Artificial variability in XMM-Newton observations of M31 and beyond

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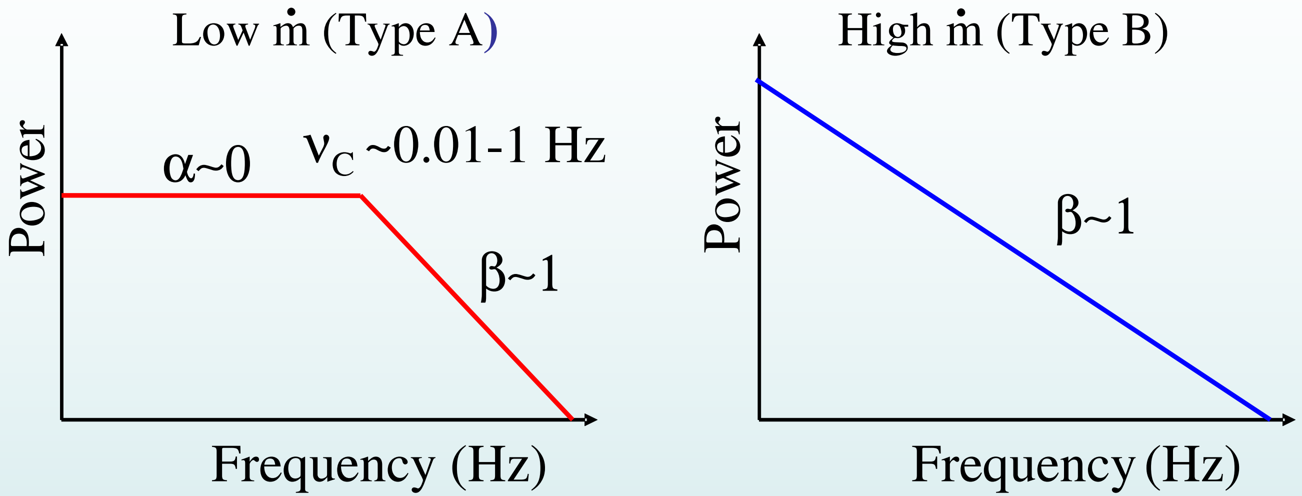
Outline

- Timing X-ray sources
- M31 survey
- Source of artificial variability
- Good news!
- Conclusions

Timing X-ray sources

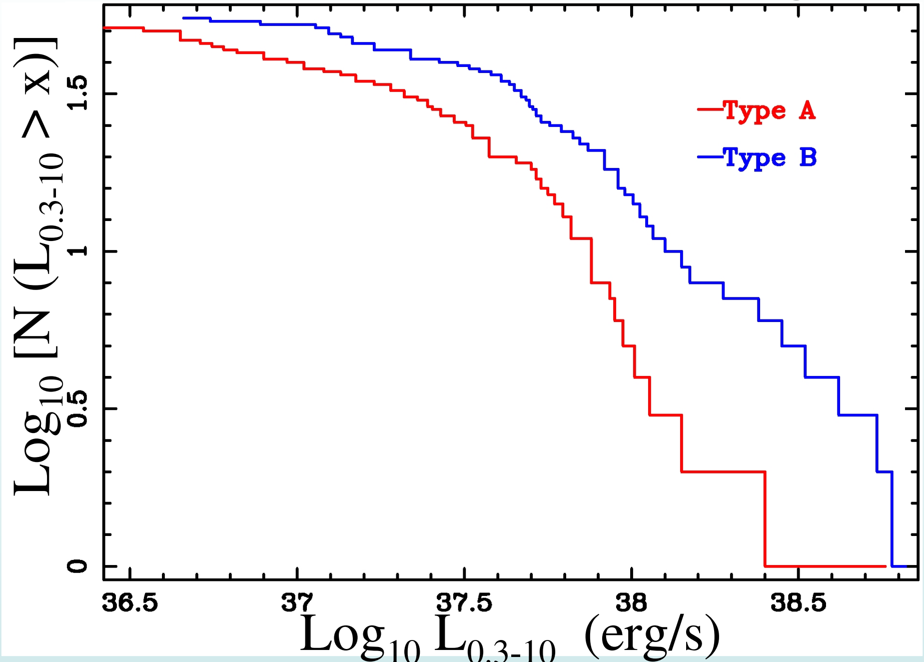
- We can learn a great deal about the nature of an X-ray source from its variability
- Observations of variability in extragalactic X-ray sources limited by sensitivity and time resolution
- XMM-Newton has highest sensitivity of any imaging X-ray observatory
- We have been interested in stochastic variability in X-ray binaries

