X-ray source variability study of the M 31 central field using Chandra HRC-I

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X-ray astronomy

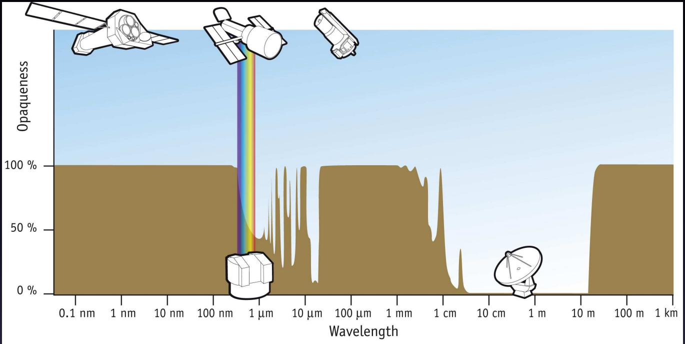


Figure: courtesy of NASA

- observe electromagnetic radiation from celestial events
- absorption of X-rays in Earth's atmosphere
- observe ideally with instruments outside the atmosphere

Brief history

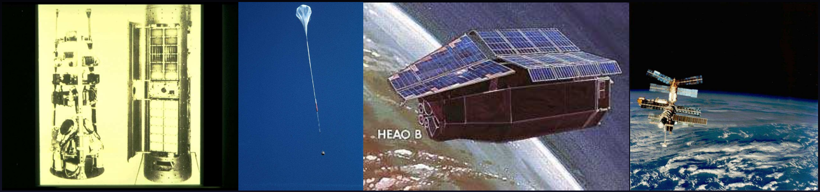


Figure: courtesy of NASA, MPE

- 1962 first extra-solar X-ray sources discovered
- observations with balloons carrying X-ray detectors ($\sim$40 km)
- 1970 first satellite missions dedicated to celestial X-ray observations (Uhuru)
- 1978 first focusing X-ray telescope aboard Einstein satellite
- many X-ray satellites since (ROSAT, XMM-Newton, ...)

Chandra X-ray observatory

- named in honor of astrophysicist Chandrasekhar
- launched July 1999 with the Columbia orbiter (STS-93)

Figure: courtesy of NASA

- transported into LEO
- transfered into highly eccentric orbit (64 h period)
- highest spatial resolution (compared to XMM-Newton, Swift and previous satellites)
- 0.2 - 10 keV

Chandra technical details

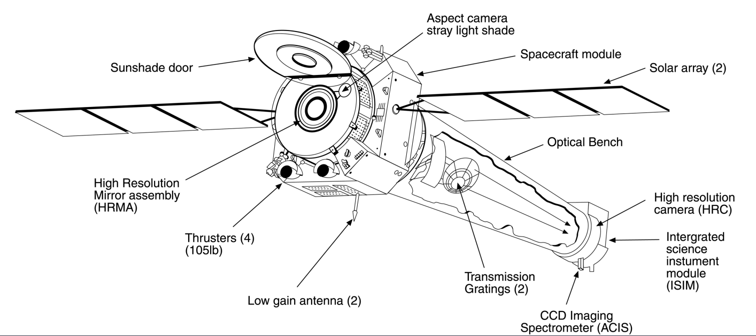
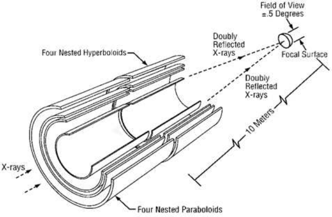


Figure: Technical illustration of the Chandra Observatory spacecraft. courtesy of NASA

Chandra X-ray mirrors and HRC-I detector



- High resolution mirror array (HRMA)
- on-axis FWHM PSF of < 0.5 arc seconds (degrades off-axis)
- 30 arc minutes field of view

