OmegaCAM: ESO's Newest Imager

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OmegaCAM, the 300-megapixel wide-field optical camera on the new VLT Survey Telescope (VST), was commissioned between March and August of this year. This new capability in ESO's arsenal takes images of 1 degree by 1 degree patches of the sky, at 0.2 arcseconds per pixel resolution and of image quality well-matched to the natural seeing on Paranal. The commissioning and OmegaCAM's scientific niche as a high image quality, ultra-violet-sensitive wide-field survey instrument are briefly discussed.

Getting to first light

On 27 March, after several weeks of intense technical preparations, the moment was finally reached: OmegaCAM had been attached to the new VLT Survey Telescope, everything was cabled up, and the first sky exposure could be taken. We sent the command, and a minute later the 32 CCDs of OmegaCAM started to read out, and the image built up on the screen. Thirty-five seconds later it was done: OmegaCAM had achieved first light! Figure 1 captures the team in the control room following first light.

Figure 1. The OmegaCAM and VST teams in the makeshift control room in the VLTI building, after achieving first light on 27 March 2011.

Getting to this point had been a long and sometimes rocky road. When we started the project, more than ten years ago (see Kuijken et al., 2002), the expectation had been that that the VST would be operational by 2005 at the latest — but fate and shipping companies decided otherwise (see Capaccioli & Schipani, p. 2). In the end OmegaCAM was completed and delivered to Garching in 2006, and has patiently waited in storage since then for its place at the VST Cassegrain focus. Because of this long wait, it is easy for us to forget how much work went into the project in its early years, and in particular into the optical and mechanical design, filter procurement, electronics, instrument control and data flow software... as well as project meetings, writing documents, reviews, writing documents, ESO progress meetings, writing documents, etc. (Not being a hard-core instrumentalist myself, if I had known at the beginning what would be involved, I might well have shied away). But it all came together on 27 March 2011, when it quickly became clear that we had a nicely working instrument, in operation, on a great new telescope. In fact, even on the first night we managed to obtain images on which the stars were as sharp as 0.6 arcseconds! Although it took some time after that point to complete the alignment and achieve good focus over the full field of view, this was a very promising start.

The OmegaCAM project

The VST was designed as a single-purpose facility, for making images of large chunks of the sky. Its optical design foresaw a camera, fully integrated into the design and optimised along with the telescope (for example, the dewar entrance window of the camera is actually a spherical lens). After a call for ESO community consortia to provide this camera, the OmegaCAM project was born in 1999.

OmegaCAM is at its heart a 32-CCD detector mosaic, with each three-edge buttable 2k by 4k CCDs manufactured by e2V, consisting of almost 300 million pixels in total. The array samples a full square degree at 0.21 arcseconds per pixel resolution, with minimal gaps between the devices.

In addition to the science CCDs the focal plane also contains four auxiliary CCDs used for guiding and wavefront sensing (seen in Figure 2b on both sides of the array). A filter exchange mechanism permits observations through any one of 12 filters, and a large shutter is used to define precisely the length of the exposures. Figure 3 shows a schematic of the camera. On account of space constraints (not so surprising given that the filters are very large, some 30 cm x 30 cm!), OmegaCAM does not store the filters in a traditional wheel, but in two stacks on either side of the focal plane. A purpose-built robotic mechanism picks out the desired filter and positions it in front of the detectors. OmegaCAM comes with

