The long-term variability of a population of ULXs monitored by Chandra

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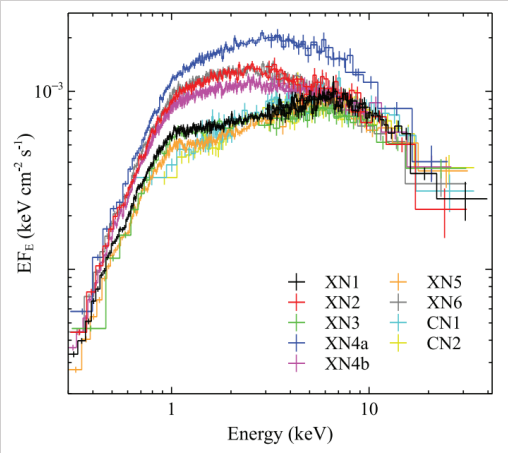
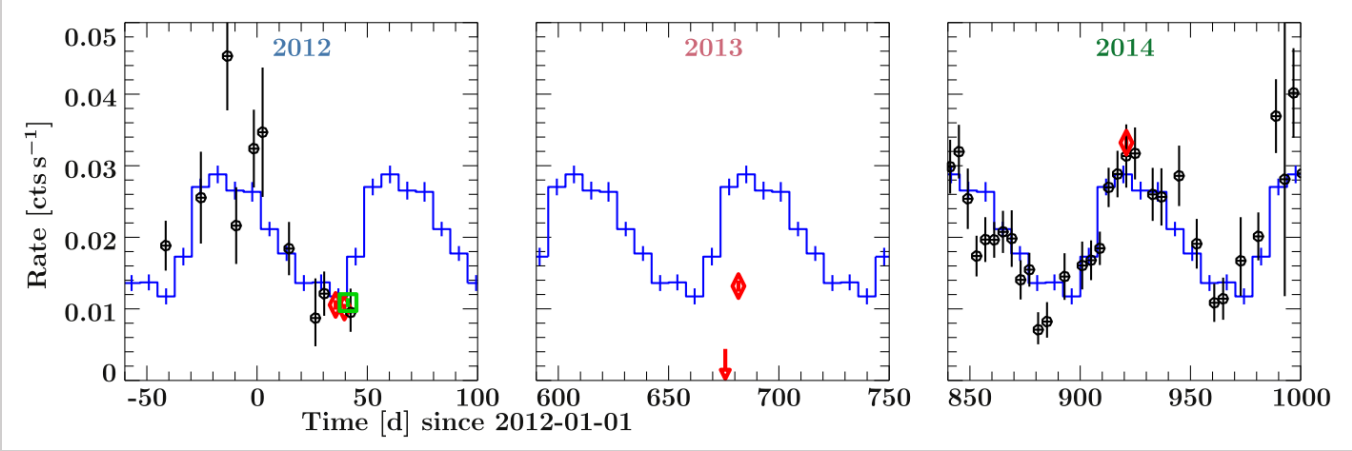
Long-term variability of ULXs

- Long-term ULX variability is interesting and takes various forms
  - Variations in spectral state between observations
  - Superorbital periodicities – often seen in PULXs, still not well understood
  - "Propeller effect" indicating a neutron star accretor?
  - Eclipses?

