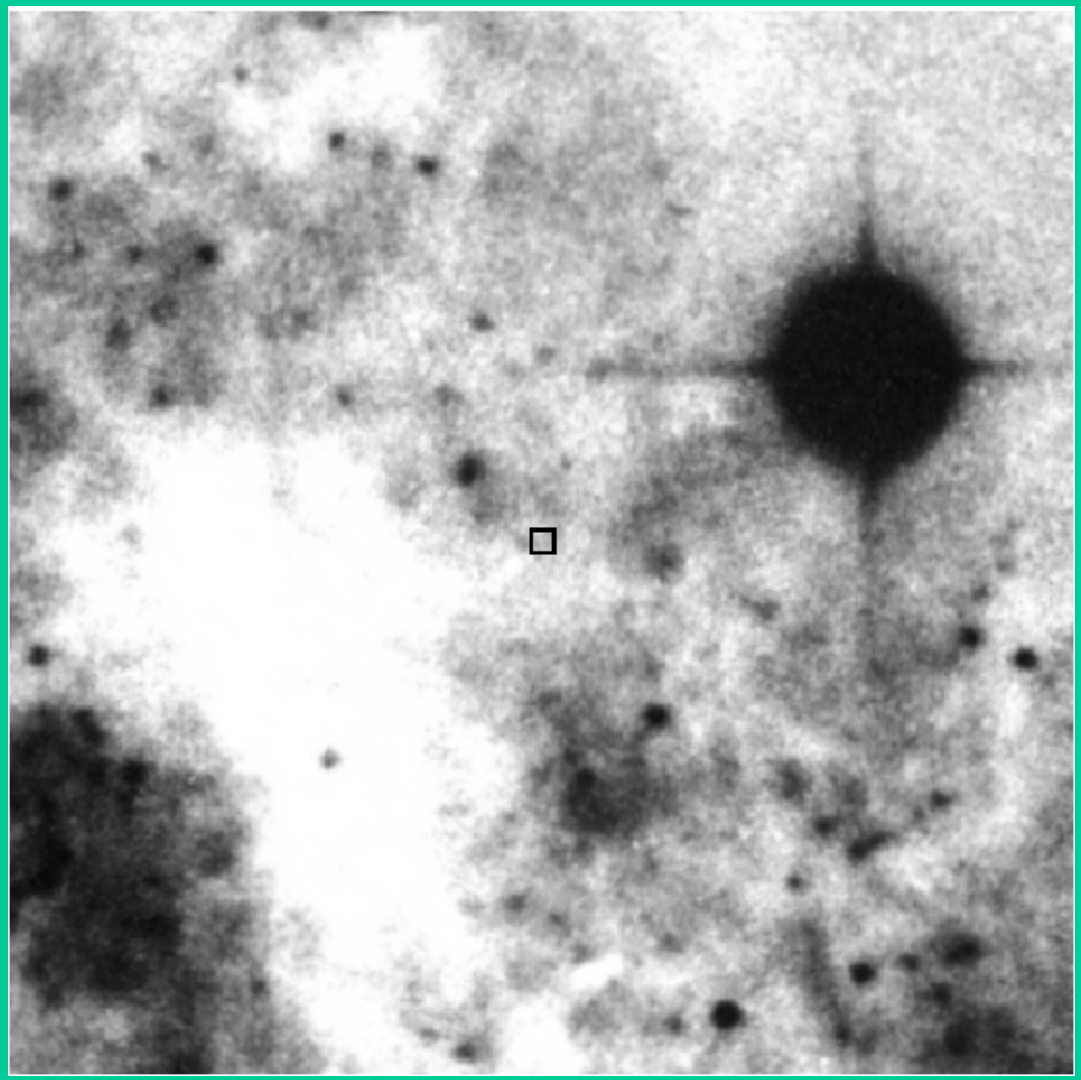
** : maximum allowed eclipse duration (Δphase)

*** : E if RX J004717.4-251811 in eclipse during *Chandra* 383

****: B period at boundary of allowed window, E- no *Einstein* exposure during eclipse

Best period candidates: **1.470243 d, 3.207928 d**

Position of RX J004717-251811 on a deep optical image



Optical counterpart of HMXRB:

LMC/SMC:
14.0-13.3 mag

NGC 253:
> 23 mag

VLT deep imaging in 0.6 arcsec seeing

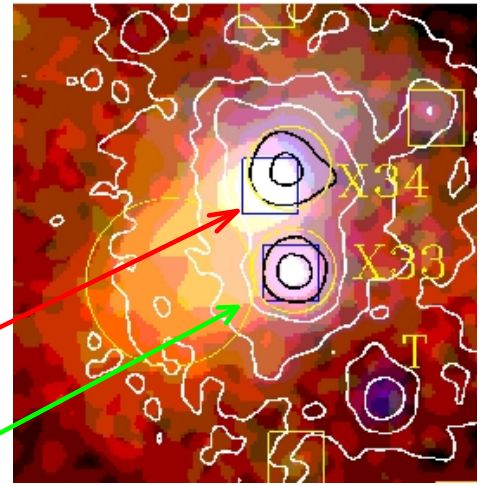
RX J004717.4-251811: Summary and outlook

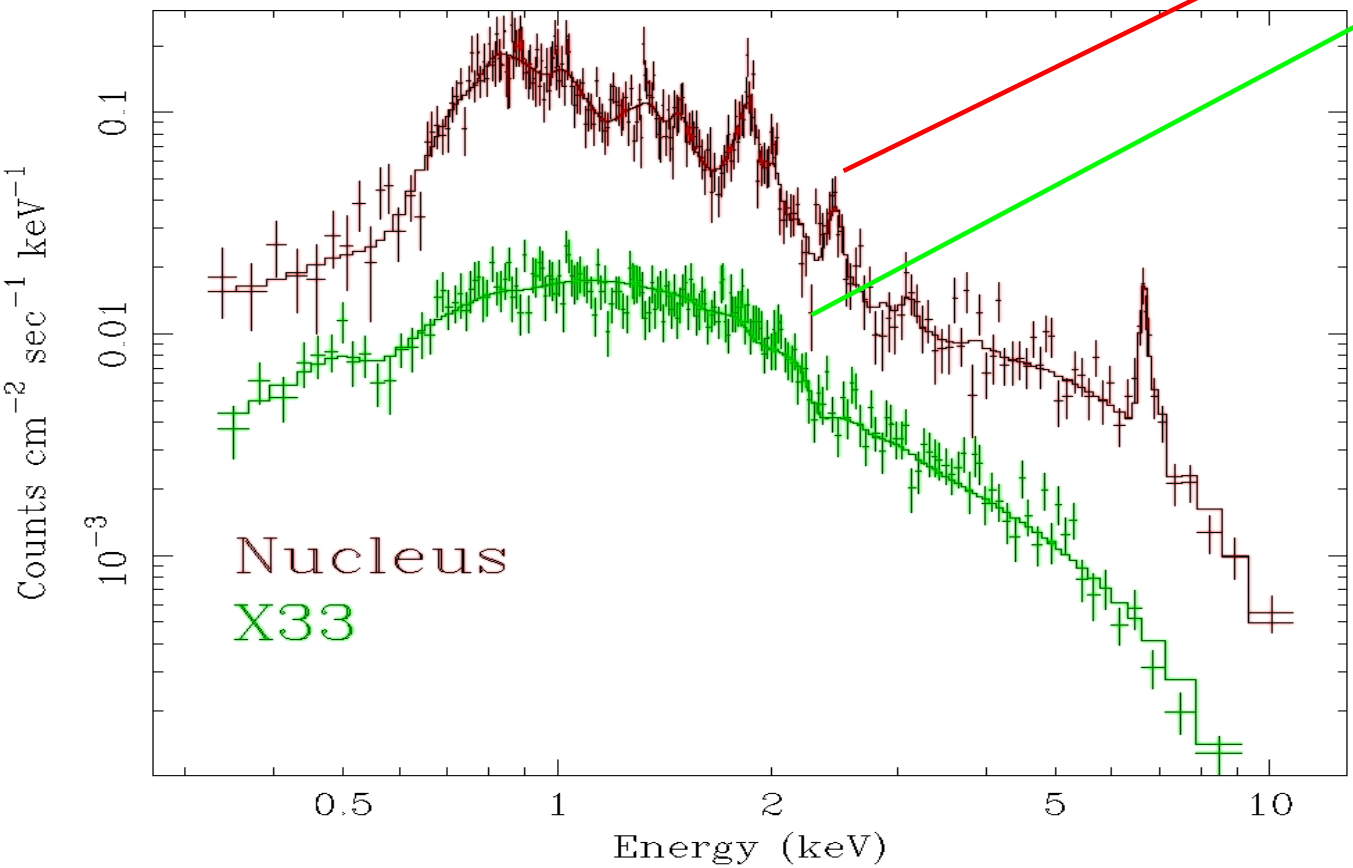
- **Change of intensity state in XMM-Newton and Chandra observation => XRB eclipse egresses**
- **First eclipsing XRB outside Local Group**
- **Using all XMM-Newton, Chandra, ROSAT and Einstein HRI observations => best periods 1.47 d and 3.21 d**
- **No pulsations detected**
- **Optical counterpart?**
- **HMXRB, showing long term variability and flares similar to LMC X-4**

Long AO2 XMM-Newton (140 ks) and Chandra (85 ks) observations will cover 1.4 d orbit, hopefully RX J004717.4-251811 in high state

