IRIS: An infra-red tilt sensor for the VLTI

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ABSTRACT

In the last two years the Very Large Telescope Interferometer (VLTI) has been operated with a wavefront controlled down to the Coudé focus of each 8m Unit Telescope. From this focus, the stellar beam is passively relayed by more than 10 mirrors distributed along a 100m subterranean path before to be coherently superimposed in the VLTI laboratory.
Experience has proven that the observation efficiency would be largely improved by controlling the tilt of the beam directly inside the VLTI laboratory.
In this article, we present the justification and basic features of the InfraRed Image Sensor (IRIS) as well as its implementation within the already packed VLTI laboratory. The forthcoming milestones of the project are presented.

Keywords: VLTI, tip-tilt, infra-red

1. INTRODUCTION

The Very Large Telescope Interferometer (VLTI) obtained first fringes in March 2001. Since that time, regular operations have taken place using either the siderostats (40 cm mirror diameter) or the Unit telescopes (8 m mirror diameter) as light collectors. In both cases, the beam tilt is only controlled at the telescope level. Before reaching the VLTI laboratory, the beam is passively relayed along typically 100m through an underground light duct and the delay line tunnel.
This configuration was initially selected to enable wavefront correction on off-axis targets considering that only a limited field of view can be relayed through the light ducts and tunnel to the interferometric laboratory. Nevertheless provision had been taken at the very beginning of the project to install the Infrared Image Sensor, IRIS, (i.e. a tilt "tracker") inside the VLTI laboratory.
Indeed experience has shown that low frequency tilt introduced by air turbulence between the telescope area and the VLTI laboratory affects significantly the VLTI efficiency. Because most of the current VLTI instruments (i.e. VINCI, AMBER) and the fringe trackers (i.e FINITO, FSU) use monomode fibers to filter spatially the incoming wavefront, any tilt error affects directly the coupling into the fiber and therefore the observation efficiency.

This paper presents the design and implementation of IRIS. The main challenge of this tilt sensor is to operate with any combination of VLTI instrument and fringe tracker, with equal performance

