30 Years of Infrared Instrumentation at ESO: Some Personal Recollections

Alan Moorwood[1]

[1] ESO

This is a brief account of the development of infrared instrumentation at ESO from the first single pixel photometers, built in the optically dominated late 1970s, through the revolution ushered in by the development of panoramic infrared detectors and the VLT, to a tiny glimpse of the 42-metre E-ELT, whose instruments will probably operate predominantly in the infrared, with the aid of adaptive optics. In support of my personal memories, I have combed *The Messenger* for facts and include here the most accurate timeline I could construct, together with references for those who wish to read more, and by way of acknowledging some of those who contributed to this story.

Early Days at Geneva and La Silla

When I joined ESO as an Infrared Staff Astronomer in Geneva in October 1978 the infrared (IR) instruments on offer at the 1-metre telescope on La Silla were a 1–5 μm near-IR photometer from the Max-Planck-Institut für Radioastronomie (MPIfR) in Bonn and the Kapteyn Institute 2–30 μm photometer from Groningen. Almost state of the art at the time, the first was equipped with a single InSb detector cooled with liquid nitrogen and the second with a liquid helium cooled germanium bolometer. Filters had to be changed manually while listening, like a safe breaker, for the wheel to catch in the detents. Detector signals were monitored on a strip chart recorder and recorded on ½ inch magnetic tapes. Eyepieces were provided for acquisition and guiding. Observing was carried out day and night, as I discovered to my cost when awarded three weeks observing in one run in July, when it is also pretty cold at night in the 1-metre dome.

In those days, chopping secondaries and the skill and bravery required to fill cryostats safely with liquid nitrogen and liquid helium (still not easy) classified infrared astronomy as a dark art that most ESO staff doubted would ever catch on. In Geneva, however, plans agreed by the external Instrumentation Committee were already afoot for the provision of both more advanced IR spectrophotometers for the 3.6-metre telescope and an undersized, F/35, chopping secondary for performing sky subtraction at up to 30 Hz, plus upgraded instrumentation for an unspecified smaller telescope. A recommendation to follow the new spectrophotometers with a medium resolution near-IR grating spectrograph had also been made at an ESO Workshop on Infrared Astronomy (in which I participated on the Swedish island of Utö in June 1978, shortly before taking up duty) and was later endorsed by the Instrumentation Committee. At the time, this proposal was received with little enthusiasm by most of ESO's astronomers, who were almost exclusively working at visible wavelengths and had their hearts set on another long slit spectrograph. Maybe it all worked out for the best, however, as the ESO Multi Mode Instrument (EMMI) was subsequently developed for the ESO New Technology Telescope (NTT), which had not even been conceived at that time. The telescope engineers also used some questionable language in describing what they thought about the new IR top end and using the 3.6-metre in daytime. Nevertheless, the near- and mid-IR spectrophotometers (equipped with ~1%

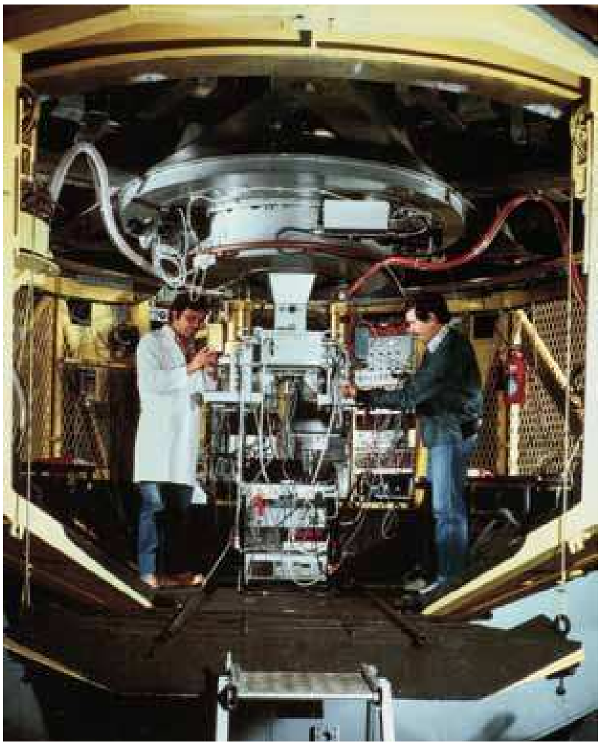

Figure 1. (Left) Installation of the first infrared spectrophotometers at the F/8 focus of the 3.6-metre telescope.

