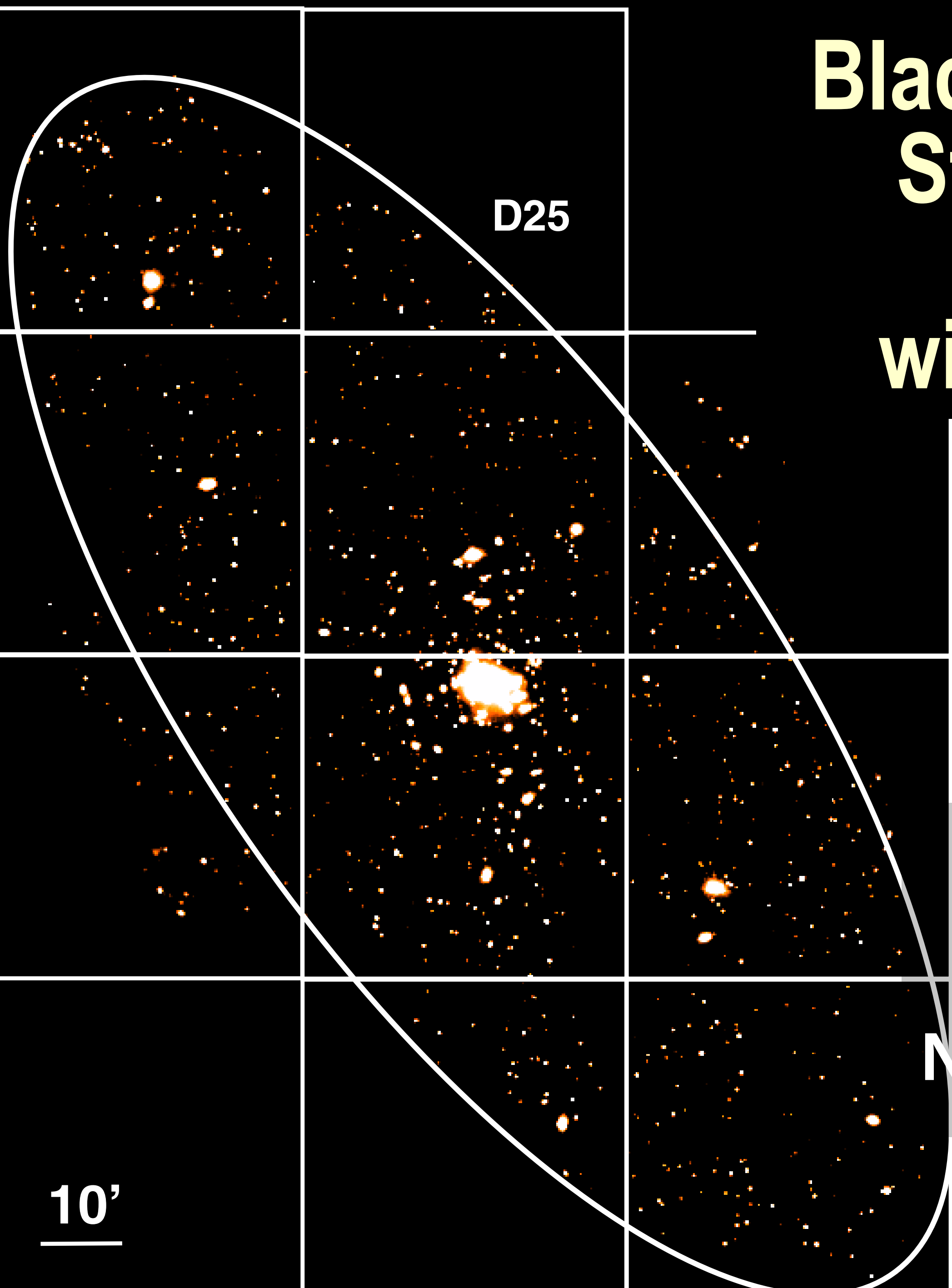
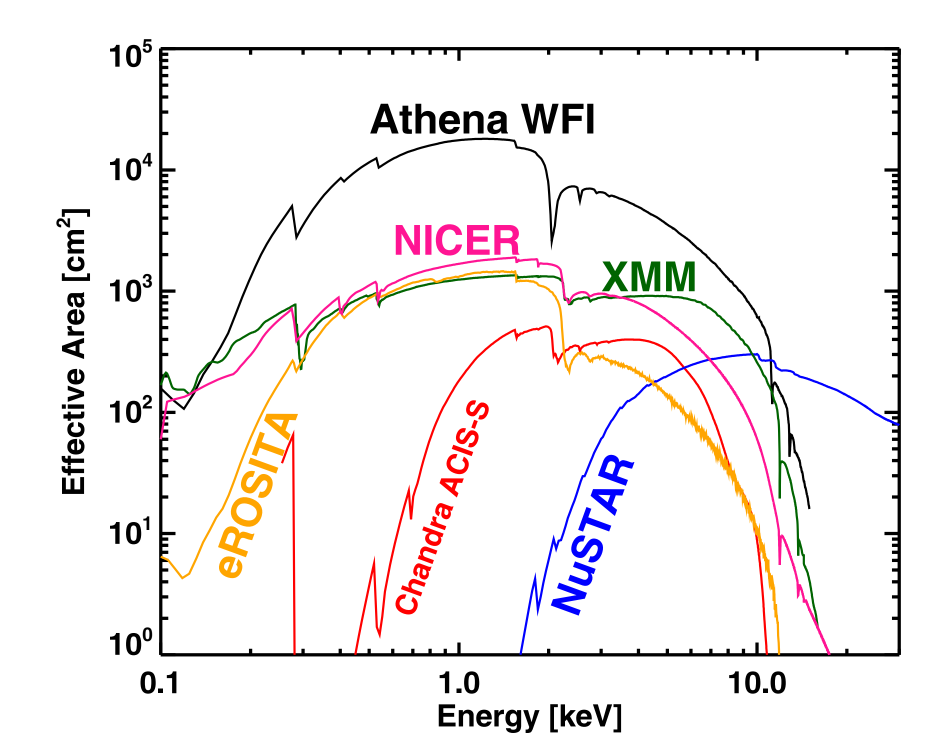
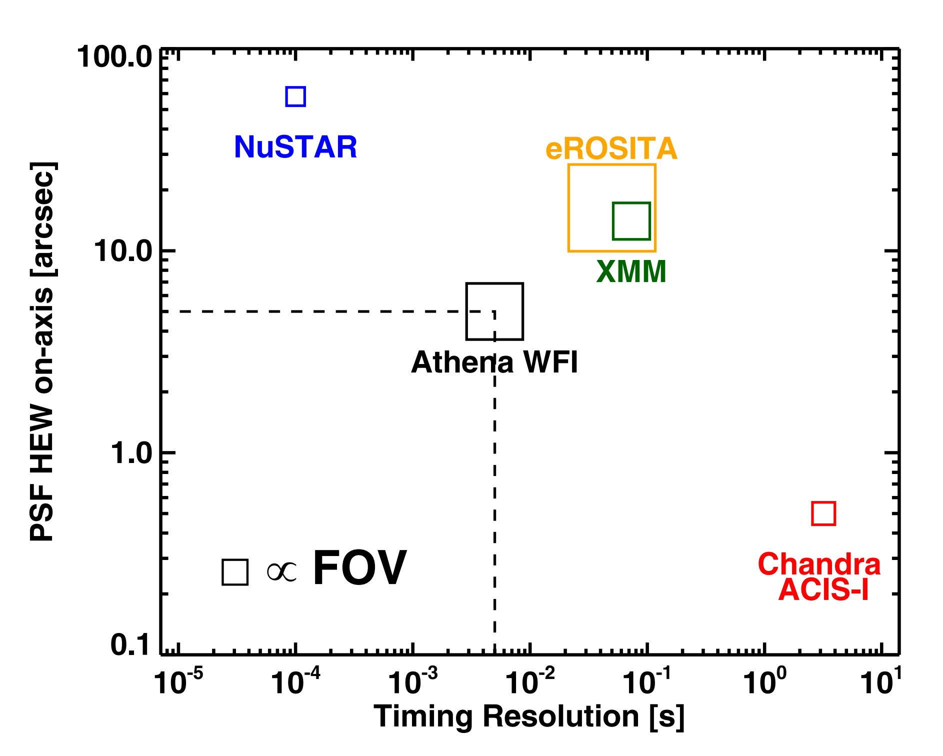


Black Hole and Neutron Star Populations in Nearby Galaxies with the Athena WFI

Ann Hornschemeier
(NASA GSFC)
Neven Vulic (GSFC/UMCP

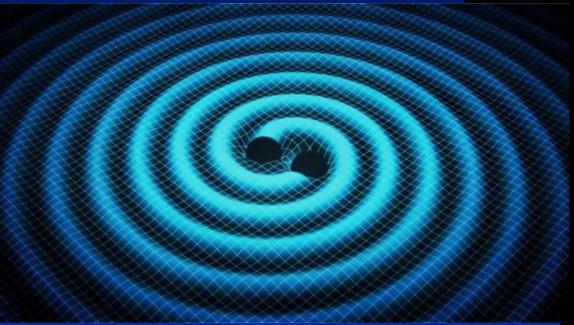
Athena WFI capabilities
40' x 40' FOV, 5" PSF,
1.4 m^2 eff. area, 5 ms timing



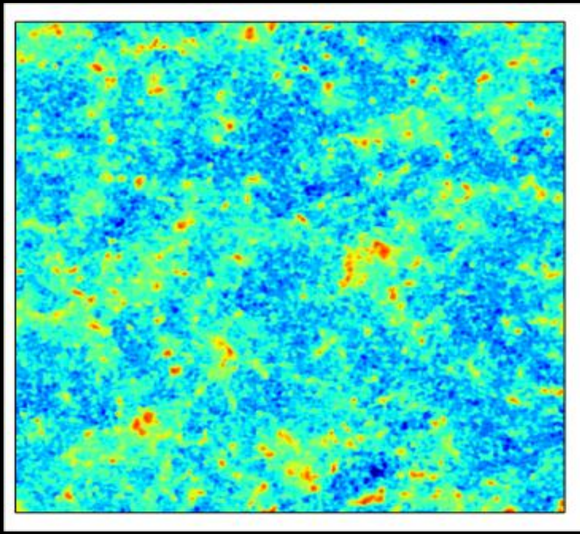


Important things we can learn from BH and NS populations

How supernovae work.