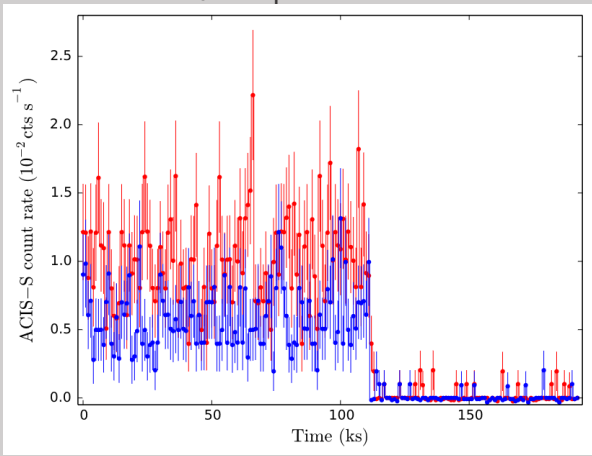
NGC 1313 X-1, Walton+20





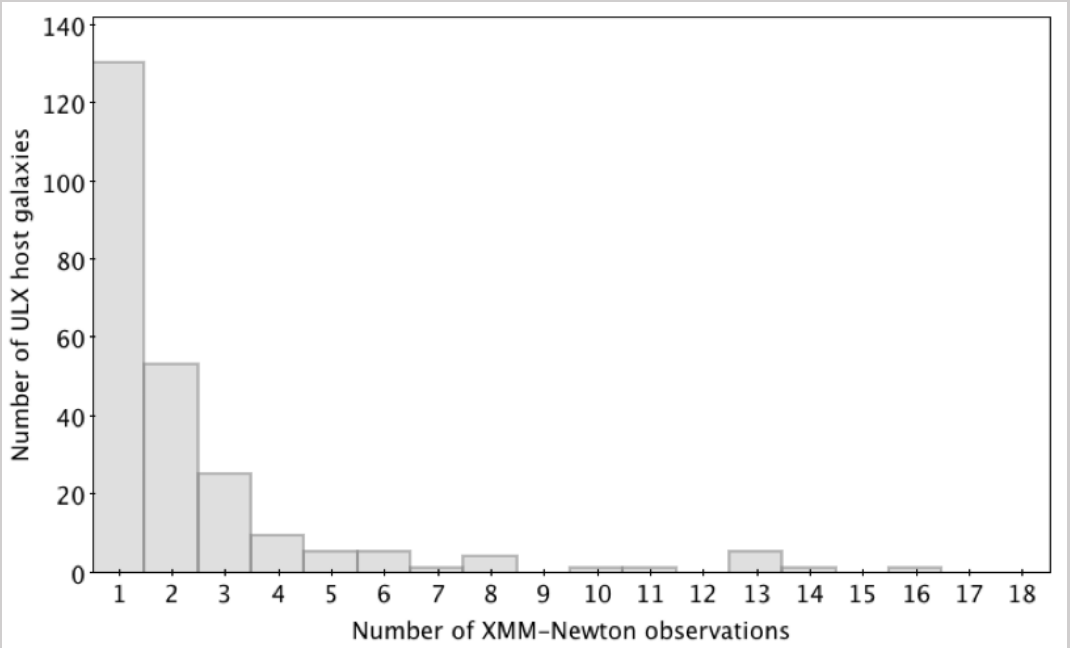
NGC 5907 ULX-1, Fürst+17

M51 ULX-1, Urquhart & Soria 2018



Long-term variability of ULXs

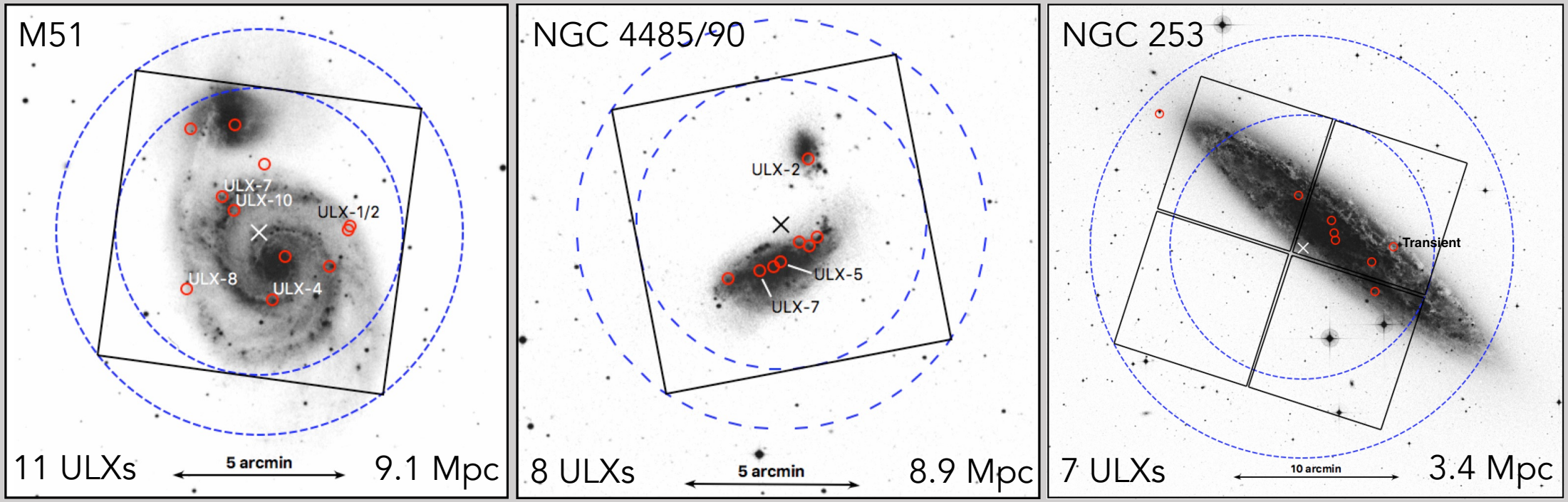
- However, we do not have a good **population-level** understanding of long-term ULX variability
  - Only a small number of particularly interesting and/or highly luminous ULXs have been monitored over long timescales
    - We still see a wide variety of behaviour from these sources! (see e.g. Gúrpide+21)
  - The majority of the ULX population has been observed only a handful of times to a depth sufficient to probe high levels of variability