EPIC PN spectra

- **nuclear area**
- **X33 (BH XRB)**

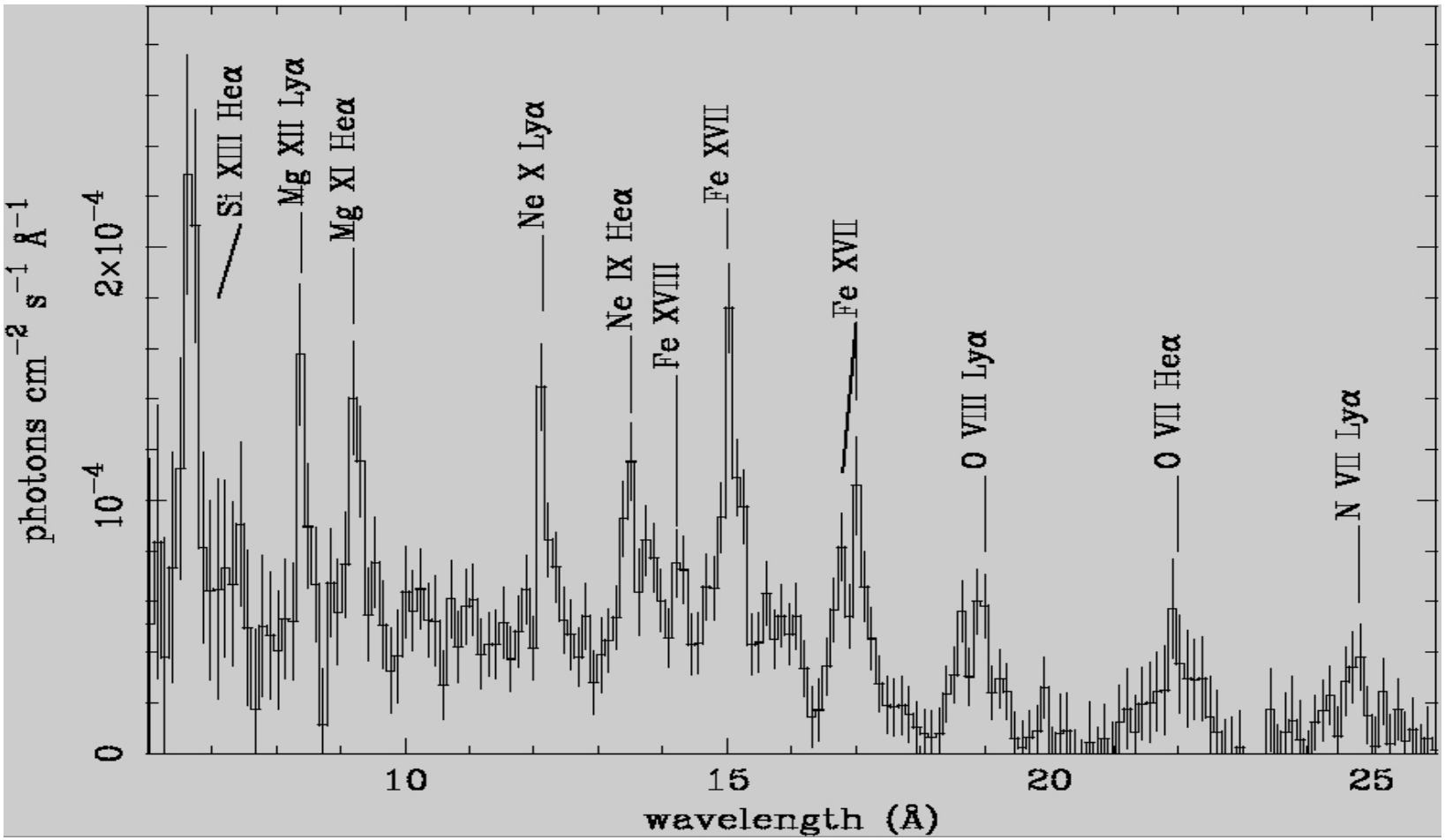




3 MEKAL spectra
N_H = (0.3, 1.8, 13) x 10^{22} cm^{-2}
kT = (0.6, 0.9, 6.3) keV

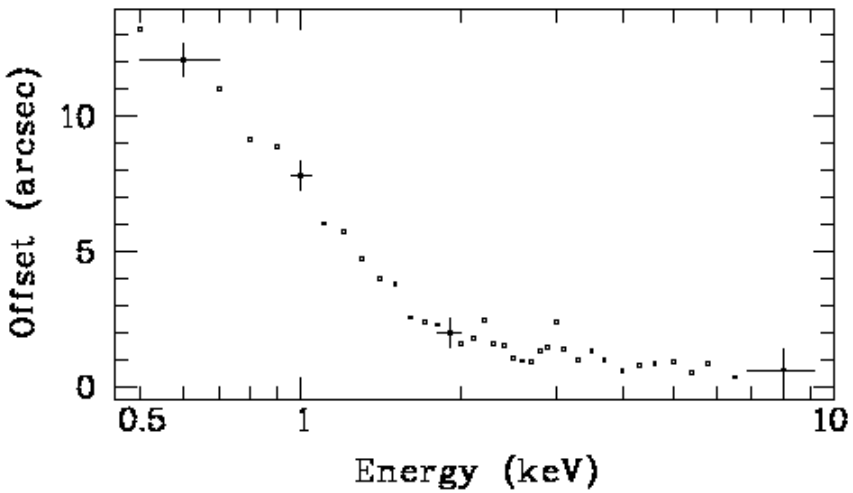
DiskBB
N_H = 5 10^{21} cm^{-2}
kT = 1.6 keV
$r_{in}(\cos i)^{0.5}$ = 10 km
photon index 4.3

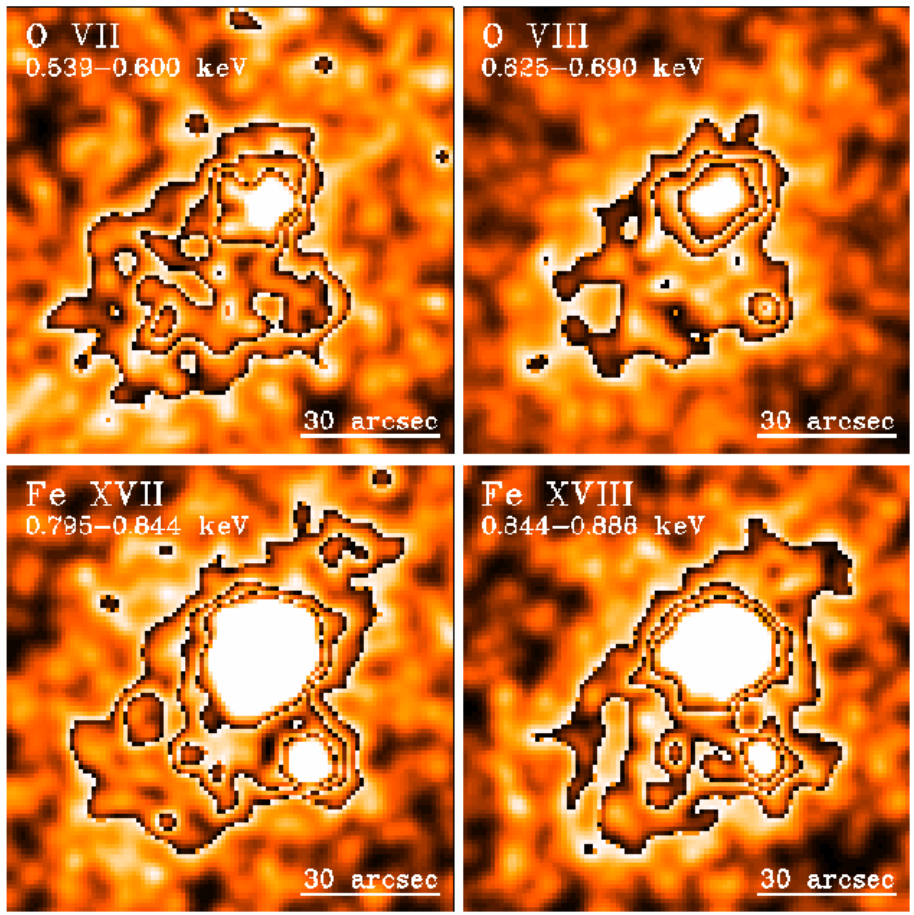
XMM-Newton RGS spectra of NGC253 nuclear area



- **RGS spectrum is dominated by nuclear outflow emission**
- **kT = 0.3-1.5 keV, *collisionally* ionized**

Energy dependence of nuclear position and images in emission line region of different ionisation states





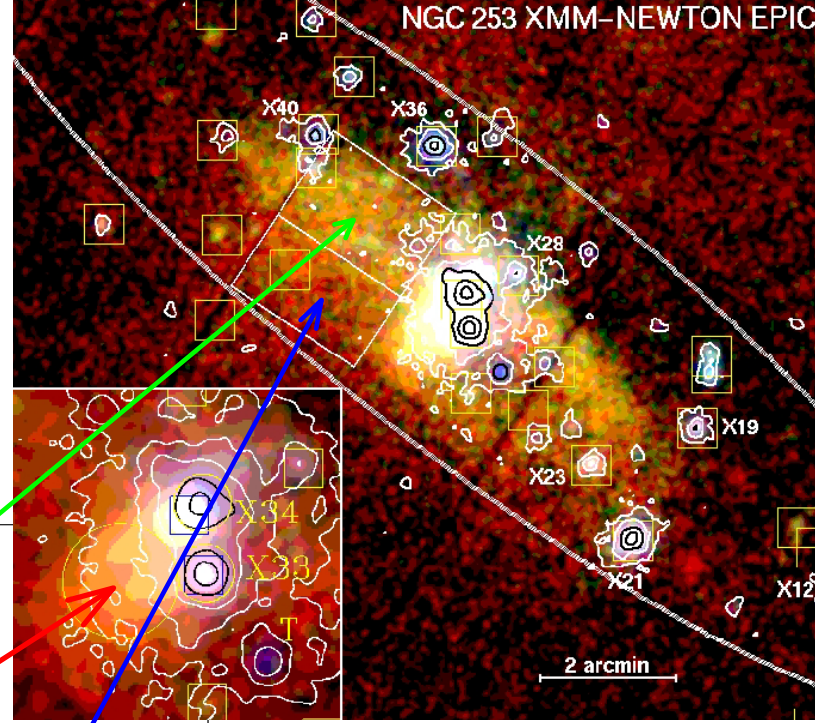
At the distance of NGC253 10“ correspond to 125 pc

