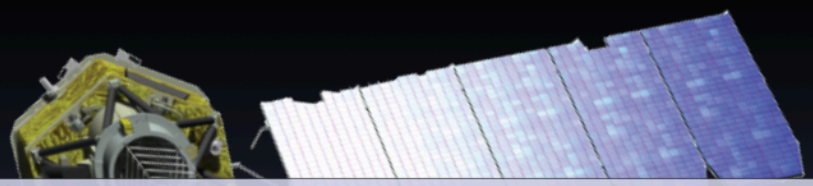
Nuclear Spectroscopic Telescope Array (*NuSTAR*)



A Hard X-ray View of Starburst Galaxies with *NuSTAR*

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Abstract

We are observing six nearby starburst galaxies jointly with *NuSTAR* and the soft (0.3-10 keV) X-ray imaging telescopes *Chandra* and *XMM-Newton*. These observations are providing crucial new input on disentangling the key mechanisms that dominate the hard (>10 keV) X-ray emission from star-forming galaxies, as well as the balance between accretion onto supermassive black holes and that onto stellar-mass black holes and neutron stars (i.e., X-ray binaries). *NuSTAR*'s broad energy response allows us to sensitively disentangle accretion states of the X-ray binary populations detected in these external galaxies. Below, I highlight first results coming from NGC 253 (Lehmer et al. 2013; Wik et al. submitted), M83 (Yukita et al. in-prep) and Arp 299 (Ptak et al. submitted). Additional observations of NGC 3310, NGC 3256, and M82 will be forthcoming in the next year.

Goals

The primary objectives for our work are to:

1. Examine spatially-resolved hard X-ray emission,
2. Characterize the *NuSTAR* point source population,
3. Determine the galaxy-wide spectral properties, and
4. Investigate hard X-ray luminosity - star formation rate (SFR) relation for *NuSTAR* compact binaries.

Summary

1. For NGC 253 and M83, several point sources are resolved by *NuSTAR*. The brightest point sources have *NuSTAR* colors and luminosities consistent with ULXs and intermediate state BH binaries.
2. For Arp 299, the *NuSTAR* emission is dominated by a nearly Compton-thick AGN.
3. The galaxy-wide spectra for all three galaxies (excluding the AGN in Arp 299) are well modeled by broken power laws, that decrease rapidly above 5-10 keV.
4. The L_X (10–30 keV) vs. SFR relation appears lower than previous predictions.

Spatially-Resolved Hard X-ray Images of Star-forming Galaxies and Their Spectral Properties

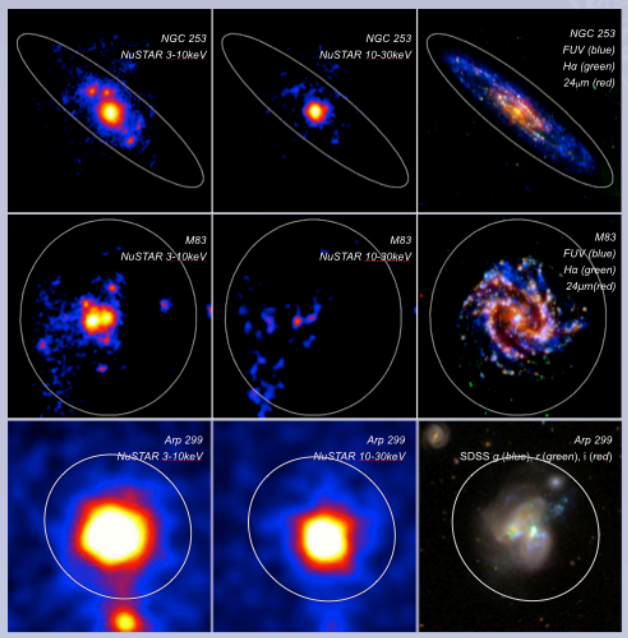

Figure 1: Top (left to right). The NuSTAR smoothed background-subtracted 3-10keV and 10-30 keV images and SFR tracer images of NGC 253. White ellipse indicates the optical size (D_{25}). Middle: The same as the top panel but for M83. Note that the elevated emission in the east in the NuSTAR M83 images is due to stray light. Bottom: The same as the top panel, but for Arp 299. The bulk of the emission is due to a single nearly Compton thick AGN. The "softer" source outside the galactic extent is a serendipitous AGN.

