VLTI Image alignment monitoring

Ph. Gitton, M. Cantzler, B. Koehler, P. Kervella

European Southern Observatory
Karl Schwarzschild Str.2, D-85748 Garching bei München, Germany
pgitton@eso.org, http//www.eso.org/

ABSTRACT

In its current configuration, the VLT Interferometer (VLTI) combines the light collected by two telescopes and directs it towards the commissioning instrument called VINCI. In an interferometer, the optical path ranging from a telescope to the point where beams are combined is referred as an arm of the interferometer. This arm contains a large number of optics that have to be aligned at installation time **and** kept aligned during the period of use of the interferometer. The method used to perform the initial alignment is reported in a separate article. This paper is focussed on the methods used to assess the stability of the image alignment of each interferometer arm. Collected data sets are presented and interpreted.

Keywords: Interferometry, Very Large Telescope, VLTI , alignment, commissioning

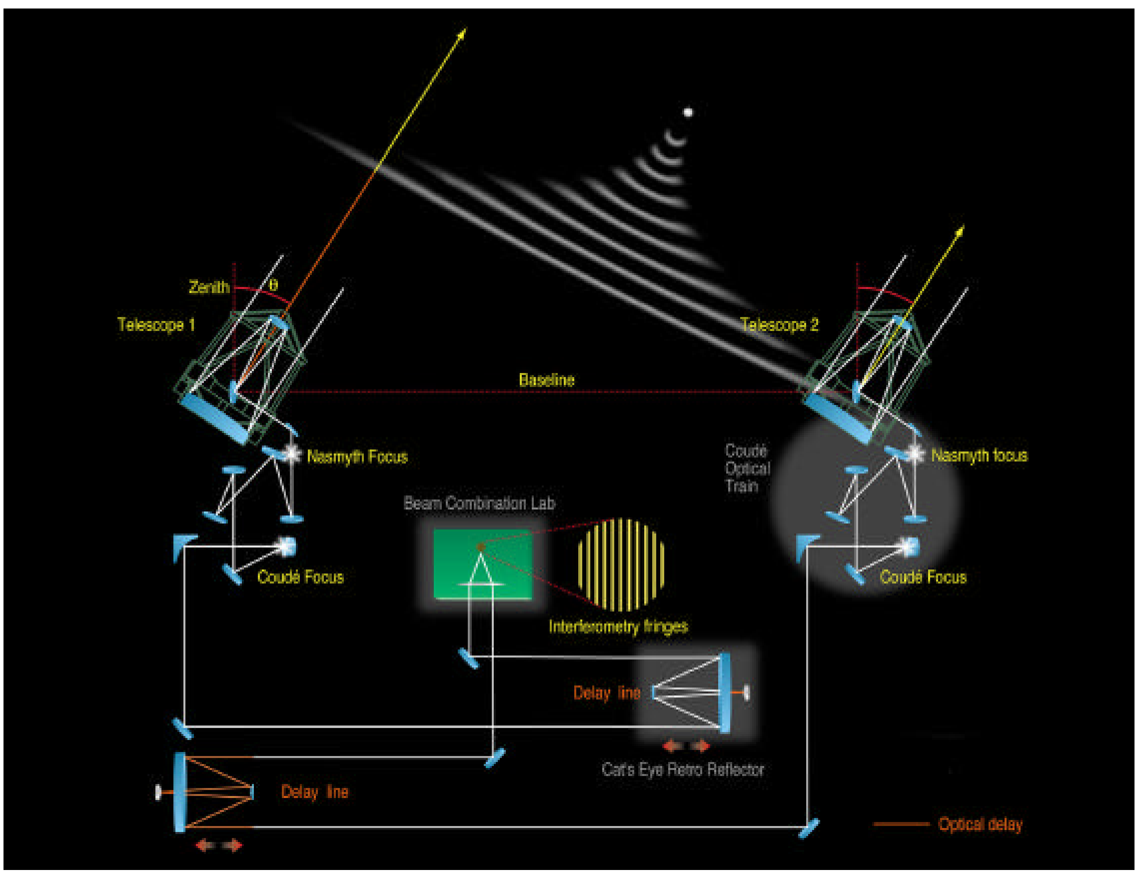

Figure 1: The full VLTI when using the Unit Telescope as photons collectors

1. INTRODUCTION

In its current state, the VLTI can be used in two general configurations as the photon collectors can either be the siderostats (SID, 40 cm aperture) or the unit telescopes (UT, 8m aperture). The siderostats are used for commissioning purposes and will be retired as soon as the first two auxiliary telescopes (AT) will be available.

The configuration that includes the Unit Telescopes is illustrated in figure 1. In each arm of the interferometer, the beam undergoes 18 reflections before entering the VLTI laboratory. In the case of the siderostat, the optical chain is reduced and undergoes only 12 reflections before entering the VLTI laboratory as shown in figure 2.

