

Compact mid-IR sources east of Galactic Center source IRS5

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ABSTRACT

Aims. Mid-infrared observations of the Galactic Center show among the extended mini-spiral a number of compact sources. Their nature is of interest because they represent an interaction of luminous stars with the mini-spiral material or mass losing sources that are enshrouded in dust and gas shells. Characterizing their nature is necessary to obtain a complete picture of the different stellar populations and the star formation history of the central stellar cluster in general. Prominent compact MIR sources in the Galactic Center are either clearly offset from the mini-spiral (e.g. the M2 super-giant IRS 7 and the bright dust enshrouded IRS 3) or have been identified earlier with bright bow shock sources (e.g. IRS 21, 1W, 10W and IRS 5). There are, however, four less prominent compact sources east of IRS 5, the nature of which were unclear until now.

Methods. We present near-infrared K-band long slit spectroscopy of the four sources east of IRS 5 obtained with the ISAAC spectrograph at the ESO VLT in July 2005. We interpret the data in combination with high angular resolution NIR and MIR images obtained with ISAAC and NACO at the ESO VLT.

Results. The K′-band images and proper motions show that the sources are multiple. For all but one source we find dominant contributions from late type stars with best overall fits to template stars with temperatures below 5000 K.

Conclusions. The brightest sources contained in IRS 5NE, 5E and 5S may be asymptotic giant branch stars and a part of the MIR excess may be due to dust shells produced by the individual sources. However, in all cases an interaction with the mini-spiral cannot be excluded and their broad band infrared SEDs indicate that they could be lower luminosity counterparts of the identified bow shock sources. In fact, IRS 5SE is associated with a faint bow shock and its spectrum shows contributions from a hotter early type star which supports such a classification.

Key words. Galaxy: center – galaxies: nuclei – infrared: ISM

1. Introduction

The Galactic Center (GC) at a distance of ~8 kpc (Ghez et al. 2005; Schödel et al. 2002, 2003; Eisenhauer 2003, 2005) is known as a bright source of near- and mid-infrared (NIR and MIR) radiation since the late 1960s (Becklin & Neugebauer 1968, 1969; Low et al. 1969). The main source of NIR radiation is photospheric emission from a dense stellar cluster, i.e. a crowded field of point sources, while almost all of the MIR radiation originates from extended gas and dust features as well as dust emission from the circum-stellar regions of a dozen individual sources interacting with the more extended GC interstellar medium (ISM).

The GC stellar cluster shows some intriguing characteristics: it is extremely dense, with an unusual observed stellar population (Genzel et al. 2003; Eisenhauer et al. 2005). Recently, Schödel et al. (2007) presented AO assisted high-resolution NIR imaging observations of the stellar cluster within 20′′ (about 0.75 pc) of Sgr A*, the massive black hole at the center of the Milky Way. Schödel et al. (2007) extracted stellar number counts and colors, and derived from them the detailed structure of the nuclear stellar cluster and an extinction map across it. The bright members of the central stellar cluster are mainly (80% of all $m_K \leq 14$ mag stars; Ott et al. 1999) late-type red giants (e.g. IRS 7 and IRS 10E in Fig. 1), many of which are suspected to lie on the asymptotic giant branch (AGB). It is also composed of young massive stars which have energetic winds (e.g. Krabbe et al. 1995; Najarro et al. 1997; IRS 13E in Fig. 1) and are arranged in two stellar disks (Genzel et al. 2003; Paumard et al. 2006). Spectra of AGB stars show strong 2.3 $\mu$m CO band-head absorption and the massive, hot and windy stars (He-stars) exhibit He/H emission. These emission line stars dominate the NIR luminosity of the central few arcseconds. All bright and compact MIR sources in the GC are either clearly offset from the mini-spiral (such as the M2 super-giant IRS 7 and the bright dust enshrouded IRS 3) or have been identified earlier with bright bow shock sources (such as IRS 21, 1W, 10W and IRS 5).

