Time Domain Studies of Neutron Star & Black Hole Populations: The Post *Chandra* and *XMM-Newton* Era

N. Vulic (NASA GSFC/UMCP/CRESST), A. E. Hornschemeier (NASA GSFC/JHU), J. Wilms (Erlangen), A. Zezas (Crete/CfA), A. R. Basu-Zych (UMBC/NASA GSFC/CRESST), T. J. Maccarone (Texas Tech), A. F. Ptak (NASA GSFC/JHU), M. Yukita (JHU/NASA GSFC)

Motivation

What are the most important conditions and processes governing the growth of stellar-origin compact objects? The identification of compact object type as either black hole (BH) or neutron star (NS) is fundamental to understanding their formation and evolution. To date, time-domain determination of compact object type remains a relatively untapped tool. Measurement of orbital periods, pulsations, and bursts will lead to a revolution in the study of the demographics of NS and BH populations, linking source phenomena to accretion and galaxy parameters (e.g., star formation, metallicity). To perform these measurements over sufficient parameter space, next generation X-ray telescopes having a large field of view, improved angular resolution, increased sensitivity/effective area, and timing capabilities are required.

Key Themes

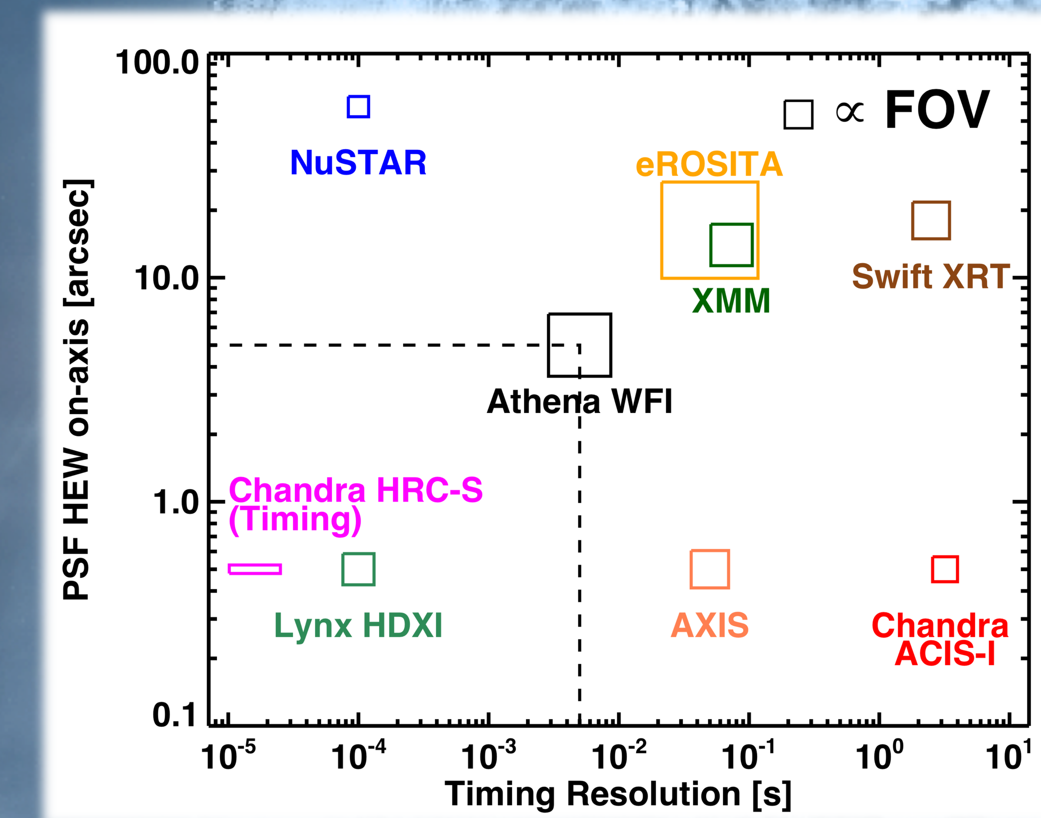
How Supernovae Work

Heating of The Early Intergalactic Medium

Origin of Gravitational Wave Sources

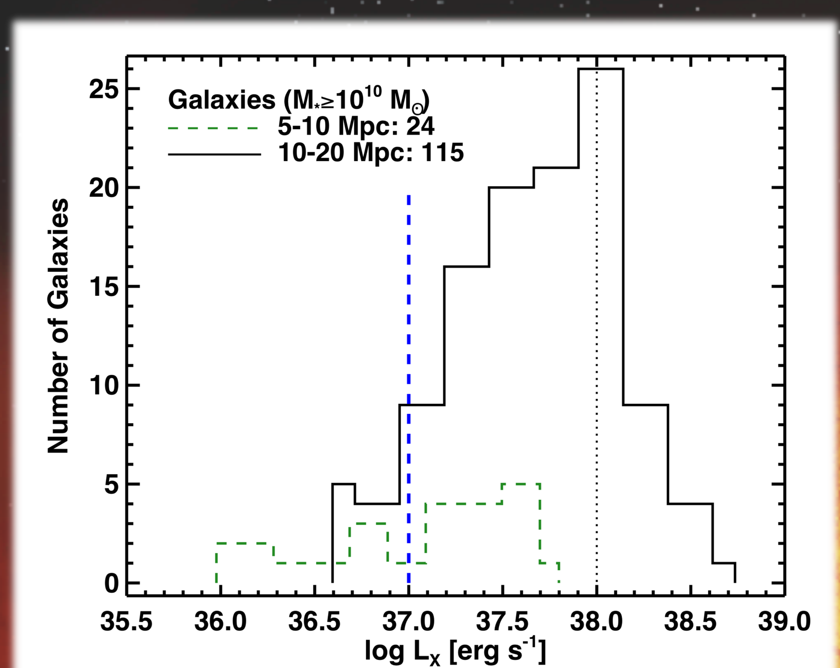
Science Questions

- **Prevalence of super-Eddington pulsars & the accretion mechanism?**
- **Progenitor paths for gravitational wave sources?**
- **Role of supernova kicks in dynamical evolution of BH/NS populations?**



The *Athena* wide-field imager (WFI) will be a time domain survey machine in the X-ray band. *Athena* WFI will have an ideal combination of angular/timing resolution, field of view, and sensitivity to revolutionize the study of accreting black hole and neutron star systems (observed as X-ray binaries).