PDS of LMXBs



- Van der Klis (1994, 1995): XB power density spectra (PDS) depend more on accretion rate than primary (NS or BH)
  - Low $\dot{m}$, PDS broken power law (Type A, Barnard et al., 2004), r.m.s. ~10-40% (vdK95)
  - High $\dot{m}$, PDS simple power law (Type B, Barnard et al., 2004), r.m.s. < ~6% (vdK95)
  - vdK94 suggested A to B transition at constant fraction of Eddington limit

Our M31 Survey

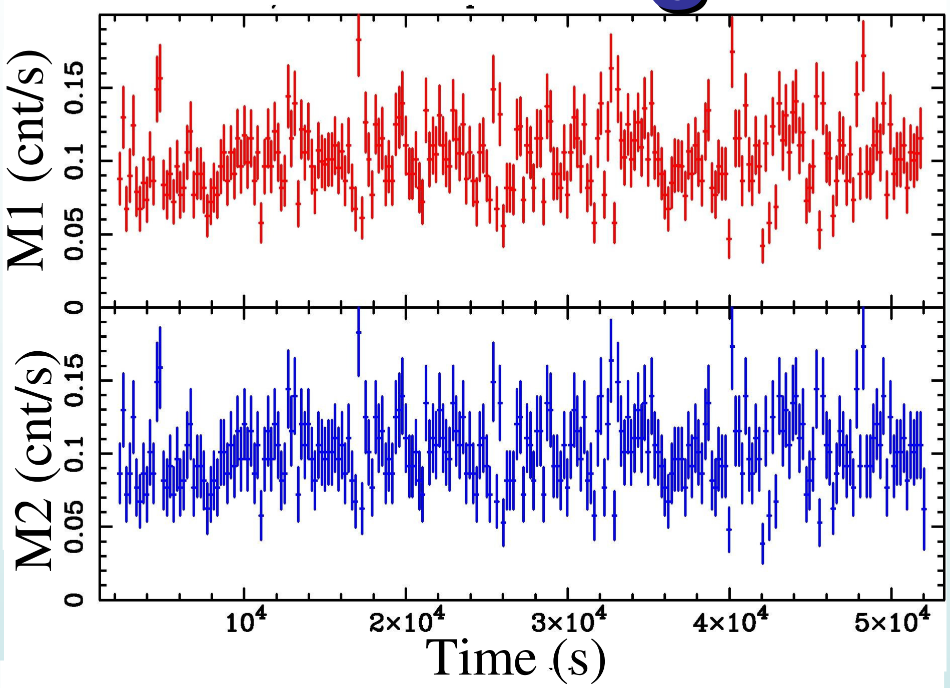


- We have studied PDS of bright X-ray sources in XMM observations of M31
- We class those X-ray sources showing Type A > $4\mathrm{x}10^{37}$ erg s^{-1} as BH; No BH Type B below ~$4\mathrm{x}10^{37}$ erg s^{-1}
- All consistent with expected behaviour from Galactic LMXBs if transition from A to B at ~10% Eddington

The source of the artefacts

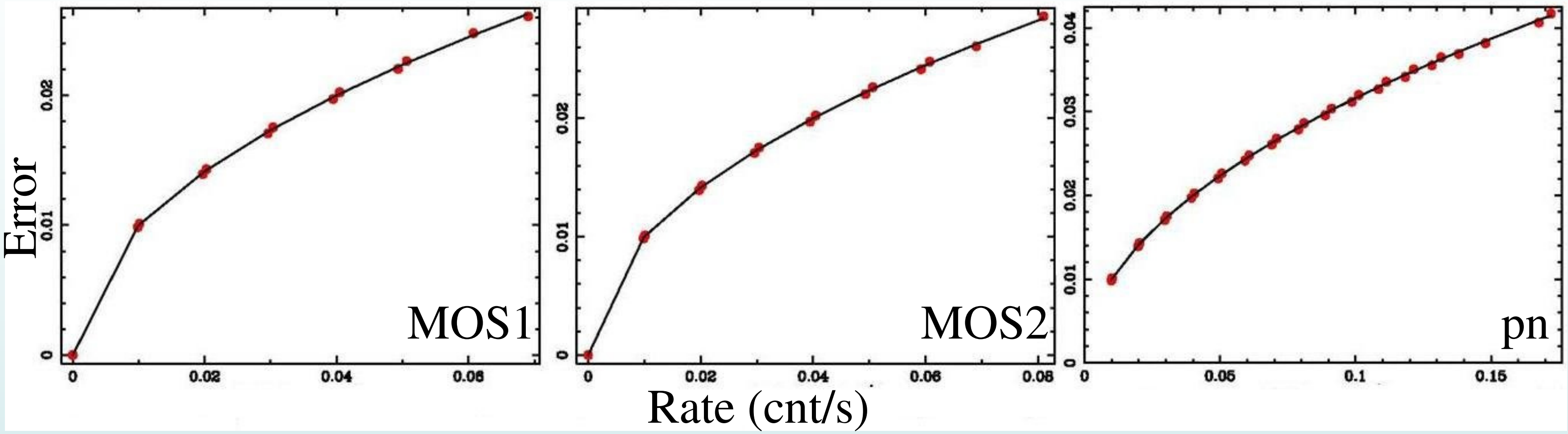
- SAS is standard software for analysing XMM-Newton data
- SAS tool evselect produces different lightcurves depending on how time filtering is done
- Three methods of time filtering
  - In expression: "(TIME in [t_1:t_2])&&…", Method 1
  - Adding keywords to events file header: TLMIN1 = t_1, TLMAX1=t_2, Method 2
  - Additional time constraints when generating lightcurves: evselect timemin=t_1 timemax=t_2… , Method 3
- Methods 2 & 3 equivalent but not equivalent to Method 1, although this is not mentioned in any documentation
- **This applies to all XMM-Newton observations, not just those of M31**

