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NEAR-INFRARED OBSERVATIONS OF SAGITTARIUS A*

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RESUMEN

Se presentan y discuten observaciones recientes de Sagittarius A*, el agujero negro supermasivo en el centro de nuestra Galaxia. Desde 2003 esta fuente ha sido observada fotométricamente, polarimétricamente y espectroscópicamente en las bandas H, K y L (1.5–4.1μm). La emisión se manifiesta como brotes que ocurren unas cuantas veces por día con duración típicamente de 1–3 horas. Estos “destellos” muestran sub-estructuras cuasi periódicas en escalas de $\sim$15 minutos. Están significativamente polarizados y muestran un índice de color espectral variable. En conjunto, las observaciones apuntan a que la fuente de emisión de la radiación sincrotrónica en el cercano-IR es producida por zonas calientes de plasma en descomposición orbitando al agujero negro en órbitas relativistas.

ABSTRACT

We present and discuss recent near infrared observations of Sagittarius A*, the supermassive black hole in the centre of our Galaxy. Since 2003 this source has been observed photometrically, polarimetrically, and spectroscopically in H, K and L bands (1.5–4.1μm). The emission shows up in form of outbursts occuring few times per day and lasting typically 1–3 hours. These “flares” show quasi-periodic sub-structures at timescales of $\sim$15 minutes. They are significantly polarised and show a variable spectral colour index. All in all, the observations point towards decaying plasma hotspots orbiting the black hole on relativistic orbits as a source of NIR synchrotron emission.

Key Words: black hole physics — accretion, accretion discs — Galaxy: centre

1. INTRODUCTION

The centre of our Milky Way hosts the 3.6-million-$M_\odot$ supermassive black hole (Schödel et al. 2002) and radio source Sagittarius A* (SgrA*). Discovered in radio in 1974 by Balick & Brown (1974) it has since then been observed extensively in a variety of wavelength bands ranging from X-ray to radio. This black hole is generally invisible in NIR wavelengths and was not detected in this spectral range before 2002 when diffraction-limited observations at optical 8 m class telescopes became possible (Genzel et al. 2003; Ghez et al. 2004; see Figure 1 for an example). In the last years we have continued and extended our near-infrared (NIR) observations in order to understand the underlying physical emission mechanism; the main results of these efforts are presented here.

2. TRACING THE EMISSION: OBSERVATIONS

Since 2002 we have regularly carried out observations on the 8.2 m Unit Telescope (UT) 4 (Yepun) of the ESO Very Large Telescope (VLT) on Cerro Paranal, Chile. *Photometric* observations were obtained using the 1024×1024-pixel NIR camera system NAOS/CONICA (Rousset et al. 2003; Lenzen et al. 2003; NACO for short). The diffraction-limited (resolutions of 40–60 mas) NACO images were obtained in H and K bands. *Polarimetric* observations were carried out using NACO with a Wollaston prism separating the infalling light into ordinary and extraordinary beams of perpendicular polarisations. Please note, that throughout this article only linear polarisation is discussed. *Spectroscopic* data were collected using SINFONI, an adaptive optics assisted integral field spectrometer (Eisenhauer et al. 2003; Bonnet et al. 2003), in K band. SINFONI produced diffraction-limited data cubes with 64×32 pixels in the two spatial axes and 2048 pixels in the spectral axis.

All in all, these observations uncovered four main characteristics of the NIR emission from SgrA*, out of which three are illustrated in Figure 2 using the example of an observation obtained in May 2006.

(1) SgrA* emission is *flaring*. In NIR wavelengths it is regularly detected in form of outbursts. These flares correspond to an increase of flux by factors up to $\sim$10 from the background level within some ten

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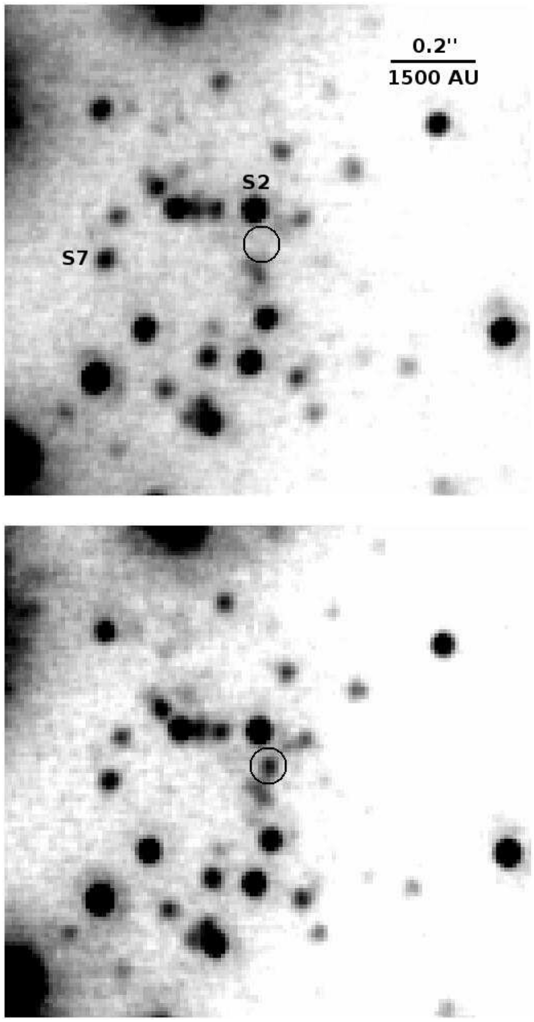

