New Frontiers Opened by Chandra in Cosmological Studies of Galaxies
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INTRODUCTION

The deepest extragalactic X-ray surveys with Chandra show that galaxies are beginning to rival AGN as the most luminous point sources at the faintest X-ray fluxes. These X-ray-detected galaxies provide probes of accreting binaries and hot gas in galaxies over important Gyr timescales that simply were not accessible before the Chandra mission. However, most distant (z > 0.2) Chandra studies of evolution of X-ray emission from star-forming galaxies are severely limited by the lack of highly complete X-ray observed samples in the local Universe. This paper discusses new results arising from archival Chandra studies of galaxies in the Sloan Digital Sky Survey Data Release 2 (SDSS DR2) and of pointed X-ray observations in the Coma cluster of galaxies. These projects are filling in the “local” observational needs of deep X-ray surveys.

X-ray from Normal/Starburst Galaxies

X-ray Number Counts
• Through stacking analysis (Hornschemeier et al. 2012), fluctuation analysis (Miyaji et al. 2003), and careful extension of the measured galaxy number galaxy number counts (Hornschemeier et al. 2012; Hornschemeier et al. 2011), it is clear that X-ray detected galaxies can dominate X-ray surveys for 0.5-2 keV fluxes of N > 10^{-15} erg cm^{-2} s^{-1} (see Figure 1).

Origin of X-rays in star-forming galaxies:
• Accretion on to compact stellar remnants (i.e., neutron stars, black holes)
• Recombination into X-ray emitting plasma through X-ray emitting gas
• For comparison, the Milky Way:
• L_x ~ 10^{39} erg s^{-1}, 0.5-2 keV
• Dominated by a few (1-4) X-ray binaries (XRBs) (Grimm et al. 2002)

X-ray correlations with star-formation rate (SFR)

LOCAL, (d < 50 Mpc)
• The slopes of the X-ray binary luminosity functions within galaxies correlate with star-formation rate (SFR) (Kangas et al. 2002; Collier et al. 2011)
• The total X-ray binary luminosity of galaxies correlates with SFR (Collier et al. 2011; Rau et al. 2003; Povich et al. 2009)

DISTANT, (z > 0.1)
• Total L_x correlates with L* (Buote et al. 2002)
• Total L_x correlates with L_La (Bour et al. 2002)
• Total L_x correlates with L* (Lahav et al. 2001)
• X-ray properties of Lyman Breaks (LB, z > 2), and LBGs at z < 0.2-0.3 consistent with local XRBs (Bresolin et al. 2001; Collier et al. 2011; Rau et al. 2003; Povich et al. 2009)

Current Problems in Cosmological X-ray SFR Studies
• Linearity of X-ray/SFR relation is under debate (Grimm et al. 2005), claims it is non-linear.
• Normalization of the X-ray/SFR relation is uncertain by at least a factor of 3 (Hornschemeier et al. 2014)
• There has been an X-ray luminosity function for field galaxies constructed in the local Universe.

Figure 1: X-ray counts from normal/starburst galaxies (top panel) and Coma cluster galaxies (bottom panel).

Figure 2: BPT Diagram from Hornschemeier et al. (2004).

Figure 3: X-ray luminosity vs. SFR

SDSS Project:

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SDSS

The SDSS Project

• Sloan Digital Sky Survey (SDSS; Abazajian et al. 2006) galaxies are sufficiently local (z ~ 0.1) to provide the needed calibration for high-z studies.
• We have begun a project using archival Chandra observations to find serendipitous X-ray detections of SDSS galaxies
• Using the program XASSET (Ptak & Griffiths 2003) to characterize X-ray sources in Chandra-ACIS observations of at least 10 ksec depth, we have identified 42 X-ray-detected SDSS DR2 galaxies.
• The optical spectroscopic types are given in Table 1.

Figure 2: BPT Diagram from Hornschemeier et al. (2004).

Table 1: Optical Spectroscopic Types of SDSS galaxies Observed in the Coma Cluster

<table>
<thead>
<tr>
<th>Spectroscopic Type</th>
<th>Number</th>
</tr>
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<tr>
<td>LINERs</td>
<td>10</td>
</tr>
<tr>
<td>AGNs</td>
<td>32</td>
</tr>
</tbody>
</table>

Figure 3: X-ray luminosity vs. SFR

Coma Project:

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COMA

COMA X-ray-detected galaxy project

• Characterizing the first (dwarf) end of the X-ray galaxy luminosity function is even more difficult.
• We have looked to clusters of galaxies for the galaxy numbers for efficient observations.
• We take advantage of the extensive Subaru photometric and spectroscopic survey of Coma (e.g., Poggianti et al. 2001).
• This field (see Figure 5) was chosen as a compromise between galaxy density and brightness of the intracluster medium in the X-ray band.

Preliminary Results:
• There are 23 Coma member galaxies in the Chandra-ACIS field.
• We detect 35% of the giant galaxies, half of which are clearly AGN.
• Our X-ray upper limit on the dwarf galaxies is 1.2 x 10^{-15} erg s^{-1}, 0.5-2 keV.
• The detailed results will be presented in Hornschemeier et al. (2009).

Figure 5: X-ray counts from Coma cluster galaxies (top panel) and Coma cluster galaxies (bottom panel).

Acknowledgments/References

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References