VLTI Observations of IRS 3: The brightest compact MIR source at the Galactic Centre

The dust enshrouded star IRS 3 in the central light year of our galaxy was partially resolved in a recent VLTI experiment. This observation is the first step in investigating both IRS 3 in particular and the stellar population of the Galactic Centre in general with the VLTI at the highest angular resolution. We outline what scientific issues can be addressed by a complete MIDI dataset on IRS 3 in the mid-infrared.

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The nature of star formation and evolution close to a super-massive black hole is of broad astrophysical interest. Due to its proximity (~ 8 kpc), the centre of our galaxy (GC) offers a unique variety of experiments and observations, which grows together with the technical progress and the commissioning of new instruments. At present, the angular resolution of the VLTI already allows us to resolve the dust envelopes of some stars in the GC. A structural analysis on the scale of tens to hundreds of AUs opens the way for a detailed study of stellar properties, as well as of the interaction between a star and the GC environment.

The unusually large number of massive, young stars in the stellar cluster at the GC (e.g. Genzel et al. 2003, Eckart et al. 2004, Moultaka et al. 2004) is indicative of an active star formation history despite the tidal forces exerted by the gravitational potential of the central black hole. The presence of numerous stars in short-lived phases of their development, such as dust producing Wolf-Rayet (WR) stars, indicates that the most recent star formation episode took place not more than a few million years ago. IRS 3 with its 1–2 arcsec extended mid infrared (MIR) excess is one of the most prominent of these sources (Viehmann et al. 2005; Moultaka et al. 2004).

Why is this source a good starting point for VLTI observations of the GC region with MIDI, the MID-infrared Instrument for the VLT Interferometer? Pott et al. (2004) reviewed the technical aspects of VLTI-GC observations, which are ideally suited to study the capabilities of the new instruments close to the system limits under normal observing conditions. Here we focus mainly on astrophysical aspects.

The nature of IRS 3 is not yet identified unambiguously. In the late 1970s, it was argued that IRS 3 is a dust-enshrouded supergiant with a compact circumstellar dust shell. IRS 3 was found to be the most compact and (together with IRS 7) hottest MIR source (T ~ 400 K) in the central cluster, with total integrated flux densities of about 30 Jy at 8 µm to 12 µm.

Given its high luminosity of ~ $5 \cdot 10^4\ L_\odot$ IRS 3 may in fact be a star at the very tip of the Asymptotic Giant Branch (AGB). These most luminous dust-enshrouded AGB stars will stay at a high luminosity during their entire mass loss phase. Their mass-loss rates, derived from observations, span a range from about 10^{-7} to $10^{-3}\ M_\odot yr^{-1}$ (van Loon et al. 1999) with wind velocities of the order of 10–20 km/s. In general the more luminous and cooler stars are found to reach higher mass-loss rates. This is in agreement with model calculations. For a synthetic sample of more than 5 000 brighter tip-AGB stars a collective mass-loss rate of $5.0 \times 10^{-4} M_\odot yr^{-1}$ was found. Of these, 20 are carbon-rich super-giants with a large IR excess and a mass-loss rate well in excess of $10^{-6} M_\odot yr^{-1}$, including 10 dust-enshrouded, extreme tip-AGB stars seen in their short-lived (~ 30 000 yrs) super-wind phase with a mass loss of $>10^{-5} M_\odot yr^{-1}$. They produce about 50% of the collective mass-loss of the whole sample.

A recent identification of a carbon-rich WR star of type WC5/6 as a near infrared counterpart of IRS 3, based on the detection of a 2.11 µm He I/C III line (Horrobin et al. 2004), is probably applicable to a K ~ 15 faint star ~ 120 mas east of the bright source. However, given the fact that most other dust enshrouded sources in the central stellar cluster have been associated with hot and luminous young stars, an identification of IRS 3 with a massive WR star in its dust forming phase cannot be fully excluded either. Extensive mass loss associated with bright continuum emission takes place in the WC stage. Products of helium burning are dredged up to the surface, enhancing the carbon and further depleting the hydrogen abundance.