Gravitational wave sources



Early heating of the primordial IGM

Key science questions, Athena WFI observations of nearby galaxies

- What is the prevalence of super-Eddington accreting pulsars and how does this fit into compact object evolution scenarios?
- What are the progenitor paths for the massive compact objects being found by e.g., LIGO/Virgo?
- What is the role of SN kicks in dynamical evolution of NS and BH populations?

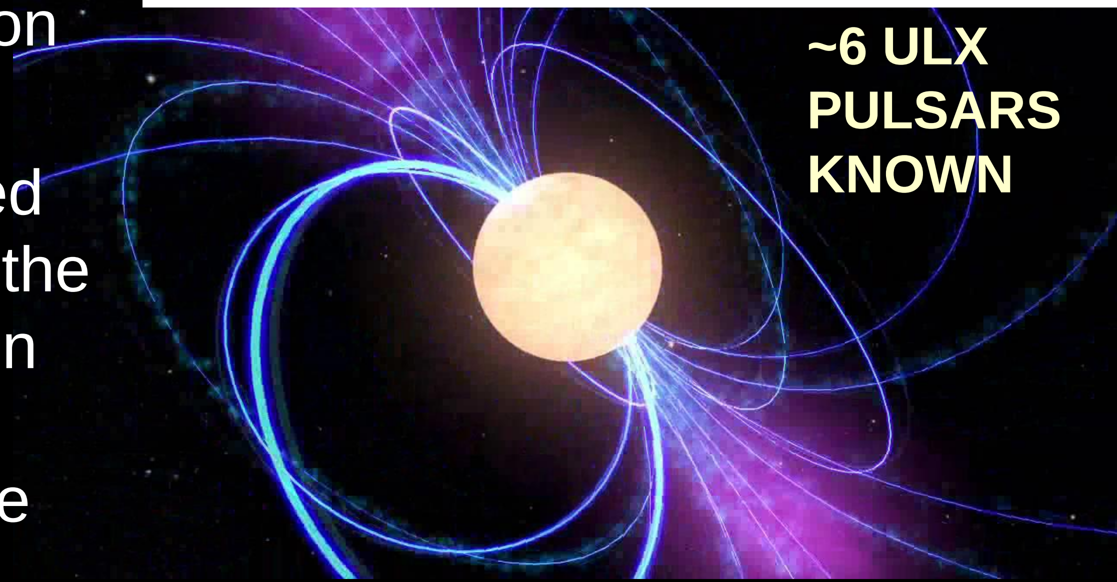
SUPER-EDDINGTON ACCRETION ONTO PULSARS:

How prevalent is this? How does this fit with the rest of the pulsar population?

ULX pulsars, a major challenge to our understanding of accretion

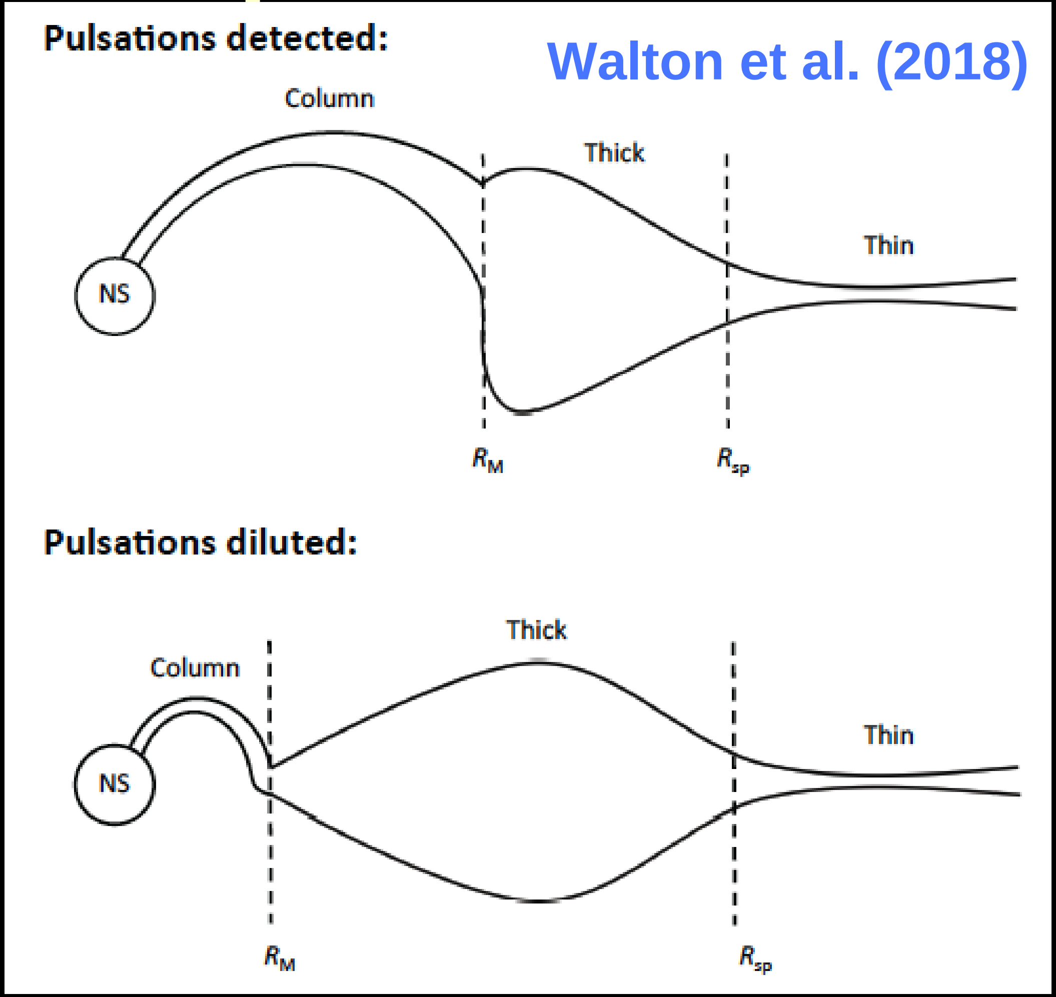
- **<u>ULX PULSARS</u>**
  (Bachetti et al. 2014, Feurst et al. 2016, Israel et al. 2017, Kosec et al. 2018, Brightman et al. 2018; Carpano et al. 2018, Wilson-Hodge et al. 2018)
- Up to 500 times Eddington limit for a 1.4 $M_{\odot}$ NS
- Athena WFI time-resolved spectroscopy: separate the (pulsed) accretion column from the (non-pulsed) accretion flow beyond the magnetosophere

Enabled by time resolution
(e.g., NuSTAR & XMM)
and searches in time domain
(*EXTraS)*