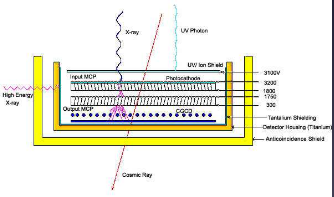


Figure: courtesy of NASA

- High Resolution Camera in imaging mode (HRC-I)
- Micro-channel plate detector
- sky pixels of 0.13 arc seconds

Expected M 31 X-ray sources

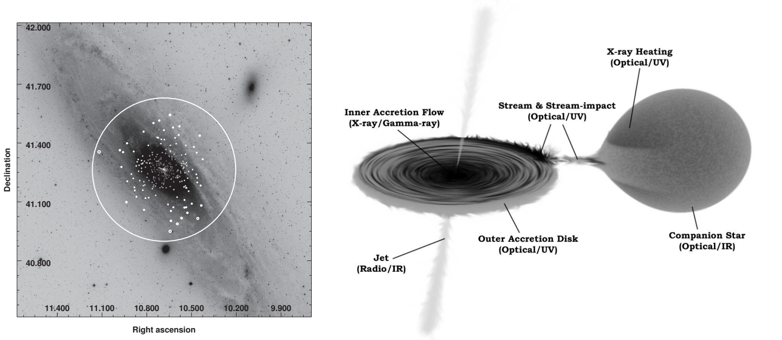


Figure: DSS 2 image with X-ray regions, illustration from Hynes et al. 2010

- X-ray binary Zoo (WD, NS, BH, companion star)
- nova explosions
- supernova remnants
- active galactic nuclei and foreground stars

Chandra HRC-I observations

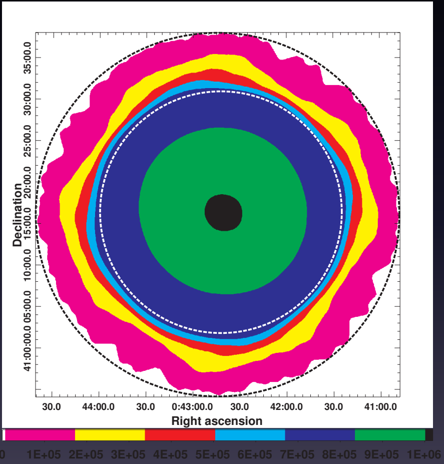


Figure: Contour plot of merged exposure map

- 64 Chandra HRC-I M 31 center observations (∼1 Ms, 11.6 d)
- 1999 to 2002 ∼1.2 ks to 5.2 ks
- Kaaret 2002: 46.7 ks (longest individual observation)
- 2004 to 2005 ∼20 to ∼50 ks observations to monitor M 31*
- 2006 to 2012 41 nova monitoring observations of ∼20 ks

Chandra HRC-I observations

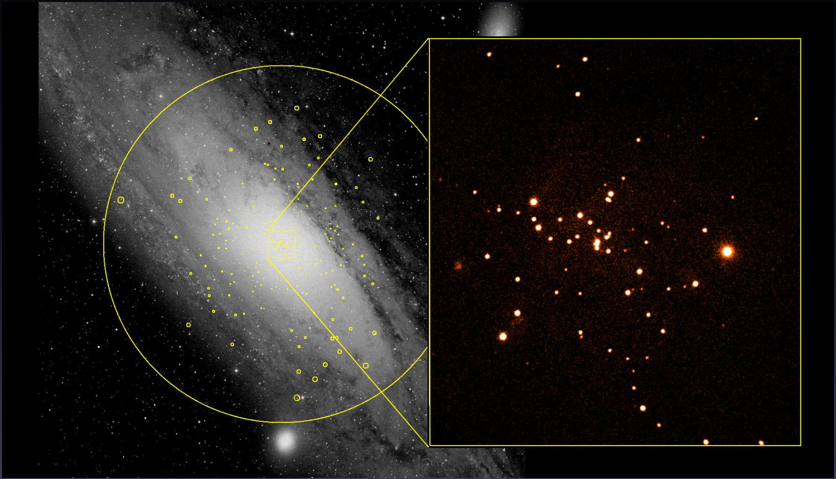


Figure: DSS II blue filter image (1x1 degree, obtained from SkyView), zoom-in to ∼1 Ms HRC-I X-ray image

