

# WIDE FIELD INFRARED IMAGING ON THE VLT WITH HAWK-I

*HAWK-I IS A NEW WIDE FIELD INFRARED CAMERA UNDER DEVELOPMENT AT ESO. WITH A 7.5 ARCMINUTE SQUARE FIELD OF VIEW AND 0.1 ARCSECOND PIXELS, IT WILL BE AN OPTIMUM IMAGER FOR THE VLT, AND A MAJOR ENHANCEMENT TO EXISTING AND FUTURE INFRARED CAPABILITIES AT ESO.*

MARK CASALI, JEAN-FRANÇOIS PIRARD, MARKUS KISSLER-PATIG, ALAN MOORWOOD, ROLLI BEDIN, PETER BIEREICHEL, BERNARD DELABRE, REINHOLD DORN, GERT FINGER, DOMINGO GOJAK, NORBERT HUBIN, GOTTHARD HUSTER, YVES JUNG, FRANZ KOCH, MISKA LE LOUARN, JEAN-LOUIS LIZON, LEANDER MEHRGAN, ESZTER POZNA, ARMIN SILBER, BARBARA SOKAR, JÖRG STEGMEIER

EUROPEAN SOUTHERN OBSERVATORY

**T**HE DEVELOPMENT OF EVER-larger format infrared detectors with excellent uniformity, quantum efficiency and noise performance has made infrared imaging a central tool in modern astronomical research. As an example, Figure 1 shows the steady increase in the amount of VLT-ISAAC near-infrared imaging time since its commissioning, to its current level of around 26 runs or 300 hours per observing period. In addition to ISAAC, NAOS-CONICA on the VLT and SOFI on the NTT also provide near infrared imaging. The reasons for the strong demand are many and varied. Fundamentally, the infrared allows the study of astronomical phenomena in otherwise inaccessible regions of time and space.

On a cosmological scale, galaxies within the redshift range  $1.5 < z < 4$  have their rest-frame visible wavelengths shifted to the near IR. This then becomes the natural wavelength in which to study them, allowing a direct comparison with local galaxies. Indeed broadband IR colours allow their distances (redshifts) to be estimated photometrically.

Searches in the infrared for extra high redshift ( $z > 6$ ) young galaxies are underway at the VLT. Nearby galaxies benefit from IR imaging which reveals the older stellar population, less obscured by dust.

Closer to home, the star forming regions within our own galaxy are often hidden by dust. So in order to study important aspects of young clusters such as the initial mass function, infrared imaging is necessary to penetrate the dust, if a complete census of objects is to be compiled.

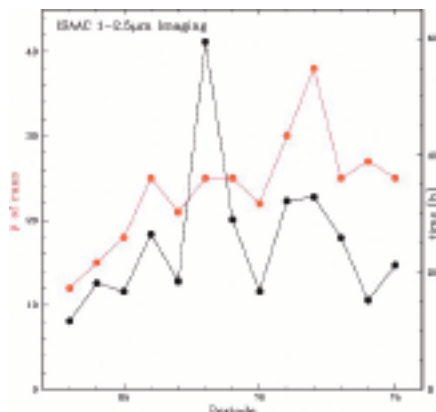
The infrared part of the spectrum also contains major emission lines. Perhaps the most important of these are due to quadrupole transitions of molecular hydrogen, the most common form of hydrogen in dense clouds. This line, usually shock excited, can reveal spectacular large-scale outflows from young stars.

Another important advantage of the near-infrared is the better image quality that is achieved compared to visible wavelengths. Since the size of the seeing disc has an inverse one-fifth power law dependence on wavelength (depending somewhat on the atmospheric turbulent outer scale), images of point

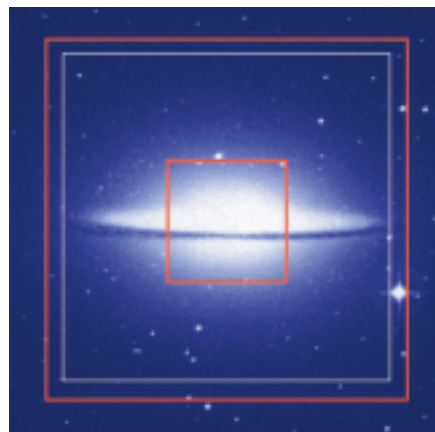
sources at  $K$ -band can be 20% smaller than in the visible and consequently sharper.

