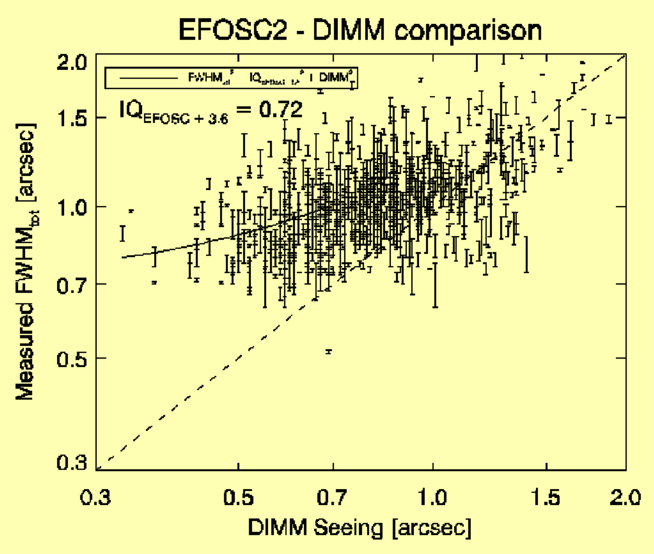

Figure 4 shows that the image quality is, on several occasions, better than that measured by the Dimm monitor. Local site effects and the mirror fans are most likely the reason for the better seeing measured at EFOSC2 on these occasions. Image quality can be as good as 0.6 arcsec and ranges up to 1.5 arcsec, with the coma variation being the main reason for the measured spread in EFOSC2 seeing quality.

The present status of the image quality at the 3.6-m, despite the two remaining limitations, is already within the objectives fixed at the beginning of the study. We have achieved the goal of 0.9 arcsec within 60 deg Zenithal Distance and image quality as good as 0.6 arcsec has been measured with EFOSC2. The EFOSC2 sampling limit of two pixels is now often attained.

For the last few months, the EFOSC2 image quality is logged together with the external seeing. Figure 4 speaks for itself about the present quality of images. The EFOSC2 image quality is already acknowledged by the ESO community.

The Infrared mode of the telescope with the F/35 chopping M2 mirror has also been improved. The image quality obtained at 10 and 20 microns with the new TIMMI2 is diffraction limited.

The 2.2-m Status

During 2000, the telescope has been greatly improved with the large decrease in the contribution from astigmatism. A separate article describes these activities.

Observers often report the image quality as very good, and sub-arcsec images are often obtained when the outside seeing is good. The limiting resolution of the Wide Field Imager pixel size is often reached when the seeing is below 0.5 arcsec and the mirror colder than the outside air.

Image quality limitations still exist but are more related to thermal contributions rather than opto-mechanical features.

The Danish 1.54-m Status

The ongoing problem of the spherical aberration varying with the temperature has been studied again. Experience gained on the 3.6-m, NTT and 2.2-m presented a possible explanation of this challenging feature. Again, the opto-mechanical mirror support seems to be guilty and the behaviour of the axial fixed points with temperature variations is the most probable explanation. A bending effect at the mirror edge, where the spherical aberration is more sensitive, could produce the 0.3 arcsec variable term of this aberration. The defocus, astigmatism, quadratic and coma terms are almost stable and below 0.2 arcsec.

The telescope focus has been shifted to compensate the high constant term of the spherical aberration. However, the variability of this aberration was not confirmed at the time when the amount by which to shift the focus was decided. Although the right correction may not have been applied, observers are not reporting poor image quality. The main limitation of image quality at the Danish 1.54-m is still the instrument detector sampling. Even after the recent detector changes (October 2000), the sampling of 0.81 arcsec (2 pixels of 0.015 mm with a scale of 27 arcsec/mm) is often reached when the night seeing conditions are around or below 0.6 arcsec. (The previous CCD suffered from diffusion transfer increasing in fact the pixel size.)

