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EPIC detection of SgrA* flares

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Abstract. X-ray observations are one of the most promising means to elucidate the accretion and radiation mechanism of Sgr A*, the radiative counterpart of the Galactic Nucleus (GN). Due to high absorption and source confusion, the GN could not be convincingly detected for a long time other than in radio. The *Chandra* observatory detected Sgr A* in quiescence in 1999 and then in flaring state in October 2000. The EPIC camera onboard the *XMM-Newton* satellite, with its much better sensitivity, is particularly suited to detect the flare emission. *XMM-Newton* observed the GN for ~ 75 ksec between 2000 and 2002. We report here on EPIC detection of 2 flares from the GN, we then discuss briefly the constraints set on the emission models and future prospects.

Key words. Galactic Nucleus - X-rays

1. Introduction

Since its discovery, the radio source SgrA* has been considered the counterpart of the supermassive Black Hole (SMBH) at the center of our Galaxy. (see Melia & Falcke (2001) for a review). Despite extensive study however, no firm detection at other wavelengths was obtained for around 25 years. By itself this result indicates that Sgr A* is a faint source with respect to the SMBHs in AGNs. This result is puzzling because the environment of Sgr A* is very complex and rich in diffuse matter which should be accreted by the SMBH. The suggested accretion rate would imply a luminosity much greater than the observed one.

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This lack of detection is however also due to the very strong absorption and source confusion present in the Galactic Nucleus direction. In the last few years very exciting results have been obtained in NIR and in soft X-rays. NIR observations of the orbital motion of nearby stars have determined the mass of the SMBH to be $3.7 \pm 1.5 \times 10^6$ $M_\odot$ (Schödel et al. 2002). Moreover very recently flares in L, H and K bands have been observed with the emission growing by a factor 3-5 in ~ 5 minutes (Genzel et al. 2003) and a total duration of ~ 30 minutes. In hard X-rays, the first detection of hard X-ray emission at a position consistent with SgrA* (Belanger et al. 2003) with the IBIS/ISGRI telscope onboard the INTEGRAL observatory has been reported.

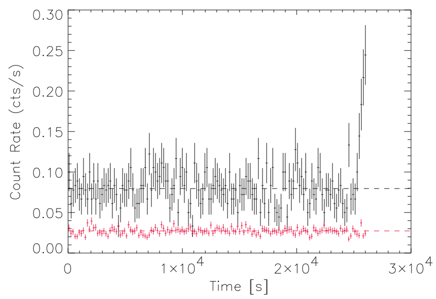

Fig. 1. September 2001 Flare: The 2 – 10 keV count rate collected with both MOS cameras from the region within 10″ from Sgr A* (black upper curve) compared to the one from different region of the CCD (red lower curve).

In soft X-rays, the *Chandra* Observatory first detected SgrA* in X-rays in 1999 and measured a quiescent luminosity of only $L_X[2-10\,\mathrm{keV}] \approx 2\times10^{33}$ erg s^{-1}. It then detected in October 2000 a bright 3 h flare, characterized by rapid variability (Baganoff et al. 2001). The luminosity increased to

$L_X[2-10\,\mathrm{keV}] \approx 10^{35}$ erg s^{-1} in 4000 s, the power law spectrum hardened, with a change of the photon index from 2.7 (quiescent phase) to an index of 1.3, and a rapid decrease on a timescale of 600 s was observed, implying an emitting region size < 20 Schwarzschild radii (R_S). We report the detection of two other X-ray flares from Sgr A* observed with *XMM-Newton* on September 4 2001 and on October 3 2002 (Golwurn et al. 2003; Porquet et al. 2003).

2. Observations and Results

XMM-Newton observed SgrA* during a Guaranteed Time Program aimed at measuring the diffuse emission in a region around the Galactic Center. During this program around 75 ksec of observations were performed on SgrA*. The observations were performed in three sections of ~ 25 ksec each in September 2001, February 2002 and October 2002. The above mentioned flares were detected in the first and third observation.

2.1. September 2001 Flare

XMM-Newton was pointed towards the galactic nucleus for about 26 ks. The EPIC MOS and PN cameras were used in standard *Full Frame* imaging mode with the medium filter. The recorded image of this complex region is dominated by the diffuse emission of the Sgr A East region. Point sources can also be distinguished and an excess around is Sgr A* clearly present.