Figure 2. (Right) F/35 chopping secondary mirror on the 3.6-metre telescope.

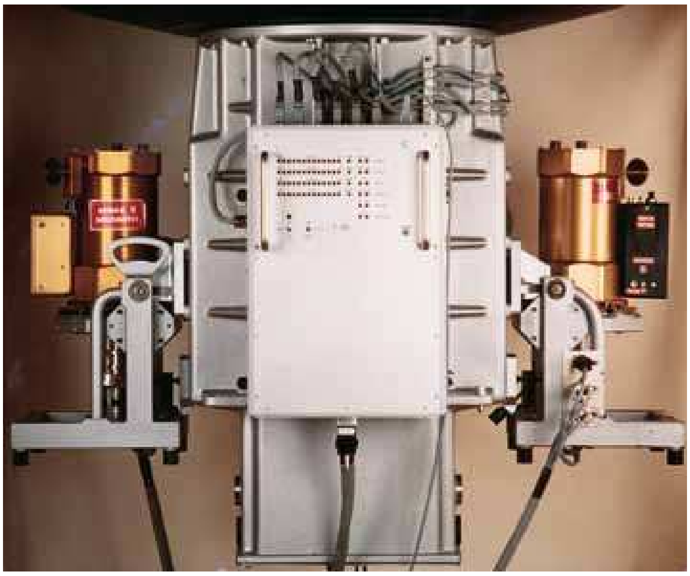

Figure 3. F/35 infrared spectrophotometers on the 3.6-metre telescope. The righthand dewar contains a liquid/solid nitrogen cooled InSb diode for 1–5 µm photometry and the lefthand one a liquid helium cooled bolometer for 8–25 µm photometery through broadband and narrowband circular variable filters. The support unit contains dichroic mirrors and a novel acquisition and guiding system using visible and IR TV cameras and a 2D tilting pupil mirror to explore the field.

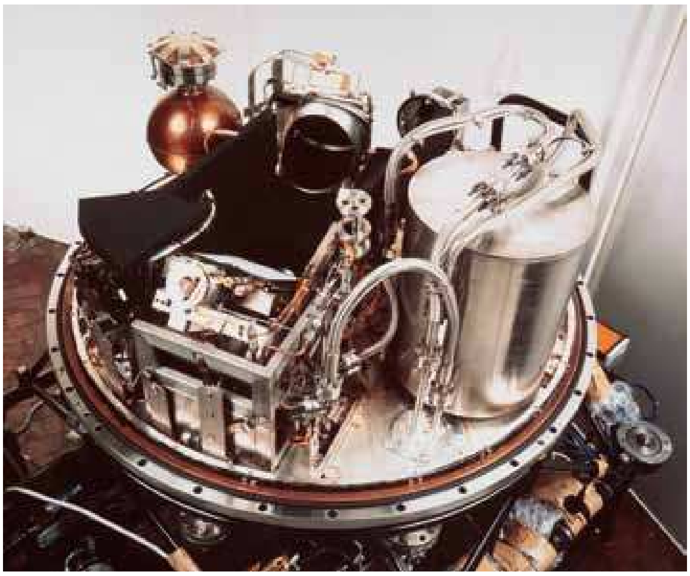

Figure 4. IRSPEC used for medium resolution 1–5 µm spectroscopy at the 3.6-metre and NTT telescopes. Its novel design includes the use of a warm bench to support all the optical units that are cryogenically cooled by a continuous flow of liquid nitrogen from the internal tank on the right. It was also the first infrared spectrograph equipped with a monolithic infrared array detector — initially a 1 x 32 linear array of InSb diodes (cooled by liquid/solid nitrogen in the small copper dewar) and later a 2D 58 x 62 InSb array (cooled by the first mechanical closed cycle cooler used at ESO). In operation, the instrument was enclosed by a dome-shaped cover and evacuated.