ESO/INAF-VST/OmegaCAM/O. Iwert

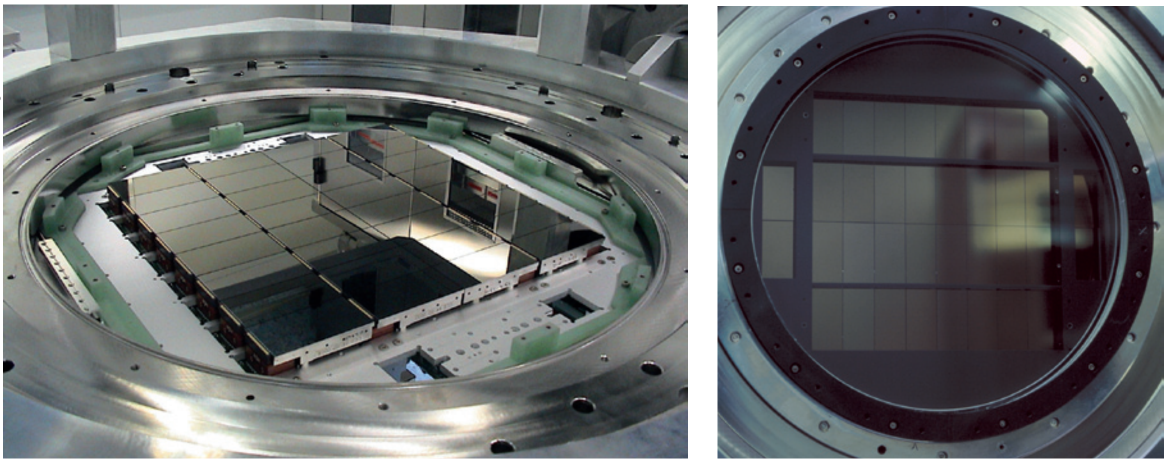


Figure 2. The detector mosaic at the heart of OmegaCAM. Left: A view of the open mosaic, populated with test devices in the lab. Right: The final science CCD array in its dewar ready for installation in the instrument.

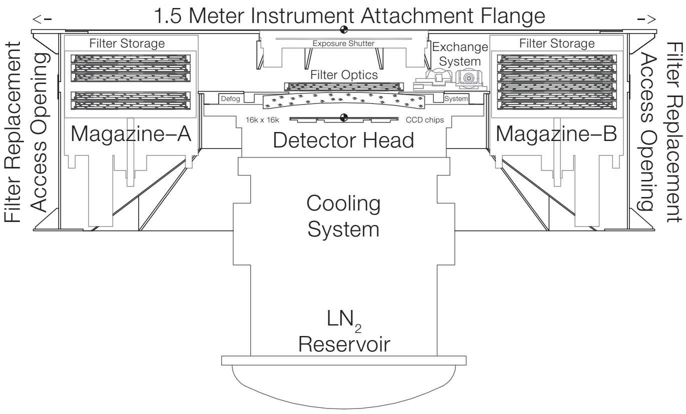


Figure 3. Schematic view of the main components of OmegaCAM.

Figure 4. Cables, cables, cables... OmegaCAM behind the VST.

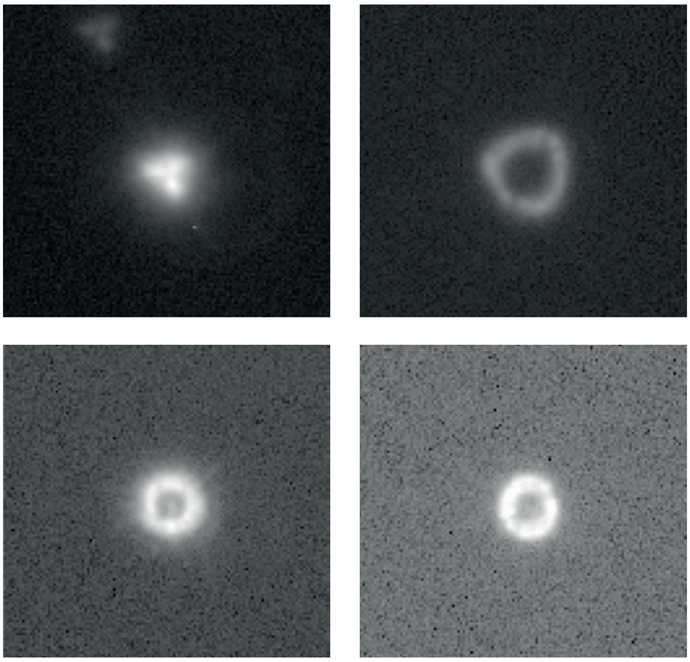
broad Sloan *u, g, r, i, z* and *B, V* filters, as well as a Strömgren-v and several narrowband filters. Many of the narrowband filters are segmented, with four quadrants that each have a different bandpass; a special calibration filter with *u, g, r, i* quadrants for extinction measurements is also part of the set. A large tank for liquid nitrogen to cool the detectors completes the "raw" instrument.