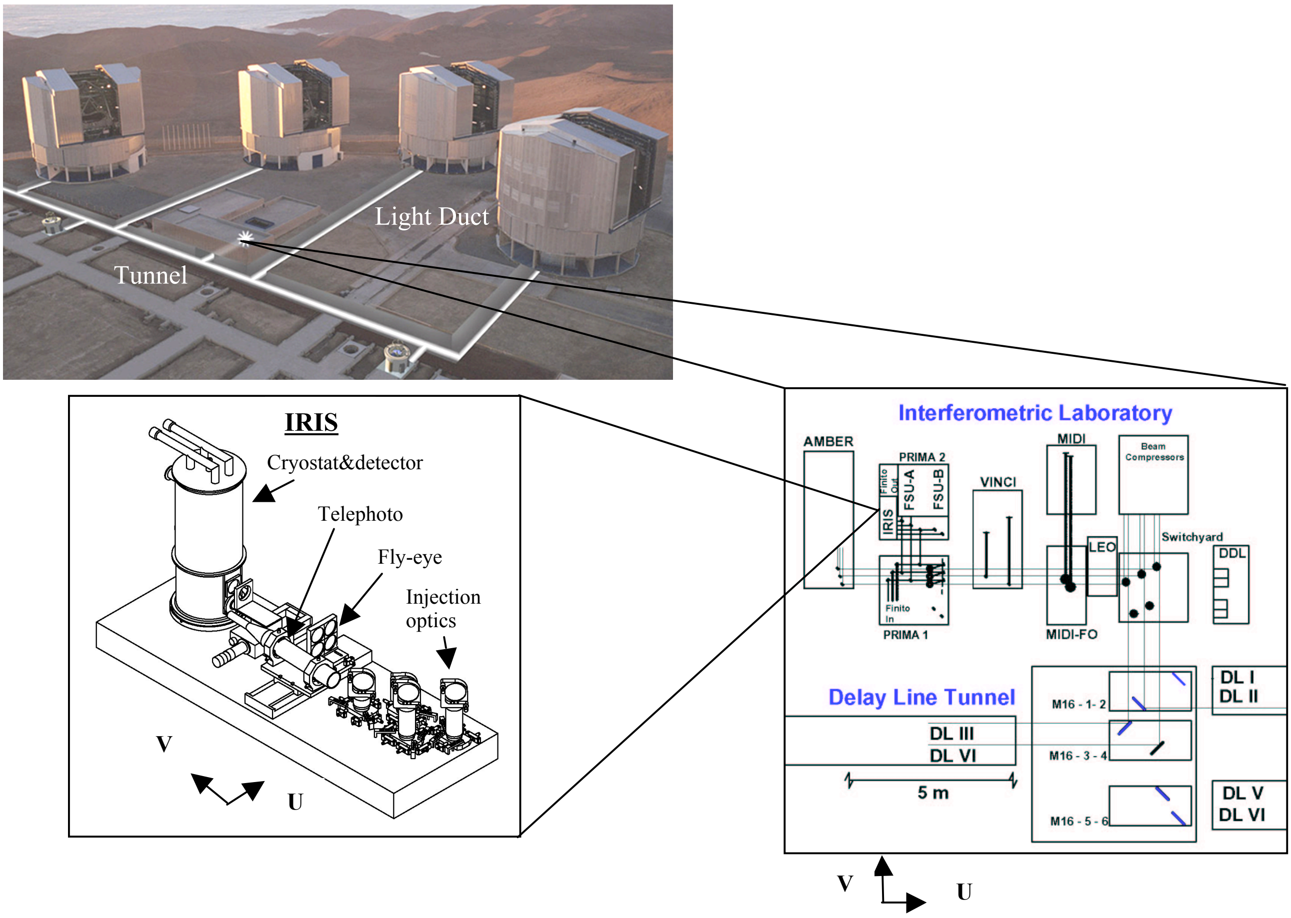


Figure 1: Location of IRIS within the VLTI

2. JUSTIFICATION

As recalled in the introduction, the possibility of installing a tip-tilt sensor in the VLTI laboratory has always been considered to overcome possible tilt introduced by air turbulence in the optical path downstream of the telescope areas. Then, the choice of having this device operating at infra-red wavelengths is supported by the following arguments:

- *The VLTI throughput down to the VLTI laboratory is optimized in the Infrared:*
  The design of the VLTI optical train is such that most of the visible wavelength feeds the adaptive optics system at the transmitted Coudé focus. Hence, the transmission of the VLTI down to the laboratory is much better in the infrared wavelengths (from 1.2 µm upwards).

- *The Atmospheric differential refraction can be minimized*
  Tip-tilt sensing at telescope area is made at visible wavelengths while the instruments make use of the infrared wavelengths (from J to N). This means that the effect of atmospheric dispersion between the science wavelength and the effective wavelength of the sensor has to be estimated using a model (this is particularly relevant for long observations away from zenith). For a given uncertainty on the effective sensing wavelength, the corresponding error is minimized when working at a wavelength as close as possible to the science wavelength.

- *The science objects have a larger photon flux in the infrared than in the visible.*

3. IRIS REQUIREMENTS

The main functional requirements of IRIS are imposed by the necessity to perform tilt correction for various combinations of VLTI instrument and fringe tracker. This requires operating at several pre-defined wavelength and correcting for transversal atmospheric dispersion. This also imposes operational constrains since any configuration change must be performed remotely.

Indeed, IRIS must operate in parallel with the current instruments, VINCI, MIDI, AMBER observing respectively in the [K], [N], [JHK] spectral bands. Furthermore these instruments are enhanced by two possible fringe trackers, FINITO or FSU, which are tracking respectively in the [H] and [K] spectral band. In addition, the straylight of one spectral line from the PRIMA laser metrology [2], λ=1.319 μm, must be sufficiently attenuated.