Long term X-ray variability

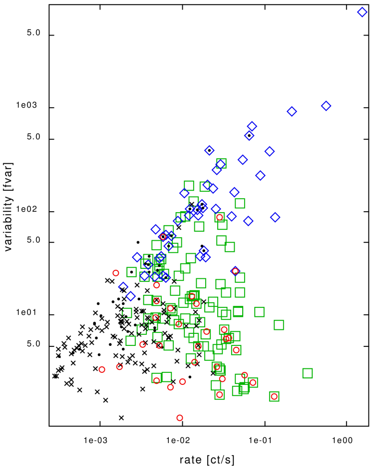


Figure: variability over count rate

- wavelet based source detection (318 sources)
- luminosity (assuming power law spectrum $\Gamma = 1.7$, Galactic foreground absorption ($N_H = 6.6 \cdot 10^{20}$ cm^{-2}),780 kpc distance and isotropic radiation)
- derived light curves
- fvar = fmax/fmin
- identified two variability classes (OB, HV)

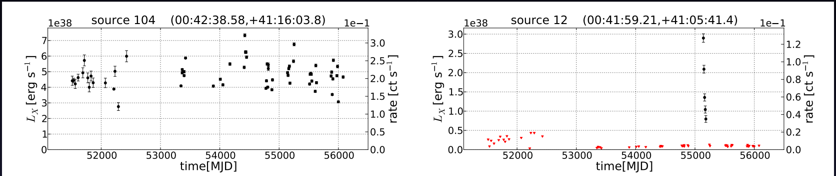
Source class criteria

class [a]	criteria	identified	classified
XRB	hard X-ray source, HV, OB	3	101
GIC	correlation with optically confirmed GIC, hard spectrum	32	1
SSS	X-rays mostly below 1 keV	0	6
nova	correlation with optical nova	45	
SNR	softer X-ray source and/or extent, correlation with radio or optical SNR	6	1
AGN	hard X-rays, radio identification	1	1
fgStar	softer X-rays, optical identification	7	4
unclassified		110	

[a] classes are adopted from Stiele et al. 2011 and candidates are designated by $<>$ in Table 1 (available via CDS).

- variability classification
- correlations: X-ray catalogs, GIC catalog, nova catalog, radio catalog
- optical finding charts (Kitt Peak 4 m)

X-ray binaries



- outburst and highly variable sources
- mainly thermal bremsstrahlung and blackbody X-ray radiation
- mostly low-mass, no high mass classified
- X-ray binary classes in the catalog: Super-soft sources, novae, field and globular cluster sources

X-ray binaries in globular clusters

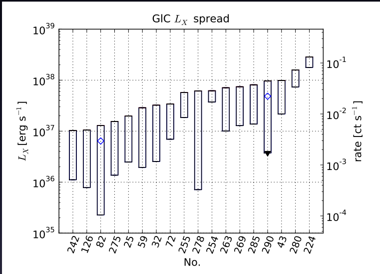
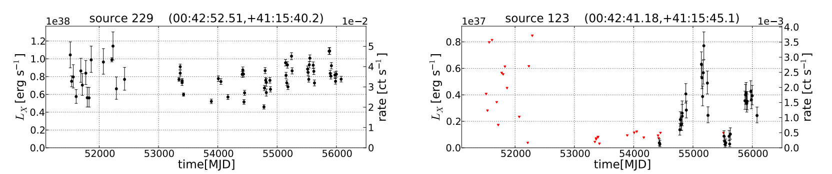
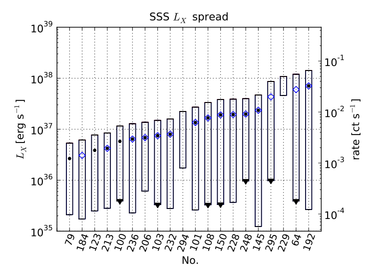


Figure: illustration of the spread of luminosity for the globular cluster sources classified as variable