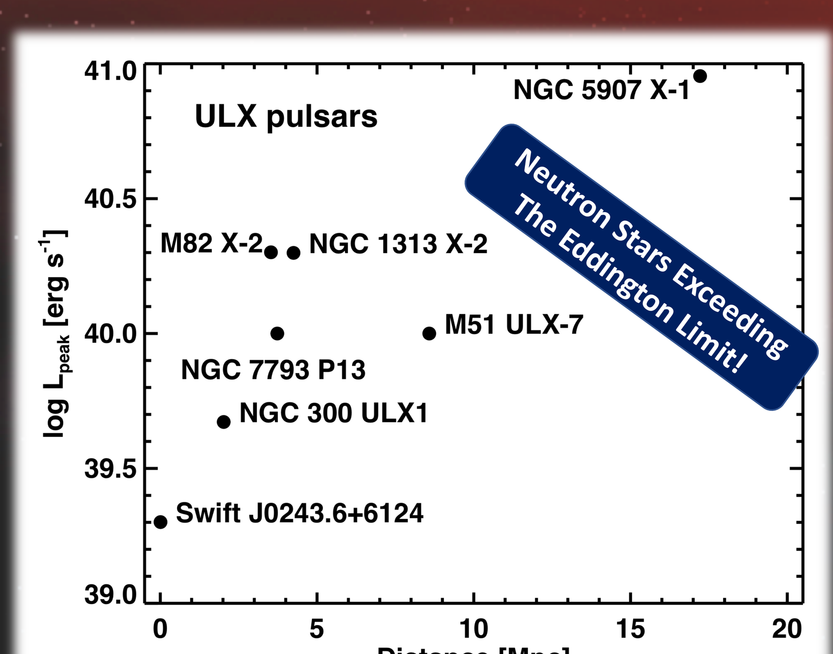
Nearby Galaxies with Chandra



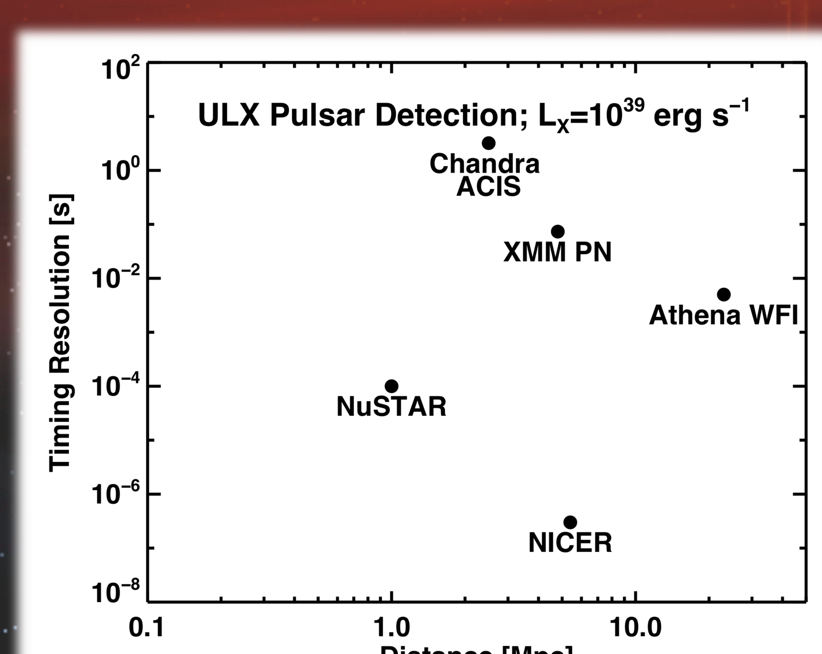
Chandra has transformed our understanding of accreting compact objects (X-ray binaries - XRBs) over cosmic time, from the local Universe to high-redshift. Nearby galaxy XRBs have historically been classified by their donor star as high-mass or low-mass. Compact object classification has been limited to the Galaxy, Magellanic Clouds, and a few of the brightest nearby extragalactic systems.

The number of galaxies surveyed to limits sufficient to characterize the bulk of actively accreting systems (≃10^36 erg/s) remains relatively modest; *Athena* WFI will swiftly reach such sensitivities. Sensitivity limits for nearby galaxies in the *Chandra* archive. Vertical lines roughly indicate the NS Eddington limit and the transition luminosity for LMXBs having evolved red giant donors to less luminous LMXBs with main sequence donors.

Ultraluminous X-ray Pulsars

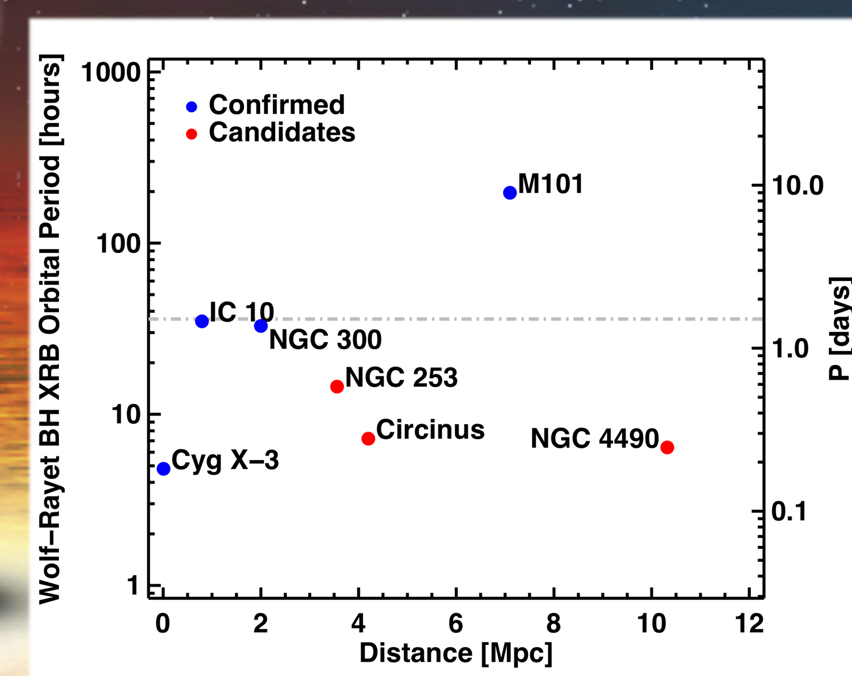


Some neutron stars emit as much as 100 times above the Eddington limit, an accretion process that is not understood. The peak L_X (0.5-10 keV) vs. host galaxy distance for currently known ULX pulsars.