Thus, IRIS must image the stellar beam in any of the J, H or K band. The corresponding effective wavelength is referred as the IRIS sensing wavelength (λ_{IRIS}). But in addition IRIS must stabilize the tilt of the instrument or fringe tracker beams at any arbitrary wavelength between 1.2 μm and 25 μm. The selected stabilization target wavelength is defined as the IRIS zero wavelength (λ_{ZWL}). In general the IRIS sensing wavelength will be different from the IRIS zero wavelength. It therefore requires within IRIS a compensation scheme based on a model of the atmospheric dispersion.

IRIS must also measure the image position of up to four beams simultaneously. These four beams can either come from 4 different telescope pointing at the same object or from 2 different telescopes working in dual feed mode (see [1]). In this case, there is one pair of images for each of the two stellar objects. The brightness difference can be up to 4 magnitudes.

Finally, IRIS is also required to execute tip-tilt offsets without interruption of the sensing task. This shall be valid for offsets around the nominal position up to 0.5 arcsec/sky.

The main performance requirements of IRIS are listed below:

- The acquisition of the stellar objects (up to 4) shall not take longer than 1 minute in total. For this requirement, it is assumed that the actuators require two iterations to reach the desired accuracy and that it takes them 5 sec to apply a command.
- The acquisition shall be possible on any object having a brightness, m_K such that $2 \leq m_K \leq 14$
- IRIS shall be able to deliver tip-tilt error vectors at a frequency up to 10 Hz. The error made when evaluating these errors vectors (e.g. the centroiding precision) shall be smaller than 3 arcsec/lab RMS (equivalent to 6.8 marcsec/sky RMS for the UTs, resp. 30 marcsec/sky RMS for the ATs). This applies for a star magnitude up to 14 (resp. 10.7) in any of the IRIS sensing bands (J, H and K) on the UTs (resp. on the ATs).
- The opto-mechanical stability of IRIS shall be better than 2.6 arcsec/lab PTV during any period of 12 hours.

4. POSSIBLE IMPLEMENTATIONS

The light collectors used by VLTI (ATs, UTs, siderostats) are not equipped with transversal atmospheric dispersion correctors. Consequently each telescope can only provide a single wavelength that remains angularly fixed in the VLTI laboratory during observation. This puts additional constraints on the system as detailed in this section.

The stellar beam once routed in the VLTI laboratory is usually split via dichroics into several beams with different spectral contents. This allows feeding with the adequate spectral bands the different sub-systems that are required to work simultaneously. This includes in general the science instrument itself, a fringe tracker and now a tip-tilt sensor (IRIS).