- most Galactic globular clusters contain X-ray binaries
- globular clusters can be resolved and confirmed optically in M 31
- In M 31 at least 17% contain X-ray sources
- X-ray outburst ratio seems lower
- might be explained by difference between field and globular cluster population

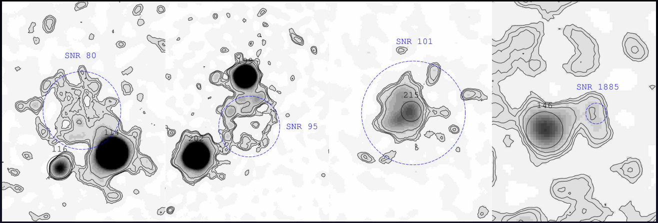
Super-soft sources and novae





- photon counts mostly below 1 keV
- associated with white dwarfs in binaries
    - steady hydrogen burning
    - nova explosions: rapid X-ray outburst or slow evolution

Supernova remnants



SNR ID [a]	RA(J2000) [h:m:s]	Dec(J2000) [d:m:s]	counts [b]	significance [b]	diameter [arc seconds] [c]
SNR 80	00:42:40.37	+41:15:52.2	446	3.2	7.8
SNR 95	00:42:47.81	+41:15:26.3	731	4.5	8.7
SNR 101	00:42:50.44	+41:15:56.4	856	6.7	7.9
SNR 1885A [d]	00:42:42.89	+41:16:05.0	28	2.6	1.4

[a] taken from Sjouwerman and Dickel (2001)
[b] calculated with CIAO tool aprates
[c] visually estimated from smoothed merge image
[d] position taken from Fesen et al. (1999)

Summary

- HRC-I catalog submitted to Astronomy and Astrophysics
- Deepest X-ray observations of the central area of M 31
- 61 new catalog sources
- 17 detected for the first time
- 2 new supernova remnant candidates
- Largest sample of X-ray binary long term light curves in M 31

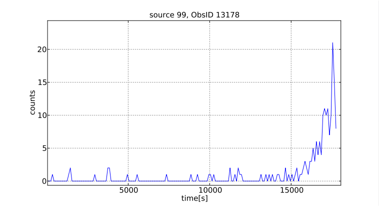
References

- Hofmann et al. 2013 (submitted to A&A) and references therein
- `http://chandra.harvard.edu`

Questions?

Thank you for your attention

Foreground and background



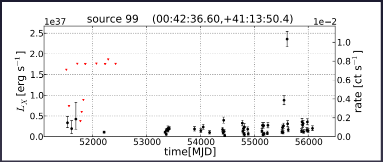
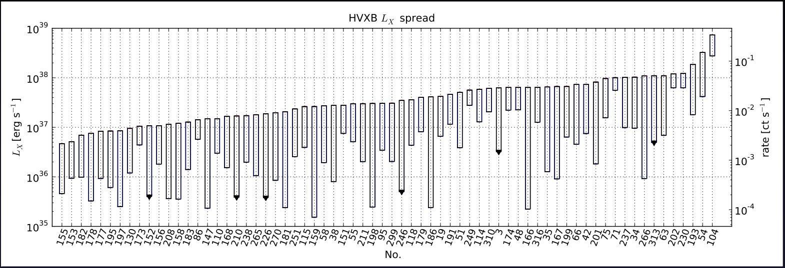
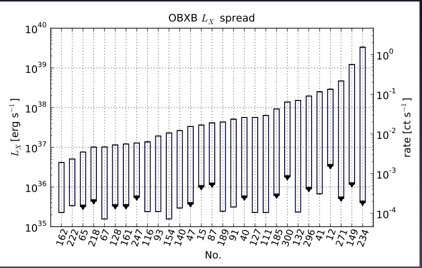


