HAWK-I

A new ‘wide field’ 1-2.5 µm imager for the VLT

ABSTRACT

HAWK-I (High Acuity, Wide field K-band Imaging) is a 0.9 µm – 2.5 µm wide field near infrared imager designed to sample the best images delivered over a large field of 7.5 arcmin x 7.5 arcmin. HAWK-I is a cryogenic instrument to be installed on one of the Very Large Telescope Nasmyth foci. It employs a catadioptric design and the focal plane is equipped with a mosaic of four HAWAII 2 RG arrays. Two filter wheels allow to insert broad band and narrow band filters. The instrument is designed to remain compatible with an adaptive secondary system under study for the VLT.

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1. Introduction

The current near infrared imaging capabilities at ESO are provided by SOFI at the NTT (1-2.5µm; max. field 5x5’ with 0.29” pixels), and ISAAC (1-5µm; max field for 1-2.5µm of 2.5x2.5’ with 0.147” pixels) and NACO (1-5 µm; max field ~ 1’x1’ but fed by AO and more typically 20”x20” with ~ 20mas pixels) at the VLT.

Typically about 15% of all proposals to ESO request near infrared *direct* imaging with SOFI and ISAAC. Both of these cameras are currently equipped with almost state of the art 1kx1k array detectors. Both, however, have been in operation for several years (since 1998 and 1999 respectively) and cannot be sensibly upgraded to accommodate the new generation of 2x2k arrays now being installed singly (e.g. in ISPI which is already offering twice the linear field of SOFI at the CTIO 4m telescope) and as mosaics (in WFCAM at UKIRT, NEWFIRM at the KPNO 4m, WIRCAM at CFHT, VISTA...). All of the mosaic cameras, however, are planned primarily as survey instruments with pixels of ~ 0.3” selected for maximum field-of-view and are being installed on 4m-class telescopes.

The VLT 2nd Generation Instrument Plan contains near-infrared multi-object spectroscopy (KMOS) as a high priority mode and single object J and H band spectroscopy is included as part of the X-shooter instrument proposal. The originally planned wide field J and H band imaging capability has been lost with the cancellation of NIRMOS.

From a scientific viewpoint, ISAAC at the VLT has demonstrated the discovery and study potential in many areas of near infrared imaging with an 8m telescope with the excellent image/seeing quality of the VLT. It has been shown e.g that deep images requiring a few x10hrs of integration can contribute uniquely to the discovery and study, including morphology, of ‘mature’ galaxies at $z > 3$. Closer to home, it has been used to find and study stellar discs and ‘stellar’/planetary mass objects down to ~ 1 Jupiter mass. These and many more scientific applications are promoted and discussed in the document Science Case for 0.9-2.5µm Infrared Imaging with the VLT. An important general conclusion is that future work in most of these areas will require sampling the best seeing on Paranal and/or require comparable depth but over larger areas than possible with the 2.5x2.5’ ISAAC field. In most cases, mosaicing would be prohibitive in integration time or total time (to achieve the required seeing) or would not meet the required photometric or PSF uniformity. There is thus clearly a future scientific requirement for ‘wide’ field imaging at the VLT. An analysis of all observations performed with SOFI and ISAAC also shows that the Ks band filter has been used most often and about a factor two more than the next most used J band filter. Until the availability of JWST it is likely that ground based 8m class telescopes will provide the best sensitivity achievable in this band (HST is small and warm and SIRTF starts at ~ 3.5µm).

From an implementation viewpoint the specifc HAWK-I proposal was triggered by the cancellation of NIRMOS whose four 2kx2k buttable near infrared arrays were already in manufacture at Rockwell and could only be cancelled at high cost (although it was still possible to extend their long wavelength cut-offs from 1.9 to 2.5µm). With pixels of ~ 0.1" sufficient to sample the best Paranal seeing these detectors could provide an (almost) contiguous field of 7.5x7.5' which is more than an order of magnitude larger than that of ISAAC. Such a camera would thus be an excellent substitute for the lost J and H band NIRMOS imaging (smaller field but better sampling) and include the scientifically powerful K-band. It could also be built at ESO within the financial and manpower resources already committed to build the 4 NIRMOS cameras.

In summary therefore, the scientific case for near infrared imaging at the VLT is strong and the specific HAWK-I camera as proposed is attractive in that it provides a ten times larger field than ISAAC; substitutes the lost NIRMOS J, H band capability; adds the important K-band and could be built using already allocated resources.