Pending Issues

A further step on improving the image quality of the telescopes will be considered this year. A large part of the stray light level affecting the depth of the image, is related to the telescope baffling quality as well as the cleanliness of the optical surface. At least three cases must be considered, the first case is when there is a high density of bright stars in the field, the second when there are very bright objects close to the target and the last case when there is a bright star almost alone in the field. The improvement of the telescope baffling will reduce at least the second case. The others depend primarily on the light diffusion by the optical surfaces. Of course, the mirror polishing quality improved dramatically between the construction of the 3.6-m and the VLT, but this benefit could be easily lost if the cleanliness of the mirror surface is not ensured.

The baffling status of the 2.2-m, the NTT and the 3.6-m telescopes must be verified and recommendations will be issued.

Image Quality Improvement of the 2.2-m

A. GILLIOTTE, ESO

Historical Overview

On the very first period of operation of the 2.2-m telescope, a direct CCD camera was offered to the community. With a pixel size of 0.35 arcsec and a small field of 3 arcmin, the telescope image quality was never reported as being bad or showing asymmetric, elliptical images. In the mid-1990s, a new imaging instrument called EFOSC2 was installed at the telescope. Observers soon began seeing variable image elongations across the full field, which were later identified as coming from the instrument and not the telescope. Meanwhile, the optical quality of the telescope was measured to be as good as 0.35 arcsec d80% close to zenith, using our portable Shack-Hartmann called Antares. The optical quality of the EFOSC instrument was strongly dependent on the precision with which focus had been achieved, and subsequent variations with temperature. The EFOSC camera focus did not include temperature compensation as was the case with EFOSC1 on the 3.6-m. The focus degradation introduced field curvature and increasing astigmatism as one moved off-axis. Optical quality tests with EFOSC after refocusing the camera and performing a careful thorough focus sequence re-established the instrument and telescope quality within the resolution delivered by the two pixels sampling 0.7 arcsec.

Image Quality Degradation

After the installation of the Wide-Field Imager (WFI), several observers reported bad, elongated images. The defect was identified as astigmatism which was found to increase for large North and East telescope orientations. On several occasions, even observations at zenith showed the same features. Only a telescope "shake-up" could remove the astigmatism, and even then, only temporarily.

Optical tests were performed on several occasions with the new Curvature Sensing Method (CSM) and these confirmed the astigmatism variation for large zenithal distances. Earlier tests only performed at zenith showed the correct quality. Observations with direct CCD and EFOSC2 in the past were not of sufficiently high spatial resolution to detect the problem. Therefore, the defect could have been present all along since the early days and gone unnoticed until the arrival of the WFI.

Optical Tests

The tests could not reproduce the defect at zenith. Therefore, it seems that there was some dependence on the history of telescope movements. As had previously been done at the 3.6-m, the optical tests were performed by systematically moving the telescope along the same sequence each time. First, a blank sequence was followed to set the telescope properly, followed by South-North and East-West series. The CSM uses an ST8 SBIG CCD mounted on a translation stage to obtain the two defocused intra and extra focal images. Thirty-second exposures were performed to ensure that variations in the seeing were averaged out. This CCD is good in terms of sampling, with 9 µm pixels and a correct linearity to restore the beam intensity variance. The beam heterogeneity between both extrafocal images is produced by the optical aberrations.

The WFI image quality is very good when correct focus is achieved. The small difference in the filter optical thickness must be properly compensated by telescope focus offset. Temperature changes also introduce variation in the telescope focus. For conditions of very good seeing, the focus must be performed as carefully as possible. The WFI pixel size is only 0.24 arcsec, and with this, the sensitivity to telescope imaging defects is increased.

The astigmatism aberration was confirmed during all optical tests. It is always a challenge to identify the origin of the astigmatism, but unfortunately this can take a long time. Any kind of stress or buckling on the telescope mirror will trigger the first elastic deformation mode, and this corresponds to the optical astigmatism term.

From the outset, all supporting elements of both mirrors should be suspected. A complete check of all fixed points as well as astatic levers (radial and axial) needs to be performed. Because astigmatism was almost symmetric over such a large field, the aberration could not have been produced by a misalignment of the mirrors. In this case, the origin points more to how the mirrors are held. The defect appears at large inclination and sometimes remains at zenith. In a first pass, the main mirror support system should be studied followed by the secondary mirror if nothing is found.