## HAWK-I: AN OPTIMUM VLT IMAGER

Infrared detectors are expensive – around 10 times the cost of comparably sized CCDs. So achieving both adequate image sampling and an ambitious field of view tends to require a large number of detectors and has historically been difficult. However, thanks to recent developments in IR detector technology which reduce the cost per pixel, the situation has greatly improved. HAWK-I, the High Acuity Wide-field  $K$ -band Imager, will be a near-optimum camera for the VLT. Table 1 shows the key instrumental parameters. The 7.5 arcminute square field results in outer corners of the HAWK-I field which will encroach slightly into the vignetted area of the Nasmyth field, resulting in 0.4% lower throughput in the field corners in all bands, and an approximately 25% higher background flux there in  $K$ -band. So this is practically the largest IR field possible at Nasmyth while keeping reasonably uniform sensitivity in all bands. By then assembling a mosaic



**Figure 1:** Statistics of near-infrared ISAAC imaging as a function of observing period. The red line shows the allocated number of runs, and the black line the number of hours, per period.



**Figure 2:** The galaxy M104 (Sombrero) with superimposed fields of HAWK-I (7.5') and ISAAC (2.5') in red, and FORS1 (6.8') in white.

Table 1: The key HAWK-I parameters.

Detectors	4 × 2k × 2k
Pixel scale	0.106"
Field of view	7.5' × 7.5'
Optical image quality (excluding seeing)	< 0.2 arcsec at 80 % encircled energy
Optics-only throughput	90 %
End-to-end system throughput	50 %
Number of filter positions	10
Wideband filters ordered	Y, J, H, Ks
Rest-wavelength narrow-band filters (microns)	1.58 (CH <sub>4</sub> ) 2.167 (Brγ) 2.122 (H <sub>2</sub> )
Cosmological narrow-band filters (microns)	1.061 1.187 2.090

of four 2k × 2k detectors to fill this field, a pixel scale of 0.1 arcsec/pixel results, which is sufficiently small to adequately sample the best seeing at Paranal, even with future ground layer adaptive optics correction. The end result is an imager with the best possible performance, limited predominantly by the telescope design and atmospheric seeing conditions. The enhanced field of view compared to ISAAC is shown in Figure 2.

#### HAWK-I, VISTA AND KMOS

ESO users will also have access to imaging data from the 4m VISTA IR camera (Emerson et al., 2004), which should be commissioned in Chile on a similar timescale (2007) giving ESO astronomers enormous infrared imaging power. With its 16 2k × 2k Raytheon detectors and 0.34 arcsec pixels, VISTA will cover 0.6 sq. degrees in a single exposure, and will be a natural pathfinder for HAWK-I and other VLT instruments. Peculiar, interesting or clustered objects discovered with VISTA will become targets for deep imaging and small mosaics at higher spatial resolution with HAWK-I/VLT. The two instruments will complement each other very well.

HAWK-I is also expected to be a major contributor of targets for infrared multi-object integral field spectroscopy with the second-generation KMOS instrument, which has a comparable field but no imaging mode.

#### WHAT IS SPECIAL ABOUT THE HAWK-I DESIGN?

Although HAWK-I is a relatively simple imager, there are ambitious and novel aspects in the design which will enhance its performance. At the heart of the instrument are its detectors. HAWK-I will use four Rockwell Hawaii 2RG arrays to make its impressive focal plane. These new-generation detectors operate from 0.8 to 2.5 microns with excellent uniformity and low dark current. They are also three-side buttable allowing a com-

Figure 3: Drawing showing the HAWK-I focal plane, consisting of four coplanar Rockwell Hawaii-2RG detectors.

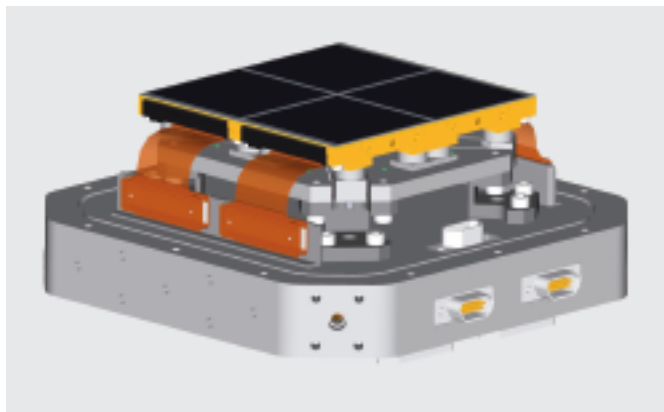


Figure 4: This cutaway drawing shows the optical components of HAWK-I and parts of the surrounding cryostat.

