The Interplay among Black Holes, Stars and ISM in Galactic Nuclei
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IR excess stars and shock filaments at the Galactic center

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Abstract. In this paper we report on our recent results connected with the direct environment of the super massive black hole of the Milky Way. The data are obtained using the VLT facilities (ISAAC and NAOS/CONICA instruments) in the near- and mid-infrared wavelength ranges. We provide a calibration of the foreground and local differential (in wavelength and spatially) extinction of the Galactic Center and report on the discovery of a new complex of infrared excess sources (possibly young stars) located at the northern part of the IRS 13 cluster. Finally, we discuss the origin of filamentary structures observed in the L-band images.

1. Introduction

The center of our Galaxy is the ideal place to study in detail the central region of a galaxy and the environment of the central super massive black hole (SMBH). Recently, it has been shown that the center of the Milky Way is inhabited by a SMBH of $\sim 3.6 \times 10^6$ $M_\odot$ (Schödel et al. 2002; Ghez et al. 2003). The entire central parsec is powered by a cluster of young and massive stars as the IRS 16 complex (Blum et al. 1988, Krabbe et al. 1995, Genzel et al 1996, Eckart et al. 1999, Clénet et al. 2001). In addition to the massive supergiants, a population of dust embedded objects associated with dust emission are also found in the Galactic Center stellar cluster as IRS 1, IRS 3 and also the IRS 21 and IRS 8 sources that have been identified as bowshock sources (Tanner et al. 2002, Rigaut et al. 2003). The presence of a large number of young massive stars in the region is problematic and many scenarios describing their formation have been proposed.

In order to study the direct environment of the central Galactic black hole, we have obtained near- and mid-infrared observations of the central parsec of the Milky-Way using the ISAAC instrument at the VLT Unit telescope 1 (UT1) and the adaptive optics system NAOS/CONICA at the VLT UT4. The details of the observations are given in Eckart et al. (2004) and Moultaka et al. (2004). These observations gave us information about the local ISM and the nature of the sources of the central region.

2. Intrinsic spectra and calibration of the extinction

The L-band spectra of twelve of the brightest sources located in the central parsec of the Galaxy, as well as K-band spectra (Genzel et al. 1997, Ott et al. 2003) or K-band fluxes, have been fitted with reddened blackbody continua (see an example in Fig. 1). The values of the K-band extinction vary from 2.7 to 4.5 *mag* and the blackbody temperatures agree well with the known nature of the sources. The results of the fitting procedure have been well supported by an independent way of calibrating the foreground extinction which allowed us to derive the L-band spectrum of the extinction along the line of sight (see Fig. 1) and the intrinsic spectra of the different central objects. The

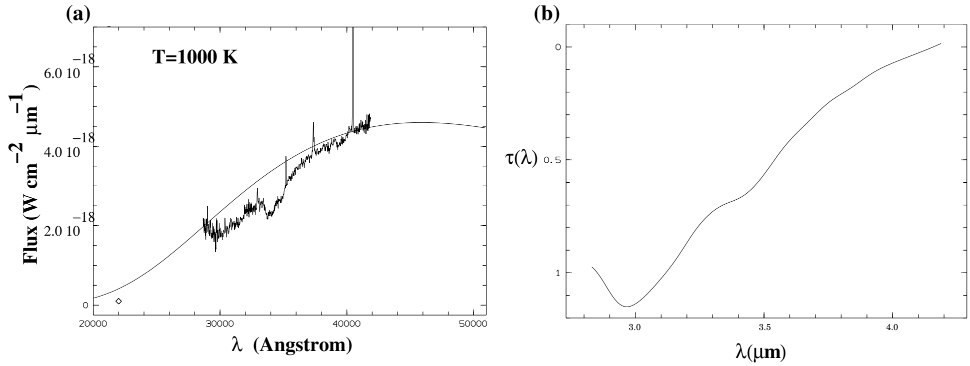

Figure 1. *Left:* The ISAAC integrated spectrum of the IRS 13N complex fitted with a reddened blackbody spectrum of T=1000K and a *K*-band extinction A_K=3.9 *mag*. *Right:* The optical depth spectrum of the line of sight *L*-band extinction towards the Galactic Center.

overall shapes of the obtained spectra corrected from the forground extinction are in good agreement with the shapes of blackbody continua having the same temperatures as the ones obtained by the fitting procedure. Moreover, the intrinsic spectra of the IRS 16 sources match well pure Rayleigh Jeans continua whereas the other sources show additive absorption features in their spectra (see Fig. 2).