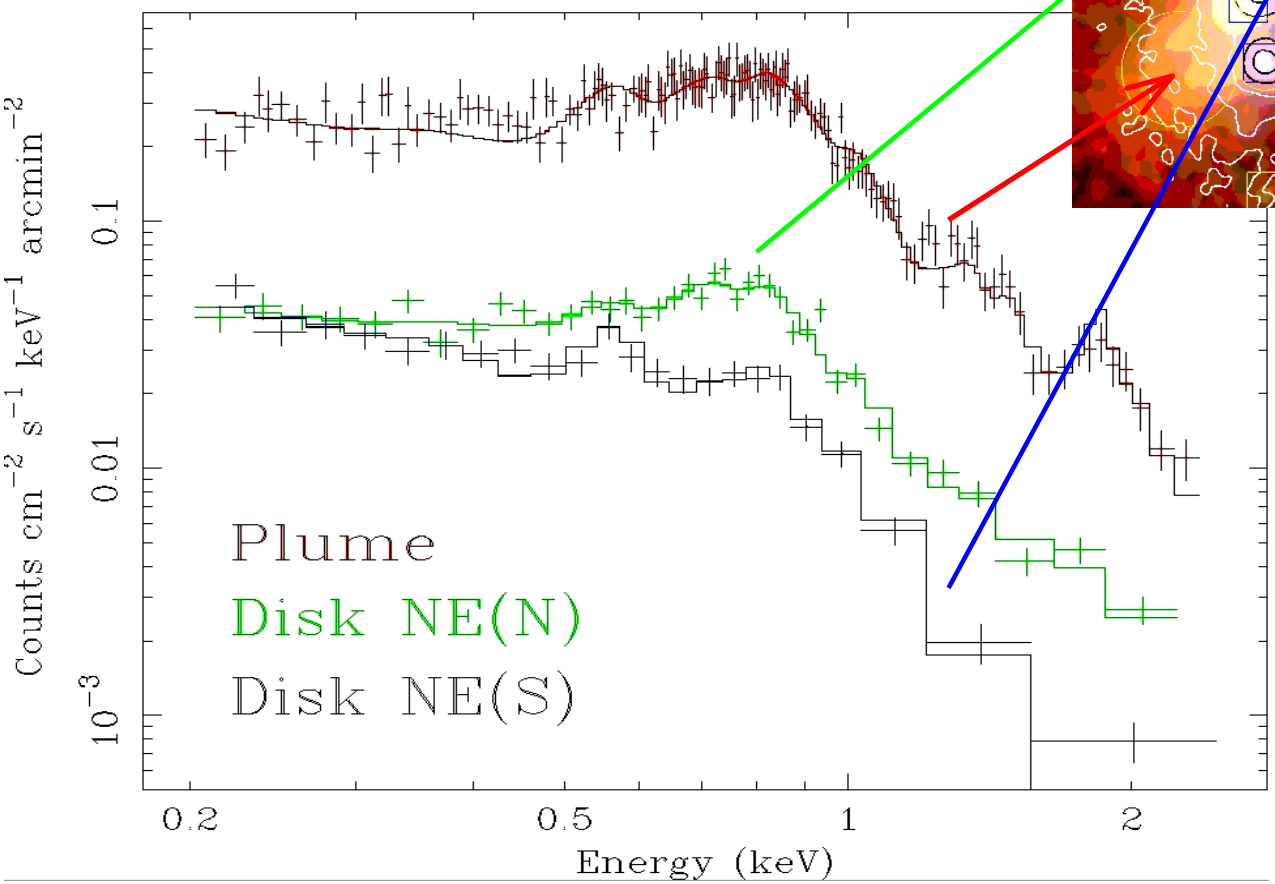
NGC 253 ISM EPIC PN spectra

Plume: 3 MEKAL spectra

$N_H = (0, 0, 1.3) \times 10^{21}$ cm^{-2}

kT = (0.15, 0.5, 0.9) keV





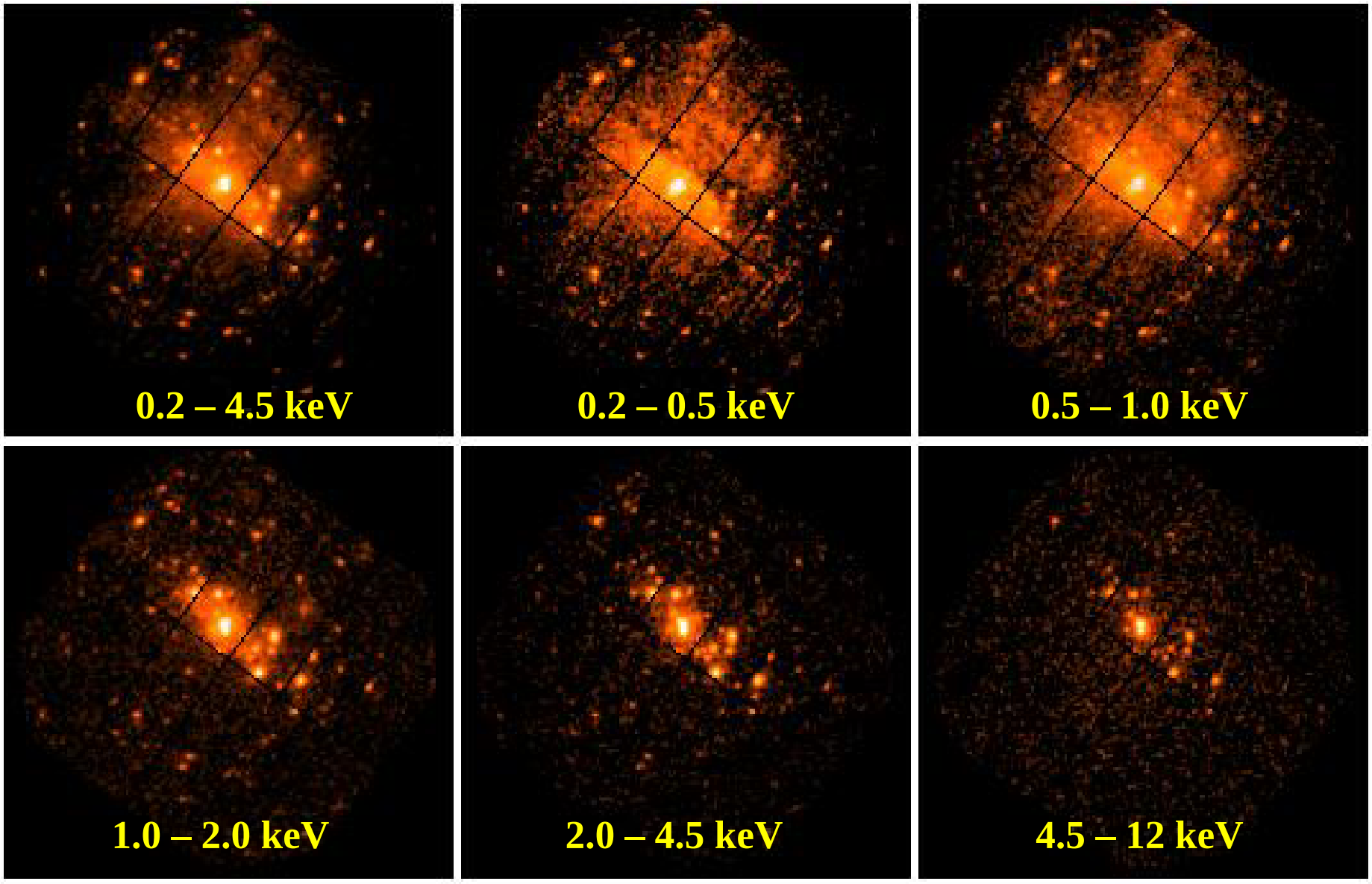
Disk NE (N and S) 2 MEKAL spectra:

0.13 keV unabsorbed (from near halo)

+

0.5 keV absorbed (from within disk)

