Tracing Star Formation in the X-ray: From ULIRGs to Dwarf Starbursts

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Introduction

Starburst galaxies have halos of hot (T > 10^6 K) thermal gas. X-ray observations have shown that these halos can extend tens of kpc away from the galactic disks. Pockets of intense star formation are thought to generate outflows of hot gas which can flow out of the galaxy into the halos. The outflows are driven by stellar winds and supernovae which inject mechanical energy and metal-enriched gas into the winds.

X-ray halos are also observed in dwarf starbursts and Ultraluminous Infrared Galaxies (ULIRGs). If these halos are driven by superwinds, they could explain the metal abundances observed in the IGM at high redshifts. Although metal loss is thought to be easier in lower mass systems, higher mass systems, like the ULIRGs, have higher total SFR and could account for a significant fraction of the observed abundances. X-ray studies of the halos in all star forming galaxy types thus provides an important window in understanding the effects of superwinds on their environments.

Galaxy Sample

The sample consists of Chandra ACIS-S observations of nine ULIRGs, six edge-on starburst galaxies (previously studied in Strickland et. al. 2004), and seven dwarf galaxies. Four of the ULIRGs have been subclassified as AGN ULIRGs due to the detection of Fe Kα in the nuclear region. The sample spans almost 5 orders of magnitude in X-ray luminosities.

Adaptively Smoothed Images (0.3-8.0 keV)

The diffuse X-ray spectra and thermal model fits for the dwarf starburst NGC 1569 and AGN ULIRC NGC 6240.

Sample X-ray Spectra

Physical Scale

The morphology of the X-ray emission is remarkably similar throughout the physical scales represented in the sample. These images are truecolor adaptively smoothed images where red is 0.3-1.0 keV, green is 1.0-2.0 keV, and blue is 2.0-8.0 keV. The smaller boxes in the MKN 231 image represent the physical size of the dwarf starburst NGC 3077 (factor of 50 smaller) while the larger box is the scale of the edge-on starburst NGC 3628.

Similar X-ray & Hα Morphologies

The Hα images on the left are very similar to the adaptively smoothed X-ray images on the right. This suggests that the diffuse X-ray emission traces the star formation.

X-ray vs. FIR Luminosities

On the left we show that the diffuse X-ray luminosity is correlated with the FIR luminosity. In the right plot we have divided X-ray and FIR luminosities by the K-Band luminosity. This plot shows that there is an almost constant conversion between the SFR and X-ray gas.

Size of the X-ray Emitting Region

Here we have plotted the 90% X-ray (0.3-1.0 keV) flux enclosed radii vs. the FIR (left) and K-band (right) luminosities. Stellar mass appears to be better correlated with the size of the X-ray emitting halo than the SFR.

Gas & Dust Temperature

There appears to be a slight correlation between the gas and dust temperatures. However, these plots do show that the ULIRGs have systematically higher gas temperatures than the starbursts and dwarf starbursts. This is true far from the central regions of the ULIRGs as shown in the plot on the right, where we have plotted the gas temperatures for only the outer halo regions of the ULIRGs.

Conclusions

• We find that the diffuse X-ray emission has enhanced α-element/Fe ratios (~3) relative to solar. This is consistent with enrichment from SN II’s.
• The fairly constant ratio (~ 4 x 10^5) between FIR & X-ray luminosity suggests a common efficiency of turning mechanical energy from SN outflows into hot gas throughout a wide range of high SFR galaxy types.
• X-ray halos are formed from star formation powered outflows.
• Larger galaxies have larger winds.
• The ULIRGs have higher gas temperatures but otherwise, have similar diffuse X-ray gas properties as other star forming galaxies.