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The infrared K-band identification of the DSO/G2 source from VLT and Keck data

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Abstract. A fast moving infrared excess source (G2) which is widely interpreted as a core-less gas and dust cloud approaches Sagittarius A* (Sgr A*) on a presumably elliptical orbit. VLT K_s-band and Keck K'-band data result in clear continuum identifications and proper motions of this $\sim 19^m$ Dusty S-cluster Object (DSO). In 2002-2007 it is confused with the star S63, but free of confusion again since 2007. Its near-infrared (NIR) colors and a comparison to other sources in the field speak in favor of the DSO being an IR excess star with photospheric continuum emission at 2 microns than a core-less gas and dust cloud. We also find very compact L'-band emission ($<0.1''$) contrasted by the reported extended ($0.03''$ up to $\sim 0.2''$ for the tail) Brγ emission. The presence of a star will change the expected accretion phenomena, since a stellar Roche lobe may retain a fraction of the material during and after the peri-bothron passage.

Keywords. black hole physics — Galaxy: center — infrared: stars

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Sgr A* at the center of our galaxy is associated with a $4 \times 10^6 L_\odot$ supermassive central black hole. It is a highly variable radio, near-infrared (NIR) and X-ray source. In early 2014 the dusty G2/DSO object (Gillessen *et al.* 2012ab, Eckart *et al.* 2013b) will pass by Sgr A* at a distance between 120 and 200 AU (1500 and 2400 Schwarzschild radii; Phifer *et al.* 2013, Gillessen 2013b) and is expected to loose matter or even be completely disrupted during the periapse section of its orbit - possibly resulting in quite luminous accretion events. We expect that the NIR/X-ray flux density of Sgr A* will increase substantially. The enhanced activity will be strong in the mm- and sub-mm part as well. To probe the accretion process and investigate geometrical aspects (outflow and disk orientation) of the enhanced activity, (sub-)millimeter/radio observations between June 2013 and (beyond) April 2014 in parallel with the NIR polarization observations will be essential. So far our NIR VLT, sub-mm APEX and mm ATCA monitoring runs in June, August and September did not show any exceptional flux density variations. The activity, however, expected in 2014 will also give an outstanding opportunity to improve the derivation of the spin and inclination of the SMBH from NIR/mm observations.

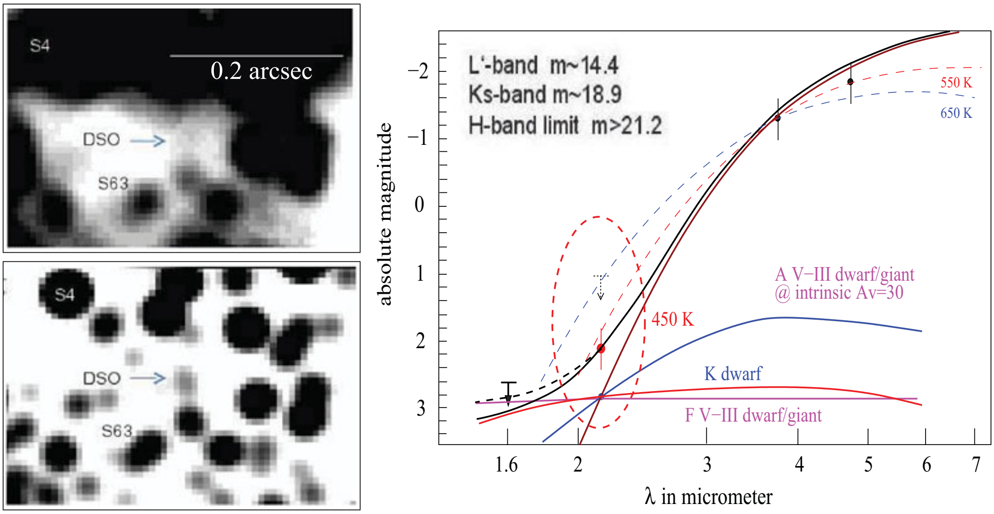

Figure 1. **Left:** Identification of the DSO/G2 source in the raw and deconvolved Keck images from August 2010. **Top:** raw adaptive optics images; **Bottom:** deconvolved with a PSF extracted from the image and re-convolved with a Gaussian to an angular resolution close to that achieved during these observations. **Right:** Decomposition of the DSO spectrum including our K_s-band detection and H-band limit. A mixture of dust and stellar contribution is possible. The dashed ellipse highlights the 2 μm limit (Gillessen *et al.* 2013ab) and our detection. [A COLOR VERSION IS AVAILABLE ONLINE.]