A third, less numerous component of the GC stellar cluster, consists of luminous objects with steep, red and featureless (K-band-) spectra and a strong infrared excess. Although clearly extended in MIR images they are quite compact in this wavelength range compared to the mini-spiral or the dust shell around IRS 3 (Viehmann et al. 2006). These clearly extended dust embedded MIR sources (e.g. IRS 5, 10W in Fig. 1) are bow shock sources, caused by bright emission-line stars with strong winds plowing through the ambient gas and dust of the northern arm of the mini-spiral (Tanner et al. 2002, 2003, 2005; Rigaut et al. 2003; Geballe et al. 2004, 2006). There are also fainter dust embedded sources (e.g. the IRS 13N cluster in Fig. 1; Eckart et al. 2004) which could represent a low luminosity class of bow shock sources in the GC.
sources or even young dust embedded stars that have been recently formed. In this paper we investigate compact MIR sources close to or within the northern arm of the mini-spiral.

Infrared images longward of 2 µm show four bright compact objects (Viehmann et al. 2006) located to the east of the bright northern arm source IRS 5. They are especially prominent in high angular resolution MIR images as obtained with VISIR (see Fig. 1 and a zoom towards the described sources in Fig. 2). These sources have an exceptional appearance since they are quite compact compared to the bulk of the 10 µm emission which is associated with the extended mini-spiral. The nature of these four compact sources, which we refer to as IRS 5NE, 5E, 5S and 5SE (see Fig. 1; IRS 5SE includes 5SE1 and 5SE2), is currently unclear: they are almost as bright as IRS 7 (M2 supergiant in Fig. 1; Carr et al. 2000) in the N-band, while they appear much less prominent (but still detectable) at shorter wavelengths (K-band), although they remain bright in L- and M-bands. We present first high angular resolution images, proper motions and K-band long-slit spectroscopy as obtained with the ESO VLT, in order to further investigate the properties of these sources.

2. Observations and data reduction

2.1. Proper motion data

The K’-band (2.18 μm) images from which we derived the proper motions of the sources were taken with the NAOS/CONICA\(^1\) adaptive optics assisted imager/spectrometer (Lenzen et al. 1998; Rousset et al. 1998; Brandner et al. 2002 at the UT4 (YEPUN) at the ESO\(^2\) VLT\(^3\), Cerro Paranal, Chile. The data set includes the images from epochs 2002.339, 2003.356, 2004.512, 2005.263.

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\(^1\) Nasmyth Adaptive Optics System/Conde Near Infrared Camera; Lenzen et al. (2003), Rousset et al. (2003).

\(^2\) European Southern Observatory.

\(^3\) Very Large Telescope.
2004.521 and 2006.413 with an angular resolution of \( \sim 56 \) mas. Data reduction (bad pixel correction, sky subtraction, flat field correction) and formation of final mosaics was performed using the DPUSER software for astronomical image analysis (T. Ott; see also Eckart et al. 1990). The absolute positions of sources in our AO images were derived by comparison to the VLA positions of IRS 10EE, 28, 12N, 17, 7 and 15NSE as given by Menten et al. (1997) and Reid et al. (2003) (for identification of different GC sources see e.g. Fig. 2 in Viehböck et al. 2005). The radio positions and the positions in the \( K' \)-band image agree to within less than a single 27 mas pixel i.e. less than a \( K' \)-band diffraction limited beam. The stars used for the transformation were chosen to be uniformly distributed across the field. In addition to the MIR excess sources east of IRS 5 we have randomly selected 27 objects in the field for comparison. The positions and \( K' \)-band proper motions of all sources are listed in Table 1 and shown in Figs. 3 and 4. The proper motions of the overall source sample in Table 1 are in agreement with random motions. Within the width of the velocity distributions of about \( \sigma_{\text{field}} = 150 \text{ km s}^{-1} \) their median velocities of about \( -63 \text{ km s}^{-1} \) to the east and \( 2 \text{ km s}^{-1} \) to the north are close to zero with random orientations.

### 2.2. ISAAC observations

On July 27th and 28th 2005, \( K \)-band (2.2 \( \mu m \)) spectroscopy observations of the four MIR sources east of IRS 5 (\( m_K, \text{obs} \sim 8 \) to 11 mag) were obtained with the ISAAC\(^6\) infrared spectrometer mounted at the UT1 (ANTU) at the ESO VLT. The seeing-limited spectra (0.7 to 1.6\( '' \)) were taken with a long-slit of 0.6 \( \times \) 120" (two slit positions A and B; see Fig. 1) in ISAAC’s lower resolution mode \( (R = \lambda/\Delta \lambda = 840) \). The observations were made with an integration time of 100 s per frame with total integration times of 2400 s for IRS 5S and 1200 s for the remaining 3 objects IRS SNE, SSE, and SE.

