Molecular Clouds: X-ray mirrors of the Galactic nuclear activity

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Abstract. We present the result of a study of the X-ray emission from the Galactic Centre (GC) Molecular Clouds (MC), within 15 arcmin from Sgr A*. We use \textit{XMM-Newton} data spanning about 8 years. We observe an apparent super-luminal motion of a light front illuminating a MC. This might be due to a source outside the MC (such as Sgr A* or a bright and long outburst of a X-ray binary), while it can not be due to low energy cosmic rays or a source located inside the cloud. We also observe a decrease of the X-ray emission from G0.11-0.11, behaviour similar to the one of Sgr B2. The line intensities, clouds dimensions, columns densities and positions with respect to Sgr A*, are consistent with being produced by the same Sgr A* flare. The required high luminosity (about $1.5 \times 10^{39}$ erg s\textsuperscript{-1}) can hardly be produced by a binary system, while it is in agreement with a flare of Sgr A* fading about 100 years ago.

1. Introduction

In the central few hundreds parsecs of the Milky Way a high concentration of MC is present (Morris & Serabyn 1996; Bally et al. 1987; Tsuboi et al. 1999). Sunyaev et al. (1993; 1998) first realised that these clumps of material can behave like mirrors of past bright X-ray events occurring in the GC. Thus, several authors have studied the X-ray bright MC (Koyama et al. 1996; Murakami et al. 2001) to constrain the past activity of the GC and, in particular, of Sgr A*, the counterpart of the supermassive black hole at the GC (Schödel et al. 2002; Gillessen et al. 2009). On the other hand, cosmic ray irradiation can explain the high X-ray emission from these MC equally well (Valinia et al. 2000; Yusef-Zadeh et al. 2002; 2007; Dogiel et al. 2009; Bykov 2003). Here we study the MC emission during the 8 years \textit{XMM-Newton} monitoring of the 15 arcmin around Sgr A*.

2. Spectral analysis

We first define the MC selecting the brightest regions in the CS maps (Tsuboi et al. 1999). We then extract and simultaneously fit the EPIC-pn and MOS...
spectra. We observe that in each MC a narrow and neutral Fe Kα+β line, with equivalent widths of the order of 0.7-1 keV, is required. The MC power law emission is extremely flat with a spectral index between $\Gamma \sim 0.8 - 1$, moreover most of the MC require a neutral Fe K absorption edge ($\tau \sim 0.2 - 0.4$). These features are the signature of a reflection component from cold matter (Nandra & George 1994; Ponti et al. 2006; 2009; Bianchi et al. 2009a,b).

2.1. G0.11-0.11

The upper left panel of Figure 1 shows the Fe K line light curve of the MC, G0.11-0.11. The Fe K emission is clearly variable with a strong decrease of the order of 50 % within the 8 years of XMM-Newton monitoring. A similar decline is shown by the Sgr B2 MC (Inui et al. 2009; Terrier et al. 2009a,b). Assuming that G0.11-0.11 is located at its minimal distance from Sgr A* and that it is illuminated by it, we estimate a Sgr A* luminosity of $L \geq 10^{39}$ erg s$^{-1}$, occurring more than 75 years ago (Sunyaev & Churazov 1998; Amo-Baladrón et al. 2009). These values are surprisingly similar to the ones inferred from the study of Sgr B2 (Koyama et al. 1996). Moreover both light curves are in a decay phase, with similar variations (Inui et al. 2009; Terrier et al. 2010a,b). We thus assume that the flare luminosity illuminating Sgr B2 and G0.11-0.11 is exactly the same and thus we constrain the position of G0.11-0.11. It has to be about 17 pc behind the plane of Sgr A*. The upper right panel of Fig. 1 shows that in this location G0.11-0.11 is illuminated by the same light front hitting Sgr B2. Although, this does not rule out other possibilities for the Fe K emission, it is a strong constraint in favour of the single flare hypothesis.

3. Spatial variations

Fast and important variations occur also in the MC spatially located between G0.11-0.11 and feature 2 (see Muno et al. 2007) and called “the bridge” (Armstrong et al. 1985; Sakano et al. 2006; Ponti et al. 2010). The different parts of the bridge (from bridge 1 to 4, see Fig. 1) show similar Fe K intensity variations (with significance between 8-12 $\sigma$, each). Moreover the light curve evolutions are consistent with being the same, with only a time delay between them.

3.1. Discovery of superluminal echo in the bridge region

Fig. 1 shows the continuum subtracted, exposure corrected EPIC (pn+MOS) image of the bridge in the Fe K band (6.28-6.53 keV). The continuum is measured in the 4.5-6.28 keV band and subtracted after the extrapolation in the Fe K band assuming a power law spectral index emission of $\Gamma = 2$.

