HAWK-I: the new wide-field IR imager for the VLT

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ABSTRACT

HAWK-I is a new wide-field infrared camera under development at ESO. With four Hawaii-2RG detectors, 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. HAWK-I will eventually make use of ground-layer AO achieved through a deformable secondary mirror/laser guide star facility planned for the VLT.

Keywords: instrumentation, infrared imaging, infrared camera

1. INTRODUCTION

The 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. There has been a 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 at ESO. 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 very high redshift ($z>6$) young galaxies is 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 dependance on wavelength (depending somewhat on the atmospheric turbulent outer scale), images of point sources at K band can be 25% smaller than in the visible and consequently sharper.

Ground-based and Airborne Instrumentation for Astronomy, edited by Ian S. McLean, Masanori Iye,
Proc. of SPIE Vol. 6269, 62690W, (2006) · 0277-786X/06/$15 · doi: 10.1117/12.670150

2. HAWK-I : AN OPTIMUM VLT IMAGER

Infrared detectors are expensive – around 10x 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 Accuity Wide-field K-band Imager, will be a near-optimum camera for the VLT. Table 1 shows the key instrument 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 of four 2k x 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 1.

Table 1. The key HAWK-I design parameters.

Detectors	4 x 2k x 2k Hawaii 2RG	end-to-end system throughput	50%
Pixel scale	0.106”	number of filter positions	10
field of view	7.5’ x 7.5’	wideband filters	Y,J,H,Ks
optical image quality (excluding seeing)	<0.2 arcsec at 80% encircled energy	rest-wavelength narrowband filters (microns)	1.58 (CH_4), 2.167 (Brγ) 2.122 (H_2)
optics-only throughput	90%	cosmological narrowband filters (microns)	1.061, 1.187, 2.090

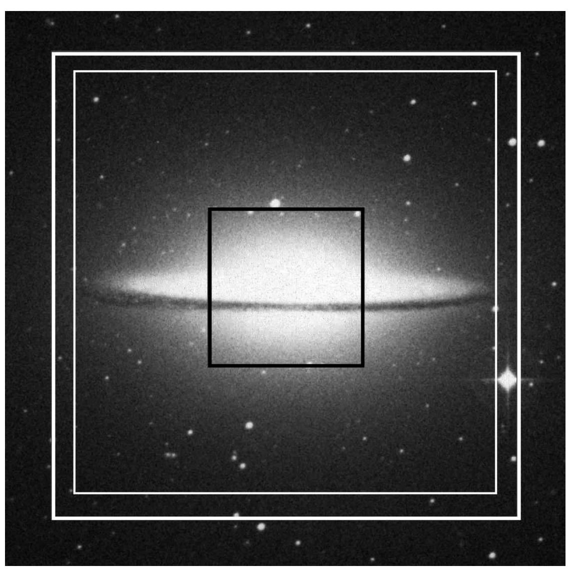

Fig.1 Picture shows the Sombrero galaxy with overlaid fields of view of VLT-ISAAC (central black square), VLT-FORS2 (inner white square) and VLT-HAWK-I (outer white square).

3. 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[1] arrays to make its large 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 compact focal plane with a cross-shaped gap of 2.7 mm or 15 arcsec. The detectors will be assembled in a molybdenum 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. With a final f-ratio of f/3.8, the detectors will need to be accurately coplanar. This will be achieved through a commercial 2-d laser ranging device, and adjustments of the detector post spacers. All four detectors have been received at ESO and have been tested, showing QEs within specifications and good cosmetic quality.

