Galaxies and Their Constituents at the Highest Angular Resolutions
IAU Symposium, Vol. 205, 2001
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Chandra Observations of Starburst Galaxies M82 and NGC 3256

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Abstract. We present high resolution *Chandra* X-ray imaging of two starburst galaxies, M82 and NGC 3256. The central x-ray source observed by ROSAT and ASCA in M82 is resolved into 3 or 4 sources. Most of these sources are variable, suggesting that the point sources are powered by accretion. The brightest of these central sources is $\sim 10^{41}\, ergs\, s^{-1}$ in the high state, and is responsible for the variability observed by ROSAT and ASCA. Assuming this source radiates at the Eddington limit, the mass is $\sim 500 M_{\odot}$. The diffuse hard (2-10 keV) emission in M82 is spatially coincident with diffuse radio emission and Pα. This is consistent with diffuse hard X-ray emission arising from hot thermal gas in the starburst region. Approximately 14 sources with $L_X > 10^{39}\, ergs\, s^{-1}$ were detected in NGC 3256, including both nuclei. Two of these sources have $L_X > 10^{40}\, ergs\, s^{-1}$. This observation suggests that "super Edington" sources may be preferentially associated with starburst galaxies (see also paper by Fabbiano in this volume)

1. Introduction and Observations

Starbursts galaxies are complex X-ray sources. Pre-*Chandra* observations show extended soft X-ray emission associated with "superwinds" driven from the heart of the starburst region. There is also evidence for hard X-ray emission, variously interpreted as arising from obscured AGN, X-ray binaries or Inverse Compton scattering of infrared photons off relativistic electrons (Moran, Lehnert & Helfand 1999). Pre-*Chandra* X-ray observations did not have sufficient spatial resolution to distinguish between these components.

M82 and NGC 3256 are both well-studied starbursts. M82 is a nearby (3Mpc), nearly edge-on dwarf interacting with M81. It is a modest starburst with infrared luminosity $L_{IR} = 10^{10} L_{\odot}$. Previous X-ray observations have revealed a bright central variable source, and extended soft X-ray emission associated with the superwind (Cappi et al 1999). The origin of the central source is very controversial, the most popular theories being (1) an X-ray luminous super-

https://doi.org/10.1017/S0074180900220998 Published online by Cambridge University Press

nova remnant, probably the X-ray counterpart to the luminous radio supernova remnant 41.95+57.5 (Stevens, Strickland & Wills 1999), (2) an AGN (Tsuru et al 1997) or (3) a massive binary (Ptak & Griffiths 1999). NGC 3256 is a classic merger induced starburst, with double nuclei and tidal tails. It is the most X-ray luminous starburst known, with $L_X > 10^{42}\, ergs\, s^{-1}$. A good fraction of the the X-ray emission arises from a superwind, but the X-ray spectrum has a hard tail which has been interpreted as evidence for IC emission (Moran et al 1999).

M82 was observed with the *Chandra* X-ray Observatory (CXO) High Resolution Camera in October 1999 (exposure 36ks) and then again in January 2000 (exposure 18ks). It was observed with the Advanced CCD Imaging Spectrometer (ACIS) five times between September 1999 and January 2000. The exposure time for the first ACIS observation was 16ks, and subsequent observations were 5ks. NGC 3256 was observed for 25ks with ACIS-S in Janurary 2000.

2. Discrete Sources and the Origin of Hard Diffuse Emission

Chandra resolves the central region of M82 into several discrete sources, as shown in Figure 1. Figure 1 shows two HRC images taken 3 months apart. We find 32 sources, 12 of which are variable with timescales of a few months (Ward et al 2001). The brightest source is CXOU J095550.2+694047, marked with a cross in Figure 1. It is very highly variable, increasing in flux a factor of 7 between Oct 1999 and Jan 2000. In January it had a luminosity of $\sim 10^{41}\, ergs\, s^{-1}$, and dominated the X-ray flux from the entire galaxy. This source is almost certainly responsible for the variability seen in ASCA and ROSAT observations (Ptak & Griffiths 1999). With the excellent positional accuracy of *Chandra* we can confidently place CXOU J095550.2+694047 4 arcsec away from the radio supernova remnant 41.95+57.5. This, plus the variability, suggest the bright source is dominated by accretion as suggested by Ptak & Griffiths 1999, and argues against the hypernova theory (Kaaret et al 2001, Matsumoto et al 2001)

Fourteen sources in NGC 3256 have been detected with $L_X > 10^{39}\, ergs\, s^{-1}$, including both nuclei. Two of these have luminosities comparable to CXOU J095550.2+694047. These sources, plus many of the sources in M82 have luminosities greater than the canonical Eddington limit for a $1.6 M_{\odot}$ neutron star ($10^{38} ergs\, s^{-1}$), and are therefore excellent black hole candidates, with masses in the range 10-500$M_{\odot}$. CXOU J095550.2+694047 is the most clear-cut example of a "super Eddington source" because it's luminosity is so extreme and it's variability well determined from *Chandra* (Ward et al 2001), ASCA (Ptak & Griffiths 1999) and BepposSAX (Cappi et al 1999). If this source is radiating at the Edington Limit, the mass is $\sim 500 M_{\odot}$ (Kaaret et al 2001, Matsumoto et al 2001). The X-ray luminosity function of these two starbust galaxies is in stark contrast to that observed in the galaxy or M31 where very few super luminous sources are observed (see also results for the Antennae presented by Fabbiano in this volume.) It is intriguing to speculate that we are observing a new population of black hole accretion sources with masses mid-way between galactic black hole binaries and supermassive black holes in AGN.