The reddened blackbody continua were then used to derive optical depth spectra of the central sources and to measure the optical depth values of the 4 prominent absorption features observed in the central parsec: the water ice feature at $3.0\mu m$ and the hydrocarbon features at $3.38\mu m$, $3.42\mu m$ and $3.48\mu m$. The large range of values obtained for the absorption features optical depths suggests that these features are mainly arising from the local environment and are associated with the individual sources. For further details, see Moultaka et al. (2004).

3. Young stars at the Northern part of the IRS 13 complex

The NACO images have revealed a new complex of IR excess colour sources located at about 0.5" north of the IRS 13 cluster. Eight sources have been resolved in the deconvolved images and labeled from α through η. The L-band images are shown in Fig. 2.

In order to explain the unusual colours of these sources, we provide three different interpretations: the sources could be bright young stars that are deeply embedded in the gas and dust of the minispiral or simply located behind a dense clump of gas and dust. The second possibility is that they could be O-or B-type stars heating the gas and dust in their vicinity. In this case, they could be low luminosity analogues of the bowshock sources. In both cases, extinctions well above $A_V \sim 30$ *mag* are needed. The third interpretation is that they may be young stellar objects as they show similar luminosities ($\sim 10^3 L_\odot$) in addition to their red colours and, when corrected from the visual extinction value $A_V \sim$30 *mag* toward the Galactic Center, their colours are shifted to the region of YSO and Herbig Ae/Be stars in the Colour-Colour diagram (Ishii et al. 1998) (see Eckart et al. 2004 for further discussion). In addition, the ISAAC spectrum of the IRS 13N region has been well fitted with a reddened blackbody continuum of temperature T=1000K (see Fig. 1). The corrected spectrum from the foreground extinction is redder than the one of the IRS 13 cluster (Fig. 2) especially longward of $3.5\mu m$. This shows that the L-band excess is due to the emission of warm (T$\sim$1000K) dust. The NACO spectra show

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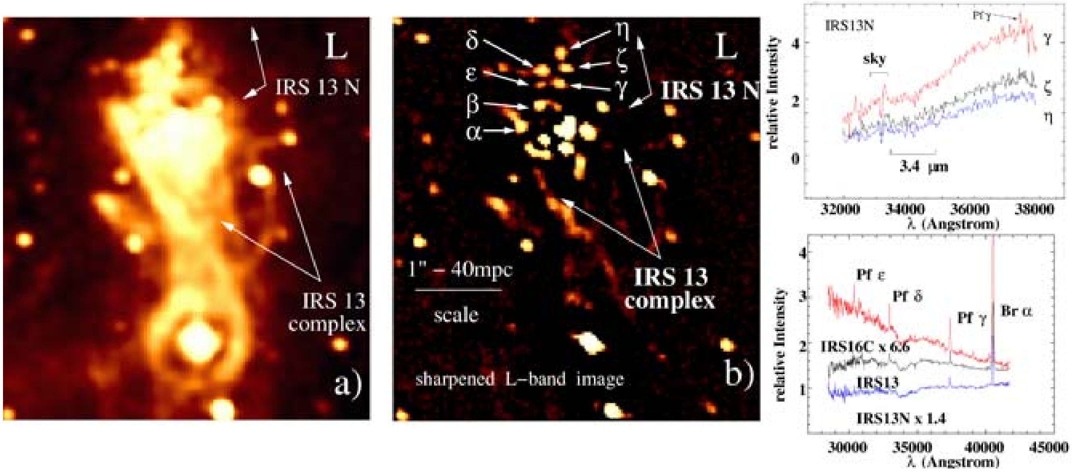

Figure 2. *L'*-band images of the IRS 13/IRS 2 region. The ring structures in panel (a) are artifacts of the deconvolution algorithm. Panel (b) is a high-pass filtered image showing the location of the newly discovered excess sources α through η. *Top right:* NACO *L'*-band AO spectra of the IRS 13N sources η, ζ and γ. *Bottom right:* ISAAC spectra corrected for the line of sight extinction of the sources IRS 16C, the IRS 13 complex and the group of IR excess sources IRS 13N.

