ULXs and other X-ray sources in nearby galaxies

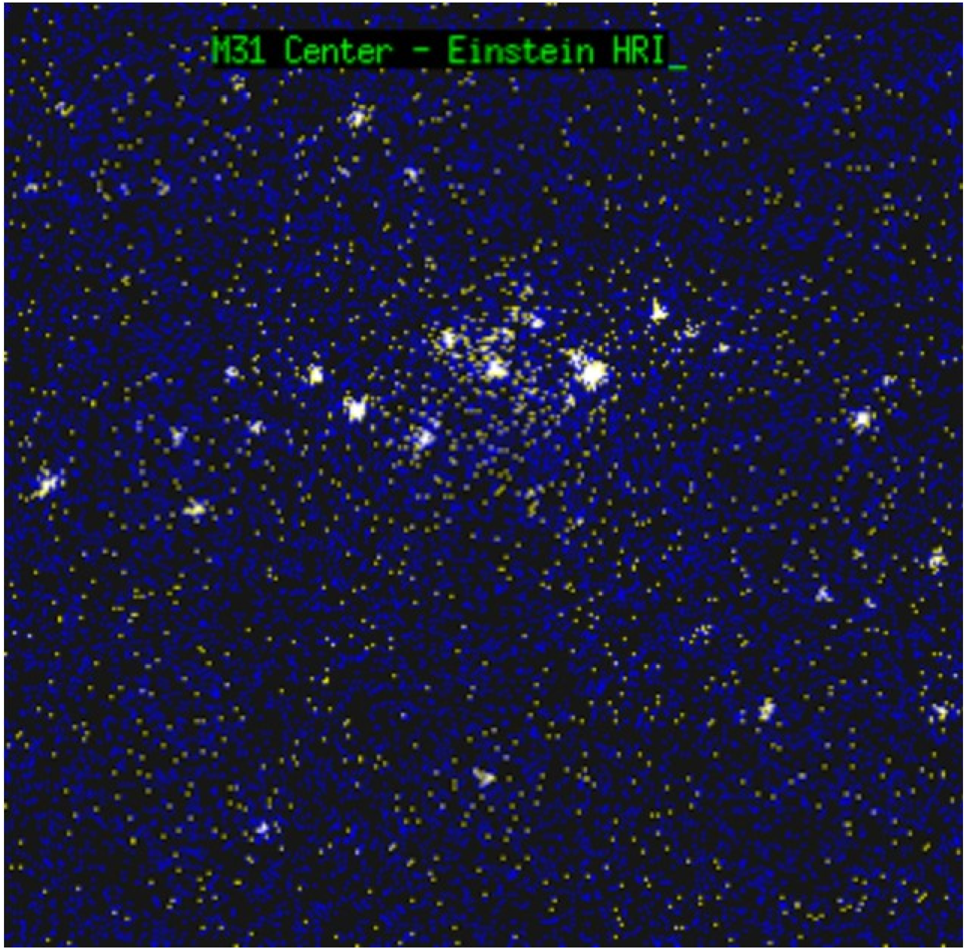
Natalie Webb

Institut de Recherche en Astrophysique et Planétologie, Toulouse, France

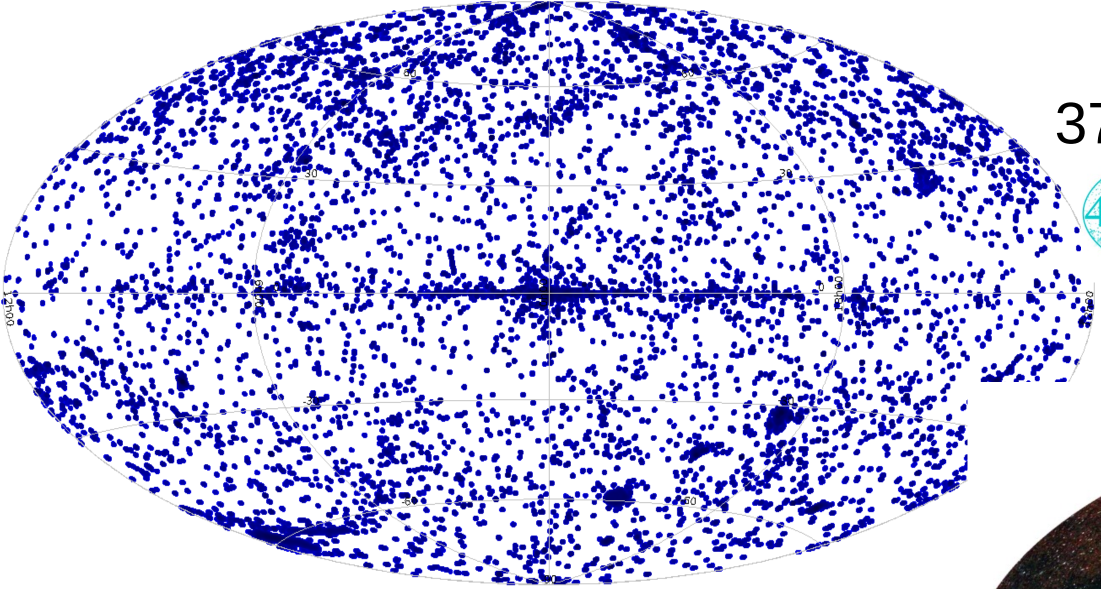
X-ray sources in nearby galaxies

- Non-nuclear extra-galactic sources discovered with launch of Einstein (Nov. 1978, Giacconi et al. 1979; Fabbiano 1989)
- >100 galaxies observed
- Detected :

  - X-ray binaries (XRBs)
  - ultraluminous X-ray sources (ULXs)
  - supernova remnants
  - pulsars
  - hot gas

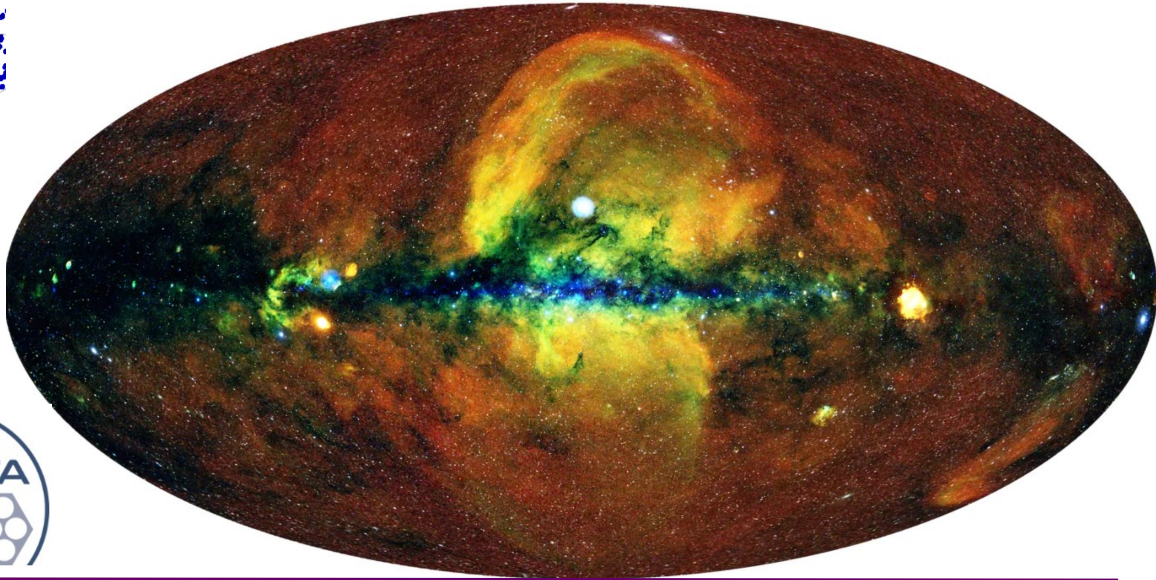


Large X-ray surveys with XMM-Newton, eRosita, Swift, ...