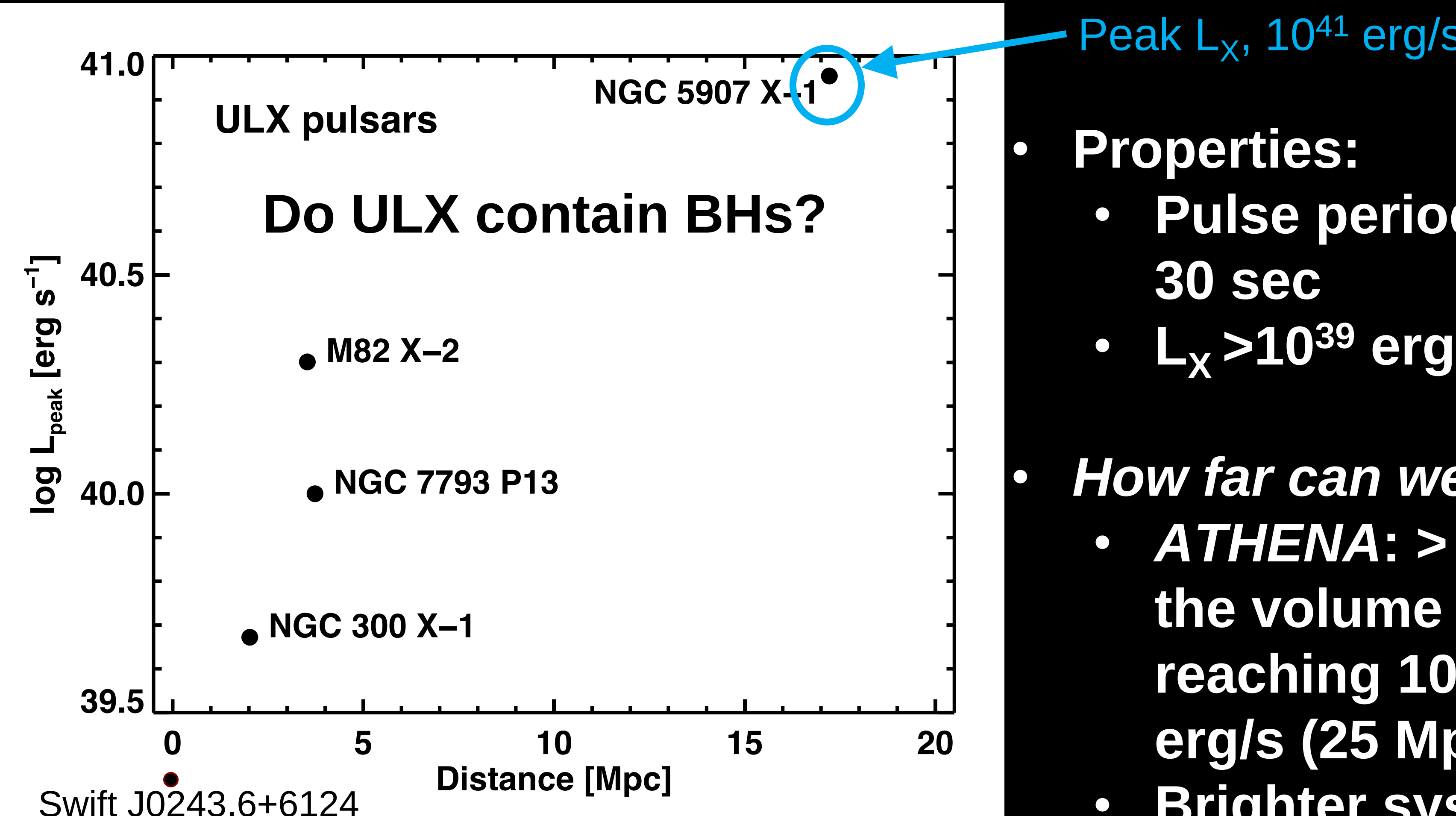


Could all ULX sources contain pulsars? Perhaps. (Walton et al. 2018)

- Pulsed spectrum from accretion column can explain hard excess in all the ULX systems



Broadening the sample with Athena WFI



- **Properties:**
  - **Pulse periods ~1-30 sec**
  - **L_X >10^{39} erg s^{-1}**
- ***How far can we go?***
  - ***ATHENA*: > 100X the volume for reaching 10^{39} erg/s (25 Mpc)**
  - **Brighter systems to much larger distances (>250 Mpc)**

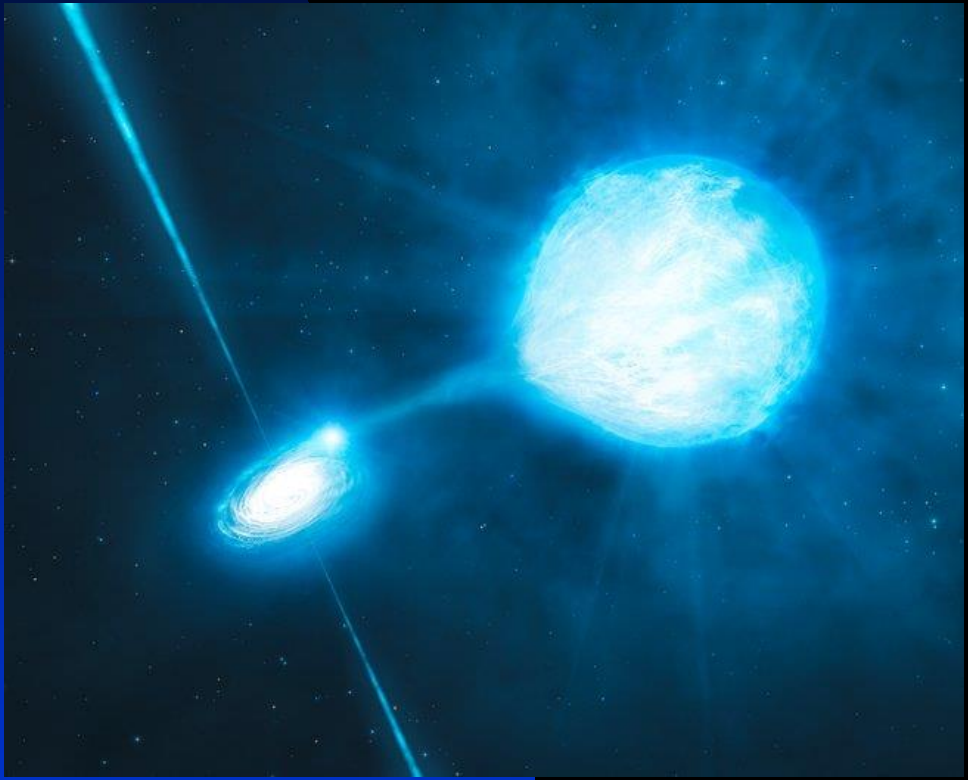
5 confirmed, 1 candidate (M51)

UNDERSTANDING THE FORMATION OF MASSIVE STELLAR BHS:

The example of Wolf Rayet X-ray Binaries

(a rare, but important, population)

Wolf Rayet X-ray Binaries: The biggest, baddest accreting stellar-origin BHs?



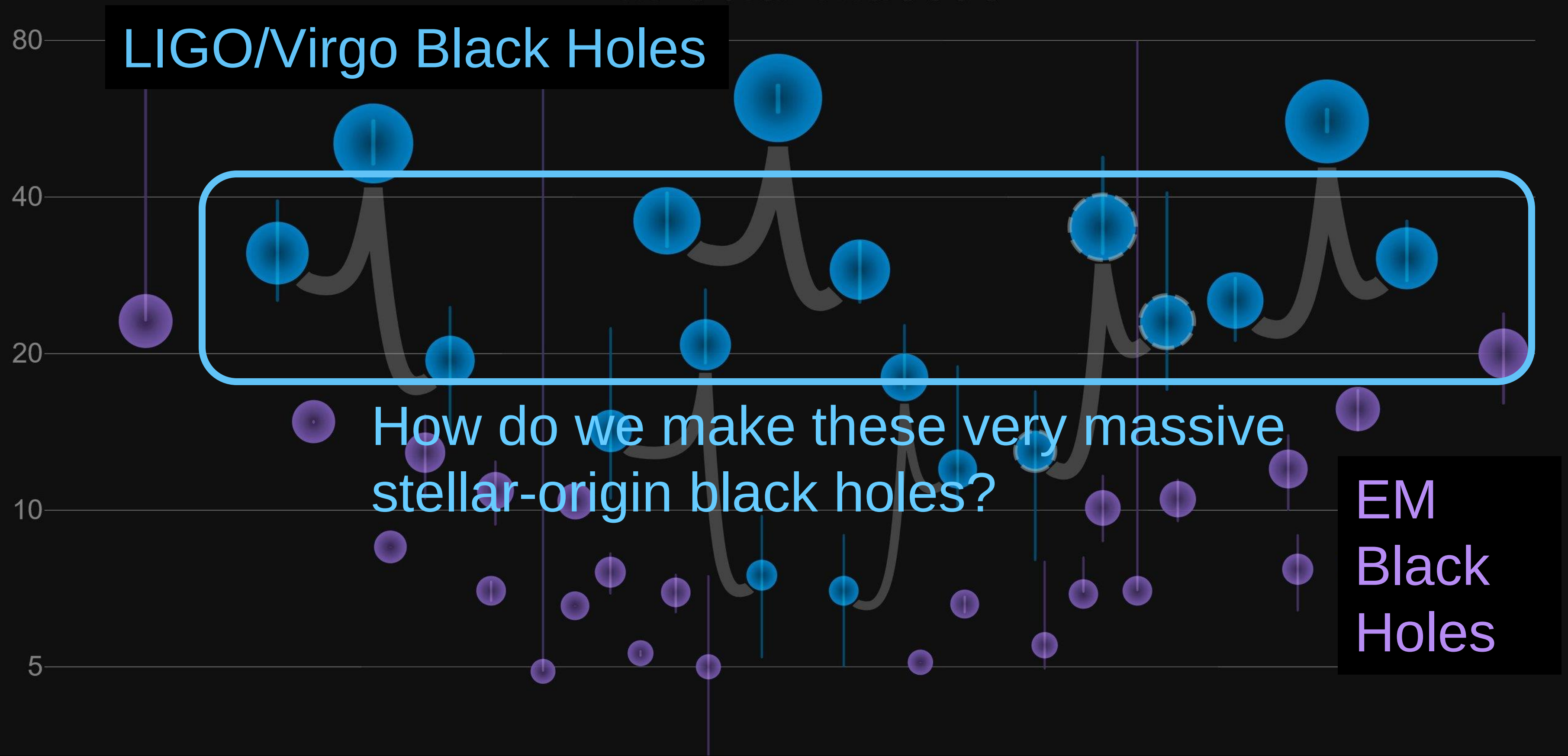
Artist's rendition of the WR XRB NGC 300 X-1

- Wolf Rayet stars are luminous, massive stars with strong stellar winds
- The orbital periods are short (most are less than a day)
- Likely only contain BH (not NS): van den Heuvel (2017)