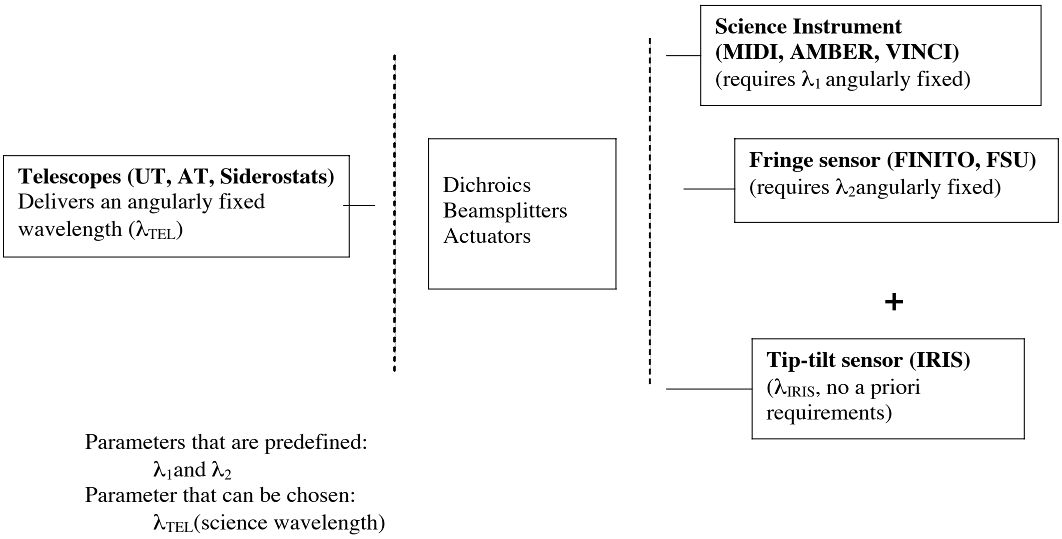


Figure 2: Diagram of sub-systems required to work simultaneously

- The science instrument and the fringe sensor
  Generally, the selected science instrument and the fringe sensor spatially filter the incoming beam(s) via mono-mode fiber which are fixed with respect to the VLTI laboratory. Therefore they expect a beam angularly fixed with respect to the VLTI laboratory at their operating wavelength. Due to atmospheric transversal dispersion, the offset angle between the various wavelengths used by each sub-system varies over time as a function of telescope zenith distance and field orientation. This means that the telescope tracking wavelength (λ_{TEL}) can be chosen to be equal to the working wavelength of the instrument (λ_1) but an actuator is then needed if the working wavelength of the fringe sensor is different from the one of the instrument. This is the case of the FINITO fringe sensor implemented in VLTI that works in the H band while the AMBER instrument relies on an angularly fixed K band. Hence, FINITO includes its own actuator called ACU (Atmospheric Compensation Unit) that allows correcting for atmospheric transversal dispersion. This actuator is controlled in open loop and its motion is computed using a model of atmospheric dispersion.

  During observations with AMBER and FINITO, $\lambda_{TEL}=\lambda_1$ and $\lambda_{z=ZWL}=\lambda_1$

- The tip-tilt sensor (IRIS)
  As for the tip-tilt sensor, the sensed wavelength might be different from both the science wavelength and the fringe sensor wavelength. This leaves two options for the tip-tilt sensing principle:
    - An actuator applies a pre-computed and varying tilt on the beam so that the corresponding image does not move in the focal plane. This allows using a fixed 4 quadrant system or an area detector where the beam is focused on a constant position.
    - The spot is forced to follow a pre-computed trajectory in the focal plane. This requires to use an area detector.

  Actually in both cases the differential angular offsets have to be computed using an atmospheric dispersion model. In the first case, this offset is applied mechanically via some steering mirrors while in the second case, it is used to update the reference pixel that serves as target position.

In the case of IRIS, it has been preferred to use an area detector and compute the trajectory that the stellar spot has to follow. This trajectory is computed based on the following elements:

- the wavelength to be stabilized at IRIS level (λ_{ZWL}). The imaginary spot that would be formed on the IRIS array detector would be fixed and its corresponding position is referred as the Zero Point. Physically, this Zero

Point is the optical conjugate of the fiber in which the flux shall be injected (either the fringe sensor or the science instrument).

- The Zero Point itself.
- The effective wavelength of IRIS (λ_{IRIS}) which depends on the filter used.
- The pupil orientation on the IRIS array detector which is a function of telescope altitude, azimuth and a fixed offset angle.