4XMM-DR14

1035832 detections, 692109 sources
372313 (36%) with spectra & lightcurves
Released: 9th July 2024
Covers 1383 sq degrees of sky
(Webb et al. 2020)



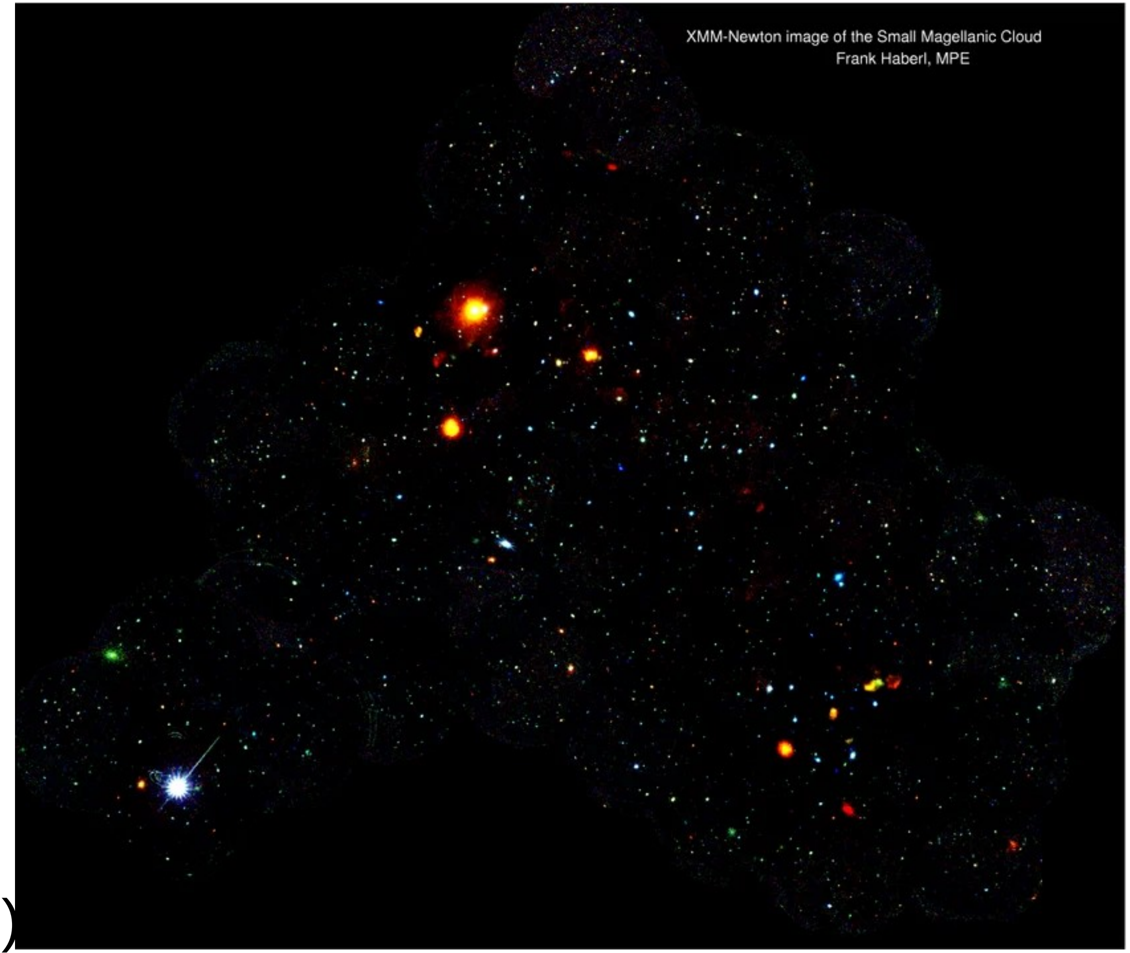
930000 sources
~200000 (20%) with spectra
Released: 31st January 2024
Covers half the sky
(Merloni et al. 2024)

eROSITA

X-ray binaries in nearby galaxies – example SMC

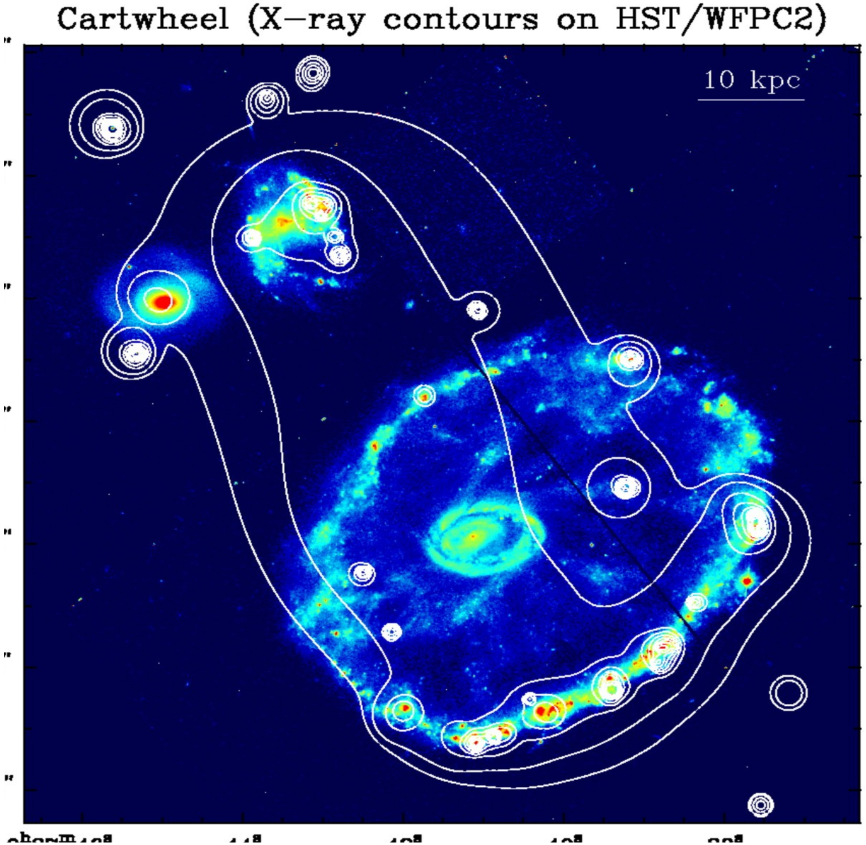
- 3053 XMM-Newton SMC sources:
  - 49 HMXB
  - 4 super-soft X-ray sources (SSS)
  - 34 foreground stars
  - 72 background AGN
- candidates :
  - HMXBs (45)
  - faint SSSs (8)
  - AGN (2092)
  - galaxy clusters (13)

  (Sturm et al. 2013)
- SMC has large pop. of HMXBs due to recent star formation (Harris & Zaritsky 2004; Rezaeikh et al. 2014)