Surrounding the instrument is a true spider's web of cables and tubes, which supply cooling water, electronic connections for controlling the instrument functions, power, alarm signals, and of course the data connections from the CCDs to the readout electronics. It is very fortunate that there will be no other instruments on the VST, since connecting up the instrument is quite a job — see Figure 4!

Scientific niche

Even though OmegaCAM started operation quite a bit later than originally planned, it is still scientifically very powerful, despite of competition from other observatories.

OmegaCAM is the largest wide-field imager in the southern hemisphere: while this will surely change in the future, for the moment we can take advantage of the fact that many of the other "pixel monsters" (particular the Megacams on the Canada France Hawaii Telescope [CFHT] and MMT, and Pan-STARRS) are in the north. Furthermore the operational synergy with the VLT and VISTA should not be underestimated: ESO now has an unrivalled "survey system" that covers *u*–*K*-bands from a superb site. The *u*-band sensitivity is high, because of the choice of CCDs in OmegaCAM; new optical wide-field imagers are concentrating on redder sources and are increasingly sacrificing *u*-band sensitivity for the near-infrared. Zero points and filter throughput curves for the VST/OmegaCAM system are listed in the appendix to this article; many more details are available in the user manual[1] maintained by the ESO user support group[2].



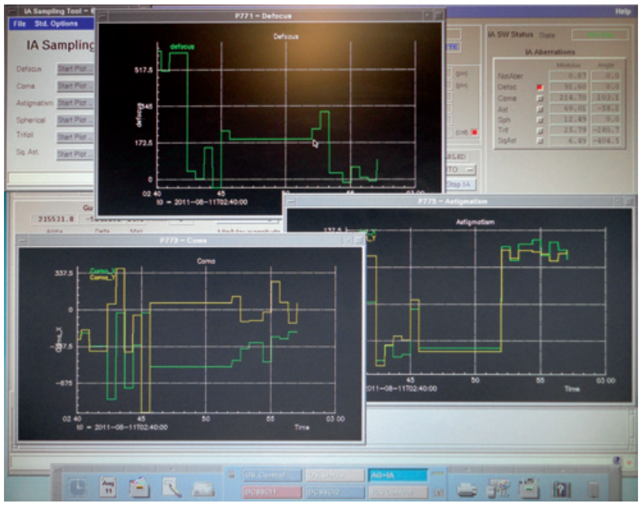


Figure 5. Left: Before (top) and after (bottom) pictures of the pairs of defocused star images recorded on the OmegaCAM image analysis CCDs. In the ideal case both doughnuts should be round and of the same size. Right: Automatic displays of the calculated aberrations on the instrument control panel.

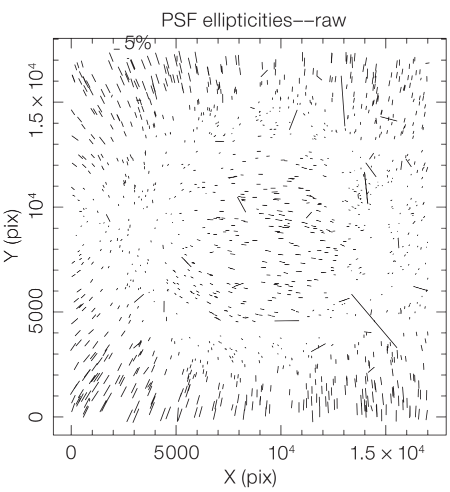


Figure 6. Illustration of the superb image quality of the VST/OmegaCAM system, represented here as a map of ellipticity vectors over the full field. The residual pattern in the (small!) ellipticities is a consequence of the slight curvature of the focal plane combined with small field astigmatism. The size of the stellar images over the field varies less than 5% over the full field and is equal to the outside DIMM seeing measurements, even in this 0.6-arcsecond-seeing image.

