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ABSTRACT

I review recent results from our deep ROSAT and Chandra observations of two galaxies, M101 and NGC 4631, in fields of exceptionally low Galactic extinction. Large amounts of X-ray-emitting gas are detected in these galaxies. Such gas is produced primarily in massive star forming regions and have an average characteristic temperature of a few times 10^6 K. Cooler gas ($\sim 10^6$ K) is found typically outside galactic disks and may represent outflows from blown-out superbubbles. Propagation of star formation, driven by the expansion of hot gas, appears to be operating in giant HII complexes. A substantial fraction of photo-evaporated gas in such complexes may be mass-loaded into hot gas, which explains their large X-ray luminosities. These processes likely play an important role in determining the global properties of the interstellar medium, especially the disk/halo interaction.

1. Introduction

X-ray observations of nearby disk galaxies are important to the understanding of the hot interstellar medium (ISM) and its role in galaxy evolution. We are conducting an extensive study of the face-on spiral galaxy M101 based partly on an ultra-deep (230 ks) ROSAT HRI image, and we have also obtained a Chandra observation on the edge-on galaxy NGC4631. These observations, together with data in other wavelength bands, provide us with complementary perspectives of hot gas and its interaction with other galactic components in late-type disk galaxies.

2. M101

This face-on galaxy allows us to study the production of hot gas not only under normal circumstances but also under localized starburst conditions. Diffuse ~ 0.25 keV emission is present in the central ($R \lesssim 10$ kpc) region of the galaxy (Snowden & Pietsch 1995). Enhanced X-ray emission is also detected in several giant HII complexes (GHCs; Williams & Chu 1995). Wang et al. (1999) have reported the results on discrete X-ray sources detected in the M101 field. But some of these sources apparently represent peaks of extended X-ray-emitting features.

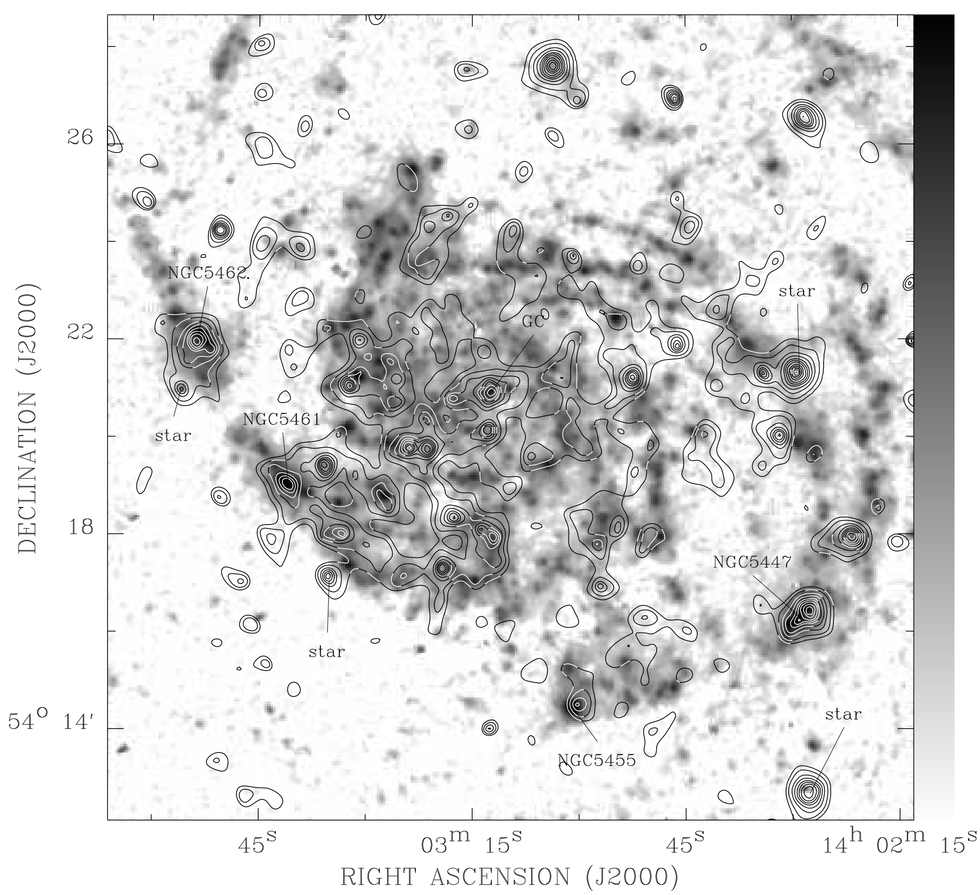

Fig. 1.— RHRI contours (Wang et al. 1999) overlaid on an Hα image of M101.