XMM-Newton image of the Small Magellanic Cloud
Frank Haberl, MPE

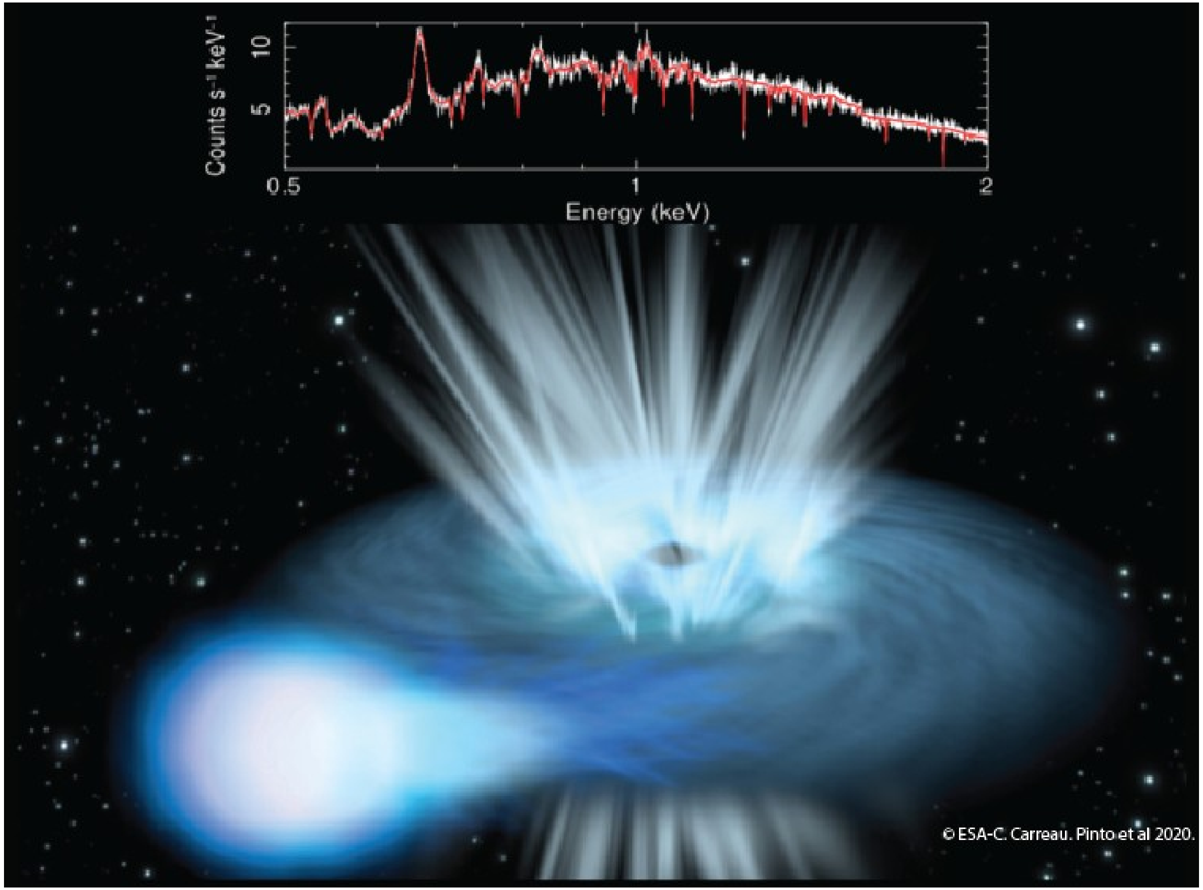
Ultra Luminous X-ray Sources (ULXs)

- X-ray sources with L > 10^{39} erg s^{-1}
- Located outside nucleus of host galaxy
- Many believed to be black holes
- If spherical accretion, implies intermediate mass black holes
- Difficult to reconcile with mass available for star formation and star formation rate (King 2004)
- Emission can appear to exceed Eddington limit if collimated (geometrically thick accretion disc/ relativistic boosting)



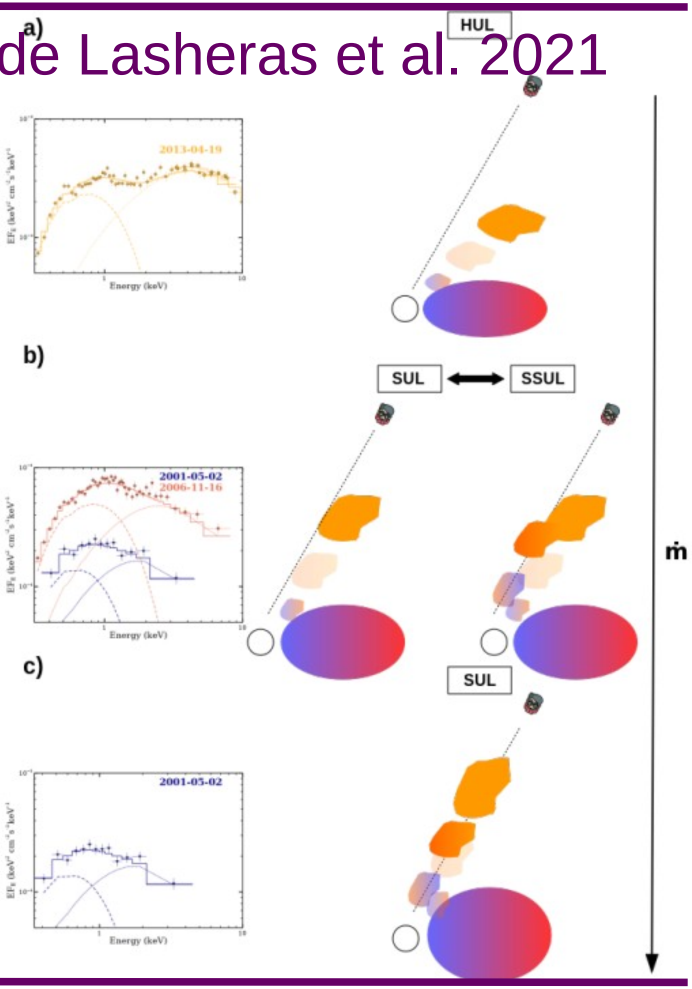
(From Gao et al. 2003)

