Chandra High-Resolution Camera Observations of the Luminous X-Ray Source in the Starburst Galaxy M82

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ABSTRACT

We have analyzed Chandra High Resolution Camera observations of the starburst galaxy M82, concentrating on the most luminous x-ray source. We find a position for the source of R.A. = 09\textdeg{}55\arcmin{}50\arcsec{}, decl. = +69\degree{}46\arcmin{}46\arcsec{} (J2000) with a 1\sigma radial error of 0.7\arcsec{}. The accurate x-ray position shows that the luminous source is not at the dynamical centre of M82 nor coincident with any suggested radio AGN candidate. The source is highly variable between observations, which suggests that the source is a compact object and not a supernova or remnant. There is no significant short term variability within the observations. Dynamical friction and the off-center position place an upper bound of \(10^{5} - 10^{6}\) M\textsubscript{\odot} on the mass of the object, depending on its age. The x-ray luminosity suggests a compact object mass of at least 500 M\textsubscript{\odot}. Thus, the luminous source in M82 may represent a new class of compact object with a mass intermediate between those of stellar mass black hole candidates and supermassive black holes.

Key words: black hole physics – galaxies: individual: M82 – galaxies: starburst – galaxies: stellar content – X-rays: galaxies

1 INTRODUCTION

One of the most enigmatic results to emerge from X-ray population studies of spiral and other luminous star forming galaxies is the discovery of unresolved X-ray sources which appear to have luminosities factors of 10 to 100's times the Eddington luminosity for a neutron star (e.g. Roberts & Warwick 2000; Zezas, Georgantopoulos, & Ward 1999; Wang, Jiang, & Pietsch 1999; Colbert & Mushotzky 1999; Fabbiano, Schweizer, & Mackie 1997; Marston et al. 1995; for a review of early results see Fabbiano 1989). The origin of such sources is controversial. Some are located near the dynamical centre of the host galaxy, and hence may be low luminosity AGN. However, many are well outside the central regions of the galaxies and require an alternative explanation. Some of these highly luminous x-ray sources may be very luminous supernova remnants exploding into a dense interstellar medium (Fabian & Terlevich 1996), or they may be accretion powered binary sources, in which case they are excellent black hole candidates with masses near or above 10 M\textsubscript{\odot} (Makishima et al. 2000). Deciding between these various alternatives has been complicated by the limited spatial resolution of pre-Chandra X-ray missions.

One of the most extreme and controversial examples of a highly luminous x-ray source in a nearby galaxy is the bright X-ray source that dominates the central region of the nearby starburst galaxy M82. Previous Einstein, ROSAT, and ASCA observations have shown that this source is variable and is close to the centre of M82 (Watson, Stanger, & Griffiths 1984; Collura et al. 1994; Ptak & Griffiths 1999). It has been interpreted as a low luminosity AGN (Tsursu et al. 1994), a highly x-ray luminous supernova (Stevens, Strickland, & Wills 1999), and an accreting black hole with a mass in excess of 460 M\textsubscript{\odot} (Ptak & Griffiths 1999). In this paper we discuss early Chandra observations of M82 made using the High Resolution Camera (HRC; Murray et al. 1997). The central x-ray ‘source’ in M82 is resolved into several sources in the HRC observations. We present an analysis of the brightest Chandra source. Our results suggest that this source may be a black hole with a mass intermediate between stellar-mass Galactic x-ray binaries and supermassive black holes. We describe the observations in § 2, our analysis in § 3, and conclude in § 4.

2 OBSERVATIONS

M82 was observed with the Chandra X-Ray Observatory (CXO; Weisskopf 1988) using the High Resolution Camera
Figure 1. The central region of M82 from the October 1999 observation. The contours were calculated using a counts map with 0.53″ pixels smoothed with a Gaussian with FWHM = 1.06″. The contours indicate 2.5, 5, 10, 40, and 160 counts per pixel in the smoothed map. The position of X41.4+60 is marked with an ‘X’. Crosses indicate positions of other sources.

(HRC; Murray et al. 1997) and the High-Resolution Mirror Assembly (HRMA; van Speybroeck et al. 1997) on 1999 Oct 28 04:24 UT to 14:48 UT for an exposure of 36 ks and on 2000 Jan 20 14:51 UT to 20:25 UT for an exposure of 18 ks. The HRC is a microchannel plate imager having very good spatial and time resolution, but essentially no energy resolution. Each photon detected by the HRC is time and position tagged, making possible timing studies of individual sources in crowded fields. The HRC contains a wiring error, discovered after launch (Murray et al. 2000), which induces a 3–4 ms error in the event time tags for this observation. As we restrict ourselves to frequencies below 1 Hz, this error has no effect on the analysis presented below. The HRC position tags have a precision of 0.132″, referred to as ‘one pixel’. This resolution oversamples the Chandra point spread function (PSF) which has a half-power diameter of 0.76″ (Jerius et al. 2000). We used a 15.6 pixel radius to extract source light curves.

We applied aspect to X-ray events from the HRC and filtered the data using event screening techniques (Murray et al. 2000) to eliminate ‘ghost’ events produced by the HRC electronics. An image for each observation was generated from the filtered event lists, see Fig. 1. We used the standard Chandra software routine wavdetect to search for and determine the position of point sources (CIAO V1.1 Software Tools Manual). We found several sources in each observation including both transients and persistent sources.