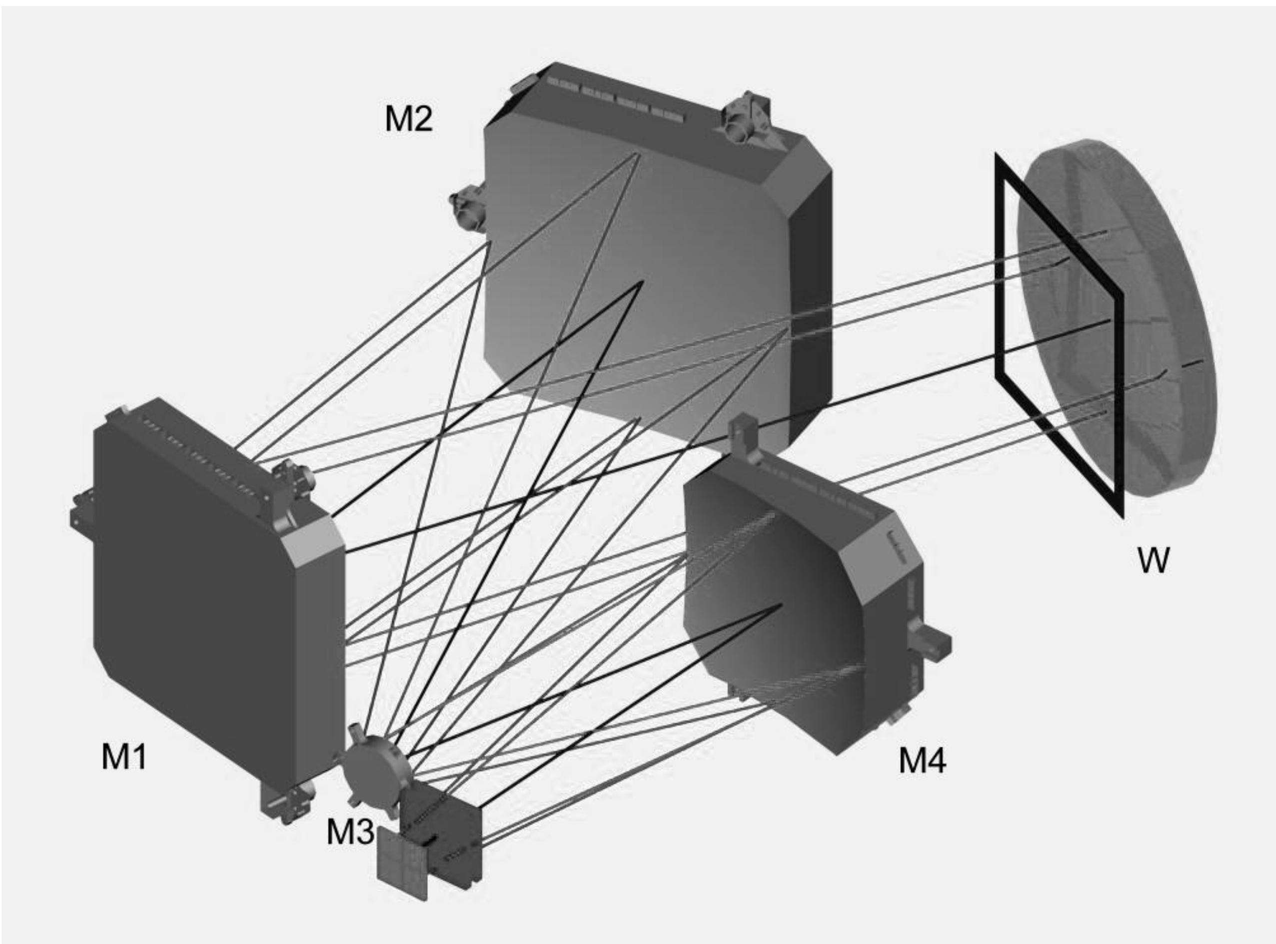

Fig.2 The HAWK-I optical layout. W is the cryostat window.

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 2. The window forms a pupil image at M3 which is the system cold stop. M1 is a large flat mirror, M2 is a tilted spherical mirror, M3 is an off-axis ellipsoid and M4 is an off-axis asphere. The high throughput of the design will give HAWK-I a signal-to-noise improvement of 10-20% over other typical imagers such as ISAAC. The reflective optics have been manufactured by Axsys Technologies, Michigan. They are all diamond-turned aluminium, and nickel plated on one side only. By keeping the nickel layer thin (30 microns) FEA analysis showed the dominant deformation upon cooling would be low order and mainly defocus. All mirrors are gold coated.

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. A special reflective baffle design has been implemented to deal with this problem. Annular reflective baffles with spherical surfaces will be used just inside the window. These are outside the science field and serve the purpose of reflecting a good fraction of the thermal radiation from the window straight back thus keeping it warm. Calculations show these will result in considerably warmer temperatures at the front window surface. Since we were concerned that this might also enhance scattered light in the instrument, the baffles are being coated by a special multi-layer coating which is highly reflective beyond 3 microns, yet absorptive at shorter wavelengths. As a final precaution against condensation, a control system will switch on dry air flow over the window if the relative humidity gets too high.