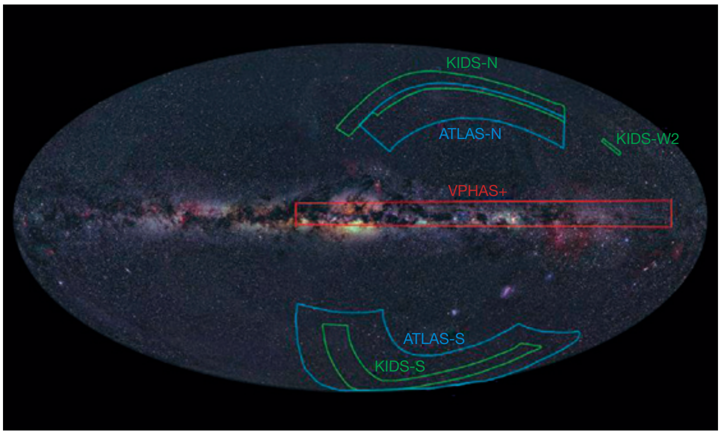
But the strongest reason for the scientific niche occupied by OmegaCAM and the VST is image quality. Many of the largest imaging surveys — at least in cosmology — are focussing on understanding the growth of structure, as a probe of dark energy. One of the most powerful ways to measure this is by means of gravitational lensing, a difficult technique that relies on superb image quality (as it is based on measuring the shapes of galaxies as accurately as possible). Paranal offers excellent seeing much of the time, and the VST and OmegaCAM have been designed explicitly to take full advantage of the natural seeing. The combination of a fully active telescope, wavefront sensing in OmegaCAM, an optical design with little aberration over the full field and a constant plate scale, a deployable atmospheric dispersion corrector, and flexible scheduling to take optimal advantage of the best seeing periods make this a unique facility. Much of the later work in the commissioning of the telescope and camera was rightly concentrated on realising this image quality: meticulously aligning the telescope optical axis with the instrument rotator, making sure OmegaCAM is parallel to the flange, and fine-tuning the real-time wavefront sensors in the instrument.

The wavefront sensors provide a robust way of maintaining the telescope focus on the science array. They work by registering star images that are significantly out of focus: for this purpose two auxiliary CCDs are mounted out of the focal plane, one 2 mm above and one 2 mm below. Stars show up as doughnut-shaped on these CCDs, and by insisting that both "doughnuts" have exactly the same shape, the telescope focus is forced to lie exactly halfway between these planes (see Figure 5). Similarly, higher-order aberrations can also be measured from the way the doughnuts are distorted into elliptical or triangular shapes. Using these "image analysis CCDs", aberrations are continuously measured during scientific exposures, and as soon as the shutter is closed the telescope is corrected, ready for the next exposure.

The other two auxiliary CCDs are mounted in focus, and make up an autoguider that guides using two stars on either side of the field (so that the centre of the image remains on track). Together the two guide CCDs and the two image analysis CCDs ensure the best possible image quality on the 32 science arrays. This is exemplified in Figure 6, where a map of the image ellipticity across the field is shown.

Data flow and calibration

Calibrating wide-field images accurately can be tricky, particularly since an open wide-field telescope provides many paths for stray light, and interference filters



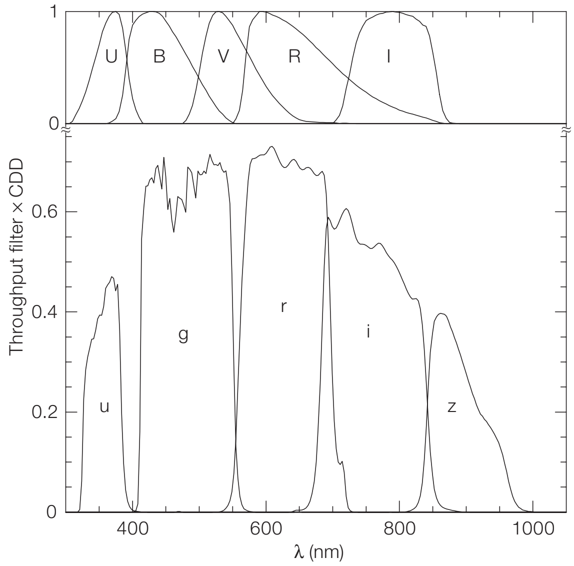


Figure 7. (Top) Sky projection of the three public surveys that will take most of the VST's observing time in the first three years: VPHAS+ which will study the Galactic Plane, ATLAS which can be seen as a southern twin to the Sloan Imaging Survey, and KiDS, a deep/wide cosmological survey. See Arnaboldi et al. (2007) for more details.