2. Science Case

Science cases for wide-field near-infrared instruments have already been addressed above. Given the wide field, fine sampling and the high sensitivity of HAWK-I, the deepest scientific impact is expected in the areas of surveys of faint sources. Primarely deep mutlicolor surveys of galaxy evolutions will profit from the new facility, including morphological studies of mature galaxies in the redshift range 1.5 to 4. In that respect, HAWK-I will provide the completement to large field optical surveys such as the GOODS Chandra/SIRT field that is currently inefficiently covered by ISAAC. Another strong science case in the high redshift universe is provided by the cosmological narrow band filters that will allow efficient surveys of emission line objects at redshifts 7 to 9, exploring the very first star forming objects in our universe. But also multi-wavelength observations of *nearby* normal and active galaxies will be enhanced by HAWK-I, as it will be matched to the ground-based wide-field *optical* imagers in order to provide a deep view into the closest resolved stellar populations beyond the Milky Way. Further, HAWK-I will be very well suited for the search in our Galaxy of the most massive (embedded OB) and least massive (hot Jupiters) stars, leading to a better understanding of the stellar IMF. Finally, HAWK-I will also be a perfect instrument for the study of outer solar system bodies, such as distant, icy minor bodies, or the study of long period comets.

Clearly, HAWK-I will allow rapid progress in very diverse areas of modern astronomy by filling a niche of wide-field, well sampled near-infrared imagers on 8m-class telescopes.

3. Instrument Overview

An overview of the HAWK-I instrument is presented in Figure 1. HAWK-I is a cryogenic instrument designed to be installed on the adapter/rotator of any of the Nasmyth foci of the VLT.

With the exception of the entrance window, the optical baseline is based on an all reflective configuration. The purpose of the optical configuration is to adapt the F-number of the input beam to the pixel FOV requirement (0.1"/pixel) and to limit the stray light reaching the detector thanks to a cold field stop located at the entrance of the instrument and the M3 mirror acting as a cold pupil stop.

Just before the light reaches the detectors, two filters wheels allow the insertion of Broad Band (Y, J, H, K_s) and Narrow Band (interstellar lines and cosmological) filters.

The HAWK-I focal Plane is equipped with a mosaic of four 2Kx2K Rockwell HgCdTe MBE HAWAII 2 RG arrays. The packaging of these 2x2 mosaic detector is provided by GL Scientific reusing the design developed for the JWST program. The acquisition system is based on the IRACE system (Infrared Array Control Electronics) developed at ESO.

The optics and focal plane are mounted on a spherical cold structure which provide the mechanical stability between the different elements. This assembly is cooled to cryogenic temperature using two Leybold closed cycle coolers. The detectors and the filter wheel unit are connected to the second stage of the Close Cycle Cooler and will operate at a temperature close to 80 K. A temperature below 140 K is required for the rest of the instrument.

The vacuum vessel containing the instrument is interfaced to the Nasmyth adaptor. The interface flange is designed such that it can accommodate the further installation of wavefront sensors required for the operation with a later adaptive secondary mirror of the telescope.