Earnshaw+18

Chandra monitoring campaign

- Three ULX-rich galaxies: M51, NGC 4485/90, NGC 253
  - 10 observations each on ~monthly cadence over the course of a year to a depth of ~10^{38} erg/s, carried out over 2020 and 2021

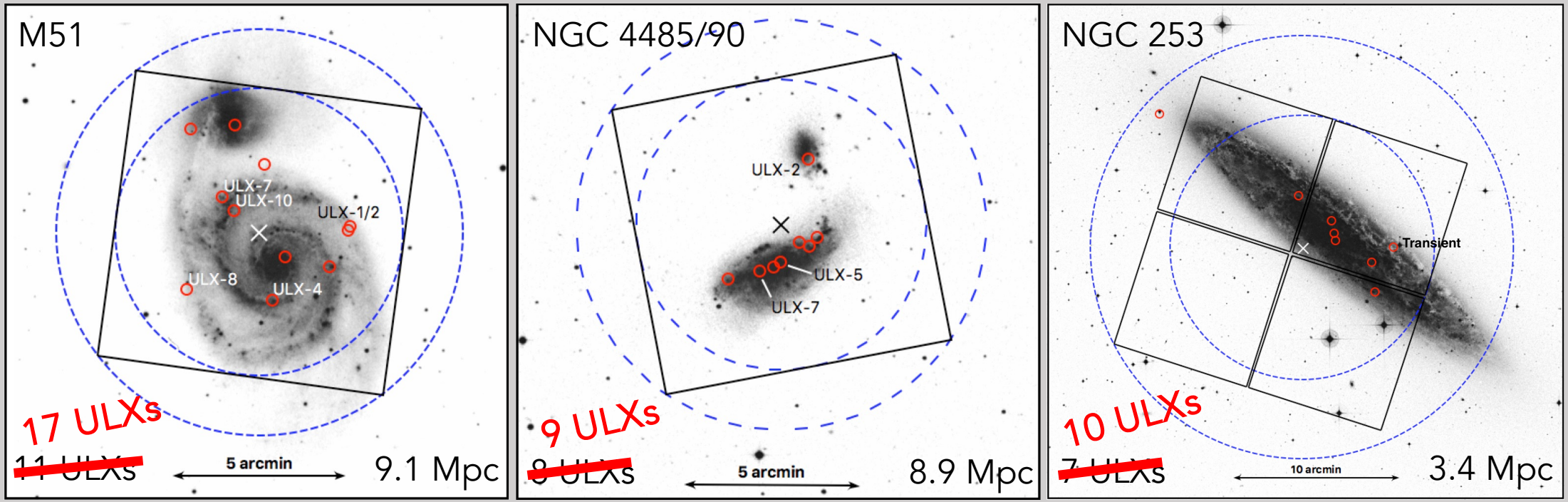


Source detection and flux/HR estimation

- Source detection performed using CIAO routine *wavdetect*
- Sources detected at 5-sigma were matched across observations, and then fluxes or upper limits were calculated for each observation using CIAO routine *srcflux*, using predicted PSF size where a source was not significantly detected
- ULXs defined as having $L_X >\sim 10^{39}$ erg/s in at least one observation, or previously detected as such in archival data
- Hardness ratios calculated using Bayesian Estimation of Hardness Ratio (BEHR) with 0.3–2 and 2–10 keV soft and hard energy bands
- Spectra extraction using *specextract* and fitting with power-law for some brighter sources to validate HR approach