Fig. 1. A flare from SgrA* observed in April 2004 in H band. The position of SgrA* is encircled; additionally, two photometric comparison stars (S2 and S7) labeled. The time difference between these two images is 44 minutes.

minutes. The typical length of a flare is in the range of 1–3 hours. The flare event rate (i.e. the number of flares per time) is in the order of few (about 3) events per day. In four cases NIR and X-ray flares were observed to be simulaneous within the available time resolutions (few minutes; Eckart et al. 2006). Empirically (and within the limits of low-number statistics), these outbursts show a general trend: flares are the more seldom, the more luminous they are.

(2) SgrA* flares show a quasi-periodic *sub-structure* on time scales of minutes. Quasi-periodic signals in NIR flares have now been found in the range of 13–30 minutes. The respective flare lightcurves show characteristic structures: an over-

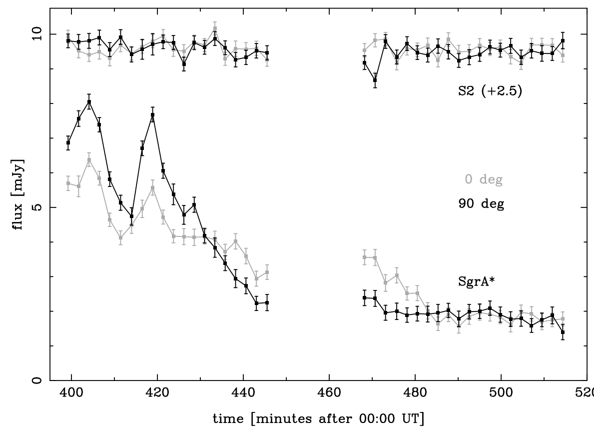

Fig. 2. Emission from SgrA* as observed on May 31st, 2006. Shown here are the lightcurves of SgrA* and a omparison stars (S2) separately for two polarisation angles. The values for S2 are shifted along the flux axis. This data set nicely summarises three main characteristics of the SgrA* NIR activity: (1) The emission occurs in form of an outburst lasting for at least 80 min and then vanishes again; (2) there is a short-time modulation of the flux on a time scale of ∼15 min; and (3) the flare intensity depends on the polarisation angle, i.e. the emission is polarised.

all profile (rise, maximum, decay) lasting about 1–2 hours is repeatedly modulated in cycles of 13–30 minutes. This sub-structure is generally quite weak – indeed the "double peak" of the flare shown in Figure 2 is the strongest case (in terms of amplitude) seen so far – and detected only in a minority of all observed flares.

(3) SgrA* emission is *polarised*. For three NIR flares so far observed polarimetrically we found polarisation degrees of 15–20% and angles of $\sim 80°$ on sky at times of maximum fluxes. Concerning the observed polarisation angle, it is important to note that this angle was found repeatedly in three measurements covering a time span of two years. This strongly suggests that the geometry of the emission region is stable in time (Meyer et al. 2006a; Trippe et al. 2007).

(4) SgrA* flares show a *featureless spectrum* with colour indices $\alpha = -3... + 2$ (defined via $\nu L_\nu \propto \nu^\alpha$). The flare colour varies with the source flux: the stronger the flare, the bluer the colour (Gillessen et al. 2006).

3. UNDERSTANDING THE PHYSICS: INTERPRETATION

Using the observations described above as well as information gathered during the last years from radio and X-ray observations, we see strong indication that the flare emission in SgrA* is synchrotron radiation from material orbiting the black hole (Meyer et al. 2006b; Trippe et al. 2007). In this picture, a hot ($\sim 10^{12}$ K), relatively small ($R < 0.3 R_{\rm S}$) plasma bubble arises from the accretion disk few times per day. This can occur due to violent stochastic processes like magnetic reconnection or infall of matter. The plasma bubble orbits SgrA* on or close to the innermost stable circular orbit, cools, and gets sheared along its orbit due to tidal disruption. After few revolutions (each lasting ∼15–25 min) the plasma has cooled down and the flare vanishes. Recent numerical simulations based on this scenario are able to reproduce the observations well (Hamaus et al. 2008, ApJ, submitted).

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