HAWK-I has two six-position filter wheels for a total of 10 useable filter + two open positions. Darks will be obtained by selecting two different narrowband filters in each wheel. The final filter selection is shown in Table 1. Apart from the usual broad and narrowband filters, note the methane-band filter for detection of cool brown dwarfs, and three cosmological narrowband filters for detection of redshifted Lyman and Hydrogen alpha emission lines.

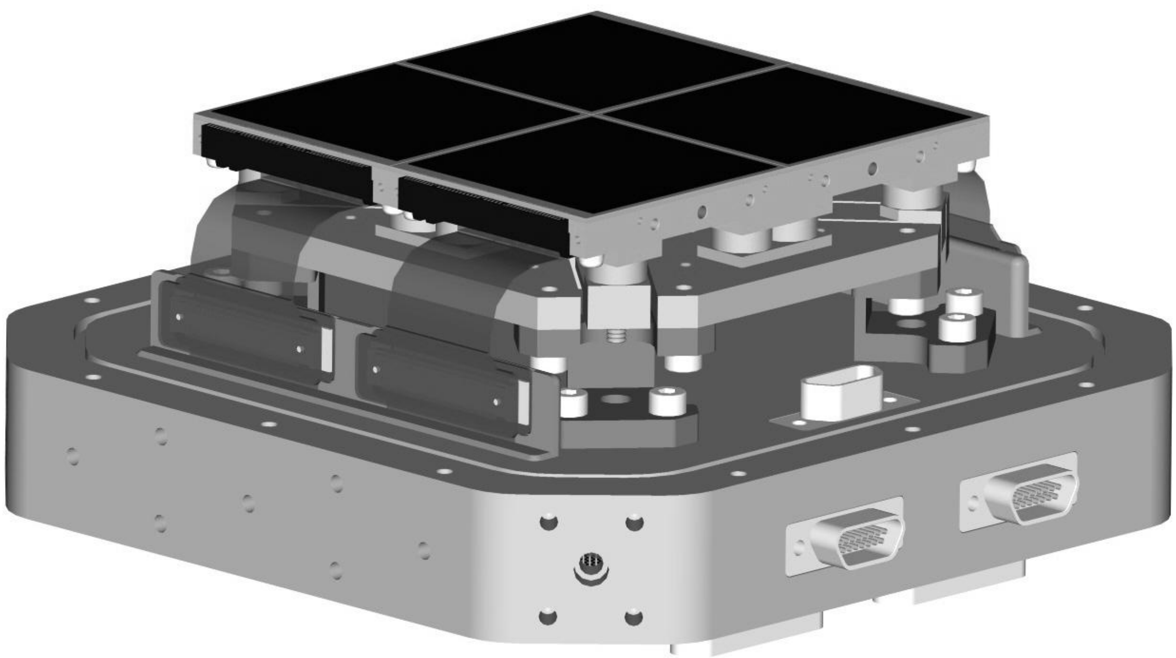

Fig. 3. Drawing of the four 2RG detectors on their GL Scientific mount.

4. VACUUM VESSEL AND CRYOGENICS

HAWK-I will be mounted on the UT4 Nasmyth port, as shown in Fig. 4. The vacuum vessel is stainless steel and has two access ports for easy access to filters and detectors.