Combined EPIC lightcurves



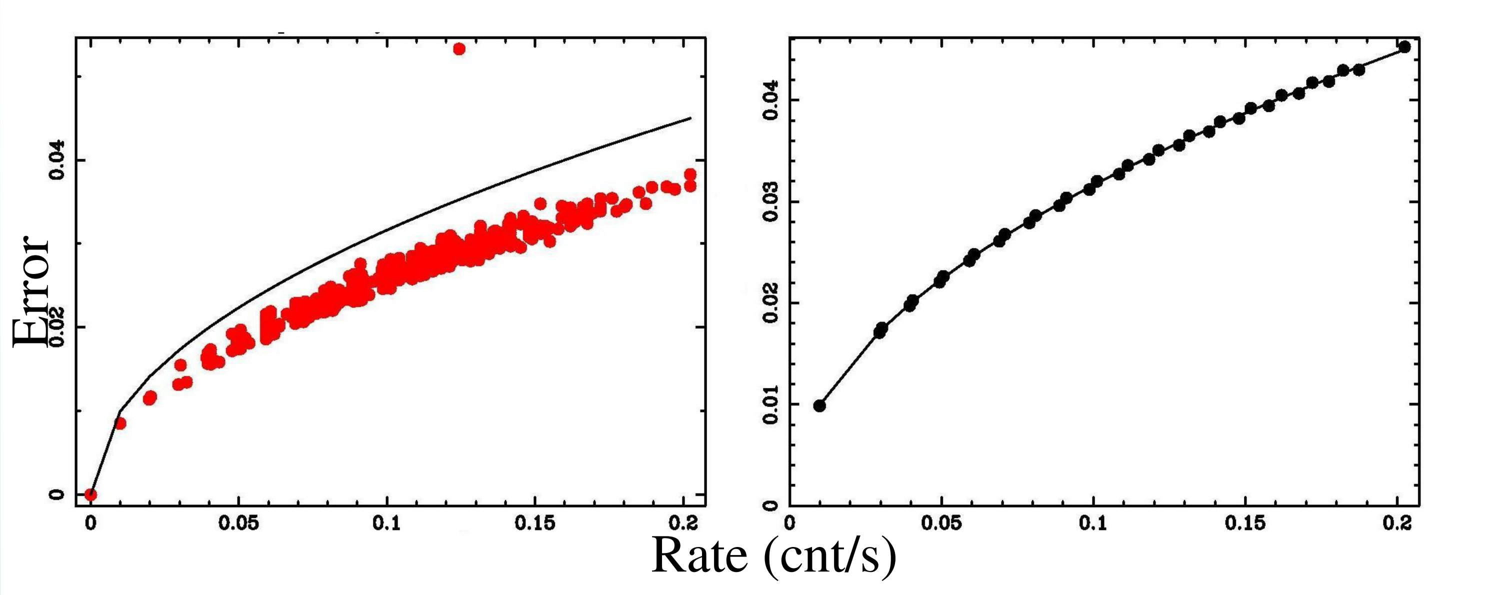
- EPIC lightcurves combined using the lcmath ftool
- Best fit line of constant intensity gives variability
  - Method 1 χ^2/dof = 408/239, mean = 0.102 count s^{-1}
  - Method 2 χ^2/dof = 280/240, mean = 0.102 count s^{-1}
- Need to find out which is correct