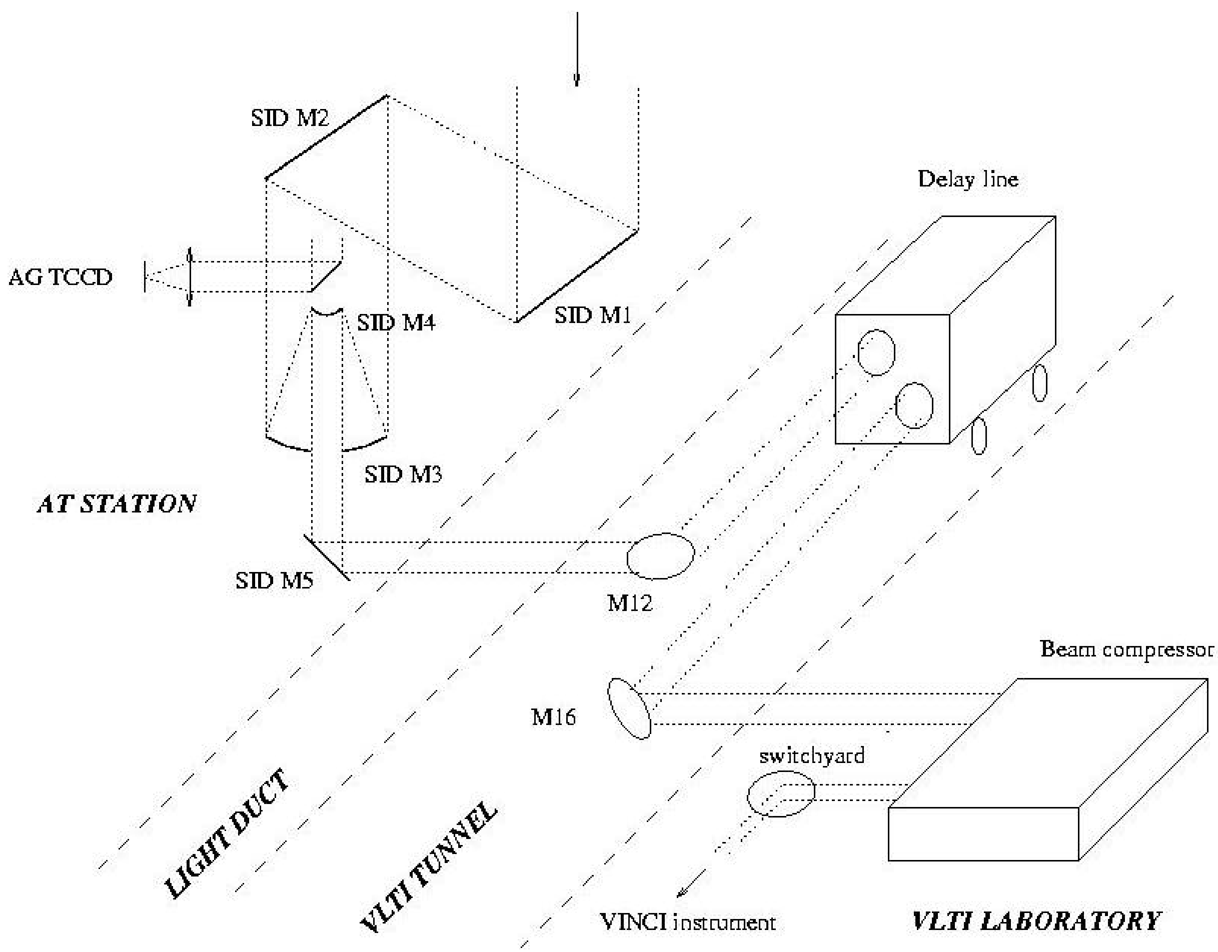

Figure 2: The interferometric arm when VLTI is in SID configuration

The differences (in gray) and commonalities in the interferometer arm between the two configurations are summarized in table 1:

Physical location	Elements of the interferometric arm	Number of Reflections (Unit Telescope case)	Number of Reflections (Siderostat case)
Telescope	Telescope optics	11 (M1 to M11)	5 (SID M1 to SID M5)
VLTI tunnel	M12 units	1	1
	Delay lines	5	5
	M16 units	1	1
VLTI Laboratory	Beam compressor	3	3
	Switchyard	1	1
	VINCI feeding optics	1	1
	VINCI injection optics	3	3
	Total	26	20

Table 1:Reflections in the interferometer arm for the 2 possible configurations

A sensor of the telescope auto-guider (AG) is located in each arm. In the UT configuration, this sensor makes use of 4 avalanche photo-diodes located in a focal plane after the dichroic M9. In the SID configuration, the sensor is a Technical CCD (referred as AG TCCD on figure 2) fed by a fraction of the stellar light via a small folding mirror located just after the mirror SID M2.

2. THE CONFIGURATION WITH SIDEROSTATS AS PHOTONS COLLECTOR

The siderostat acts as an afocal telescope which delivers an 80 mm collimated beam. This beam diameter is reduced to the standard beam diameter used by all VLTI instruments (18 mm) after passing through the beam compressor installed in the VLTI laboratory. After reflection on two flat mirrors (switchyard and VINCI feeding optics), the beam can either be directed towards the alignment tool (that includes the Image Alignment Sensor (IAS TCCD)) or towards the injection optics. The optical stream that forms the arm can be represented schematically as shown in figure 3:

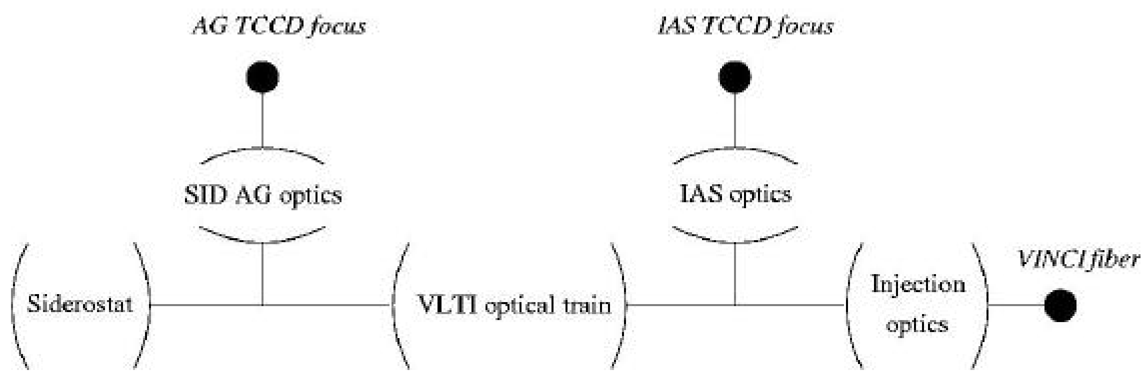

Figure 3 : Schematic of the interferometer arm with SIDs

The arm of the interferometer contains three points that needs be optically conjugated:

- The reference point of the siderostat auto-guider TCCD (AG REF point)
- The reference point of the alignment tool TCCD (IAS REF point)
- The fiber head on the VINCI instrument

The aim of the image alignment is to ensure that the infrared image of the stellar object observed is formed on the fiber head so that the injection efficiency is maximum. If the system would be perfectly stable in terms of image alignment, it would be sufficient to identify at a pixel on the AG TCCD optically conjugated to the fiber head only once. However it is not the case and, as it has been anticipated during the development phase of VLTI that the optical conjugation will be changing, an alignment procedure has been devised.

Image alignment procedure

Part I: Conjugation of the VINCI fiber on IAS REF point (done once a night)

The first part of the image alignment procedure is done just before operations start. It consists in moving the injection parabola in order to optically conjugate the fiber with a reference point on the IAS TCCD (for each arm). This is done using the artificial source Leonardo located in the interferometric laboratory. This source is supposed to mimic precisely in terms of alignment the stellar beam. The successive steps are the following:

1. The beam is directed towards the IAS TCCD by inserting a beam splitter cube before the fiber injection optics. This mode is referred to as the alignment mode and is illustrated in figure 4.

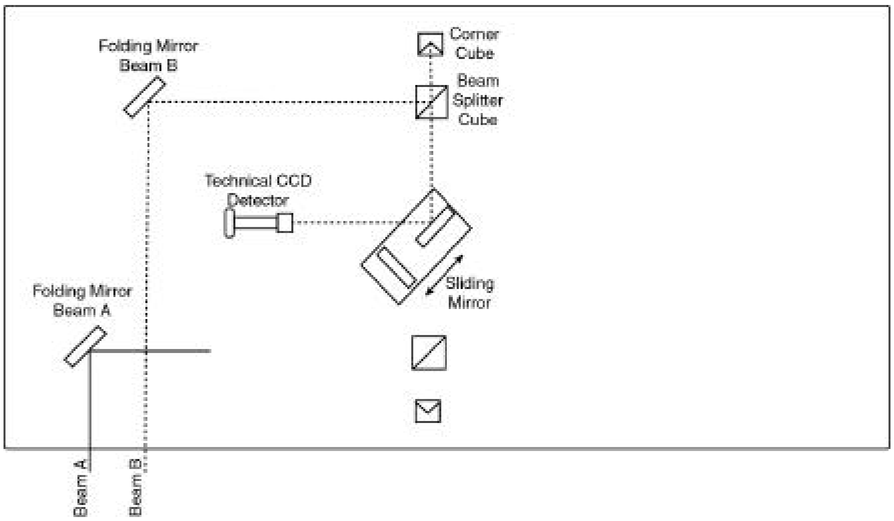

Figure 4: Alignment mode for beam B

2. The centroid coordinates of the image formed on the IAS TCCD are measured and logged (IAS REF point)
3. The beam-splitter previously inserted is removed to allow the beam to reach un-deflected the fiber injection optics. This mode is referred to as the stellar interferometric mode and is illustrated in figure 5.

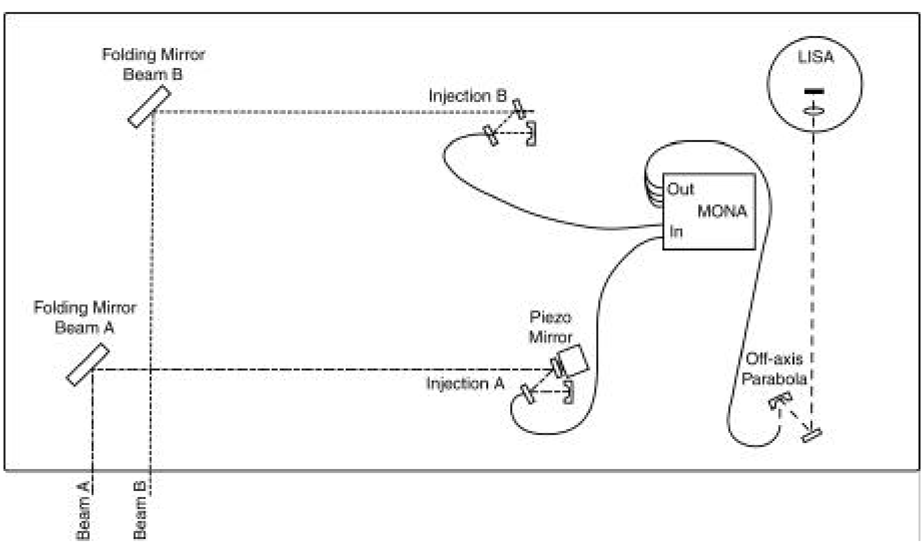

Figure 5: Stellar interferometer mode

4. The injected flux (monitored on the infrared camera) is optimized moving the injection parababola in tip and tilt (PAR REF positions). Values are logged.