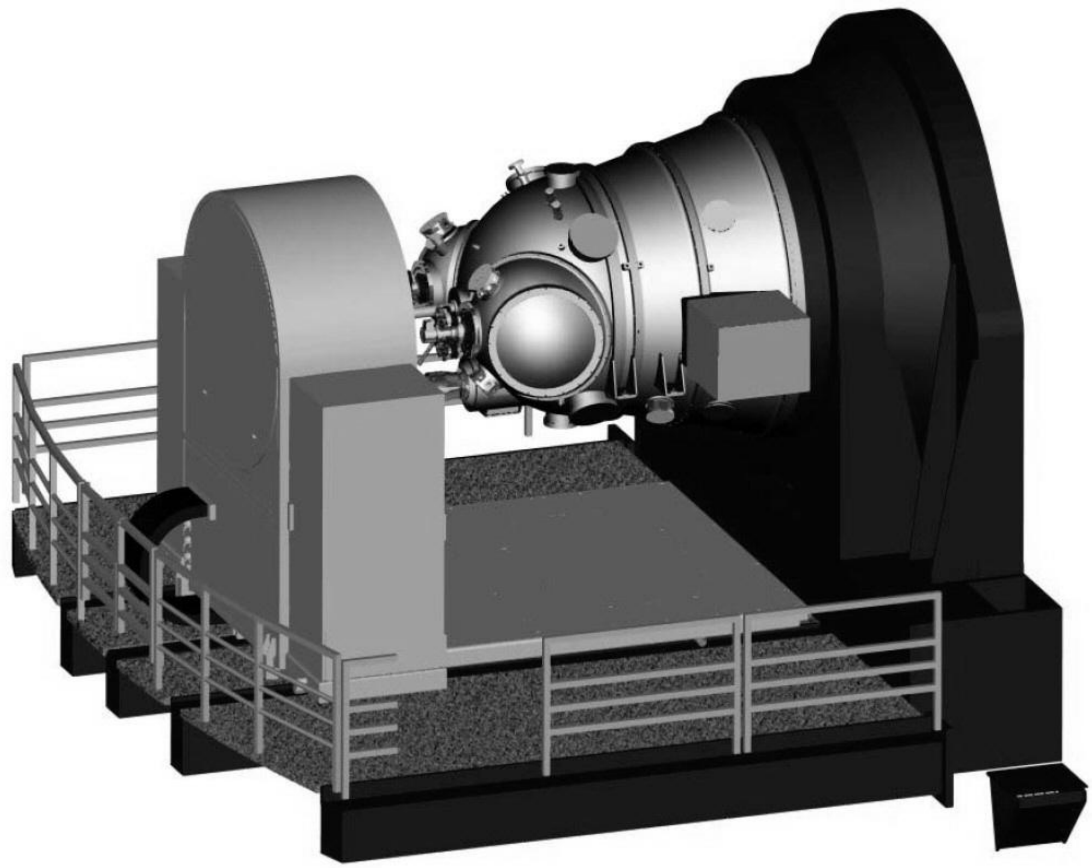

Fig. 4. HAWK-I shown mounted on the Nasmyth port of UT4. The large assembly to the left is the cable co-rotator. The HAWK-I space and mass budgets have margins to allow for the wavefront sensors and pickoffs required for the Adaptive Optics Facility (see section 6).

Cryogenically HAWK-I is straightforward, since the 2.5 micron cutoff of the 2RG detectors means that internal components do not have to be cooled to very low temperatures. Two closed cycle helium refrigerators will be used to help distribute more even cooling throughout the cryostat. The optics are mounted inside the large aluminium spherical cold structure shown in Fig. 5. The structure shape was chosen to minimize flexure, as the Nasmyth co-rotator rotates the instrument. The total instrument weight is 2.2 metric tonnes.

Fig. 5. The HAWK-I cold structure. The large reflective optics are mounted inside. One of the access hatches for filters and detectors is visible at top right.

5. HAWK-I, VISTA AND KMOS

ESO users will also have access to imaging data from the 4m VISTA[2] IR camera, which will be commissioned in Chile on a similar timescale (2007) giving astronomers enormous infrared imaging power. With its 16 2kx2k 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.

On a slightly longer timescale (2010) ESO will take delivery of KMOS, a cryogenic spectrometer with 24 individually deployable integral field units. The IFUs may be deployed over a 7.2 arcmin field, similar to the HAWK-I field, thereby allowing a well-matched combination of both IR imaging and spectroscopy.

6. HAWK-I AND THE VLT ADAPTIVE OPTICS FACILITY

ESO has approved the construction of an adaptive optics facility (AOF) for the VLT. It will consist of a deformable secondary mirror, four laser guide stars, and associated wavefront sensors. Of course an AO correction over the 7.5 arcmin HAWK-I field of view will not deliver diffraction limited images; in the case of HAWK-I the AOF will be used for ground layer correction only (GLAO). As a minimum requirement, the Adaptive Optics aims to reduce the 50% encircled energy diameter by 15 % in Y and 30% in Ks band, when the natural seeing is 1 arcsec. Current modelling suggests this will be achieved. The ultimate goal of the AO system is to correct the atmospheric turbulence such that the instrument resolution becomes the limiting factor at times of very good seeing. That is, the AOF will provide the equivalent image quality to 0.2 arcsec seeing. This would impact virtually all observing programmes with better sensitivity and spatial resolution. 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-I AO was held the day after the HAWK-I instrument final design review in December 2004. It is anticipated the AOF will be available for use with HAWK-I in 2012.

Although the GLAO capability will 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 wavefront sensing module to be incorporated.

7. PROJECT COMPLETION

The HAWK-I project successfully completed its Final Design Review on November 17th, 2004. All major components have been ordered and most have now been received. We expect that the integration phase will begin in earnest in August 2006, with a first light commissioning in early 2007.

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