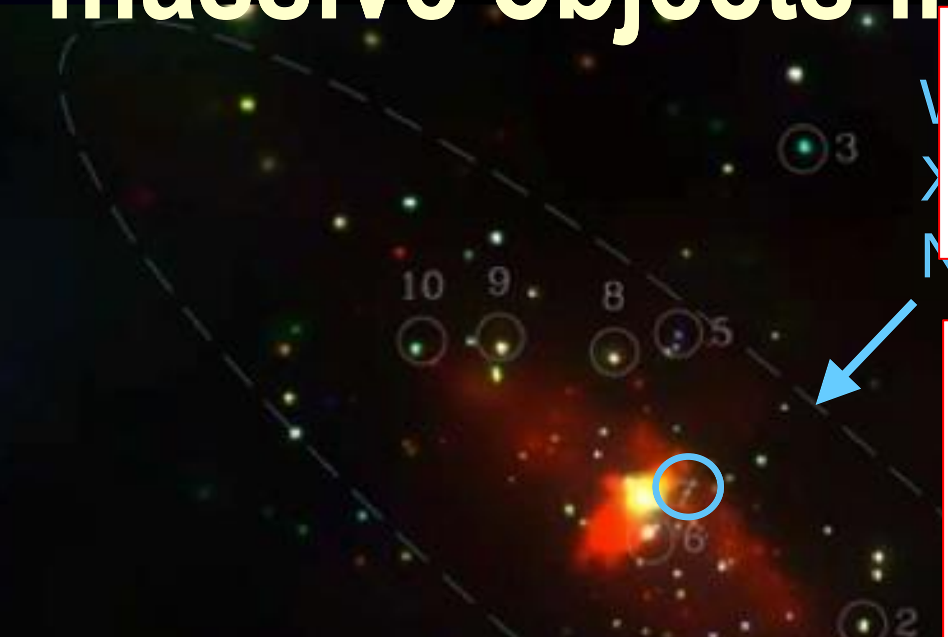
Why might you care about a BH in a relatively tight orbit with a very massive star?

Masses in the Stellar Graveyard

in Solar Masses

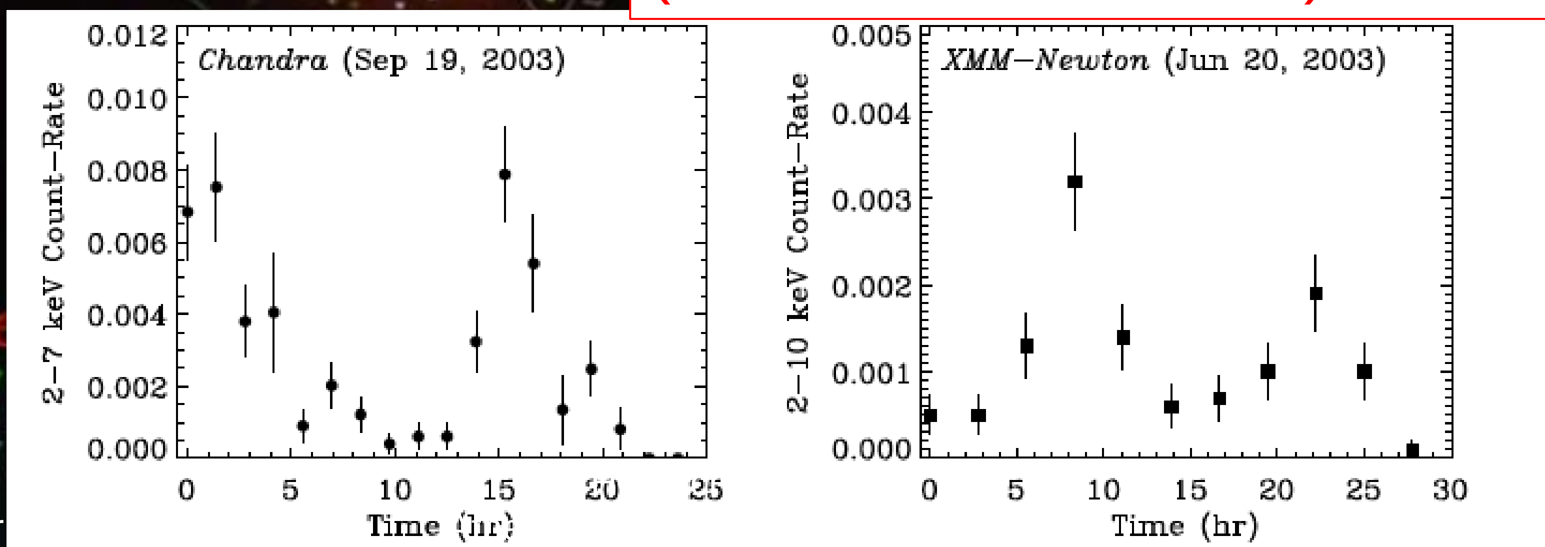


Time domain discovery space: massive objects in tight orbits



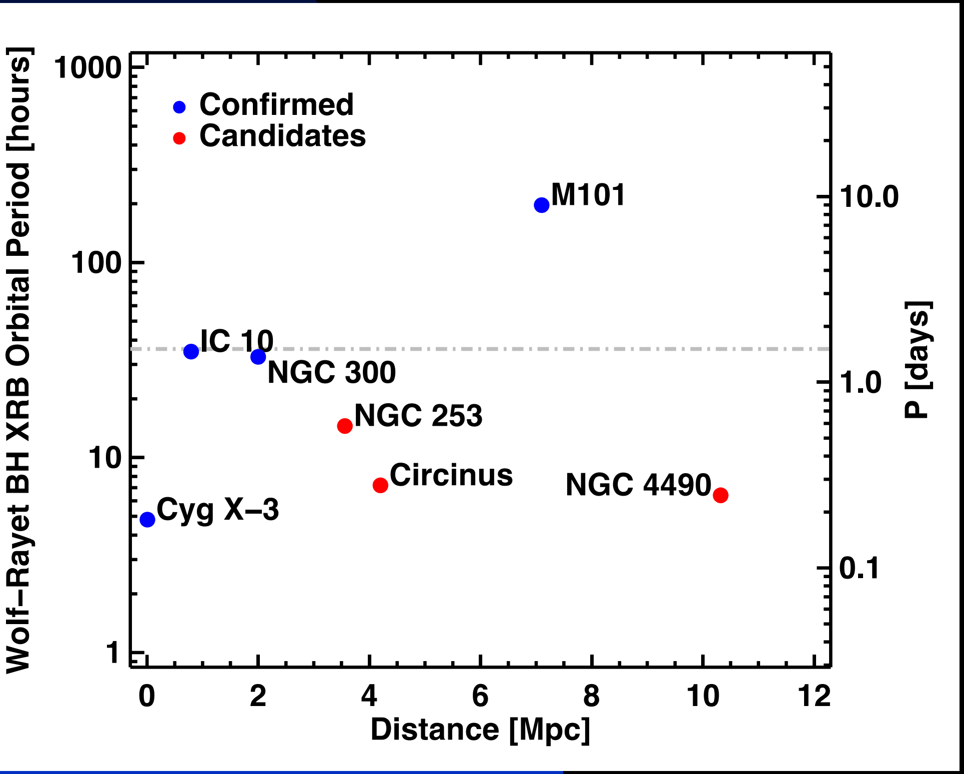
ENABLED by combination of light collecting power (effective area) and PSF

Using archival Chandra data
From observation 9 years prior:
Periodicity of ~14-15 hours
(Maccarone et al. 2014)



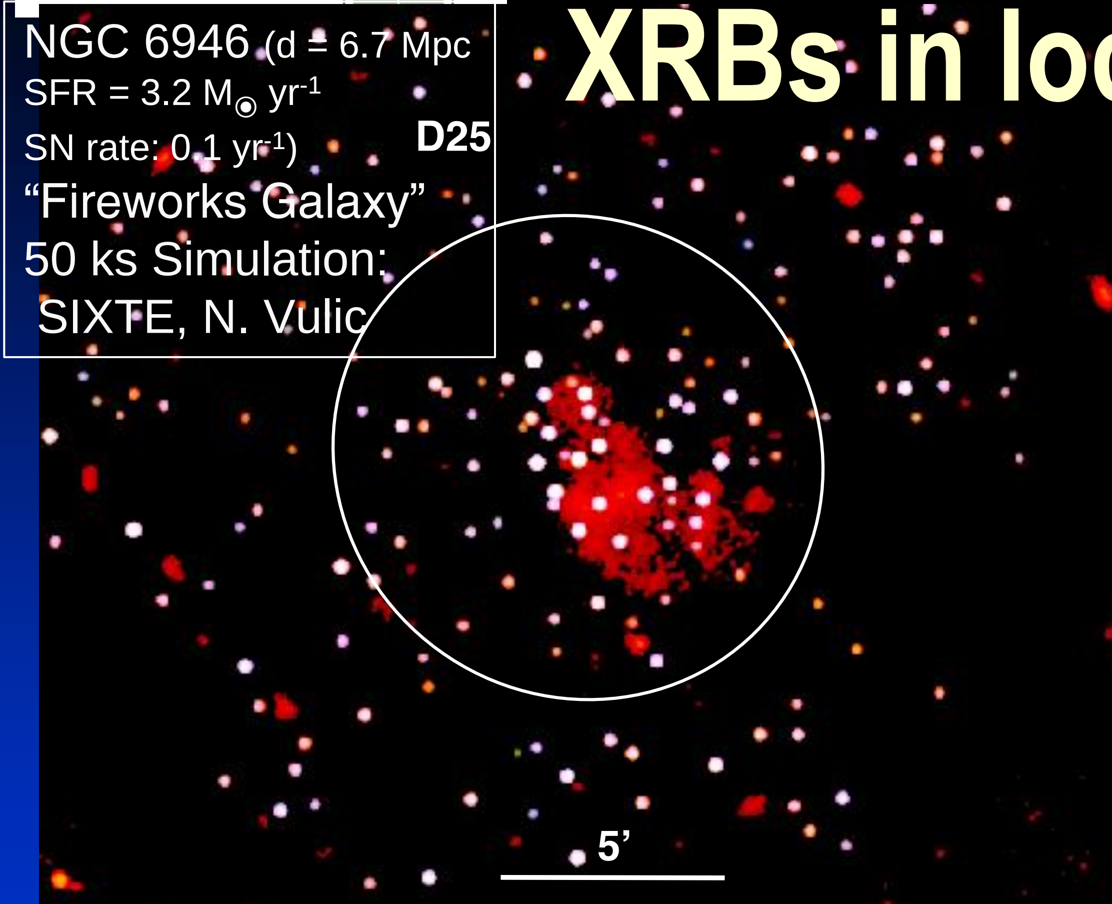
WR XRBs are rare! (but important)