Gillessen *et al.* (2012ab) interpret the G2/DSO source as a preferentially core-less gas and dust cloud approaching Sgr A* on an elliptical orbit. Eckart *et al.* (2013a) present the first K_s-band identifications and proper motions of the DSO. As further support, Eckart *et al.* (2013b) present the results of the analysis of 4 epoch of public Keck K'-band adaptive optics imaging data (2008 to 2011; see Table 1 in Eckart *et al.* 2013b). Based on the comparison to VLT NACO L'- and K_s-band data (Eckart *et al.* 2013ab, Gillessen *et al.* 2013) we can clearly identify the DSO in its K'-band continuum emission as measured by the NIRC2 camera at the Keck telescope. The G2/DSO counterpart can even be seen in the direct (not deconvolved) Keck adaptive optics data (Figure 1, left). For all four public Keck epochs (2008, 2009, 2010, 2011) very similar structures compared to those derived from the VLT data presented by Eckart *et al.* (2013a).

The NIR colors of the DSO imply that it could rather be an IR excess star. Very compact L'-band emission is found (pointing at the presence of a star), contrasted by the broad Brγ emission (pointing at the presence of a very extended optically thin tail or envelope) reported by Gillessen *et al.* (2012ab) and modeled by Burkert *et al.* (2012) and Schartmann *et al.* (2012). The presence of a star will change the expected accretion phenomena (observable through expected excess mm- NIR and X-ray flux) since a stellar Roche lobe may retain much of the material (Eckart *et al.* 2013ab) during and after the peri-bothron passage.

1. The broadband spectrum of the DSO

In Figure 1 (right) we show a possible spectral decomposition (Eckart *et al.* 2013a) of the DSO using the M-band measurement by Gillessen *et al.* (2012a). The interesting arising question is about the nature of the G2/DSO K-band emission. Could the K_s-band flux density be due to emission from warm dust? Most of the minispiral dust filaments are

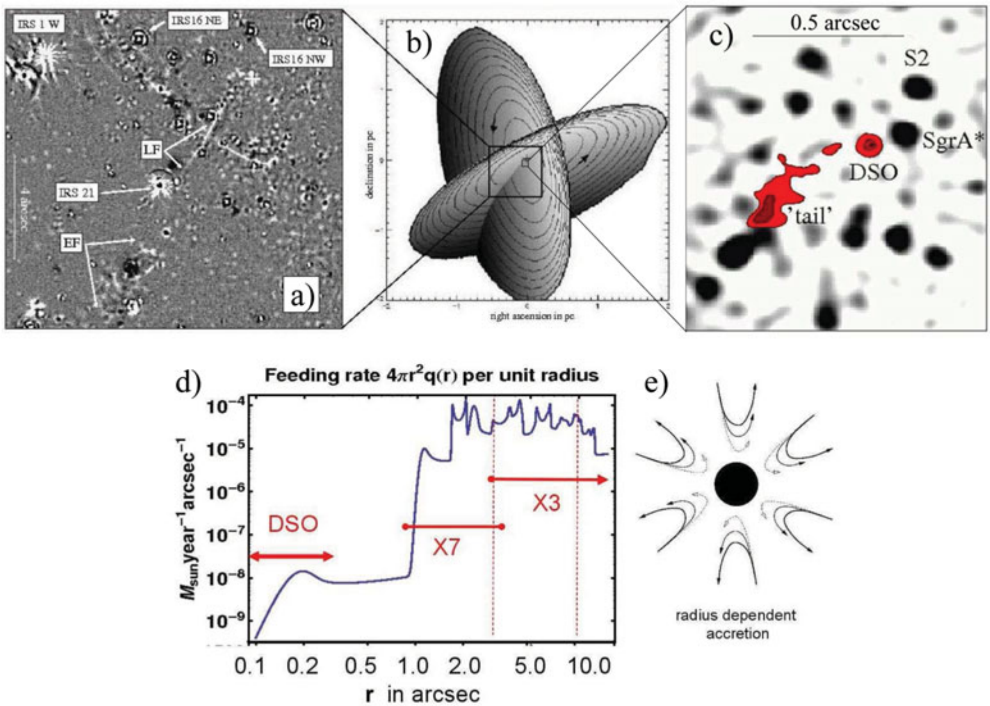

Figure 2. a-c) The orientation of the G2-tail emission (Gillessen *et al.* 2013) with respect to other features at similar position angles like the interaction zone of the disk system associated with the minispiral; **b)** Vollmer & Duschl (2000) and a dust filament visible in high-pass filtered L-band images (in **c)**). The linear feature LF crosses the northern arm and the extended feature EF is associated with the eastern arm (Eckart *et al.* 2006). **d)** Mass input into the feeding region around the Sgr A* black hole. Using square averaged wind velocities feeding is averaged over stellar orbits (Shcherbakov & Baganoff, 2010). The approximate distances of the DSO and the two cometary shaped sources X3 and X7 (Muzic, Eckart, Schödel *et al.* 2007, 2010) are shown. **e)** Sketch of the radius dependent accretion onto the central black hole. Only a very small fraction of the matter that can be accreted reached the center. A dominant fraction of it is blown away in an outward-bound wind component. [A color version is available online.]