circular variable filters) were produced (in a caravan on the CERN site at Geneva), installed (involving a lot of walking around on the primary mirror cover looking for laser beams) and used initially at F/8 with a focal plane chopper until the infamous F/35 was ready (see Figures 1–3). A similar system was built for the 1-metre and, later, the 2.2-metre, which was also equipped with an F/35 chopping secondary built by the Max-Planck-Institut für Astronomie (MPIA) in Heidelberg. In 1985 the 3.6-metre was also provided with a linear scanned IR speckle detector built by the Observatoire de Lyon. All of these systems were productive, but eventually rendered obsolete following the miraculous development of 2D panoramic IR array detectors in the mid-to-late 1980s.

Before the first cameras were finished we had already built the IRSPEC near-IR cryogenic grating spectrograph, shown in Figure 4, which was conceived on Utö and equipped with a linear diode array.

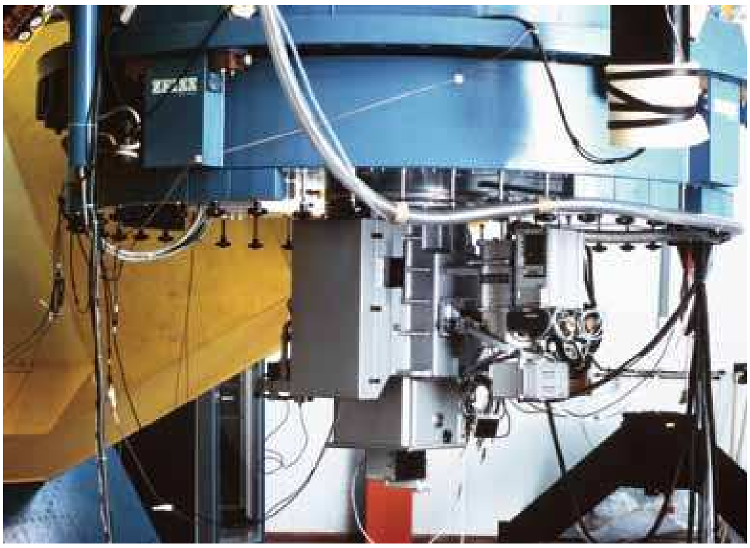

Figure 5. The F/35 IRAC1 camera mounted at the MPG/ESO 2.2-metre telescope.

When installed on the 3.6-metre in 1985, it was one of the first, and certainly the largest of its type, and the first equipped with a monolithic array (initially the 1 x 32 InSb Cincinnati charge injection device (CID) array and later the famous 58 x 62 Santa Barbara Research Center (SBRC) tank buster InSb array). Its large size also pushed us to develop its unique continuous flow liquid nitrogen cooling system, which has influenced many subsequent cooling systems at ESO. In 1990 IRSPEC was transferred to the NTT and replaced in 1998 by SOFI (Son of ISAAC). Before that, ESO's first imager had been IRAC1 for the 2.2-metre telescope (Figure 5), which was a good camera and the first to provide narrowband imaging with a circular variable filter (CVF). Due to US export restrictions, however, it had to be initially equipped with a 32 x 32 pixel Hg:Cd:Te array bonded to a CCD readout, which sort of worked in the thermal IR, but suffered low efficiency due to a threshold problem in the low background