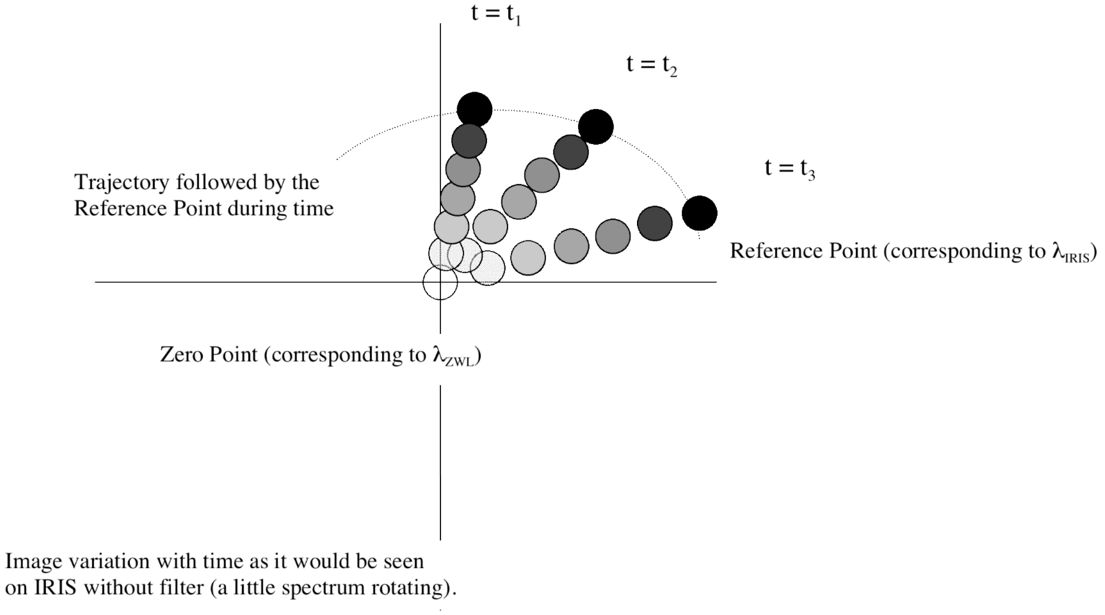


Figure 3: Trajectory followed by the reference point

5. ARCHITECTURE

IRIS is installed in the VLTI laboratory on the PRIMA 2 table (Figures 1 and 4). VLTI delivers to IRIS (at the entrance of the reserved area, along the –U direction) four collimated beams. The four beams are focused on the IRIS detector via a so-called fly eye. This optical device is formed of four similar doublets as sketched on Figure 5.

A holographic notch filter can be positioned into the beam to filter out the wavelength of the PRIMA metrology that would be otherwise much brighter than the stellar spots. The beam enters then the cryostat where both the filter wheel and the detector are located.

The fly-eye can be remotely moved and replaced by a telephoto objective which images the Power Spread function (PSF) of the VLTI stellar beam. The diameter of a "perfect" PSF is sampled by 4 pixels of the detector in the J Band.

