THE XMM-Newton VIEW OF THE GALACTIC CENTRE

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Abstract

In X-rays, the Galactic Centre (GC) Region appears as a complex of diffuse thermal and non-thermal X-ray emission intermixed with a population of luminous discrete sources. Here we present some new findings from the XMM-Newton GC survey, focusing particularly on Sgr A*, Sgr A East, the Radio Arc region, and a newly discovered X-ray non-thermal filament.

1 Introduction

Our Galactic Centre Region provides, arguably, the best available laboratory in which to study the central activity of galaxies. Recent measurements of the proper motion of infrared stars around the dynamical centre of the Galaxy coupled with the enhanced radio brightness of the region, strongly support the presence of a super massive black hole of mass \((2–3) \times 10^6 \, M_\odot\) (e.g., Genzel et al. 2000) in Sgr A*. A number of unusual phenomena are also observed in the Galactic Centre Region: e.g., magnetic radio filaments, high density, fast-moving molecular clouds, massive star clusters, and high-temperature plasma extending over scales in excess of a few hundred parsecs, etc.

A wide-angle XMM-Newton survey of the Galactic Centre Region was carried out in the period 2000–2001 utilising 11 pointings in total, each with 10–25 ksec exposures (see Warwick 2002). This XMM-Newton Galactic Centre survey along with a complementary Chandra survey (Wang et al. 2002) has revealed the complex X-ray structure of the region. Here we report some of the recent discoveries which have stemmed from the XMM Galactic Centre Survey, focusing particularly on Sgr A*, Sgr A East, the Radio Arc region, and an X-ray non-thermal filament designated XMM J174540–2904.5.

2 Global image

Fig. 1 shows a false colour X-ray image of the Galactic Centre Region taken with XMM-Newton in which Galactic north is up. Most of red dots are presumably foreground stars. Two persistent (1E 1740.7–2942 and 1E 1743.1–2843) and one transient (SAX J1747.0–2853) X-ray binaries are apparent as very bright sources in these observations. There is extended high surface brightness emission coincident with the Sgr A and Radio Arc (or G0.1–0.1) regions. The Arches star cluster and SNR G0.9+0.1 are also prominent in the hard energy band. In addition to these identifiable sources, low-surface brightness emission is evident over the whole region. The configuration is, however, highly asymmetric with the region to the Galactic west of Sgr A being brighter and having a more complex morphology than that to the east. We also point out
that there is an extended and clumpy structure extending from Sgr A towards the (Galactic) south-west direction on a scale of several tens of parsecs.

3 Sgr A*

With the moderate angular resolution of XMM-Newton, Sgr A* cannot be resolved. However, we have detected an X-ray flare from Sgr A*. Since the flare was detected in the last tens of minutes of an observation and was increasing in brightness right up to the end of the observation, the peak luminosity is unknown; the maximum luminosity observed was $4 \times 10^{34}$ erg s$^{-1}$. The flare nature is basically consistent with those detected by Chandra (Baganoff et al. 2001). Full details are given in Goldwurm et al. (2002).

4 Sgr A East

4.1 Images

The Sgr A region which is characterised by extremely bright radio structure, consists of Sgr A East and West. Sgr A East is an oval shell-like radio morphology, and in projection surrounds Sgr A West, which includes Sgr A*. From its shell-like structure, Sgr A East is supposed to be a supernova remnant (SNR), SNR 000.0+00.0, although alternative interpretations have also been proposed.

Fig. 2 shows the XMM-Newton MOS1+2 image of the Sgr A region. The X-ray emitting region is contained within the radio shell of Sgr A East, as is also readily apparent from the Chandra observation (Maeda et al. 2002). We also made a 6.7-keV line narrow-band image corresponding to helium-like iron, since the X-ray spectrum of Sgr A East apparently shows that line (see Sec.4.2). The underlying continuum is subtracted using an adjacent bandpass and assuming an averaged spectral shape (Fig. 2 right panel). The 6.7-keV line is found to be clearly more concentrated in the core of Sgr A East than the continuum. This implies that the core of Sgr A East is more abundant in iron or higher in temperature, or perhaps a combination of these factors (see Sec.4.2 for detail).