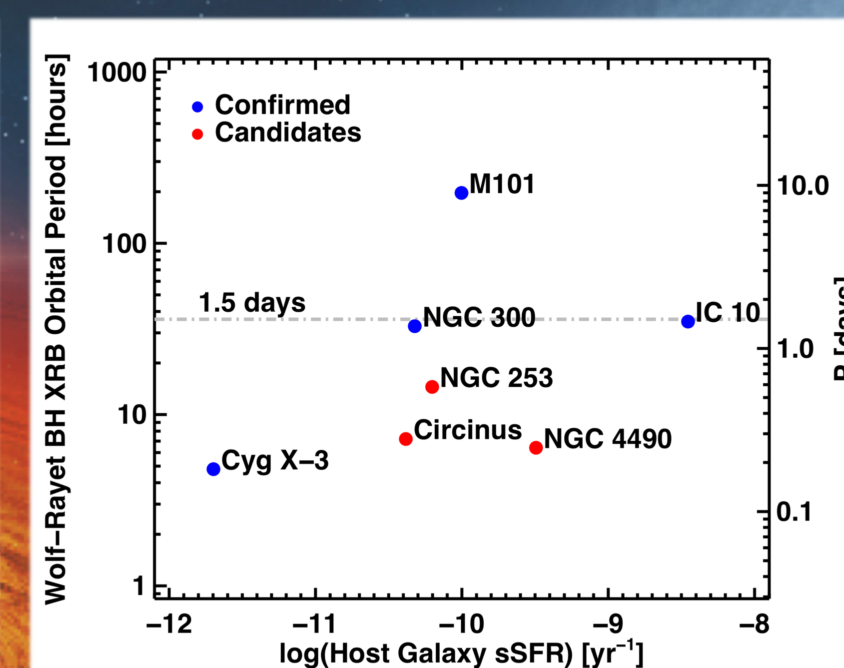


***Athena* WFI will greatly expand the search volume for ULX Pulsars.** Shown are limits for detection of ULX pulsars based on a 20% pulsed fraction. The sensitivity and collecting area of current X-ray telescopes limit the detection of ULX pulsars having $L_X\simeq10^{39}$ erg s^{-1} to $d\approx5$ Mpc.

Wolf-Rayet X-ray Binaries

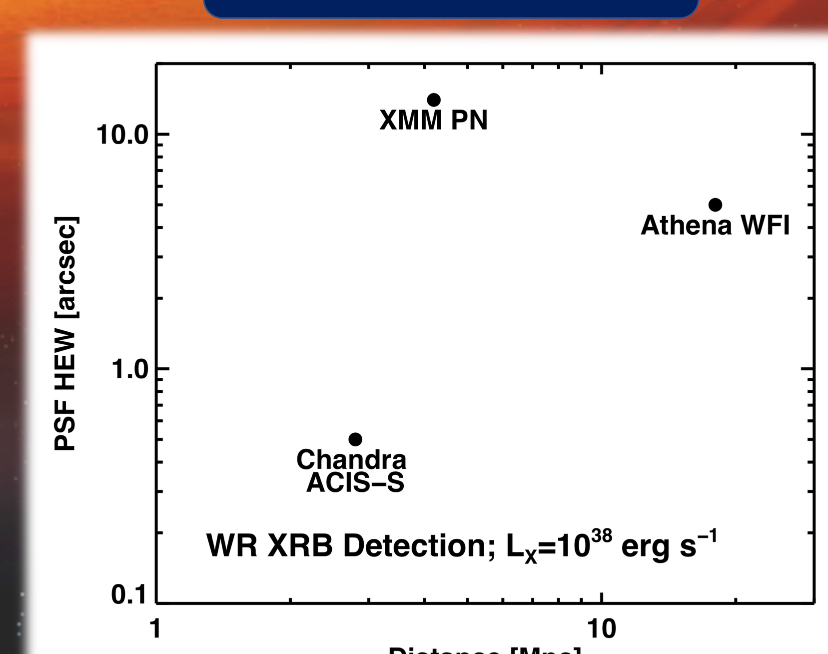


Host galaxy distance for currently known/candidate WR XRBs. Those with P_{orb} < 1.5 days will merge within a Hubble time.