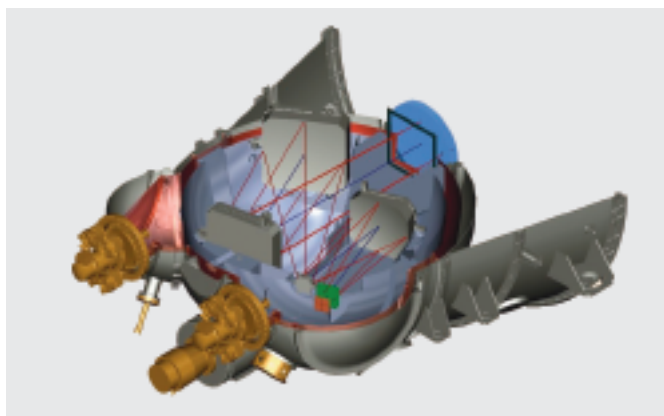
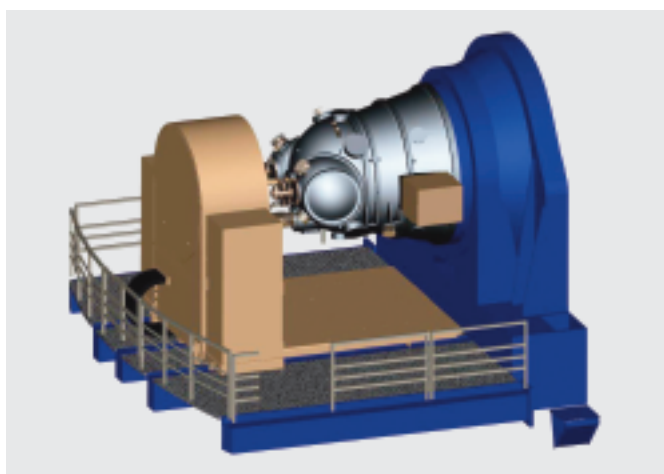


Figure 5: This drawing shows HAWK-I attached to the Nasmyth adapter (blue). The cable de-rotator (brown) is also shown.



compact focal plane with a cross-shaped gap of 2.7 mm or 15 arcsec. The detectors will be assembled in a package developed by GL Scientific which allows all 32 channels per detector to be read out. A CAD drawing of the assembly is shown in Figure 3.

A unique aspect of HAWK-I will be its very high throughput. This is achieved with a powered window and all-reflective design to achieve an optics-only throughput of 90%. The layout is shown in Figure 4. The window forms a pupil image at M3 which is the system cold stop. The high throughput alone will give HAWK-I a signal-to-noise improvement of 10–20% over other typical imagers such as ISAAC. The window is very large, at 404 mm of clear aperture, and is made of infrared-grade fused silica. Windows this size can suffer from potential frosting as the centre cools by radiating into the cold cryostat,

while conductive coupling to the warm edge is poor. Special care is being taken with baffle design and an emergency warm-air supply to ensure that condensation does not occur during operation.

HAWK-I has two six-position filter wheels for a total of 10 useable filter and two open positions. Darks will be obtained by selecting two different narrowband filters in each wheel. The filter selection has been one of the tasks of the Instrument Science Team chaired by Adriano Fontana (Monte Porzio). The final selection is shown in Table 1. Apart from the usual broad and narrow-band filters, note the methane-band filter for detection of cool brown dwarfs, and three cosmological narrow-band filters for detection of redshifted Lyman and hydrogen alpha emission lines. HAWK-I will attach to the Nasmyth adapter as shown in Figure 5.

#### PROJECT PROGRESS

The HAWK-I project completed its Final Design Review on November 17<sup>th</sup> 2004, and is now entering the main manufacturing phase, although procurement of some long-lead time items, such as optics and detectors, has been underway for some time. The beginning of assembly and integration should be in September this year, leading to a Preliminary Acceptance in Europe in mid-2006, and Provisional Acceptance Chile at the end of 2006.

#### HAWK-I AS A FIRST-LIGHT INSTRUMENT FOR A VLT ADAPTIVE SECONDARY MIRROR

ESO is currently studying the possibility of equipping HAWK-I with a Ground Layer Adaptive Optics (GLAO) system called GRAAL (Arsenault et al., 2004). Of course an AO correction over the 7.5 arcmin field of view will not deliver diffraction limited

images. But as a minimum requirement, the Adaptive Optics must reduce the 50% encircled energy diameter by 15% in Y and 30% in Ks band, when the natural seeing is 1 arcsec. The ultimate goal of the AO system is to correct the atmospheric turbulence such that the instrument resolution becomes the limiting factor. That is, the Adaptive Optics system will provide the equivalent image quality to 0.2 arcsec seeing. This would impact virtually all observing programmes with better sensitivity and spatial resolution.