XMM-Newton NGC 253 AO2 EPIC PN

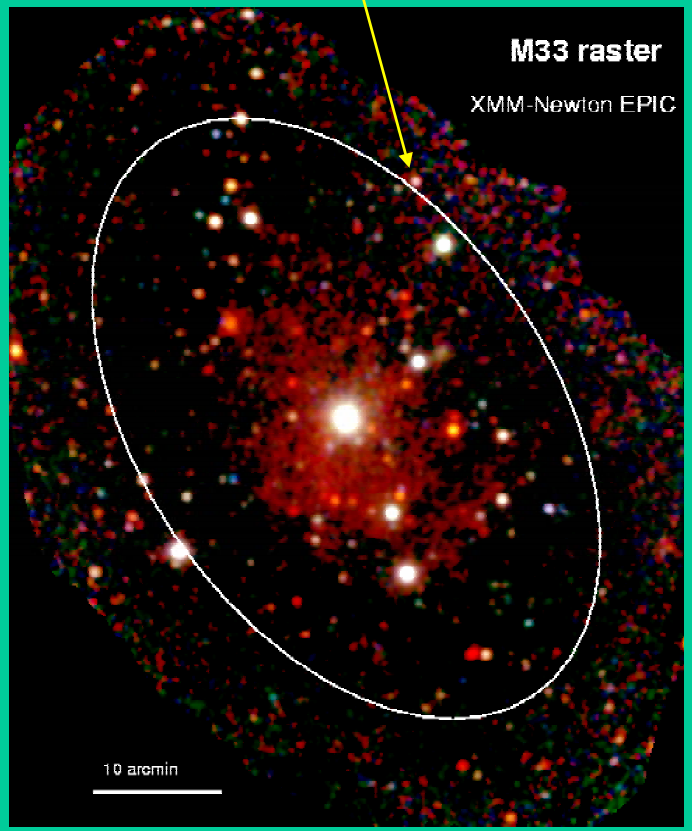


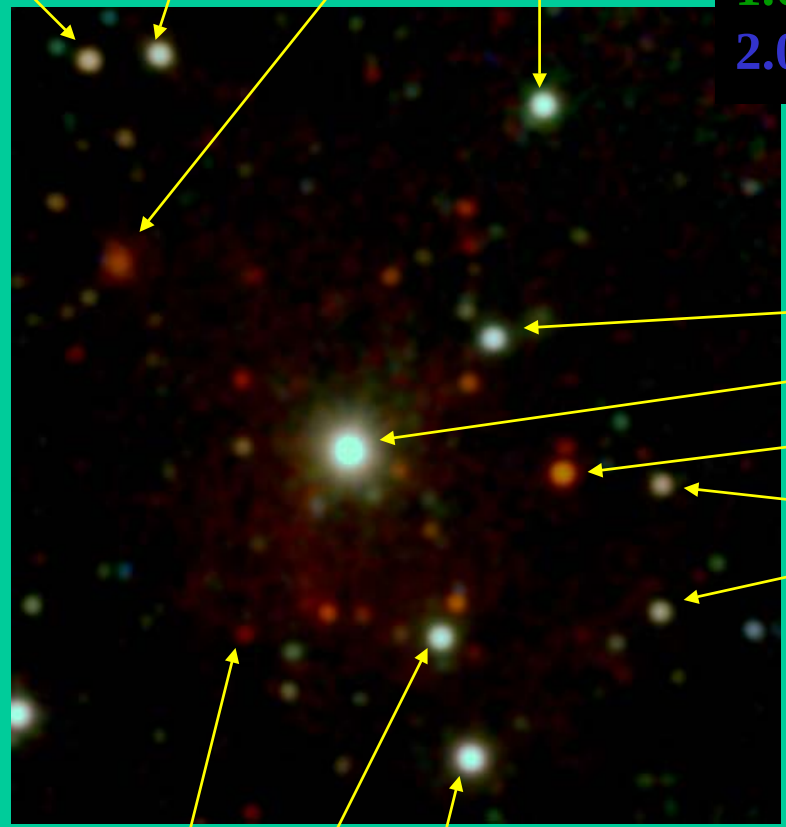
Summary

- **Nuclear and plume emission**
- **XRB, transients, SNR in disk**
- **ISM in disk**
- **Hot gas (~0.15 keV, filamentary) in halo**
- **Advantage of simultaneous multi-instrument observation for NGC 253 nuclear area**

Combination of XMM-Newton collecting power and Chandra resolution for interpretation

XMM-Newton view of M33
EPIC colour images

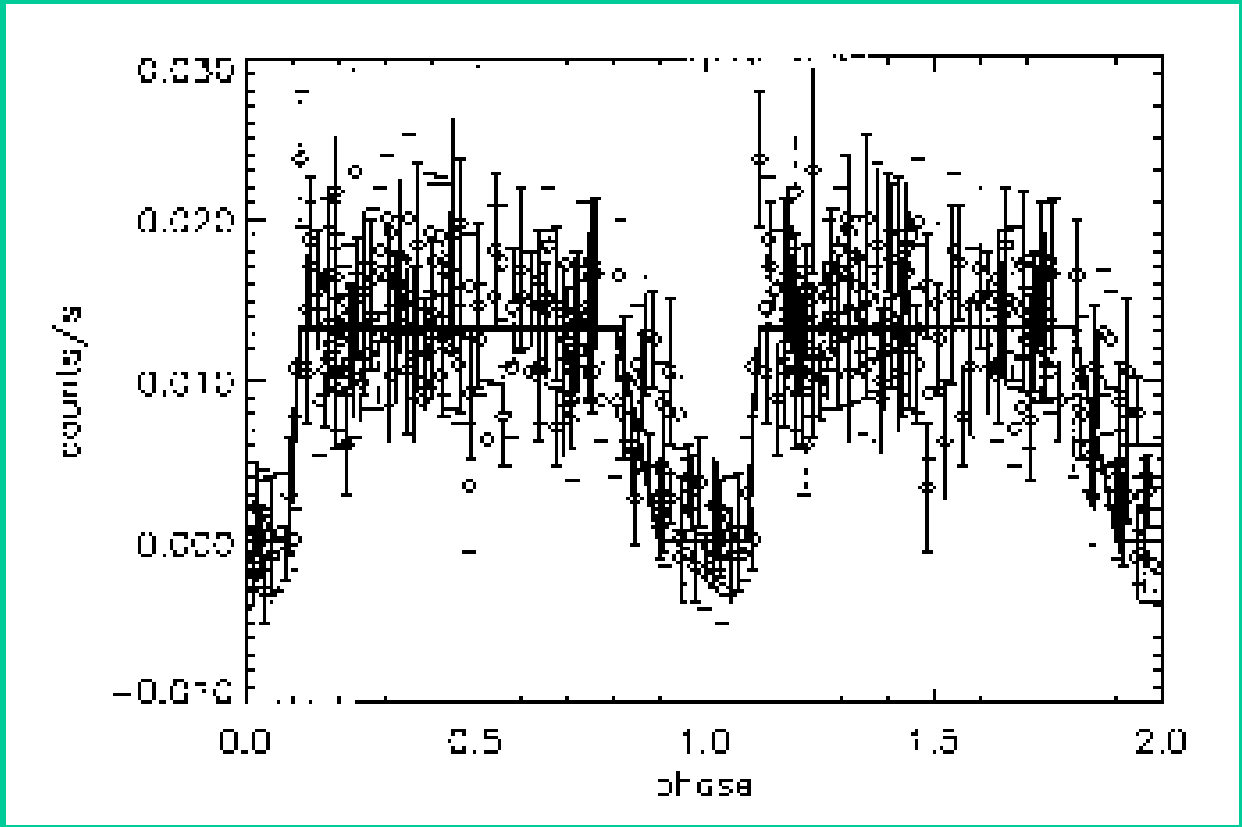




0.2 – 1.0 keV
1.0 – 2.0 keV
2.0 – 4.5 keV

Xn1
X-9a
X-9b
NGC604
X-4
X-5
X-8
X-3
X-1
X-2
Xn2
X-7
X-6

Eclipsing X-ray binary M33 X-7



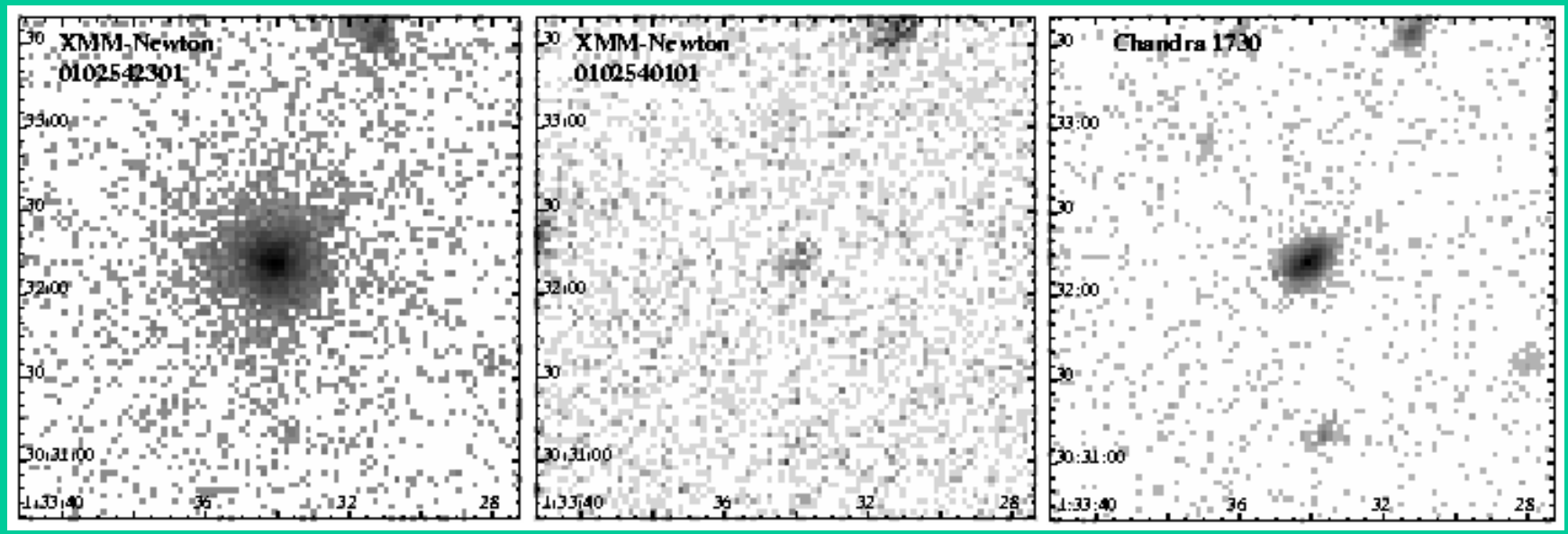
Einstein + ROSAT observations:

3.45 d period **0.31 s pulsation?**

Peres et al. 1989, ApJ 336, 140; Dubus et al. 1999, MNRAS 302, 731

Eclipsing X-ray binary M33 X-7

W. Pietsch, B.J.Mochejska, Z.Misanovic, F.Haberl, M.Ehle,
G.Trinchieri 2004, A&A 413, 879

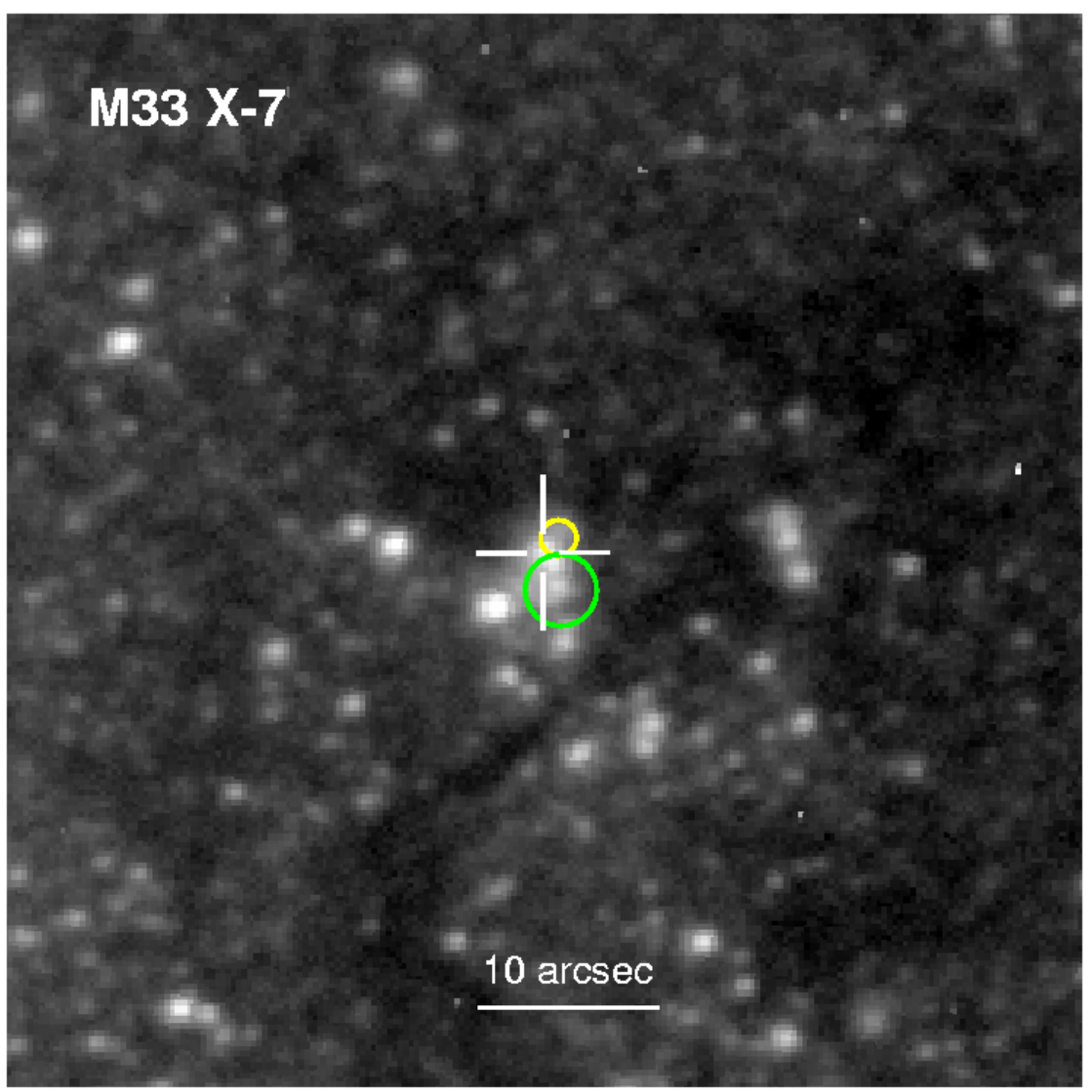


On state **Eclipse** **On state**

XMM-Newton EPIC **Chandra ACIS I**

0.5-4.5 keV images

Eclipsing X-ray binary M33 X-7



Optical identification

Star with V 18.9 mag with 3.45 d variability in unresolved emission

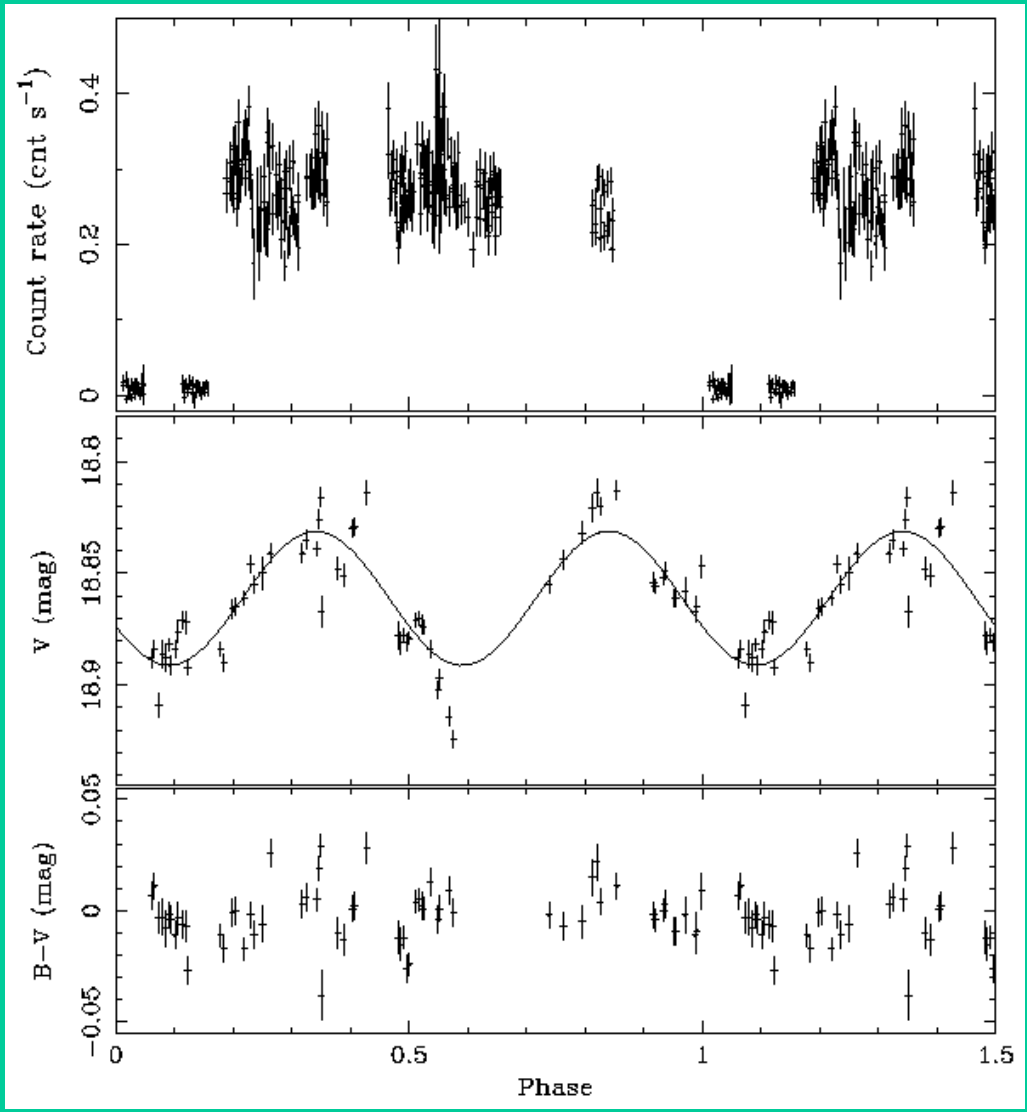
DIRECT image by B. Mochejska

Green circle: ROSAT error box

Haberl & Pietsch 2001

Yellow circle: Chandra error box

Eclipsing X-ray binary M33 X-7



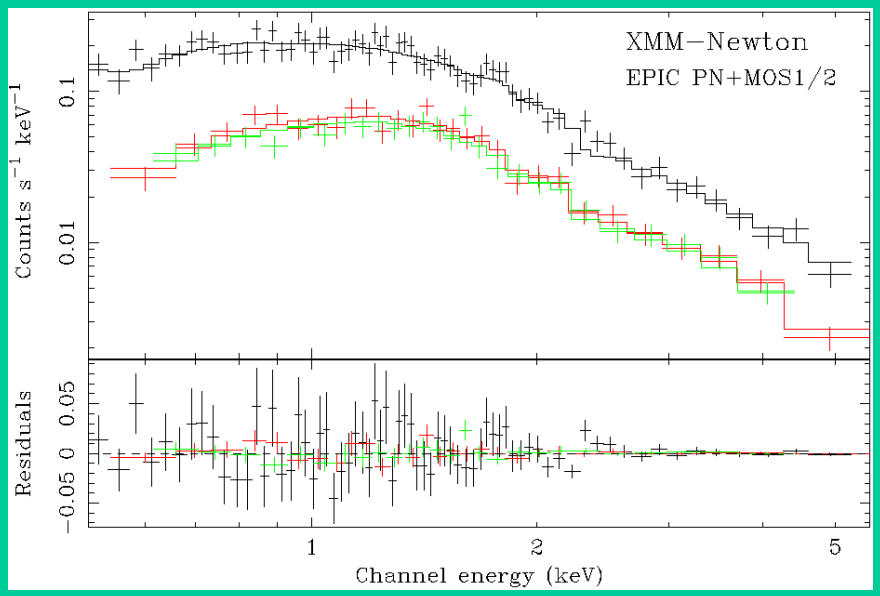
XMM-Newton EPIC TS GT and AO2

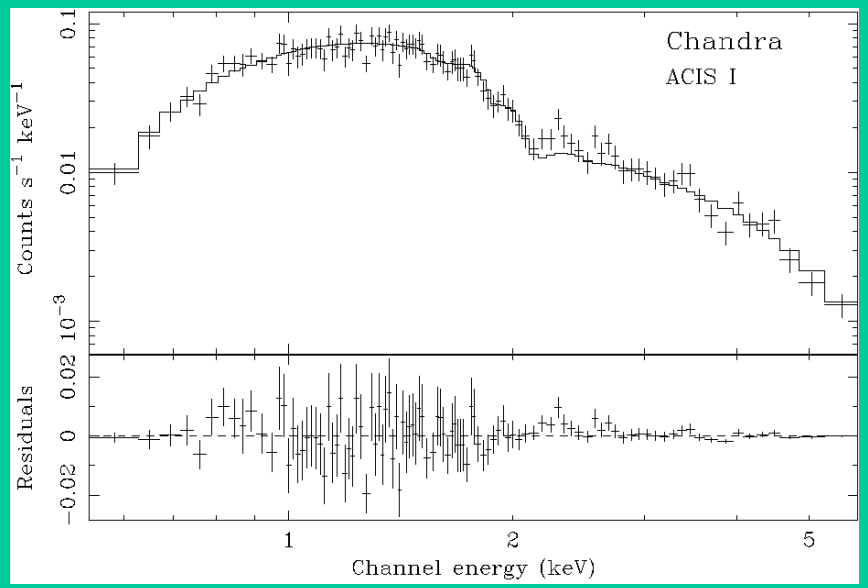
