Table 3.

	Interferometry		Computation	
	P/V	RMS	P/V	RMS
Mirror surface	148 nm	24 nm	107 nm	25 nm

P/V values comes from the presence in the laser beam of some artefacts which generate a few local sharp defects.

It is worth noting that the RMS value of the high frequency defects generated by the axial support is three times lower when the mirror is resting on the tripods. This factor of three is in very good agreement with the computation.

In order to evaluate the noise of the measurements, we have computed the difference between the average of three batches of fifty interferograms of the mirror resting on the tripods. The RMS error on the mirror surface error is 5.6 nm.

Table 4.

	Interferometry		Computation	
	P/V	RMS	P/V	RMS
Mirror surface	59 nm	7.3 nm	37 nm	8 nm

5. Conclusion

Joe Dalton was delivered in time and well within specifications. It is now lying on the grinding machine at REOSC, where everything is ready for the next steps: glueing of the axial interfaces (in August 1993), followed by the exciting tasks of grinding it aspherical to a few microns accuracy, and then polishing to optical accuracy. Looking forward to meeting Bill, William and Averell!

Ground-Based Astronomy in the 10 and 20 μm Atmospheric Windows at ESO – Scientific Potential at Present and in the Future

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1. Introduction

This article is especially written for those who have little or no experience with astronomical observations in the infrared, especially longwards of 2.2 μm. In recent issues of the *Messenger* (Käufl et al. 1992, Käufl 1993) there were several reports on instrumentation at ESO for observations in the 10 and 20 μm atmospheric windows (N and Q band in Johnson's photometric system). In this article a description of the perspectives of ground-based astronomy in these windows will be given. A special focus is set on the astronomical applications with respect to what is possible (and what not) with the present equipment; which improvements are anticipated at the VLT and how these observations compare to air-borne and space-based infrared astronomy.

2. Targets for Ground-based Infrared Observations at Wavelengths longer than 5 μm[1]

2.1 Atmospheric constraints

The terrestrial atmosphere has a substantial opacity in the infrared due to rotational-vibrational transitions of trace molecules (e.g. CO_2, H_2O, CH_4, O_3). In some spectral regions these molecular transitions blend creating a practically opaque sky. The region between 8 and 13 μm, however, is reasonably free of interfering molecular transitions. Remaining absorption lines in the window itself and at the "red" edge are rather stable and observations can be easily corrected for these perturbations. On the "blue" edge H_2O is a source of variable opacity following the rapid variations of local humidity. Close to this edge more careful observing procedures are required. Beyond ≈ 13.3 μm the atmosphere becomes opaque due to the ν_2-band of CO_2 and opens again around 16.5 μm. A forest of lines of H_2O, however, prevents the sky from getting clear so that even in the best part of the 20 μm window the average opacity more or less corresponds to 50 % and is variable. Beyond 20 μm the water vapour lines become a real problem. The term "Q-window" is misleading and should be replaced by "Q-venetian-blind". Depending on site and local weather, limited astronomical observations are possible up to 30-35 μm. Beyond ≈ 35 μm the atmosphere remains opaque until the sub-millimetre region (≥ 300 μm) is reached.

In conclusion, long wavelength infrared astronomical observations are constrained to:

- $\lambda \approx$ 8–13 μm with very good conditions
- $\lambda \approx$ 16.5–30 μm with reasonable to poor conditions

2.2 Wien's Law, Kirchhoff's Law and their consequences

Wien's law relates the maximum of the Planck curve for black body radiation with its temperature

$$\lambda_{max} = \frac{2898\,\mu m}{T[K]}$$

For a telescope at ambient temperature λ_{max} lies exactly in the centre of the 10 μm atmospheric window. Translated into the words of optical astronomy this is equivalent to observing stars from within a furnace (like the one in which the VLT blanks have been casted) rather than from a dark astronomical site.