ULX configuration

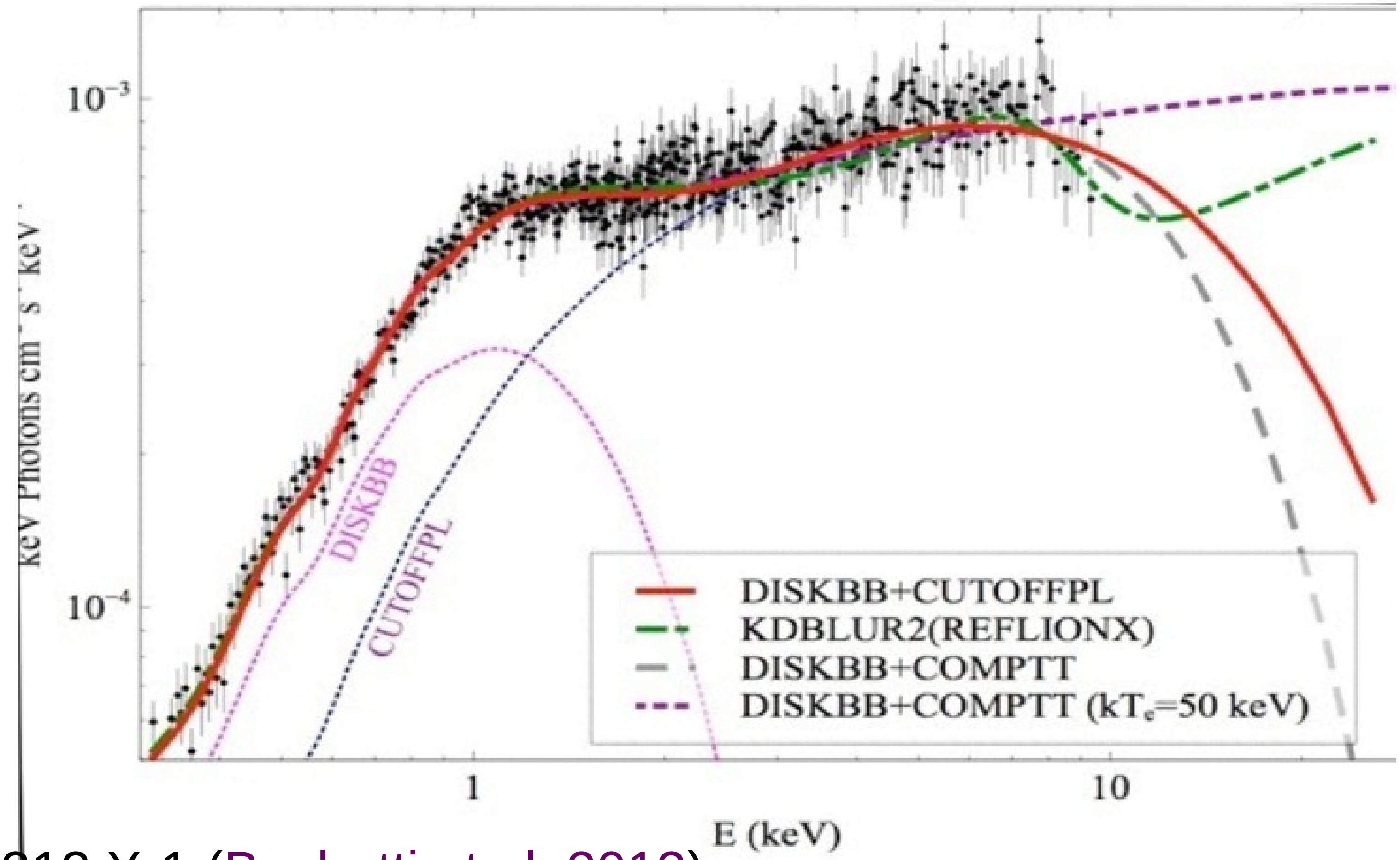


© ESA-C. Carreau. Pinto et al 2020.

Gurpide Lasheras et al. 2021

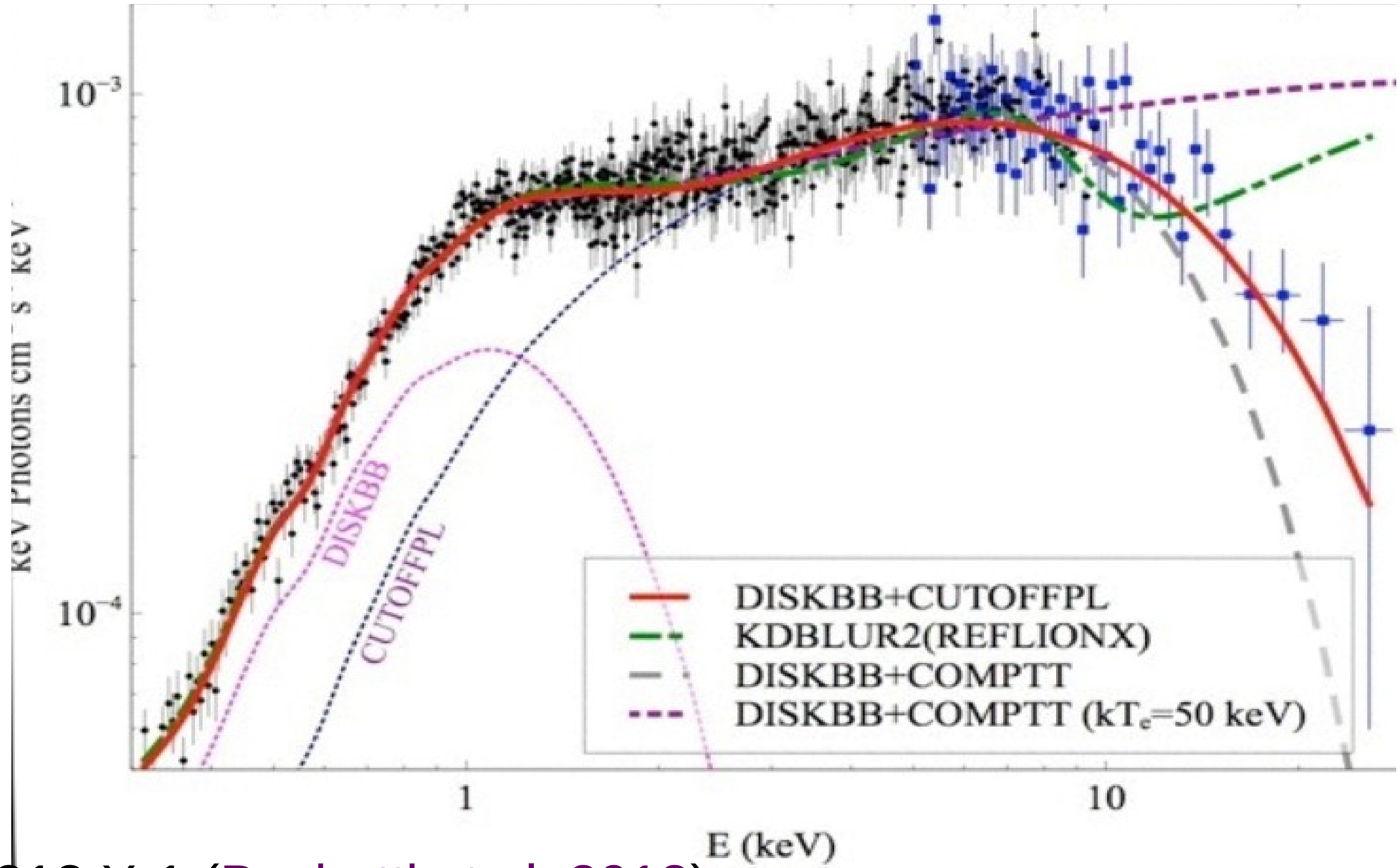


NuSTAR reveals super-Eddington accretion onto ULXs



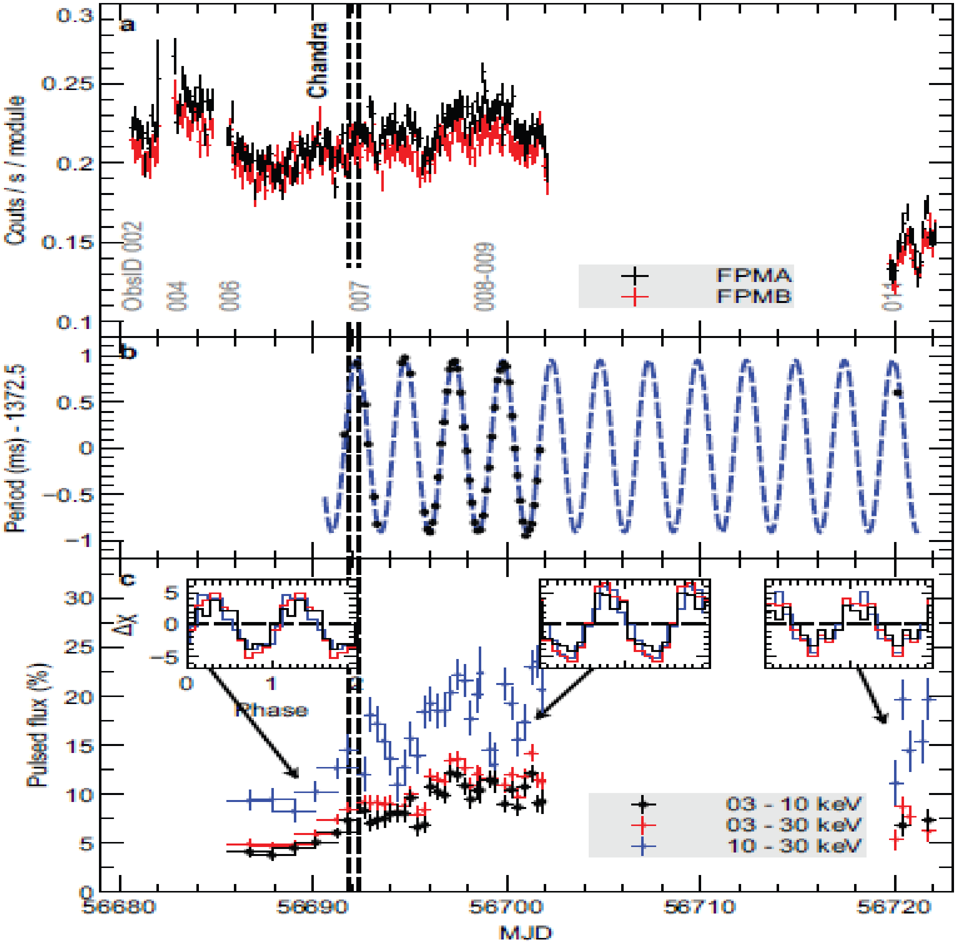
NGC 1313 X-1 (Bachetti et al. 2013)

