Abstract

We can learn a lot about the formation of compact objects, such as neutron stars and black holes, by studying the X-ray emission from accreting systems in nearby star-forming galaxies. The harder (E>10 keV) X-ray emission in particular allows strong discrimination among the accretion states and compact object types. A NuSTAR survey of M33 was conducted to study the distribution of X-ray binary (XRB) accretion states in an actively star-forming environment. The 6 NuSTAR observations of M33 allow us to construct diagnostic diagrams, which is used to infer XRB accretion states. We have characterized XRB accretion states for ∼28 sources. The XRBs are classified by their compact object types using NuSTAR color-intensity and color-color diagrams. We further characterize the black holes by their accretion states (soft, intermediate, and hard) and the neutron stars by their weak or strong (accreting pulsar) magnetic field.

M33

In the NuSTAR archive, 6 observations are public in the direction of the galaxy M33. There are three fields (each with two separate epochs): Field 1: Observation ID 50310001002 and 50310001004; Field 2: 50310002001 and 50310002003; and Field 3: 50310003001 and 50310003003.

NuSTAR diagnostic diagram

Figure 1: Three-color NuSTAR image mosaic of the M33 legacy fields. The image was constructed from 4–6 keV (red), 6–12 keV (green), and 12–25 keV (blue) exposure-corrected adaptively smoothed images. In the right corner is the Spitzer Infrared Array Camera 3.6 um image of M33.

Figure 2: Point spread function calibrated point source image fits for M33 X-8: left panel displays smoothed, background-subtracted count data from both epochs. Middle panel is the best-fit model, and the white contours in all the three panels outlines the smoothed model image. The right panel shows the residual between data and model with a smaller color scale color bar. The yellow contours presents the data. Both the yellow and white contours present identical intensities.

Figure 3: Hardness-intensity diagram for X-ray sources in M33 (black square), and pulsars, hard/intermediate/soft-state BH XRBs in the Milky Way (magenta, blue, green, red symbols) and Ultraluminous X-ray sources (ULXs) studied by NuSTAR (gray upside-down triangles). The hardness ratio is from M = 6–12 keV and S = 4–6 keV band count-rates. My surveys thus far constrain the accretion-state distributions for luminous XRB populations in M33. These M33 observations constrain the distribution of accretion states for a low-luminosity HMXB-rich population.

Figure 4: Color-color diagram. The black squares with error bars are the 28 sources in M33.

Figure 5: NuSTAR: 50310002001. Pulsations: Instrument A 99.46 ± 5.68 mins, 12.08 ± 0.09 mins; Instrument B 100.2 ± 5.68 mins, 12.08 ± 0.09 mins.

Conclusion

In contrast to a similar NuSTAR survey of M31 (with a low-mass XRB-dominant population), the source population is dominated by high-mass XRBs, allowing the study of a very different population with similar sensitivity. These results provide a significant improvement in our knowledge of high-mass XRB accretion states that prove valuable for theoretical XRB population synthesis studies.

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