Only six examples known!



- Few HMXBs survive to the WR XRB phase: unstable mass transfer in the Common Envelope phase? (e.g., Munoz et al. 2015, van den Huevel et al. 2017)
- This single source (the NGC 253 WR XRB) implies Advanced LIGO detection rates up to ~10 per year (Maccarone et al. 2014)

Athena WFI: Time domain studies of XRBs in local galaxies



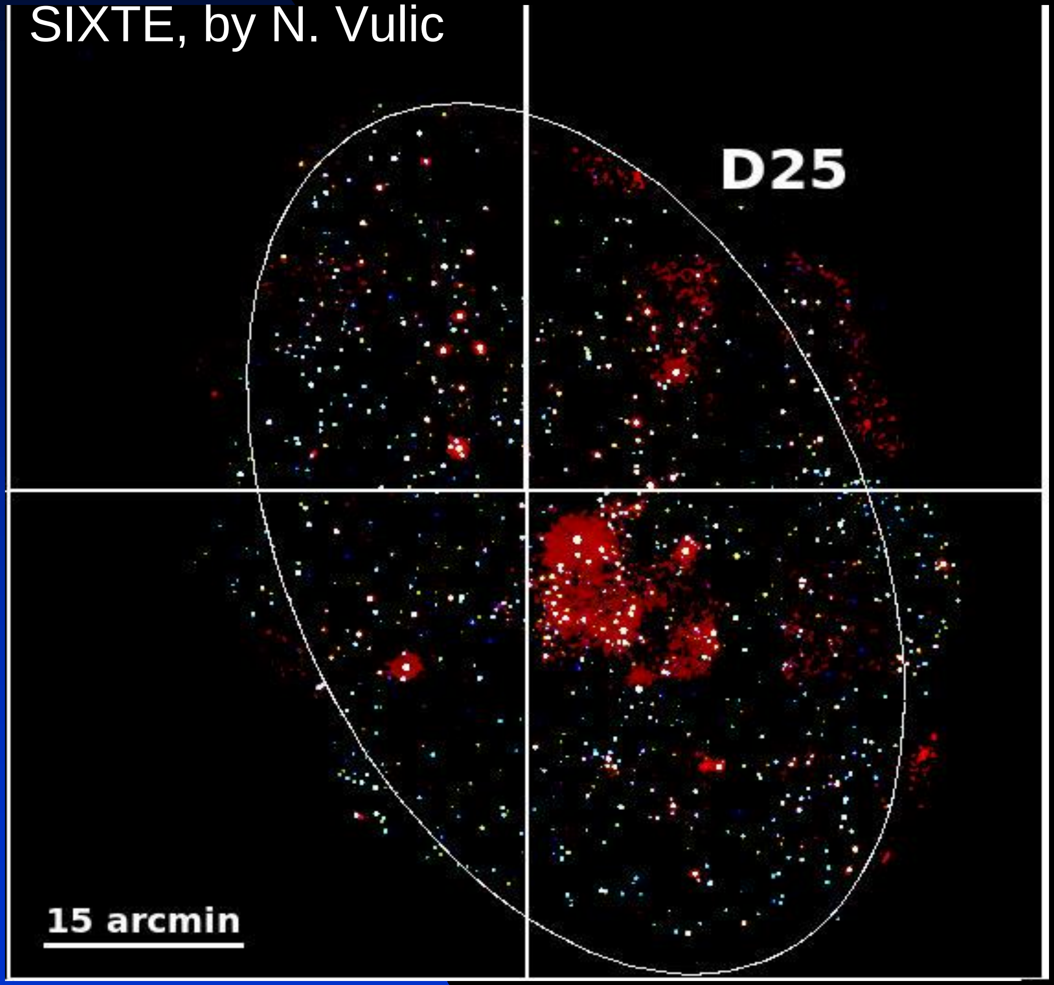
- **TIMING CAPABILITY:** (~5 ms timing resolution) - → young, ULX pulsars (0.4-30 s pulse periods) easily found and/or verified
- **SURVEY POWER** (collecting area w/ good PSF × solid angle)

→ search for short orbital period (hours) variability, e.g., WR XRBs

→ combine w/ground-based facilities: compact object masses

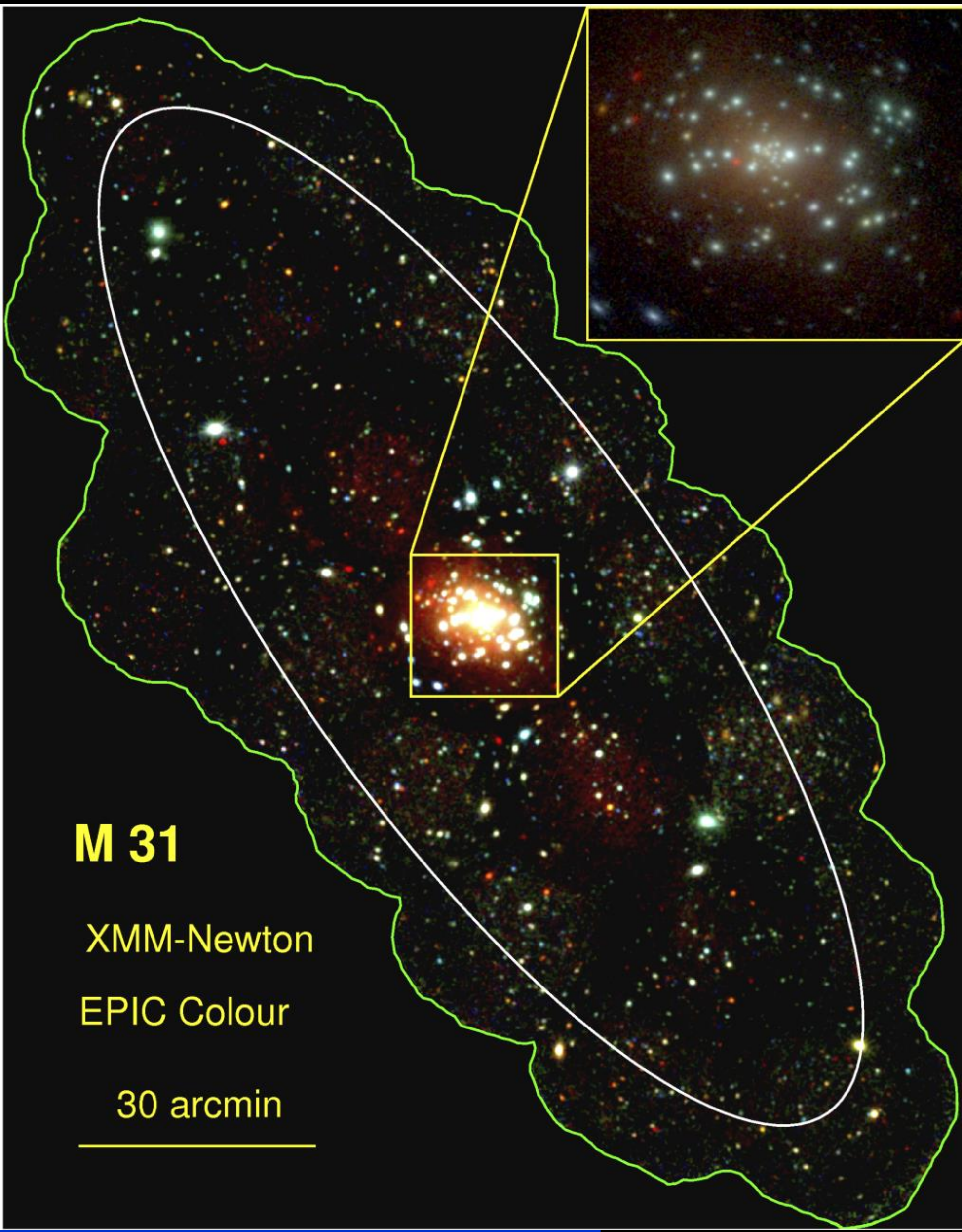
M33: Young compact objects

M33 (d=875 kpc, SFR=0.3 $M_{\odot}$/yr)
ATHENA WFI 25 ks x 4 pointings
SIXTE, by N. Vulic