The diffuse emission in both M82 and NGC 3256 is dominated by soft ($\sim$0.3-1.5keV) X-rays which correlates with the Hα emission. This soft emission is almost certainly associated with the superwind. Both galaxies have some ex-

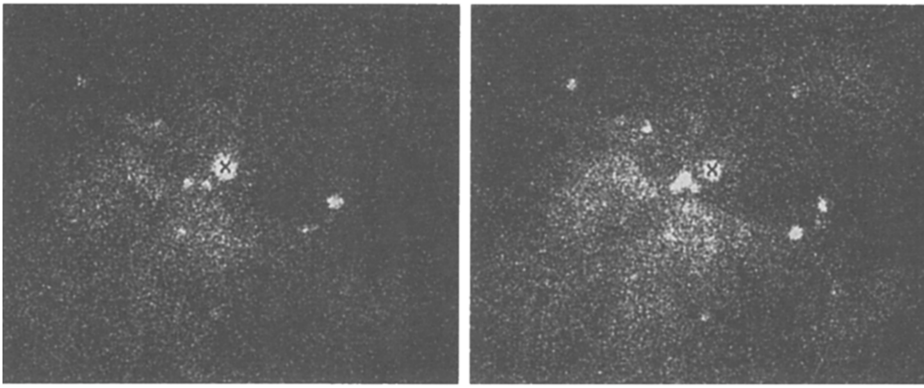

Figure 1. *Chandra* HRC observations of the central region of M82. The image on the left was obtained in January 2000, and the image on the right in October 1999

tended hard (~1.5-10keV) emission. In M82 the hard emission is more centrally concentrated than the soft emission, and correlates well with the diffuse radio, Pα and infrared emission (Figure 2). This is consistent with the hard diffuse emission originating in very hot, thermal gas in the starburst region. This interpretation is strengthened by the detection of Fe line emission (Cappi et al, Griffiths et al 2000). The hard X-ray emission in NGC 3256 is dominated by the luminous point sources described above (see also Figure 3). This does not support the suggestion made by Moran, Lehnert & Helfand that the hard X-ray emission in this galaxy is dominated by IC.

Acknowledgments. This work was supported by NASA contract NAS 5839073 (CXC)

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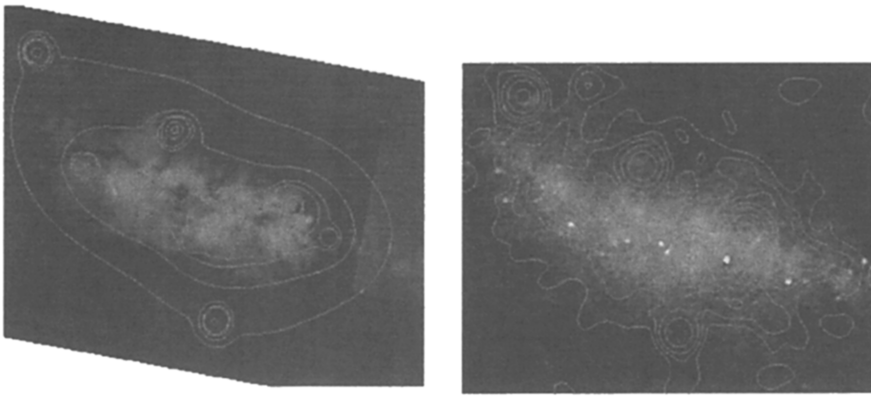

Figure 2. Contours of hard (2.5-5keV) X-ray emission superimposed on the (NICMOS) Hα emission (right) and hard X-ray emission superimposed on the diffuse radio emsission (left).

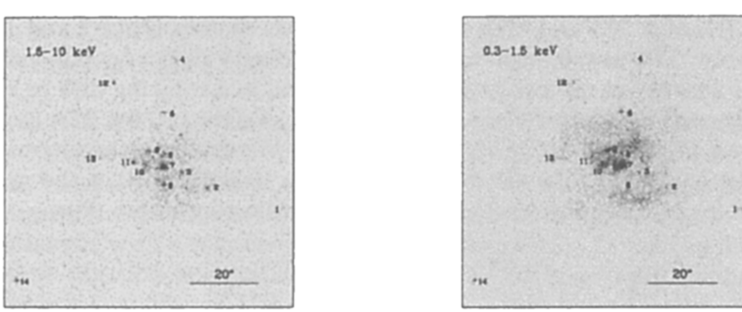

Figure 3. NGC 3256 imaged by *Chandra* in the hard (left,1.5-10keV) and soft (right, 1.5-10keV) bands. The extended emission is dominated by soft flux. Some extended hard emission is visible, but the hard flux is dominated by luminous point sources.

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