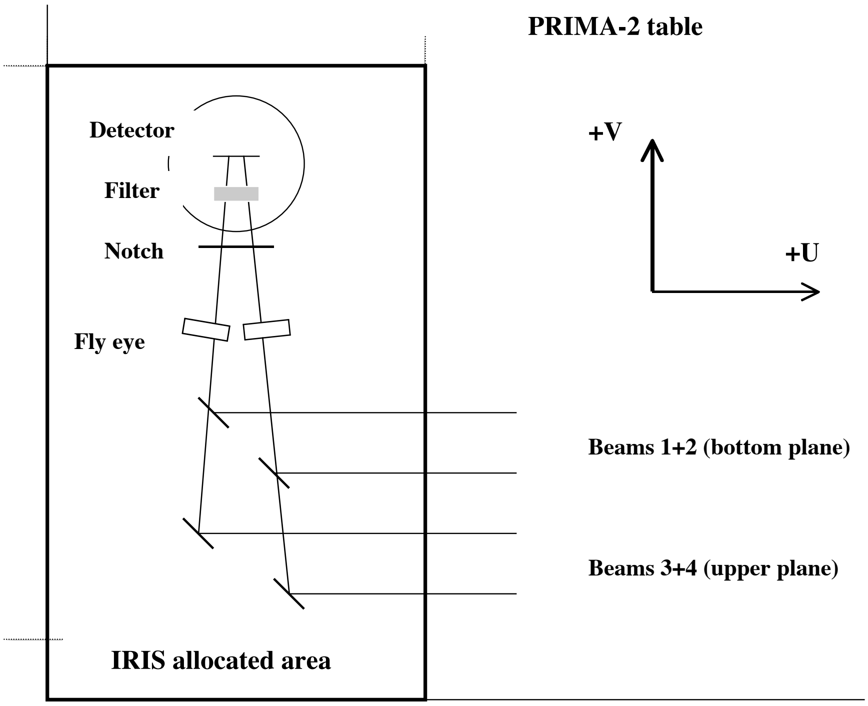


Figure 4: Conceptual sketch of IRIS

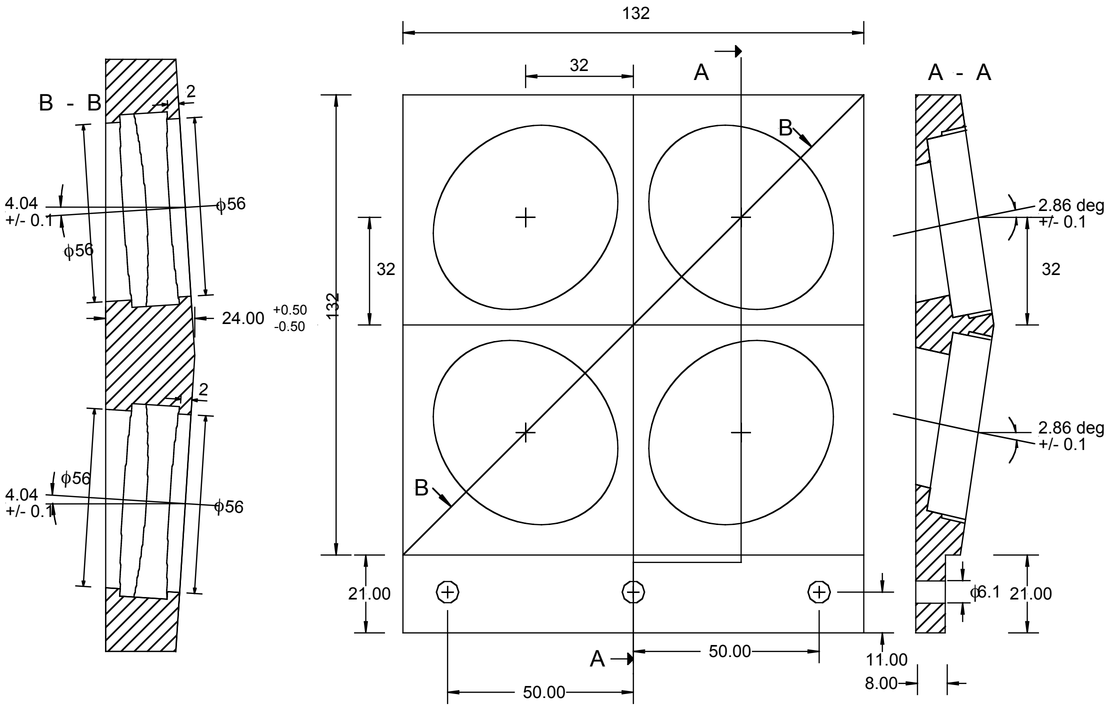
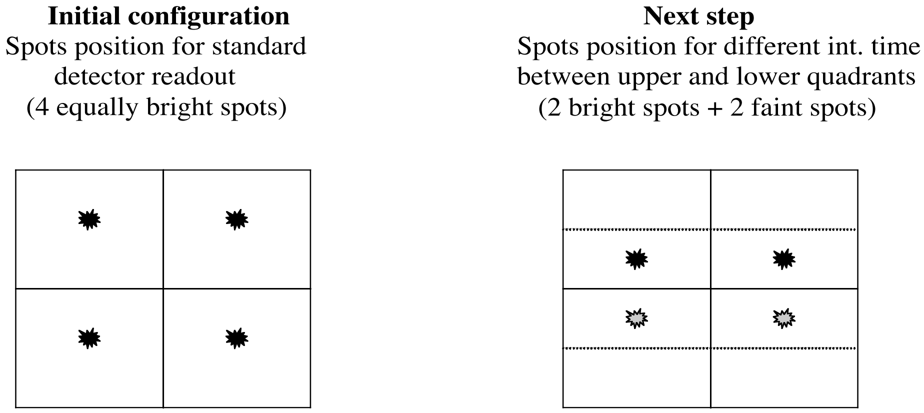


Figure 5: Sketch of the IRIS fly eye

The four beams are focused on the infra-red array (256x256 PICNIC detector with a cutoff wavelength of 2.5 µm) which is kept at cryogenic temperature (77 K). As there are up to 4 beams to handle simultaneously, it has been chosen to focus one beam per quadrant.