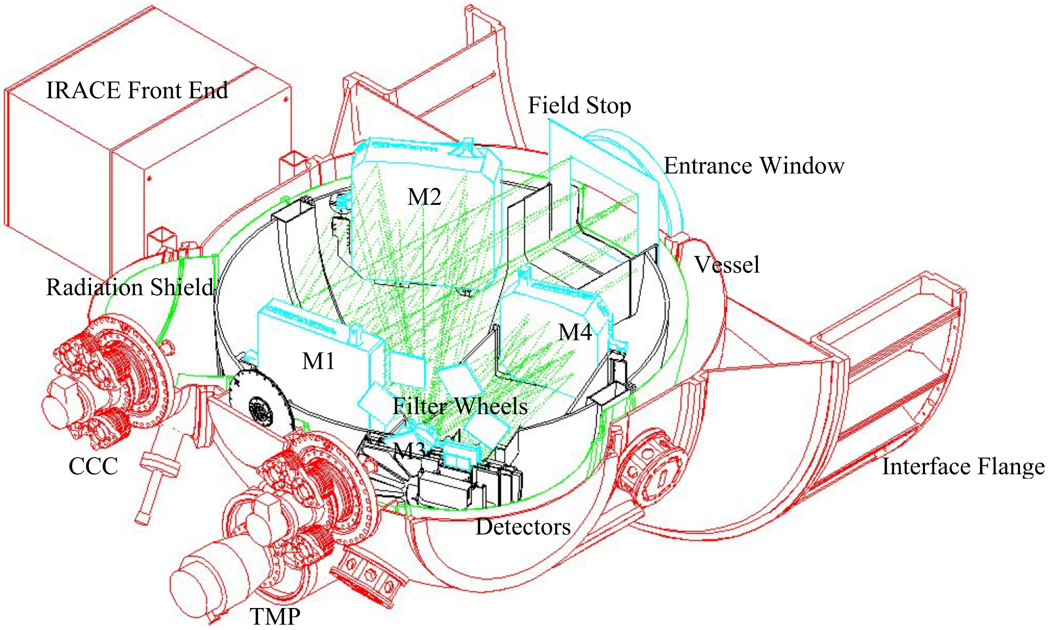


Figure 1: HAWK-I Overview

The specification of the camera is largely determined by the fact that the four 2kx2k 0.9-2.5µm Rockwell array detectors are already in manufacture; that this is the largest number of arrays we can mosaic anyway and that we wish to be seeing limited under the best conditions on Paranal. We have thus provisionally specified 0.106”pixels (cf. ISAAC 0.147”) which yields a field of 7.5’x7.5’. Moreover, this pixel sampling of 0.106” is now fully compatible with the best wide field imaging capabilities provided with the Adaptive Secondary without any loss of resolution.

Table 1 summarizes the main items of the technical specification.

Table 1. HAWK-I Top Level Requirements

Parameter	Value
Scale	0.106”/pixel
Field	7.5’.x 7.5’
Image quality (80% encircled energy)	< 0.2 arcsec
Distortion	<0.3%
Optical throughput (excluding filters)	>90%
Number of Filter Slots	9 (4 Broad Band, 5 Narrow Band)
Filter transmission	>80% BB, >60% NB
Detectors	4x 2kx2k HgCdTe MBE arrays
Detector Q.E.	> 70%
Read noise	<20e (double correlated)
Dark current	< 1 e/sec
Instrument Temperature	<140 deg K
Detector Temperature	~80 deg K

4. Optical Design

An important task of the preliminary design phase has been to perform a selection between a full dioptric design and a catadioptric design. Both configurations were satisfactory in terms of optical requirements. Finally, the preference has been given to the reflective design for the following reasons:

- the reduction of the potential development risks in relation with the poor knowledge of dn/dT behavior of infrared material at cryogenic temperature
- the removal of all potential risks of lens misalignment/breakage during integration transportation, earthquake and thermal transition
- a higher throuput without the development of any specific anti-reflect coating
- the confidence, based on previous experience at ESO, that is possible to manufacture aluminum alloy mirrors with a very good optical quality and without significant deformation at cryogenic temperature.
- a large reduction of the potential problems linked to ghosts

The catadoptric solution has also some drawbacks:

- the size of the vessel is increased to accommodate the optical layout. This leads to an increase of the total mass of the instrument and consequently to some increase of the mechanical cost.
- the mirror solution introduces some limited distortion (0.2%) that needs to be corrected before stacking jittered images. This can be dealt easily by modern data processing tools.

An overview of the final optical layout is given in Figure 2. The entrance window of the vacuum vessel is used to image the pupil on the M3 mirror. A cold baffle stops the light outside of the instrument field of view. The first folding mirror (M1) is used for beam accommodation. Then, the camera is constituted of one large spherical mirror M2 and two aspherical mirrors M3 and M4 allowing to adapt the telescope beam to the required F/4.36.

The mirrors are made from aluminum alloy blanks by diamond turning. The blank undergeos a deep ageing process to removed all residual constraint inside the material. The final shaping of the mirrors are made by diamond turning on a thin layer of nickel. A final post-polishing allows to achieve the roughness requirement. An isostatic mount system is used to interface the mirror with the cold structure without inducing any degradation of the optical quality.

The two filter wheels are located just before the detector mosaic. The size of the filter to cover the whole field of view will be 105 x 105 mm^2. The beam incidance angle versus the filter is quasi constant for all points of the field to keep the spectral filtering uniform over the whole field of view.