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Table 1. Proper motion data (and their 1\( \sigma \) uncertainties) of the compact IRS 5 \( N \)-band sources derived from NACO \( K' \)-band data, covering the epochs 2002.339, 2003.356, 2004.512, 2004.521 and 2006.413 with a resolution of \( \sim 56 \) mas. Positive velocities go from west to east and south to north. The epoch 2002 \( K' \)-band positions are referred to SgrA* with a 1\( \sigma \) uncertainty of 0.1".

| Source | \( \Delta \alpha \) | \( \Delta \delta \) | \( \nu_{\text{RA}} \) | \( \nu_{\text{Dec}} \) |
|--------|-----------------|-----------------|----------------|----------------|
| IRS 5  | 9.31            | 9.15            | 43 \pm 18     | -27 \pm 12     |
| IRS SNE1 | 13.79          | 9.60            | -156 \pm 34   | 82 \pm 20      |
| IRS SNE2 | 13.31          | 9.88            | -346 \pm 10   | 279 \pm 12     |
| IRS SE1 | 11.68           | 8.50            | -48 \pm 30    | 183 \pm 25     |
| IRS SE2 | 13.31           | 9.88            | -299 \pm 10   | 216 \pm 12     |
| IRS S1  | 9.80            | 7.31            | 105 \pm 14    | 2 \pm 13       |
| IRS S2  | 9.62            | 7.32            | 102 \pm 14    | -34 \pm 16     |
| IRS S3  | 9.42            | 7.19            | 179 \pm 22    | -46 \pm 16     |
| IRS SE1 | 10.00           | 6.06            | 60 \pm 19     | -22 \pm 16     |
| IRS SE2 | 11.30           | 5.91            | -150 \pm 10   | 24 \pm 10      |

\(^4\) ESO program IDs: 60.A-9026(A), 073.B-0775(A,B), 077.B-0552(A).  
\(^5\) ESO program ID: 075.C-0138(A).  
\(^6\) Infrared Spectrometer And Array Camera, Moorwood et al. (1998).  
\(^7\) Image Reduction and Analysis Facility, distributed by the National Optical Astronomy Observatory (NOAO), operated by the Association of Universities for Research in Astronomy, Inc. (AURA) and under cooperative agreement with the National Science Foundation (NSF).  
\(^8\) Interactive Data Language.
of IRS 5 were multiplied by a blackbody of temperature equal to the effective temperature of the standard stars. The spectra were wavelength calibrated using Xenon-lines from additionally observed data frames. Flux density calibration was applied with zero points from literature (FD$_{0,K} = 657$ Jy, Skinner 1997) and high resolution NACO images (compared to IRS 16NE and 16NW). Strong atmospheric CO$_2$ absorption result in lower signal-to-noise ratios (SNRs) in the 1.98 to 2.06 $\mu$m spectral regions. At shorter wavelengths the SNR of the spectra suffer from residual telluric H$_2$O absorption and the strong (~30 mag; see below) extinction towards the GC region.

3. Results

3.1. Structures and proper motions of individual sources

In this section we discuss the structures and proper motions of the individual compact MIR sources east of IRS 5 as obtained from our high angular resolution $K'$-images.

**IRS SNE:** the $K'$-band images show two sources with a separation of 0.4″. Both sources are moving towards the northwest but their velocity difference is large with respect to the uncertainties and $\sigma_{\text{field}}$. This implies that the two sources are not physically associated.

**IRS SE:** the situation is similar to that of IRS 5NE. IRS 5SE1 and IRS 5SE2 are an apparent double source with an east-west separation of 0.5″ and a large proper motion velocity difference. IRS 5SE2 is about half as bright as IRS 5SE1. Both sources are moving towards the northwest. The images also indicate several sources which are at least 1 mag fainter than IRS 5SE1 and have separations of less than 0.5″ from it. They are too faint to determine their proper motions.

**IRS SS:** here a minimum of 3 sources within a 0.6″ diameter region is moving towards the east-southeast. Their proper motion velocity difference is small with respect to the uncertainties and $\sigma_{\text{field}}$. This implies that these sources could be physically associated. A firm statement on this requires a determination of their radial velocities in the near future.