NuSTAR reveals super-Eddington accretion onto ULXs



NGC 1313 X-1 (Bachetti et al. 2013)

But NuSTAR also revealed the unexpected



M82 X-2($L_{\max\ (0.3\text{-}10.0\ \mathrm{KeV})}$~$1.8\mathrm{x}10^{40}$ erg s^{-1})

Pulse period = 1.37 s (30 σ)
Spin up = -2 x10^{-10} s/s
Sinusoidal period = 2.53 d
Eccentricity < 0.003

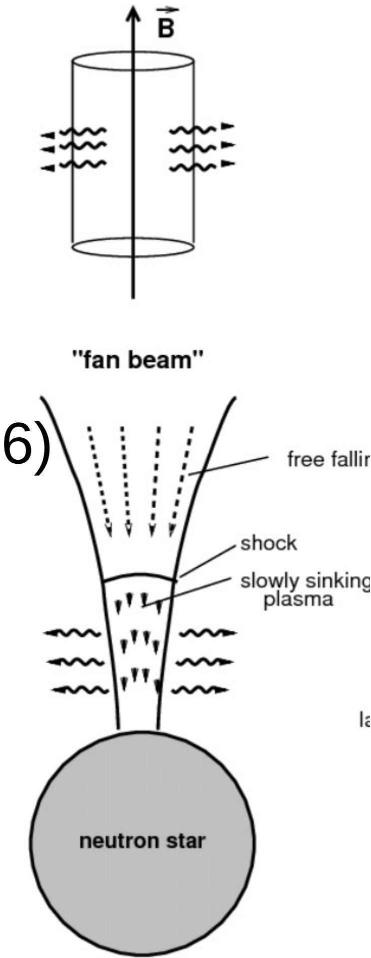
Pulse period and spin up
=> neutron star (NS)

Lack of eclipse => i < 60°
If M_{NS} ~1.4 $M_{\odot}$=> $M_{companion}$ > 5.2 $M_{\odot}$

Bachetti et al. (2014)

So what about the other ULXs ?

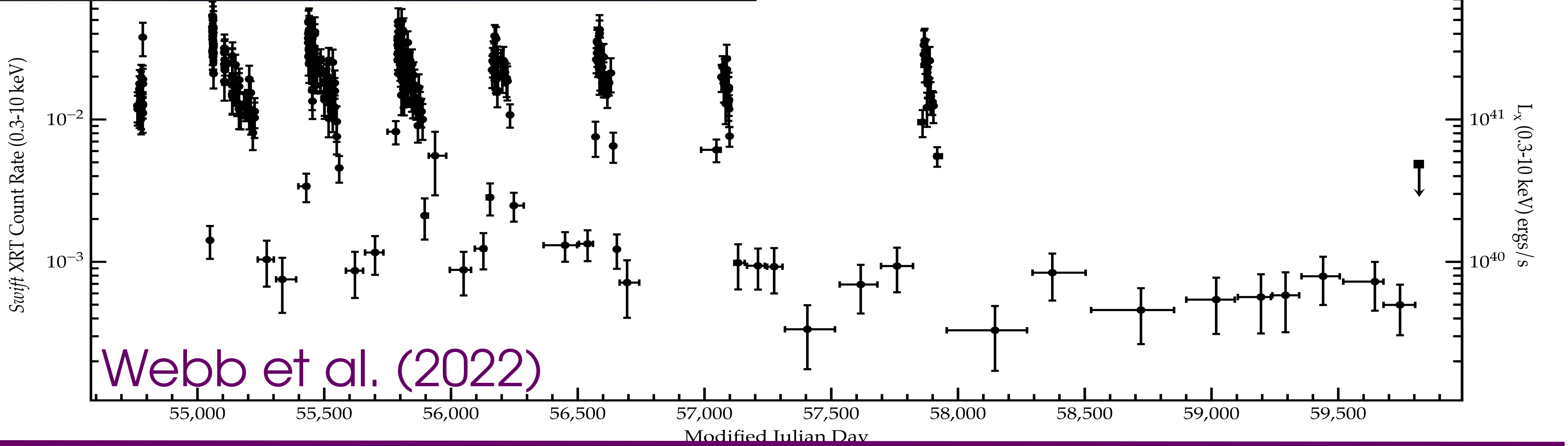
- 8 pulsating ULXs discovered
- 2 PULXs in NGC 7793 (Quintin et al. 2021)
- Many papers propose many ULXs may contain neutron stars
- Models describing how super-Eddington emission may be generated (e.g. Gnedin & Sunyaev 1973, Basko & Sunyaev 1976)
- PULX show hardest ULX spectra and highly transient
- Some softer, less variable ULXs may contain black holes
- Difficult to find models with stellar mass compact objects for sources with $L_X > 10^{41}$ erg s^{-1} (hyper luminous X-ray sources)
- Such sources may contain more massive black holes



Hyper Luminous X-ray sources (HLXs)

HLX-1 associated with ESO 243-49 at 95 Mpc (Farrell, Webb et al. 2009, Nature; Wiersema et al. 2010)

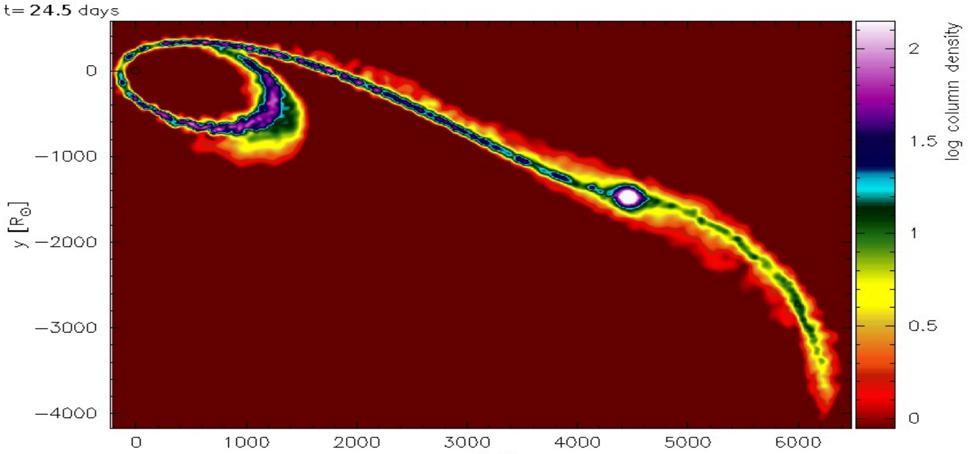
$L_{x(max)} = 1.2 \times 10^{42}$ erg s^{-1} (Godet, Barret, Webb et al. 2009)