Rate vs. Error



- Binned MOS1, MOS2 and pn lightcurves of a source to 100 s, obtained Rate vs. Error: 600 points per curve
- Curve for Poisson errors also shown for each: $E = N^{0.5}/t = (R.t)^{0.5}/t = (R/t)^{0.5}$, R=rate, t=binsize, E=error
- All these individual lightcurves have Poisson errors
- So combined lightcurve should also have Poisson errors

Method 1&2 Rate vs. Error



- Combined Method 2 lightcurve has Poisson errors
- However Method 1 lightcurve has errors < Poisson!
- Methods 2 & 3 give synchronised lcs and correct sum
- Method 1 gives unsynchronised lcs and artificial variability

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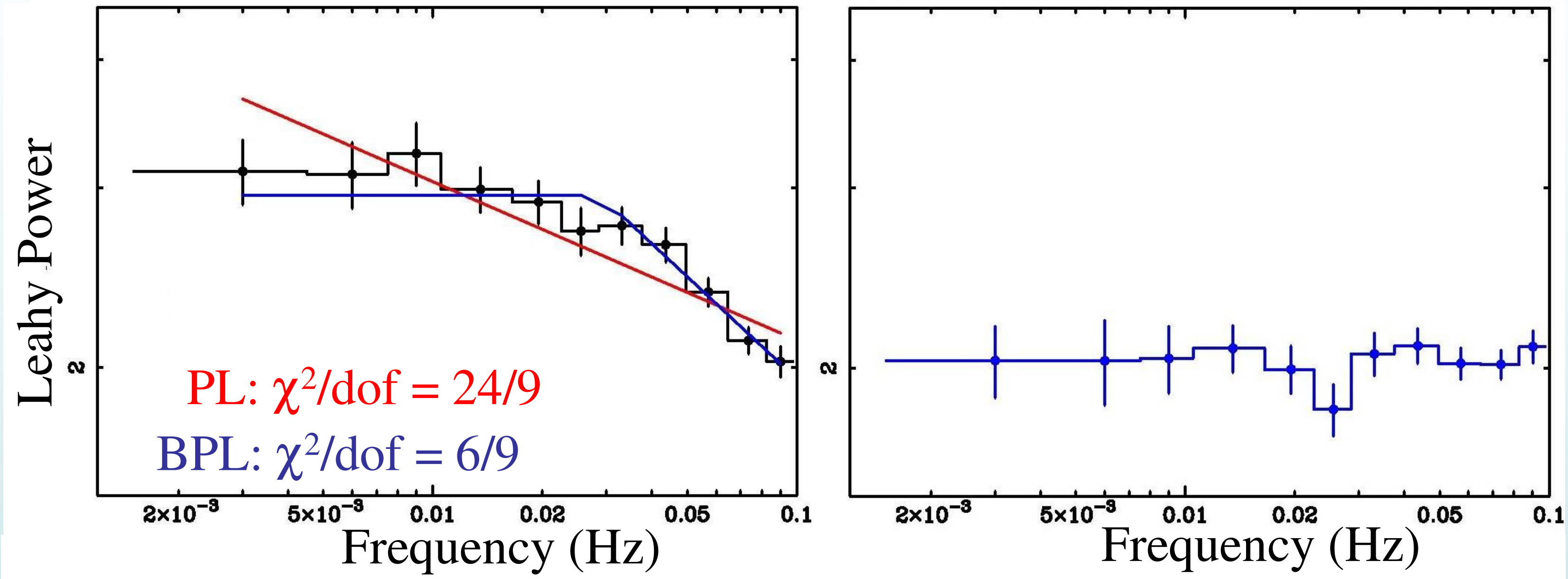
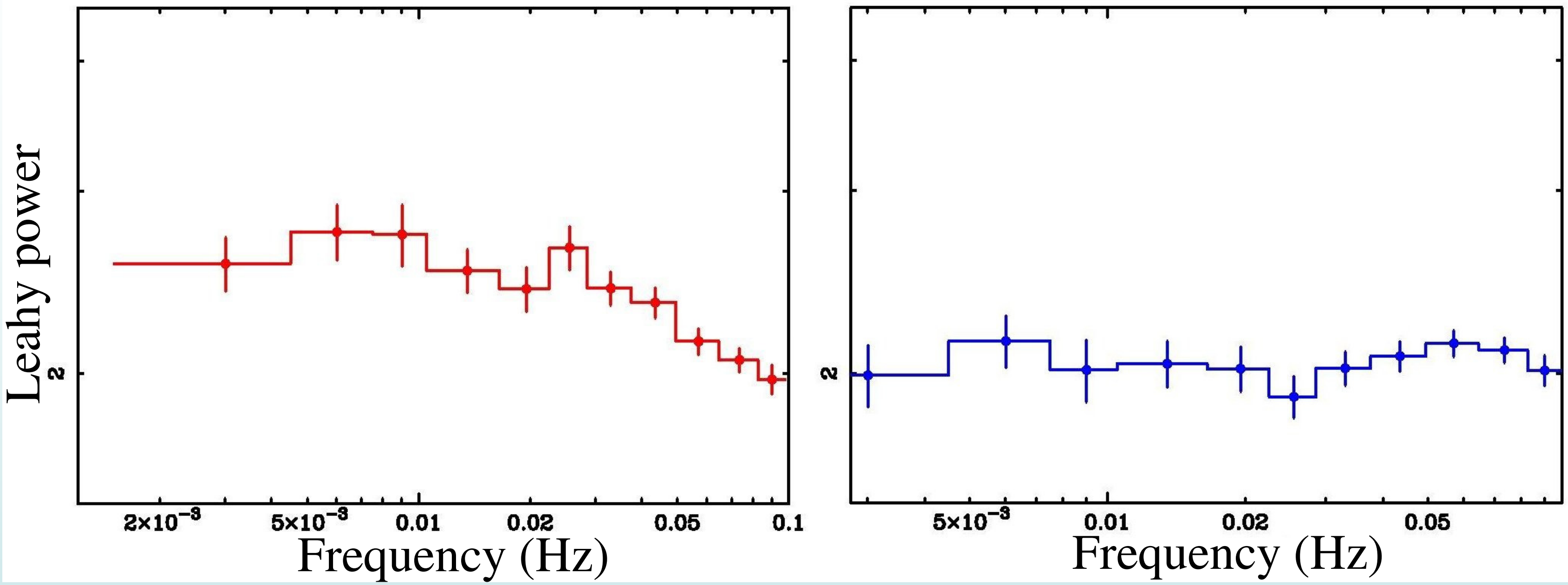
Combined PDS