Chandra archive

Optical V and B-V light curve re-analysis of DIRECT data by B. Mochejska

Improved binary ephemeris

Eclipsing X-ray binary M33 X-7





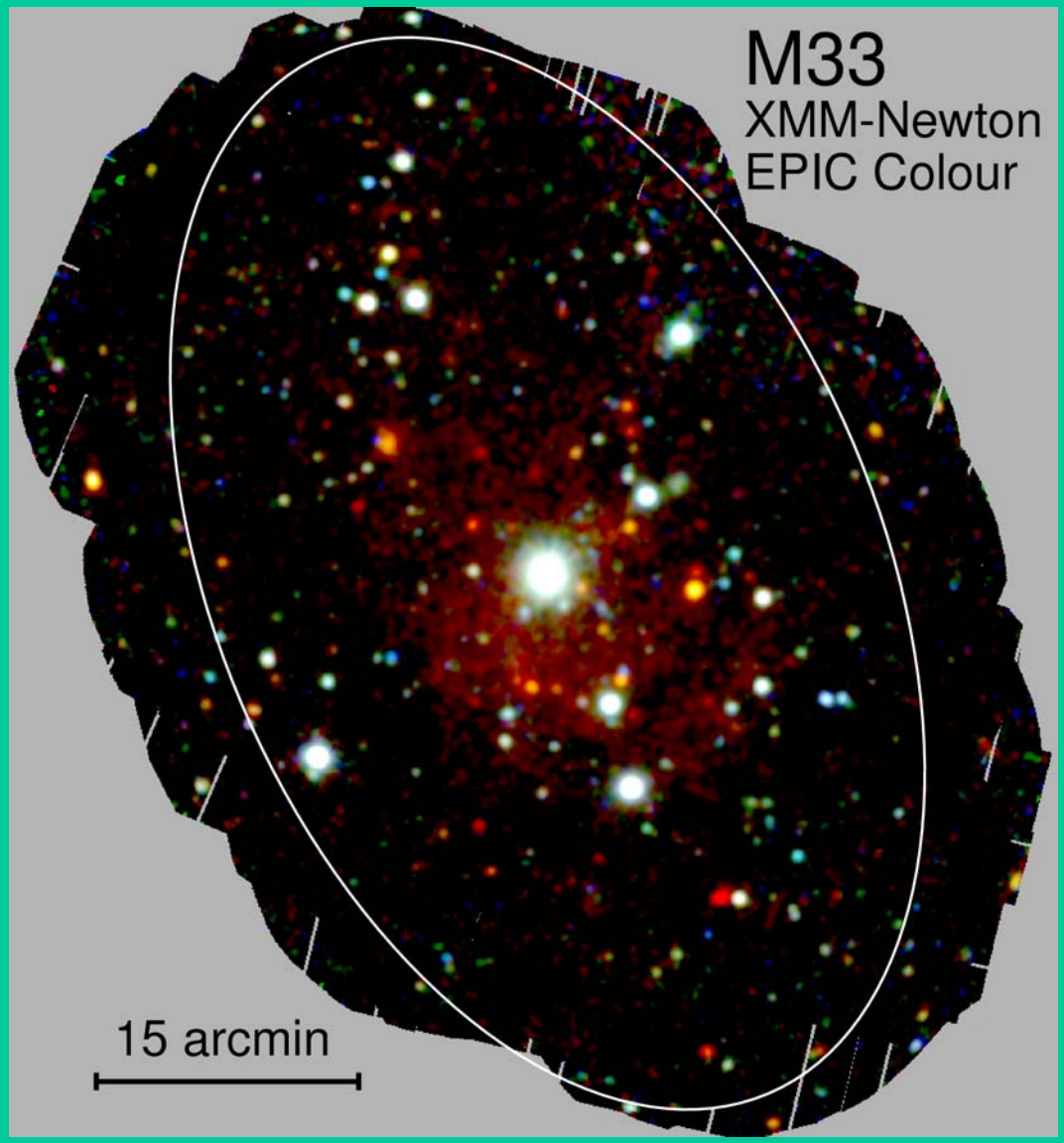
Best fitting spectral models:
Absorbed bremsstrahlung or disk blackbody

First eclipsing black hole (high mass) X-ray binary ?
Dedicated XMM-Newton AO3 proposal for pulsations and spectra, not accepted

XMM-Newton survey of the Local Group galaxy M33

W.Pietsch, Z.Misanovic, F.Haberl,
D.Hatzidimitriou, M.Ehle, G.Trinchieri

2004, A&A submitted



408 X–ray sources

X-ray properties

Correlation with catalogues from other wavelength

Optical identification

Identify foreground and background sources

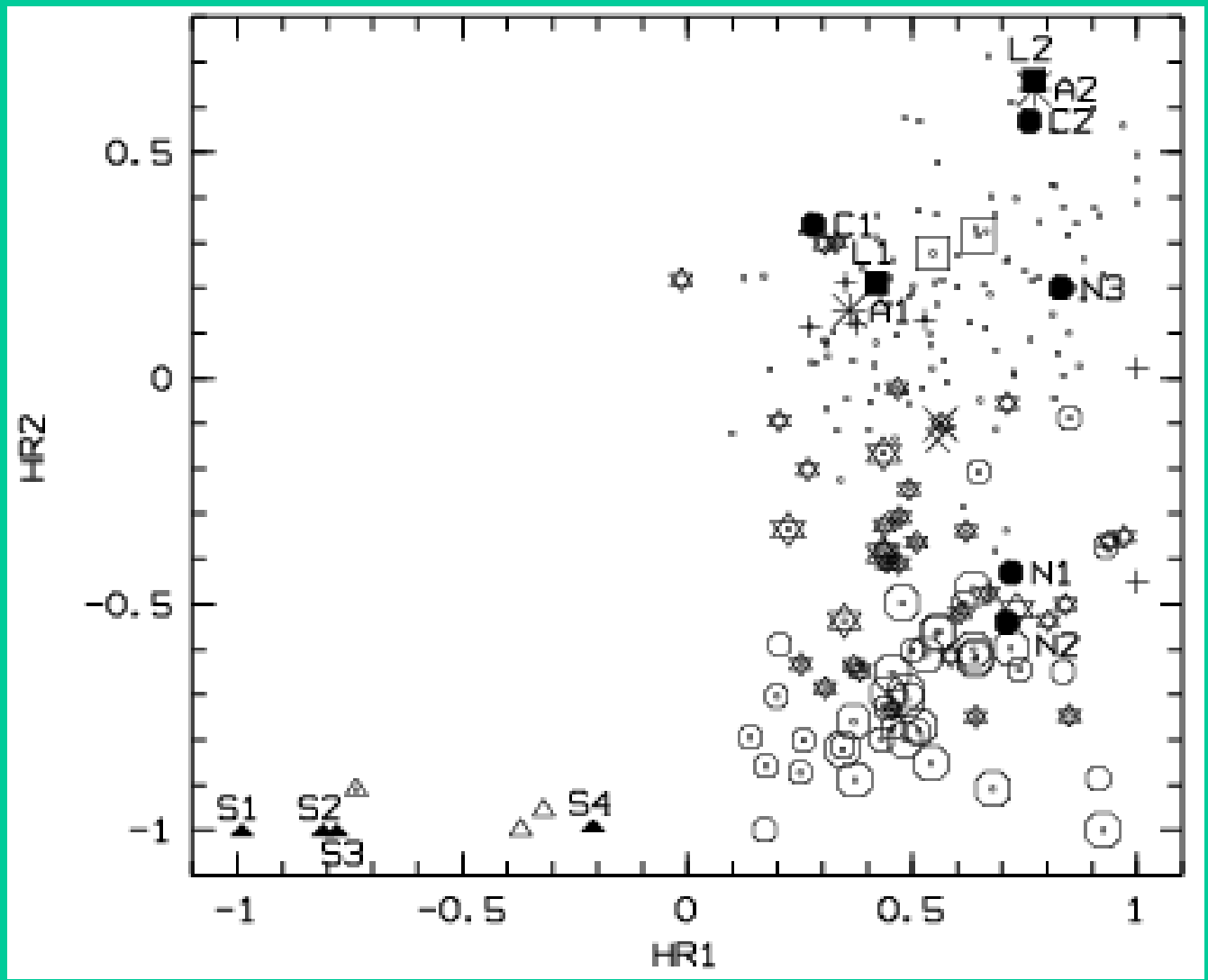
Characterisation of X-ray source population of M33