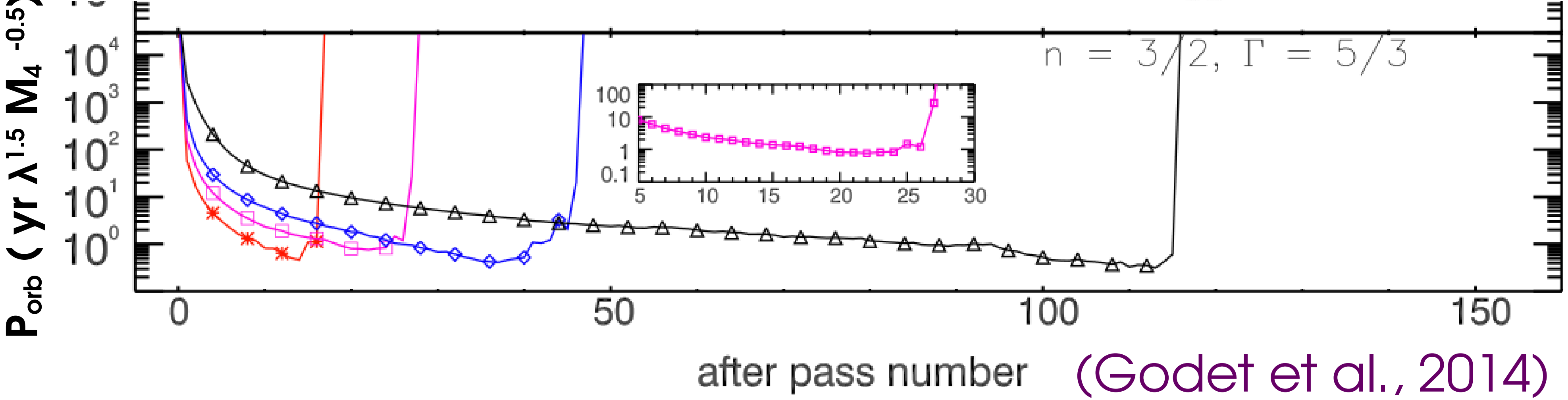


Webb et al. (2022)

ESO 243-49 HLX-1

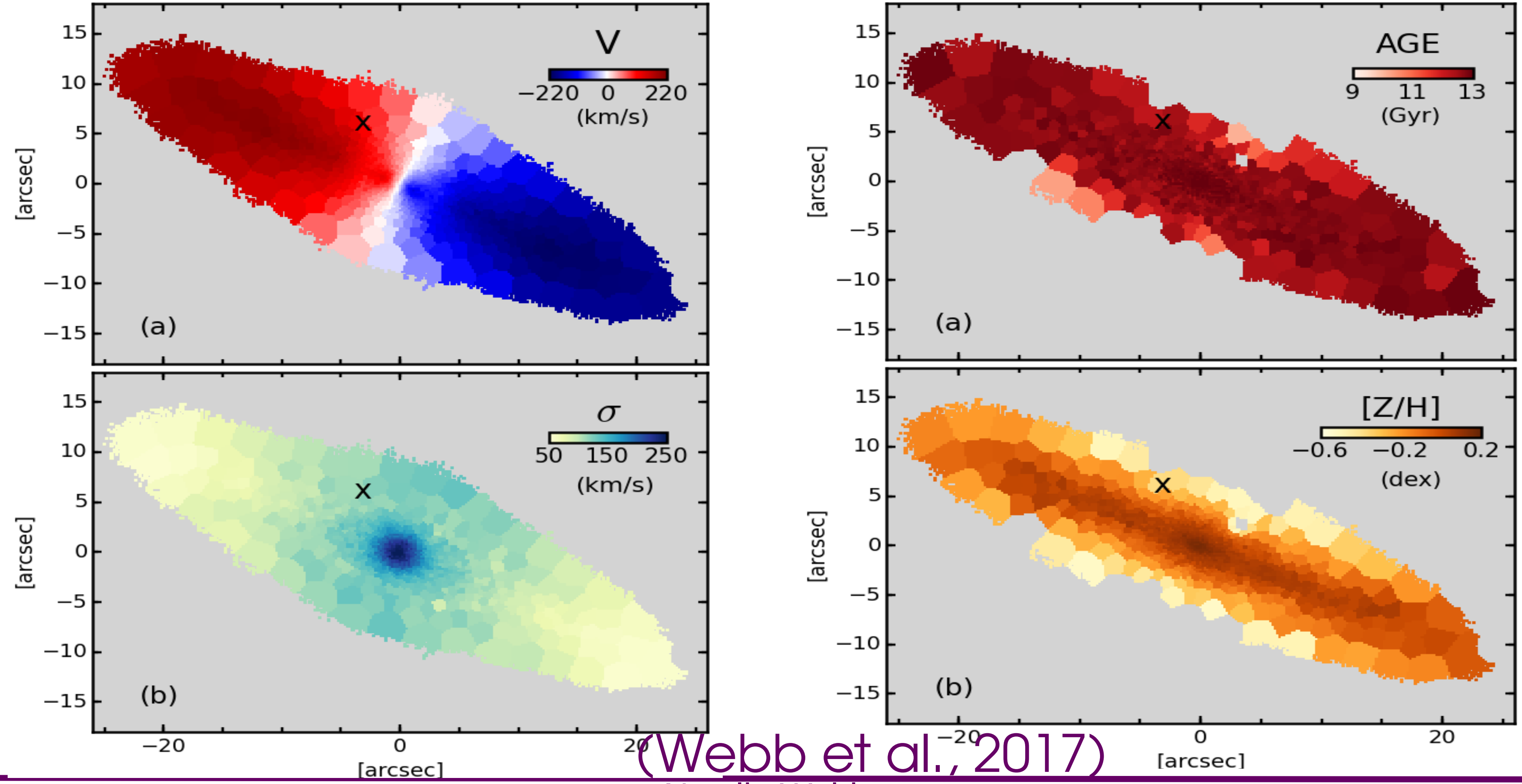
- Orbital evolution of polytropic companion, n=1.5, $\Gamma=5/3$
- Initial periapsis separation from IMBH (relative to tidal radius) of 2.3 (red), 2.4 (magenta), 2.5 (blue), 2.7 (black)
- $\lambda = R/0.01R_\odot$ and $M_4=M_{BH}/10^4\ M_\odot$





(Godet et al., 2014)

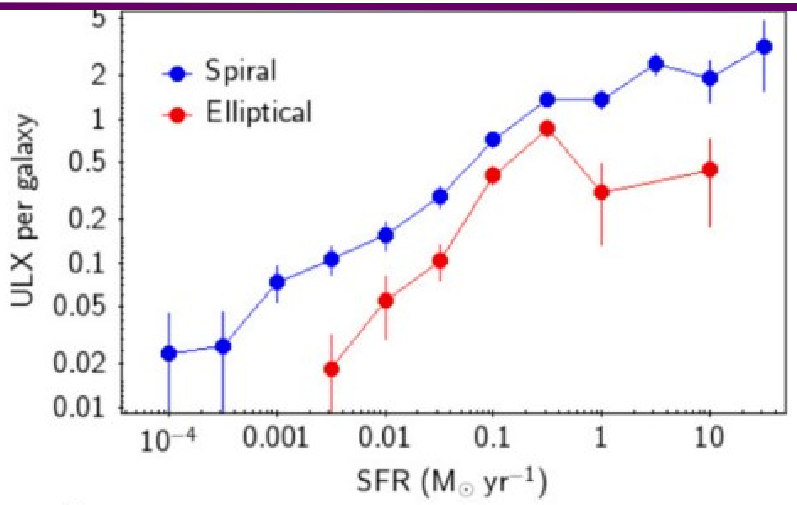
Searching for the origin of HLX-1

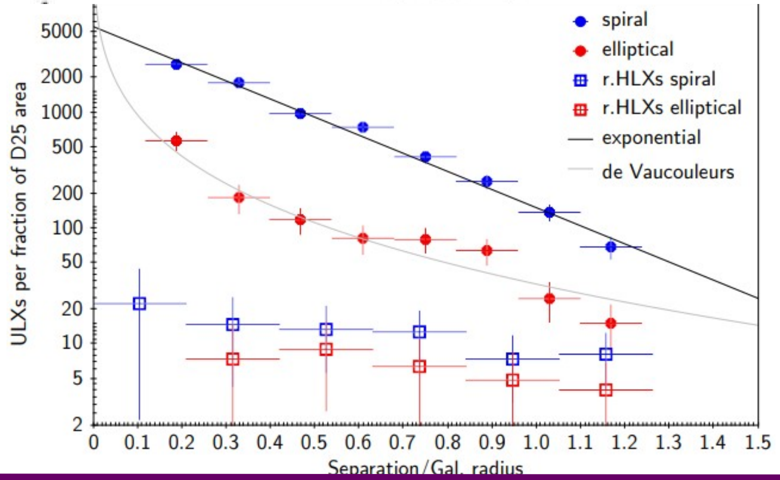


(Webb et al., 2017)