To those readers not familiar with infrared astronomy it is also useful to recall Kirchhoff's law

$$\alpha(\lambda, T) = \varepsilon(\lambda, T)$$

which states that for all wavelengths and temperatures the emissivity equals exactly the absorptivity. For ground-based infrared astronomy this means that e.g. a

[1] Some of the argumentation holds also for the range of 3–5 μm. This transition region between the near infrared and the thermal infrared, however, is outside the scope of this article.

change in opacity from 5 % to 20 % has the minor effect of reducing the signal by ≈ 16 % but increases the background radiation level by a factor of 4.

Typical background generated signals at 10 μm are of the order of 10^{10} electrons/pixel, equivalent to a magnitude $m_N \approx -2.50$ (for details of background noise limited operation see e.g. H. U. Käufl et al. 1991). In spite of the high background it can be expected (based on experience with today's instrumentation) that a limiting magnitude at *N* of the order of 12 will be achievable with ESO's VLT, i.e. 14.5 magnitudes fainter than the background.

At this point the reader may ask the question: why bother to try to observe under such conditions at all? Part of the answer is again Wien's law: if one wants to study radiation from the cold universe one cannot do it at short wavelengths. For objects colder than 500 K the radiation is best (i.e. with the highest signal to noise ratio) detected at wavelengths around 10 μm. Also many objects (most stars, galaxies and QSOs) tend to have $m_V - m_N > 0$. Usually, however, this is not quite sufficient to outweigh the background induced loss in sensitivity compared to visible wavelengths. There is, however, a substantial number of infrared bright but obscured sources with $m_V - m_N \approx 15$ to 25. In some of these cases it is not even sure if the light at V is radiation from the object itself or just scattering of interstellar light on the dust-shell.

2.3 On the scientific interest in dust[2]

By now it is well known that there is a lot of dust in the universe which comes in all grain sizes, basically from macroscopic grains to aggregates of several 100 atoms (e.g. the PolyAromatic Hydrocarbonates, PAH). Working at $\lambda \geq 2.2$ μm allows one to actually penetrate dust aggregations. For a nice example see e.g. the article by Peletier and Knapen (1992) who compare V and K images of the edge-on galaxy NGC 7814. The strong dust-lane apparent in the V image is fairly transparent at 2.2 μm. Observation of the dust itself (e.g. to study its chemical composition) is governed by Wien's law and much of the dust is simply too cold to be observable in the infrared, even at the longest wavelengths accessible from the ground. But there exist interesting exceptions: compact objects and PAHs.

Many objects are sufficiently compact so that the dust is hot enough to be observable with ground-based IR astronomy. Usually these dust shells provide for a "calorimeter" which allows to determine bolometric fluxes from the integrated infrared radiation with very little uncertainties. It is also in many of these objects (especially stars on the Asymptotic Giant Branch, AGB) where the dust is actually being produced. While the physics of the mass-loss of these objects is poorly understood (see e.g. the review paper by Lafon and Berruyer, 1991) it is now clear that they are of some importance for galactic evolution, since all stars having main-sequence masses $\leq 8 M_\odot$ will follow the track from a red giant via the AGB to a Planetary Nebula, leaving a white dwarf as compact remnant and returning the rest of the mass to the interstellar medium. The 2nd ESO/CTIO workshop held in La Serena in 1992 was also entirely devoted to this topic (proceedings edited by H.E. Schwarz, now available from ESO). Dust is of course also of extreme interest in the context of young stars and star formation, especially of low mass stars. This ranges from Herbig-Haro type objects to circumstellar disks in young stars. A recent highlight in this context: sub-arcsec spatial resolution 10 μm images of the disk of β-Pictoris obtained with TIMMI at ESO's 3.6-m telescope (P.O. Lagage, private communication).

The PAHs – normally too cold to be detectable – are small enough that the energy of single UV photons hitting them raises their temperature to typically 1000 K. The PAHs then cool via their well-known molecular vibrations giving rise to several strong features in the 10 μm atmospheric window.