The fact that the beams will eventually corresponds to two object of different brightness can be handled by using different integration times. This is possible with the PICNIC detector but requires the bright and faint spots to be located at different locations within the quadrant. As initially only object of the same brightness will be imaged on IRIS detector, the nominal locations of the spots will be at the center of each quadrant as indicated in Figure 6.



Initial configuration
Spots position for standard
detector readout
(4 equally bright spots)

Next step
Spots position for different int. time
between upper and lower quadrants
(2 bright spots + 2 faint spots)

Figure 6: Nominal image positions on the IRIS detector

6. PERFORMANCE

The fly eye focal length has been designed so that the output beams have a focal ratio of 33. This yields a pixel scale of 14 arcsec/lab. This corresponds to 0.14 arcsec_sky/pixel for observation with the AT and 0.031 arcsec_sky/pixel for observation with the UT. A simulator has been used to compute the expected centroiding precision based on the following assumptions:

- Duty cycle of the detector readout mode: 100%
- Readout noise of the detector: 30 electron RMS
- Infinite depth of detector wells (no saturation possible)
- fixed pattern noise (irregularities of the pixels area):1% RMS
- FWHM of the image equal to its diffraction limited value
- The dark current has been estimated based on solid angle.
- Standard centroiding technique based on moment calculation.
- 100% transmission between switchyard and IRIS entrance

Figure 7 shows the resulting curve obtained in the case of the H filter and demonstrates that the requirement of 6.8 marcsec/sky RMS down to magnitude 14 is fulfilled. During the test period in Garching, refined centroiding techniques will be tested which might lead to an extra gain in performance.

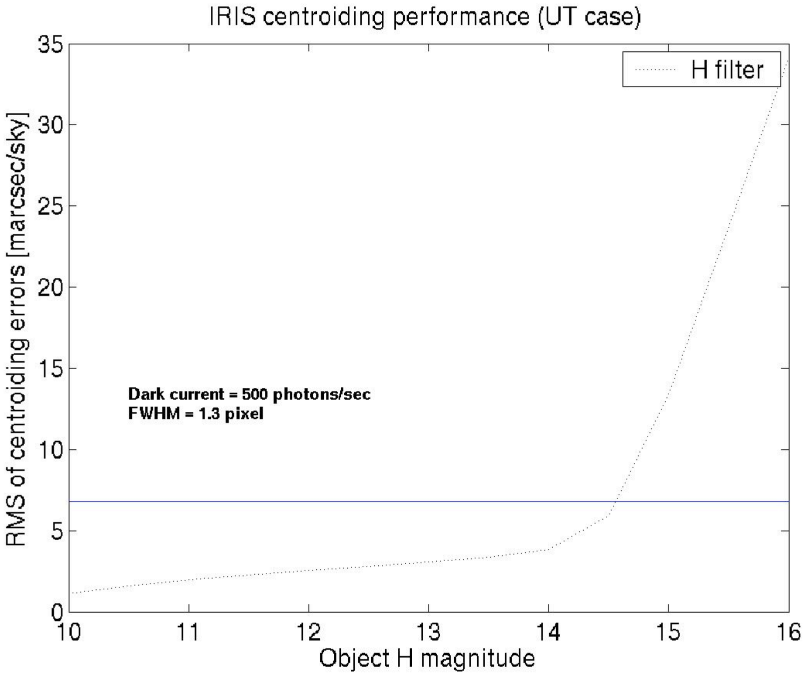


Figure 7: RMS of centroiding errors vs object H magnitude.

