The High Energy X-Ray Probe (HEX-P)

Resolved X-ray Populations in Extragalactic Environments

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Overview:

HEX-P is a probe-class mission concept that will combine high spatial resolution X-ray imaging (<10 arcsec FWHM) and broad spectral coverage (0.1-150 keV) with an effective area far superior to current facilities (including XMM-Newton and NuSTAR), to enable revolutionary new insights into a variety of important astrophysical problems. We will present simulations of HEX-P observations of a variety of extragalactic environments (e.g., normal, starburst, and passive galaxies) to demonstrate the power of the HEX-P observatory. We will show that HEX-P will (1) provide unique information about X-ray binary populations in external galaxies, including accretor demographics (black hole and neutron stars), accretion state distributions, and cadences of state transitions; (2) detect and characterize, for the first time, inverse Compton emission associated with particle accelerations in starburst environments; and (3) put into clear context the contributions from X-ray emitting populations to both ionizing surrounding interstellar mediums in low-metallicity galaxies and heating the intergalactic medium in the z > 8 Universe. More information on HEX-P, including the full team list, is available at https://hexp.org/.

Introduction and Motivation:

In the context of galaxy evolution, X-ray phenomena trace the most energetic of processes, providing critical information for a variety of phenomena. Supernovae and their remnants probe the detailed physics of exploding stars; diffuse emission from hot gas traces the impact of recent star formation on galactic and intergalactic scales; and X-ray binaries (XRBs) provide unique constraints on compact object, binary, and massive-star population demographics, as well as the physics and environmental impact of accretion onto compact objects.

HEX-P will characterize XRB populations and hot gas properties in galaxies spanning a broad range of environment (passive-to-starburst galaxies and rarer populations of low-metallicity galaxies and analogs to high-redshift systems). HEX-P will also open new areas to be explored in X-ray galaxy science, including, high-energy inverse Compton emission associated with particle accelerations in starbursts. Figure 1 provides a model 0.5–50 keV spectrum of NGC 253, a nearby (4.5 Mpc) starburst galaxy. A variety of components are expected to contribute and dominate across the HEX-P response.

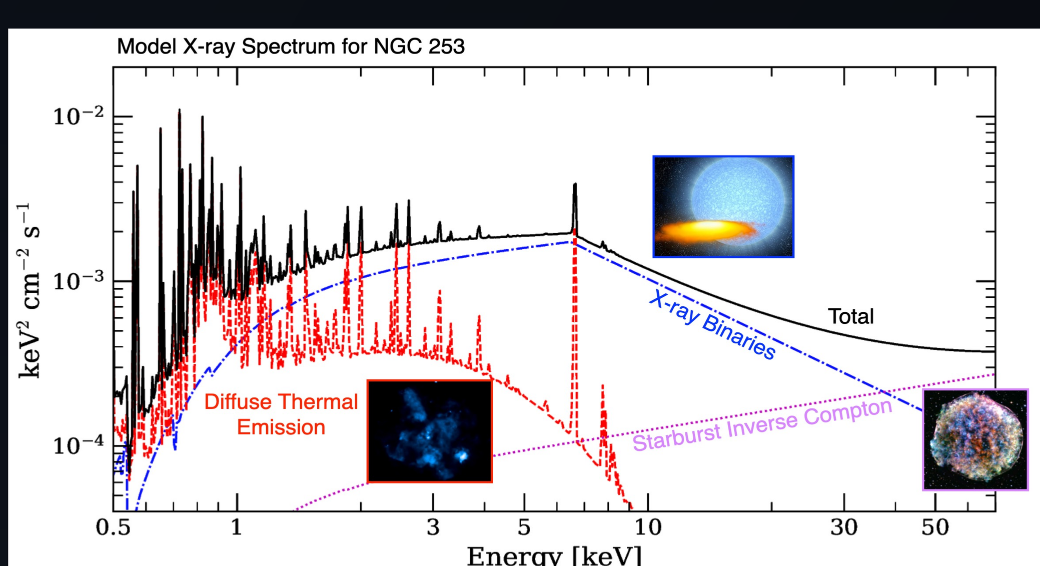

Figure 1: Spectral model for starburst galaxy NGC 253 broken down into components. The broadband capabilities of HEX-P will allow for simultaneous investigations of several interesting galaxy phenomena, including diffuse thermal emission, X-ray binary populations, and inverse Compton associated with particle accelerations.

Do you have ideas for how HEX-P would revolutionize your science? Get in touch!