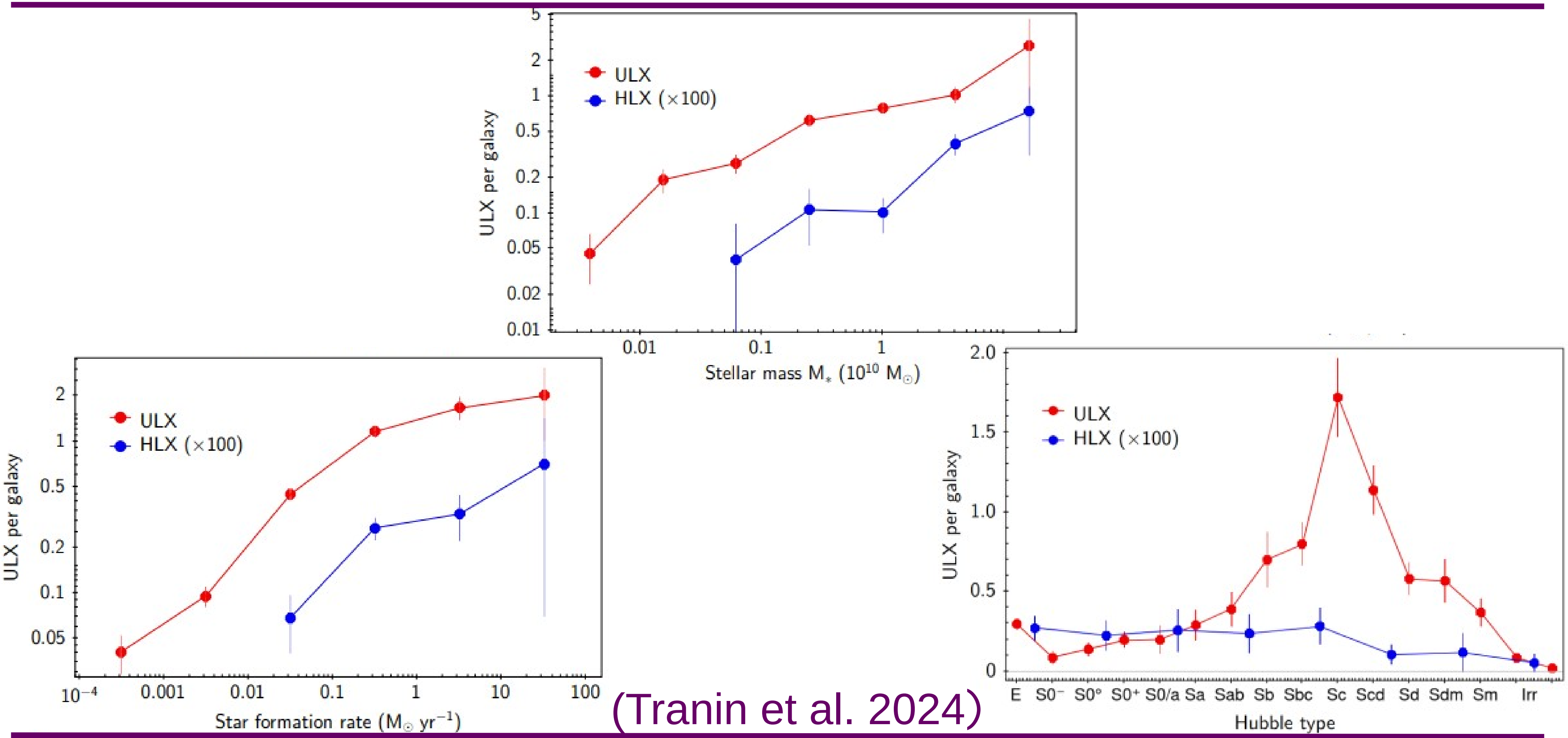
Comparing and understanding ULXs & HLXs

- Naive Bayes classifier (Tranin et al. 2022) on 15 multi-wavelength parameters of XMM-Newton, Swift and Chandra sources
- Identified 356 X-ray binaries, 1901 ULXs and 191 HLXs (3σ & ~2 % contaminants, Tranin et al. 2024)
- ULX & XRB hardness comparable, but XRBs more variable
- See also Bernadich et al. (2022) & Walton et al. (2021) for recent ULX catalogues and Barrows et al. (2019) for HLX catalogue





Comparing ULXs & HLXs

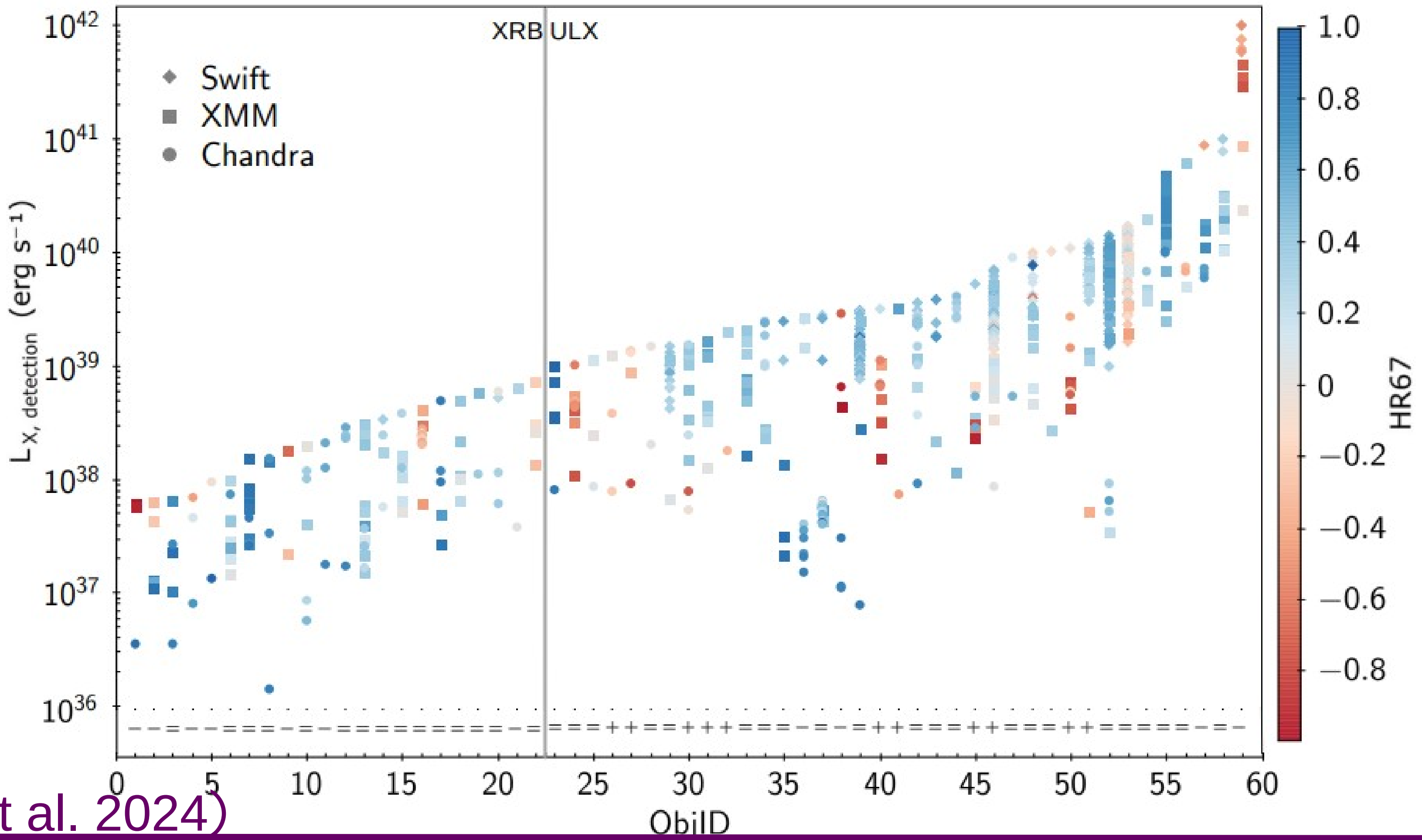


(Tranin et al. 2024)