Conclusion: By the principle of transitivity, when the injection parabola is set to its PAR REF position, the pixel of IAS TCCD conjugated to the VINCI fiber is perfectly known (IAS REF point)..

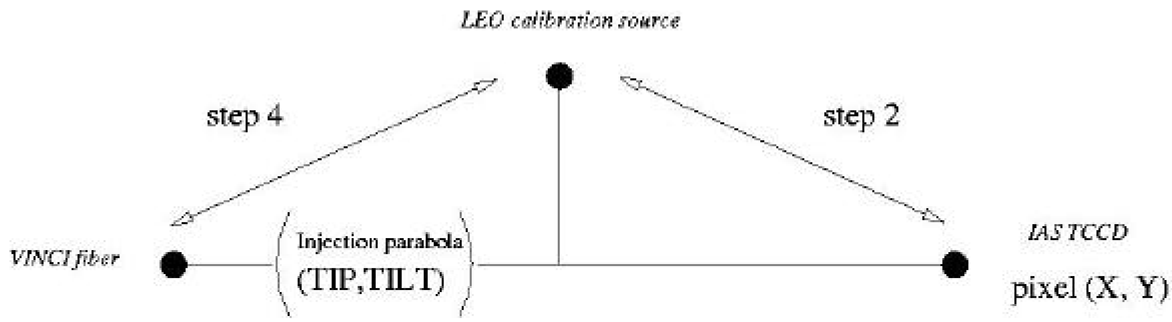

Figure 6: Steps of the alignment procedure, part I

Part II: Conjugation of the AG REF point with the IAS REF point (done for each new target)

The following steps are executed sequentially:

1. VLTI is preset (telescopes + delay lines).
2. The beam is directed towards IAS TCCD by inserting a beam-splitter before the fiber injection optics (see figure 4).
3. An offset is sent to the auto-guider of the telescope associated with this arm to center the stellar image on the IAS REF point. The new AG TCCD guiding point is logged (AG REF point).
4. The beam-splitter previously inserted is removed and the injection parabola is set to its PAR REF position (See figure 5).

As a result of these various actions, the visible stellar light image is formed very close to the fiber head.

Part III: Final injection adjustment (for each new target)

The previous actions are still insufficient to ensure that the infrared light is properly injected in the VINCI fiber for the following reasons:

- atmospheric refraction can displace the visible and K images as far as 1 arcsec from each other
- the centroids are measured with a finite precision
- the positioning of the stellar light on the IAS REF point is done at +/- 1.5 pixel
- the various moving elements used (parabolae and sliders) have some repeatability errors

Therefore the final step to ensure that the injection of the infrared light is optimum has to be executed. It is done by scanning the parabola on a limited range around its PAR REF position to optimize the flux on the infrared camera.

Stability of the IAS REF point

- The alignment procedure in part I does not give directly the stability of the optical conjugate of the VINCI fiber on the IAS TCCD but it can be computed. To this end, the TIP and TILT variations of the injection parabola are mapped on the IAS TCCD and subtracted from the measured X,Y position. This mapping has been established experimentally by back lighting the VINCI fiber and imaging it on the IAS TCCD. Then a simple calibration allows one to get the following rotation matrix:

$$\Delta X = M_{11} \times \Delta TIP + M_{12} \times \Delta TILT$$
$$\Delta Y = M_{21} \times \Delta TIP + M_{22} \times \Delta TILT$$

$$M_{11} = -0.0421,\ M_{12} = -0.8920,\ M_{21} = M_{12},\ M_{22} = -M_{11}$$

The criteria to assess the conjugation stability can then be expressed as:

$$\mathrm{var}\ X_i = (X_i - X_0) - M_{11} \times (TIP_i - TIP_0) - M_{12} \times (TILT_i - TILT_0)$$
$$\mathrm{var}\ Y_i = (Y_i - Y_0) - M_{21} \times (TIP_i - TIP_0) - M_{22} \times (TILT_i - TILT_0)$$

where **i** is the index of measurement.

The results are given below for both arms of the interferometer and are expressed directly in units of arcsec/sky. The curves show that there have been substantial variations during the period considered (December 2001 to July 2002). These variations are significantly above the measurement noise. They are typically of 6 arcsec/sky peak to valley (PTV) except for the X axis of arm B where it is 4 times larger. In this case, the data show that the optical conjugation between LEO and the X axis of the IAS TCCD axis X was quite stable (5 arcsec/sky PTV) while the optical conjugation between LEO and VINCI fiber shows a large drift (35 arcsec/sky). The main origin of the drift is therefore the injection optics in arm B. It is worth reminding that the injection optics in arm B are mounted on a large translation stage (which is used to equalize the optical path length in each arm of the instrument) unlike in arm A. A slow angular deviation of this unit over the months is very likely the source of the large drift.

