The X-Ray Source Population of the Andromeda Galaxy M 31

Wolfgang Pietsch

Max Planck Institut für extraterrestrische Physik

Outline

- Introduction to X-ray source populations in galaxy fields
- X-ray source population of the Andromeda galaxy M 31 field mainly based on XMM-Newton observations
  - Type I X-ray burst sources in M 31
  - Optical novae in M 31 as supersoft sources
  - Identification of new supernova remnants in M 31
  - Source classification by time variability in center area of M 31
- First results from XMM-Newton M 31 large program
- Prospects for future XMM-Newton observations of nearby galaxies

Introduction: X-ray sources in nearby galaxy fields

- Within galaxy (all approximately same distance)
  - X-ray binaries (XRBs)
    - Low mass XRBs (?dips with orbital period, bursts, ...)
    - High mass XRBs (?eclipses with orb. period, pulsations, optical id,...)
    - Bright transients
  - Supersoft X-ray sources
    - Classical SSS as known from Magellanic Clouds
    - Optical novae
  - Supernova remnants
    - Thermal remnants
    - Plerions
  - Nuclear source
  - Ultraluminous X-ray sources
  - Diffuse emission in disk and halo
- Foreground stars
- Galaxies, galaxy clusters and AGN in background

X-ray observations of M 31 (II)

- Observations with Chandra

  central region (ACIS-I and HRC 204 and 142 sources)
  Garcia et al. 2000, Kong et al. 2002, Kaaret 2002

  3 disk fields Kong et al. 2002

  inner disk with HRC (116 sources) Williams et al. 2004

  SNRs spatially resolved Kong et al.2002, 2003, Williams et al. 2004

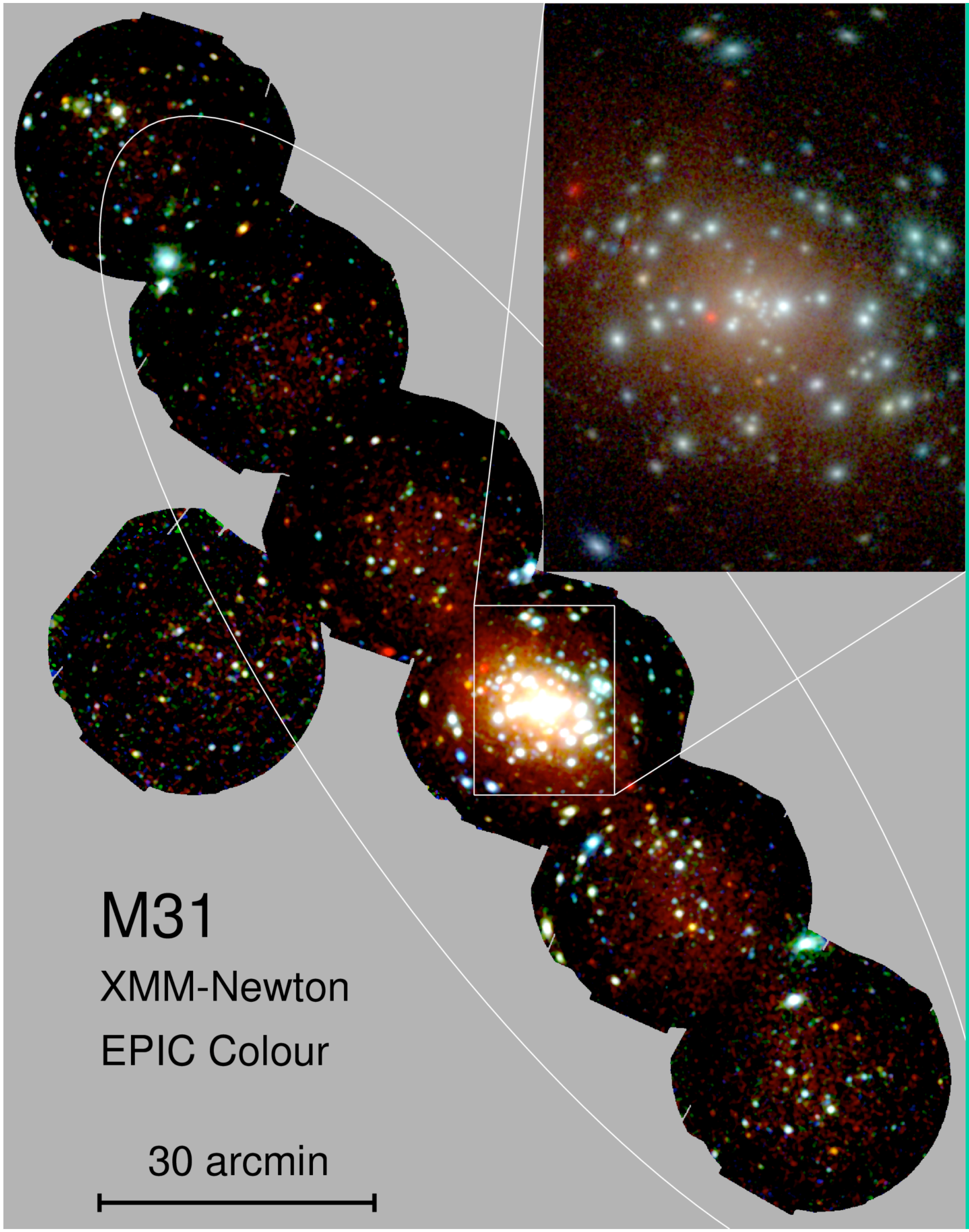
  XRBs in GC Di Stefano et al. 2002

  SSS and QSS Di Stefano et al. 2004, Greiner et al. 2004

- XMM-Newton observations

  6 pointing directions along major axis (center area with several exposures), halo pointings

  results on individual sources or source classes, time variability
  Shirey et al. 2001, Osborne et al. 2001, Trudolyubov et al. 2001, 2002, 2004, 2006, Barnard et al. 2003, 2004, 2005, Mangano et al. 2004



The Andromeda Galaxy M 31

W. Pietsch, M. Freyberg, F. Haberl et.al. 2004, A&A 434, 483

- Similar analysis to M 33 based on archival data
- 856 sources in fields
- Hardness ratio and time variability
- classification and identification

M 31 centre

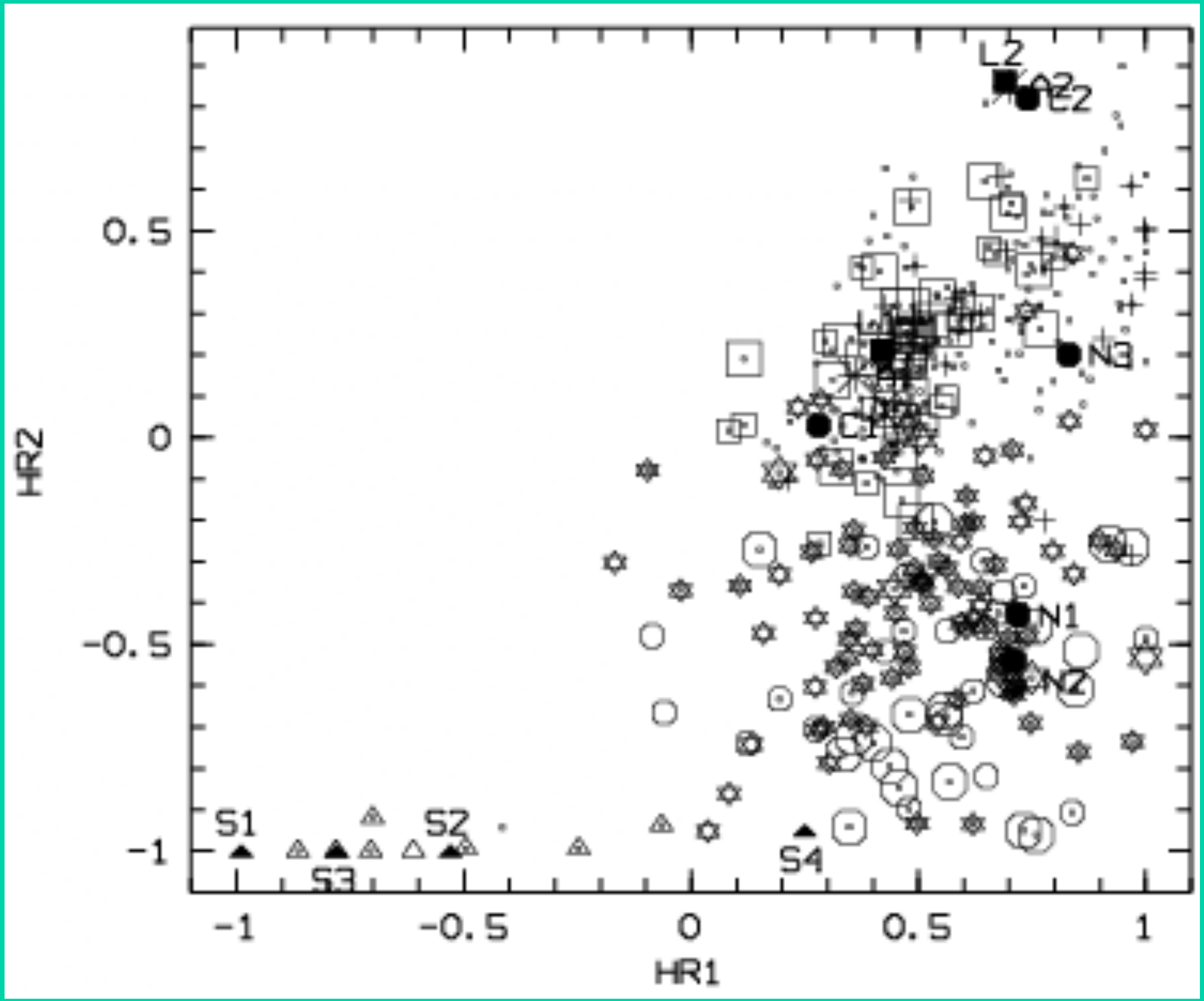
All EPIC mosaic (~100 ks)

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

Movie of centre area by blinking four observations with separation of half a year plus one 2.5 year later

Hardness ratio plots of M 31 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