Of course, the tests were conducted during short test periods within long stretches of observing time. This meant that it was mandatory to keep the telescope in a stable condition for the observers; which means that the tests could only be done in small conservative steps.

A Contribution from the Instrument Operation

An additional problem was discovered which almost certainly contributed to the early reports of image problems. In the early days, the focus offsets produced by changes in temperature, were only applied to the nominal reference filter, and not automatically corrected when a different filter was used. For large focus offsets, the instrument was shifted out of focus and this produced the field astigmatism image elongations. This problem is now fixed. Note that this "astigmatism" differs from that caused by elastic deformation of the mirror. Field astigmatism varies within the field whereas the "stress" astigmatism is constant. Of course, in some cases a combination of both effects could have been present.

The Opto-Mechanical Contribution

All the tests were performed with the participation of the mechanic team and long, fruitful discussions took place with the team members. A first check was conducted on the lateral astatic pads after dismounting the mirror cell from the telescope. The mirror is kept laterally in position by a reference sphere in contact with the Cassegrain hole. Radial astatic levers maintain the mirror laterally by pushing or pulling, and no force is applied when the mirror is horizontal. All levers were found to be moving freely without mechanical stress. However, the reference sphere was found to be dirty on the northern side. The cause of this is thought to be cleaning of the mirror when it is inclined, allowing some of the Carbon Dioxide snow to fall into the Cassegrain hole, taking dust from the mirror surface with it.

The design of the mirror cell includes the facility to keep the mirror in a "park" position. In this case the mirror rests on three supports without the control of astatic levers. Three axial fixed points define the mirror orientation while the mirror is supported over the astatic levers under the control of pneumatic pressure. When the air pressure is removed, the mirror moves down by around 2 mm and the three axial fixed points move down within a spring tension device. The springs are used to keep the fixed points in contact with the

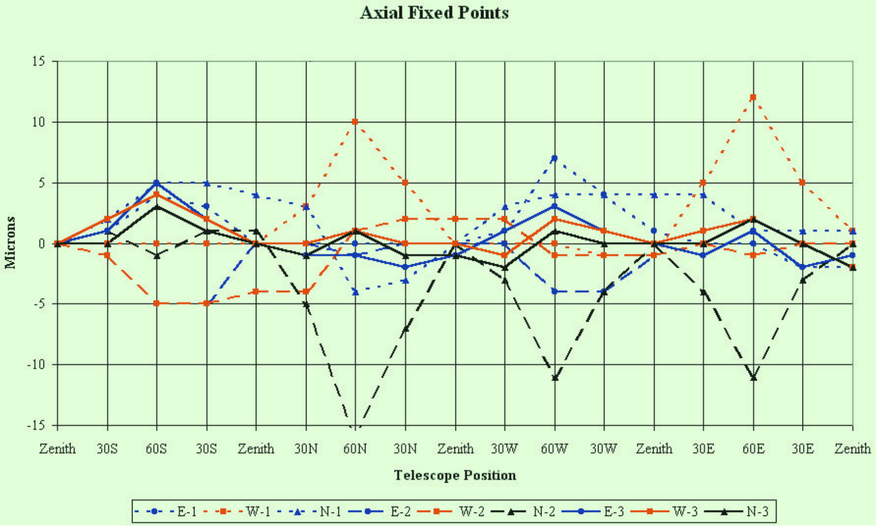

Figure 1: Behaviour of the axial fixed points with changes in telescope position. The measurements shown were made during three intervals: before the April tests (short dashed lines), during the June tests (long dashed lines) and after all tests (solid line).