The spectroscopic observation of dust in the 10 μm atmospheric window is best done with a resolution $\frac{\lambda}{\Delta\lambda} \approx 300$ because only this resolution allows for an unambiguous discrimination of broad solid-state dust features, narrow PAH-transitions and very narrow emission lines.

2.4 Molecules

Many molecules of astrophysical importance (e.g. SiO, CO_2, C_2H_2, C_2H_4, C_2H_6, SiH_4 or NH_3) have rotational-vibrational transitions between 8 and 13 μm creating absorption lines in spectra of cool stars. These spectra contain practically all information on chemistry and physical conditions of photospheres and circumstellar envelopes. Depending on quality (noise, resolution) such spectra allow to retrieve much of this information. Molecular spectra usually form bands which allow to select "strategic" portions containing transitions sensitive to temperature and/or gradients and with optical depths close to unity. Isotopic shifts of transitions are easily resolved. In AGB objects the molecular spectra tend to originate from the region where the dust formation and the acceleration of the outflowing material to its terminal velocity takes place. Dust and parent molecules can be observed simultaneously. Radio observations, on the contrary, are usually restricted to rotational transitions in the vibrational ground state and thus to cold material in regions where the dust formation is completed and the material has been accelerated to its terminal velocity. Typical linewidths are of the order of the sound-speed. The spectral resolution should match this, i.e. approach the km/s realm.

Two of the three lowest energy quadrupole transitions of molecular hydrogen in the vibrational ground state (H_2 (0,0) *S* (2) at 12.38 μm and H_2 (0,0) *S* (1) at 17.03 μm) are observable from ground-based telescopes. Since they are partially overlapping with telluric lines such observations require a spectral resolution high enough to discriminate against the atmosphere, regardless of their instrinsic line width.

2.5 Ions and atoms

A variety of atomic lines are accessible for ground-based observations in the 10 and 20 μm atmospheric windows. Those include normal hydrogen recombination lines (H I(7-6) at 12.36 μm or H I (9-7) at 11.30 μm) and forbidden lines (e.g. [FV] at 13.4 μm, [N II] at 12.79 μm, [NaIV] at 9.04 and 21.3 μm, [PIII] at 17.87 μm, [SIII] at 18.68 μm, [SIV] at 10.52 μm, [ClIV] at 11.76 and 20.37 μm, [ArIII] at 8.99 and 21.84 μm, [ArV] at 13.07 μm, [KVI] at 8.84 μm and [CaV] at 11.47 μm, for more details as well as a discussion on the formation of these lines in H II regions see e.g. the original article by Simpson 1975). Many of these lines have already been utilized to assess physical conditions of ionized materials while others still await their discovery in the interstellar medium. Of extreme interest for quantitative modelling in this context is that extinction corrections are much simpler or even not required at all, since most objects are practically optically thin at $\lambda \approx 10 - 20$ μm. For a very recent example see e.g. Jennings et al. (1993) who report fully resolved spectra of [CoII] at 10.52 μm, [NiI] at 11.31 μm and [FeII] at 17.94 μm in SN 1987A, 612 days after outburst.

Since typical intrinsic linewidths are of the order of 10–30 km/s they can be observed with maximum sensitivity if one uses a spectrograph which just not resolves these lines. At a spectral resolution exceeding ≈ 20 km/s kinematic studies inside of objects opaque for visi-

[2] This is not at all complete, just a couple of examples.

ble light become possible. Observing such lines in external galaxies requires highest sensitivity and therefore is best done with a resolution matching the typical velocity dispersion inside the field of view of one pixel (i.e. resolutions between 10 and 500 km/s are required).