Hot gas (a few times 10^6 K) as traced by the RHRI correlates well with recent star forming regions in the galaxy (e.g., Fig. 1). In particular, enhanced diffuse X-ray emission features line up well with the active southeast arm, which harbors such GHCs as NGC 5461 and NGC 5462, which are more luminous than the 30 Dor complex in the LMC. We further find that the radial distribution of "diffuse" X-ray emission is nearly identical to that of the far-UV radiation and is substantially flatter than that of optical light, which is produced chiefly by old stellar populations. Thus the hot gas originates primarily in recent star formation regions. In comparison, the cooler gas ($\sim 10^6$ K) as traced by the ROSAT PSPC 0.25 keV image (Snowden & Pietsch 1995) is seen only in the inner $4'$ radius, consistent with an origin in the galaxy's corona or a combination of blown-out bubbles.

Fig. 2 provides a close-up of a region at the western end of the two Hα branches of the southeast spiral arm (Fig. 1). This region happens to be covered by archival HST WFPC2 observations. An apparent ring of HII regions coincides spatially with an HI supershell, as proposed by Kamphuis (1993). Whereas the RHRI emission is primarily associated with the HII ring, the softer PSPC 0.25 keV emission peaks in the interior of the ring. Thus, the X-ray-emitting gas within the ring appears to be cooler than that in the HII regions. If the HI supershell is indeed powered by the mechanical energy input from massive stars, its dynamic age is several times 10^7 yrs, about an order of magnitude greater than that of the HII regions. This can naturally be explained by the propagation of star formation, which is likely triggered by the expansion of the supershell.

The HST image also presents morphological evidence for outflows from HII regions into the interior of ring. These frothy HII regions appear being torn apart, being stripped away, and mass-loading the interior of the supershell. Similar feedback activities are also evident in the GHC NGC 5462.

3. NGC4631

ROSAT observations have shown that X-ray emission, particularly in the 0.25 keV band, extends beyond both the cold and warm gas disks of the galaxy (Wang et al. 1995). The Chandra ACIS-S observation of the galaxy provides us with a new opportunity to further the study. While the analysis of the data is still on-going, Fig. 3 shows unambiguously the presence of extraplanar diffuse X-ray emission. The X-ray morphology resembles the radio halo of the galaxy (e.g., Hummel et al. 1991), indicating a close connection among outflows of hot gas, cosmic rays, and magnetic field. A spatially-resolved spectroscopy will further enable us to study the detailed chemical and thermal properties of the hot gas, constraining the dynamics of the corona. The results will have strong implications for our understanding of the feedback from galaxies as well as their structure and evolution.