**IRS SSE:** high-resolution NAO/CNICA $K'$- and $L$-band images (see Fig. 1) reveal that the southernmost of the four sources, which appears slightly extended (≈0.2″; compared to IRS7) in the VISIR images, is in fact an apparent double source, consisting of a “blue” point source to the east (SE2) and a fainter point source to the west (SE1). The spectrum we obtained from IRS SSE probably includes flux density contributions from both objects. We calculated a separation between the two objects as 0.4 ± 0.1″. Their proper motion velocity difference is large with respect to the uncertainties and $\sigma_{\text{field}}$. This implies that the two sources are not physically associated. IRS5 SE1 shows a tail like structure (in the $L'$-band) that appears to be the main source of emission at longer wavelengths. The extended dust feature has the appearance of a bow-shock. Since IRS5 SE2 is blue and bright it may be associated with a luminous star that interacts with the surrounding ISM. The position angle of the bow shock with respect to the proper motion of the source it is physically associated with, depends on the geometry and density structure of the local ISM it is moving in. Here offsets by ~45° appear to be possible (see Fig. 2).

3.2. Stellar types

To derive the stellar types of the observed sources we compared the reduced spectra shown in Fig. 5 with standard star templates from Wallace & Hinkle (1997) of spectral types from O- to M- and different luminosity classes. Since the template spectra are continuum normalized to one, we had to multiply them by a blackbody of temperature equal to the effective temperature of each stellar type. The spectra were also convolved with a Gaussian distribution to match the resolution of our observed spectra.

The comparison was done by fitting the continuum of the source spectra (from 2.0 to 2.29 $\mu$m) with $A_K$ extincted template spectra, the apparent magnitude $m_K$, the depth $d$ and the equivalent width (EW) of the $^{12}$CO absorption bandheads. The fitting procedure is explained hereafter.

A small amount of apparent residual broadening of the CO bandheads may be due to the following fact: most of the sources are apparently associated with small clusters of fainter stars. As the spectra are taken against the underlying stellar cluster in moderate seeing in a 0.6″ diameter slit 4 to 6 sources that are individually up to 2 mag fainter than the program source may lead to a systematic broadening of the order of the cluster.
velocity dispersion of 1σ ~ 150 km s\(^{-1}\) (corresponding to a 3σ value of up to 450 km s\(^{-1}\)) and 50% for the sources with flux densities below that value. The H-, K- and L-band values have errors up to 75%. For the calculations, zero flux densities from Skinner et al. (1997) were used (FD\(_0\)H = 1020 Jy, FD\(_0\)K = 657 Jy, FD\(_0\)L = 253 Jy). The colors H – K and K – L are shown.

Table 2. Extinction corrected flux densities (FD) of the compact N-band sources in Jansky's (Viehmann et al. 2006) and H-, K- and L-band flux densities and magnitudes (m) from NACO high resolution images (compared to IRS 16NE and 16NW). Errors are around 30% for sources of more than 0.5 Jy and 50% for the sources with flux densities below that value. The H-, K- and L-band values have errors up to 75%. For the calculations, zero flux densities from Skinner et al. (1997) were used (FD\(_0\)H = 1020 Jy, FD\(_0\)K = 657 Jy, FD\(_0\)L = 253 Jy). The colors H – K and K – L are shown.

| Name   | m\(_H\) | m\(_K\) | m\(_L\) | H – K | K – L | FD\(_{16}\) \(\mu\) | FD\(_{2\mu}\) \(\mu\) | FD\(_{3\mu}\) \(\mu\) | FD\(_{4\mu}\) \(\mu\) | FD\(_{5\mu}\) \(\mu\) | FD\(_{6\mu}\) \(\mu\) | FD\(_{7\mu}\) \(\mu\) | FD\(_{8\mu}\) \(\mu\) |
|--------|---------|---------|---------|-------|-------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| IRS 5  | 4.4     | –       | –       | –     | –     | 4.270             | 4.880             | 5.110             | 4.210             | 5.850             | 3.210             | 2.850             |
| IRS SNE| 14.8    | 12.7    | 9.5     | 2.1   | 3.2   | 0.001             | 0.006             | 0.047             | 0.800             | 0.510             | 0.600             | 0.560             | 0.950             | 0.740             |
| IRS 5E | 14.6    | 13.0    | 10.7    | 1.6   | 2.3   | 0.002             | 0.004             | 0.016             | 0.210             | 0.590             | 1.060             | 1.540             | 1.580             | 1.720             |
| IRS 5S | 14.3    | 12.4    | 9.9     | 1.8   | 2.5   | 0.002             | 0.007             | 0.032             | 0.430             | 0.630             | 0.510             | 0.380             | 0.630             | 1.060             |
| IRS 5 SE1 | –       | 12.2    | –       | –     | –     | 0.004             | 0.180             | 0.500             | 0.970             | 1.100             | 2.840             | 3.580             |
| IRS 5 SE2 | 13.2    | 11.6    | 10.5    | 1.7   | 1.0   | 0.005             | 0.016             | 0.018             | –                 | 0.040             | 0.090             | 0.130             | –                 |
| IRS 13N| 13.0    | 12.4    | 10.0    | 0.6   | 2.4   | 0.006             | 0.007             | 0.028             | 1.580             | 0.380             | 0.650             | 1.110             | 0.350             | 0.580             |