M33 zoom in

Hardness ratio plots of M33 sources

$HR_i = (B_{i+1} - B_i)/(B_{i+1} + B_i)$

B1: 0.2-0.5 keV
B2: 0.5-1.0 keV
B3: 1.0-2.0 keV
B4: 2.0-4.5 keV
B5: 4.5- 12 keV



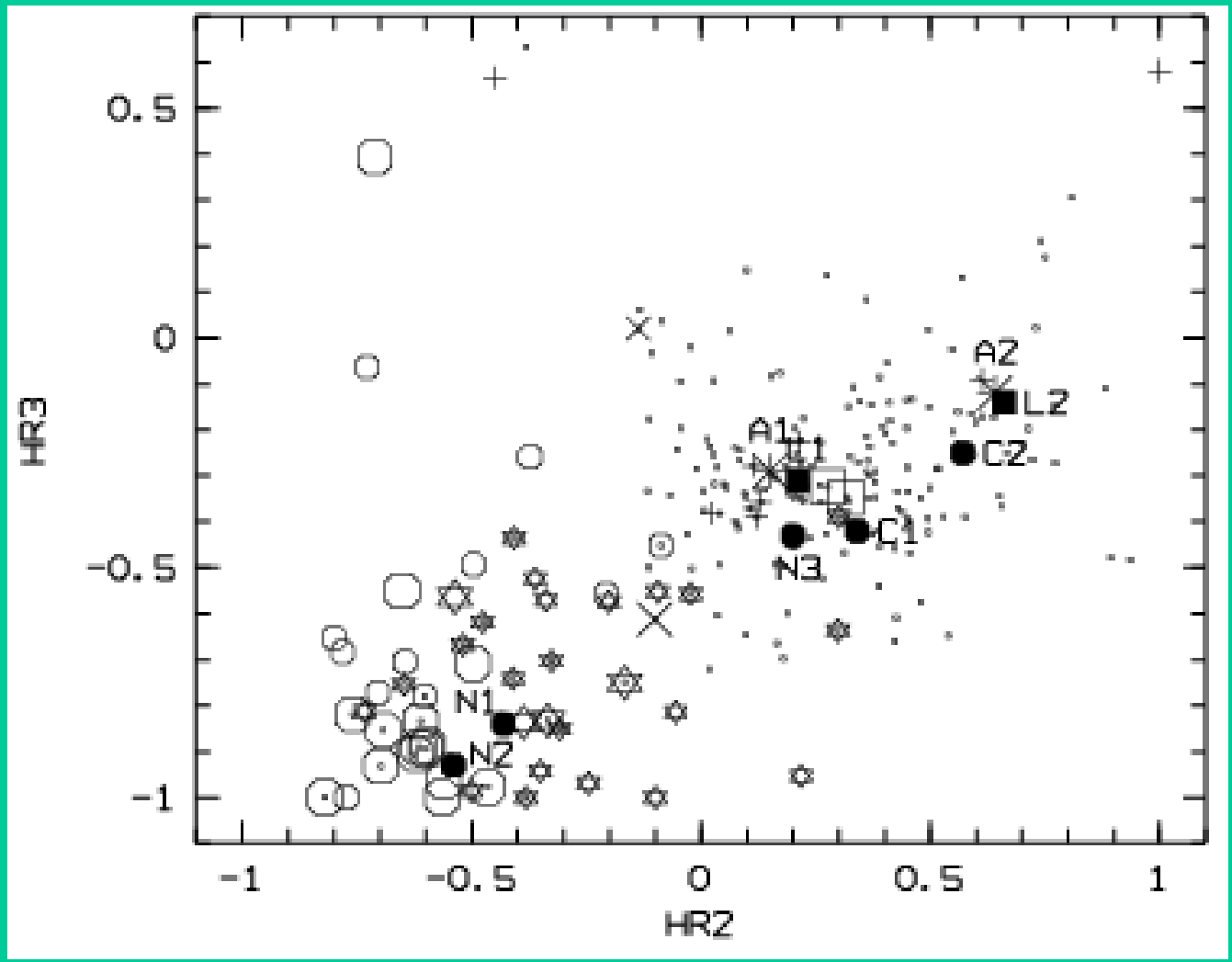
fg-star
AGN

SSS
SNR
XRB

Hardness ratio plots of M33 sources

$HRi = (Bi+1 - Bi)/ (Bi+1 + Bi)$

B1: 0.2-0.5 keV
B2: 0.5-1.0 keV
B3: 1.0-2.0 keV
B4: 2.0-4.5 keV
B5: 4.5- 12 keV



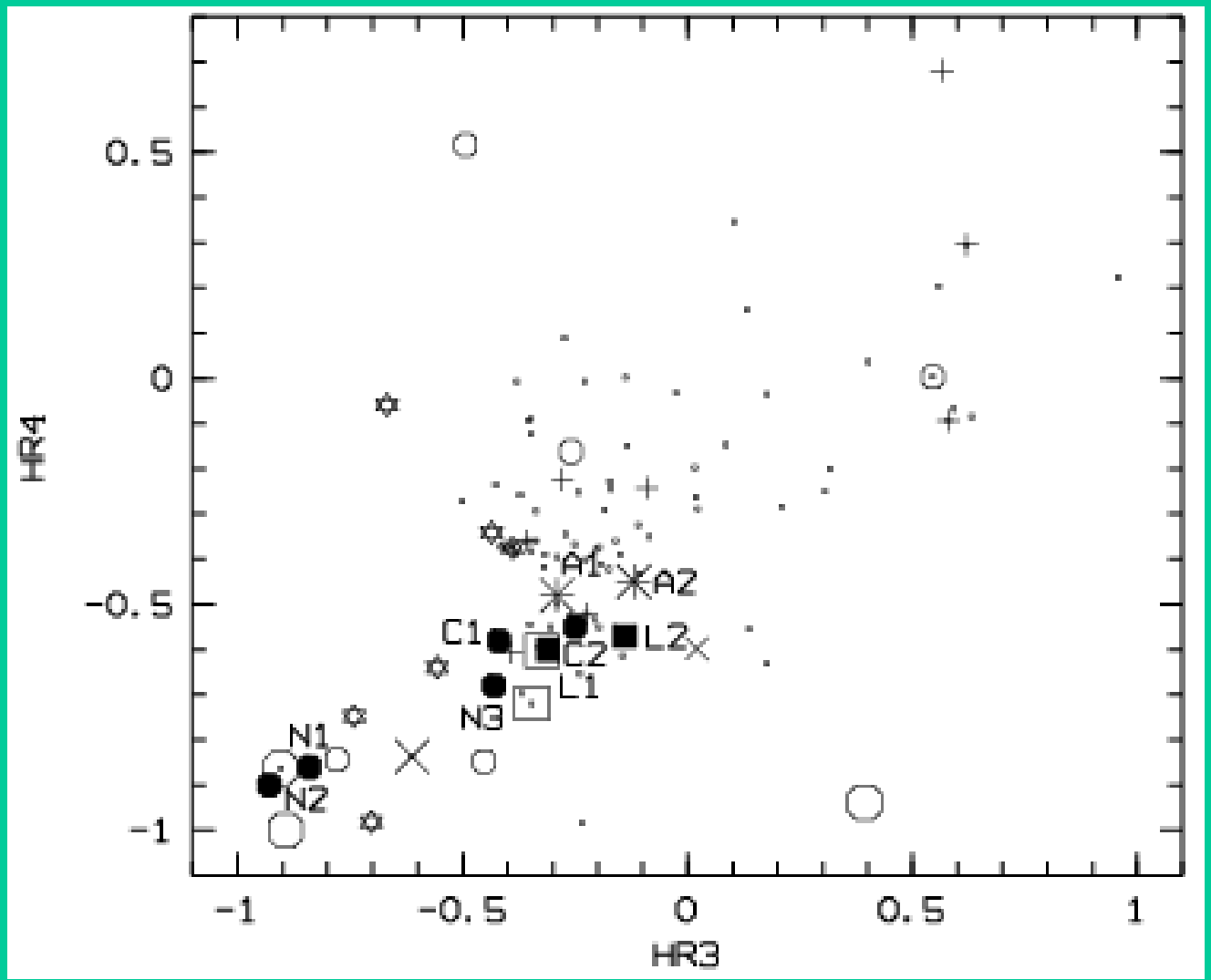
fg-star
AGN

SSS
SNR
XRB

Hardness ratio plots of M33 sources

$HRi = (Bi+1 - Bi)/ (Bi+1 + Bi)$

B1: 0.2-0.5 keV
B2: 0.5-1.0 keV
B3: 1.0-2.0 keV
B4: 2.0-4.5 keV
B5: 4.5- 12 keV

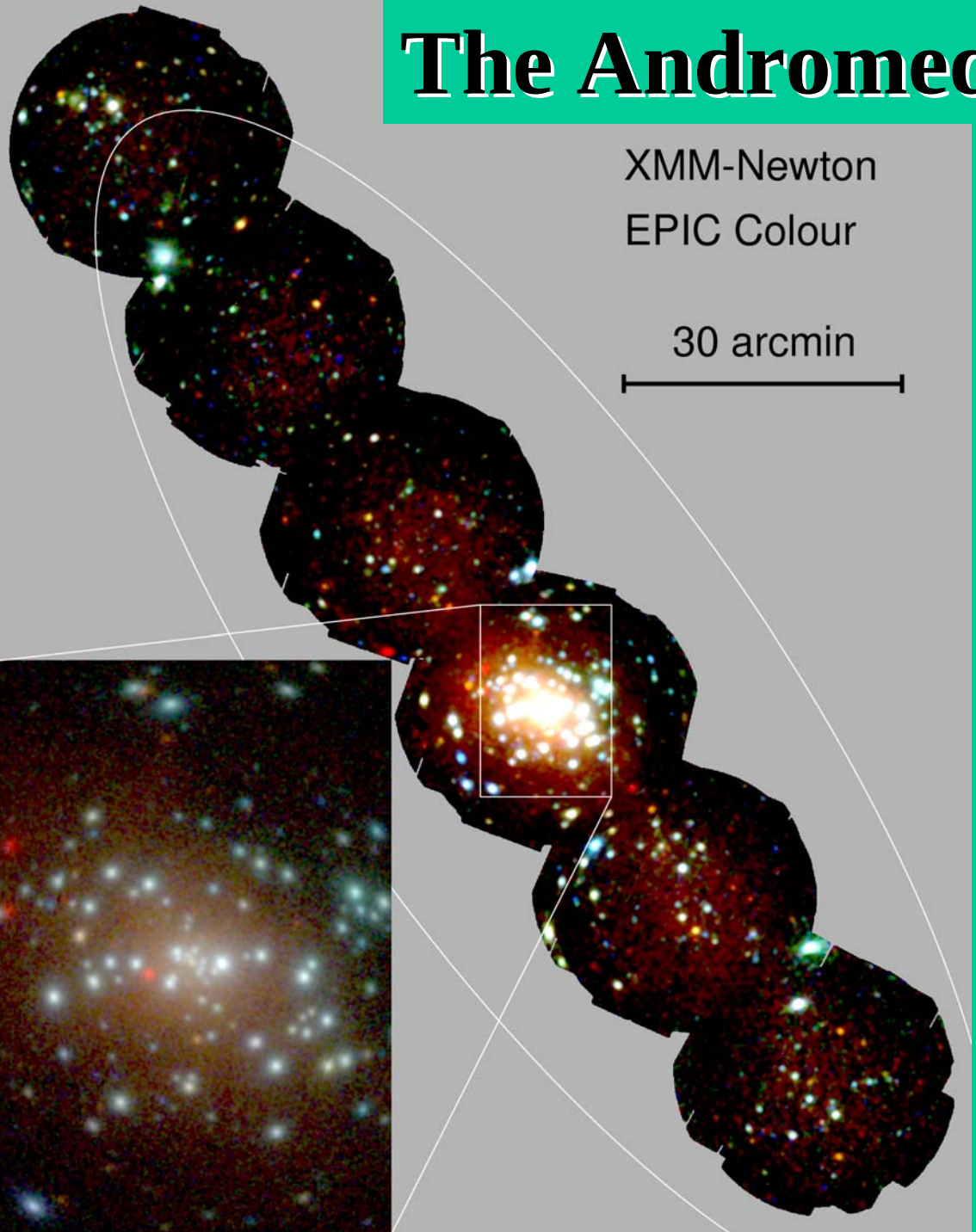


fg-star
AGN
SSS
SNR
XRB

X-ray sources in M33 field: identification and classification