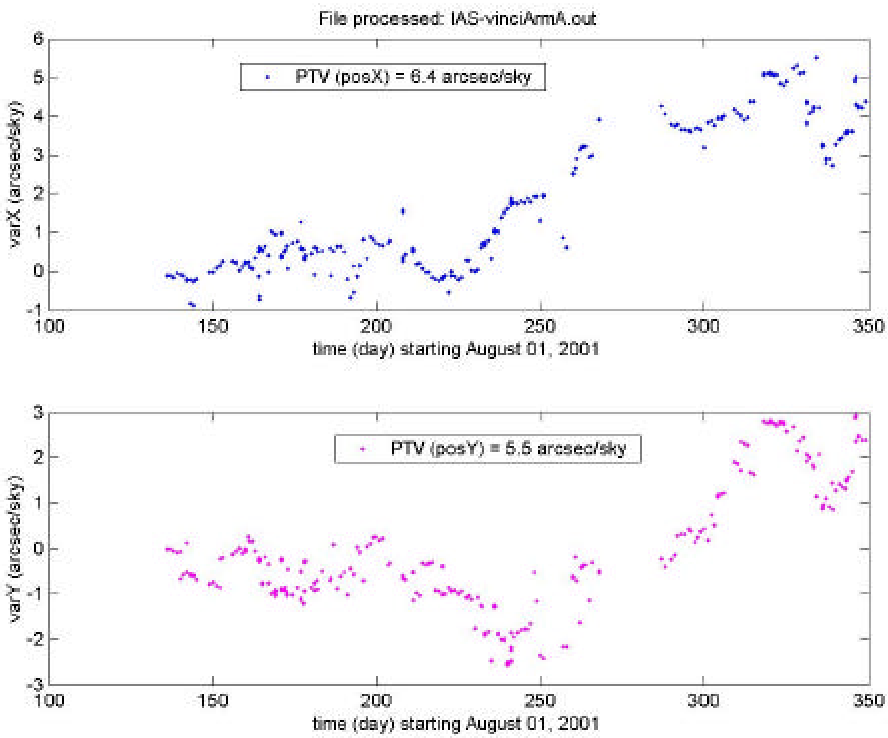

Figure 7: Coordinates of the computed conjugated image of VINCI fiber on IAS TCCD (arm A)

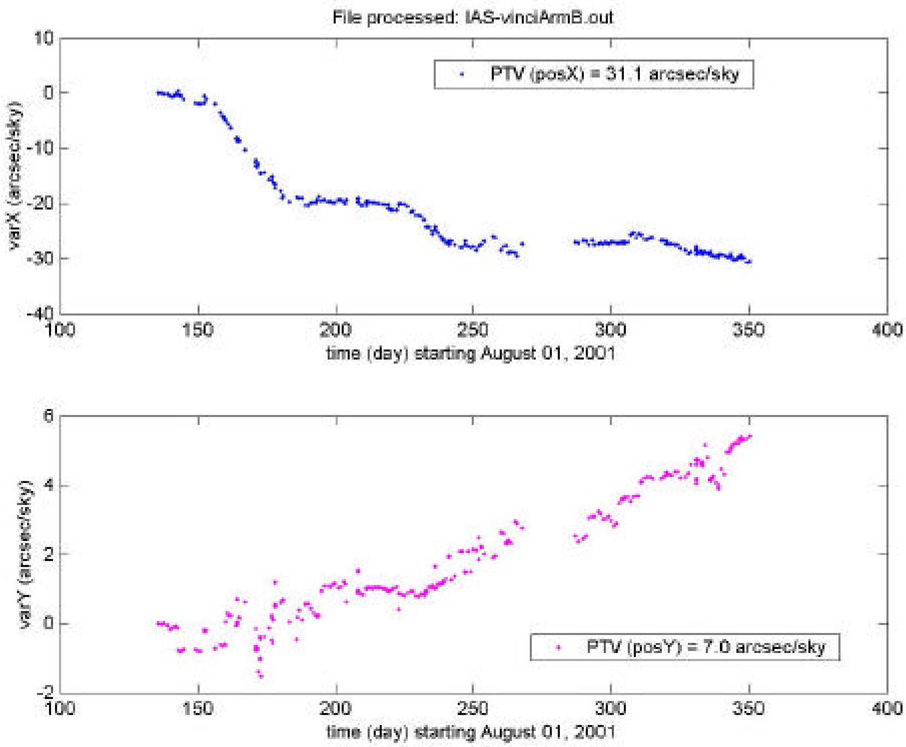

Figure 8: Coordinates of the computed conjugated image of the VINCI fiber on IAS TCCD (arm B)

Stability of the AG REF point

At every preset, the exact coordinates of the AG REF point are measured as part of the alignment procedure. A time series obtained over a period of 7 months for siderostat #2 is displayed in figure 9. The following can be derived from the curves:

- The standard deviation of the data over 7 months is 12.8 arcsec/sky along X axis and 6.9 arcsec/sky along Y axis.
- There is a clear slow drift of typically 15 to 30 arcsec/sky depending on the axis over a 7 months period. This means roughly 2 to 4 arcsec/sky per month.
- The data have been plotted as a function of external temperature. The figures 10 and 11 clearly show that the variations from day to day are partially correlated with external temperature. This indicated that the main origin of the drift is at the level of the siderostat or in the light duct as the rest of the elements forming the optical arm of the interferometer are underground and therefore at a temperature which is insensitive to the external one.
- There are very often large variations within the same night

A specific study has been done of the variations within a night. This study was done considering the nights during which at least 10 data were available. More than 120 nights fulfilled this condition, allowing one to make a statistical analysis that leads to the following points:

- The variations within a night have a typical range of 9 arcsec/sky and can reach 15 arcsec/sky in some cases.
- For some unexplained reasons, within a night, the average drift of the AG REF point on the siderostat #2 is of –6 arcsec/sky along X and –3 arcsec/sky along Y while for siderostat #1 it is very close to zero for both axis.

The variability within a night of the conjugation between the siderostat auto-guider detector and the VINCI instrument is corroborated by experience. In normal operations, the stellar image is fixed on the AG REF point of the siderostat which