Table 3. Measured parameters of the observed and template spectra (taken from Wallace & Hinkle 1997) and physical parameters of the template stars.

| Object | EW | d | m\(_K\) | Stellar Type | Temp. |
|--------|----|---|---------|--------------|-------|
| IRS SNE| 0.239 | 0.892 | 13.2 | – | – |
| IRS 5E | 0.365 | 0.849 | 13.6 | – | – |
| IRS 5S | 0.326 | 0.885 | 12.9 | – | – |
| IRS 5 SE1 | 0.188 | 0.931 | 11.8 | – | – |
| IRS 5 SE2 | 0.084 | 0.984 | 12.8 | – | – |
| IRS 13N | 0.239 | 0.892 | 13.2 | – | – |
| IRS 5S | 0.002 | 0.966 | 11.4 | B0V | 28000 |
| IRS 591 | 0.009 | 1.000 | 13.5 | B3V | 22570 |
| IRS 3323 | 0.000 | 0.904 | 13.3 | G5III | 4400 |
| IRS 3212 | 0.028 | 0.848 | 13.2 | G7III | 4286 |
| IRS 2985 | 0.283 | 0.834 | 13.2 | G8III | 4229 |
| IRS 6703 | 0.226 | 0.846 | 13.2 | G8III | 4229 |
| IRS 8317 | 0.016 | 0.755 | 12.9 | K0III | 4114 |
| IRS 8694 | 0.047 | 0.773 | 12.9 | K0III | 4114 |

Fig. 5. The fully reduced spectra of IRS SNE, 5E, 5S and 5SE. The most prominent absorption and emission lines are marked. The flux densities are shifted for display purposes (IRS SNE: +15 × 10^{-15} W/m^2/\(\mu\)m, 5E: +10 × 10^{-15} W/m^2/\(\mu\)m, 5S: +5 × 10^{-15} W/m^2/\(\mu\)m, 5SE: +5 × 10^{-15} W/m^2/\(\mu\)m). Note the lower SNR for wavelengths smaller than 1.94 \(\mu\)m and at around 2.02 \(\mu\)m. For spectral flux calibration – see 2.2.
best shown in Fig. 6. Their physical parameters as well as the value of the $K$-band extinction $A_K$ needed for the best fit are listed in Table 4.

All observed objects except IRS 5SE can be represented by late-type giants with surface temperatures in the range of $\log(T) = 3.6$–$3.7$ (or 4000 K < $T$ < 5000 K) and with apparent $K$-band magnitudes of 10 to 14 mag. These values are consistent with the expected properties of stars on the AGB at the distance of the GC assuming an average $K$-band extinction of 3.4 mag (see also Fig. 14 in Rafelski et al. 2007). The only exception is IRS 5SE. From our fits we derive that for IRS 5SE the temperature is likely to be higher than 5000 K, but in this case the template stars miss to fit the observed apparent brightness by about 2 mag. This is a strong indication that we observe in fact an blend of an early- and a late-type star and that the observed CO bandheads are correspondingly too weak compared to the continuum – resulting in the described discrepancies.

Table 4. The stellar templates that best fit the observed spectra. Listed are the $K$-band extinctions needed in the best fit and the differences of the fitted parameters between the templates and the observed sources. All but IRS 5SE can be represented by a G-type giant. See text for further comments.

| Object   | Stellar type | Temp. [K] | $\Delta$EW [nm] | $\Delta d$ [nm] | $\Delta m_K$ [mag] | $A_K$ [mag] |
|----------|--------------|-----------|-----------------|----------------|------------------|-------------|
| IRS SNE  | G8III        | 4229      | 0.013           | 0.046          | 0.0              | 3.4         |
| IRS SE   | G8III        | 4229      | 0.082           | 0.015          | 0.4              | 3.3         |
| IRS SS   | G7III        | 4286      | 0.070           | 0.037          | 0.3              | 3.3         |
| IRS 5SE  | B3V          | 22570     | 0.129           | 0.069          | 1.7              | 2.7         |

