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Observations of NIR polarized light from Sagittarius A*

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Abstract. We present a brief overview of results obtained from near-infrared polarized observations of Sgr A*, which is associated with the supermassive black hole at the center of the Milky Way. The observations have been carried out using the NACO adaptive optics instrument at the VLT UT4 in the infrared K_s-band from 2004 to 2012. Several polarized flares have been observed in this time interval which allow us to determine the statistical properties of NIR linearly polarized light from Sgr A*. Linear polarization at 2.2 μm and its variations can help us to constrain the physical conditions of the accretion process around this supermassive black hole.

Keywords. black hole physics — Galaxies: nuclei, Infrared — Methods: statistical — physical data and processes: polarization

1. Introduction

Sagittarius A* (Sgr A*) is a compact radio source associated with a 4 million solar mass black hole located at the Galactic center (Eckart & Genzel 1996,1997). Sgr A* shows variability in the radio, near-infrared (NIR) and X-ray regimes. Since 2004 it has been observed in polarimetry mode using a Wollaston prism in the NACO instrument at the VLT (Eckart *et al.* 2006a; Eckart *et al.* 2008a; Zamaninasab *et al.* 2010). Several authors have investigated the statistical properties of Sgr A* flare activity. Zamaninasab *et al.* (2010) showed that there is a correlation between the variations of the total flux, the polarization degree and the polarization angle. Based on multi-wavelength observations in 2009, Eckart *et al.* (2012) modeled the flaring activity of Sgr A* as a signal from synchrotron (for the NIR emission) - synchrotron-self-Compton component (for the X-ray flux densities) using the NIR/X-ray flux density excursions as observables and obtaining the observed spectrum of variable mm/sub-mm flux density. The latest statistical analysis of the NIR K_s-band flux density distribution of Sgr A* was carried out by Witzel *et al.* (2012). They cover observations from 2003 to early 2010 and show that the variability of Sgr A* is fitted well by a single state, pure power-law distribution. They also show that a two state emission process (one of them active at the detection limit for Sgr A*) is not necessary (Dodds-Edden *et al.* 2011).

Here we report on the analysis of 13 NIR K_s-band light curves of Sgr A* taken with the VLT in polarimetry mode. The purpose of this investigation is to constrain the polarimetric properties of this source by analyzing its polarized flux density distribution. Moreover, polarimetric observations can help us to investigate the changes in the

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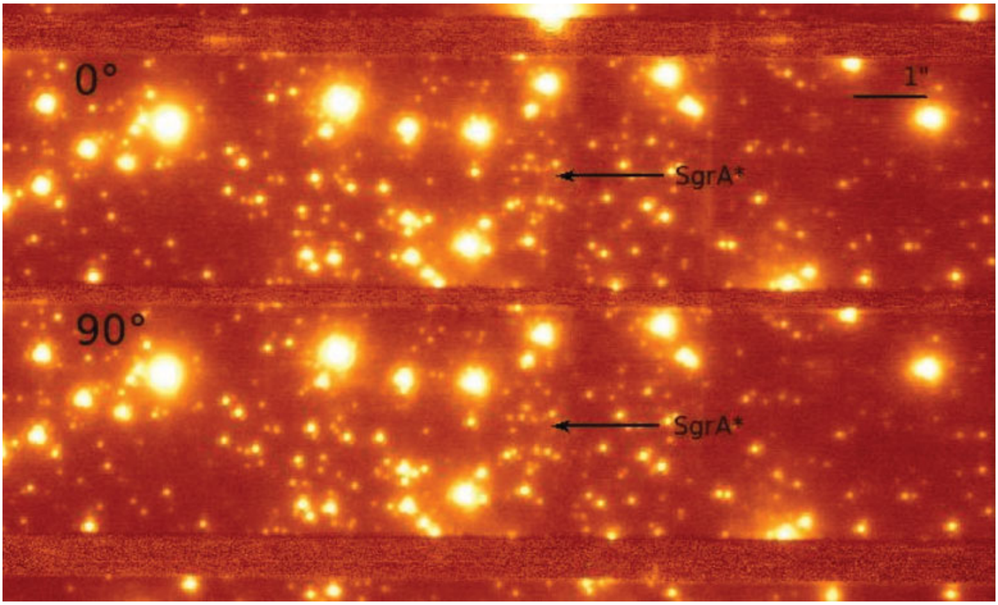

Figure 1. The arrangement of the Wollaston prism images on the NACO detector. The two central strips show the images in orthogonally polarized light.
[A color version is available online.]

polarization degree and the polarization angle during the flare activity besides studying the total flux density light curves.