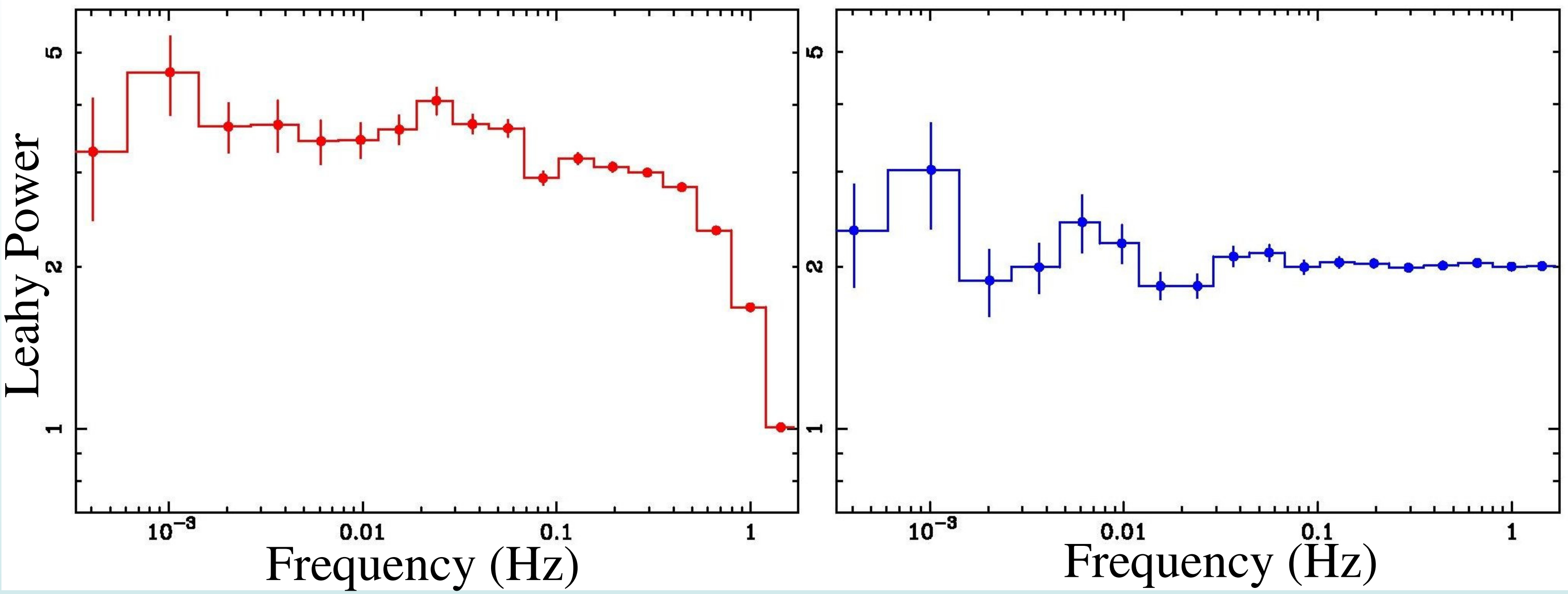
- Method 1 PDS requires broken power law… Type A
- Method 2 PDS consistent with Poisson
- Type A artificial… but how is it formed?
- Still investigating: we can reproduce Method 1 lcs, but don’t yet understand what causes Type A PDS