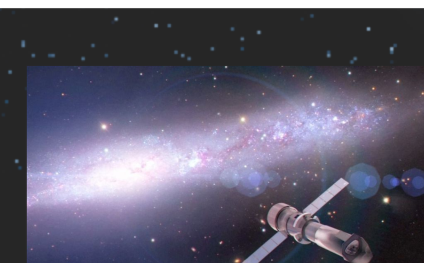


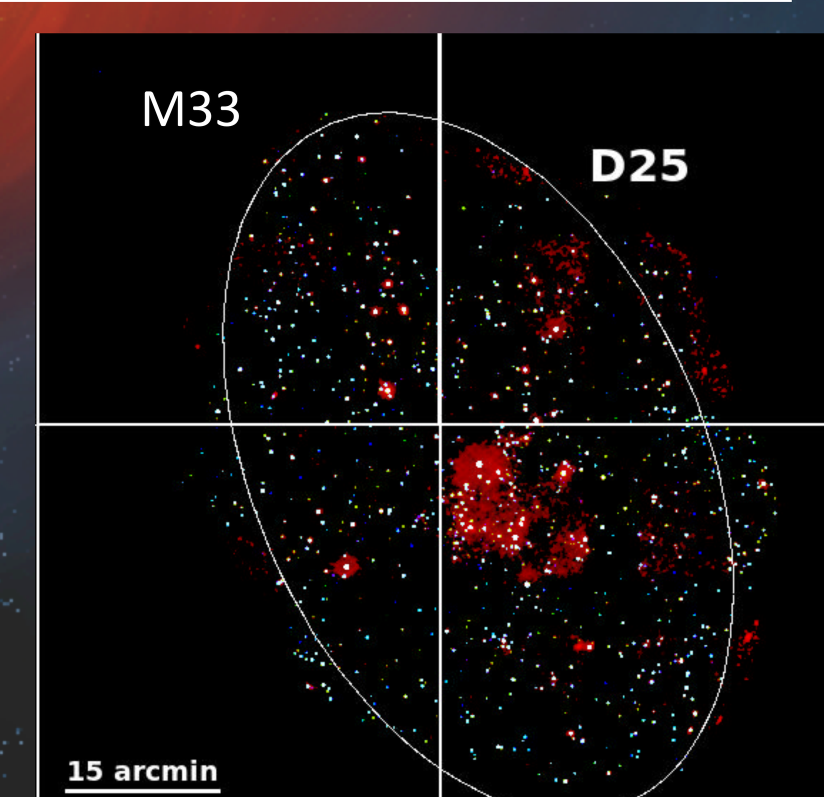
Host galaxy specific star formation rates (sSFR) of WR XRBs. The Milky Way is expected to have ≈10 WR XRBs, half of which have L_X at the Cyg X-3 level.

WR XRBs are potential Gravitational Wave progenitors!