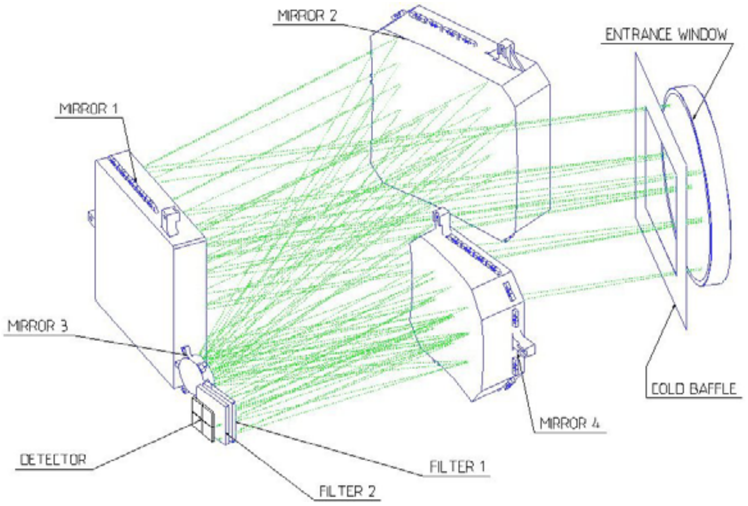


Fig. 2: HAWK-I Optical Design

5. Mechanical Design

The complete instrument implementation on the Nasmyth platform of the VLT is shown Figure 3. The figure shows also the maintenance platform carrying the cable rotator, closed cycle cooler compressor and the electronic cabinets.

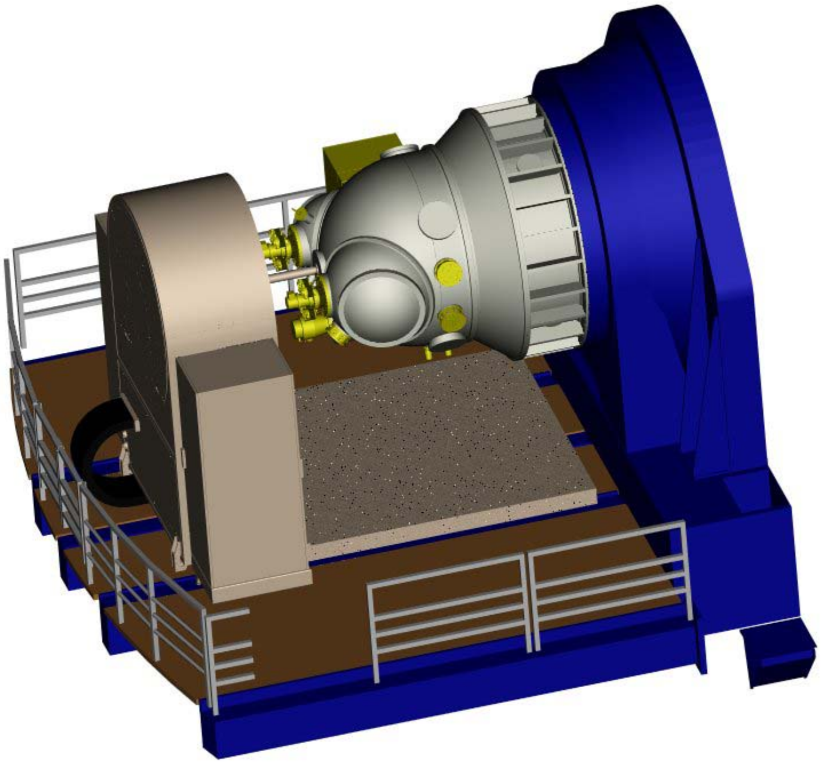


Fig. 3: HAWK-I installed at Nasmyth

The HAWK-I instrument is centered on the Nasmyth adaptor by the interface flange. The vacuum vessel is split into three elements:

- the vessel front part which extends to the interface flange diameter. This area is reinforced to provide sufficient stiffness for the integrated entrance window and to the center part connection flange.
- The vessel center part which provides all necessary supply ports and the mechanical connections to support the cold mechanics.
- The access to the detector, filter unit, filter exchange, the connection of the closed cycle coolers, pre-cooling lines and electrical cables.