3.3. Spectral energy distributions, colors

In a recent paper (Viehmann et al. 2006), we described spectral energy distributions (SEDs) from $H$- to $Q$-band (1.6 to 19.5 $\mu$m) to investigate colors, infrared excesses and extended dust emission of GC sources. The SEDs showed characteristic features. We could clearly distinguish between four types of sources (Fig. 7): the luminous northern arm bow shock sources (type 1), the lower luminosity bow shock sources (type 2), the cool stars (type 3) and the hot stars (type 4). (Note: although the lower type 2 source has a stronger curved short wavelength spectrum – and therefore looks more like a type 3 source in that spectral domain – it is clearly identified as a lower luminosity bow shock source, see Viehmann et al. 2006; Clenet et al. 2004). This classification may be used to clarify the nature of the presently unclassified sources east of IRS 5 discussed in this work. The $H$-, $K$- and $L$-band luminosities were derived from the comparison of IRS 13N and the sources east of IRS 5 with IRS 16NE and 16NW ($m_K, H - K$ and $K - L$ from Blum et al. 1996b). For the calculations ($m = -2.5 \log(FD_{\lambda 1}/FD_{\lambda 2})$), zero flux densities from Skinner 1997 were used ($FD_{\lambda 1} = 1020$ Jy, $FD_{\lambda 2} = 657$ Jy, $FD_{\lambda 3} = 253$ Jy). The compact mid-IR sources east of IRS 5 are less luminous and situated close to or within the northern arm of the mini-spiral and therefore show similar characteristics to identified lower luminosity bow shock sources. However, with the exception of IRS 5SE, their appearance on high resolution $K$- and $L$-band NAOS/CONICA images obtained with adaptive optics does not indicate bow shock structures (see Fig. 1 and e.g. Moultaka et al. 2004, 2005; Viehmann et al. 2005; Clenet et al. 2004). Moreover, all our sources show SEDs that are either flat between 4.7 and 20 $\mu$m, like the type 2 sources of Viehmann et al. (2006) (IRS 5NE and IRS SS, see Fig. 7), or increase towards longer wavelengths (IRS 5E, IRS 5SE1 and IRS 5SE2).
Fig. 7. The SEDs of the different types of MIR-sources introduced by Viehmann et al. (2006) compared to the five compact MIR sources located east of IRS 5 and the unclassified source IRS 13N: type 1: luminous northern arm bow shock sources, type 2: lower luminosity bow shock sources, type 3: cool stars and type 4: hot stars. For the SEDs shown in the right panel see data and error estimates in Table 2 and the corresponding caption. There is a strong onset of dust emission longward of 2.2 \( \mu m \) in these sources. The strongest change is present in the IRS13N sources (see Eckart et al. 2004). For sources without such a strong IR-excess (e.g. IRS 5 SE2) the transition from the non-thermal to the thermal IR is smoother.

This is similar to IRS 13N where a strong foreground extinction and/or dust emission (\( T > 500 \) K) was assumed (Eckart et al. 2004). The object could be identified as a cluster of stars that heat the local environment of the mini-spiral or young stars with ages of 0.1 to 1 Myr.

The sources east of IRS 5 show very weak luminosities in \( H \)- and \( K \)-band. In the NIR two-color diagram (Fig. 8) IRS 5NE, IRS 5E and IRS 5S are located close to the positions of group II Herbig Ae/Be stars with ages of about 0.1 to 1 million yr after correction for the 30 mag of the foreground extinction. These Herbig Ae/Be stars are young stars of intermediate mass (2–8 \( M_\odot \)), embedded in dust that is not confined in disks (e.g. Hillenbrand et al. 1992). Since the sources east of IRS 5 show similar SEDs as the IRS 13N sources and their \( K \)-band spectra are fitted by intermediate mass giants, their colors and SEDs are most probably due to the dust they are embedded in. IRS 5SE1 is less luminous in the NIR and MIR. This matches the fit of the spectrum by a giant of higher temperature than the other sources east of IRS 5.