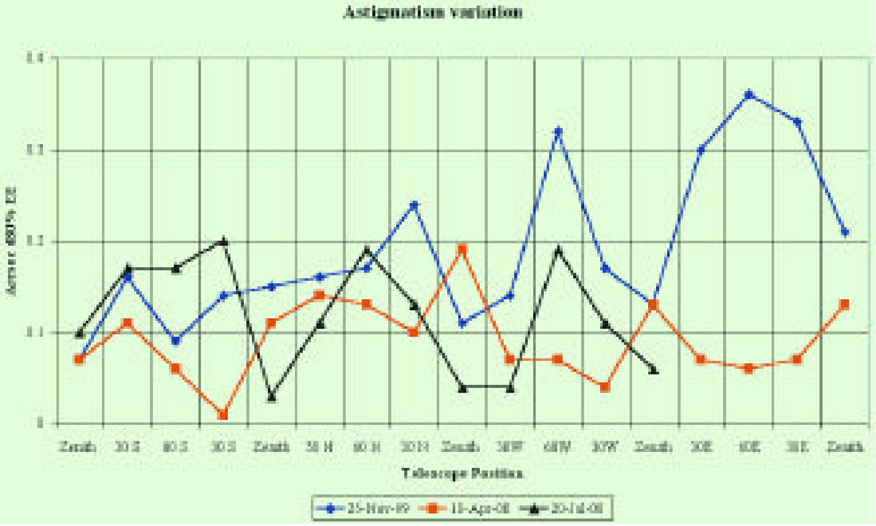

Figure 2: Variation of the astigmatism over the same range of telescope positions as Figure 1. The large deviation of the astigmatism for the east and west part of the cycle is clearly visible. Part of the last July sequence was not performed because of bad weather. The larger variations found during the last test night are due partially to a local thermal effect.

reference position with the correct applied force on zenith. The astatic levers are distributed around two rings. Two manual air pressure controllers distribute the pressure equally on all levers. Each unit delivers air pressure to one ring only. At the beginning of the observation, the telescope start-up operation includes the air pressure distribution on the mirror cell. The mirror raises until the mirror weight is in equilibrium with the astatic levels, assuming the correct positioning of the fixed points in contact with their respective references. Due to the lack of load cell, the force applied on the mirror is not known (it is a non-active optics). Departure on force distribution cannot be verified directly. The only part allowing access to the mirror position check are the three axial points, where linear gauges have been installed.

A Summary of the Tests

At each telescope position during the measurement sequence, a check of both mirror position and the amount of aberration was made.

April 2000 Period

During this test period, the behaviour of the western fixed point was not correct for large inclinations towards the north and east. A correlation with an increase of astigmatism and triangular aberration terms was also identified. The three fixed points were checked during the re-aluminisation of the 2.2-m that took place on April 20. Effectively, the west point was found to be tilted with improper mechanical contact which increased the force of the springs. The effect was to raise the mirror when the cosine astatic forces decreased. Therefore, the pad pushing against the mirror introduced astigmatism and a small triangular deformation.

June 2000 Period

After a complete overhaul of the three fixed points a new round of tests was performed. Now the northern fixed point showed a new pattern with a slight decrease of the applied force in inclined telescope positions. The spring tension had to be increased to obtain the correct force, both at zenith and at large inclination.

The last measurement of the axial fixed points showed the correct pattern, with a slight decrease for each inclined position, due to the decrease in the cosine component of the mirror weight.

July 2000 Period

A new check of the aberrations in the telescope was undertaken. The fixed points again showed the correct behaviour for the sequence of measurements. However, the spherical aberration term as well as those of the astigmatism increased "abnormally" at some telescope positions.

Figure 1 shows the range of movement in the axial fixed points over the full range of telescope position at different times. Figure 2 and 3 show the behaviour of the astigmatism and the triangular aberration during the different test periods.

The thermal contribution

"Unforeseen" aberrations appeared in July, and only temporarily. They are related to local thermal activity that acts to produce a wavefront deformation. In this case, "thermal aberration" would be a more correct term to describe what takes place. On this test night the cold temperature of the outside air was producing large local effects.

This effect is a good demonstration of the limitations that can exist in telescope imaging quality, not just from misalignment of the telescope (with mirror deformation in an improper cell design) but also from thermal convection.