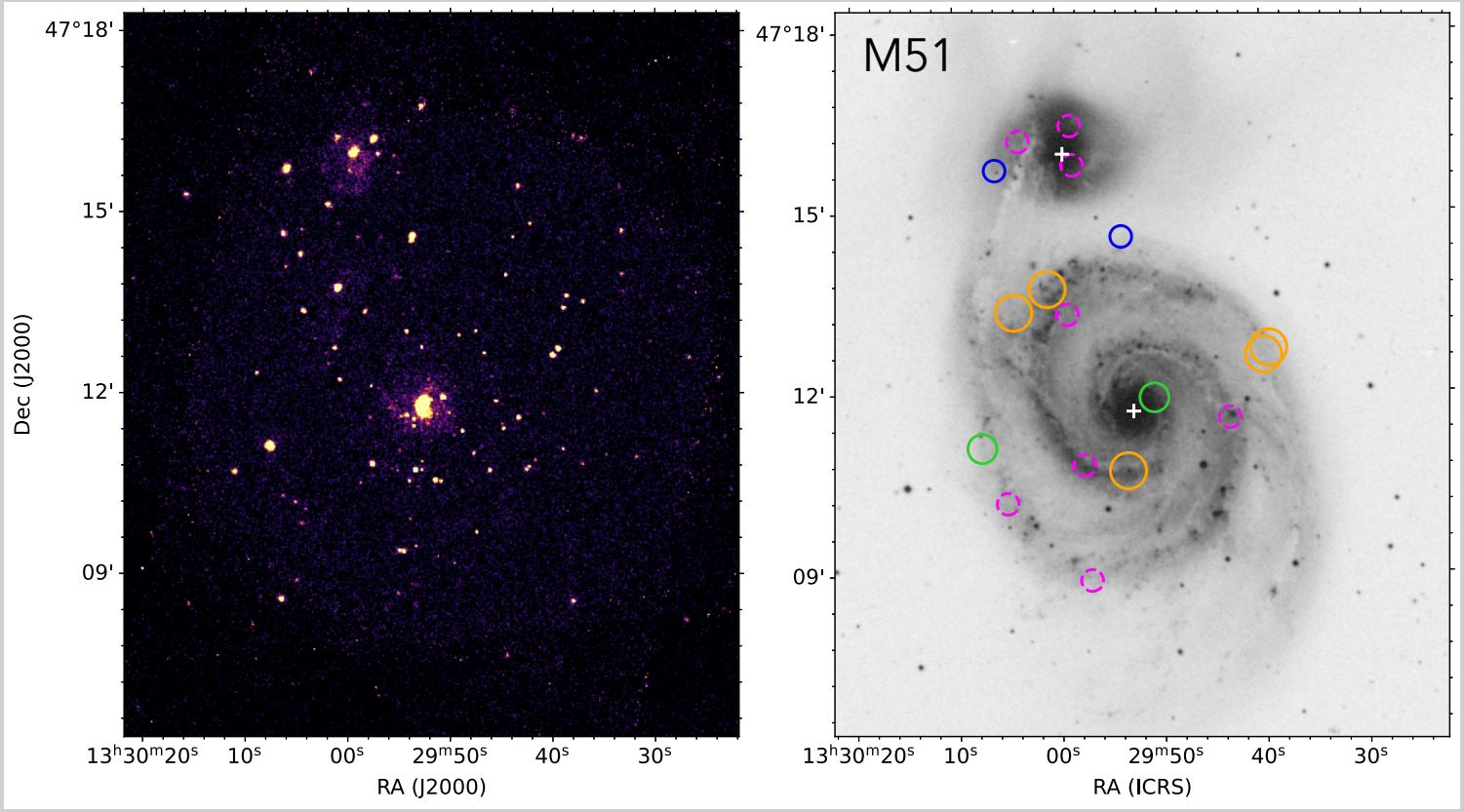
Chandra monitoring campaign

- After matching with Walton et al. (2022) catalogue, final sample contains 36 ULXs (i.e. sources observed at >10^{39} erg/s at least once by either XMM, Chandra, or Swift)