As shown by Viehmann et al. (2005), the dust shell of IRS 3 is interacting with the GC ISM. They find the photocentre of IRS 3 in the ISAAC M-band image shifted by ~ 160 mas to the NW with respect to the L-band image. About 1″ to the southeast of IRS 3 high-pass filtered L- and M-band NAOS/CONICA images show a sharp interaction zone of the outer part of the dust shell with the wind arising from the IRS 16 cluster of hot, massive Helium stars.

We designed a VLTI experiment with MIDI (N-band, 8–12 µm) to investigate the dust shell of IRS 3. The lower spectroscopic resolution used (R = 30) offers dispersed visibility data over the entire *N*-band, as well as a spectrum of the uncorrelated flux density. The first VLTI detection of a star in the GC was achieved in June 2004: We partially resolved IRS 3 with the VLTI using MIDI on the 47 m UT2-UT3 baseline (see Figures 1 and 2).

It was found that ~ 25 % of the flux density of IRS 3 is concentrated in a compact (i.e. unresolved) component with a size of ≤ 40 mas (i.e. ≤ 300 AU). This agrees with the interpretation that IRS 3 is a luminous compact object in an intensive dust forming phase. In general, the visibility amplitude was found to increase with wavelength by ~ 0.05. Although the uncertainty of a single visibility value (5–10 %) seems to be too large to unambiguously identify such a trend, the error on the slope (i.e. wavelength dependent variation) of a visibility dataset over the entire *N*-band is of the order of 1 % only. This trend indicates that the compact portion of the IRS 3 dust shell is extended and only partially resolved on the UT2-UT3 baseline. We also find indications for a narrower width of the 9.3 μm silicate line towards the centre, indicating the presence of fresh unprocessed small grains closer to the central star in IRS 3 (van Boekel et al., 2003).

In addition, the remaining six of the seven brightest (*N*-band) MIR excess sources in the GC were observed (IRS 1W, 2, 8, 9, 10, 13) with the same instrumental setup. Most of them are located in the Northern Arm of the ISM or associated with the mini-spiral of ionised gas and warm dust (Figure 1). They appear to be hot stars with strong, fast winds that create bow shocks as they plough through the gas and dust of the mini-spiral. The MIR emission associated with theses sources arises most probably from these bow shocks that can be resolved at 2 μm.

All of these six sources are fully resolved at a 2 Jy flux level, i.e. only upper limits on the visibility limits could be estimated with the baseline used. Therefore, IRS 3 is not only the hottest but also the most compact bright source of MIR emission within the central stellar cluster.

We will conduct further VLTI/MIDI observations of IRS 3 to enlarge the *uv*-plane coverage (Figure 3). The foreseen baselines UT3-UT4 (62 m) and UT1-UT4 (130 m) are complementary to UT2-UT3 in terms of length and orientation. The final dataset will cover an angular resolution of about 13 mas at the longest baseline up to 100 mas. These observations will be ideally suited to provide information about the radial structure and symmetry of the correlated flux, about the inner edge of the dust shell, as well as about a possible binary character of IRS 3. Collisions of winds in binary systems may support dust formation through density increase and rapid cooling of the material.

A bright compact source like IRS 3 is also technically essential for future VLTI phase-reference experiments at 10 μm in order to investigate other nearby sources, e.g. the Sgr A* black hole. For this purpose it is important to know the strength and compactness of IRS 3 on the longest baselines.