The cold assembly (Fig 4) is comprises two hemispherical shells made from aluminum alloy and supports inside, the AL mirrors and outside and the filter wheel unit. The cold structure is made from aluminum alloy and behaves like the mirror material. The interface between the vessel and the cold structure is made via 5 epoxy spiders which provide a good thermal insulation and sufficient stiffness. A radiation shield inserted between the vessel and the cold structure is connected to the closed cycled cooler to reduce the vessel thermal radiation.

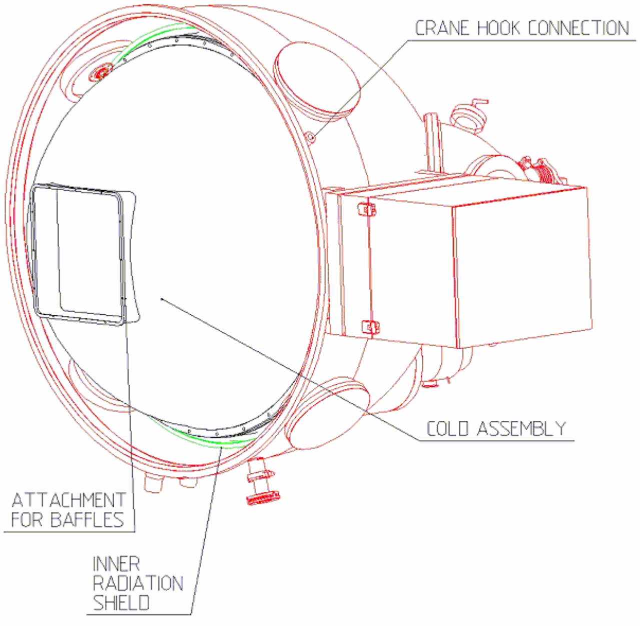


Fig. 4: HAWK-I internal structure

The filter wheel unit houses two filter wheels which carry four and five framed filters as well as the required open and closed positions (Fig 5). The filter assembly is radially attached to the wheel. This arrangement allows an easy exchange of the filters. The filter wheels are rotated using Phytron stepper motors (VSS57) via a preloaded gear system

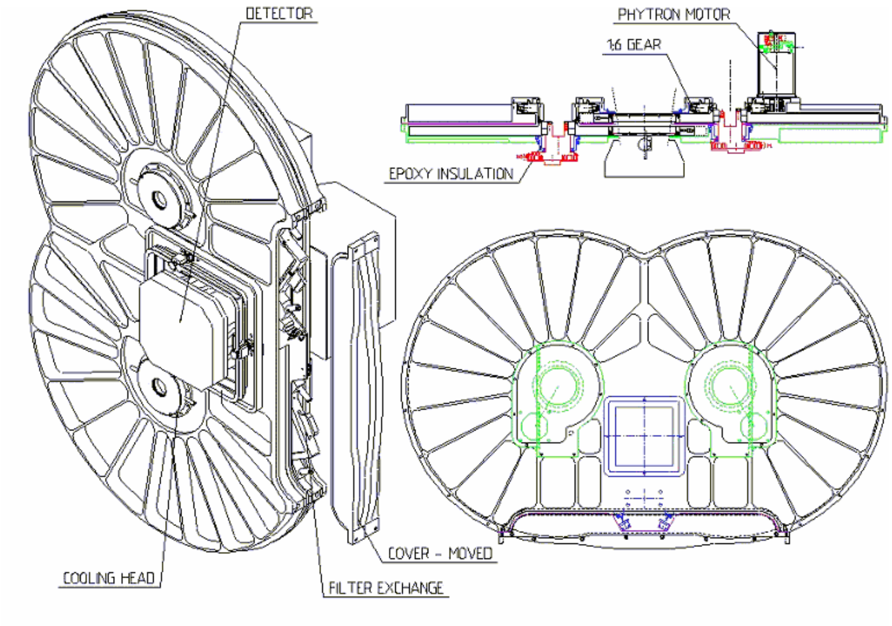


Fig. 5: HAWK-I Filter wheel unit

The detector mount (Fig 6) is attached to the back of the filter wheel unit. The detectors are cooled down via the second stage of the close cycle cooler.