2.6 Magnetic fields

The ratio of Zeeman-splitting to Doppler-width for atomic lines increases linearly with the wavelength of observations, i.e. Zeeman-splitting of lines at 10 μm is 20 times larger than at 0.5 μm. Brault and Noyes (1983) observed and identified for the first time such Zeeman splitting of transitions of Mg I at 12 μm in solar spectra. Deming at al. (1988) used these lines to map with arcsec spatial resolution magnetic fields around sunspots. Applying such techniques on other stars so far is quite difficult because of a lack of suitable instrumentation on large enough telescopes.

3. State of the Art, Now and in the Near Future

3.1 The IRAS database

With the publication of the IRAS catalogues a great wealth of precise high quality data readily accessible to non-specialists became available to the astronomical community. Thus the scientific value of infrared astronomy became recognized in a much broader community than was reached in the pioneering days. Still the IRAS mission had its limitations:

- being largely a survey-type mission the sensitivity is not extremely high: 250–1000 mJy at 10–20 μm (for point sources; equiv. m_N = 3.9–5.3, m_Q = 2.5–4.0)
- spatial resolution is limited (≈ 25 arcsec)
- spectroscopic data are only available for the brightest sources while the spectral resolution of $\frac{\lambda}{\Delta\lambda} \approx 25$ allows only for rather restricted investigations/conclusions.

Just for comparison it should be noted that in the 10 μm window a bolometer at the ESO 1-m telescope would allow for deeper photometry.

3.2 Do not wait for ISO

"This star is not in the IRAS catalogue, so we have to wait for ISO to settle this question" (quote from a colloquium speaker at ESO). This is just one example of the widely spread belief that follow-up observations in the infrared at long wavelengths need to wait for ISO (the ESA Infrared Space Observatory). Clearly ultimate sensitivity on point sources and especially on extended sources at 10 μm can only be achieved with cryogenic telescopes from space; but space-based infrared observing platforms are like apparitions of bright comets: they are rare and short transient things (e.g. 18 months for the case of ISO). Any form of synoptic observations (e.g. bolometric light curve of a Mira) are virtually excluded. Also observations requiring sub-arcsec spatial resolution (and consequently telescopes larger than 4 m) can only be done from ground. In addition, as a rule of the thumb, the higher the spectral resolution the less it is advantageous to observe from space. In that sense the working group on infrared aspects for the VLT also recommended to equip the VLT with instrumentation which complements the performance of space observations (c.f. Moorwood, 1986). At this point I would also like to add the advice: do not wait for the VLT. In the following chapters I will describe what is available at ESO now or in the near future and what is planned to be available at the VLT.

3.3 TIMMI, ESO's 10 μm Camera/ Spectrometer

Recently ESO has complemented its suite of infrared instrumentation (the photometers/bolometers at the 1-m, 2.2-m and 3.6-m telescopes, IRSPEC, the 1–5 μm medium resolution spectrograph at the NTT, and IRAC2, the 1–2.5 μm near-infrared camera at the 2.2-m telescope) by adding TIMMI (see e.g. Käufl et al. 1992 for a detailed description of the instrument). While this camera has been first offered on a shared risk basis in period 52, ESO has already received 24 observing proposals asking for a total of 85 nights. TIMMI will now be mounted for 2 (out of 6 available) full moon periods in the coming semester. The proposals cover a great variety of topics: solar system, stars (young, old, circumstellar disks, outflow), interstellar medium and galaxies. They involve broad- and narrow-band imaging and mostly rely on sub-arcsecond resolution which is only possible from a good 3–4-m-class ground-based telescope. A further increase of the demand is expected once the spectroscopic mode ($\frac{\lambda}{\Delta\lambda} \approx 300$, 1-pixel sampling in long slit mode) of the camera is implemented. It should be noted that there are more than 10 similar camera projects under way or already in use worldwide. Still TIMMI is to the best of our knowledge the only system available without restrictions to visiting astronomers.