- In 100 ks, L_{XP}~10^{34} erg/s: ~109 HMXBs with L_X>10^{35} erg/s and >100 SNRs
- XMM-Newton 900 ks total, ~100 ks depth (Williams et al. 2015): 55 HMXB candidates.
- Lack of short-period (1– 10s of sec) pulsars?
- Obscured HMXBs: 4-12 keV band with deeper exposures (>75 ks)

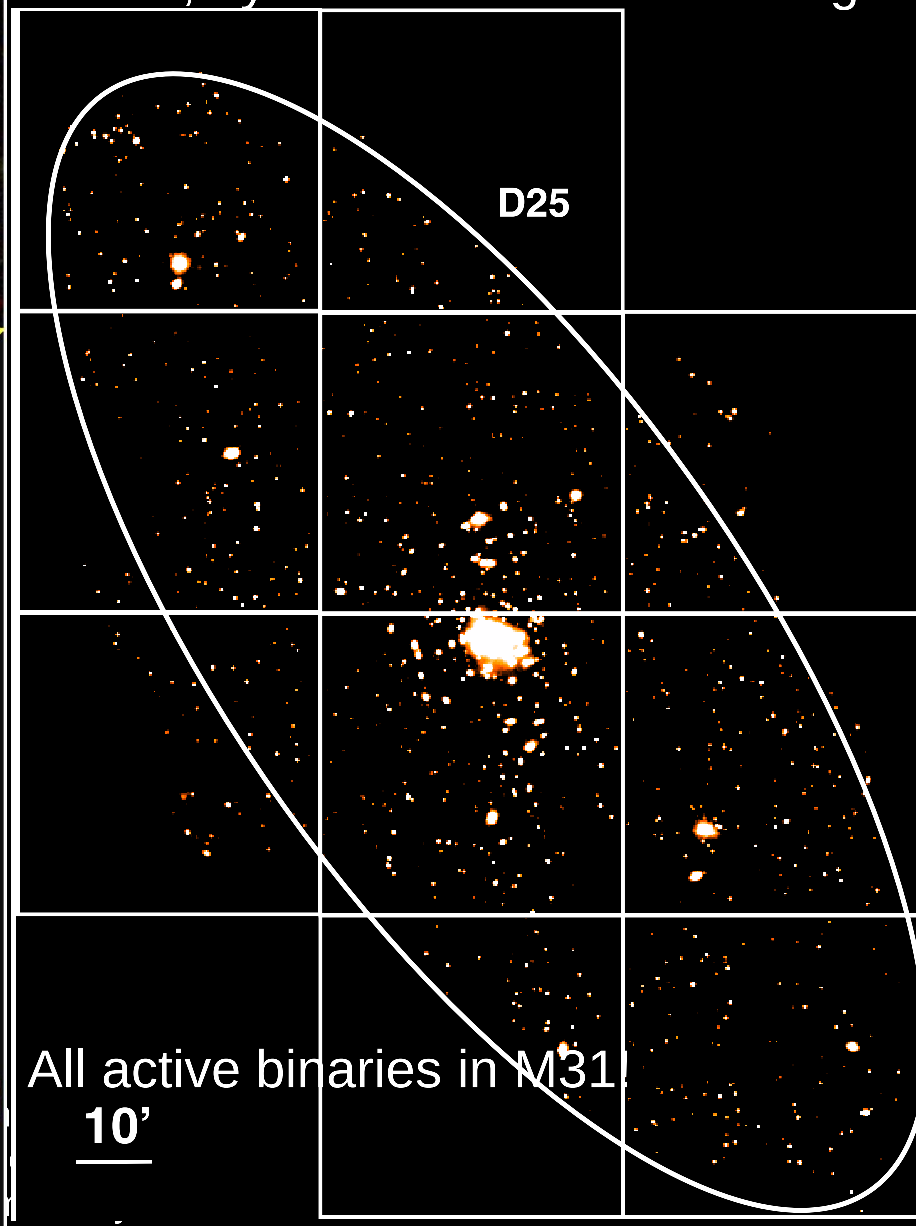
M31 *XMM* survey (Stiele et al. 2011) ~100 ks x ~20 pointings



M31 *ATHENA* WFI simulation

10 ks x 10 pointings (L_{XP} ~ 2 x10^{34} erg/s!)

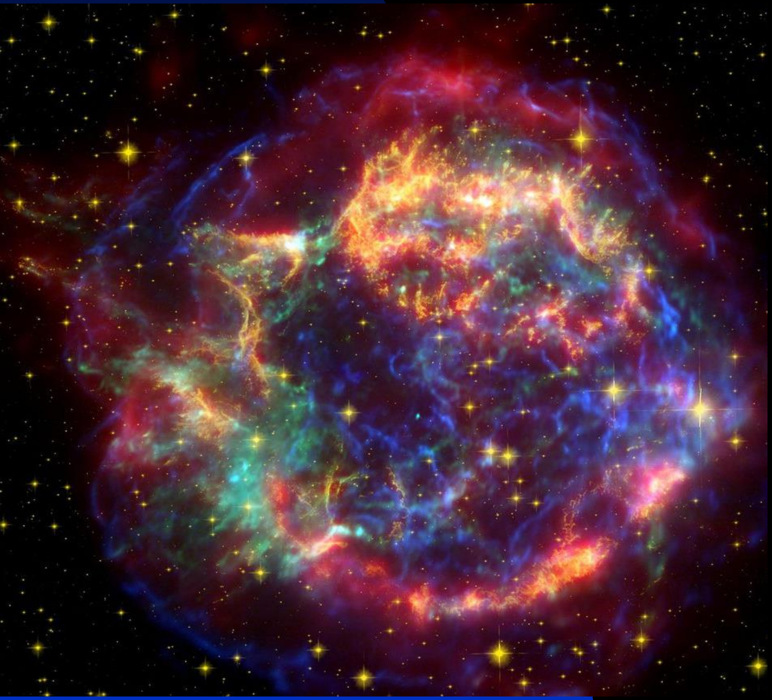
SIXTE, by N. Vulic



SUPERNOVA KICKS:

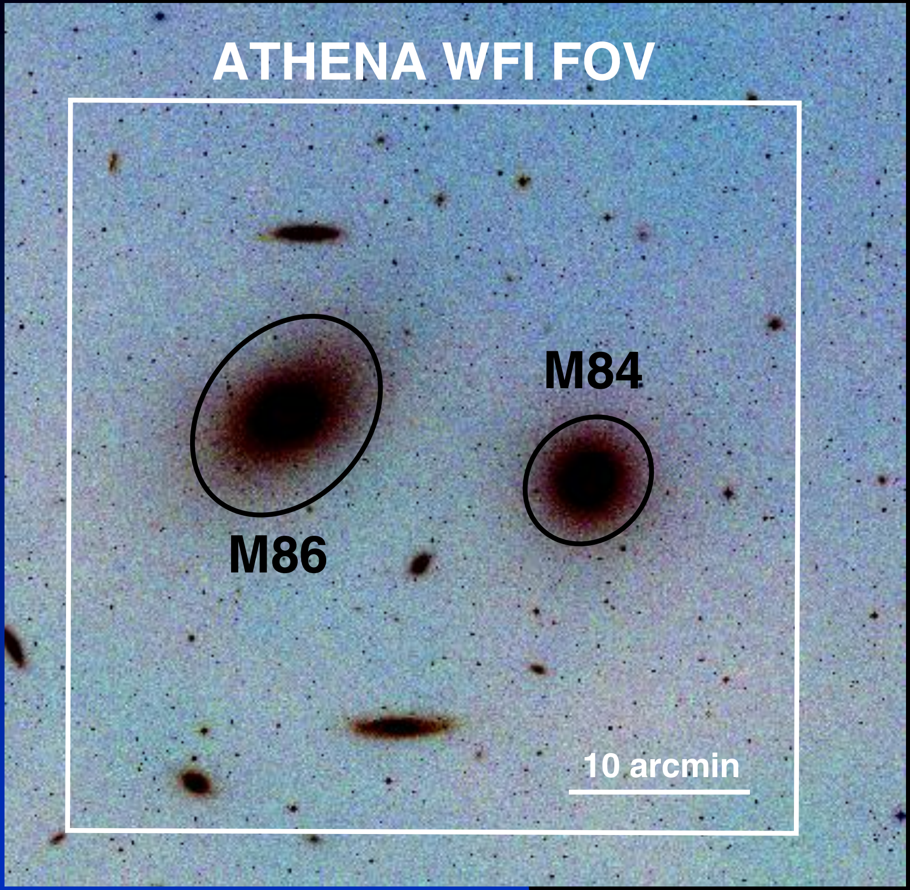
The dynamical evolution of LMXB systems

Supernova Kicks inferred from LMXB distribution



- Asymmetry in mass ejection and/or neutrino emission can lead to SN kicks
- Suggestive evidence, centered on NS:
  - Excess LMXBs in ellipticals found with Chandra at $L_X < 10^{38}$ erg/s (Zhang, Gilfanov & Bogdan 2013)
  - Intracluster LMXBs found in Virgo (3.5σ result, Hou et al. 2017)
- Stellar mass BH SN kicks?
  - Large natal kicks for BHs possible (Repetto et al., 2012; Repetto & Nelemans, 2015)
  - BH-LMXBs, as transients, less luminous on average (e.g. Wiktorowicz et al. 2014; Corral-Santana et al. 2016; Belloni & Motta, 2016).