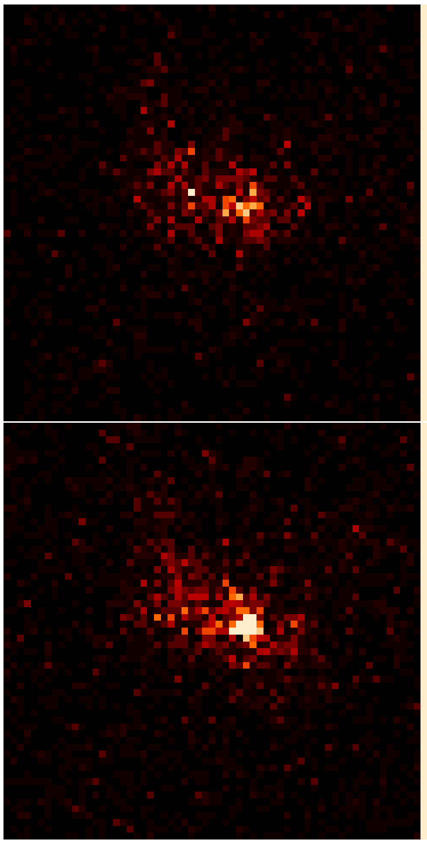

Fig. 2. September 2001 Flare: 2 – 10 keV images of the 5′ × 5′ region around the galactic nucleus obtained from MOS events integrated in the 1000 s before the flare (top) and in the 1000 s including the flare (bottom). Pixels were rebinned to a size of 5.5″ × 5.5″. Sgr A* position is right in the middle of the central bright pixel visible in the bottom image.

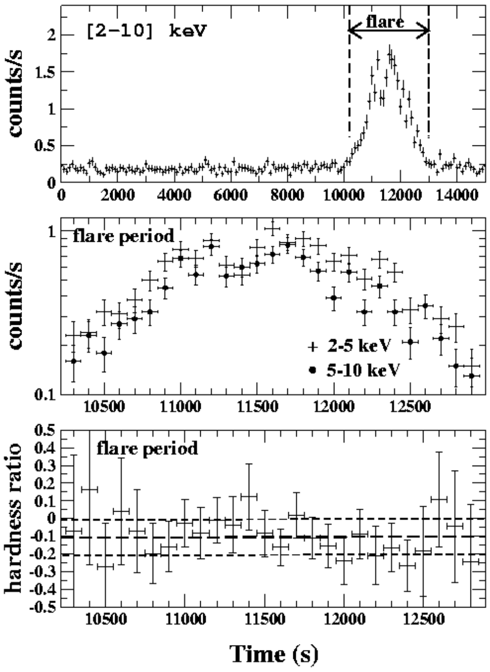

Fig. 3. October 2002 Flare: EPIC light curves (MOS 1+MOS 2+PN) and hardness ratio (HR) within a radius of 10″ around Sgr A* position. The time binning is 100 s, and the error bars indicate 1σ uncertainties. Upper panel: The 2-10 keV light curve shows the quiescent and the flare periods. Middle panel: The 2-5 keV and 5-10 keV light curves during the flare period. Lower panel: quiescent subtracted HR during the flare period. Long dashed line: mean HR value, short dashed lines: 1σ error bars.

This work focus on the search for variability of a central point source at the Sgr A* position. To optimize the signal to noise ratio and considering the 15″ half power diameter of the *XMM-Newton* point spread function, we extracted and analyzed counts from the 10″ radius region centered on Sgr A*. The observed count rate is stable around 0.08 cts s^{-1} till the last 900 s (fig. 1). Then it gradually increases to reach 0.24 cts s^{-1}, $\approx 7\sigma$ over the average value before the flare. This increase is not detected in the count rate extracted from a region far from the source. Images integrated during the 1000 s before the flare and during the last 1000 s including the flare, clearly show the brightening of a central source (fig. 2). An analysis of the flaring source location shows that it is compatible with Sgr A* within 1.5″ (i.e. within the residual systematic uncertainties). The nearest X-ray point source identified by *Chandra* and associated with the IR and radio object IRS 13, is at an angular distance of 4″. We conclude therefore that this flare is associated with Sgr A*.
The spectra extracted from the same region as for the lightcurves before and during the flare were analyzed using a composite spectral model and fitted parameters determined with the *Chandra* data (thermal and point sources components fixed, free power law for Sgr A*). The best fit gives a slope of $\alpha = 0.9 \pm 0.5$ for Sgr A* power law during the flare. Another spectral fit was made using the data before the flare as background component for the data during the flare, and we obtained $\alpha = 0.7 \pm 0.6$ similar to the first fit. In spite of the large uncertainties the flare spectrum appears harder than the one measured with *Chandra* during the quiescent period. The flare luminosity we obtained (averaged over 900 s at 8 kpc) is $L_X[2-10\ \mathrm{keV}] = (3.8 \pm 0.7) \times 10^{34}$ erg s^{-1}.
We conclude that in September 2001 the EPIC camera detected a flare from Sgr A* similar to the one detected by *Chandra*. Moreover, despite the flare's short duration and small luminosity, we were able to put rough constraints on the emission. This detection of a relativley weak and short Sgr A* flare demonstrates that EPIC indeed is able to provide significant results on this fascinating object.