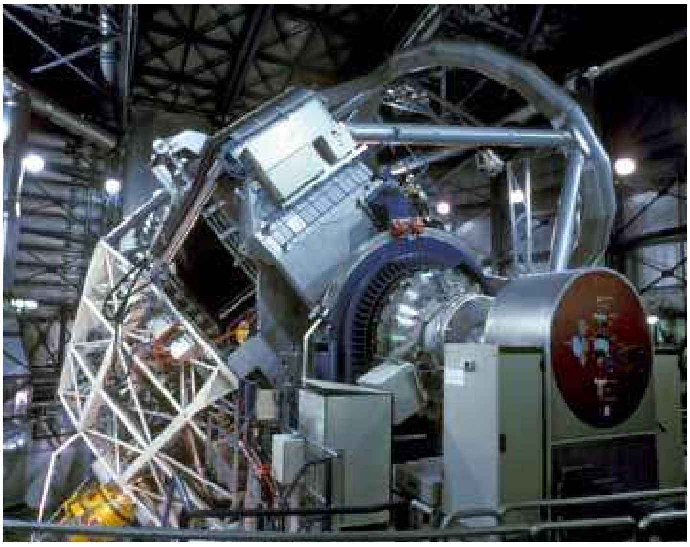

Figure 6. ISAAC at the VLT (UT1). This multimode 1–5 μm imager/spectrometer/polarimeter built by ESO was the first infrared instrument installed on the VLT in 1998 and is still operational and in high user demand. The box attached to the vacuum vessel houses the detector electronics and can be compared with the size of the amplifiers used on the early photometers in Figure 1. The unit in the foreground is the co-rotator needed to avoid tangling the large number of cables and high pressure He hoses for the closed cycle coolers, as the instrument itself rotates at the Nasmyth focus. On its rear is a diagram of the optical layout inside the vacuum vessel.

Figure 7. CRIRES, last of the first generation instruments on the VLT (UT1). The black box to the left houses the adaptive optics system and the vacuum vessel contains the 1–5 μm, R = 100 000, cryogenically cooled echelle spectrograph.

near-IR. Coupled with poor cosmetics, this detector lacked popularity and was replaced eventually with an improved 64 x 64 pixel Hg:Cd:Te array and finally a 58 x 62 pixel SBRC array in 1994. In the meantime, IRAC2 was built by ESO and equipped with a scanning Fabry Perot and one of the first of the famous Rockwell 256 x 256 Hg:Cd:Te NICMOS3 arrays that were a spin-off from the Hubble Space Telescope NICMOS development. In 1998, SOFI replaced IRSPEC at the 3.5-metre NTT — it is still there and in high demand for 1–2.5 μm imaging, polarimetry and grism spectroscopy with its 1k x 1k Hawaii 1 Hg:Cd:Te array.

Partly in parallel with the above, the 3.6-metre F/35 focus was increasingly used for mid-IR imaging and spectroscopy, first with the *N*-band (10 μm) TIMMI camera, built by the CEA around a 64 x 64 Ga:Si array evolved from the smaller one flown on the ISO satellite and, later, TIMMI2 developed by the University of Jena and ESO and equipped with a Raytheon 240 x 320 As:Si array. The F/8 focus of the 3.6-metre was also used for the pioneering efforts in adaptive optics with COME-ON and COME-ON+/ADONIS developed with ONERA, Observatoire de Meudon and others which have paved the way for the current VLT systems.

In case it has not yet become apparent, it is worth mentioning here that in striving to offer the best available detectors, ESO's infrared detector group has also evolved into a major asset, which has achieved worldwide recognition through its fundamental research and characterisation work, performed in addition to just providing detector systems (including the latest in acquisition electronics/software). By providing much appreciated technical feedback it has also established a positive working relationship with manufacturers over the years, which has resulted in improved detectors with additional features for the whole community. It has also paid off in ensuring that the VLT has been equipped with state-of-the-art detectors from the start and continues to be upgraded as new devices become available. ESO is now responsible for most of the detector systems at, or planned for, the VLT.

The VLT

The VLT was a revolution! Infrared array detectors had continued to get bigger — requiring even larger optics and hence mechanisms and surrounding cryogenic systems — even before taking into account the increases needed to adapt to the larger 8-metre telescopes. We were suddenly talking about instruments weighing tons rather than kg, rotating at the Nasmyth foci and with lots of control and detector electronics, compressors, cooling pipes — you name it, we had it. It turned out we actually had to write down the specifications to remember them, use advanced design and failure mode and effects analysis software, have project plans and meetings and even reviews to check where we were. It was our equivalent of NASA going to the Moon.