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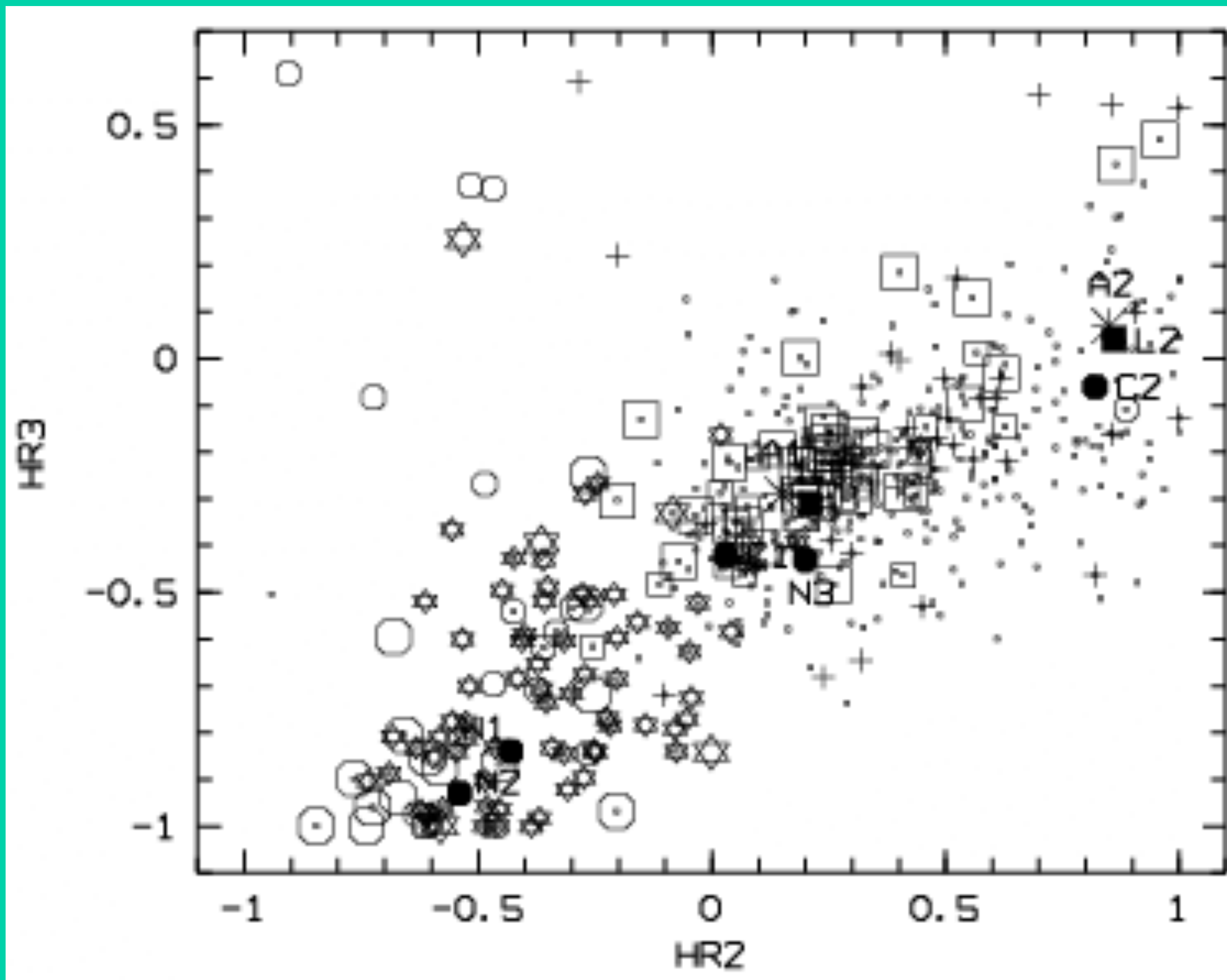

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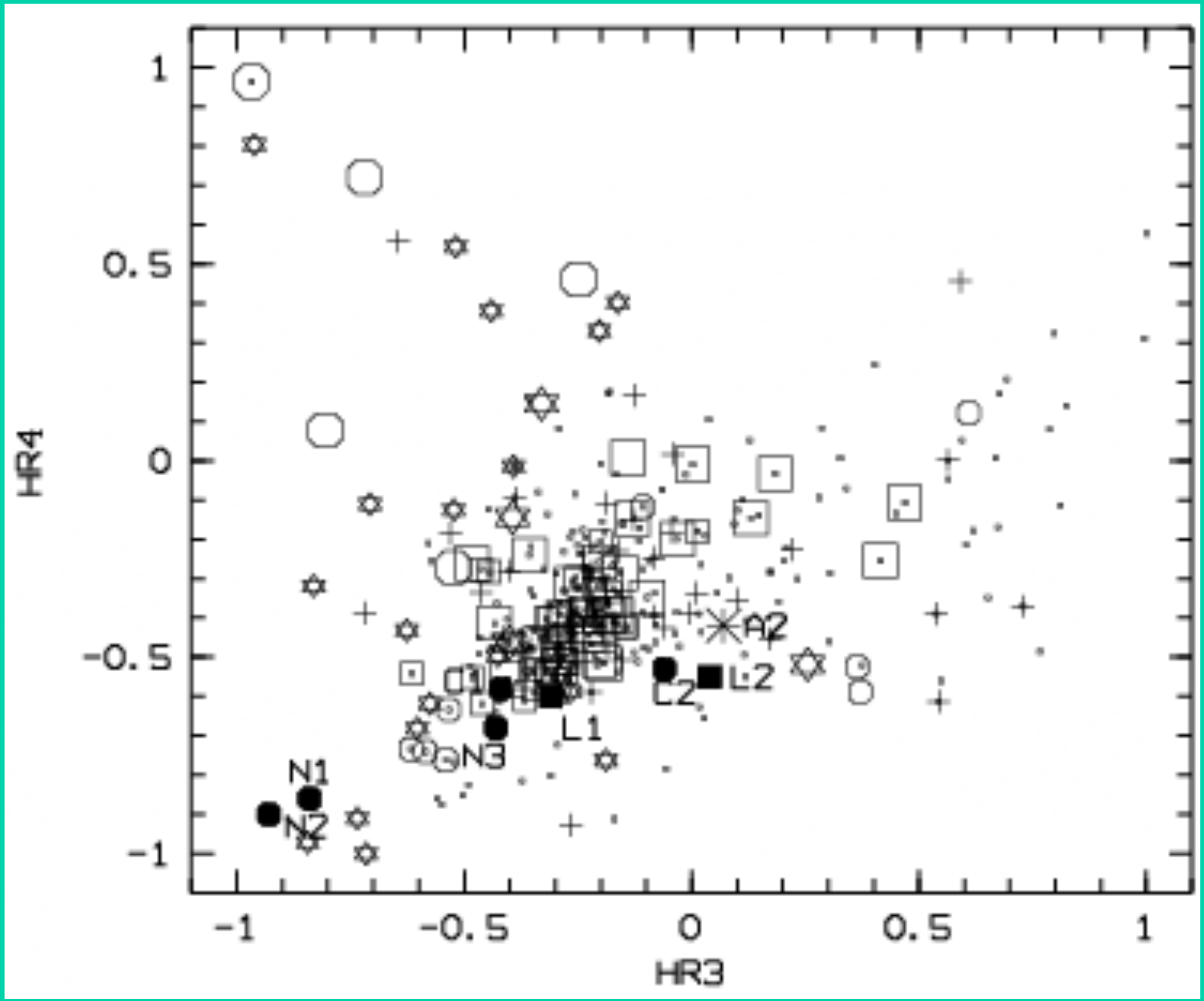

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fg-star
AGN

SSS
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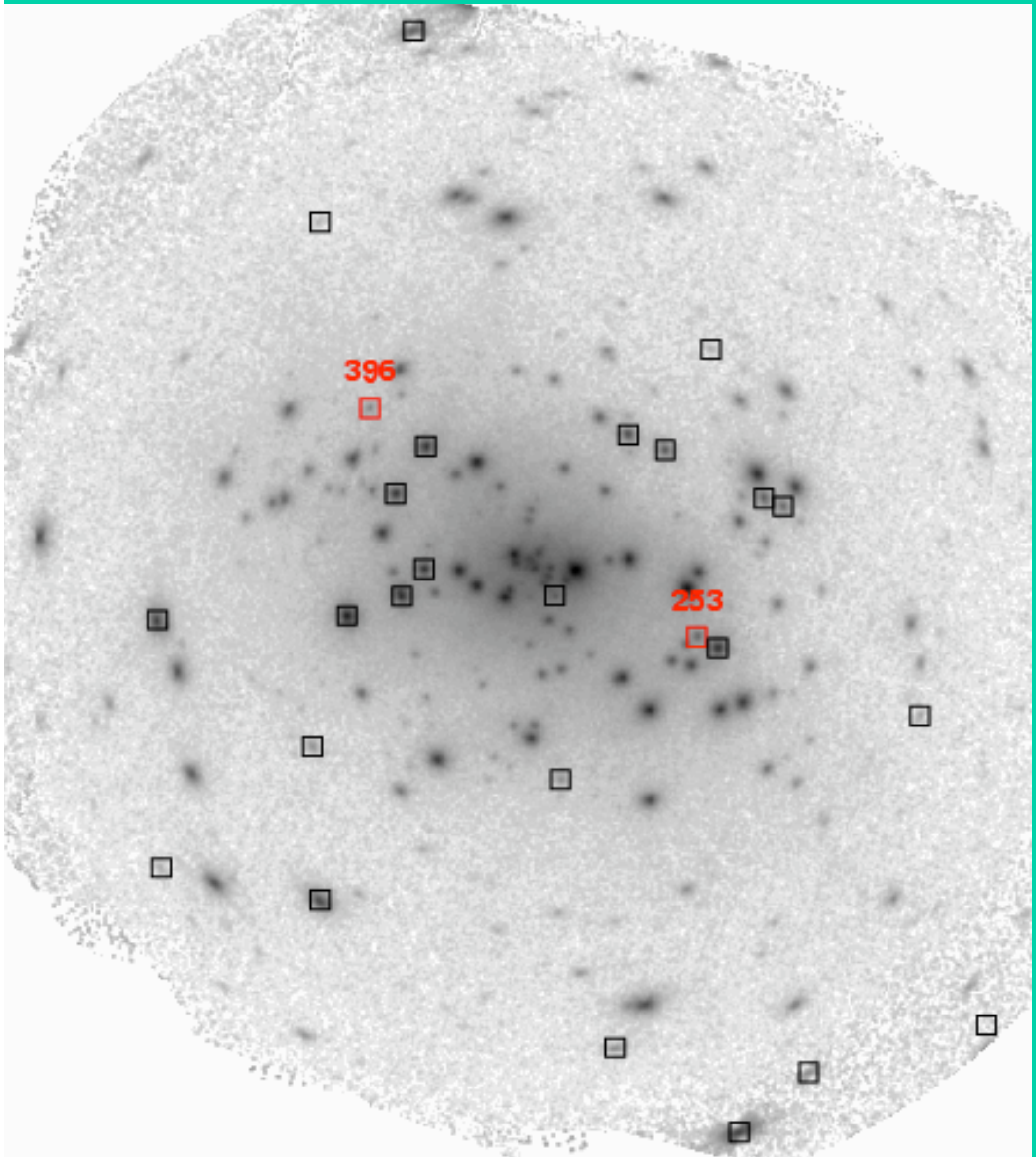
X-ray sources in M 31 field: identification and classification

	identified	classified
• foreground stars	6	90
• AGN	1	36
• Galaxies	1	
• Galaxy clusters	1	1
• SSS		18
• SNR	21	23
• Globular clusters	27	10
• XRB	7	9
• Hard		567