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Hard X-ray Constraints on XRBs:

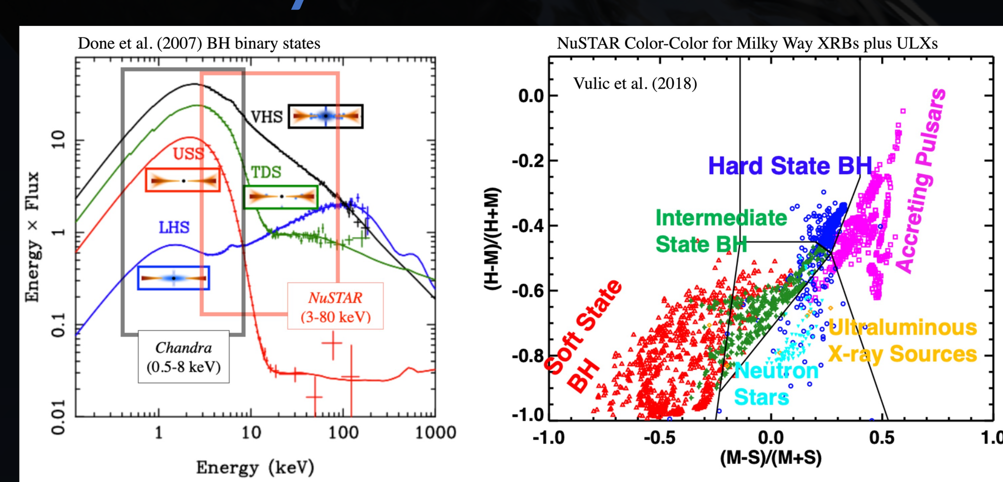

Figure 2: (Left) RXTE spectra of Milky Way black hole XRB GRO J1655−40 in various accretion states. The response range of Chandra and NuSTAR are shown to illustrate the power of > 10 keV sensitivity in characterizing the various accretion states. (Right) NuSTAR color-color diagram (S=4-6 keV, M=6-12 keV, and H=12-25 keV) of several well studied Milky Way XRBs (see color annotation), showing that isolation of source type and accretion states are possible with > 10 keV information.

With the launch of NuSTAR, it became possible to investigate the >10 keV properties of luminous XRBs in relatively nearby extragalactic environments (D < 10 Mpc). As illustrated in Fig. 2, the > 10 keV emission from binary populations provides a unique handle on the intrinsic properties of the XRBs, including the identities of the compact objects (black hole versus neutron star) and the nature of the accreting systems (e.g., states of accretion disks in black holes and state of magnetization for neutron stars). These constraints are critical for the successful development of binary evolution models; however, the large PSF of NuSTAR restricted inferences to only the nearest galaxies. HEX-P will dramatically improve characterization of XRB populations in galaxies spanning a broad range of environment.

Simulated Galaxy Sample:

To demonstrate the potential of HEX-P for studying galaxies (in particular at hard X-rays), we simulated with SIXTE the X-ray emitting populations in four different galaxy environments:

<u>NGC 253:</u> One of the nearest starburst galaxies, HEX-P will detect dozens of luminous XRBs and characterize their compact-object types. HEX-P will provide unprecedented constraints on the hot interstellar medium and inverse Compton from particle accelerations (see Fig. 1).

<u>Bulge of M31:</u> The bulge region of M31 provides a rich environment with a high concentration of LMXBs associated with the old host stellar population. HEX-P can quickly characterize accretion states and effectively monitor state transitions.

<u>Maffei 1:</u> A nearby (D ~ 4 Mpc) massive elliptical galaxy. HEX-P will uncover the compact object and accretion state distributions for a large number of LMXBs formed in field and globular cluster environments.

<u>NGC 3310:</u> A low-metallicity, high-SFR galaxy that contains a rich population of ultraluminous X-ray sources (ULXs). In general, low-metallicity galaxies have been observed to harbor an excess of ULXs per SFR. HEX-P will uncover whether ULXs formed in low-metallicity environments differ fundamentally from those found in more typical galaxies.

Results of Simulations:

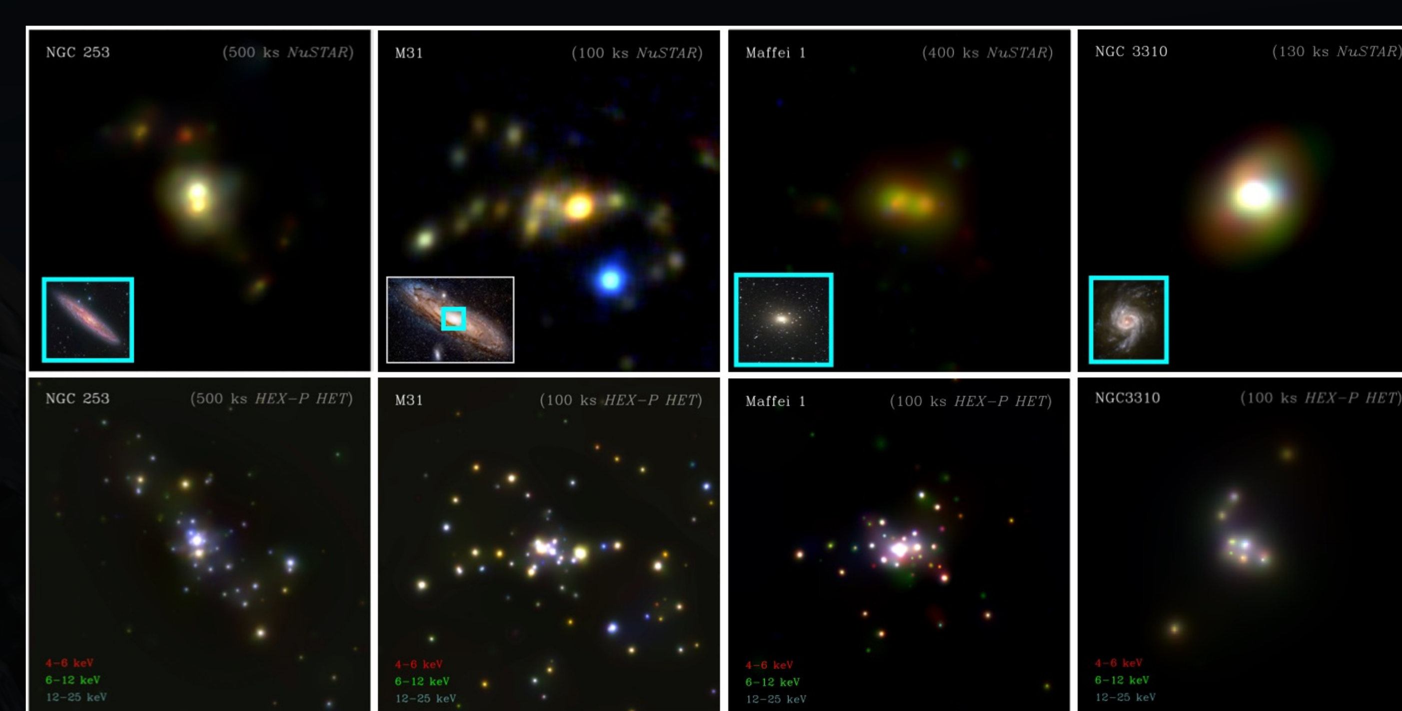

Figure 3: (Top Row) NuSTAR three-color images (red=4-6 keV, green=6-12 keV, and blue=12-25 keV) with optical inset images of NGC 253, the bulge of M31, Maffei 1, and NGC 3310. The XRB populations in these galaxies are highly confused and mainly detected at lower energies. (Bottom row) HEX-P simulated images of the same regions in the top row. HEX-P clearly isolates the underlying XRB populations and detects far more sources to much lower luminosity limits than achieved by NuSTAR.