Results

- We sorted the population into four categories:
  - Persistently bright, no large change in flux
  - Moderately variable by factor of 3 to 10
  - Highly variable by factor >10
  - Not a ULX during period of monitoring



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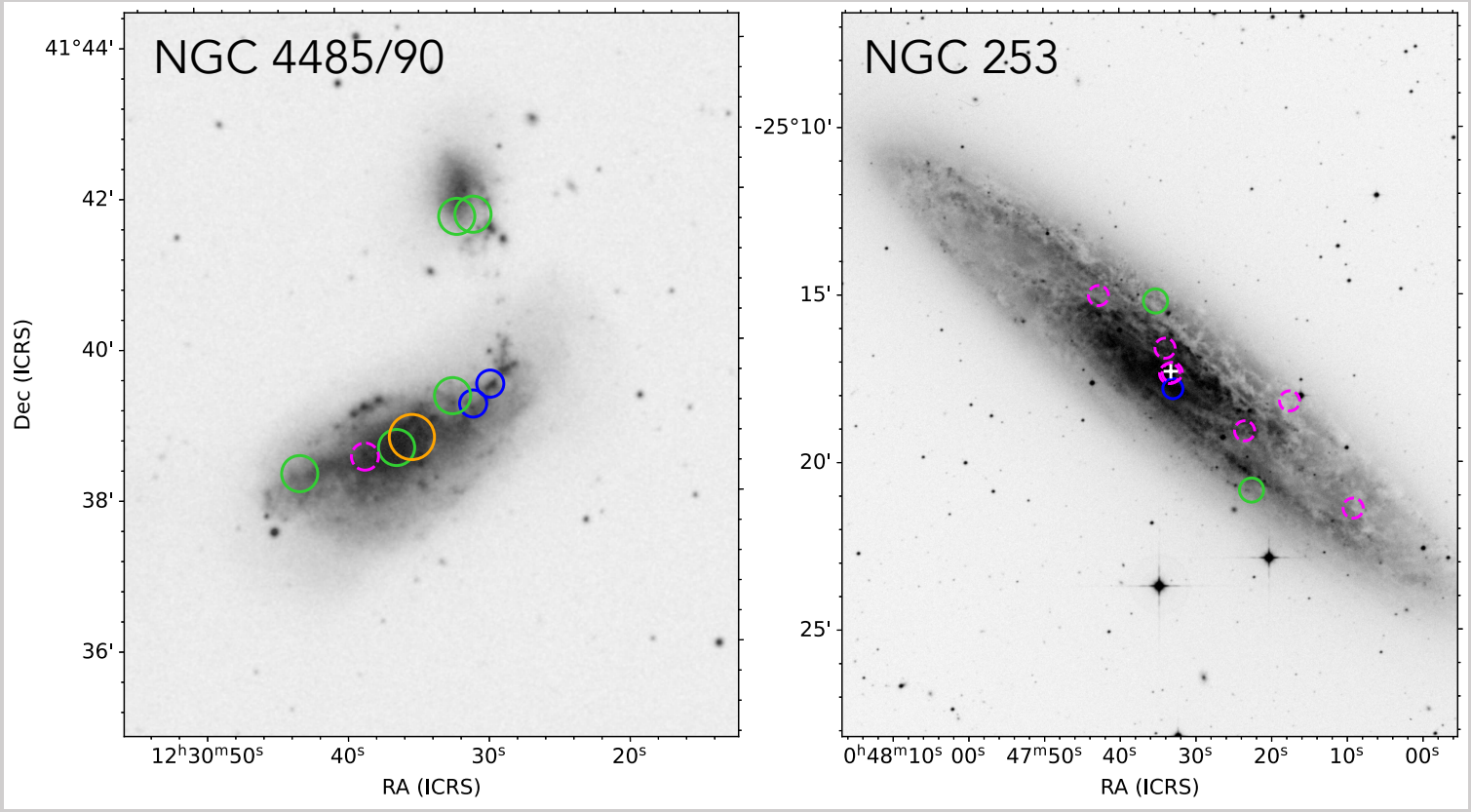
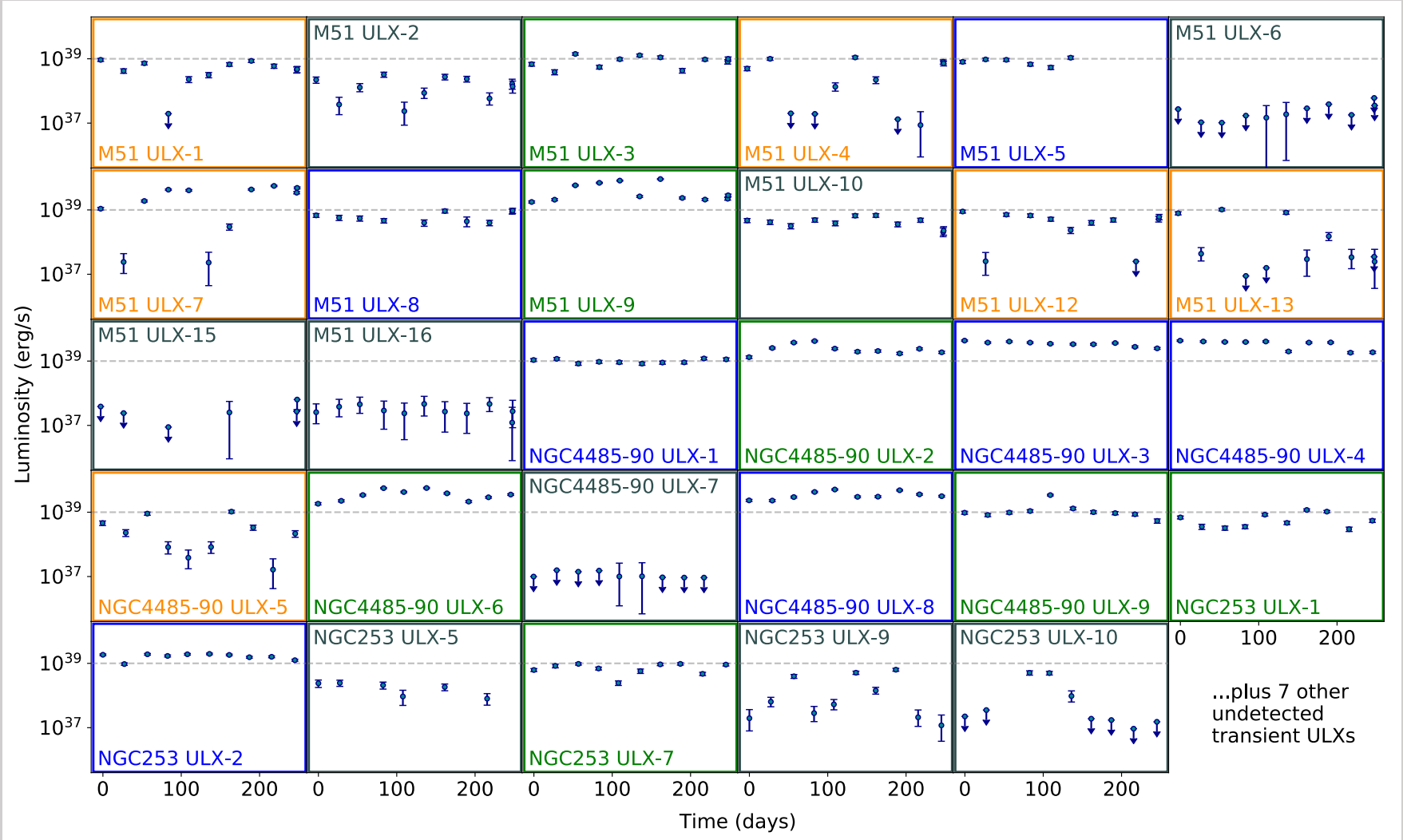