Summary catalogue

- HR2-HR1 diagram important to select SSS, thermal SNRs and foreground stars
- f_x/f_{opt} separate SNRs and foreground stars
- Hard X-ray spectra very important for classification: should separate
  - XRBs
  - Active nuclei
  - Plerions
- Individual papers on bright sources (Osborne et al, Barnard et al., Trudolyubov et al., Mangano et al.)
- Time variability studies to identify XRBs (Barnard et al.)

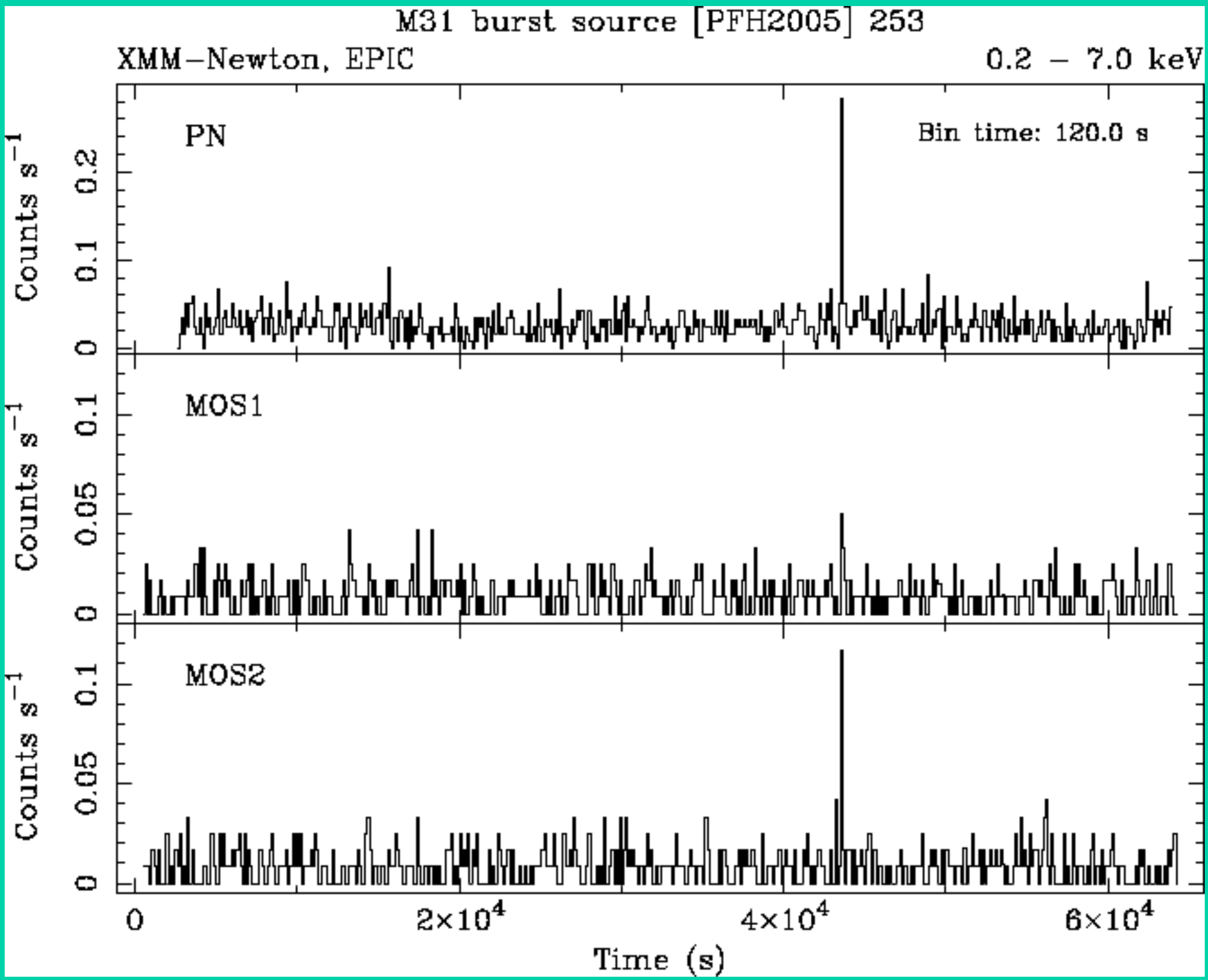
XMM-Newton detection of type I X-ray bursts in M 31



W. Pietsch & F. Haberl
2005, A&A 430, L45

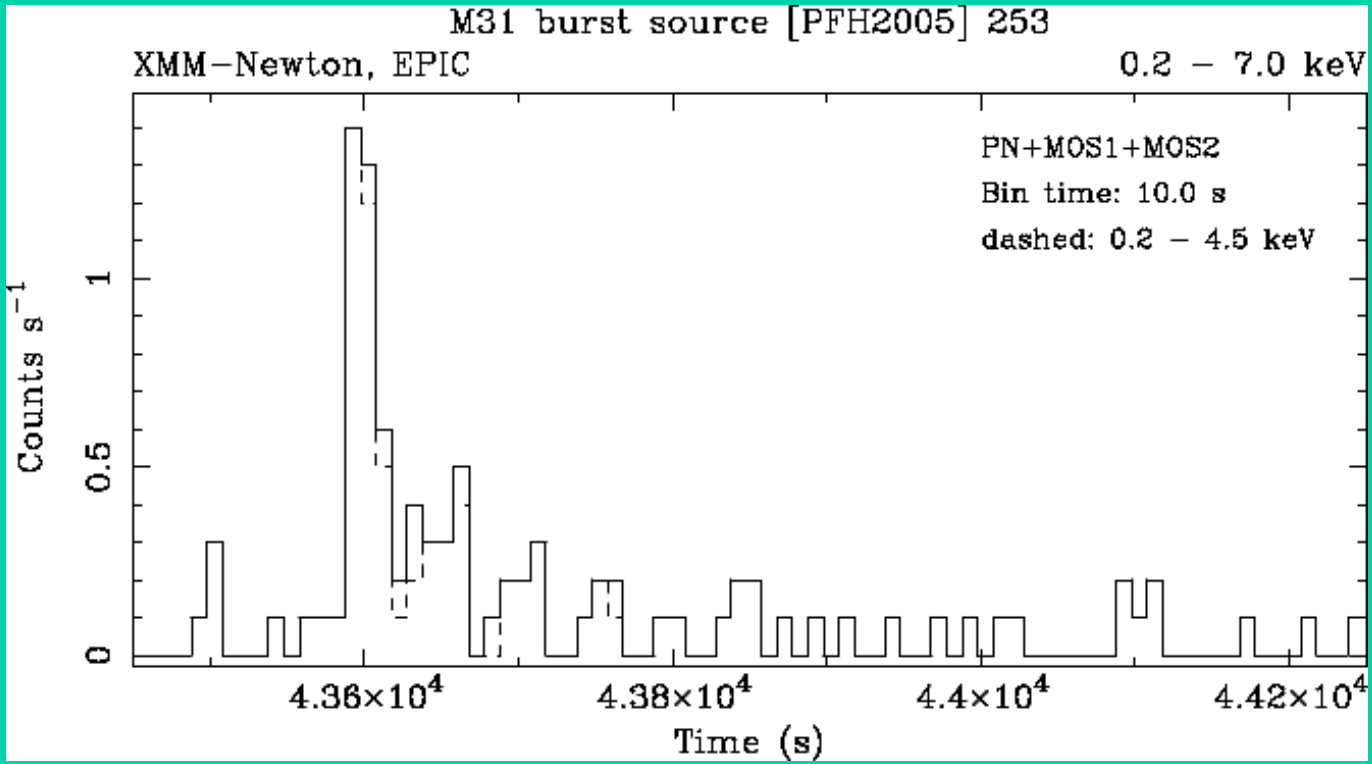
- search for X-ray bursts in GC candidates from catalogue paper
- 37 sources in fields
- most GC sources in center field that got longest exposure
- two burst sources detected in X-ray faint GCs, neutron star LMXBs