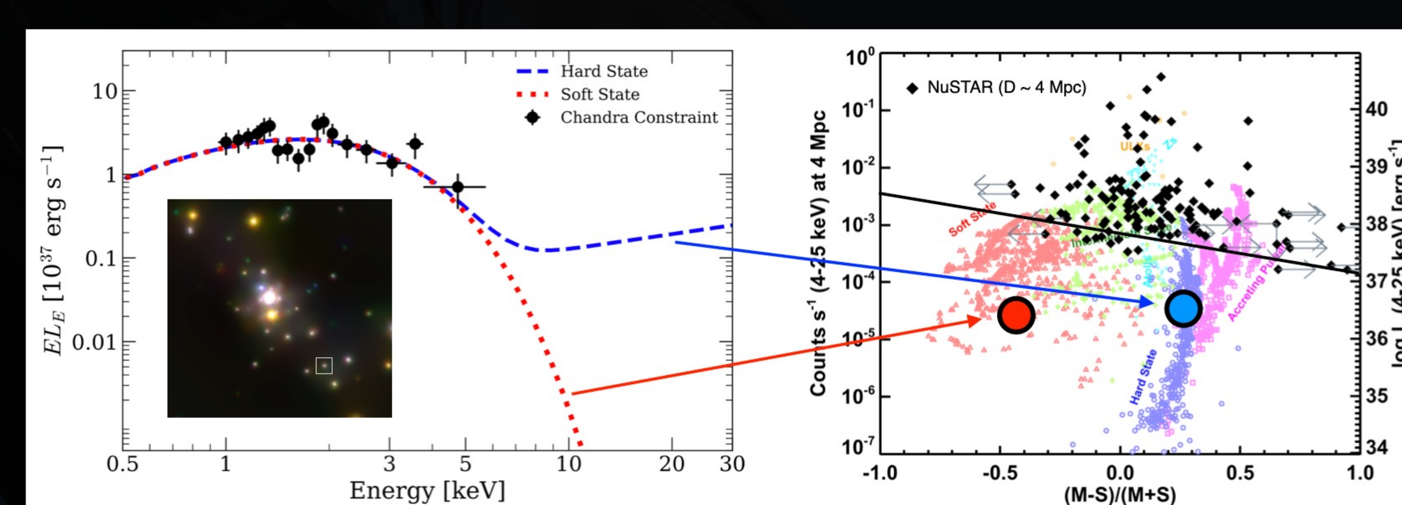

Figure 4: (Left) Chandra constraints on a relatively low-luminosity XRB in NGC 253, a source detected in our HEX-P simulations (see inset HEX-P image). Extrapolations to >7 keV show that the Chandra spectrum does not clearly constrain the nature of the source, which becomes clear only above 10 keV. (Right) Intensity-color diagram for Milky Way XRBs (colored symbols) and NuSTAR constraints on XRBs in galaxies at ~4 Mpc (black symbols). HEX-P will reach > 1 order of magnitude lower than NuSTAR (e.g., large red and blue circles)

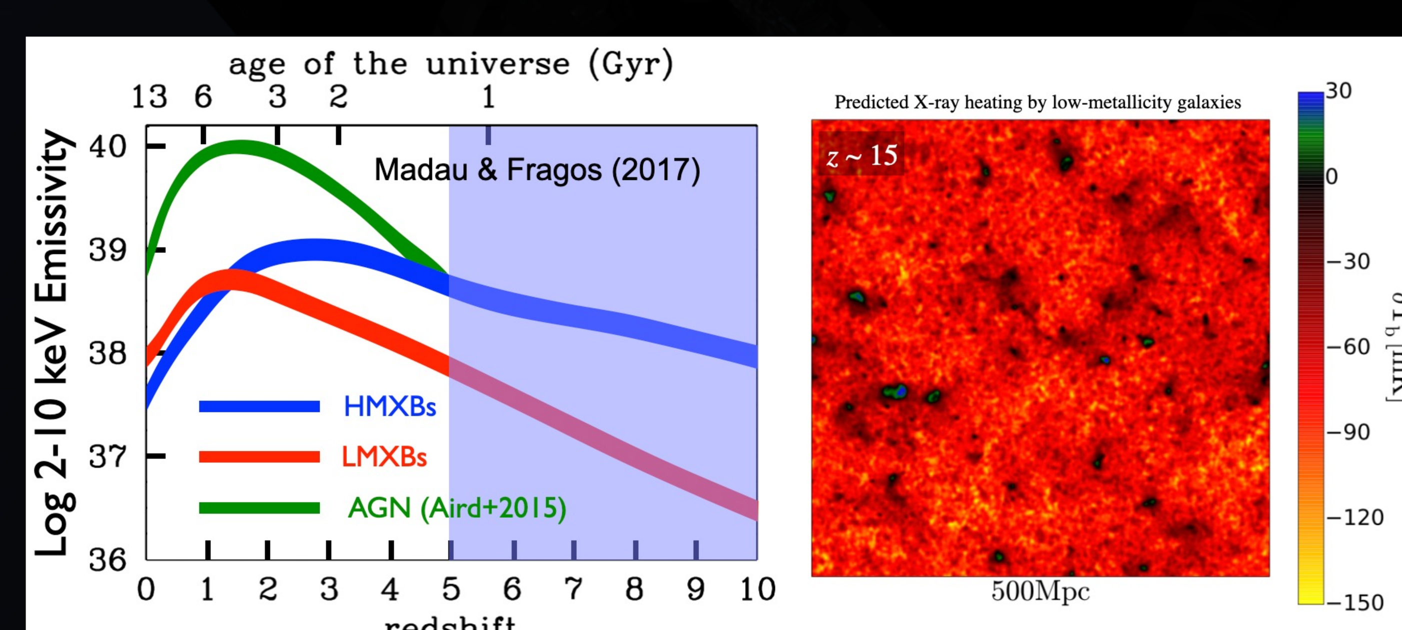

Figure 5: (Left) Model X-ray emissivity of the Universe as a function of redshift, showing XRBs are expected to dominate the high-redshift Universe X-ray emission. (Right) Intergalactic medium temperature structure (relative to the CMB) of the Universe at z~15 from a cosmological simulation that includes the effects of X-ray heating. HEX-P will investigate the broadband spectral energy distributions of local analog galaxies (low-metallicity starbursts) in the local Universe to better inform our understanding of X-ray heating at high-redshift.

HEX-P
HIGH ENERGY X-RAY PROBE

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