Background subtraction



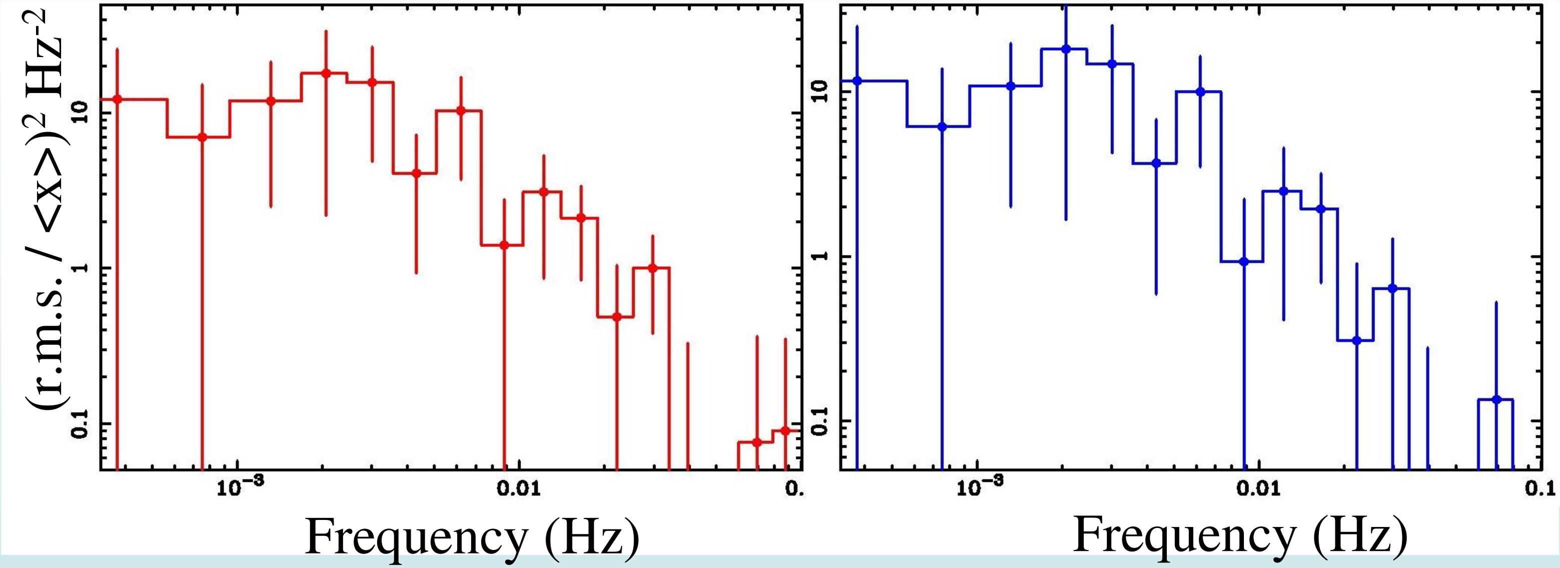
- PDS of background-subtracted pn lightcurves for a M31 source, using Methods 1 & 2
- Method 1 shows artificial Type A
- Hence background-subtraction also affected!

IMBH in NGC 4559?