externally heated and have a dust temperature of the order of 200 K (Cotera *et al.* 1999). Only in the immediate vicinity of embedded stars (i.e. IRS 3, IRS 7 - at 0.5$''$ angular resolution these are the hottest dust sources known until now) the dust temperature is of the order of 200-300 K (see Cotera *et al.* 1999). For the DSO we need 650 K (Gillessen *et al.* 2012a) to explain the K-band emission only by dust. So it would have to be exceptionally hot and/or have an exceptional overabundance of small grains. At a temperature of only 450 K this scenario can be excluded (Figure 1, right). Applying the same surface brightness of more than 14^m/arcsec^2 for the DSO to the minispiral, it would be much brighter and clearly stand out in its dust emission at 2 μm, which is in contradiction to the observations. The alternative is internal heating - however, that would require an internal heating source, i.e. most likely a star. In Figure 1 (right) we show a decomposition in which we assume that 50% of the current K_s-band flux is due to a late dwarf (blue line), an A/F giant, or AGB star (magenta line). We added to it dust at a temperature of 450 K (plotted in red) The sum of the spectra is shown by the thick black line (dashed at short wavelengths for the AF giant/AGB case). The points correspond to the L- and K_s-band magnitudes, and H-band upper limit from Eckart *et al.* (2013a) and the M-band measurement and K-band upper limit of Gillessen *et al.*

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(2012ab). Red and blue dashed curves also show their 550 K and 650 K warm dust fits. In solid blue, red, and magenta lines the emission from three different possible stellar types of the DSO core are plotted. Any of these stars embedded in 450 K dust (solid brown line) can produce the black line that fits all the NIR DSO photometric measurements. Black body luminosities and the detection of photospheric emission imply possible stellar luminosities of up to 30 $L_\odot$; i.e. masses of 10-20 $M_\odot$ are possible. Details are given by Eckart *et al.* (2013a).

The simulations by Jalali *et al.* (2013, submitted) show that dusty sources like the DSO or the IRS13N cluster can actually be formed from small molecular cloud complexes. If they are on elliptical orbits (e.g. originating from the CND). The gravitational focusing during the periapse passage close to the Sgr A* black hole is capable to trigger star formation on time scales required for young massive stars. This process actually helps forming stars in the vicinity of supermassive black holes.

2. The G2 tail

In Figure 2 and 3 by Eckart *et al.* (2013b) we compare the G2 tail emission to 8.6 μm observation taken in 2004 with VISIR at the ESO VLT and in 1994 with the Palomar telescope (Stolovy *et al.* 1996). These MIR results, the comparably low proper motion, as well as the possible linkage to the two minispiral disk systems, suggest that the 'tail' component (red in Figure 2c) might not be associated with the G2 source but rather is a back/fore-ground dust source associated to the minispiral within the central stellar cluster. The long dust lane feature that crosses the minispiral to the south-east of the DSO (Figure 7 in Gillessen *et al.* 2013) may be a consequence of the interaction between the two rotation gas disk components that are associated with the northern and eastern arms. Details are shown in our Figure 2abc (see also Figure 21 in Zhao *et al.* 2009, and Figure 10 in Vollmer & Duschl 2000). If upcoming observations can confirm that the 'tail' component is not associated with the DSO, it does not need to be taken into account in future simulations.

While the DSO has a marginal extent in Brγ line emission of about 30mas (Gillessen 2013b), it may be compared to other dusty sources in the field (see Eckart *et al.* 2013a). In fact, the DSO may be a compact source comparable to the cometary shaped sources X3 and X7 (Muzic *et al.* 2010, see also Sabha *et al.* 2014 in prep.). Its smaller size compared to X3 and X7 can be explained by the higher particle density within the accretion stream close to Sgr A* (e.g. Shcherbakov & Baganoff 2010; see our Figure 2de). Its size also depends on how earlier passages close to Sgr A* possibly influence the distribution of gas and dust close to a possible star at the center of the DSO.

3. Conclusions

The observations planned for 2014 will be essential to investigate how the close flyby of the DSO/G2 object will alter the accretion characteristics of Sgr A*. The structural evolution of the DSO will also show if the DSO harbors a star or is a pure gas and dust cloud. Further NIR imaging and spectroscopy data will also show if the extended 'tail' component is associated with the head of the DSO/G2 source. Theoretical investigations are required to study the formation process for DSO like sources and how they are linked to the conditions of star formation in the central stellar cluster. These studies will also have to address the question of whether the DSO is comparable to other dusty sources in the cluster - like the infrared excess IRS13N sources (Muzic *et al.* 2008, Eckart *et al.* 2012b) or the bow-shock sources X3 and X7 (Muzic *et al.* 2007, 2010). Independent of the answers to these problems, the DSO flyby in 2014 will undoubtedly be a spectacular event. It will reveal valuable information on the physics in the immediate vicinity of supermassive black holes.

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