Dynamical Evolution of LMXBs: Supernova Kicks?



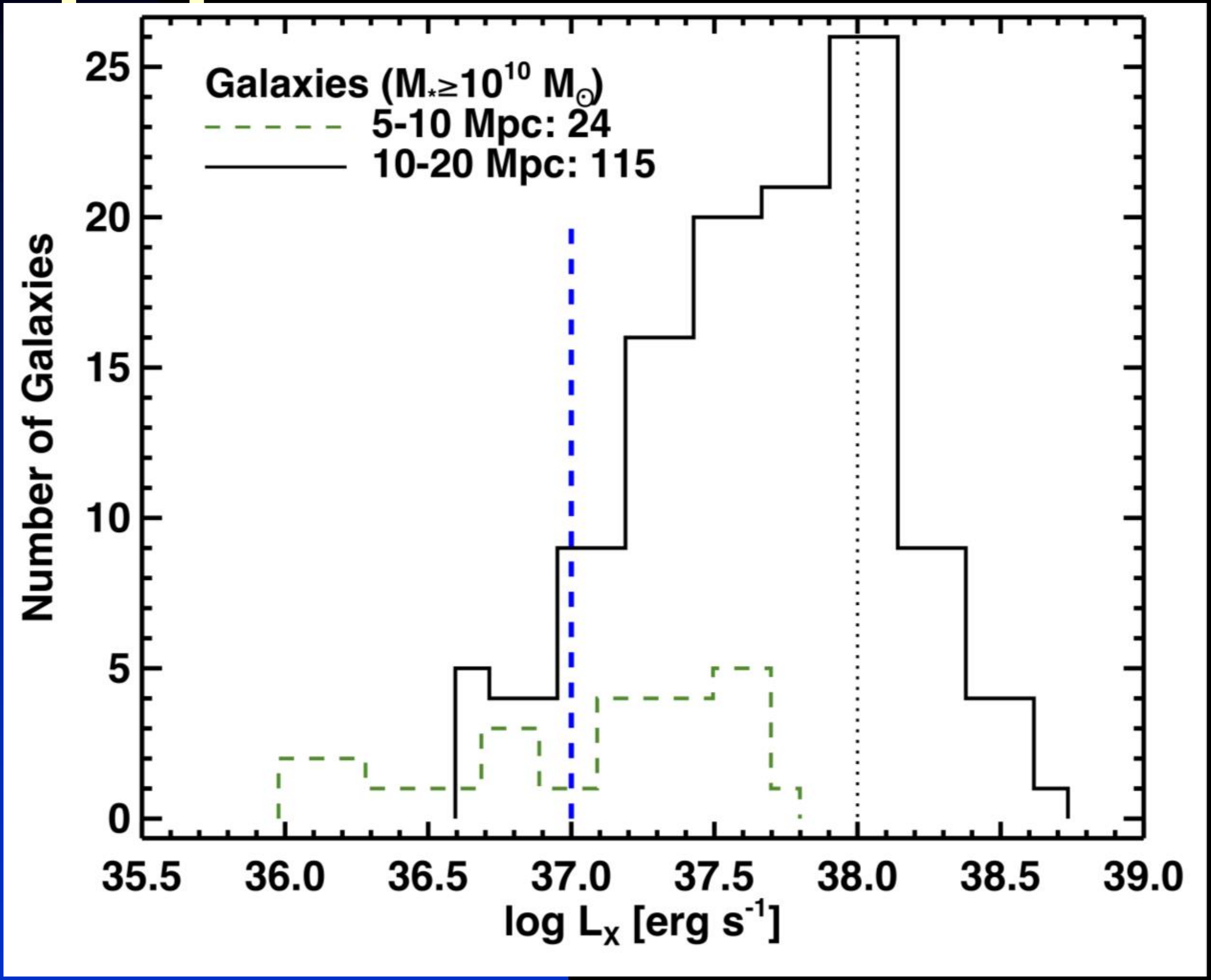
WFI FOV permits efficient/sensitive measurement of LMXBs in galaxy outskirts to required low-L_X~10^{37} erg s^{-1}

WFI t_{exp}=10 ks

ALSO: search for Ultraluminous X-ray bursts (WD-IMBH; e.g., Jonker et al. 2013; Irwin et al. 2016, Shen et al. al. 2018; arXiv:1809.09359**)**

Example: M84 and M86 in Virgo: can reach L_X = 1 x 10^{37} erg/s for both galaxies in 10 ks

How well have we studied XRB populations in the local Universe?



- Overall we probe galaxies in the upper end of the ”outbursting” binary range

THANK YOU

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xraydeep.org

<u>NASA Postdoctoral Program deadline Nov 1st:</u>

https://npp.usra.edu/opportunities/details/?ro=18198

High Energy Galaxy Surveys

Research group at NASA GSFC: Neutron stars, black holes, hot gas and galaxy evolution

xraydeep.org

THANK YOU

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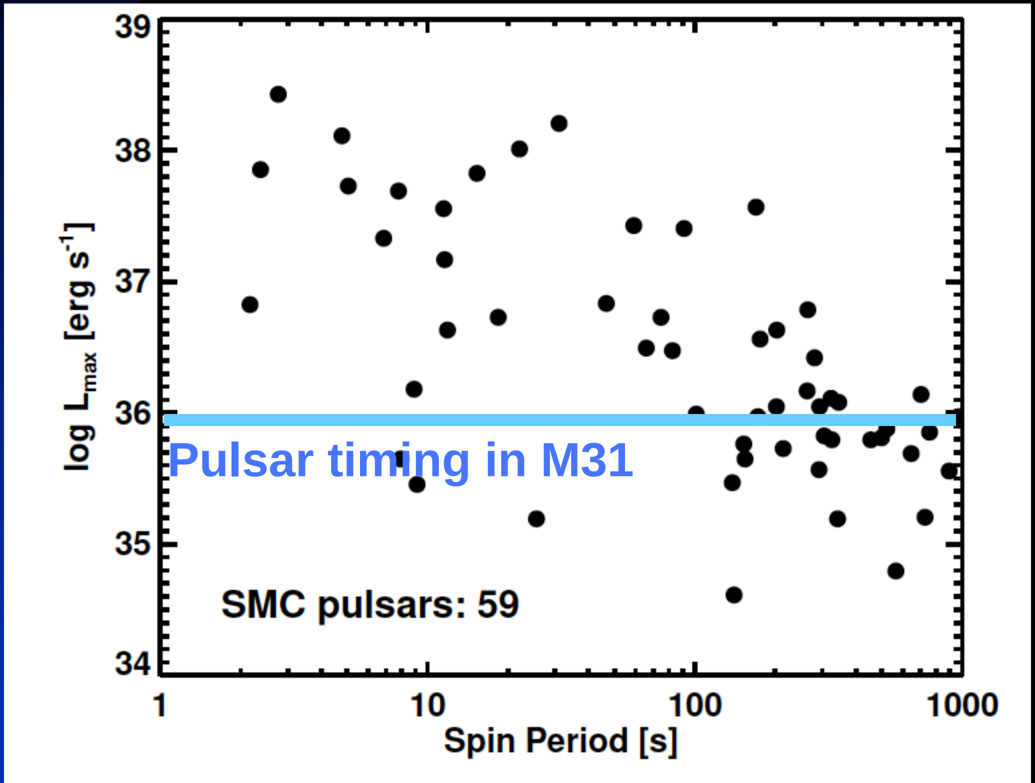
High Energy Galaxy Surveys

BACK UP

Pulsar populations: looking beyond the Milky Way and Magellanic Clouds



HMXB Pulsars: Magellanic Cloud analogs at lower-L_X
P_{spin}~few-1000 s
P_{orb}~10's-100's days