Actually the PICNIC detector has finite well depth that reach saturation when reaching 200000 ADU approximately. This means practically that for bright objects (e.g. with magnitude smaller than 8), the combination of the spectral band redirected towards IRIS via the feeding optics and the IRIS filter have to be chosen adequately to strongly reduce the photon flux. These combinations have been identified and should allow to observe without saturation objects as bright as magnitude 2 in the selected wavebands (J, H , K).

7. IMPACT ON VLTI OPERATIONS

7.1. Modes supported and associated IRIS configuration

IRIS shall be usable in parallel with any of the VLTI instruments currently foreseen. The complete list as of today of the instrument combinations that include IRIS is given in Table 1.

Mode Name	**Description**
VINCI	VINCI (K band) + FINITO (H band) + IRIS
MIDI	MIDI (N band) + FINITO (H band) + IRIS
AMBERJHK	AMBER (J,H,K bands) + FINITO (H band) + IRIS
AMBERJK	AMBER (J, K bands) + FINITO (H band) + IRIS
ASTROMET.	FSU-A (K band) + FSU-B (K band) + IRIS
MIDI-PR	MIDI (N band) + FSU-B (K band) + IRIS
AMBER-PR	AMBER (J,H,K bands) + FSU-B (K band) + IRIS

Table 1: List of instrument combinations that include IRIS

For each mode and stellar object brightness, an adequate beam routing has been defined. Within IRIS, the two elements that are configurable are the notch filter (In/Out) and the bandpass filter located inside the cryostat (J, H, K and Js). The Js filter is a special J filter that has a reduced bandpass to reject the PRIMA metrology wavelength (1319 nm).

Mode	**Notch filter**	**IRIS filter**	
		Bright case	Faint case
VINCI	Out	H	J
MIDI	Out	H	K
AMBERJHK	Out	H	K
AMBERJK	Out	H	J
ASTROMET.	In	K	Js
MIDI-PR	In	K	H
AMBER-PR	In	K	H

Table 2: IRIS configuration according to mode

7.2. Integration of IRIS in the VLTI operations

The implementation of IRIS will modify the sequence of operations that are executed before the start of the fringe detection on the science instrument. This sequence of operations is driven by the instrument through templates. This sequence is actually specific to each instrument as some of them have internal image optimization capabilities (e.g. VINCI) while other not (e.g. AMBER). The example of AMBER is detailed in the figure 8 with a list of actions to be completed chronologically.

1. VLTI preset
(telescopes, DLs, instrument, FINITO ….)

2. Acquisition at telescope Coudé focus
Start of Coudé guiding

3. Acquisition on IRIS
Raw centering on IRIS detector
Actuators: Coudé XY tables

4. Raw photometric optimization on AMBER
Actuators: the Coudé XY tables

5. Raw photometric optimization on FINITO
Actuator are the ACUs (tip-tilt motion)

6. Start the IRIS guiding

7. Fine photometric optimization on FINITO
Actuators: the ACUs (tip-tilt motion)

8. Fine photometric optimization on AMBER
Actuators: the ACUs (tip-tilt motion)

9. Fringe search on FINITO
Actuators: the main delay lines

10. Fringe search on AMBER
Actuators: the ACUs (longitudinal motion)

Figure 8: List of actions to be completed when presetting to a new object with AMBER+FINITO+IRIS

8. CONCLUSIONS

The basic design of the VLTI infra-red sensor has been presented. It will increase significantly the VLTI observational efficiency at the cost of complexity. Therefore the operation shall be as automatic as possible to limit the overheads to a minimum. The final design review of IRIS was held in April'04 and all components of IRIS are currently being procured. IRIS will be initially integrated in Garching to characterize its performance. Installation on Paranal is foreseen by the end of 2004.

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REFERENCES

1. A. Glindemann et al," VLTI technical advances – present and future", *These proceedings*, 2004
2. S.Leveque et al,"Towards nanometer accuracy laser metrology for phase-referenced interferometry with the VLTI", *Proc of SPIE*, vol **4838**,2002.