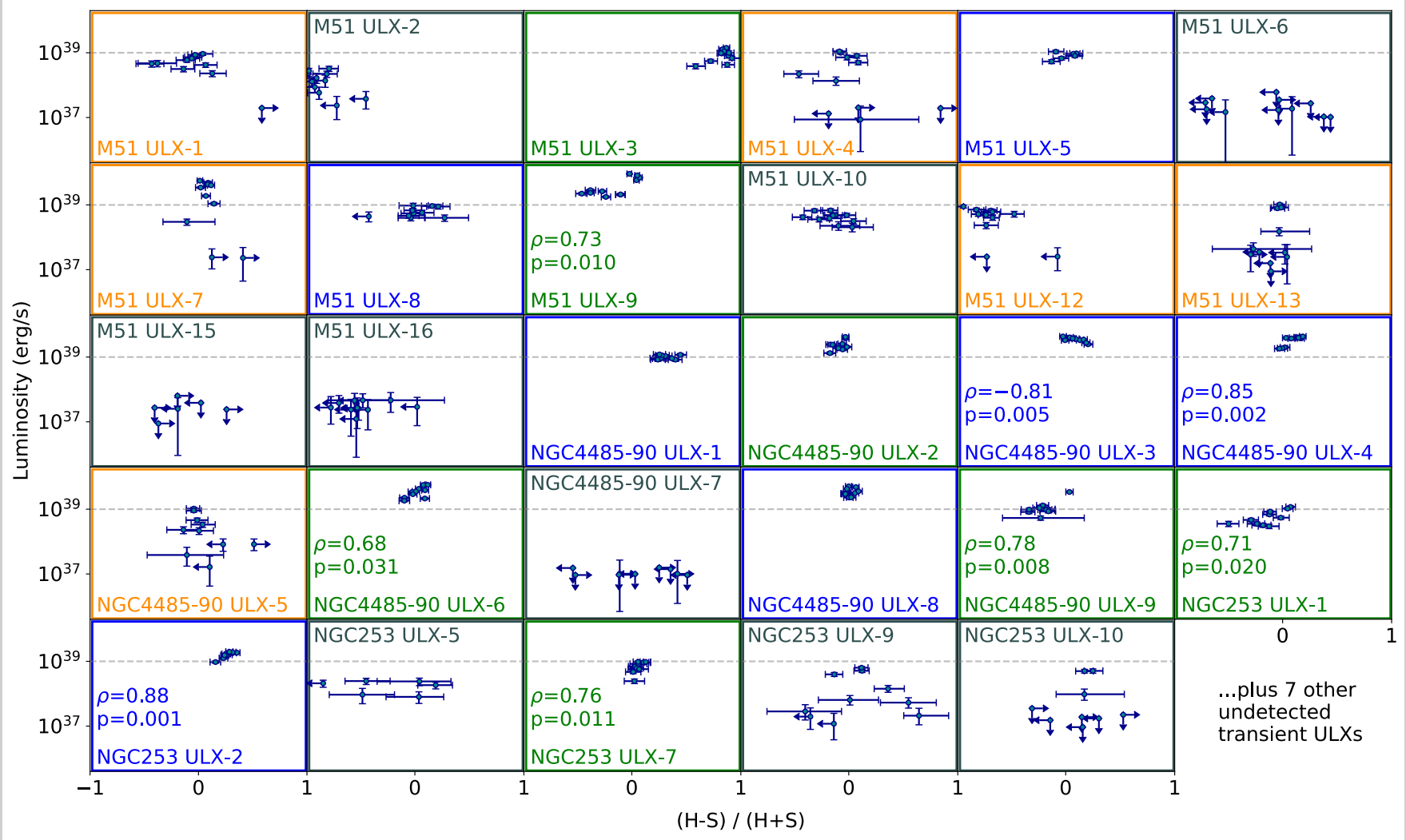
Results

- We find, across 36 sources:
  - 7 persistent
  - 7 moderately variable
  - 6 highly variable
  - 16 no longer ULXs (5 of which still close to ULX luminosities; 7 of which were not detected at all over the year)



Results

- We find, across 36 sources:
  - 3/7 significant L-HR correlations
  - 5/7 significant correlations
  - No significant correlations
- 7 positive correlations; 1 negative correlation



Summary

- Still a work in progress!
  - More timing analysis underway
  - Closer spectral study of some brighter sources
  - Comparisons with HR properties of other known variable ULXs
- Take-aways:
  - ULXs are a population that shows a variety of variability behavior, from persistent to highly variable
  - The ULX population as a whole is very changeable; there may be many more out there we haven't seen because of infrequent visits to XRB-rich galaxies

Thanks for listening!

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Backup slides

Results

- If we incorporate archival Chandra observations in our classification, most persistent and moderately variable sources retain behaviour
  - M51 ULX-2 and ULX-11 were previously ULXs in Chandra observations