Significant Fe K intensity variations occur in the regions bridge 1, 2 and 3. In 2007 the bridge 1 lights up, becoming as intense as the region MC2. This variation evolves toward North East in 2008. While, in 2009, the bridge 3 region has the higher intensity. This behaviour suggests a connection/evolution of the rising up of the different regions, suggesting an origin tied to the propagation of an event in the bridge. Nevertheless, the emitting regions are causally disconnected. The variations, in fact happens in 2-4 years, while they are separated by at least 15 light years (being the bridge located at the GC).
Figure 1.  
Left panel: Fe K intensity light curve of G0.11-0.11. The reflection features in this MC are variable (at a significance level of about 3.8 $\sigma$) with a linear decay. Right panel: Sketch of the face–on view of the Galactic Plane as seen from the direction of the Galaxy pole. Sgr A* is indicated by a star. Galactic East is toward negative abscissa and the direction toward the Earth is bottom, at negative ordinate. A Sgr A* light front observed from the Earth appears as a parabola. Surprisingly the same parabola hits Sgr B2 and G0.11-0.11, in agreement with reflecting the same Sgr A* flare (about 100 years ago). Lower panel: Fe Ka continuum subtracted mosaic images of the bridge region. A brightening of the bridge 1, 2, 3 and 4 is clear. Such variation occurs in a time-scale of about 2-4 years, but in a region of about 15 light years. This apparent super-luminal motion can be explained if the bridge is illuminated by a bright ($L > 1.3 \times 10^{38}$ erg s$^{-1}$) and distant (>15 pc) X-ray source active for several years. The primary source seems to be in the direction of Sgr A*. 
This excludes an internal source, or low energy cosmic rays as possible candidates for the observed variation. The different regions have similar intensity variations, this implies that the source has to be more distant that several times the bridge length, otherwise a detectable modulation (due to the dependence of the intensity with the square of the distance) should be detected. Thus, if the source is more distant than 15 pc, it has to be brighter than \( L > 1.3 \times 10^{38} \text{ erg s}^{-1} \). This value is close to the Eddington luminosity for a stellar mass black hole. We also note that the illumination starts from the Galactic west of the bridge and propagates towards the Galactic east, diffusing in the northern part of the bridge. This strongly suggests that the illuminating source is located east of the bridge, slightly north of it. This is the direction toward Sgr A*.

Assuming that the bridge is reflecting a Sgr A* flare with the same luminosity illuminating Sgr B2, then the bridge has to be located about 60 pc behind Sgr A*. Thus, in this hypothesis, the period of activity of Sgr A* has to have lasted at least a few hundred years.

Acknowledgments. The work reported here is based on observations obtained with XMM-Newton, an ESA science mission with instruments and contributions directly funded by ESA Member States and NASA. GP thanks ANR for support (ANR-06-JCJC-0047). The authors thank the team of astronomers that helped in building such a long monitoring campaign of the GC region.

References

Armstrong, J. T., & Barrett, A. H. 1985, ApJS, 57, 535
Amo-Baladrón, Martín-Pintado, Morris, & Rodríguez-Fernández, 2009, ApJ, 694, 943
Bally, J., Stark, A. A., Wilson, R. W., & Henkel, C. 1987, ApJS, 65, 13
Bianchi, Guainazzi, Matt, Fonseca Bonilla, & Ponti, 2009a, A&A, 495, 421
Bianchi, S., Bonilla, N. F., Guainazzi, M., Matt, G., & Ponti, G. 2009b, A&A, 501, 915
Bykov, A. M. 2003, A&A, 410, L5
Dogiel, V., et al. 2009, PASJ, 61, 901
Gillessen, S., Eisenhauer, F., Trippe, S., Alexander, T., Genzel, R., Martins, F., & Ott, T. 2009, ApJ, 692, 1075
Inui, T., Koyama, K., Matsumoto, H., & Tsuru, T. G. 2009, PASJ, 61, 241
Koyama, Maeda, Sonobe, Takeshima, Tanaka, & Yamauchi, 1996, PASJ, 48, 249
Morris, M., & Serabyn, E. 1996, ARA&A, 34, 645
Muno, Baganoff, Brandt, Park, & Morris, 2007, ApJL, 656, L69
Murakami, H., Koyama, K., & Maeda, Y. 2001, ApJ, 558, 687
Nandra, K., & George, I. M. 1994, MNRAS, 267, 974
Ponti, G., Miniutti, G., Cappi, M., Maraschi, L., Fabian, A. C., & Iwasawa, K. 2006, MNRAS, 368, 903
Ponti, G., et al. 2009, MNRAS, 394, 1487
Ponti, G., Terrier, R., Goldwurm, A., Belanger, G., & Trap, G. 2010, arXiv:1003.2001
Reid, Menten, Zheng, Brunthaler & Xu, 2009, ApJ, 705, 1548
Ross, R. R., & Fabian, A. C. 2005, MNRAS, 358, 211
Sakano, Warwick, & Decourchelle 2006, Journal of Physics Conference Series, 54, 133
Schödel, R., et al. 2002, Nature, 419, 694
Sunyaev, R. A., Markovitch, M., & Pavlinsky, M. 1993, ApJ, 407, 606
Sunyaev, R., & Churazov, E. 1998, MNRAS, 297, 1279
Tsuboi, M., Handa, T., & Ukita, N. 1999, ApJS, 120, 1
Valinia, A., Tatischeff, V., Arnaud, K., Ebisawa, K., & Ramaty, R. 2000, ApJ, 543, 733
Yusef-Zadeh, F., Law, C., & Wardle, M. 2002, ApJL, 568, L121
Yusef-Zadeh, F., Muno, M., Wardle, M., & Lis, D. C. 2007, ApJ, 656, 847