The feasibility of a deformable secondary mirror and laser system for the VLT is currently being investigated. The results of this study, as well as the operational impact of such a facility, will be reviewed in the third quarter of 2005, with a decision to proceed with the development, including laser tomography, to be taken possibly at the end of 2005.

Although a GLAO capability would come well after HAWK-I commissioning, the requirements for AO have been incorporated into the HAWK-I design already. These include allowing sufficient weight budget and space between the cryostat window and instrument rotator for an AO module. Tip-tilt correction must be done with natural guide stars, and options exist to use either the on-chip guide star mode of the Hawaii-2RG detectors, or to have a separate NGS pickoff outside the instrument. A Conceptual Design Review for the HAWK-IAO was held the day after the HAWK-I instrument PDR in December 2004.

#### REFERENCES

Arsenault, R., Hubin, N., Le Louarn, M., Monnet, G., Sarazin, M. 2004, *The Messenger*, 115, 11  
Emerson, J. P. et al. 2004, *The Messenger*, 117, 27

## ESO's Two OBSERVATORIES MERGE

On February 1, 2005, ESO merged its two observatories, La Silla and Paranal, into one. This move will help ESO to better manage its many and diverse projects by deploying available resources more efficiently where and when they are needed. The merged observatory will be known as the La Silla Paranal Observatory.

*Catherine Cesarsky, ESO's Director General, commented on the new development: "The merging, which was planned during the past year with the deep involvement of all the staff, has created unified maintenance and engineering (including software, mechanics, electronics and optics) departments across the two sites, further increasing the already very high efficiency of our telescopes. It is my great pleasure to commend the excellent work of Jorge Melnick, former director of the La Silla Observatory, and of Roberto Gilmozzi, the director of Paranal."*

La Silla, north of the town of La Serena, has been the bastion of the organization's facilities since 1964. It is the site of two of the most productive 4 m class telescopes in the world, the New Technology Telescope (NTT) – the first major telescope equipped with active optics – and the 3.6 m, which hosts HARPS, a unique instrument capable

of measuring stellar radial velocities with an unsurpassed accuracy better than 1 m/s, making it a very powerful tool for the discovery of extra-solar planets. In addition, astronomers have also access to the 2.2 m ESO/MPG telescope with its Wide Field Imager camera. Moreover, the infrastructure of La Silla is still used by many of the ESO member states for targeted projects such as the Swiss 1.2 m Euler telescope and the robotic telescope specialized in the follow-up of gamma-ray bursts detected by satellites, the Italian REM (Rapid Eye Mount). La Silla is also in charge of the APEX (Atacama Pathfinder Experiment) 12 m sub-millimetre telescope which will soon start routine observations at Chajnantor, the site of the future Atacama Large Millimeter Array (ALMA). The APEX project is a collaboration between the Max Planck Society in Germany, the Onsala Space Observatory in Sweden and ESO.

Paranal is the home of the Very Large Telescope (VLT) and the VLT Interferometer (VLTI). Antu, the first 8.2 m Unit Telescope of the VLT, saw First Light in May 1998, starting what has become a revolution in European astronomy. Since then, the three other Unit Telescopes – Kueyen, Melipal and Yepun – have been successfully put into opera-

tion with an impressive suite of the most advanced astronomical instruments. The interferometric mode of the VLT (VLTI) is also operational and fully integrated in the VLT data flow system. In the VLTI mode, one state-of-the-art instrument is already available and another will follow soon. In addition to the state-of-the-art Very Large Telescope and the four Auxiliary Telescopes of 1.8 m diameter which can move to relocate in up to 30 different locations feeding the interferometer, Paranal will also be home to the 2.6 m VLT Survey telescope (VST) and the 4.2 m VISTA IR survey telescope.

Both Paranal and La Silla have a proven record of their ability to address the current issues in observational astronomy. In 2004 alone, each observatory provided data for the publication of about 350 peer-reviewed journal articles, more than any other ground-based observatory. With the present merging of these top-ranking astronomical observatories, fostering synergies and harmonizing the many diverse activities, ESO and the entire community of European astronomers will profit even more from these highly efficient research facilities.

(based on ESO Press Release 03/05)