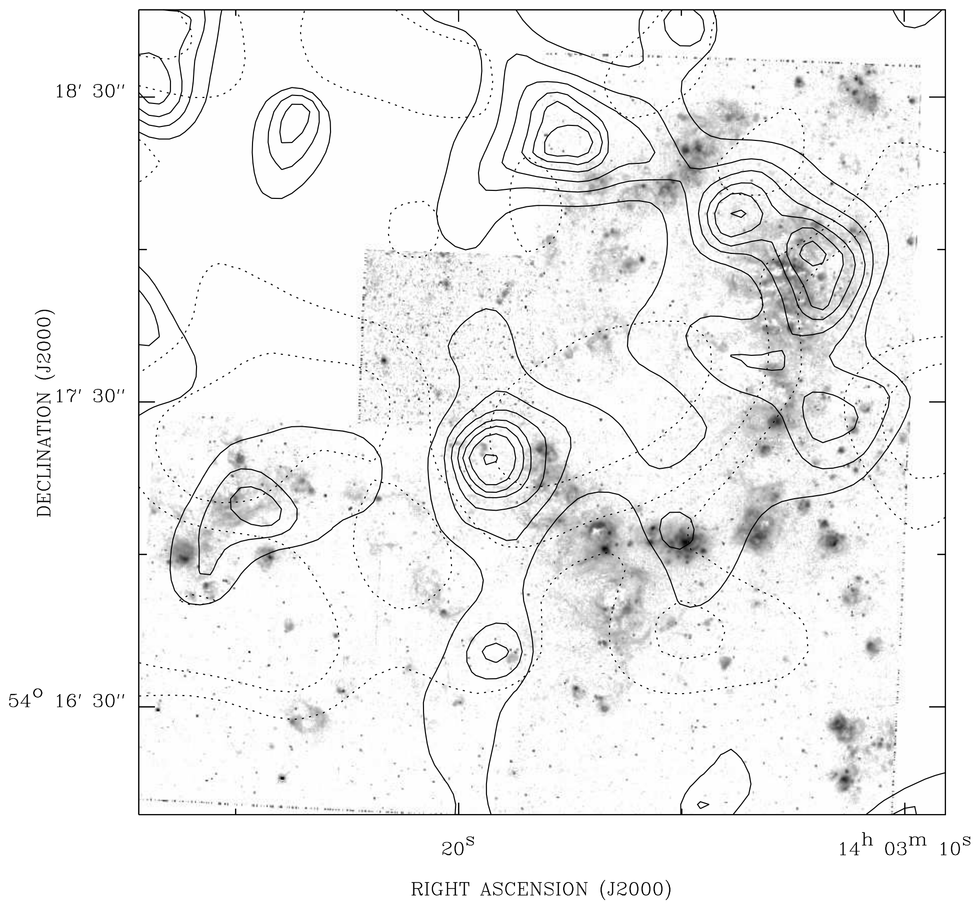

Fig. 2.— A close-up of a region imaged by HST WFPC2 (Hα). The solid contours are the RHRI contours, while the dotted ones represent the PSPC 0.25 keV intensity.

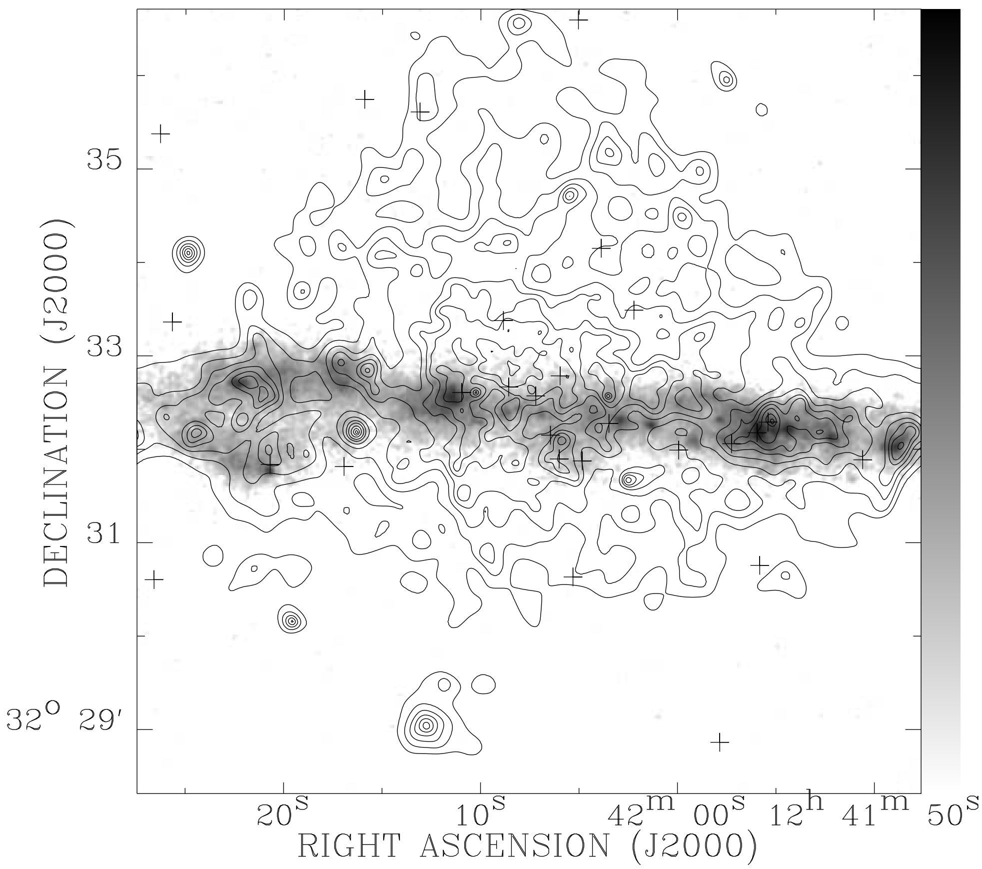

Fig. 3.— Diffuse X-ray intensity contours overlaid on a far-UV image of NGC4631. The X-ray data are from the Chandra ACIS-S in the 0.5-1.5 keV band. Point-like sources as marked by pluses have been excised.

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