3.4 Potential upgrades of TIMMI

The implementation of the spectroscopic mode in TIMMI will be done using grisms. These grisms need the grating structure to be machined directly into the base prism material (e.g. Germanium). Such devices are not easily available commercially. ESO has a contract with the Institut für Festkörpertechnologie, München, of the Fraunhofer Gesellschaft to produce such prisms. Once they are available they can immediately be built into TIMMI to provide for the spectroscopic mode. TIMMI works today with a 64 × 64-element detector (gallium doped silicon) produced by LETI/LIR of Grenoble/France. At this laboratory there is, also with ESO participation, a new device under development which will have both a substantially higher quantum-efficiency and format[3]. Since this new detector will be basically pin-compatible with the one presently in use in TIMMI, an upgrade with this device is feasible. While all modes will benefit substantially from the increase in quantum-efficiency and better sampling, the device would also allow to increase the spectral resolution for grism spectroscopy to $\frac{\lambda}{\Delta\lambda} \approx$ 500–600 with 2-pixel sampling per spectral element.

4. Present Plans at ESO for the 10 and 20 μm Atmospheric Window at the VLT

4.1 VLT specific aspects

Great care is being taken in the VLT design to preserve the intrinsic quality of the site (Paranal). The design ensures good performance in the infrared (pupil on M2 for a field of up to 3 arcmin, no baffles, in-situ mirror cleaning and washing, emissivity at Cassegrain ≈ 6% and provision of a chopping secondary).

Extrapolating the Paranal seeing measurements at 500 nm to λ ≈ 10 μm using Kolmogorov-Taylor theory yields a monthly averaged seeing between 0.3 and 0.5 arcsec, i.e. close to the diffraction limit of the VLT ($1.22\frac{\lambda}{D}$ = 0.3 arcsec at 10 μm at the VLT). According to measurements done with a 10 μm interferometer (Bester et al. 1992), this is a conservative extrapolation. Thus the spatial resolution will always be close to diffraction limited. This image quality also ensures that unresolved sources can be observed ≈ 25 times faster with the VLT than with the 3.6-m telescope. With its fairly dry atmosphere (precipitable H_2O less than 2 mm for half of the time in southern winter) Paranal is a substantial improvement for working at 20 μm when compared to La Silla.

[3] In a forthcoming issue of the *Messenger* there will be a status report of this project.

4.2 Anticipated operating modes of the 10/20 μm instrument at the VLT

According to ESO's instrumentation plan for the VLT (see e.g. S. D'Odorico, 1992) the Cassegrain focus of unit telescope 2 will carry a dedicated 10/20 μm multi-purpose instrument. Installation and commissioning of the instrument is presently scheduled for the second half of 1999. The following operating modes have been identified as the minimum to be implemented to match most scientific objectives addressed above, both for galactic and extragalactic astronomy:

- diffraction limited imaging in the N-band with variable magnification for fields as large as 80×80 arcsec with a suite of filters (incl. potentially fixed-spacer Fabry-Perot etalons)
- diffraction limited imaging for the part of the Q-band accessible with Ga:Si detectors (16.5 to 17.8 μm)
- long slit[4] spectroscopy at 7.9–14 μm with
  - $\frac{\lambda}{\Delta\lambda} \approx 300 - 500$ (i.e. covering the entire band in 'one shot')
  - $\frac{\lambda}{\Delta\lambda} \approx 7000$
  - limited access in spectroscopy to the 16.5-17.8 μm region at $\frac{\lambda}{\Delta\lambda} \geq 3000$

additional (optional) observing modes which would be highly desirable:

- high resolution (i.e. $\frac{\lambda}{\Delta\lambda} \approx 30{,}000 - 50{,}000$, potentially as high as 100,000) long-slit spectroscopy mode for 10 μm
- long slit spectroscopy mode for most of the Q-band ($\frac{\lambda}{\Delta\lambda} \approx 3000$ at ≈ 17–24 μm)