X-ray burster [PFH2005] 253 in the GC [WSB85] S5 15



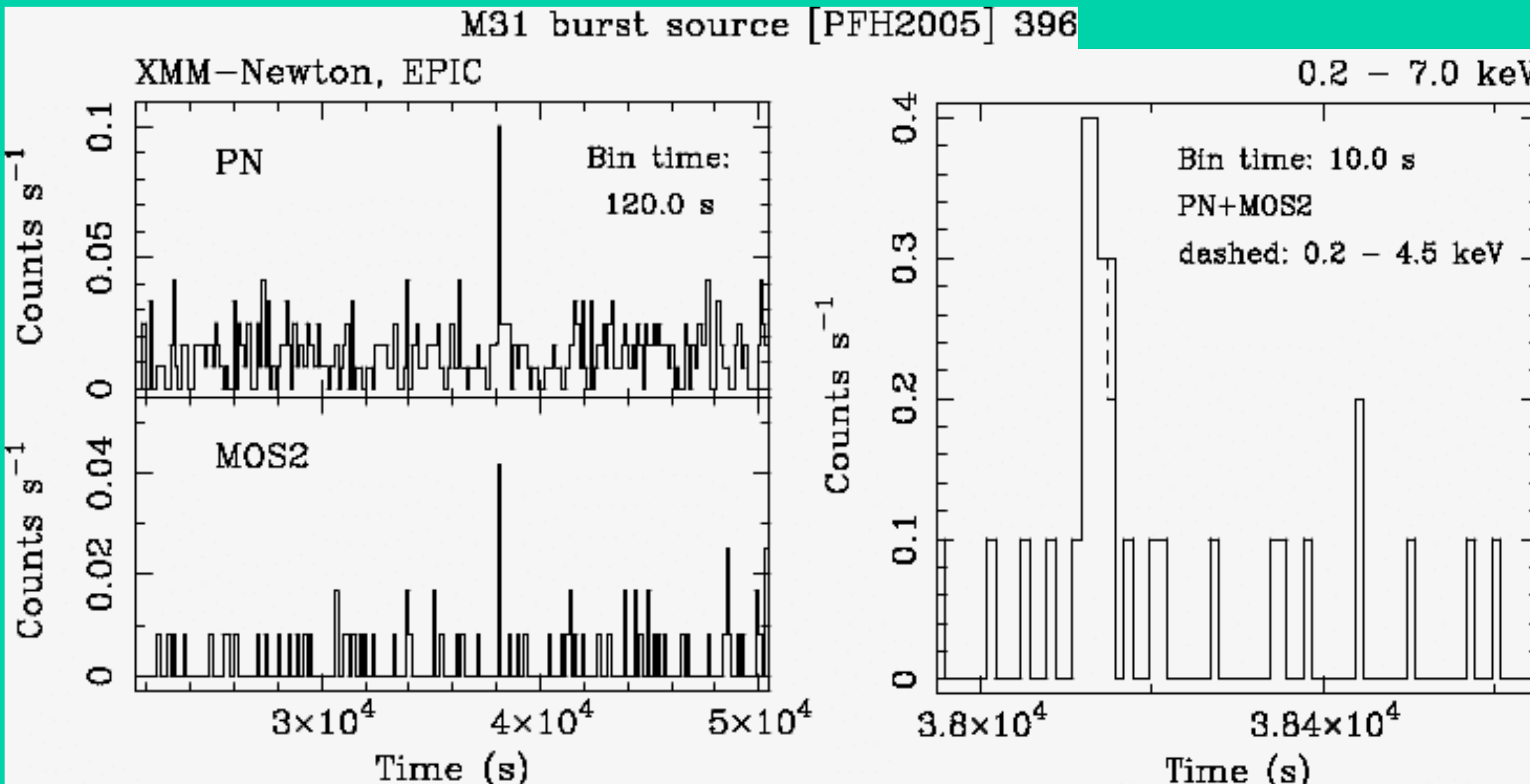
Observation c4
Jan 7, 2002

X-ray burster [PFH2005] 253 in the GC [WSB85] S5 15



Rise time	< 10 s	Total	50 cts
Maximum duration	< 20 s	Max. rate	1.4±0.4ct/s
Decay to backgr.	~150 s	corresponds to	3.8 10^{38}erg/s
Quiescent luminosity	~5 10^{36}erg/s	(Eddington limit for H-poor matter)	

X-ray burster [PFH2005] 396 in the GC B150



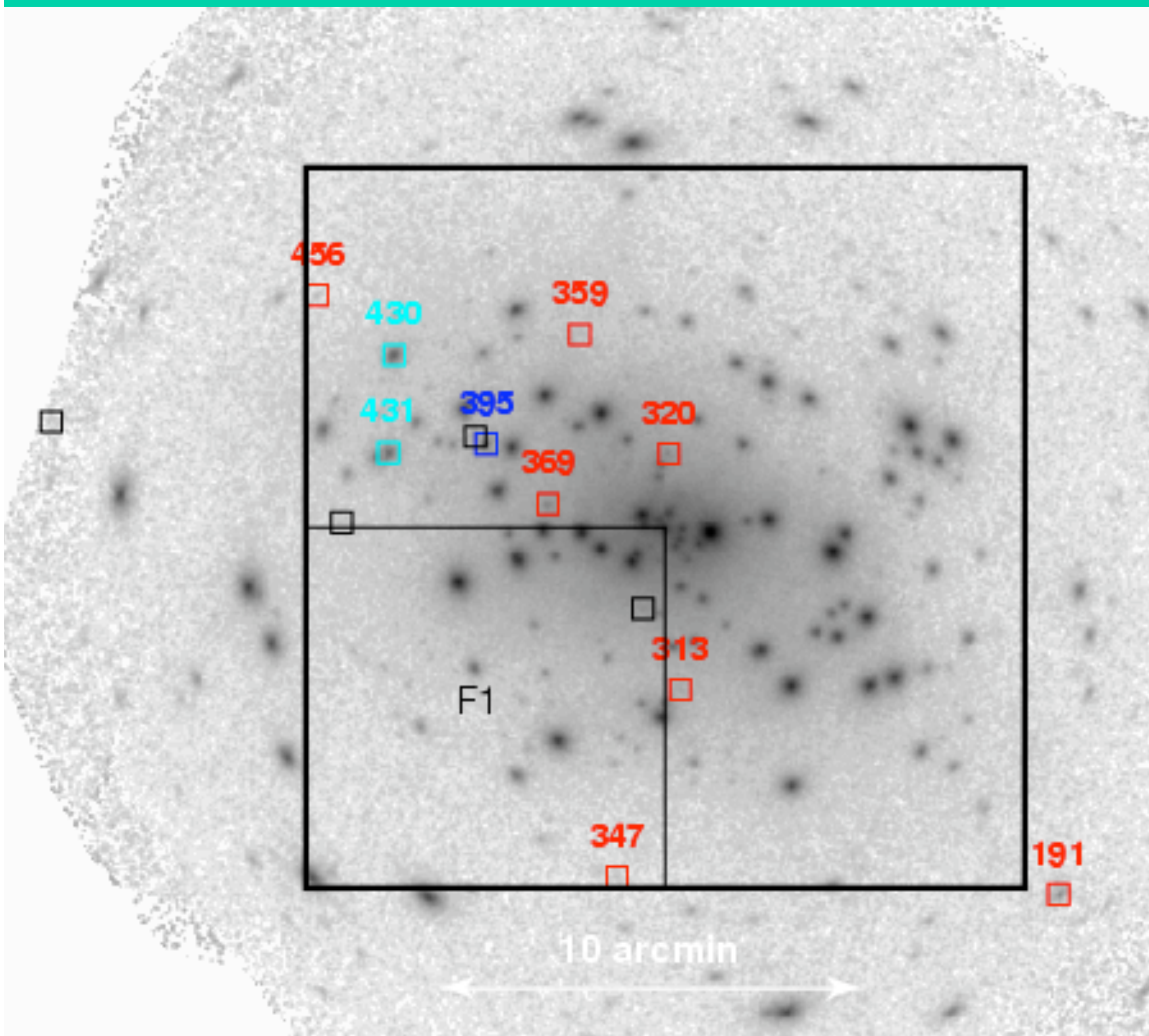
Observation c3, June 29, 2001 Quiescent luminosity ~2 10^{36}erg/s

Summary bursters

- First type I X-ray bursts detected outside the Milky Way
- Bursts originate from two sources in globular clusters or globular cluster candidates
- Radius expansion bursts radiating at Eddington limit during maximum (standard type I bursts have harder spectra and are not bright enough)
- Persistent luminosity while bursting $<5\ 10^{36}$ erg/s (in Milky Way LMXBs only burst if $L_X < 0.2\ L_{Edd}$)
- $2.9\ 10^{6}$ s EPIC pn light curves of sources in globular clusters and candidates tested (2 bursts but no superbursts)
- XMM-Newton EPIC instruments allow us to classify neutron star low mass X-ray binary systems in the Local Group by X-ray bursts

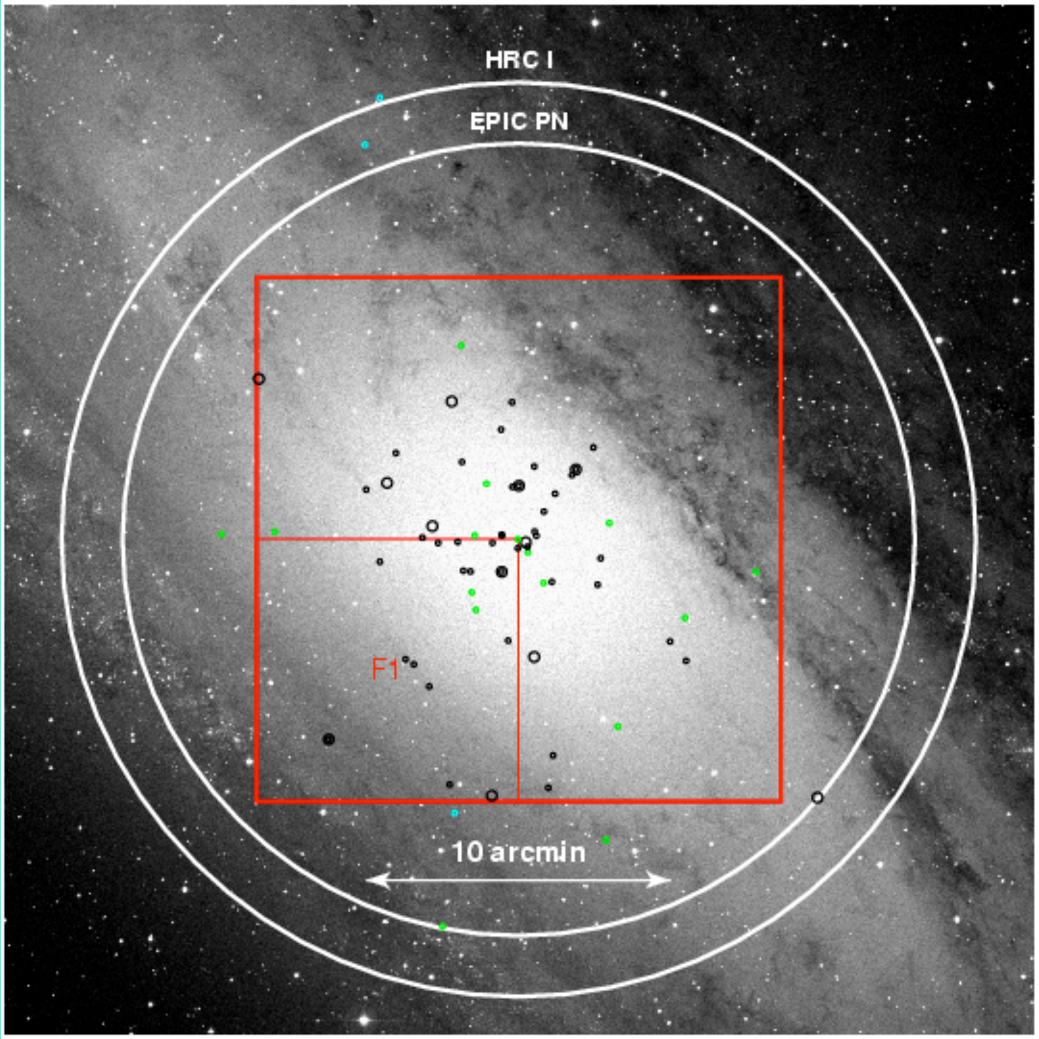
Optical novae: the major class of supersoft X-ray sources in M 31 and M 33