3.4. Emission lines

The resolution in our spectra is low. Therefore we used simple Gaussian fits to derive the emission line fluxes. We list the fluxes \( F \) and line widths \( \nu \) (corrected for the spectral resolution) of the detected features in Table 5. In this table, the uncertainties take into account that the \( \text{Pa}\alpha \) line is located in a spectral region of lower SNR. In general, no emission lines are expected, especially if the stellar source is of late type. Therefore, a different source in the line-of-sight must be the origin of the emission lines. The gas and dust of the circum-stellar media and/or the northern arm of the mini-spiral could be responsible for all detected emission lines: the consistent average line widths suggest the same source for all emission lines.

The hydrogen recombination lines \( \text{Pa}\alpha \) (1.8756 \( \mu m \)) and \( \text{Br}\gamma \) (2.1661 \( \mu m \)) are the most prominent emission features in all observed spectra. Like the HeI line at 2.0587 \( \mu m \), they either arise in gas in the vicinity of hot early type stars or in the more extended gas distribution of the mini-spiral. In this case the gas is ionized and heated by the UV radiation field in the central parsec and therefore also linked to the presence of the massive and hot He-stars.
Table 5. Fluxes and line widths (and their 1σ uncertainties) of the detected emission lines for the different observed K-band sources. The line fluxes of Brδ and Paα suffer from atmospheric calibration problems and have to be taken with caution. For spectral flux calibration – see Sect. 2.2.

| Object     | Line Feature | $F \pm \Delta F$ [10^-19 W/m^2] | $\nu \pm \Delta \nu$ [km s^-1] |
|------------|--------------|---------------------------------|---------------------------------|
| IRS SNE    | Pa α         | 551 ± 93                        | 400 ± 384                       |
|            | Br δ         | 50 ± 8                          | 554 ± 370                       |
|            | Br γ         | 50 ± 7                          | 356 ± 332                       |
| IRS SE     | Pa α         | 649 ± 147                       | 390 ± 384                       |
|            | Br δ         | 47 ± 9                          | 492 ± 370                       |
|            | Br γ         | 87 ± 18                         | 357 ± 332                       |
| IRS SS     | Pa α         | 649 ± 106                       | 490 ± 384                       |
|            | Br δ         | 45 ± 7                          | 493 ± 370                       |
|            | He I 21       | 21 ± 3                          | 428 ± 349                       |
|            | Br γ         | 72 ± 11                         | 402 ± 332                       |
| IRS SSE    | Pa α         | 770 ± 176                       | 489 ± 384                       |
|            | Br δ         | 96 ± 15                         | 508 ± 370                       |
|            | He I 21       | 29 ± 4                          | 532 ± 349                       |
|            | Br γ         | 98 ± 15                         | 429 ± 332                       |

4. Discussion

Here we discuss the properties of the compact MIR sources east of IRS 5 based on their spectra, proper motions as well as their clustering and possible interaction with the local ISM of the GC.

Proper motions: The compact MIR excess sources close to the northern arm of the mini-spiral show proper motions to the east-southeast and northwest. These motions are different from the overall motion of the gas contained in the northern arm which moves predominantly southward in this section of the mini-spiral (Paumard et al. 2006; Muzic et al. 2007). However, the motions of the compact sources may well be consistent with the motion of objects that are located in the clockwise and counter clockwise rotating stellar disks of the central cluster. In that case, the spatial extent of the two stellar disks would be larger than currently assumed (Genzel et al. 2003; Paumard et al. 2006). The IRS SE and IRS SNE sources show proper motions towards the northwest. This is in agreement with the overall motion of sources in the clockwise rotating disk of stars. If the compact MIR bright objects east of IRS 5 were in interaction with the mini-spiral they would also be located behind the center of the stellar cluster – as the mini-spiral is in this region. IRS SSI to 3 and IRS SSE1 show proper motions to the east-southeast. This is in agreement with the overall orientation of the counter clockwise rotating disk of stars. This stellar disk also has a higher velocity dispersion compared to the clockwise rotating disk, such that the sources could also be located behind the center of the stellar cluster. Given the width of the mini-spiral and the apparent separation and proper motion of the sources their possible interaction with the mini-spiral must still be ongoing or must have been very recent (less than a few hundred years ago).

A comparison to more luminous and well studied sources in the GC stellar cluster suggests four plausible explanations for the sources discussed here:

1. They could be young stellar objects (YSOs) which have been formed while falling into the central parts of the 0.3 pc core radius stellar cluster. These objects could be bright in the MIR since they are still surrounded by their proto-stellar dust shells or disks which are about to be lost in the dense stellar environment of the central cluster. If we find evidence for this hypothesis it will have a profound influence on the yet unsolved formation process of young stars in the central cluster.