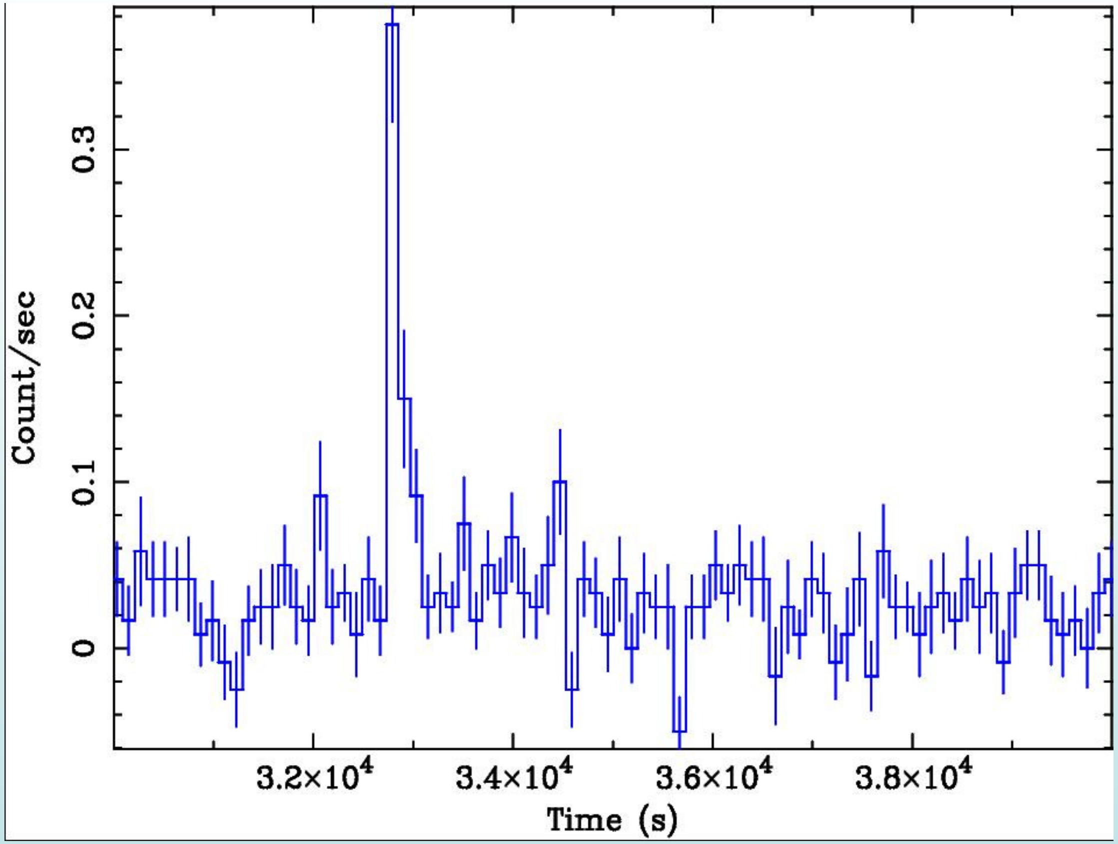
- Cropper et al. (2004) obtained Type A PDS from ULX7 in NGC 4559, at a luminosity of ~10^{40} erg s^{-1}
- We obtained Method 1 and 2 PDS from source
- Type A is artificial!

How about NGC 5408 ULX?



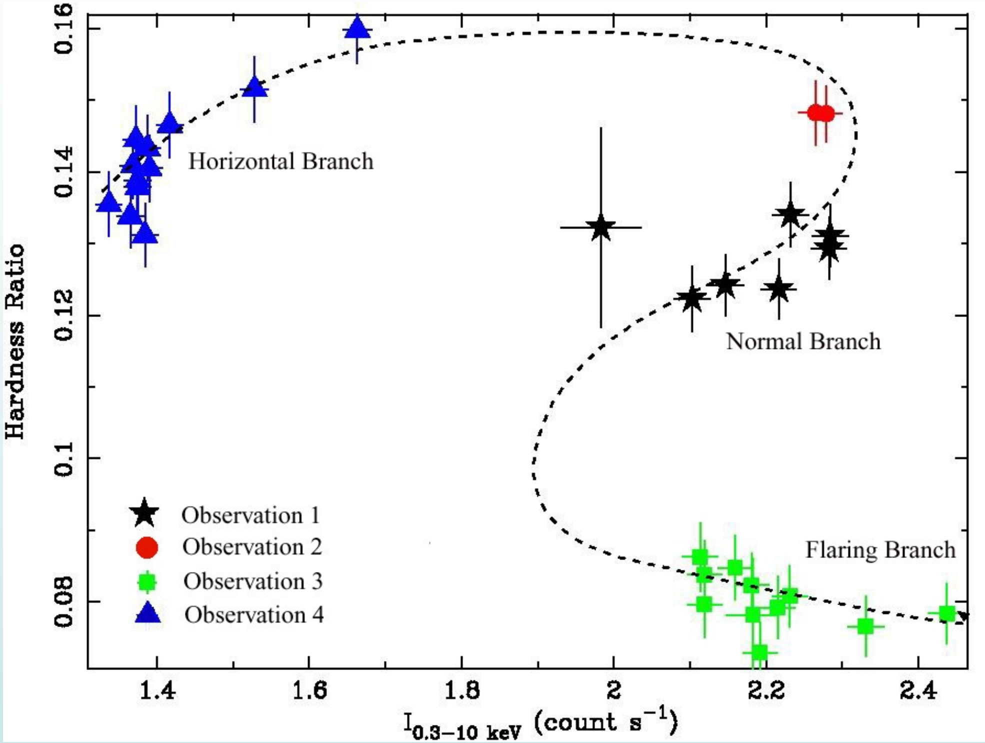
- Soria et al. (2004) report Type A PDS in 2003 XMM-Newton observation of ULX in NGC 5408.
- Method 1 and 2 PDS both show variability in only 3 ks of data. Likely Type A but break not significant

