

The Visible and Infrared Survey Telescope for Astronomy (VISTA): Looking Back at Commissioning

Jim Emerson¹
Will Sutherland¹

¹ Astronomy Unit, Queen Mary University of London, United Kingdom

The ESO near-infrared survey telescope, VISTA, is about to enter operation. Dry runs for VISTA's Public Surveys have been in progress since November 2009 and the full surveys will begin soon. Some points from the VISTA commissioning are outlined.

Introduction

VISTA, the Visible and Infrared Survey Telescope for Astronomy, is a 4.1-metre wide-field survey telescope, equipped with a 1.65-degree field, (67-Mpixel) near-infrared (NIR) camera, for performing extensive surveys of the southern skies with sensitivity matched to the needs of 8-metre-class telescopes. Over its first five years of operations, the majority of VISTA's time will be used for six ESO Public Surveys (Arnaboldi et al., 2007). NIR imaging surveys particularly target the cold, the obscured, and the high redshift Universe, to generate science directly and also in order to select objects worthy of further study by the Very Large Telescope (VLT).

Details of the design of VISTA were given in Emerson et al. (2004), a progress update in Emerson et al. (2006), pictures of the NIR camera in *The Messenger* (131, 6), the site in issue 132 (p. 55), the primary mirror (M1) installation in issues 132 and 133 (p. 6 and 67 respectively), the camera being lifted up through the azimuth floor (138, 2) and the first release of images was also described in *The Messenger* (138, 2). Here we outline some interesting points from the commissioning period.

Figure 2. A view of VISTA's camera on the telescope with all the electronics boxes mounted (with their back covers off in this image). The open lifting hatch can be seen on the right, with the yellow crane above. The white circle at the top serves both as a Moon screen, and as a screen for taking linearity sequences and instrument health monitoring frames.



Early work

The only change from the system described in Emerson et al. (2004) was that a Z filter was added in the camera, as the Raytheon Vision Systems IR detectors were measured to have a quantum efficiency (QE) that was still good even at a wavelength as short as Z (0.88 μm) — where QE $\sim 70\%$.

Commissioning generally went smoothly, with no major problems requiring redesign or re-manufacture, although most tasks tended to take rather longer than anticipated. It was heartening that there were no fundamental problems, but frustrating that many individually small problems

Figure 1. VISTA's camera is shown being mounted onto the telescope. The camera (black) has been lifted from the ground floor through a removable sector in the dome floor, using the enclosure crane (yellow at top) and the lifting arm (blue). The enclosure is rotated to place the camera behind the telescope (this picture). Next the camera is moved into the M1 hole and bolted to the Cassegrain rotator, and finally the electronics boxes are fitted.

each took time to solve. Here we focus on some points that arose, but the emphasis here on problems that were solved should not obscure the fact that VISTA now works very well, as the images from the press release in December 2009 (ESO Press Release eso0949) and the image of part of the Orion Nebula, on the front cover, demonstrate.



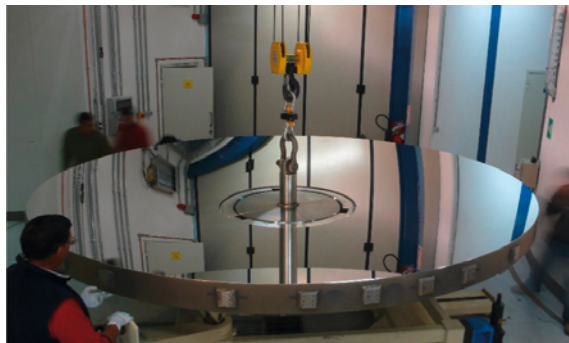


Figure 3. M1 after coating in protected silver in the VISTA coating plant.

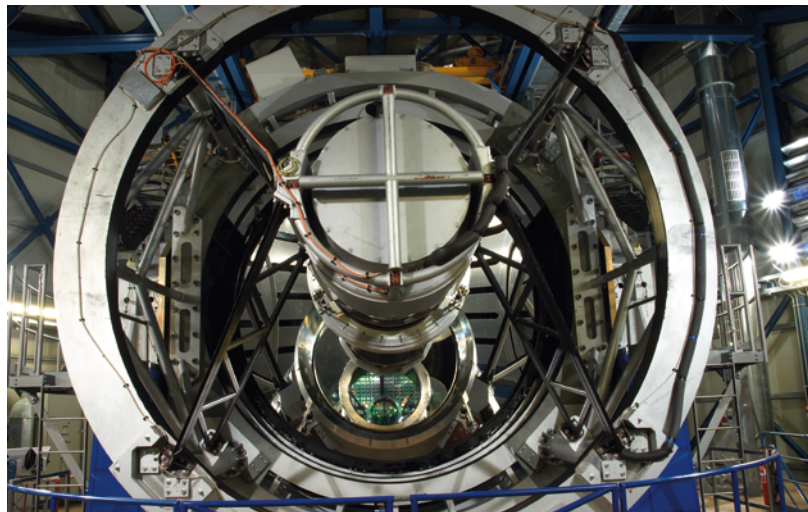


Figure 4. The VISTA telescope shown from the front at low elevation.