Here, we concentrate on the brightest source found. The other sources, including spectroscopy from observations with the Chandra Advanced CCD Imaging Spectrometer (ACIS; Bautz et al. 1998), will be described in a forthcoming paper (Ward et al. 2001).

3 RESULTS

The brightest source in both observations is at a location of R.A. = 09h 55m 50.2s, decl. = +69° 46′ 47.7″ (J2000). Following the convention of naming sources in M82 via their offset from R.A. = 09h 51m 00s, decl. = +69° 54′ 00″ (B1950), we refer to this source as X41.4+60 in the remainder of the paper. For wider use, we also denote the source as CXOU J095550.2+694047. The position uncertainty is dominated by the accuracy of the aspect reconstruction which we take to have a 1σ radial error of 0.7″ (Aldcroft et al. 2000).

The source lies 9″ from the kinematic centre of M82 (Welchew, Fomalont, & Greisen 1984), 12″ from the 2.2 μm peak (Rieke et al. 1980), 4″ from the very luminous supernova remnant 41.95+57.5 (Kronberg & Wilkinson 1977; Wills et al. 1997), and 13″ from the suggested AGN candidate 44.01+59.6 (Wills et al. 1997; Seaquist, Frayer, & Frail 1997; Wills et al. 1999). The radio source 41.31+59.6, which is likely a compact supernova remnant (Muxlow et al. 1997),
X41.4+60 is a highly variable x-ray source. In the first observation, the HRC count rate from the source is 0.07 c/s, 2 mJy except during 1981 (Kronberg et al. 2000). In the second observation, the HRC count rate from the source is 0.52 c/s – a factor of 7 brighter. In observation, the HRC rate of 0.03 c/s, so the true conversion factors may differ from these values if the source spectrum varies with flux. The flux in the second observation is comparable to the highest fluxes observed from the central source in M82 with ASCA (Ptak & Griffiths 1999). Taking a distance to M82 of 1.0–1.5×10^{40} erg s^{-1} in the 0.2–10 keV band for the first observation and 7–11×10^{40} erg s^{-1} for the second. Correcting for absorption would increase these luminosities; conversely, the true luminosity may be lower if the x-rays are beamed. These luminosities are near or above the highest values found for non-nuclear sources in a ROSAT sample of nearby galaxies (Roberts & Warwick 2000). For each observation, we extracted a light curve for X41.4+60, see Fig. 2. The source appears to have roughly constant flux in both observations. In particular, the light curve for the January 2000 observation shows no evidence of significant change in flux level over the observation, so it is unlikely that the high flux represents a flare of short duration. In both observations, the power spectra show no significant short term variability with the power comparable to the Poisson noise limit over the frequency range 0.0005-1 Hz.

We note that oscillations with a frequency near 600 s were reported in a preprint of this manuscript. In subsequent analysis, these oscillations were found to be due to instrumental effects related to the HRC response to bright sources and the algorithms used to screen ‘ghost’ events produced by the HRC electronics.

4 DISCUSSION

The luminosity of X41.4+60 in the January 2000 observation, given the assumptions concerning the spectral shape and isotropic emission noted above, corresponds to the Eddington luminosity for a 500–900M\odot object. The strong variability between observations argues against this luminosity being due to an aggregate of sources. The variability also suggests that the source is a compact object and not a supernova, although the possibility of a supernova expanding into a highly non-uniform medium cannot be excluded. Soft gamma repeaters (SGRs) produce sufficient flux; however, the longest, bright, so-called “giant”, outbursts from SGRs last only ~ 300 s over which they show substantial decay (Hurley et al. 1999). The fact that X41.4+60 shows no evidence of decay or variability over 15 ks, see Fig. 2, argues against it being a SGR. Origin of the high luminosity and variability in an accreting massive compact object appears plausible.

Dynamical friction will cause massive objects orbiting in the stellar field surrounding a galactic nucleus to spiral into the nucleus (Tremaine, Ostriker, & Spitzer 1975). The life time, t, before reaching the nucleus is related to mass of the object, M, its distance from the nucleus, and the stellar velocity dispersion. From the position given above for X41.4+60 and adopting a velocity dispersion for M82 of 100 km s^{-1} (Gaffney, Lester, & Telesco 1993), a rough upper bound can be placed on the mass of X41.4+60, M \lesssim 10^5 M\odot (t/10^{10} yr)^{-1}. If the object was formed during the
initial formation of M82 then $t \sim 10^{10}$ yr hence $M \lesssim 10^5 M_{\odot}$. Higher masses are allowed if shorter life times are assumed, e.g. $M \lesssim 10^6 M_{\odot}$ for $t \sim 10^8$ yr. This may be possible if the object was formed recently, in a process likely to be distinct from that for the formation of supermassive black holes in galactic nuclei, or if the object was ejected from the nucleus in an encounter with one or two equally or more massive black holes. If the object was formed recently and outside of the nucleus, it is likely to be less massive than the super massive black holes. If the object was formed recently and in a process likely to be distinct from the collapse of a super star cluster, it is possible that the object could arise from a supernova (Ptak 1997). The strong variability of the source argues against X41.4+60 being the x-ray position and the displacement of the source from the dynamical centre of M82 argue against X41.4+60 being the compact object mass of $\gtrsim 500 M_{\odot}$ places a lower bound on the compact object mass of $M > 10^3 M_{\odot}$ in the collapse of a super star cluster.