Figure 8. (Right) The throughput of the entire VST system for the broadband Sloan filters in OmegaCAM is shown (lower) with the passbands of the standard Johnson-Cousins UBVRI filters shown for comparison (upper).

can lead to strange reflections. Initial efforts have already resulted in photometric calibrations that are accurate to a few percent (see the Table of zero points in the Appendix), and with experience and more data this number should improve further. We have established photometric secondary standard fields, a square degree in size each, along the celestial equator and these, together with frequent observations of the celestial pole, will be the backbone of the nightly photometric calibration.

Our delivery to ESO included pipeline modules with which the instrument scientists will be able to monitor the image quality and photometric performance of the instrument. The quick-look capability that this provided during commissioning, as well as an experimental implementation of the newly laid EVALSO high-speed internet link to Paranal (see Filippi, 2010), made it possible for us to have an entire "back office" in Groningen looking over our shoulders and analysing the data on the fly, despite the considerable data volumes. Sometimes there are advantages to schedule slips: this would have been impossible in 2005!

Looking ahead

Now that OmegaCAM is about to enter operations, we can look forward to many results. The first few years will be devoted to three public surveys (see Figure 7 and Arnaboldi et al., 2007), to guaranteed time for the camera and telescope teams, and to Chilean programmes. With our guaranteed time we will initially focus on mapping the young galaxy clusters in the Hercules supercluster, capturing the full extents of dwarf spheroidals and globular clusters in the Galaxy, and searching for very short-period binary stars as possible supernova Ia progenitors.

After many years of patience and preparation, the harvest can finally begin!

Appendix: Filter characteristics

The throughput curves of the workhorse broadband Sloan filters are reproduced in Figure 8. Approximate zero points (they vary from CCD to CCD by of the order of 0.1 mag) are given in the table.

FILTER	Zero point (AB mag, 1 e⁻/s)
u	23.9
g	25.8
r	25.7
i	25.2
z	23.8
B	25.7
V	25.5

Acknowledgements

OmegaCAM was designed, built and commissioned by a consortium of institutes from the Netherlands, Germany and Italy, with significant contributions from ESO. The mechanical design was led by Harald Nicklas (Göttingen), the shutter by Klaus Reif (Bonn), electronics by Achim Hess (München), instrument control software by Andrea Baruffolo (Padua) and data flow and calibration software by Edwin Valentijn (Groningen). Olaf Iwert (ESO) led the work on the detector system, including the CCD mosaic and Jean Louis Lizon (ESO) led the cooling system. Project management was done for most of the project by Bernard Muschielok (München), after initial efforts from Don Hamilton and Günter Wiedemann. Ralf Bender (München) and Enrico Cappellaro (Padua) served as co-PI's. Our ESO project scientist was Dietrich Baade. Much of the funding was provided by NOVA, the BMBF and INAF.

I wish to express my sincere thanks to all of the OmegaCAM team for sticking with the project over the years, and for helping to deliver what I am sure is going to turn out to be a fantastic science machine. Working more closely with the VST team in the final year of the project, particularly with Pietro Schipani and his commissioning team, was a joy. Observing the Paranal operation up close, juggling the running of an observatory with learning to accommodate a new facility and helping to solve problems, was an eye-opening experience. Many thanks to all.

References

Arnaboldi, M. et al. 2007, The Messenger, 127, 28
Filippi, G. 2010, The Messenger, 141, 2
Kuijken, K. et al. 2002, The Messenger, 110,15

Links

[1] OmegaCAM manuals: http://www.eso.org/sci/facilities/instruments/omegacam/doc/index.html
[2] OmegaCAM at the VST web page: http://www.eso.org/sci/facilities/paranal/instruments/omegacam/