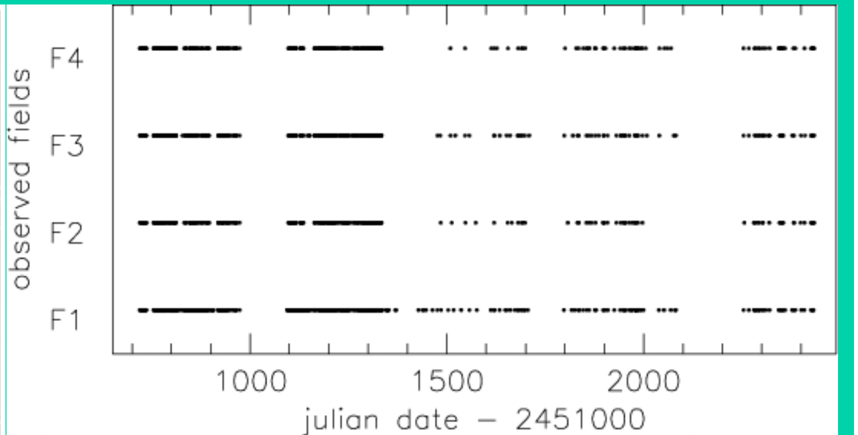
Pietsch, Fliri, Freyberg, Greiner, Haberl, Riffeser, Sala 2005, A&A 442, 879

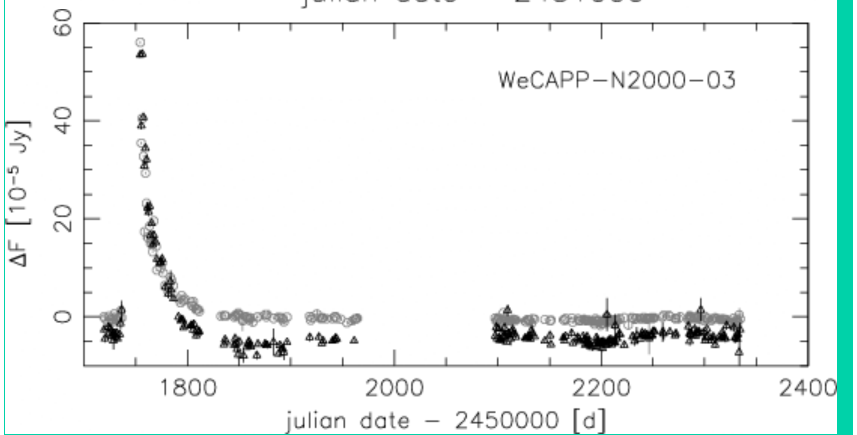


- search for optical nova correlations in XMM-Newton, Chandra and ROSAT catalogs and archival observations
- 21 X-ray counterparts in M 31 and 2 in M 33
- novae dominant class of supersoft X-ray sources in M 31 center

Optical novae detected in the on-going WeCAPP project



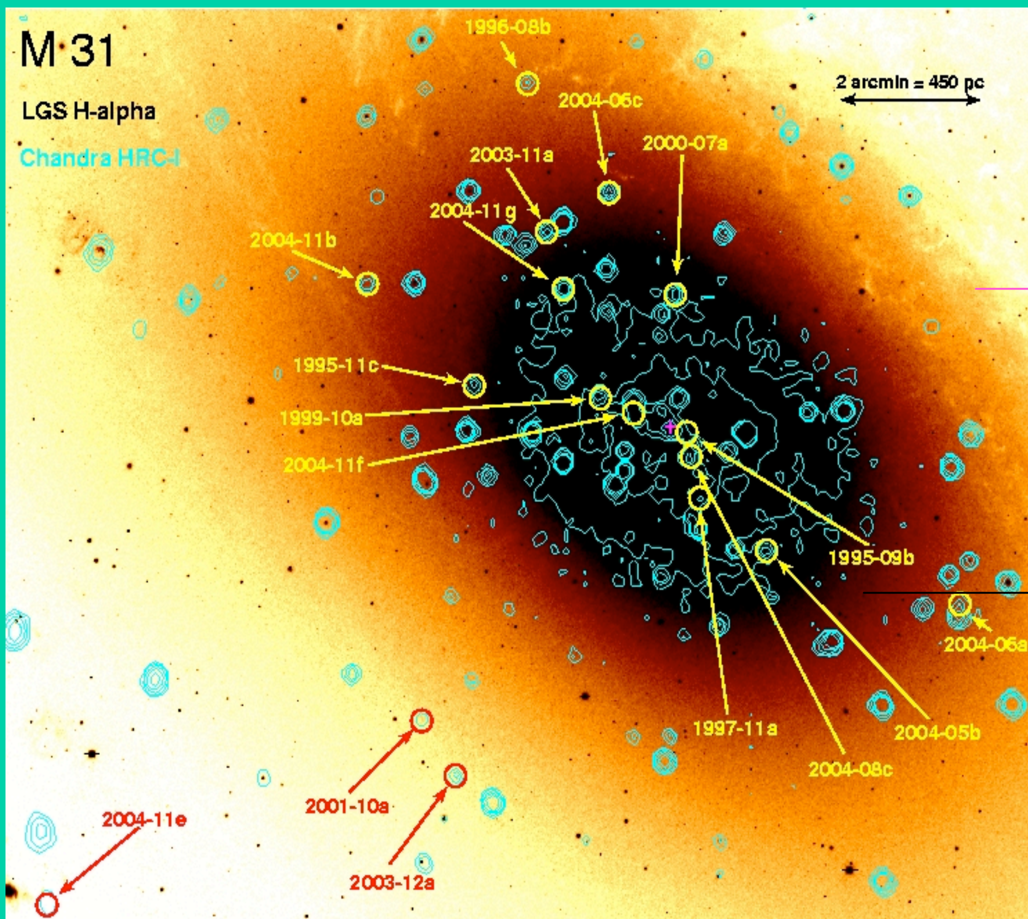


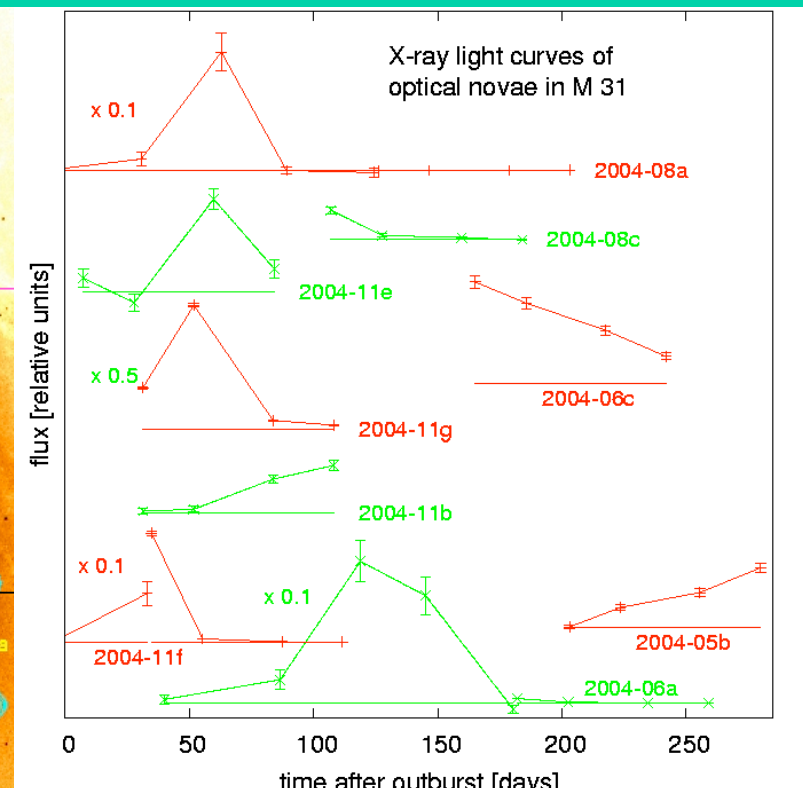


Wendelstein/Calar Alto
Pixellensing Project WeCAPP

Chandra HRC nova detections 2004/5

Pietsch et al. 2007, A&A 465, 375





Nova SSS light curves (<250 d)