4.2 Spectra

We accumulated the source spectrum of Sgr A East from a region of radius $100''$ (see Fig. 2), but excluding both Sgr A West and the region around a bright soft point source. In the spectrum, several strong emission lines at energies corresponding to Kα lines from highly ionized ions, can be seen (Sakano et al. 2002b).

From the line ratios of Kα lines from helium(He)-like and hydrogen(H)-like atoms, we found that the spectrum requires a multi-temperature plasma. When we approximate the spectrum with a two-temperature thin thermal plasma model by fitting all the spectra (MOS1, 2, and pn) simultaneously, we obtained the best-fitting temperatures to be $\sim 1$ keV and $\sim 4$ keV. The best-fit abundances for silicon, sulfur, argon, calcium, and iron vary slightly from element to element, but are mostly in the range 1–2 solar units.

We further examined the possible spectral variation within Sgr A East using spatially resolved spectra, and found that only the iron abundance varies significantly from place to place: $\sim 0.5$ solar in the outer region ($r > 60''$) to $\sim 3.5$ solar in the central region ($r < 28''$). Thus, the iron line concentration in Fig. 2 is due to an abundance gradient.

4.3 Discussion

The concentration of the iron at the centre suggests that the plasma originated in ejecta. From the derived spectral parameters and spatial extent, we estimated the total energy and mass to be $1.5 \times 10^{49} \eta^{1/2}$ erg and $1.9 \eta^{1/2}$ M$_\odot$, respectively, assuming pressure equilibrium between the low- and high-temperature components, where $\eta$ is a filling factor of the total plasma. These
results, therefore, favour an origin for Sgr A East in a type-II SN event. The most intriguing problem is the extremely high temperature of 4 keV. The special environment in the Galactic Centre Region may be responsible for it. The detailed analysis and discussion are found in Sakano et al. (2002b).

5 The Radio Arc region

This region is unique due to the bright structure both in the radio and X-ray bands. The brightest X-ray emission is coincident with the position of the molecular cloud G 0.1−0.1. On the other hand, the radio brightest structure, the Radio Arc, is not particularly luminous in the X-ray band. Another unusual characteristic is the extremely high surface brightness of the 6.4-keV line, a fluorescent Kα line from neutral iron. Whereas the X-ray reflection nebula, Sgr B2, is dim in the continuum but bright only in the 6.4-keV line (Murakami et al. 2001), this region is bright both in the continuum and 6.4-keV line. The origin of this X-ray structure remains an open question.

6 An X-ray non-thermal filament XMM J174540−2904.5

A hard extended source, XMM J174540−2904.5, newly discovered with XMM, is marked in Fig. 2. This source has a corresponding radio non-thermal structure, the Sgr A-E ‘wisp’ (Ho et al. 1985) (= ILC 359.888−0.086 = G359.88−0.07). Both the X-ray and radio images show similar elongated structure, although the X-ray emission is more localised. We found that the X-ray emission from this source is clearly non-thermal with an energy index of $1.0^{+1.1}_{-0.9}$ and heavily absorbed ($N_H = 38^{+7}_{-11} \times 10^{22}$H cm$^{-2}$). So far, this is the first X-ray/radio filament in the Galactic Centre Region which has been shown, unequivocally, to have a non-thermal X-ray spectrum.

The spectral energy distribution shows that the X-ray spectrum is steeper than that observed in the radio band but is, most likely, smoothly connected to it. Thus, the emission is presumably due to synchrotron radiation. The lifetime of the high energy particles ($\sim$7 yr) emitting X-rays is roughly comparable with the spatial extent of the structure. Hence, the X-ray source is probably the site of particle acceleration. The position of the X-ray source coincides with the peak of the molecular cloud and it is quite possible that dense environment is one factor in determining this as an efficient acceleration site. This represents one of only a few X-ray/radio non-thermal filament known in the Galactic Centre Region. The details are discussed in Sakano et al. (2002a).

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Figure 1: *XMM-Newton* MOS1+2 colour image of the Galactic Centre Region along the Galactic Plane.

Figure 2: (Left) *XMM-Newton* MOS1+2 image of the Sgr A region in the 2–9 keV band. (Right) The 6.7-keV He-like iron line image after the continuum image is subtracted. The contour for the 2–9 keV continuum is overlaid. The dashed lines represent the galactic coordinates.