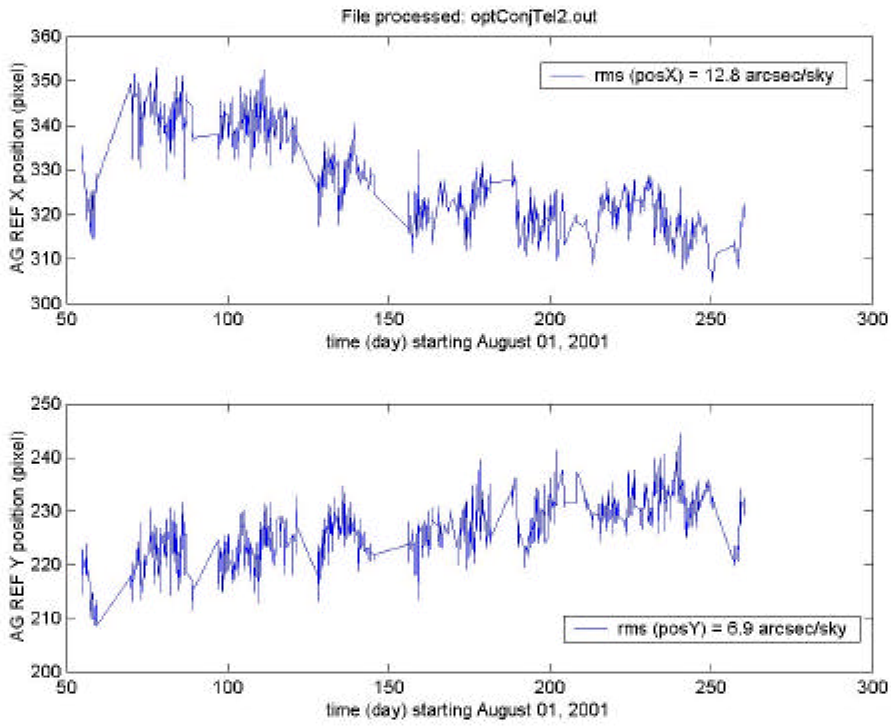

Figure 9: Variations of the AG REF coordinates with time

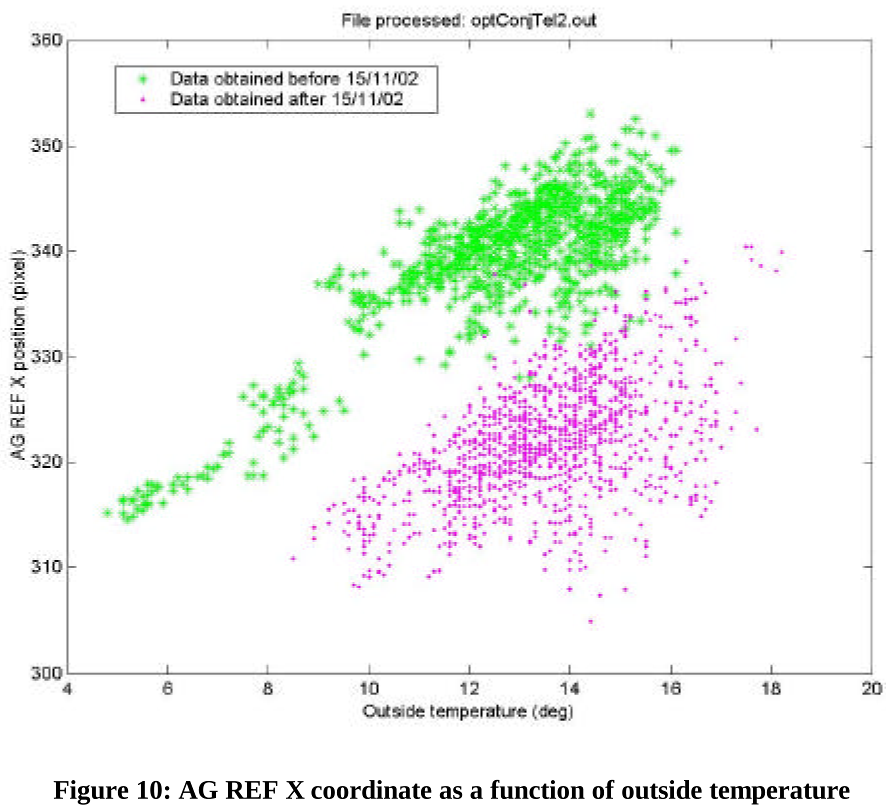

Figure 10: AG REF X coordinate as a function of outside temperature

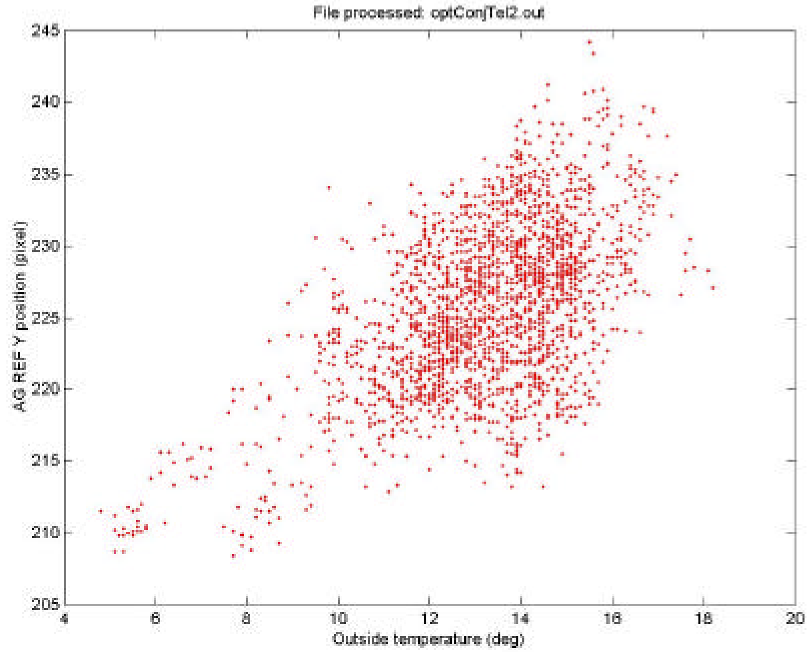

Figure 11: AG REF Y coordinate as a function of outside temperature

means that the stellar image moves on the IAS TCCD and therefore away from the VINCI fiber. This leads to a reduction.in the amount of flux injected in the fiber.

The origin of these variations during the night is being investigated using dedicated technical time. To this end, the IAS is set to image alignment mode (See figure 4) and the stellar beam is imaged on the IAS TCCD while the siderostat is guiding. Centroids of the image are computed during the length of the experiment (typically 30 minutes). A sample data set obtained while there were substantial variations (around 4 arcsec/sky PTV) is given in Figure 12.

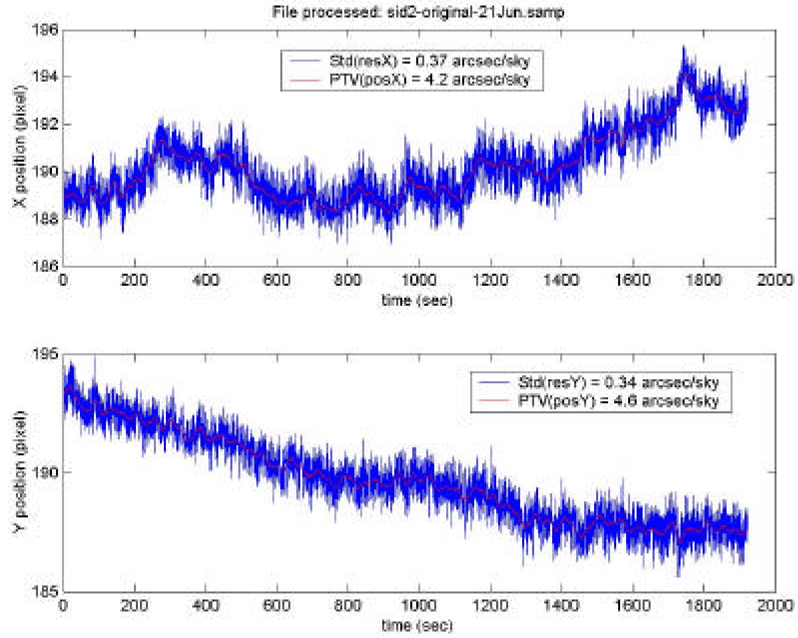

Figure 12: Variations of stellar image centroids on IAS TCCD while guiding on the siderostat

The drawback is that it requires dedicated observation time while the previous data were collected automatically during normal operations.
It has been verified that the light ducts and VLTI tunnel do not introduce these variations. The probable reasons are some thermal effects at the level of the siderostat itself. The variability of the convection effect (closely linked to wind speed) on the siderostat pier affects the optical alignment of the siderostat and is very likely the origin of the conjugation variations observed within a night.