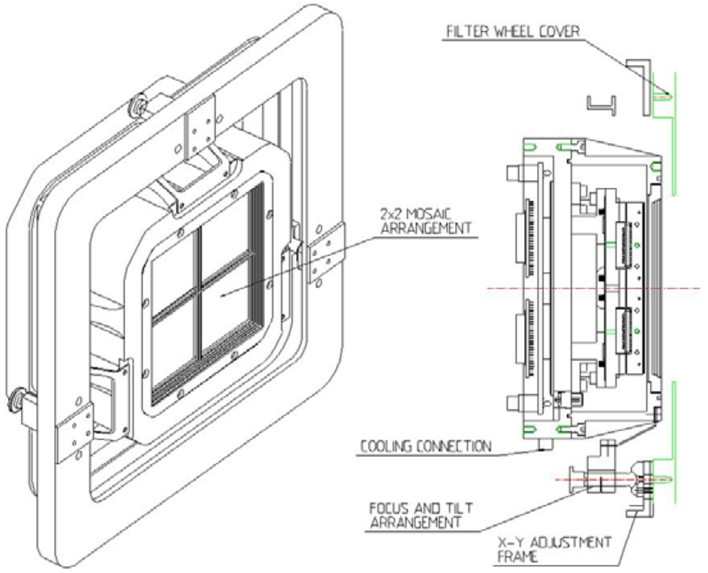
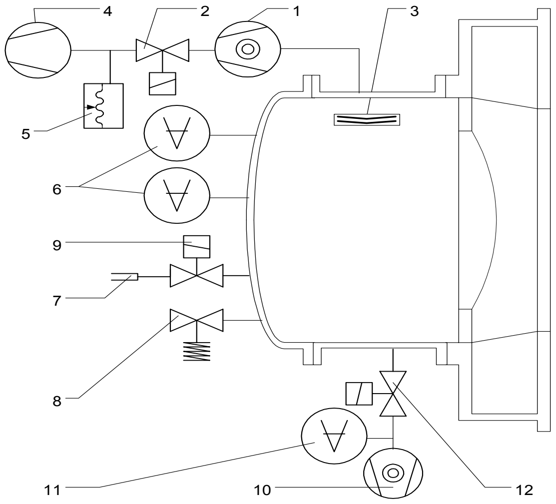


Fig. 6: HAWK-I detector mount unit

6. Cryogenic-Vacuum Design

The vacuum cryogenic design is based mostly on the successful aspects of the other ESO cryogenic instruments. An overview of the vacuum system is show Figure 7. In addition to the standard pumping system, an emergency back-up system provides some extra safety for the expensive detector system.



	Components
1	Turbo-molecular pump, magnetic bearing,
2	Vacuum insulating valve Flange
3	Sorption pump
4	Pre vacuum pump
5	Pressure switch
6	Full range vacuum gauge Flange
7	Re-pressurisation valve Flange
8	Over-pressure safety valve (0.2 bar) Flange
9	Nitrogen gas connector
10	Drytell micro
11	Full range vacuum gauge Flange
12	Vacuum Insulating Valve

Figure 7: Vacuum Design.

The cooling system based on two Leybold closed cycle coolers, maintains the instrument below 140K and the detector and the filters at about 80K. The two Leybold heads are fed with a single compressor.

A liquid nitrogen pre-cooling circuit accelerate cool-down (< 24 hrs). Because of the large size of the entrance window a defogging system will be activated when the temperature difference between the window and the dew point is too small. The Figure 8 shows a view of the cryogenic design.