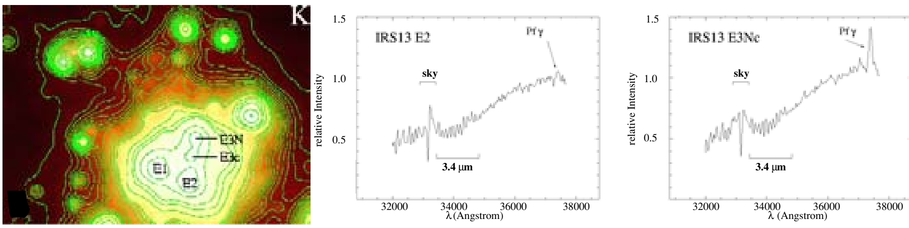

Figure 3. A detailed *K*-band NACO image of the IRS 13 complex (*left*). Sources E1, E2, and E3 composed of E3N and E3c are labeled. The image size is 1"x 1.5". NACO *L'*-band AO spectra of IRS 13 E2 (*middle*) and IRS 13 E3Nc (*right*) containing contribution from E3N and E3c.

a redder continuum from η to γ suggesting that the colors of these sources are due to dust emission. The lack of Pfγ line emission in these spectra (Pfγ emission is prominent in the integrated ISAAC spectrum of the IRS 13N region !) suggests also that this emission is likely due to an extended nebular emission.

4. A new resolved component in the IRS 13 complex

The IRS 13 complex has been resolved into 4 components in the NACO images (see Fig. 3). In addition to the well known components E1 and E2, the E3 component seems to be double. We label its components E3N (for North) and E3c (for center). The E3c component is very red (K-L=4.24 and H-K=4.05) and is also the faintest among the four components in the *H*- and *K*-bands. In addition, the NACO spectrum of the E3 region (E3N + E3c) (Fig. 3) shows a prominent Pfγ emission line which suggests that the E3 component is the broad He emission line star identified in the IRS 13 region by Paumard et al. (2001). As the E3c source is the faintest in the K-band, we argue that this newly resolved source might be a WR-type star (see discussion in Paumard et al. 2001).

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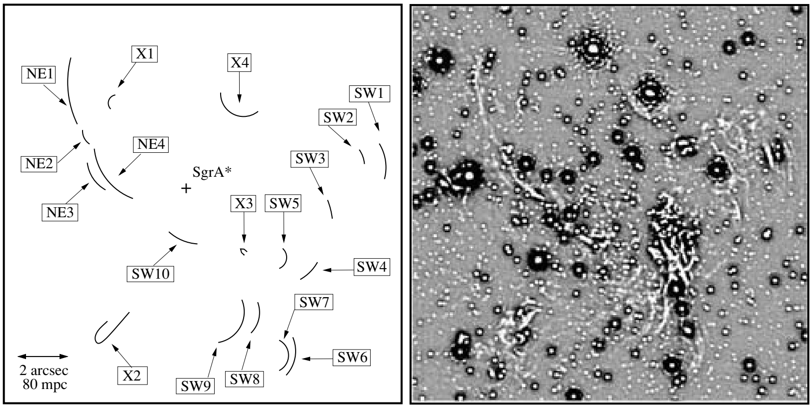

Figure 4. *Right:* High-pass filtered *L'*-band image of the Galactic center. *Left:* Schematised location and shape of the observed filaments.

5. Filamentary structures in the central parsec

The NACO L-band high-pass filtered images revealed filamentary structures in the central parsec (see Fig. 4). The filaments associated with the Northern arm of the minispiral have also been identified by Clénet et al (2003). Here we suggest that these structures are probably the result of shock fronts due to the interaction of the minispiral material with a stellar wind (in the case of the "X" filaments where local sources have been identified in the vicinity of the filaments) or a central wind (in the case of "NE" and "SW" sources). The central wind is probably produced by the collimated jet resulting from the accretion of the mass-loss material by the central stellar cluster as only 1% of this mass is accreted into the black hole and the remainder is blown away in a central wind (Quataert 2003). This work is in progress and will be presented in a forthcoming paper Eckart et al. (2004).

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