3. THE CONFIGURATION WITH THE UNIT TELESCOPES AS PHOTONS COLLECTOR

Data collected automatically: X-Y table position at each injection adjustment

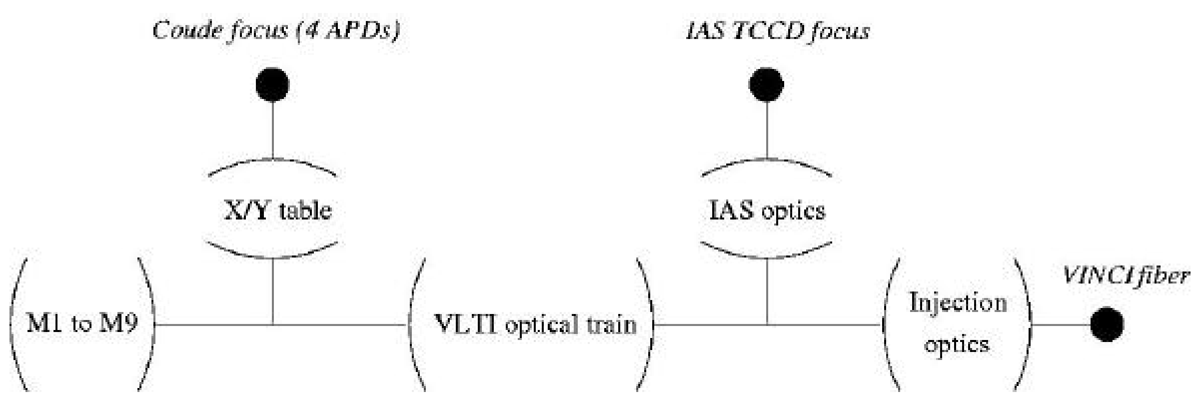

Figure 13: Schematic of the interferometer arm with the UTs

The principle is similar to that used for the siderostat configuration except that the hardware involved is different. Once the telescope is preset, the position of the translation stage supporting the telescope auto-guider (4 APDs) is adjusted along X and Y to have the stellar beam centered on the reference point of the IAS TCCD. The X/Y coordinates of the translation stage are logged. At the moment, little data have been collected as the UTs have been used only occasionally. Therefore no statistical analysis can be performed yet.

Data collected during dedicated technical time: imaging of the Nasmyth beacon on the IAS TCCD

On the unit telescopes, a laser beacon can be inserted in the image plane located between M4 and M5. This beacon can be imaged on the IAS TCCD. This has been done several times while both telescopes are tracking to have representative conditions. A typical data set is presented in figure 14.

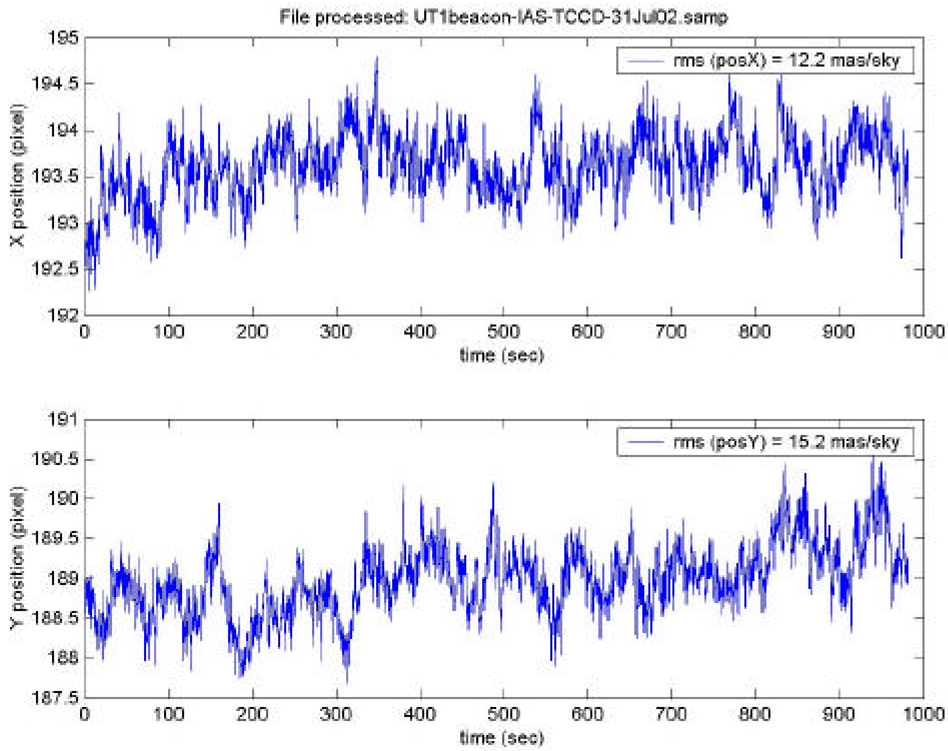

Figure 14: Variations of Nasmyth beacon image position on IAS TCCD

On this 15 minute data set, the RMS of the image motion is of the order of 15 marcsec/sky on each axis but is in normal operation partly compensated as the auto-guider is located downstream (at the level of M9). This type of test brings complementary information as it allows one to assess the image stability on a short time scale.

4. CONCLUSION

The methods used to monitor the image alignment in the arms of the VLTI have been presented.

- Fort short term variations (from seconds to hours), exclusive observing time is required.
- For long term variations (down to the day), the methods make use of data collected automatically during normal operation. This means a large set of data obtained under controlled conditions. These data form a solid base for further statistical analysis as presented here in the case of the siderostats. The analysis of more than 6 months of data confirms that the image alignment stability of the VLTI arm is mainly affected by the thermal sensitivity of the siderostats. Concerning the UT configuration, the data gathering is on-going and will also allow one to monitor and quantify the image alignment stability.