To start with, construction went smoothly, and the enclosure was ready for the telescope structure, which was installed during 2006. In early 2007, we had a run with dummy masses in place of the mirrors, and a small 20-cm telescope mounted on the Cassegrain rotator, looking up through a hole in the top-end structure (designed for this reason). This run was useful to debug the telescope software, build a preliminary pointing model, and showed that the basic tracking and slewing performance were good.

Shortly afterwards, the secondary mirror (M2) arrived and was successfully coated in protected silver. VISTA's camera was flown to Chile in January 2007 and checked out for performance on site, using a small "spot projector" mounted in front of the window. There had been no damage in transport, and the process of mounting the camera onto the telescope was subsequently tried out successfully (see Figure 1). Figure 2 shows the back view of VISTA, with the camera and its electronics boxes mounted on the Cassegrain rotator.

Primary mirror (M1) polishing

So far so good! However the time taken to complete the polishing of M1 then prevented VISTA being delivered on the timescale expected at that time. This 4.1-metre f/1 mirror is the most highly curved large mirror ever polished and this task proved to take much longer than anticipated. The fast mirror means that it

is highly aspheric, with departures from the best-fit sphere of around 0.8 mm; this means that small polishing tools were needed, different for different zones on the mirror, which increases the polishing time. This was a known difficulty from early on, but it appears that the time-scales were underestimated by the manufacturer. The lateness was especially frustrating as the very first thing the VISTA project did after securing funding was to purchase the M1 blank in 2001 and the shaping of the blank was complete by April 2003, so it was highly regrettable that completion of M1 took so long, and that the manufacturer's polishing time estimates only converged to the actual time so very near to the end. However, the quality of polishing finally achieved was high. To claw back some time, the M1 was not shipped by sea, but instead was flown from Moscow to Antofagasta in an Antonov transport plane, arriving at VISTA during Easter 2008.

The coating plant provided with VISTA then produced a very high quality and stable coating in protected silver (see Figure 3), enhancing VISTA's sensitivity compared to a conventional aluminium coating.

Camera on sky

As soon as the M1 mirror had been coated it was installed in the telescope, and a test camera containing a Shack–Hartmann system was used to set up an initial pointing model and active optics

settings. It soon became apparent that the system showed some trefoil (a third order optical aberration). It was suspected that this was associated with the M2 axial definers, and this was confirmed by mounting the M2 and its cell rotated by 180 degrees, which changed the sign of the trefoil. Then, the M2 manufacturers came to Chile, disassembled and inspected the M2 cell. They found nothing wrong, and it was carefully reassembled, in parallel with VISTA's camera being mounted in place of the test camera (see Figure 4). It was expected that the active support forces on M1 would be able to compensate for the effect of the trefoil on M2, and this indeed proved to be the case. It is still unclear how this trefoil arose. Measurements at the factory showed trefoil was not present there, when tested with similar support forces to those when mounted on the telescope. It is not possible to rotate M2 relative to its cell to see if the trefoil is due to the cell or the mirror itself. As the system image quality now comfortably meets its specification of 50 % encircled energy diameter of 0.51 arcseconds, the trefoil has been accepted, though it would be good to understand its origin and then hopefully get rid of it at source, rather than correcting with M1 forces.

The camera first observed the sky on 23 June 2008 with the auxiliary CCDs (for autoguiding and wavefront sensing), and with the IR detectors on 24 June. The first images were recognisable with the expected setup parameters, and the image quality was improved over the

subsequent nights with various adjustments to the many M1 and M2 positions and forces. The pointing and tracking was good. Figure 4 shows VISTA from the front with all components present and working. No mechanical adjustments were needed to the camera, a tribute to the engineering done by the camera team led by the Science and Technology Facilities Council (STFC) run Rutherford Appleton Laboratory.

The camera background was checked and the non-linearity of the detectors measured robustly. At this stage, image data was not being archived by ESO, so it was written to 250 GB USB disks which were taken back to the UK in hand baggage for analysis in the UK. There were occasional problems with the IRACE number-cruncher workstations overheating causing data outage; once traced, this was simple to solve.

Active optics

Over the following months the active optics corrections for achieving the best image quality were all generated for various azimuths, altitudes and temperatures, and the autoguiding and wavefront sensing software was stress-tested and made more robust. This was quite a lengthy process, since there are numerous correction terms, and the many Zernike polynomials and mirror modes are measured in detector coordinates, but require de-rotating into telescope coordinates to apply corrections to M2 position and M1 forces; thus, getting all the signs and phases right was quite time-consuming. Also, there were some complications: we found a small astigmatism co-rotating with the camera, possibly due to a thermal gradient; this was fixed in software by adding an M1 active force pattern that co-rotates with the camera.