2.2. October 2002 Flare

On October 3, 2002, Porquet et al. (2003) observed with *XMM-Newton* the brightest X-ray flare detected so far from Sgr A*. The EPIC light curve in the 2-10 keV energy range shows for the first 10 ks a quiescent period and then a very sharp and intense flare with a duration shorter than one hour (2.7 ks, see Fig 3 top panel). The flare shape is almost symmetric relative to the peak. Both the rise and decay phases can be fitted by an exponential with characteristic times of 610 s and 770 s, respec-

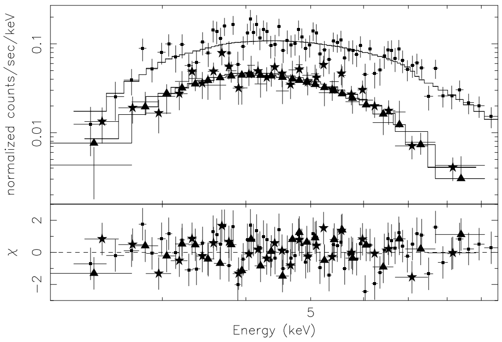

Fig. 4. October 2002 Flare: EPIC spectra of the flare, within a radius of 10 around Sgr A* position. The spectrum for the quiescent period is used as background. A power-law model has been fitted taking into account ISM absorption and dust scattering.

tively. We also observe a "micro-structure" at about 11 200 s with a significance of at least 3σ on a time-scale as short as 200 s, which can further constrain the emitting region to a size of about 7 Schwarzschild radii for a Black Hole mass of $\sim 3{\times}10^6$ solar mass. No significant difference between the soft and hard X-ray range is detected. The overall flare spectrum is displayed on Figure 4 and is very well represented by an absorbed power-law with a soft photon spectral index of $\Gamma = 2.5 \pm 0.3$ with a very large column density of about $2\times 10^{23}\,\mathrm{cm}^{-2}$. No significant spectral change during the flare is observed. The 2-10 keV luminosity at the peak flare is very high ($3.6^{+0.3}_{-0.4}\,10^{35}\,\mathrm{erg\,s}^{-1}$), i.e. about a factor 160 higher than the Sgr A* quiescent value ($2.2\times 10^{33}\,\mathrm{erg\,s}^{-1}$, Baganoff et al. (2001). This X-ray flare is very different from other bright flares reported so far: it is much brighter and softer. The present accurate determination of the flare characteristics challenge the current interpretation of the physical processes occuring inside the very close environment of Sgr A* by bringing very strong constraints for the theoretical flare models.

3. Conclusions

Several models have been put forth to explain the complex and variable Sgr A* emission, we briefly describe the characteristics of two main classes. One assumes the presence of a non-thermal population of particles (either in a jet or in the flow) while the accretion flow is regulated by an ADAF disk where convection or outflows reduce the effective accretion rate (Markoff et al. 2001). In the other class, a Bondi-Hoyle spherical accretion flow with sub-equipartition magnetic field is associated to a compact hot Keplerian flow inside the circularization region (at $< 10\,R_\mathrm{S}$) (Liu & Melia 2002). This model predicts a thermal synchrotron emission in the sub-mm band by the hot electrons in the disk and a Synchrotron Self Compton (SSC) emission dominating the X-ray band. Both models may explain the X-ray flares, soft and hard, detected with EPIC however they predict different emission at other wavelengths. Simultaneous hard/soft X-rays and radio/sub-mm/IR observations of flares are therefore fundamental to further constrain the accretion and emission models of SgrA*.

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