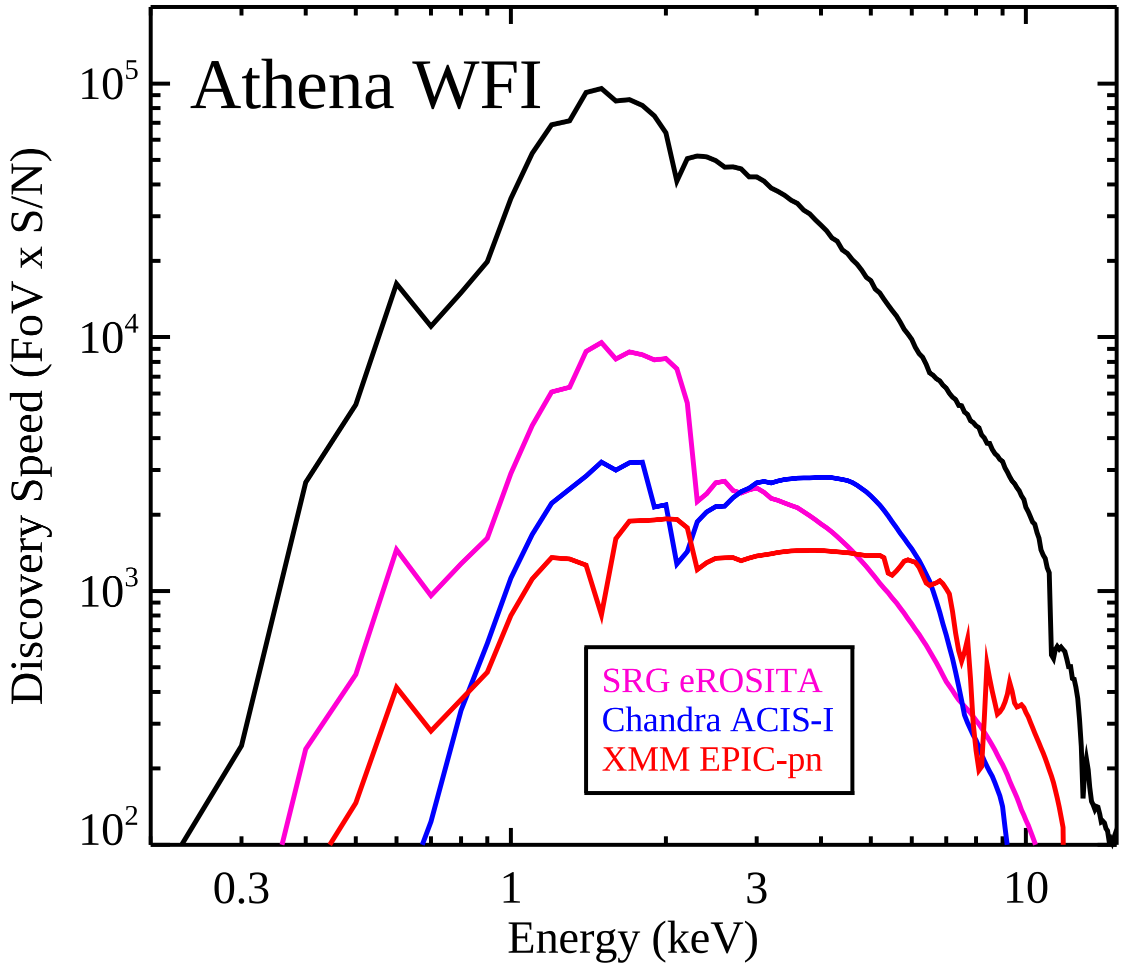
In 100 ks in M31, will detect new pulsar systems very easily.

(Haberl & Sturm 2016)

Point source discovery speed
(Wik et al. 2018)

$$\mathrm{FOM}(E) = \int_{\mathrm{FOV}} (S/N)\, d(\mathrm{FOV})$$

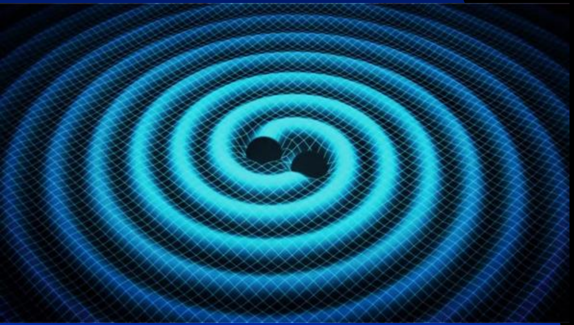
$$\propto \int_0^{\theta_{\max}} (S/N)_\theta \frac{\theta}{R(\theta, E)} d\theta$$



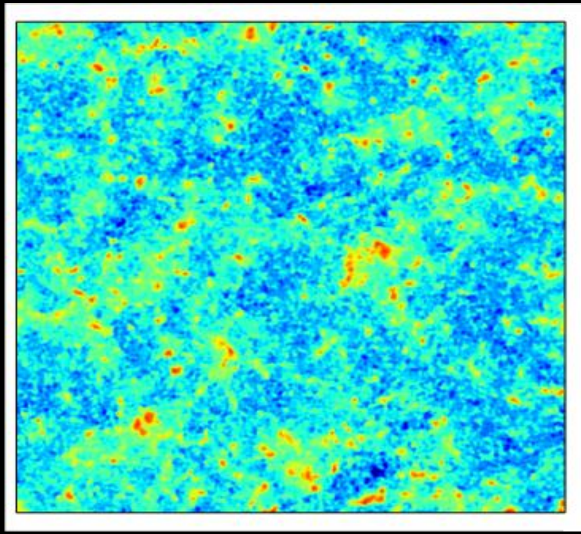
$$\mathrm{FOM}(E) = \int_0^{\theta_{\max}} \frac{A(\theta, E)}{R(\theta, E)\sqrt{B_{\mathrm{Gal}}(E) A(\theta, E) + B_{\mathrm{Det}}(E) f^2}} \theta d\theta \,.$$

Important things we can learn from BH and NS populations

How supernovae work.



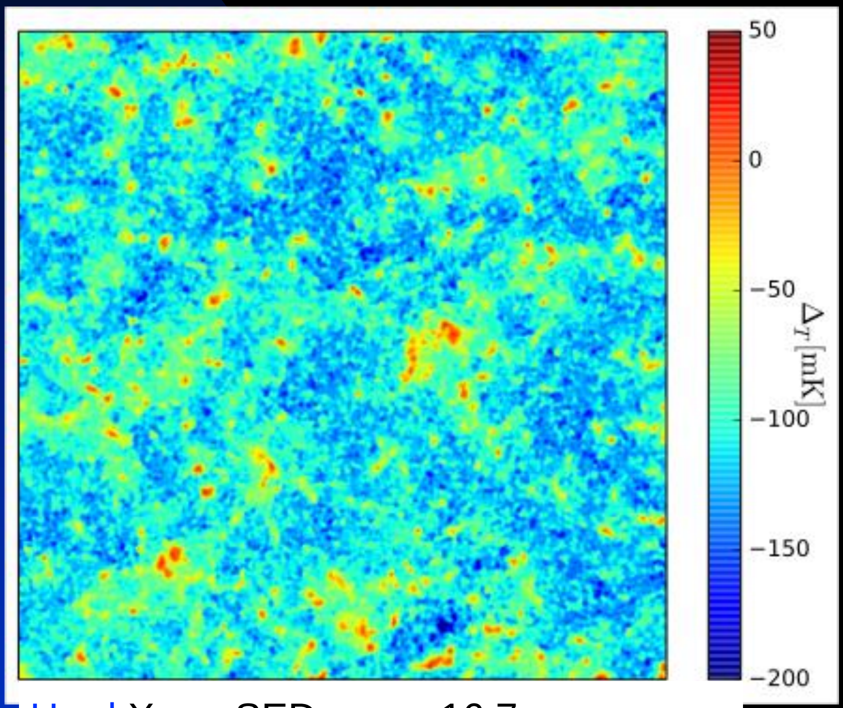
Gravitational wave sources



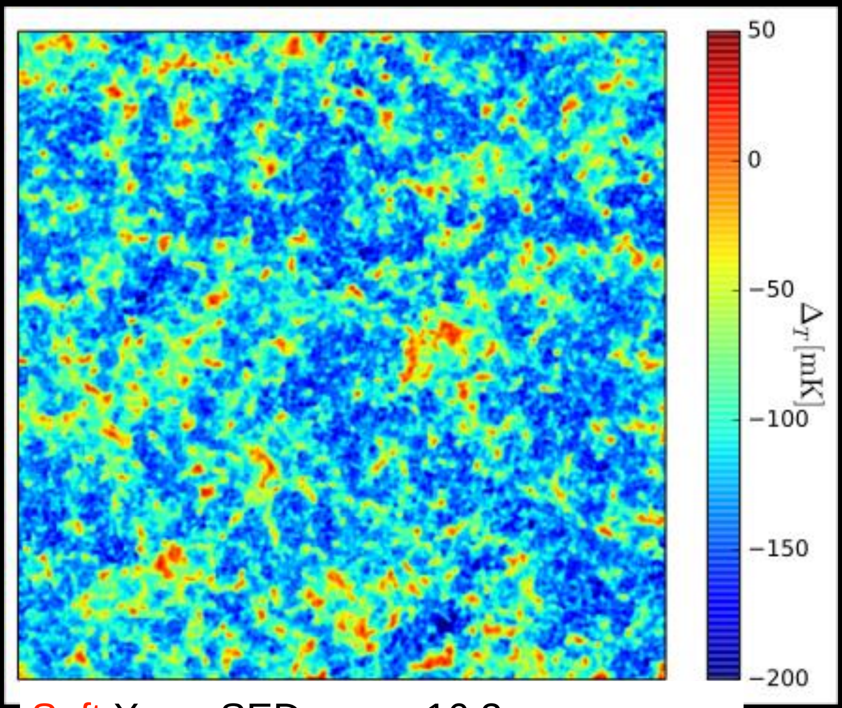
Early heating of the primordial IGM

X-rays from star formation affect high-z 21 cm measurements (Pacucci et al. 2014)

Slices of the 21cm brightness temperature map taken at the X-ray heating peak at large scales:



Hard X-ray SED: z_{peak}=16.7



Soft X-ray SED: z_{peak}=16.3

More uniform brightness temperature map, due to longer distance traveled by more energetic photons

What is the impact of X-ray binaries on the early heating of the IGM?

Two areas of impact for Athena WFI:

- Measurement of galaxy X-ray SEDs of large, volume-limited samples of galaxies in local Universe (key: 0.2-1.0 keV performance!)
- Deep studies of distant (0.1 < z < 4) galaxies in Athena WFI surveys

The X-ray output of binaries exceeds that of AGN at z>6