Natalie Webb

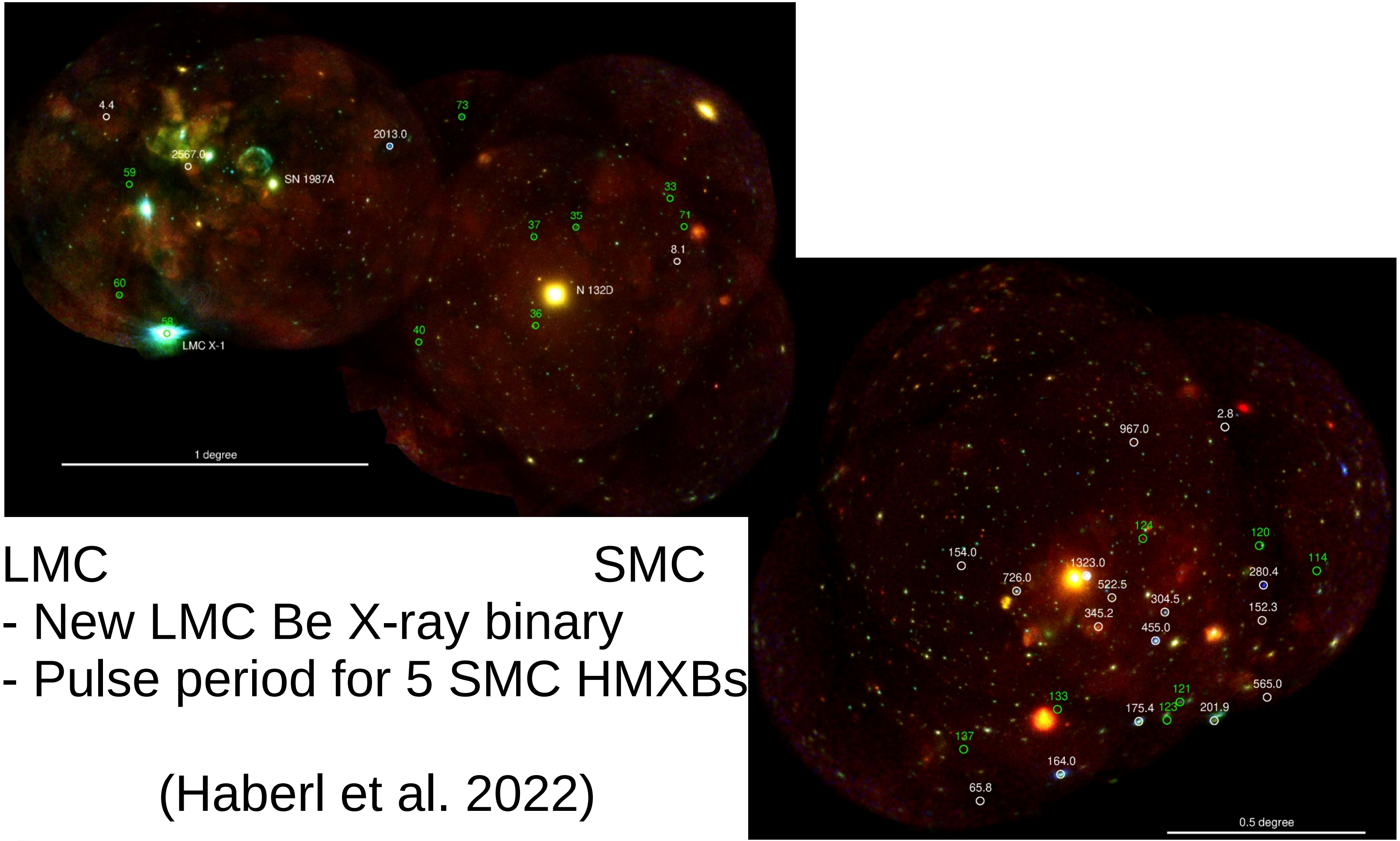
First Results from the SRG/eROSITA All-Sky Survey, Garching, September 2024

XRB, ULX & HLX spectra and variability



(Tranin et al. 2024)

eRosita view of the LMC and SMC & new transients



LMC SMC

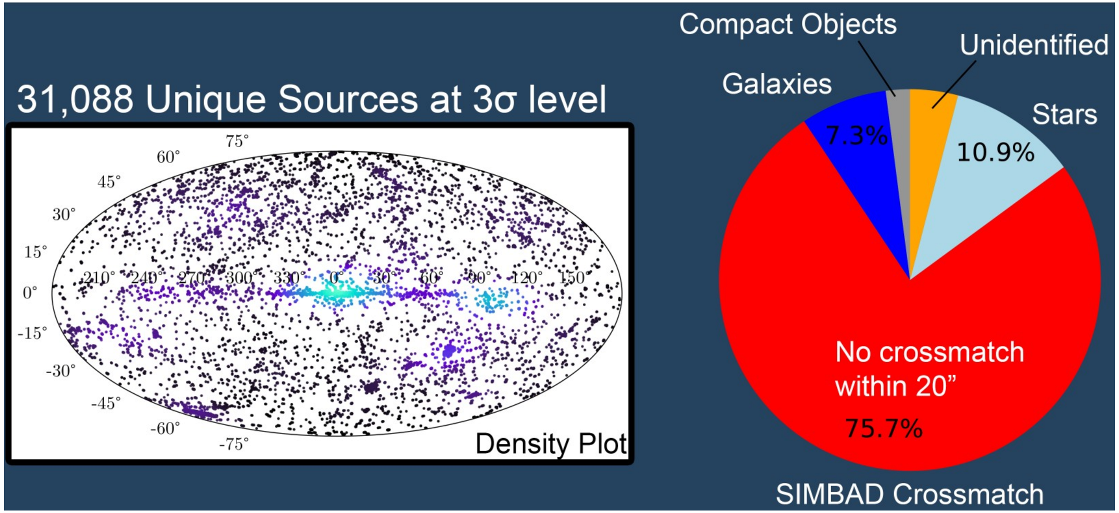
- New LMC Be X-ray binary
- Pulse period for 5 SMC HMXBs

(Haberl et al. 2022)

- S-CUBED – Swift survey SMC
- New rare transients e.g. BeXRB with WD (Kennea et al. 21)
- High variability from many long-term observations of XRBs & ULXs

Detecting transients, STONKs & EXOD

- Long & short term X-ray variability reveals new binaries (e.g. Lin et al. 2012)
- STONKS (Quintin, Webb et al. 2024) uses XMM-Newton, Chandra, Swift, ROSAT, eROSITA + upper limits to provide alerts for XMM long-term variables
- Average 0.7 XMM-Newton alerts per day
- EXOD (Pastor-Marazuela, Webb et al. 2020, Khan et al. 2025) searches for very rapid variability in XMM-Newton data (e.g. GRBs, FRB counterparts, …)
- 11273 transients (5σ) found in 15000 XMM observations, binning as short as 5 s



Summary

- Large scale X-ray surveys of galaxies reveal large populations of compact objects
- ULXs diverse population of super-Eddington NS & BH accretors
- HLXs clearly different from ULX population and may be evidence for intermediate mass black holes
- Strong variability in all compact object systems that can help us find them
- Surveying long-term variability gives insight into source nature
- New tools (e.g. STONKS & EXOD) allow to exploit variability