Color-Luminosity Diagrams and Hard X-ray Spectral Properties

Figure 2 compares *NuSTAR* point sources in M83 and NGC 253 as well as the *NuSTAR* ULX sources (NGC1313; Bachetti et al. 2013, Circinus; Walton et al. 2013) with the simulated *NuSTAR* colors for well-studied MW black hole binaries and accreting pulsars. **The ULXs in NGC 253 and M83 show similar colors and luminosity to other *NuSTAR* ULX sources. The majority of the remaining *NuSTAR* point sources have colors similar to intermediate state BH binaries.**

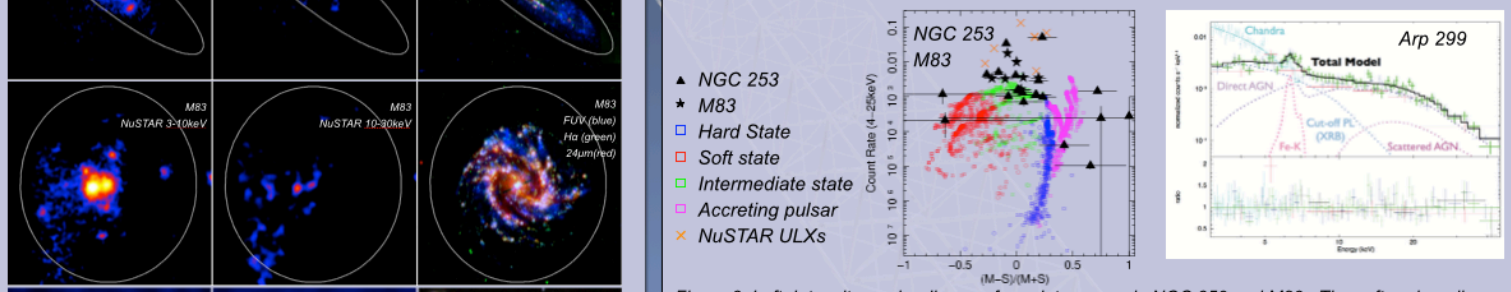

Figure 2: Left: Intensity—color diagram for point sources in NGC 253 and M83. The soft and medium colors are defined as 4-6 keV and 6-12 keV, respectively. For M83, the count rate has been scaled to the distance of NGC 253. Color symbols indicate the distributions of Milky Way sources in various accretion states based on RXTE spectra. Right: Joint Chandra and NuSTAR spectrum of Arp 299 with best-fitting components. The > 10 keV emission is dominated by a nearly Compton-thick AGN.

Galaxy-Wide 10-30 keV Luminosity vs. SFR Relation

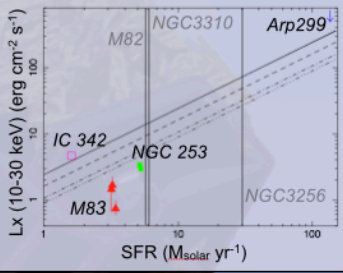

Figure 3: Correlation between hard X-ray and SFR. The diagonal lines indicate the expected Hard X-ray vs. SFR relations based on power law extrapolations [Γ of 1.6 (solid), 1.8 (dash), 2.0 (dash-dot), and 2.2 (dash-triple-dot)] of the Lx(0.5-8 keV) vs. SFR relation derived by Mineo et al. (2012). Note that the AGN activity in Arp 299 (Arp299B) may highly contaminate its SFR value. Gray vertical lines indicate the SFR values for the targets that will be observed with NuSTAR in the near future (NGC 3310, 3256, and M83).

NuSTAR www.nustar.caltech.edu

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