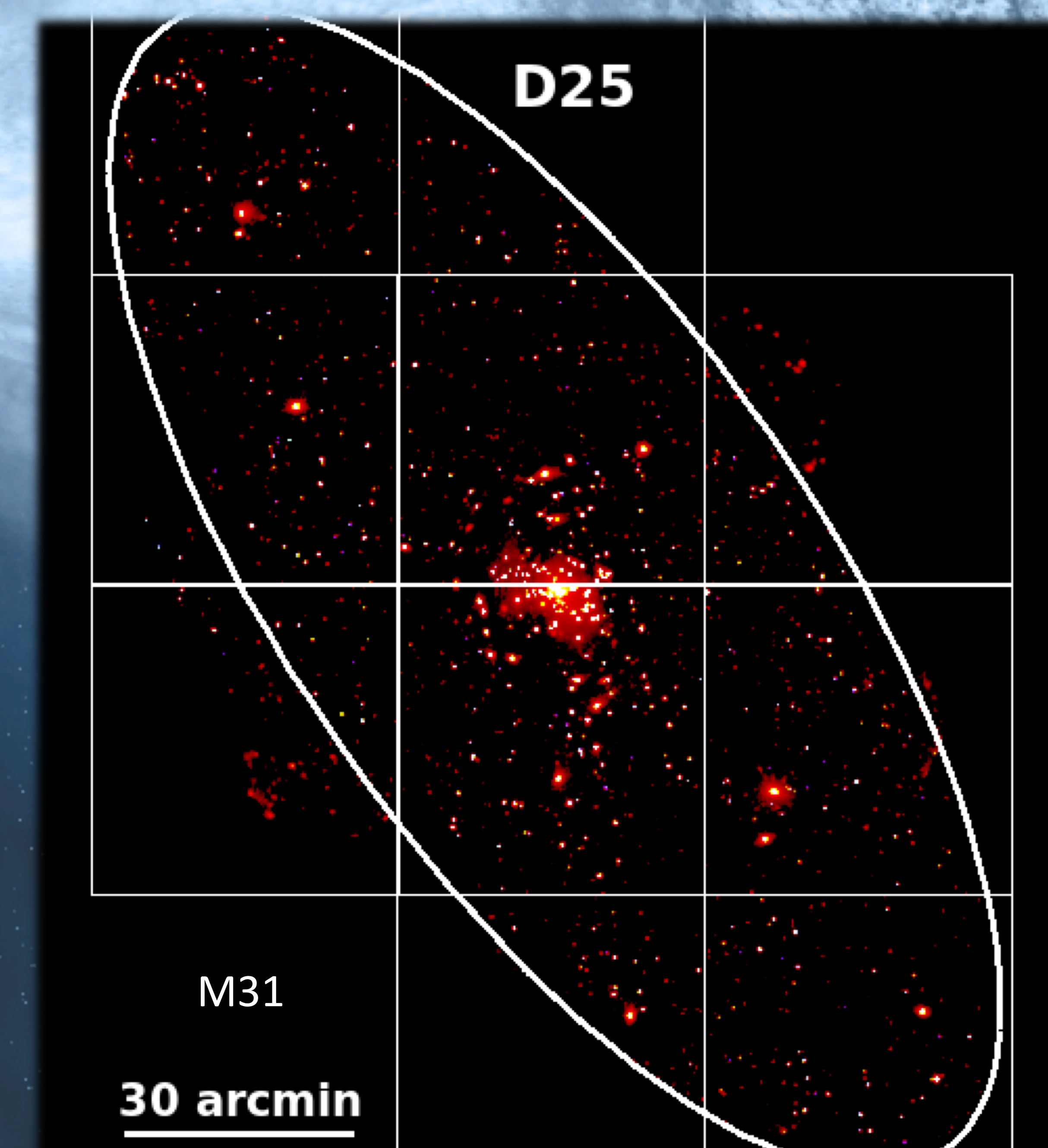


***Athena* WFI will greatly expand the search volume for WR X-ray binary systems.** Shown are limits for detection of short-period Wolf-Rayet X-ray binaries. Hundreds of WR XRBs will be discovered by measuring orbital-timescale variability.





The Athena Wide Field Imager will detect obscured HMXBs in nearby galaxies. *Athena* WFI mosaic image of the Triangulum galaxy (M33, d=875 kpc) generated with the SIXTE end-to-end simulator. The image consists of 4 pointings, each with 25 ks exposure. Obscured HMXBs with spectra similar to IGR J16318-4848 and column densities $\leq10^{23}$ cm^{-2} will be detected with 75 ks exposures, preferentially in the hard band (2-10 keV).



The Athena Wide Field Imager will efficiently survey large structures (e.g. Virgo cluster galaxies) enabling study of black hole and neutron star populations in the time domain. *Athena* WFI mosaic image of the Andromeda galaxy (M31, d=776 kpc) generated with the SIXTE end-to-end simulator. The image consists of 10 pointings, each with 10 ks exposure. In 100 ks, all active X-ray binaries in M31 to $L_X\approx10^{34}$ erg s^{-1} will be probed. Compared with *XMM-Newton*, which required 20 pointings of 100 ks each to reach 10^{35} erg s^{-1}. Pulsations can be detected for sources with $L_X\approx5\times10^{35}$ erg s^{-1} (20% pulsed fraction). The large FOV enables the study of XRBs in galaxy halos and the intracluster medium of nearby galaxy clusters.

Decadal White Paper (Vulic et al. 2019):

Time Domain Studies of Neutron Star & Black Hole Populations: X-ray Identification of Compact Object Types

Co-authors: A. E. Hornschemeier, V. Antoniou, A. Basu-Zych, B. Binder, F. M. Fornasini, F. Furst, F. Haberl, M. Heida, B. D. Lehmer, T. J. Maccarone, A. F. Ptak, G. R. Sivakoff, P. Tzanavaris, D. R. Wik, B. F. Williams, J. Wilms, M. Yukita, A. Zezas

Background Image : Cyg X-1; NASA/CXC/M. Weiss