Figure: short term and long term light-curves of No. 99

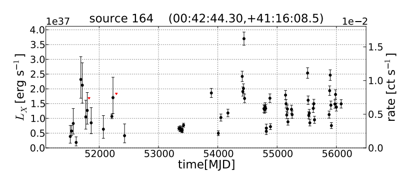
- foreground stars can show high variability due to short flares
- no known foreground CVs in field of view
- No. 207 possible galaxy merger in background
- Active galactic nuclei (moderate variability)
- erroneous luminosities given for background/foreground sources

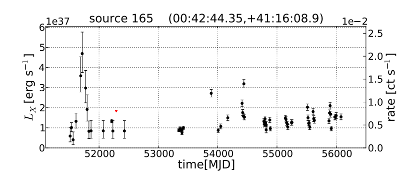
Variability classes





M 31 center





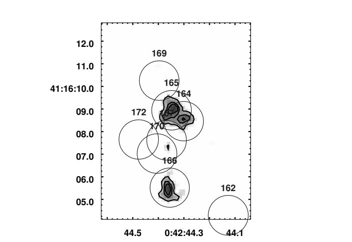
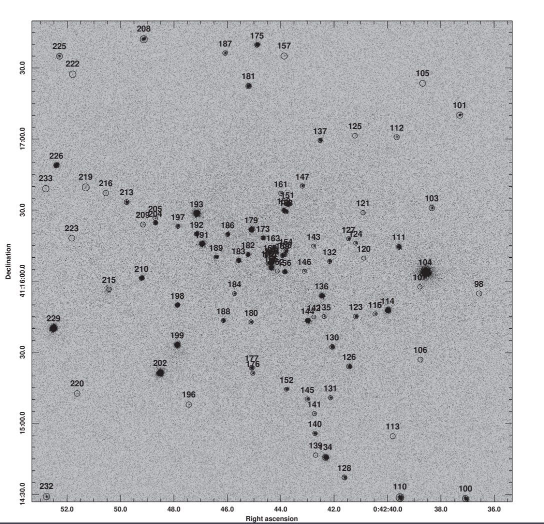


Figure: zoom-in to the center of M 31

- No. 164 at position of central super-massive black hole
- overlapping X-ray sources at the center
- highly variable double core resolved
- cross talk in light-curves

Backup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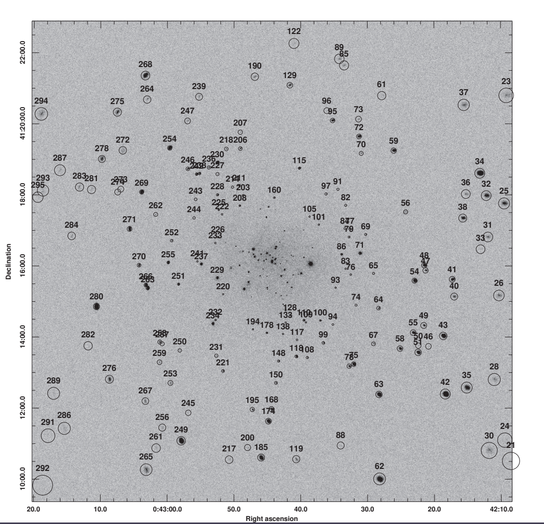
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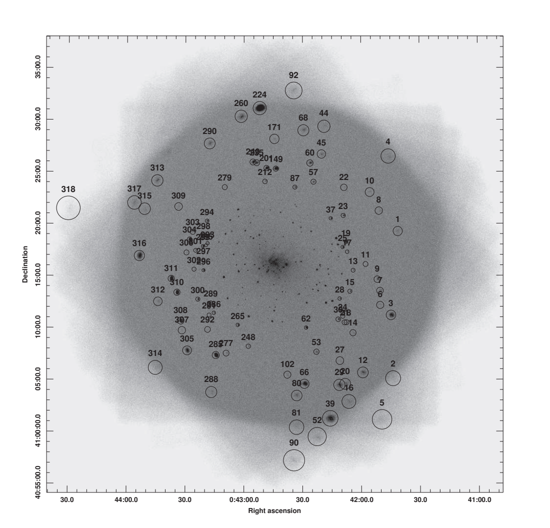
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