2. Observations and data reduction

All the observations provided here have been carried out with the NACOS/CONICA (NACO) instrument at ESO VLT UT4 on Paranal, Chile. The Adaptive Optics (AO) loop was locked on the NIR bright supergiant IRS7, located 5.6″ north of Sgr A*. We gathered the K_s-band NIR polarimetry data from 2004 to 2012. The combination of the Wollaston prism with a half-wave retarder plate in NACO enables us to measure orthogonal directions of the electric field vectors (see Figure 1). We describe here briefly the data reduction steps that we applied for the 2011 May 27 and 2012 May 17 data. For the data between 2004 to 2009, we have used a data reduction process similar to Witzel *et al.* (2012). After the first data reduction steps (sky subtraction, flat fielding, pixel cosmetics), we extracted point spread functions (PSFs) using sources close to Sgr A* in all the exposures, and then de-convolved the images with the Lucy-Richardson (LR) deconvolution algorithm. We applied a cross correlation algorithm to align the individual exposures and beam restored with a Gaussian beam. The previous steps were performed for all the polarization channels (0°, 45°, 90°, 135°). We calculated the flux densities of compact sources close to Sgr A* and at the position of Sgr A* via aperture photometry. The values were corrected for the extended background distribution and extinction (Schoedel *et al.* 2010). This process allows us to study the polarized light curves of Sgr A*. As a result we show one of the obtained light curves of Sgr A* in the upper plot of Figure 2. For a complete description of the observation and data reduction and an overview of the complete sample of light curves see Shahzamanian *et al.* (2014) in prep.

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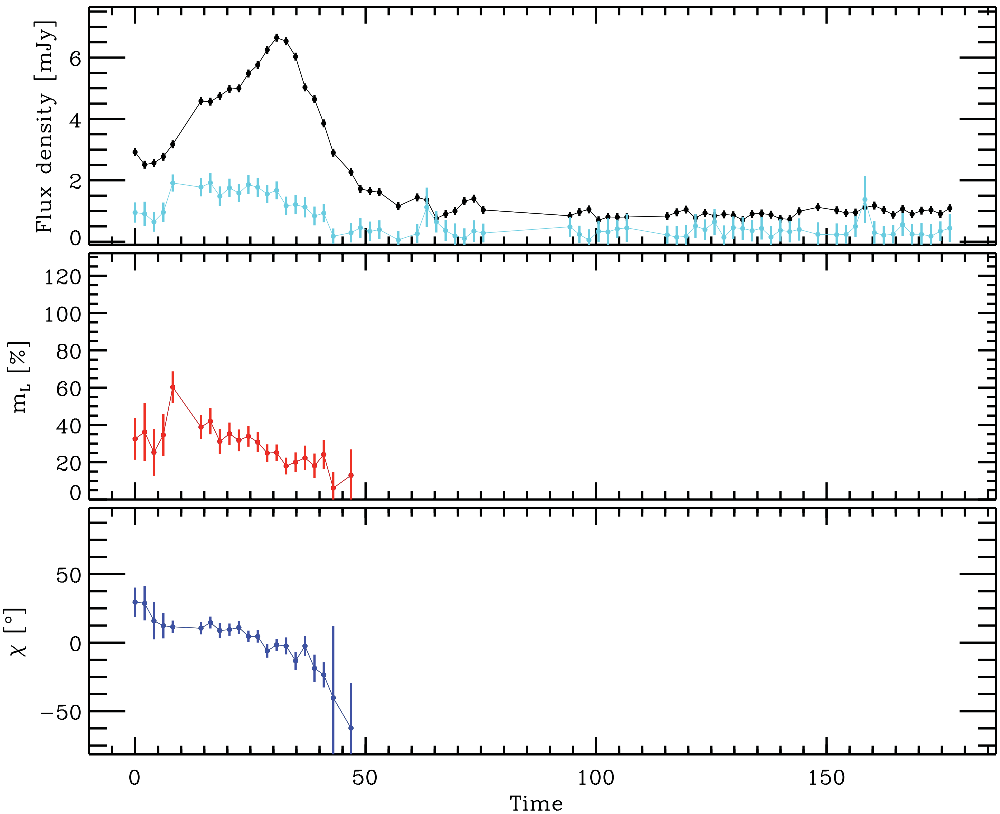

Figure 2. Typical flux density excess (flare) observed in NIR light curves of Sgr A*. **Top:** total (black) and polarized flux (cyan; polarization degree times total flux); **Middle:** polarization degree (red); **Bottom:** polarization angle (blue). The first 50 minutes in polarization degree and polarization angle panels are well defined while the rest are not due to the low flux variability. [A COLOR VERSION IS AVAILABLE ONLINE.]