ISAAC (Infrared Spectrometer And Array Cameras) was the first VLT IR instrument and was developed completely at ESO, along with some of the standards to be used in later instruments. Its installation on UT1 (Figure 6) was challenging under the pioneering conditions existing on Paranal at that time (missing doors, windows, floors, lots of dust, etc). Nevertheless, after 10 years and more than 500 refereed papers since the start of science operations, and following a certain amount of surgery, it remains in high demand for 1–2.5 μm and 2.5–5 μm imaging, polarimetry and spectroscopy

Figure 8. HAWK-I on the VLT (UT4). This near-infrared camera is equipped with four 2k x 2k Hawaii 2 Rockwell/Teledyne arrays. Although employing mirror optics to image its large 7.5 x 7.5 arcminute field of view with maximum optical efficiency it appears overly large here due to the artistic choices of lens and viewing angle.

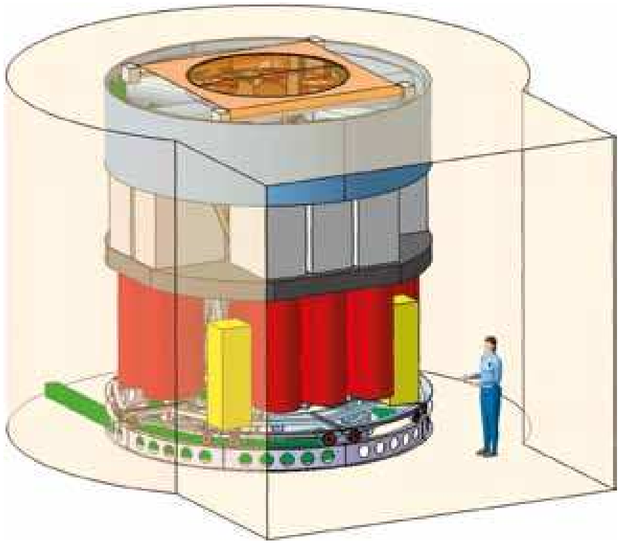

Figure 9. One concept for a multi-object infrared spectrometer at the E-ELT.

with its two arms equipped with 1k x 1k Hg:Cd:Te and InSb arrays. In order of installation it was followed by NACO (comprising the NAOS adaptive optics system developed by a consortium comprising ONERA, Observatoire de Paris and Laboratoire d'Astrophysique de l'Observatoire de Grenoble (LAOG) and CONICA, a near-IR camera/spectrometer/polarimeter/coronagraph built by the MPIA and Max-Planck-Institut für Extraterrestrische Physik (MPE)); VISIR (8–28 μm imager/spectrometer built by a consortium including the CEA, Kapteyn Institut and ASTRON); SINFONI (1–2.5 μm integral field spectrograph built by MPE and fed by an adaptive optics (AO) system provided by ESO); CRIRES (1–5 μm, AO-assisted, high resolution, spectrograph built by ESO, see Figure 7); HAWK-I (wide-field 1–2.5 μm camera shown in Figure 8, built by ESO and equipped with four 2k x 2k Rockwell/Teledyne Hg:Cd:Te arrays and designed to benefit in future from the Ground Layer Adaptive Optics provided by the Adaptive Optics Facility on UT4). Here it is worth pausing to remember that the first IR instruments offered by ESO had one pixel at the focus of a 1-metre telescope with an effective resolution of a few arcseconds. NACO and SINFONI provide resolutions down to the diffraction limit of an 8-metre telescope and HAWK-I has 16 million pixels and a resolution ~0.1 arcseconds over a field of view of 7.5 x 7.5 arcminutes. The VLTI mode in which the UTs and the 1.8-metre diameter ATs can be interferometrically combined also operates in the near- and mid-IR with its AMBER (French/German/Italian consortium) and MIDI (German/Dutch/French consortium) instruments. Also, not far from the VLT, the VISTA 4.2-metre infrared survey telescope and its VIRCAM camera (which deploys 16 2k x 2k arrays covering the equivalent of a 40 x 40 arcminute field) are currently being commissioned.