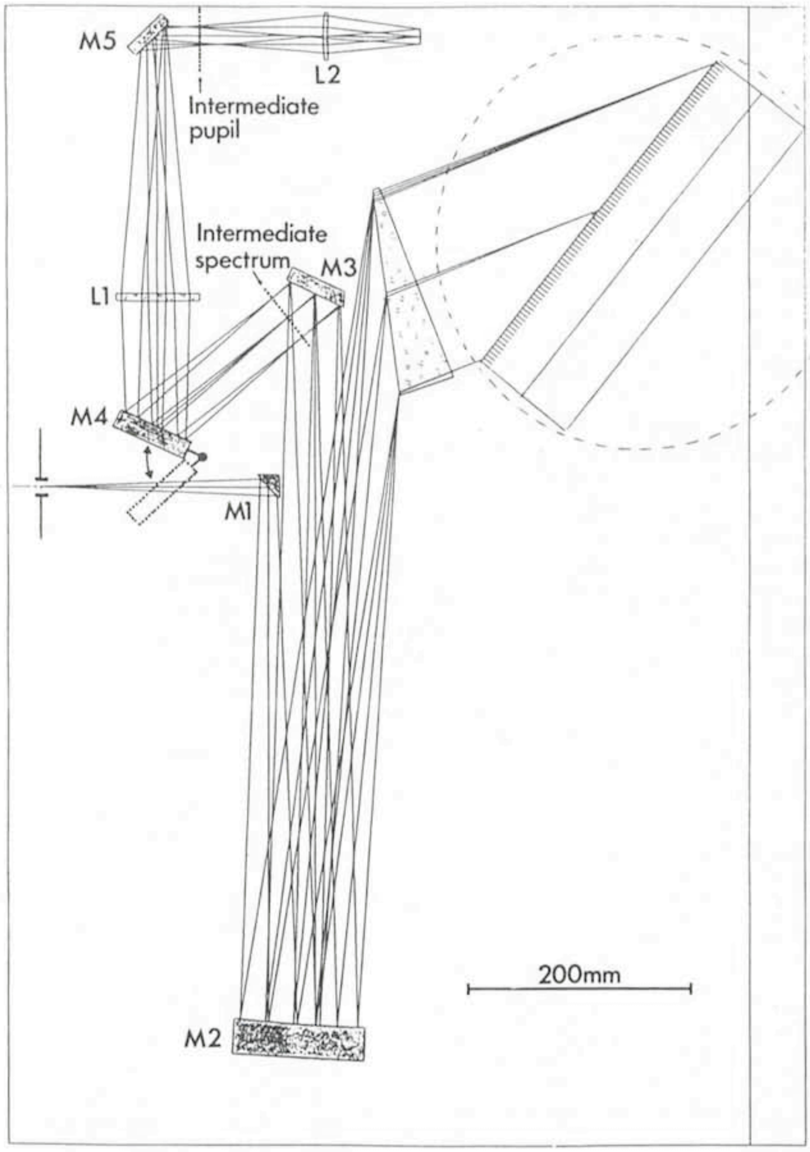
This instrument shall be manufactured by a consortium of institutes in the ESO member states. A study contract has been awarded to a team led by P.O. Lagage at the Service d'Astrophysique of CEN-Saclay (France)[5]. After completion of the study the operating modes may be revised.

4.4 Possible embodiments

In order to define the scope of the above-mentioned study contract, predesigns were made internally at ESO resulting in two proposals:

- A dedicated concept for a 10/20 μm instrument taking full advantage of the relaxed optical requirements in the infrared (Käufl and Delabre, 1992). All observing modes sketched above are feasible with generally close to optimum performance while retaining a comparatively moderate size and complexity. Figure 1 shows this instrument in its high-resolution spectroscopic mode.
- The opto-mechanical concept of ISAAC, the corresponding instrument for the near-infrared (for a description see e.g. Moorwood, 1992), lends itself to an easy modification to implement most of the above-defined observing modes. Only the implementation of high-resolution spectroscopy needs further studies.