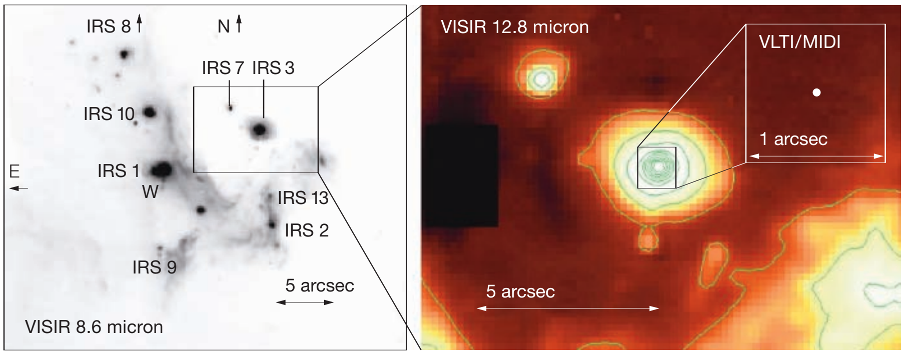

Figure 1: VISIR MIR images with the observed targets indicated and an inset demonstrating the scale on which the current UT2-UT3 VLTI/MIDI data detected a compact source with a visibility of about 25%.

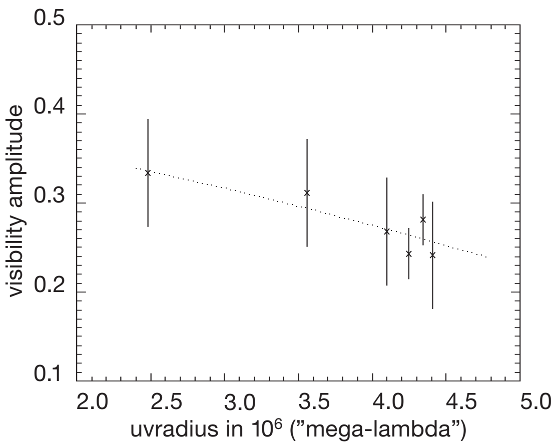

Figure 2: Median 8–12 μm visibility of IRS 3 as a function of projected baseline length. Currently the uncertainty of the visibilities is above all affected by the instrument calibration. Therefore the errors are given by the standard deviation of the instrument calibration over the entire night.

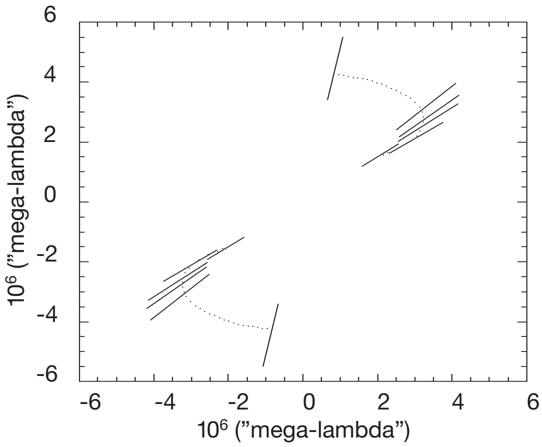

Figure 3: The *uv*-coverage of the observations in P73 is shown. The dotted line indicates the change of projected baseline length due to earth rotation. Whereas the earth rotation curve is calculated at a central wavelength of 10.34 μm the solid lines are showing the *uv*-coverage of each dispersed, calibrated visibility dataset.

References

van Boekel, R., Waters, L. B. F. M., Dominik, C. et al. 2003, A&A, 400, L21
Eckart, A., Moultaka, J., Viehmann, T. et al. 2004, ApJ 602, 760
Genzel, R., Schödel, R., Ott, T. et al. 2003, ApJ 594, 812
Horrobin, M., Eisenhauer, F., Tecza, M. et al. 2004, AN, 325, 88
Moultaka, J., Eckart, A., Viehmann, T. et al. 2004, A&A 425, 529
Pott, J.-U., Glindemann, A., Eckart, A. et al.2004, SPIE, 5491, 126
Schödel, R., Ott, T., Genzel, R. et al. 2002, Nature, 419, 694
van Loon, J. Th.; Groenewegen, M. A. T.; de Koter, A. et al. 1999, A&A, 351, 559
Viehmann, T., Eckart, A. Schödel et al. 2005, accepted by A&A, astro-ph/0411798