We are also now developing new second generation VLT/I IR instruments. Recently commissioned, X-shooter is the first to be finished and is the first combined visible-infrared instrument. Built by an ESO-led collaboration with institutes in Denmark, Netherlands, Italy and France it delivers spectra covering the UV, visible and IR (out to 2.5μm) spectral ranges simultaneously; KMOS (multi-object, integral field, near-IR spectroscopy using cryogenic deployable pick-off arms built by a UK–German consortium) and SPHERE, being developed with a French-led consortium in collaboration with ESO and designed for exoplanet studies using extreme adaptive optics and a variety of polarimetric, coronographic and differential spectroscopic high contrast modes; GRAVITY (built by a German led consortium for *K*-band astrometry) and MATISSE (built by a French-led consortium for 3–15 μm interferometric imaging and spectroscopy).

Into the future, the E-ELT

If it was difficult to match instruments to 8-metre telescopes, how about going to 42 m! Indeed some of the instruments being designed now are looking pretty big and could weigh several tens of tons (see Figure 9). They would have been even larger if it were not for the growing maturity of adaptive optics, which will assist essentially all IR instruments, thus allowing them to utilise efficiently small pixels and the high intrinsic spatial resolution of the telescope. Even so, feeding many millions of pixels with resolutions down to a few milliarcseconds could also pose its own challenges! It is also foreseen that the larger instruments will be fixed relative to gravity, thus avoiding the potential flexure problems faced by VLT instruments at its rotating Nasmyth foci. Much of the complexity has also moved to the various flavours of adaptive optics systems and the laser guide stars required to use them efficiently. Overall, however, these future systems look rather exotic, complex and expensive to somebody who observed at the 1-metre telescope on La Silla around 30 years ago!