2. They could be low luminosity counterparts of the more luminous bow shock sources (i.e. IRS 5, 10W) within the central 5″.

3. They could be a more dispersed group of stars similar to the IRS 13N complex described by Eckart et al. (2004) (Fig. 1). They are more luminous than the sources in the IRS 13N complex which may be due to the fact that they are less extinct, but show similar SEDs and colors.

4. They could be lower luminosity but dust forming AGB stars.

IRS 5NE, SE, 5S are difficult to explain as AGB stars:

Several bright (m_K = 10 to 12 mag) AGB stars represent both an intermediate-mass and an intermediate-age component of the GC stellar cluster with an age of about 100 Myr (Lebofsky & Rieke 1987; Krabbe et al. 1995; Blum et al. 1996a; Genzel et al. 2003). In addition to bright blue super giants (in the IRS 16 and IRS 13 complexes) and red super giants (IRS 7) these AGB stars dominate the H- and K-band images. Prominent representatives are IRS 12N, IRS 10EE and IRS 15NE.

A possible scenario is that the observed late type sources that are MIR bright and associated with dust emission are AGB stars up to 3 mag fainter than their brighter representatives in the central stellar cluster (see above). Luminous and dust-enshrouded AGB stars can be found close to the tip of the AGB. They will not evolve significantly in luminosity before mass loss ends their AGB evolution. The total span of mass-loss rates which can be derived from observations reaches from 10^{-7} to 10^{-5} M⊙/yr (van Loon et al. 1999) with typical wind velocities of the order of 10–20 km s^{-1} (e.g. Bergeat & Chevallier 2005; Hagen 1978). In general, more luminous and cooler stars are found to reach higher mass-loss rates. Stellar model calculations (Schröder et al. 2003) show a collective mass-loss rate of 5.0 \times 10^{-7} M⊙/yr for a synthetic sample of more than 5000 brighter tip-AGB stars, which makes them excellent candidates for MIR excess emission. Also Tanner et al. (2002; see their Table 4) have pointed out that such AGB stars could be bow shock sources with winds of up to 40 km s^{-1} and appreciable stand off distances. Therefore IRS 5NE, SE and 5S may be AGB stars and a significant amount of the MIR excess may be due to dust shells produced by the individual sources.

There are, however, indications that the sources are young:

**Indications for a bow shock source near IRS 5SE**

Our measurements allowed us to narrow down the stellar types of each observed source neglecting the influence of the mini-spiral. With the exception of IRS S5E all sources show characteristics of K-type giants with T < 5000 K. Here, however, the reduced K-band spectrum is a composition of the spectra of the individual sources IRS SE2 and IRS SE1. IRS SE2 is blue and brighter than IRS SE1. Following the analysis of the overall spectrum of IRS 5SE in Sect. 3.2 we therefore identify IRS 5SE2 as a hot early type star of at least spectral type B3 and attribute the CO bandhead contained in the overall spectrum of IRS SE to the fainter component IRS SE1. Due to confusion with IRSS SE2 the CO bandhead of the western source IRS SE1, a cool late type star that is bright in N- and Q-bands, is diluted and therefore the stellar template we derive suggests an earlier type source. All observed sources show UV excited emission features from the gas and dust clouds they are embedded in. In all of the cases we cannot exclude that the dominant part of the hydrogen recombination lines are in fact due to emission from the mini-spiral in that region. Since the spectrum of IRS S5E shows contributions from an early type star, and a bow shock structure is visible, superimposed on IRS 5SE1, we conclude that IRS S5E should be classified as a lower luminosity bow shock source.
5. Summary

We have presented new imaging, proper motion, and spectroscopic data on a class of compact MIR sources in the GC. The brightest sources contained in IRS 5NE, 5E and 5S may be AGB stars and a part of the MIR excess may be due to dust shells produced by the individual sources. They are, however, fainter than expected for AGB stars in the GC stellar cluster. In all cases an interaction with the mini-spiral cannot be excluded and their broad band infrared SEDs indicate that they could be lower luminosity counterparts of the identified bow shock sources, and at least in the case of IRS 5S and IRS 5E1 may belong to dynamically young associations of stars. The blue star IRS 5SE2 is that best candidate associated with a bow shock source.

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