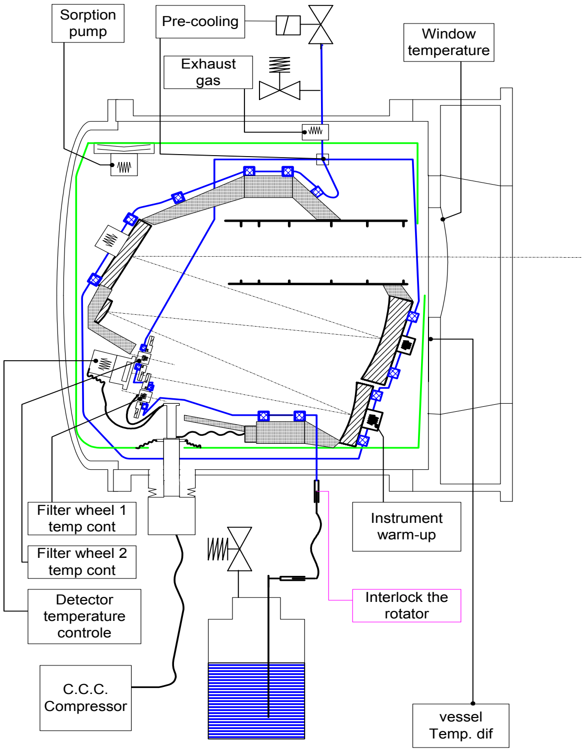


Figure 8: Cryogenic Design

7. Detector and Acquisition System

The detectors are the four 2kx2k Rockwell HgCdTe MBE buttable arrays with 2.5µm cut-off. GL Scientific in Hawaii will provide the packaging into a 2x2 mosaic using a design developed for the JWST (Figure 9). The fan-out board is developed for our application at ESO. The complete detector mount will be heat sinked by the 2nd stage of the two cryocooler heads. This two heads give the margin to adjust the detector temperature to its optimum while removing the power dissipation of the pre-amplifier.

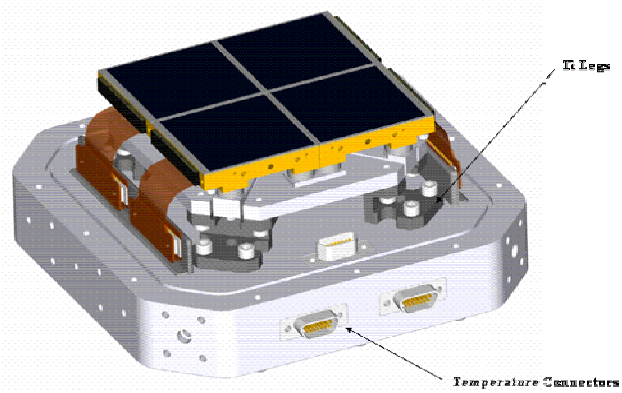


Figure 9: GL Scientific mount

The acquisition system will be able to acquire 132 channels simultaneously. This will allow to read out the detector in 1.3 seconds which is adequate for HAWK-I application. For the adaptive secondary, a fast read out of sub-window (detector guiding mode) will be also necessary to acquire a Natural Guide Star and perform the tip-tilt correction at a frequency of about 100 Hz.

The acquisition system will be based on IRACE including the necessary boards for the acquisition of the 132 channels. The number cruncher is a commercial LINUX PC, which is now part of the standard IRACE system.

8. Control Electronics and Software

The control electronics is mainly based on ESO standards and re-use of designs validated with other projects. The main requirements are: the control of 2 cryogenic functions and a cable rotator, the temperature/pressure control and monitoring. The control electronics fulfill also the requirement in terms of safety interlocks and alarms.

The requirements of the HAWK-I control software are provided intrinsically by the ESO standard software. Therefore, the development only requires to assemble and configure standard software templates, configuration and installation procedures.

9. Adaptive Optics Compatibility

HAWK-I has been design to keep open the possibility of a later use with an adaptive secondary mirror.
The adaptive optics over such a large field will not give diffraction limited images, but a factor 2 improvement of the seeing can reasonably been expected. Figure 10 presents the expected gain in terms of energy collected on one pixel with or without AO for a seeing of 0.9” in J, H, K-band.

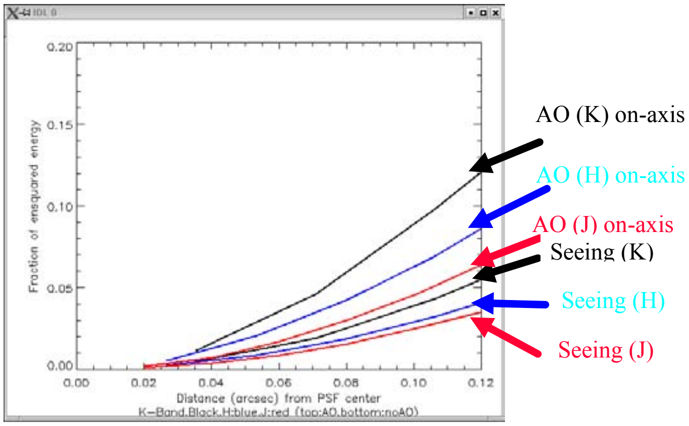


Figure 10: Energy concentration with/without Adaptive Secondary for 0.9” seeing

The Secondary Adaptive Mirror will operate with four lasers and a natural guide star. These lasers will probably be mounted on the center piece of the telescope and the laser direction will be rotated on the sky such that their images can be fixed with respect to the instrument Field of View (Figure 11). The four laser images are located at 90º near the four edges of the field and the optimal distance from the optical axis is expected to be at about 4 arcmin

The beams are then collected by reflection on the entrance window. The wavefront sensors will have to compensate for the focus variations due to telescope position (between 80 and 180 mm on Nasmyth focus) and also to rotate the beam to match the sub-pupils between the wavefront sensors and the Adaptive Secondary Mirror.