First light	Instrument	Capabilities	Telescope	*Messenger* reference
1975?	Mid-IR Kapteyn photometer	2–30 μm single pixel (bolometer) photometry	1-metre	
1976	Near-IR Bonn photometer	1–5 μm single InSb pixel photometry	1-metre	Wamsteker, W. 1976, 5, 6
1980	Near- and mid-infrared (spectro) photometers	1–30 μm photometry + 1% Circular Variable Filter (CVF) spectrophotometry.	3.6-metre F/8	Moorwood, A. 1982, 27, 11
1982	Near- and mid-infrared (spectro) photometers	1–30 μm photometry + 1% Circular Variable Filter (CVF) spectrophotometry.	1-metre	
Nov 1984	F/35 chopping secondary system and infrared (spectro)photometers	1–30 μm photometry + 1% Circular Variable Filter (CVF) spectrophotometry.	3.6-metre F/35	Moorwood, A. & van Dijsseldonk, A. 1985, 39, 1
Oct 1985	Lyon Specklegraph	1–5 μm broad and CVF linear scanning speckle interferometry	3.6-metre F/35	Perrier, C. 1986, 45, 29
Nov 1985	IRSPEC	1–5 μm spectroscopy at R ~ 1000–2500 with a 1 x 32 pixel array	3.6-metre F/8	Moorwood, A. et al. 1986, 44, 19
Mar 1987	F/35 + (spectro)photometers (with MPIA)	1–30 μm photometry and CVF spectrophotometry	2.2-metre F/35	van Dijsseldonk, A., Moorwood, A. & Lemke D. 1987, 48, 50
Jul 1988	IRAC	1–5 μm imaging and CVF with 32 x 32 and 64x64 pixel arrays	2.2-metre F/35	Moorwood, A., Finger, G. & Moneti, A. 1988, 54, 56
Apr 1990	COME-ON	3–5 μm high spatial resolution AO imaging	3.6-metre	Merkle, F. et al. 1990, 60, 9
Nov 1990/ Feb 1991	IRSPEC Transfer/upgrade	1–5 μm spectroscopy at R ~ 1500–3000 with 58x62 SBRC InSb array	NTT	Moorwood, A., Moneti, A. & Gredel, R. 1991, 63, 77
May 1992	IRAC2	1–2.5 μm imaging and Fabry-Perot spectroscopy with 256 x 256 NICMOS array	2.2-metre F/35	Moorwood, A. et al. 1992, 69, 61
Jul 1992	TIMMI	5–15 μm imaging and long slit spectroscopy with a 64 x 64 Ga:Si array	3.6-metre F/35	Käufl, U. et al. 1992, 70, 67
Dec 1992	COME-ON+	3–5 μm high spatial resolution AO imaging	3.6-metre F/35	Hubin et al. SPIE, 1780, 850
Dec 1997	SOFI	1–2.5 μm imaging, polarimetry and grism spectroscopy with 1k x 1k Hawaii 1 array	NTT	Moorwood, A., Cuby, J.-G. & Lidman, C. 1998, 91, 9
Nov 1998	ISAAC	1–5 μm imaging, medium resolution spectroscopy and polarimetry	UT1	Moorwood, A. et al. 1999, 95, 1
Oct 2000	TIMMI2	2–28 μm imaging, grism spectroscopy and polarimetry with 340 x 260 As:Si array.	3.6-metre F/35	Käufl, U. et al. 2000, 102, 4
Nov 2001	NACO	AO assisted 1–5 μm imaging, spectroscopy, polarimetry, coronography	UT4	Brandner, W. 2002, 107, 1
Oct 2001	VLTI	Interferometry with UTs or 1.8-metre diameter ATs		Glindemann, A. 2001, 106, 1
Dec 2002	MIDI	Mid-IR imaging and spectroscopy	VLTI	2003, 111, 40
Mar 2004	AMBER	Near-infrared imaging and spectroscopy	VLTI	Richichi, A. & Petrov, R. 2004, 116, 2
May 2004	VISIR	Mid-IR (*N*- and *Q*-bands) imaging and low, medium and high resolution spectroscopy	UT3	Lagage, P.O. 2004, 117, 12
May 2004	SINFONI	Near-infrared, AO assisted, integral field spectroscopy	UT4	Bonnet, H. et al. 2004, 117, 17
Jun 2006	CRIRES	1–5 μm, AO assisted, R = 10^5 spectrometer	UT1	Käufl, U. et al. 2006, 126, 32
Jul 2007	HAWK-I	0.8-2.5 μm imaging	UT4	Kissler-Patig, M. et al. 2008, 132, 7
Nov 2008	X-shooter	Simultaneous UV–IR (2.5 μm) spectroscopy		Vernet, J. et al. 2007, 130, 5
2011?	KMOS	0.8–2.5 μm MOS with 24 deployable IFUs over a 7-arcminute field	UT1	Sharples, R. 2005, 122, 2
2011?	SPHERE	Visible and near-IR observations of exoplanets using extreme adaptive optics	UT3	Beuzit, J.-L. 2006, 125, 29
2012?	MUSE	Visible integral field spectroscopy	UT4	Bacon, R. 2006, 124, 5
2013?	GRAVITY	*K*-band astrometry	VLTI	
2014?	MATISSE	Mid-IR imaging and spectroscopy	VLTI	

Table 1. ESO Infrared Instrument Timeline

Acknowledgements

I would like to particularly thank Lo Woltjer for his support of the early IR instrumentation developments when he was Director General and my colleagues in Geneva — Piero Salinari, Anton van Dijsseldonk, Bernard Delabre and, on La Silla, Daniel Hofstadt, the late Willem Wamsteker and Patrice Bouchet — for some truly pioneering efforts. Although too many people to name here have subsequently contributed to the development and amazing growth and sophistication of the IR programme in the Garching era, I would also like to single out for mention Jean-Louis Lizon and Gert Finger who have met most of our IR-specific cryogenic and detector challenges for more than 25 years now. I would also like to acknowledge the contribution made over the years by several visitor instruments that could not be mentioned here for lack of space.