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Flare emission from Sagittarius A*

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Abstract. We report a successful, simultaneous observation and modelling of the mm to NIR flare emission of Sgr A*, based on a global coordinated multiwavelength campaigns in May 2007. A multi-component relativistic spot/disk model and an adiabatic expansion model in combination with a Synchrotron Self-Compton (SSC) formalism is used to explain this flaring activity, where a mix of synchrotron and SSC components orbiting around the SMBH in a temporary accretion disk give rise to the NIR/X-ray light curves, and an adiabatic expansion of these source components later give rise to the flares in the radio/sub-mm with a time delay.

Key words. black hole physics – infrared general – accretion – accretion disks – radio Galaxy: centre, nucleus – Black Holes, individual: SgrA*

1. Introduction

The centre of our galaxy, the Milky Way, harbours a supermassive black hole (SMBH) of mass $\sim 4\times 10^6$ $M_\odot$associated with the radio and NIR source Sagittarius A* (Sgr A*) (Eckart & Genzel 1996; Schödel et al. 2002; Ghez et al. 2009). The SMBH radiates a factor 10^{-7} to 10^{-9} below its Eddington luminosity at all wavelengths, which has been explained partly due to its low observed accretion rate. This is the closest galactic nucleus to us, at a distance of 8 kpc (Reid 1993; Eisenhauer et al. 2003; Ghez et al. 2008), and is an ideal source to study the physics at the centres of galaxies at high angular resolutions.

Simultaneous multiwavelength observations provide information about emission mechanisms responsible for radiation from the immediate vicinity of the central black hole and the physics underlying it. Variability at time scales ranging from a few minutes to a few days has been observed in Sgr A* at most wavelengths, ranging from the NIR/X-ray (Baganoff et al. 2001; Porquet et al. 2003; Eckart et al. 2006) to the radio/sub-mm (Lo & Claussen 1983; Zhao et al. 1992; Tsuboi et al. 1999; Wright & Backer 1993; Tsustumi et al. 1998). Eckart et al. (2004) reported the first simultaneous flare in the near-infrared (NIR) and X-ray wavelengths, indicating that the same population of electrons were responsible for the emission at both wavelengths. The short timescales of the flares indicate that the emission arises from compact source components. There has also been evidence of delayed flaring activity in the sub-mm/radio regime following

Send offprint requests to: D. Kunneriath the flares in the NIR/X-ray (Eckart et al. 2006, 2008; Yusef-zadeh et al. 2006b; Marrone et al. 2008; Yusef-Zadeh et al. 2009). Modelling the variability seen in Sgr A* across different wavelengths gives us insight about the fundamental parameters of the SMBH, and emission mechanisms of the accretion disk, for which simultaneous observations are a requirement (Eckart et al. 2004, Eckart et al. 2006).

Large multi-frequency campaigns were performed using telescopes such as the CARMA[1](Bock et al. 2006) at 100 GHz, ATCA[2] at 86 GHz, the 1.2 mm MAMBO bolometer at the IRAM[3] 30 m telescope, and the ESO VLT in the NIR in 2007 and 2008, which successfully detected simultaneous flaring activity in Sgr A* across these frequencies, the results of which were published in Eckart et al. (2008, 2009); Kunneriath et al. (2010).

The main results of the 2007 campaign are:

- a combined long light curve of the compact source Sgr A* from the 15-19th May in the mm-regime obtained from CARMA, ATCA and the IRAM 30-m telescope using a new method to combine light curves by omitting flux density contributions from the extended emission in the galactic centre region, and
- the detection of two bright NIR flares on May 15 and 17, a mm flare following the NIR flare on May 17, and a possible third weaker flare in the NIR and combined mm data on May 19.

1.1. Modelling and discussion

The NIR/X-ray flares have been explained with a multi-component spot/disk model involving synchrotron and synchrotron self-Compton (SSC) components revolving around a temporary accretion disk very near to the SMBH. This allows for NIR flux density contributions from both synchrotron and SSC components (Eckart et al. 2006; Meyer et al. 2006a, 2007; Zamaninasab et al. 2008a, 2010). This model uses the formalism described in Gould (1979) and Marscher (1983) combined with the KY-code (Dovčiak et al. 2004), which produces the light amplification curves taking into account relativisitic effects such as lensing, time delays, polarization angle, etc., to estimate flux densities in the NIR and X-ray domain, along with magnetic fields. This model is explained in greater detail in Eckart et al. (2009).

Almost all reported flare detections from multiwavelength campaigns of the galactic centre so far have observed radio/sub-mm flares delayed by an hour or so compared to the NIR/X-ray events (Eckart et al. 2006, 2008; Yusef-Zadeh et al. 2009, 2006a; Yusef-zadeh et al. 2006b; Yusef-Zadeh et al. 2008; Marrone et al. 2008). If the events in the NIR/X-ray and radio/sub-mm were unrelated, we would expect to see an equal number of flares in the radio/sub-mm before the NIR/X-ray events as we would after the NIR/X-ray events. Hence we can safely assume that the radio/sub-mm events are in fact related to the higher frequency events. An adiabatic expansion of the synchrotron components used in the SSC model has been used to explain the flaring activity of Sgr A* in the radio/sub-mm regime occuring with a time lag of $\sim$1.5$\pm$0.5 hours (Eckart et al. 2006, 2008; Yusef-Zadeh et al. 2006a).

A quantitative description of a model involving synchrotron source components that are initially optically thick and expand with time to become optically thin at longer wavelengths was first presented in van der Laan (1966). Using this formalism we describe the

[1] Support for CARMA construction was derived from the states of California, Illinois, and Maryland, the Gordon and Betty Moore Foundation, the Kenneth T. and Eileen L. Norris Foundation, the Associates of the California Institute of Technology, and the National Science Foundation. Ongoing CARMA development and operations are supported by the National Science Foundation under a cooperative agreement, and by the CARMA partner universities.

[2] ATCA is operated by the Australia Telescope National Facility, a division of CSIRO, which also includes the ATNF Headquarters at Marsfield in Sydney, the Parkes Observatory and the Mopra Observatory near Coonabarabran.

[3] The IRAM 30 m millimeter telescope is operated by the Institute for Radioastronomy at millimeter wavelengths - Granada, Spain, and Grenoble, France.

adiabatic source components and develop a time-dependent model to study their behaviour at different frequencies. The SSC fluxes provide an important constraint to our adiabatic expansion modelling.

We derived expansion velocities $v_{\rm exp} \sim 0.005c$ - $0.017c$, compact source sizes of ~1 Schwarzschild radius, flux densities of source components of a few Jy, and a spectral index ranging from α=0.6 to 1.3 from the NIR to the mm-regime, with the mm flaring activity occuring ~1.5±0.5 hours after the NIR flares. The turnover frequencies are of the order of a few THz. The low expansion velocities of the source components may indicate expansion confined to a disk, where differential rotaion causes the expansion, or a bulk motion of components greater than the expansion velocity.

2. Alternative jet model

An alternative explanation of the Sgr A* spectrum could be emission from an extremely compact, weak jet and an underlying accretion process (Markoff et al. 2005, 2007). In this case, the flux density variations arise from jet instabilities or accretion processes followed by an adiabatic expansion within the jet.

Future mm-VLBI observations at high frequencies (≥230 GHz) and VLTI observations in the NIR should enable a deeper understanding of the central region of Sgr A*.

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