3. Data analysis

We calculated the polarization degree and the polarization angle from the normalized Stokes parameters that can be obtained from the flux densities of the 2011 and 2012 data. The middle and bottom panels of Figure 2 show the polarization degree and polarization angle of Sgr A* on 2012 May 17. We obtain an estimate on the flux density uncertainty by considering the standard deviation for the flux densities measured after the end of the flare. Rapid variations and high polarization degree indicate that the emission is most likely due to synchrotron radiation.

4. Results

We gather all the polarization measurements from 2004 to 2012 and investigate the polarized flux density distribution of all the different data sets (see Figure 3). We find that the high end of the polarized flux distribution has the same slope as the total flux density distribution in Figure 11 in Witzel *et al.* (2012). We assume that the polarized flux densities of the polarized flux distribution are distributed in the same way as the total flux density distribution. This assumption can explain to first order, the observed polarized flux distribution. Furthermore, our analysis shows (Shahzamanian *et al.* 2014 in prep.)

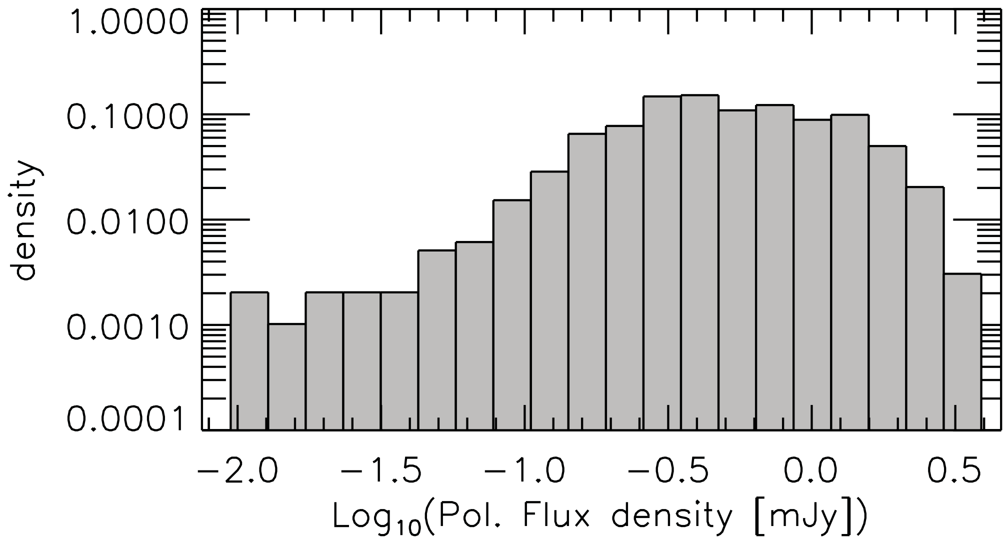

Figure 3. Histogram of polarized flux (total flux times polarization degree) in logarithmic scale. The high end of this distribution (after ~ 1 mJy) has the same slope as the total flux density distribution described in Witzel *et al.* (2012).

that the brighter flux density excursions are systematically less polarized compared to the lower fluxes. This appears to be a source intrinsic property and is in good agreement with the finding by Zamaninasab *et al.* (2010) that the polarized flares in comparison with the randomly polarized red noise show a signature of radiating matter orbiting around the supermassive black hole. Mild relativistic boosting and the formation of partial Einstein rings during the approach of an orbiting source component will lead to a bright geometrically depolarized emission during a flare event (Dovciak *et al.* 2004, 2006). Future investigations will concentrate on the polarization angle and its dependency on the strength of the flares in Sgr A* light curves.

Acknowledgements

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References

Dodds-Eden, K., Gillessen, S., Fritz, T. K., *et al.* 2011, *ApJ*, 728, 37
Dovciak, M., Karas, V., & Yaqoob, T. 2004, *ApJ*, 153, 205
Dovciak, M., Karas, V., & Matt, G. 2006, *AN*, 327, 993
Eckart, A. & Genzel, R. 1996, *Nature*, 383, 415
Eckart, A. & Genzel, R. 1997, *MNRAS*, 284, 576
Eckart, A., Baganoff, F. K., Schödel, R., *et al.* 2006a, *A&A*, 450, 535

Eckart, A., Baganoff, F. K., Zamaninasab, M., *et al.* 2008a, *A&A*, 479, 625
Eckart, A., García-Marín, M., Vogel, S. N., *et al.* 2012, *JPhCS*, 372, 012022
Schödel, R., Najarro, F., Muzic, K., & Eckart, A. 2010, *A&A*, 511, A18
Witzel, G., Eckart, A., Bremer, M., *et al.* 2012, *ApJS*, 203, 18W
Zamaninasab, M., Eckart, A., Witzel, G., *et al.* 2010, *A&A*, 510, A3+