A natural guide star is needed for tip-tilt correction. A statistic analysis of the star catalogue has shown that the probability is above 99% to find a star with a magnitude lower than 14 (sufficient for tip-tilt) in the field of view of HAWK-I. Therefore, this function will be assumed by the scientific image on the IR detector using the Guiding Mode of the HAWAII 2RG.

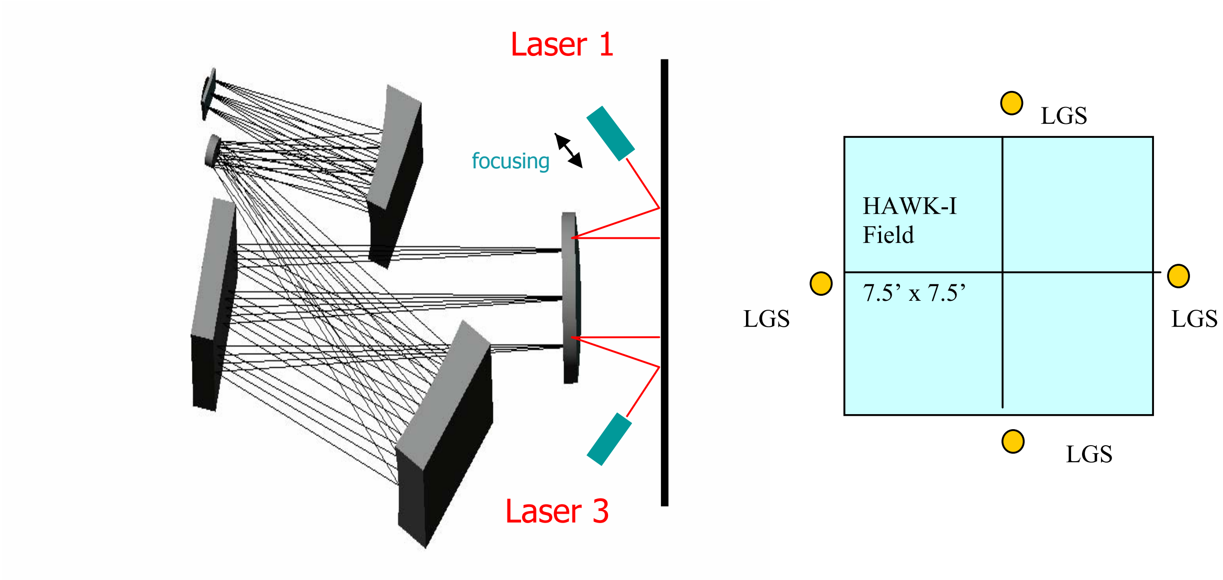


Figure 11: Laser Guide Star versus Instrument Field of View.

10. Development Plan

HAWK-I is a VLT instrument built in-house at ESO under the responsibility of the Instrumentation Division. The overall concept of the instrument is now frozen and passed the Preliminary Design Review in March 2004.

Its detailed design will continue during the next few months. Simultaneously with this detailed design phase, we have also started the procurement of the optics, the detector mount and the filters.

The Final Design Review will take place in October 2004. This review will allow the release for manufacturing of all mechanic, electronic, cryogenic parts. In the course of 2004, the 2Kx2K Rockwell detectors will be available and will undergo performance test in the ESO Test Facilities. After this test, the detectors will be integrated in the mount built by GL Scientific. All the parts should be available for integration second half of 2005.

The team will be ready for the Preliminary Acceptance Europe, 2nd quarter of 2006 followed by the Preliminary Acceptance Chile at Paranal, a few months later.

11. Conclusion

It is expected that HAWK-I will provide substantially improved capabilities for near infrared imaging with 0.1” sampling over a 7.5’x7.5’ field at the ESO VLT in 2006/07.