Focus gradients across the very large detector plane were also complicated, and we eventually decomposed these into three problems: one was a subtle software error (dependent on radial position of the wavefront sensor stars), another was a real focus gradient “fixed to the telescope”, and thirdly a smaller focus gradient “fixed to the camera”. The gradient “fixed to the telescope” was quite large,

and required a 1.3-mm lateral movement of M1 to align it to the Cassegrain axis; this should have been simple, but in practice there was not quite enough clearance in the M1 axial definers, thus requiring removal of the M1 to adjust the three axial definers. There was considerable worry here about whether the calculated sign was correct, and fortunately it was. The small camera focus gradient is still present at the time of writing, but is soon to be eliminated with a new shim between the camera and Cassegrain rotator. The co-planarity of the 16 detectors appears to be excellent, so once M1 and the camera are one-off aligned to the Cassegrain rotator axis, the active optics system automatically keeps M2 collimated, giving good images across the entire field.

Filter wheel

At first, changing the filters was very reliable, but by October 2008 it was noticed that the 1.37-metre diameter filter wheel (the only moving part inside the cold camera) occasionally failed to reach its demand position. Many experiments were done looking at the software and electronics, but the intermittent problem gradually became more and more frequent. By February 2009 there was nothing for it but to take the camera off, warm it up, open up the cryostat and look at the parts. Surprisingly it was found that a jacking screw (used for assembly and disassembly) had worked loose and had unscrewed itself enough to foul the filter wheel, scraping off a ring of paint and some metal swarf. There were flakes of paint all over the filters themselves, explaining why the flat fields had been becoming unexpectedly variable. The filter trays were removed and the filters cleaned, the debris was cleaned out of the rest of the camera, and the offending jacking screw removed. No damage to the filters or detectors resulted, and the motor drive also proved resilient. The opportunity was taken to change the order of the filters in the wheel to a more efficient one for the selected ESO Public Surveys, and to fill the one remaining empty filter tray with two paired half-sets of narrowband filters at 975 and 985 nm which were available. After the camera was pumped and cooled down again, VISTA was back on sky in March 2009.

The filter wheel has worked well ever since.

Unfortunately soon after this, one of the three closed-cycle coolers on the camera had a major breakdown; the required spare parts turned out to be very similar, but not quite identical, to those held in the Paranal stores; hence getting these parts from Europe caused another minor delay.

Azimuth and M2 support oscillations

An annoying problem was that, under certain reproducible conditions (where the azimuth axis was moving very slowly), the azimuth drive servo loop went into oscillation, exciting an 11.6-Hz resonance in the telescope structure and turning the images into “sticks”. This was fixed by installing an electronic notch filter in the servo, after which there were no more azimuth oscillations.

Another problem was intermittent small ($\sim 1/2$ arcsecond) ~ 2 Hz oscillations of the hexapod which controls the position of the secondary mirror, which was small enough to go unnoticed until the focus gradients were sorted out. This was affecting one-third to half of the data taken, and making it very hard to demonstrate the intrinsic image quality of the system. After considerable analysis and experimentation, in August 2009 new servo parameters were identified and these oscillations ceased. After this, it was possible to reliably achieve the required image quality of the final system, and to demonstrate that the 50 % encircled energy distribution was comfortably within the 0.51-arcsecond specification.

The future

The above is only a selection of (perhaps) interesting points, and a fuller description of commissioning will be presented at the 2010 SPIE meeting in San Diego. Much software-related work was also done, both to improve the system, and to ensure that the observing overheads were minimised.

VISTA is now working very well, producing images with the depth and quality



Figure 5. Orion Nebula (M 42 and M 43) composite image in ZJKs filters is shown. See ESO Press Release eso1006 for more details.

expected, with minor improvements being worked on to further enhance its reliability. The VISTA ZJKs 1×1.5 degree image of the Orion Nebula in Figure 5, of which the front cover image is a only a small part, indicates how impressive its wide-field views are.

Acknowledgements

The VISTA Project Office at STFC's UK Astronomy Technology Centre managed the integration and commissioning of VISTA and skillfully coordinated the work of all those individuals and organisations involved. The Cambridge Astronomical Survey Unit (CASU), part of the UK's VISTA Data Flow System,

provided invaluable assistance in assessing the image data acquired during commissioning.

References

- Arnaboldi, M. et al. 2007, *The Messenger*, 127, 28
- Emerson, J. et al. 2004, *The Messenger*, 117, 27
- Emerson, J. et al. 2006, *The Messenger*, 126, 41