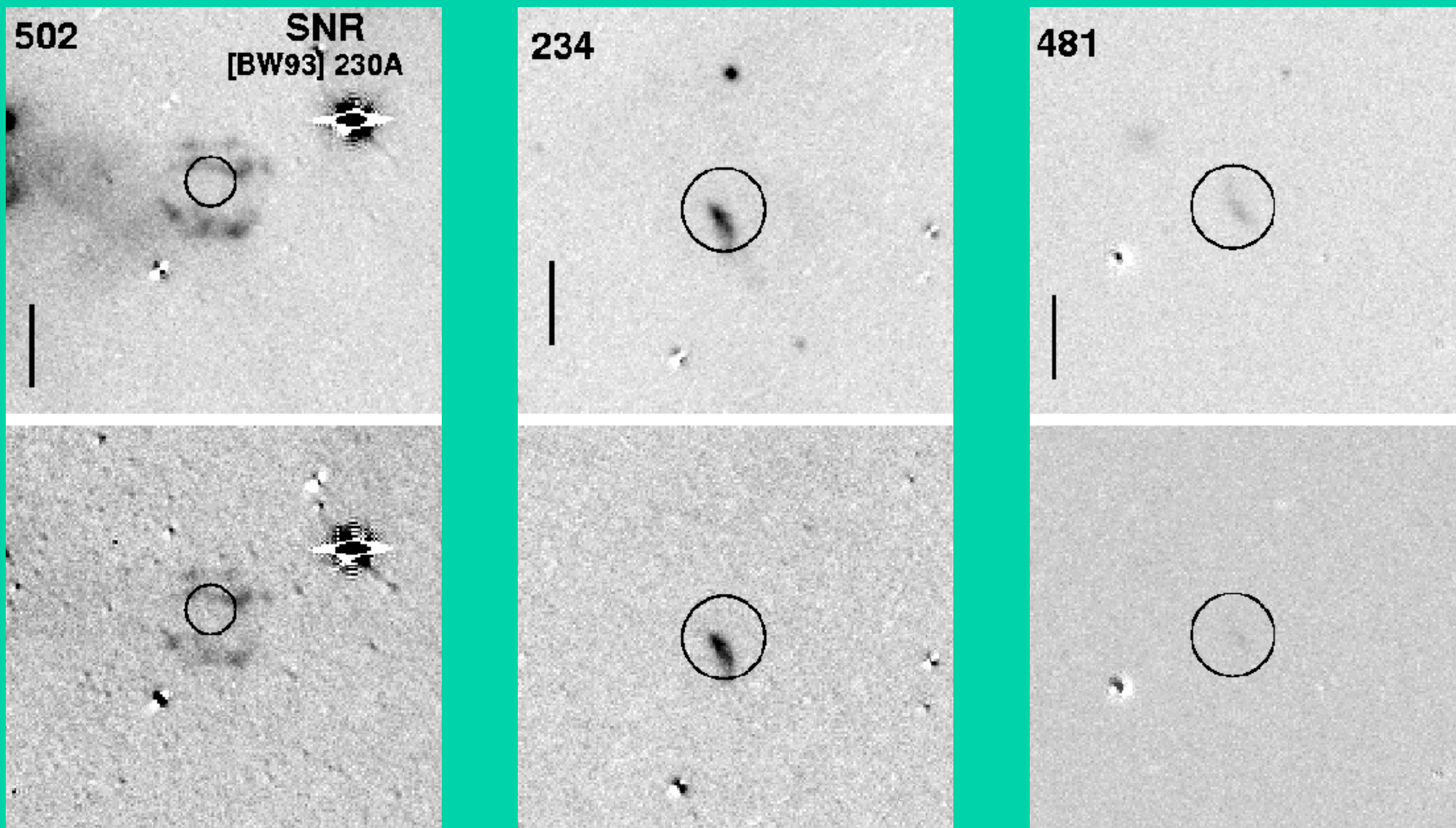
More than 30% of optical novae show SSS state

Summary optical novae

- 30 to 50 optical novae per year in M 31 (~half in bulge area)
- Novae established as major class of SSS in M 31 center
- Monitoring of bulge area gives light curves of many novae simultaneously inone XMM-Newton/Chandra field (Galactic novae can only be monitored one by one, i.e. is much less efficient)
- Spectra can be modeled by BB spectra (T <70 eV)
- Novae as SSS best detectable with XMM-Newton EPIC pn, Chandra HRC I and ACIS S
- SSS state of novae may start within 50 days after optical outburst
- X-ray outburst may last only 2-3 months, but three of the novae still bright nine years after optical outburst (similar to GQ Mus and Nova LMC 1995)
- several novae missed in optical and X-ray searches
- Number of X-ray detected optical novae much higher than previously estimated (>30%)
- X-ray light curves give estimates for ejected hydrogen mass for optical novae as well as burned mass and mass of White Dwarf by comparing with models, that include chemical composition

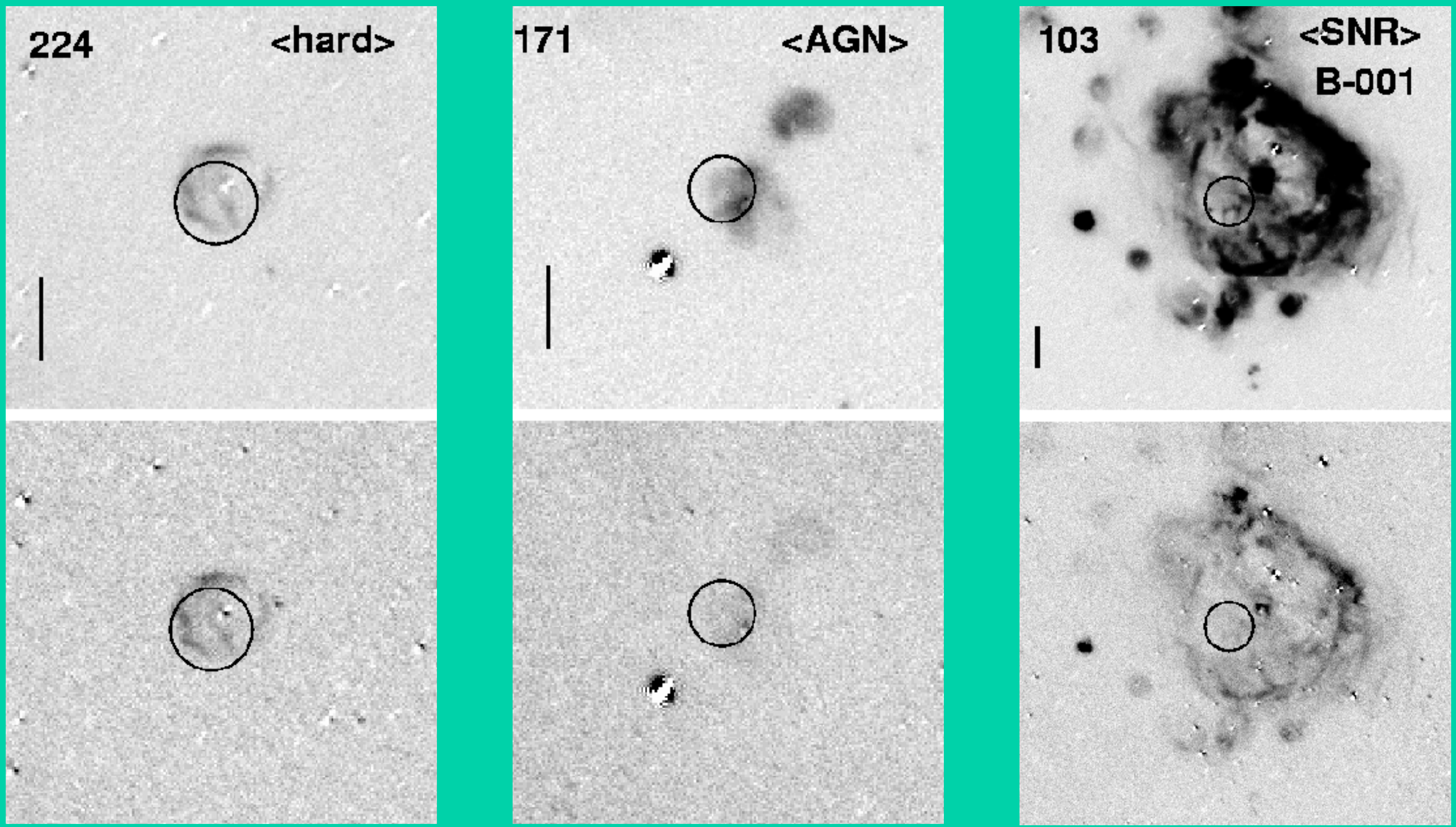
??? Recurrent novae precursor of type Ia supernovae ???

SNR identifications by comparison with Local Group survey images by Massey et al. (I)