The thermal convection can be separated in different components, such as the dome/tube seeing, dome/slit seeing, mirror seeing and local perturbations produced by extra warm sources.

The thermal conditions of each test night were different, with almost all except the last having the mirror colder than ambient air (by between zero and 2 degrees). Even so, the thermal effects were still negligible compared to the contribution of the axial fixed points to image degradation.

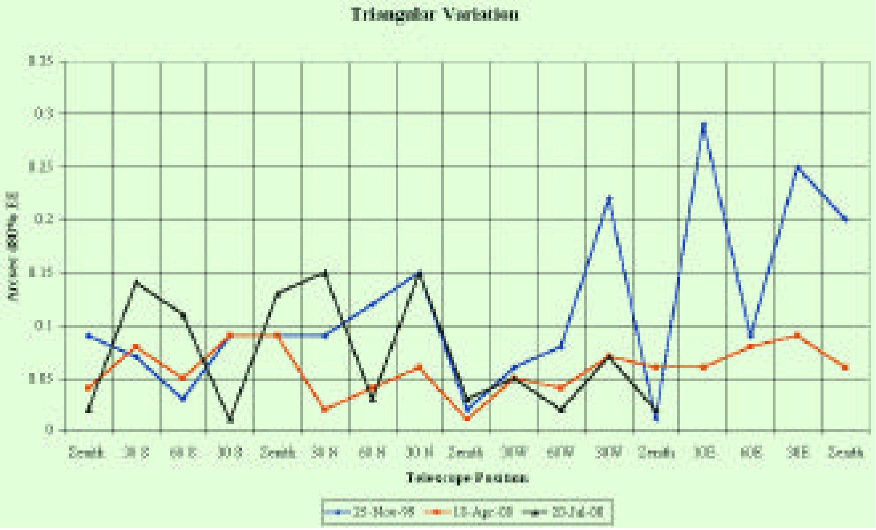

Figure 3: Variation of the triangular aberration over the same range of telescope positions. Again, the variations are large for the west and east part of the cycle before the April test. The thermal conditions of the last night (with a strong temperature decrease) produced a very unfavourable local convection effect on the mirror edge, thereby affecting the wavefront.