Good news- real M31 results



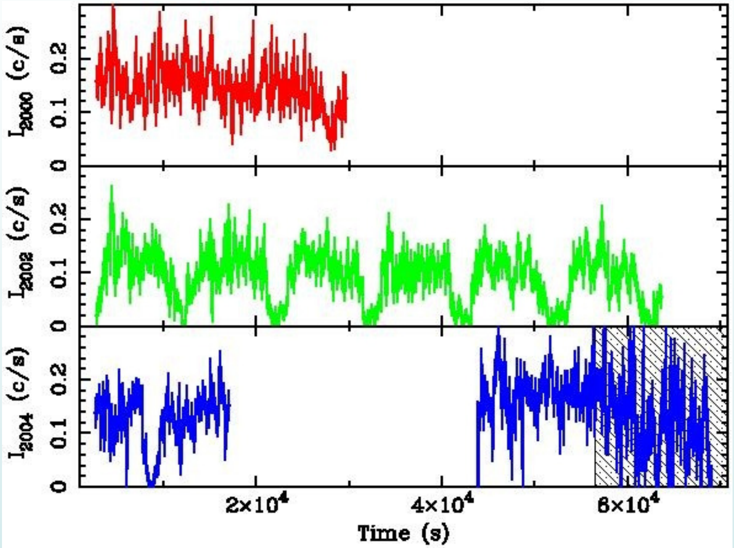
M31 X-ray burst (Pietsch & Haberl, 2005) confirmed

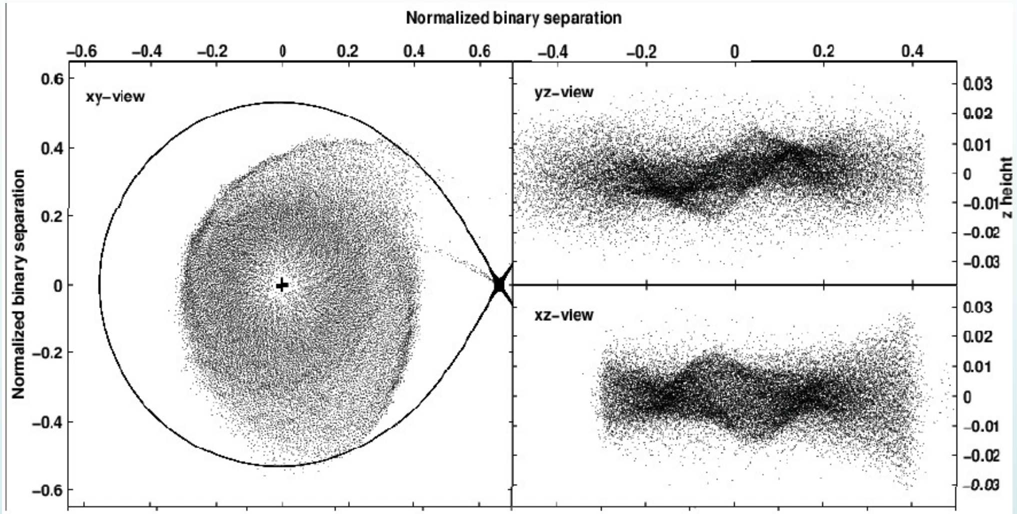
M31 Z-source



- Brightest M31 X-ray source ~$5x10^{38}$ erg s^{-1} in 0.3-10 keV band, has 3 branched HID (Barnard et al., 2003)
- Analogue of Galactic Z-source (only 9th to be found)

Disc precession in Bo 158





- ~100% on 10017 s period in one obs (Trudolyubov et al., 2002)
- However, not in all obs:- precession (Barnard et al., 2006)

Conclusions

- We have previously identified LMXBs in M31 using broken power law PDS from XMM-Newton observations
- These PDS are artefacts of the incorrect treatment of non-synchronised lightcurves
- All XMM-Newton SAS lightcurves are non-synchronised by default, even on the same CCD
- Hence all XMM-Newton lightcurves must be explicitly synchronised
- However, XMM-Newton is still a viable tool for timing extra-galactic X-ray binaries
- Type A expected for extragalactic LMXBs if sensitivity high enough
- Type A variability > 4×10^{37} erg s^{-1} in 0.3-10 keV band still indicates black hole LMXB