The final embodiment will depend on the result of the study. The ESO-internal dedicated design will be used for the sensitivity/performance estimates in the following chapter.



Optical Design of the 10/20 μm Camera/Spectrometer: The instrument is shown in its spectroscopy mode utilizing the anamorphic beam-expansion for highest resolution ($\frac{\lambda}{\Delta\lambda} = 30 - 45000$, diffr. limited). The flat entrance window is omitted. M 1 is a cylindrical and M 2 a toroidal mirror. Whereas the 2-mirror collimator produces a circular beam (diameter ≈ 50 mm) this is changed to an elliptical beam of 50 × 166 mm² by the Germanium prism operating close to the Brewster angle. Even if no suitable coating for the grazing incidence into Germanium can be found still an overall efficiency of collimator plus grating exceeding 40 % can be achieved. In the normal spectroscopy mode the expansion prism will be replaced by a folding mirror which sends the beam to a standard grating unit. M 3 is a folding mirror. Behind M 3 the intermediate spectrum is formed which could be diverted by another kinematic folding mirror (not shown) to feed a dedicated spectroscopic camera for the 20 μm atmospheric window.
M 4 (kinematic mirror) allows to select between the camera mode (dotted position) and the long slit spectroscopy mode. L 1 is the camera collimator lens (Germanium, f = 268 mm, f # = 13.4) which forms an intermediate pupil of 20 mm diameter behind the folding mirror M 5. This is also the location of the filter wheel. L 2 (mounted to a lens wheel) is one of the camera lenses. Shown here is the most critical lens (scale of $6 \frac{arcsec}{mm}$). To achieve background noise limited performance all components before the pupil stop have to be cooled below ≈ 70 K, pupil stop, filter and lens wheel have to be cooled below ≈ 50 K.

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[4] A slit length of the order of 30–40 arcsec is considered sufficient.

[5] See also *The Messenger*, **72**, p. 44 for some background.

4.5 *Sensitivity of such an instrument at $\lambda \approx 10\,\mu m$ in an astronomical context*[6]

Broad Band Imaging: The limiting flux is expected to be 5.4×10^{-4} Jansky (i.e. 12.1 mag). Operating at the diffraction limit of the VLT (i.e. 0.33″ at 10 μm) this instrument will allow to image any celestial object exceeding a brightness temperature of ≈ 90 K, irrespective of its distance as long as it is spatially resolved. For point sources this instrument will be ≈ 3 orders of magnitude more sensitive than the IRAS point source catalogue.

Narrow Band Imaging: At a spectral resolution of $\frac{\lambda}{\Delta\lambda} \approx 100$ the limiting line-integrated flux for ionic lines (e.g. [ArIII], [NeII], [SIV] will be ≈ 1.3 10^{-17} $\frac{W}{m^2}$ per 0.3×0.3 arcsec pixel. This implies that galactic Planetary Nebulae such as NGC 7009 or IC 418 would be detectable up to typically their 150-fold distance, i.e. ≈ 75 kpc. If the size of the intermediate pupil is chosen to be ≈ 20 mm, monochromatic images for a field of 30″ with a spectral resolution as high as 300 are feasible for selected transitions. Because of the better background rejection the sensitivity limits would then be a factor $\sqrt{3}$ fainter.

Low Resolution Long Slit Spectroscopy: In this mode the entire 10 μm window could be observed in one integration with $\frac{\lambda}{\Delta\lambda} \approx 300$–500 to study dust (temperature, composition) and to survey emission lines. The limiting continuum flux for this mode will be 8.7 mJansky (9.0 mag). Spectroscopy of typical galactic C stars or OH stars will be possible even if they were located at distances of 500 to 1000 kpc. Many extragalactic sources are exceeding that limiting flux (e.g. the QSO 3C48 at z ≈ 0.4 is 8 times brighter than the limiting flux given above). While 10 μm spectroscopy of QSOs will certainly be restricted to few bright quasars, these spectra will be of extreme interest because they will allow to study dust (temperature, composition) in these objects and the redshift will move a variety of interesting atomic emission lines into the observable window.