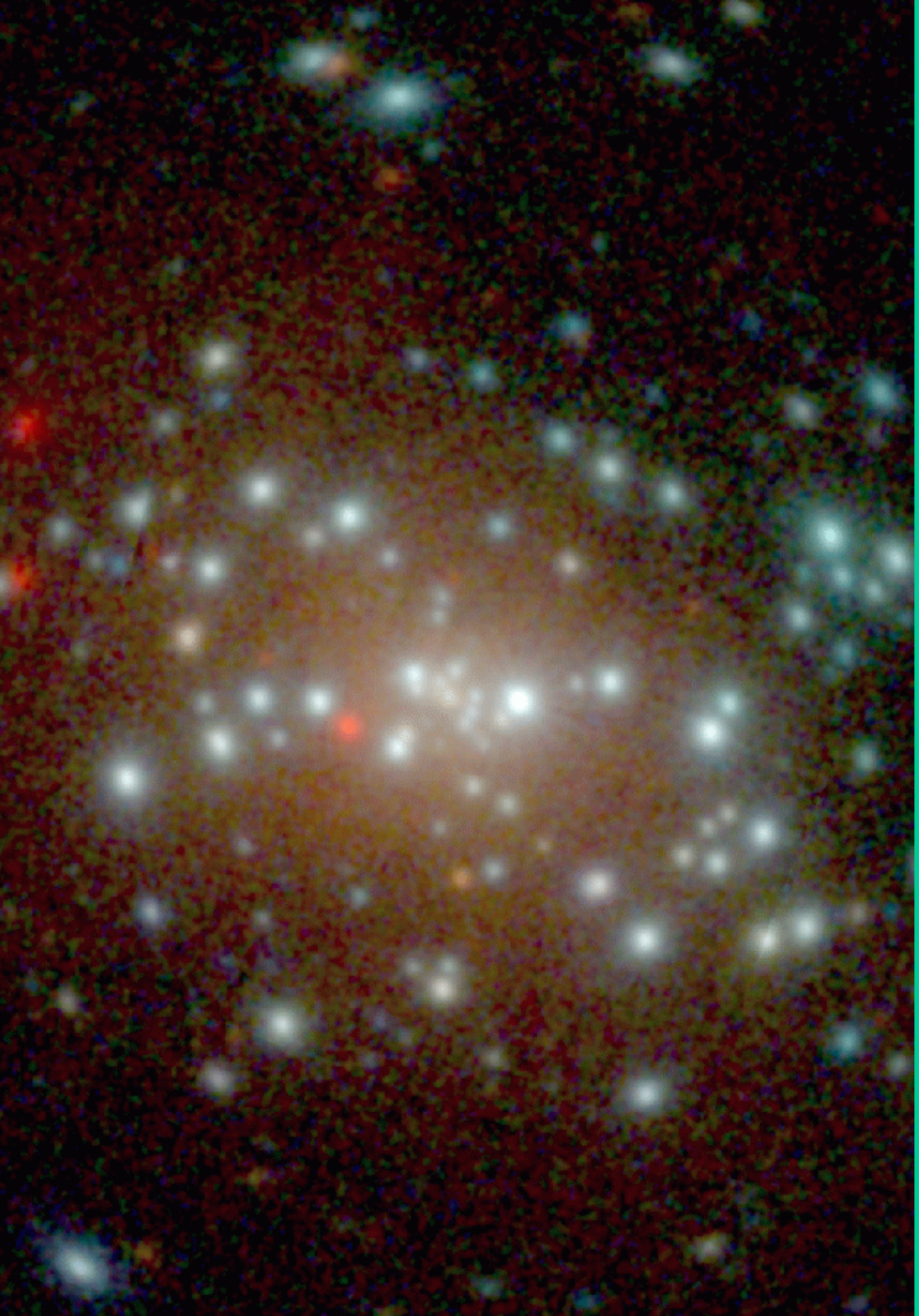
	identified	classified
• foreground stars	5	30
• AGN		12
• Galaxies	1	1
• SSS		5
• SNR	21	23
• XRB	2	
• Hard		267

The Andromeda Galaxy M31



W.Pietsch, M.Freyberg, F.Haberl et.al. 2004, in preparation

- Similar analysis to M33 on archival data
- more than 800 sources in fields
- Hardness ratio and time variability
- classification and identification in progress

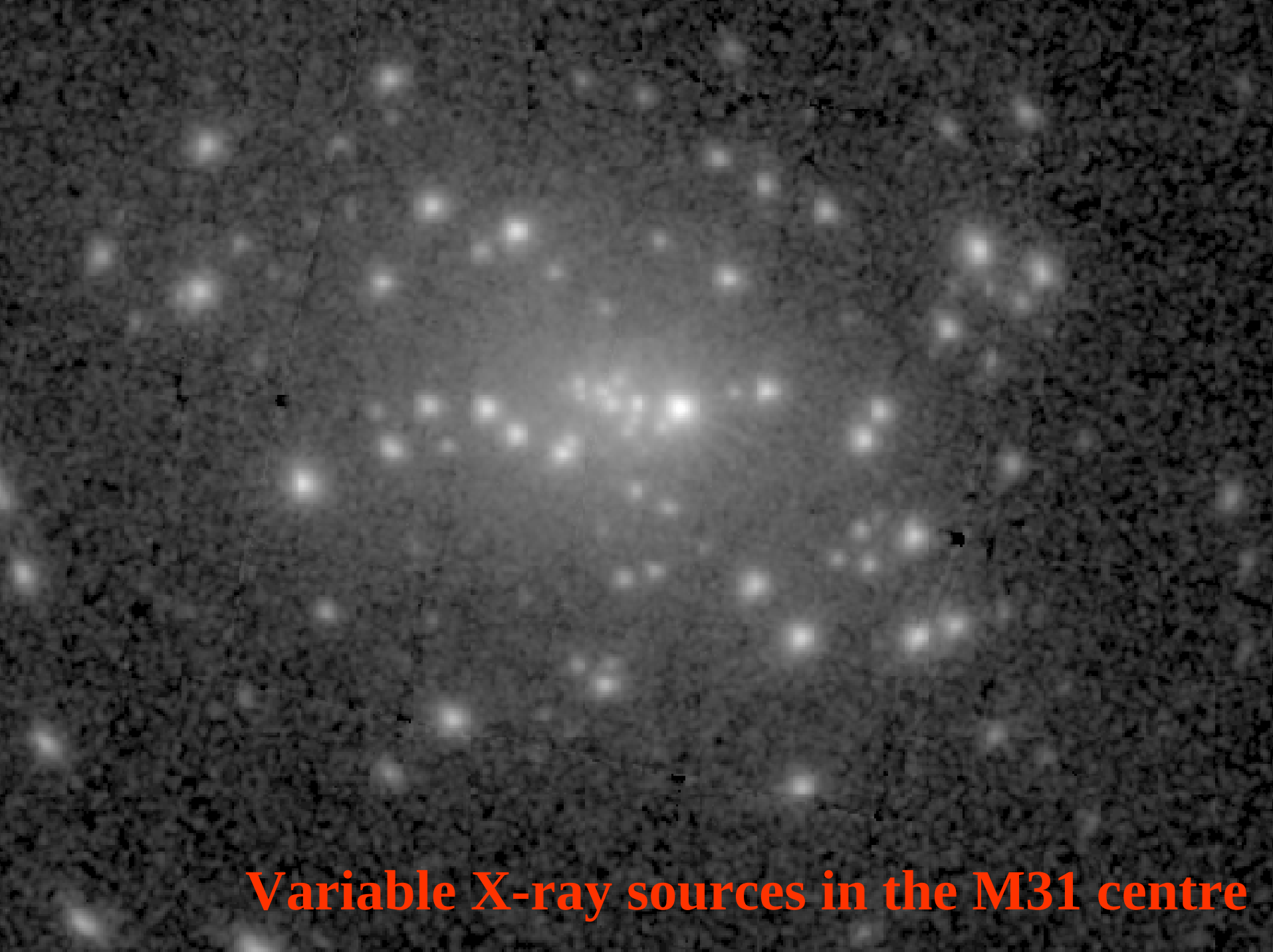


M 31 centre

All EPIC mosaic (~100 ks)

- Many LMXBs
- Galaxtic center sources not fully resolved
- SNRs
- foreground stars
- diffuse emission

Movie of centre area by blinking four observations with separation of half a year


Variable X-ray sources in the M31 centre