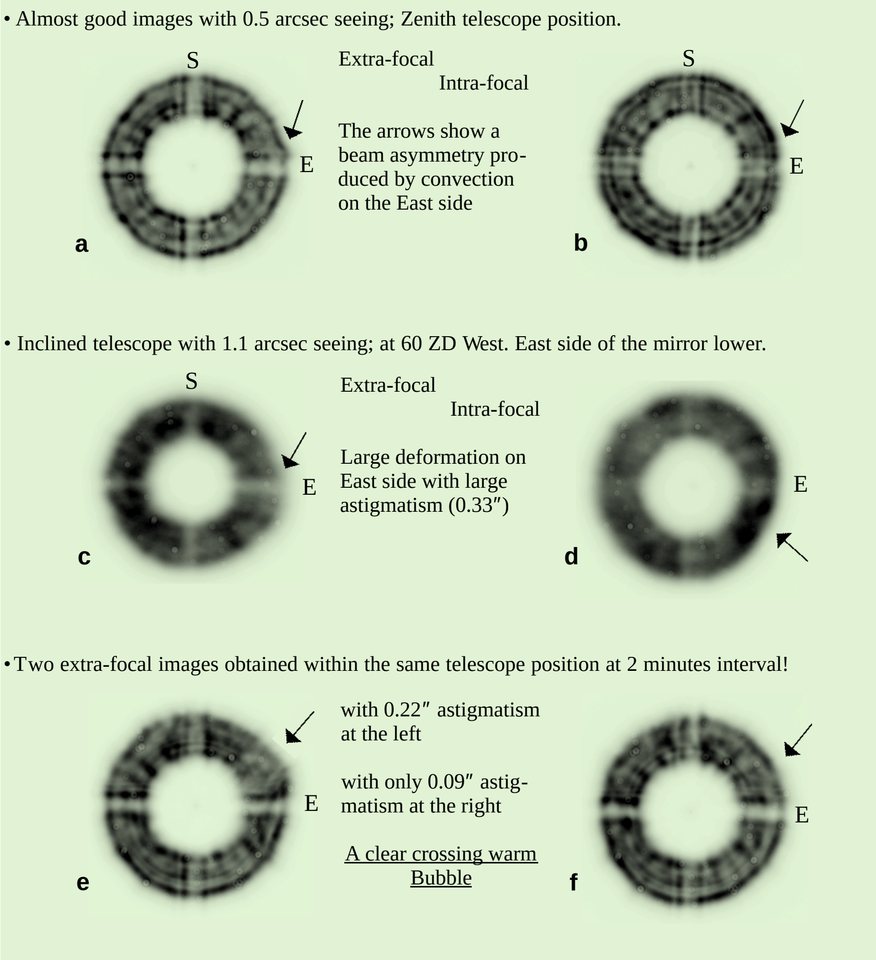

Figure 4: Thermal contribution to the image quality as seen in defocused images.

On the last night, however, the mirror was warmer by 1.5 degrees, with a corresponding degradation in the mirror seeing. The outside air temperature reached a low value of 4 degrees, causing a larger gradient with the remaining warmth of the telescope delta pads. Figure 4 clearly shows how this local effect is visible in the defocused images. The figure also shows the distortion of the defocused images due to local thermal perturbations.

Conclusion

Following the interventions performed up to and including July 2000, the telescope image quality remains good with several reports by observers as being very good. Under good external seeing conditions, it is possible to achieve sub-arcsec images, sometime approaching 0.5 arcsec. The image quality achieved with the WFI is as expected over a large part of the sky. Improvements could still be made to minimise the thermal contribution when colder temperatures are experienced. The best method (which is already in use on the 3.6-m and the NTT) would be to ventilate the main mirror with high-flux fans. A reduction in the mirror seeing, as well as local perturbations, could be achieved by blowing air across the mirror, from north to south.

The installation of load cells on the three axial fixed points will be also a forward step on the telescope improvement. The force delivered by each of the axial fixed points could be fine tuned, to reach a new minimising of the residual low astigmatism. The limit of the image quality will be then defined by the pixel size of the WFI.

Acknowledgements

We are grateful to the mechanics team for the discussions and participation during all the steps of this study. The assistance of the Medium Size Telescope Team, in allowing regular test periods and operational help, was also essential to the success of the image quality improvement.

NEWS from the NTT

O. HAINAUT and the NTT Team

A Motor-related Disaster

At the time this is being written, the NTT is running very nicely. While this is how the NTT is supposed to behave, it has not been the case during the last month. Indeed, on January 16, it was detected that one of the 4 main azimuth motors had died. The team immediately started to reconfigure the drive system to operate without that motor (in case of emergency, we can run on 2 motors only). During that process, a second motor died! We decided to stop the operation and shut down the telescope to investigate; indeed, while we can survive with 2 motors, we cannot afford to kill one per day. The two faulty motors have been removed, our (single) spare installed, and the electronics started to perform a *complete* check of all the system driving the motors. In that process, it was discovered that a third motor presented some minor signs of damages.

The next step was to open one of the faulty motors to diagnose and, ideally, to repair it. For this purpose, we invaded the dome of the Schmidt telescope, which was de-commissioned some time ago. This large room has plenty of space, is very clean and equipped with a crane, making it the ideal place for disassembling the motors. The La Silla Mechanics, Electronics and NTT Team worked almost round-the-clock to open the motor. This task is not as simple as it sounds: the motors are actually complete servo-drive units, including in a very compact design the motor itself, its water/glycol cooling system, the tachometer and the brake, the complete unit weighing 550 kg. Moreover, some special tools had to be manufactured; indeed, when the motors were delivered, it was not foreseen that they would ever have to be re-opened, and the assembly tools were left at the factory. To make the situation even more challenging, it occurred in January, which is right in the Chilean vacation period. La Silla was operated with a reduced staff. Eventually, the main motor coil was accessed, and we realised that