Medium Resolution Long Slit Spectroscopy: This mode allows for the observation of atomic and ionic emission lines combining highest sensitivity and spectrophotometric precision. Limited molecular spectroscopy will be feasible. The limiting flux for sources emitting a continuum is of the order of 60 mJansky (7.0 mag) or 2×10^{-18} $\frac{W}{m^2}$ for emission lines. Galactic PNs (e.g. NCG 7009 or IC 418) would be observable at 300 to 400 times their distance which will enhance the research capabilities on PNs in the Magellanic Clouds substantially. For compact sources, the instrument when compared to the IRAS spectroscopic channel, will have a 200 times higher spectral resolution, will be 100 times more sensitive and provide 0.3″ spatial resolution along the slit. As e.g. the QSO 3C273 exceeds the limiting flux by a factor of 8, extragalactic work at this spectral resolution even up to cosmological distances will become possible.

High Resolution Long Slit Spectroscopy: The limiting flux averaged over one pixel could be of the order of 300 to 500 mJansky. For point sources this implies that most sources in the IRAS point source catalogue are bright enough to be detected with a $\frac{S}{N} \geq 10$ within one hour. This will provide new insight into the kinematic and physical structure of optically thick or obscured compact ionized objects. In stars molecular transitions or Zeeman-sensitive hydrogen-like metal lines can be studied with this mode. Particularly interesting is also that many Asymptotic Giant Branch objects known in our Galaxy could be observed at LMC/SMC distances thus providing for a coherent sample of AGB stars where physics of mass loss and dust formation could be studied in an unprecedented way.

Imaging in the 16.5 to 17.8-μm passband: It can be expected to reach a limiting flux of 13mJy ($m_Q \approx 7$) for this mode on point sources. This would exceed the sensitivity of the IRAS 25 μm channel for point sources with a flat spectrum by a factor of 10–20. E.g. the above-mentioned QSO 3C48 is 50% brighter than the limiting flux. For many sources this channel can thus provide extremely valuable photometric information to judge the bolometric luminosities.

Performance in other parts of the Q-band is difficult to judge since one lacks a precise knowledge or models of the atmospheric spectrum at the VLT site. Furthermore, little is known about detectors which could be available to ESO to be used for this window.

5. Conclusions and Outlook

It has been demonstrated that a dedicated 10/20 μm instrument at ESO's VLT, located on Paranal, certainly an excellent site for IR astronomy, will allow to investigate a significant amount of scientific objectives ranging from the solar system to cosmological distances. In the passbands set by the terrestrial atmosphere, it will in many respects outperform space-based or air-borne observing platforms. The sensitivity increase of such an instrument at the VLT as compared to a 4-m class telescope will be substantial and give astronomers a wide access to objects in the Magellanic Clouds for programmes which today are restricted to few bright stars (also due to lack of suitable focal plane instrumentation). A big boost is especially expected for stars in their early and late stages of evolution. Infrared spectroscopy at spectral resolutions approaching photospheric sound speeds which today are rarely done and restricted to the few brightest stars will become possible for several 10000 stars, thus allowing the systematic study of samples selected with coherent criteria. It is also expected that this instrument will contribute enormously to research, where a multi-wavelength approach is required or beneficial, e.g. in the study of winds in hot stars, Planetary Nebulae, Herbig-Haro objects or other forms of low-mass star formation.

[6] Assumptions for sensitivity calculations: Background LImited Performance, quantum efficiency 30%, emissivity of sky and telescope 20% at 273 K, transmission of filters 80%, grating eff. 80% for medium resolution and 50% for high resolution mode. The limiting fluxes are always for a $\frac{S}{N}$ of 10 σ in 1 hour in the brightest pixel.

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