M 31 examples Halpha and [SII] images of SNRs and candidates

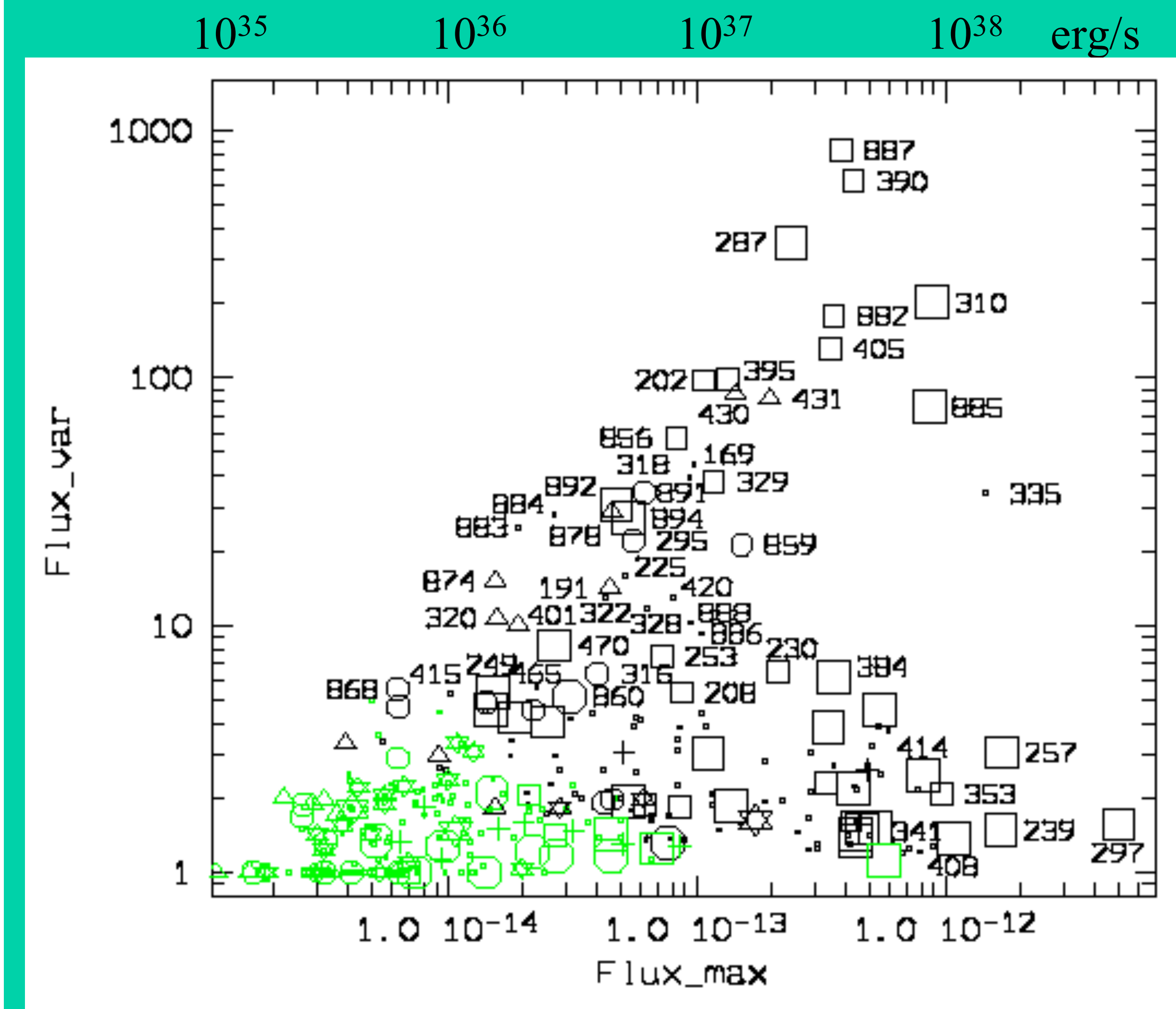
SNR identifications by comparison with Local Group survey images by Massey et al. (II)



M 31 examples Halpha and [SII] images of SNRs and candidates

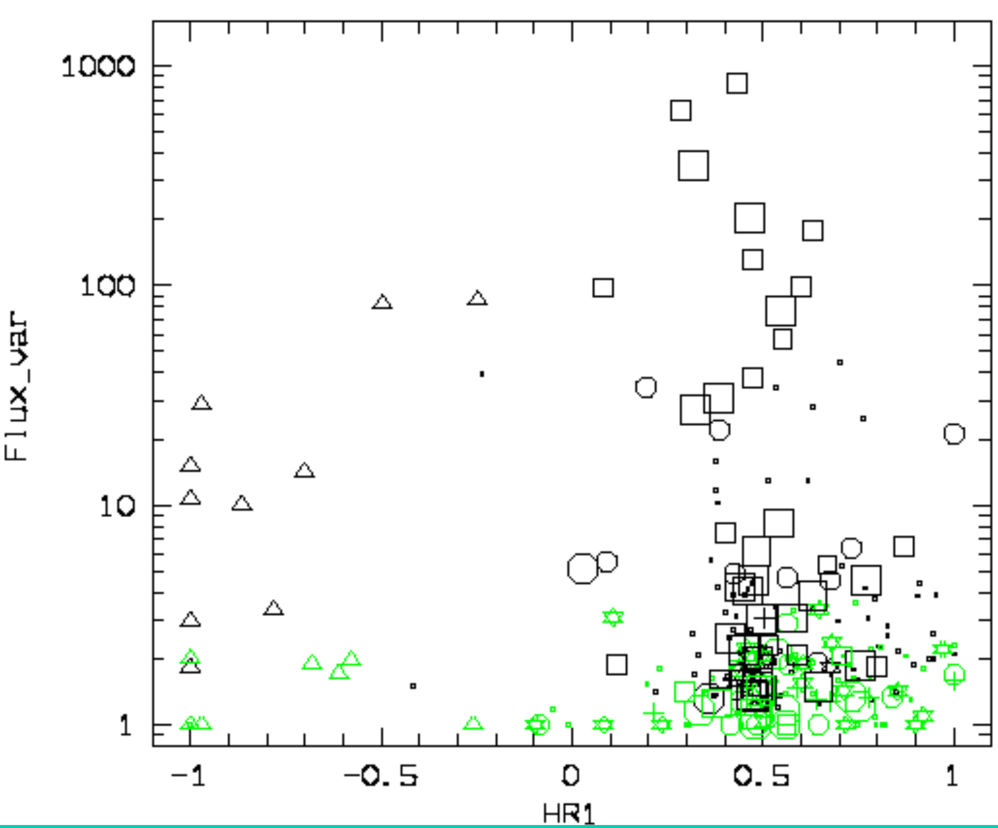
Time variability of X-ray sources in the M 31 centre field

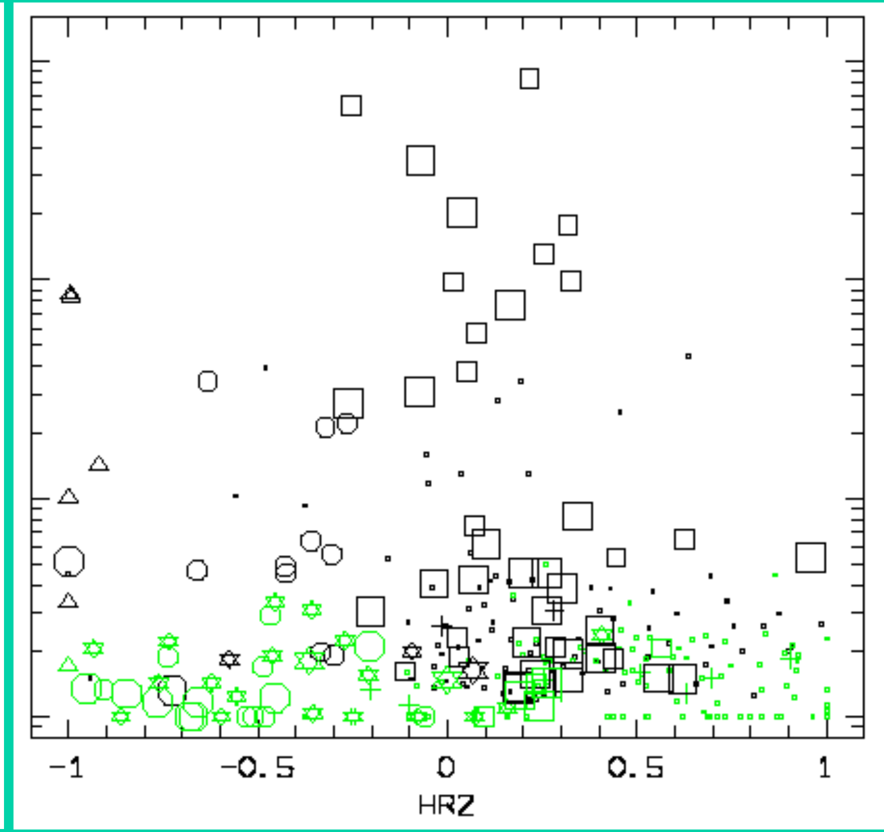
Stiele, Pietsch, Freyberg, Haberl 2007, A&A, in preparation

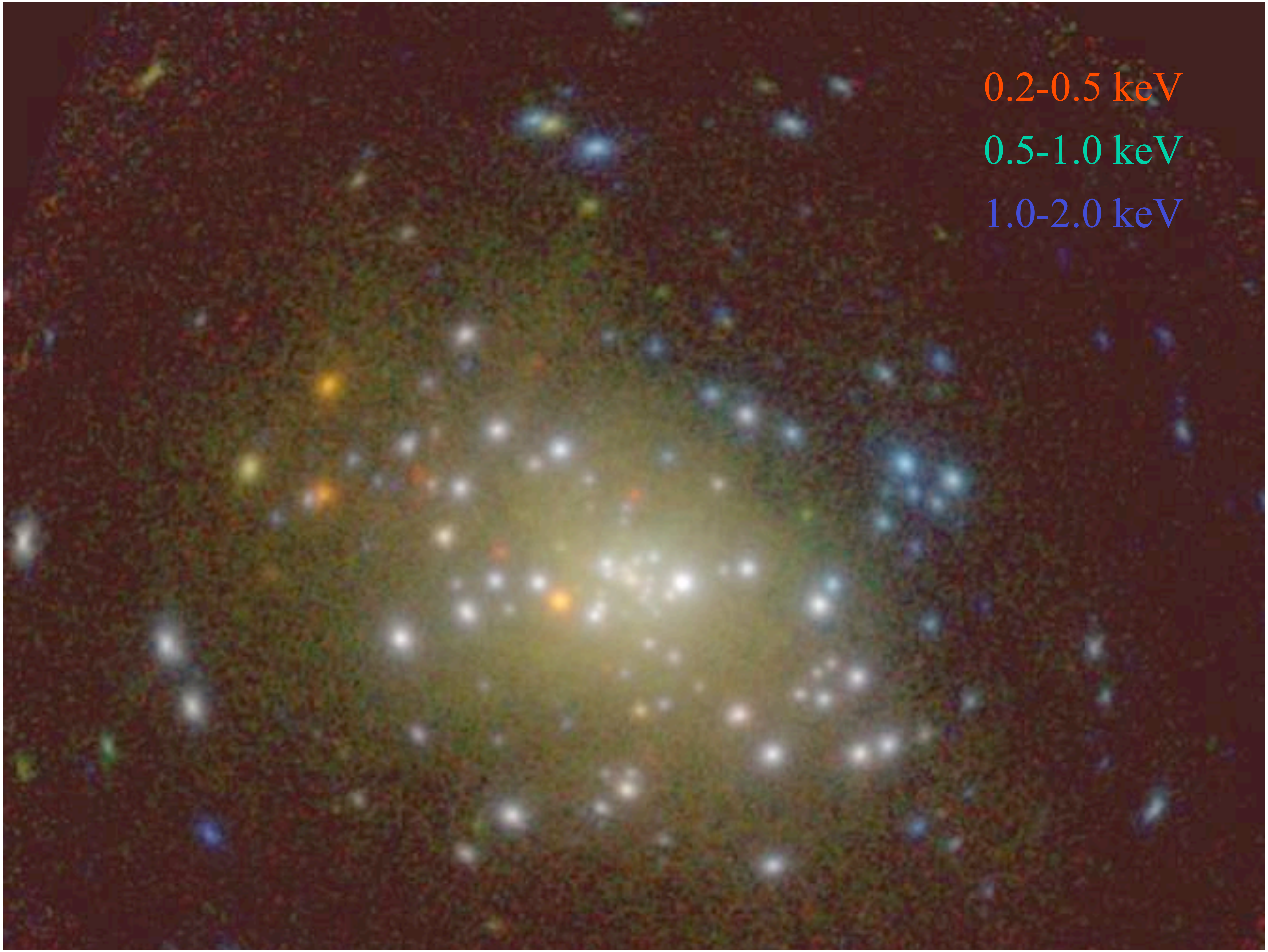


- Determine time variability between M 31 center pointings half a year apart
- Check classification of SNRs
- Classify new XRB candidate by time variability

Time variability versus hardness ratios






0.2-0.5 keV
0.5-1.0 keV
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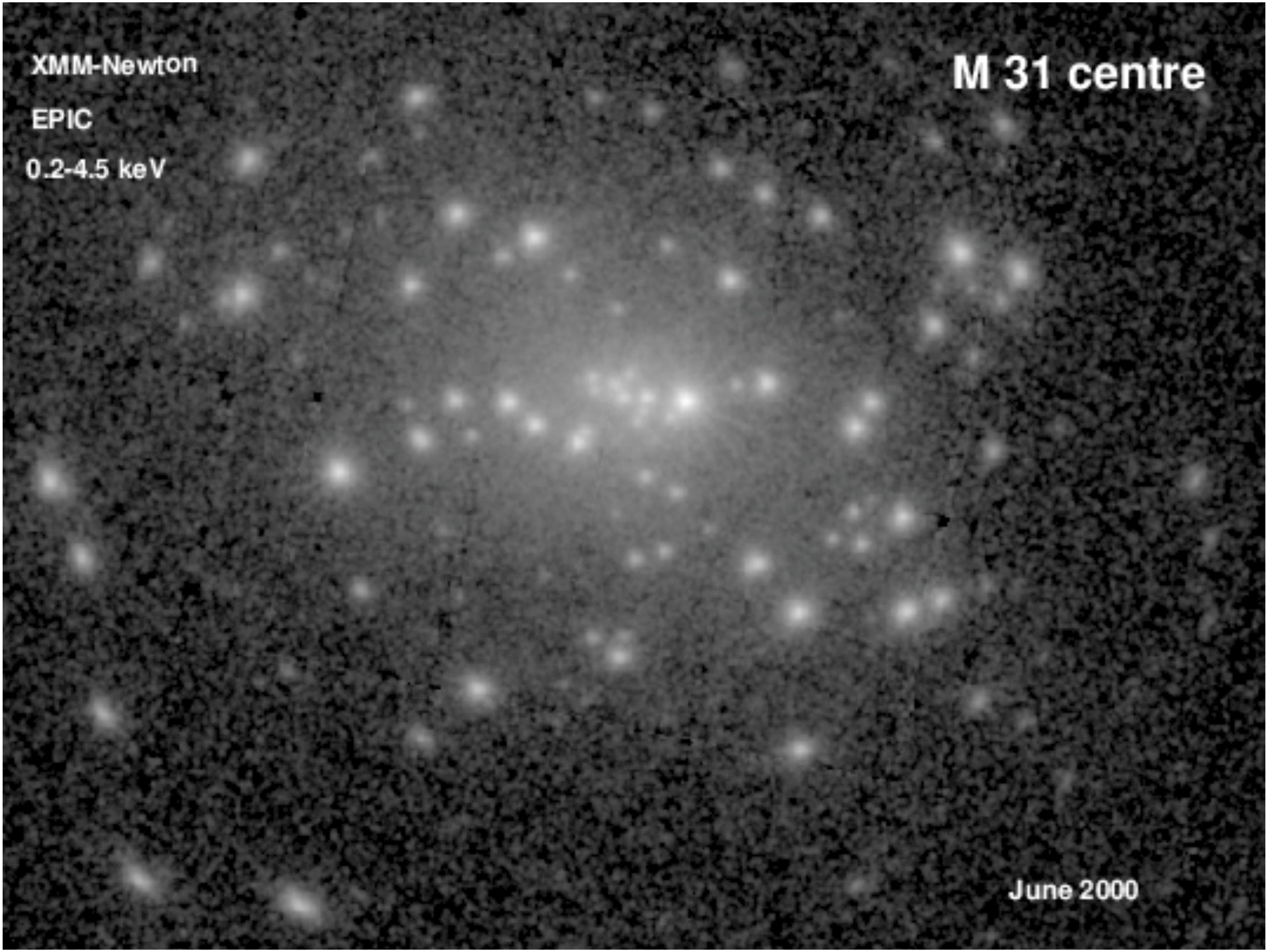
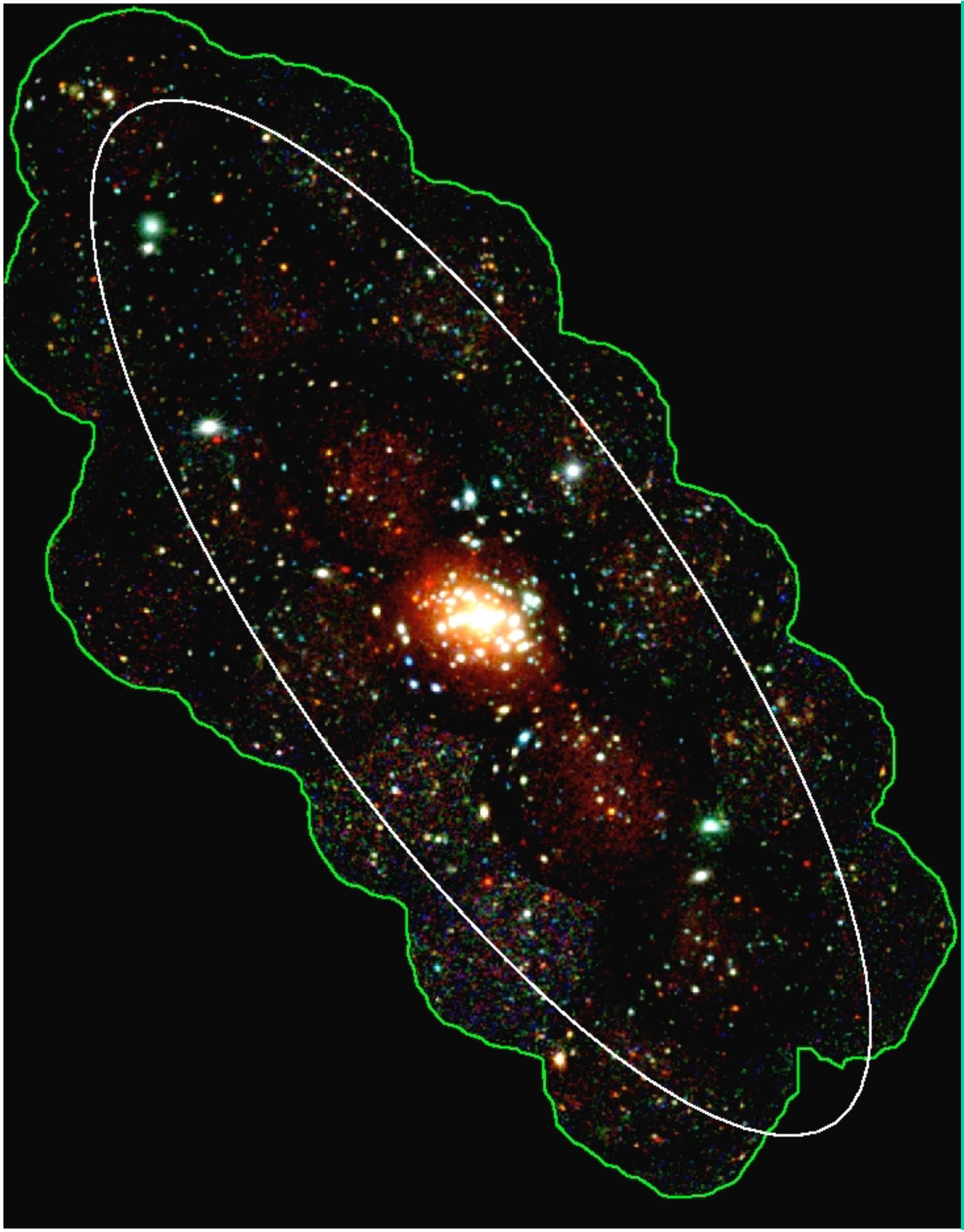

XMM-Newton
EPIC
0.2-4.5 keV
M 31 centre
June 2000



On-going M 31 programs involving XMM-Newton

- **M 31 raster survey AO5 and AO6**
  - first colour image
  - about 2000 sources
  - identification
  - population study

- **Monitoring of M 31 centre XMM-Newton/Chandra**
  - AO5 and AO6
  - monitoring optical novae as SSS sources

Summary

- XMM-Newton observations of M 31 many exciting results
- Demonstrated that X-ray sources in Local Group galaxies can be well classified
- Important: long (>50 ks) uninterrupted observations per field
- Separation of different source populations by hardness ratios and time variability very efficient
- SSS observations of optical novae demonstrate that specific source classes can be more homogeneously investigate in galaxy outside Milky Way

What XMM-Newton should do next in nearby Galaxy field

- Survey full area of SMC (see Frank Haberl's talk)
- Survey systematically large part of LMC
- Deeper observations of M 33 (100 ks exposures)
  Chandra VLP results show potential for finding XRB periods
- Continue monitoring of M 31 centre for optical novae and other transients
  2.6x2.6 dgr dayly optical survey of M 31 in 2008 with PANSTARRS

Comparison X-ray source populations to the Milky Way and other nearby galaxies