OmegaCAM: Wide-field imaging with fine spatial resolution

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OmegaCAM Instrument Consortium

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1 Introduction

On Paranal Observatory in Chile, ESO's 2.6-m VLT Survey Telescope (VST) will start operations in 2005. It is of modified Ritchey-Crétien design specifically designed for wide-field imaging, and has been optimized for excellent image quality in natural seeing. Thus, it will have active primary and secondary mirrors, a retractable atmospheric dispersion corrector, a constant focal plane scale of 0.21 arcsec per 15μ pixel over a 1.4 degree diameter field, and a theoretical PSF with 80% of its energy in a 2×2 pixel area over the whole field. OmegaCAM is the wide-field optical camera designed and constructed for this telescope by a consortium consisting of the Leiden Observatory, the Kapteyn Astronomical Institute, the University Observatories of Munich, Göttingen and Bonn, the Astronomical Observatories of Padova and Capodimonte, and ESO. It will be the sole instrument on the telescope, and will be mounted at the Cassegrain focus.

2 Overview of the instrument

2.1 Detector system

The heart of OmegaCAM is the CCD mosaic (Fig. 1), being built at ESO headquarters in Garching. It consists of a 'science array' of 32 thinned, low-noise ($5e^-$) 3-edge buttable 2x4k Marconi (now E2V) 44-82 devices, for a total area of 16384 x 16384 15μm pixels (26x26cm!). The science array fits snugly into the fully corrected field of view in the focal plane of the VST, and covers an area of 1x1 degree at 0.21 arcsec/pixel. Around this science array lie four 'auxiliary CCDs', of the same format. Two of these are used for auto-guiding (on opposite sides of the field: the field is so large that also field rotation will be auto-guided), and the other two for on-line image analysis. For this purpose the latter CCDs are deliberately mounted out of focus (one 2mm in front, one 2mm behind the focal plane), and the resulting defocused images can be analyzed on-line and used to infer aberration coefficients such as defocus, coma, or astigmatism every minute. The whole detector system is mounted behind a large, curved dewar window (the final optical element in the VST design) and is cooled using a 40-l Nitrogen cryostat. Readout of the full mosaic takes 45s, and is accomplished by two FIERA controllers (a third FIERA takes care of the four guiding and image analysis CCDs).

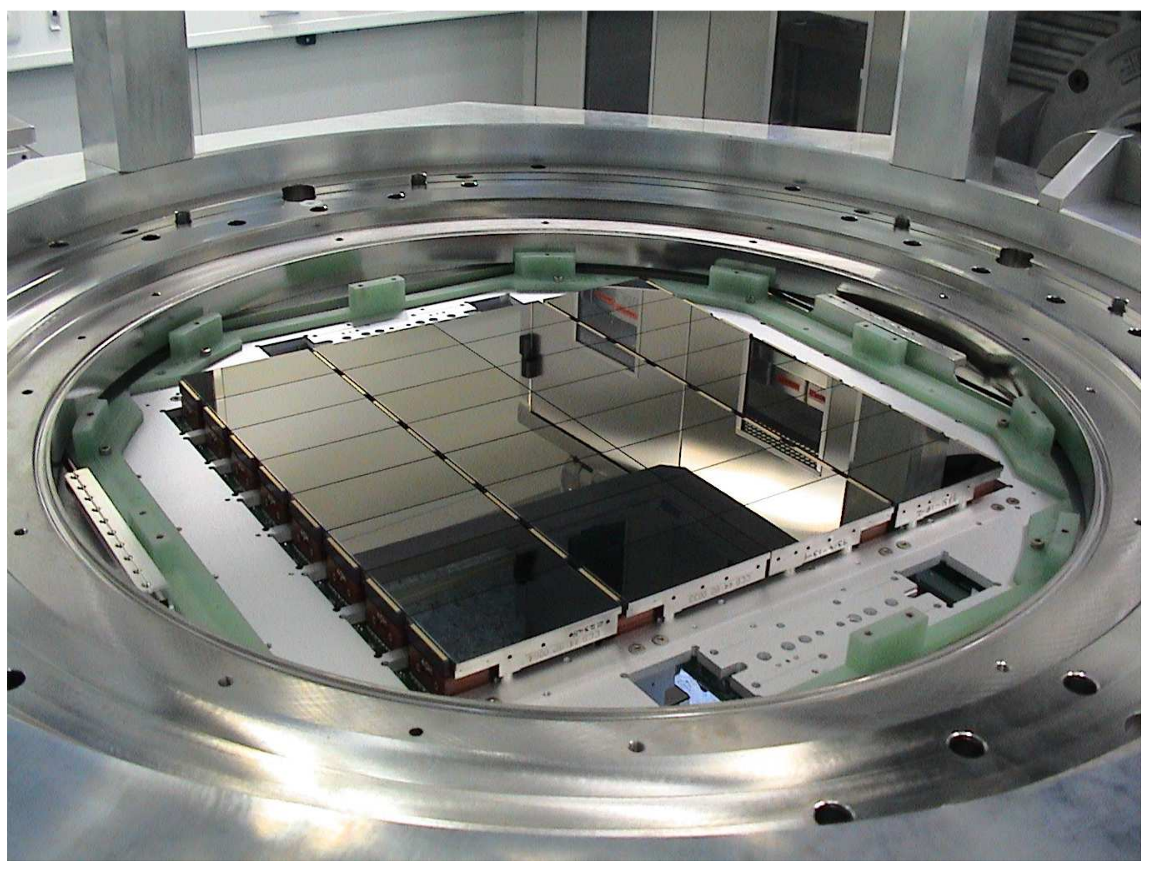

Figure 1: *The OmegaCAM focal plane in the laboratory, populated with dummy CCDs. This arrangement minimizes the amount of dead space between devices, given the constraints imposed by connecting the read-out ports. In the VST the array covers a 1x1 degree area. In addition to the 32 CCDs shown here, in the periphery the mounting holes can be seen for the four auxiliary detectors—two of these are for autoguiding, and the other two for image analysis.*

2.2 Hardware

In front of the dewar window is the mechanical part of OmegaCAM: closest to the CCD window sits the filter exchange mechanism, and above that the shutter. The housing provides the mechanical link between the telescope flange and the detector/cryostat system.

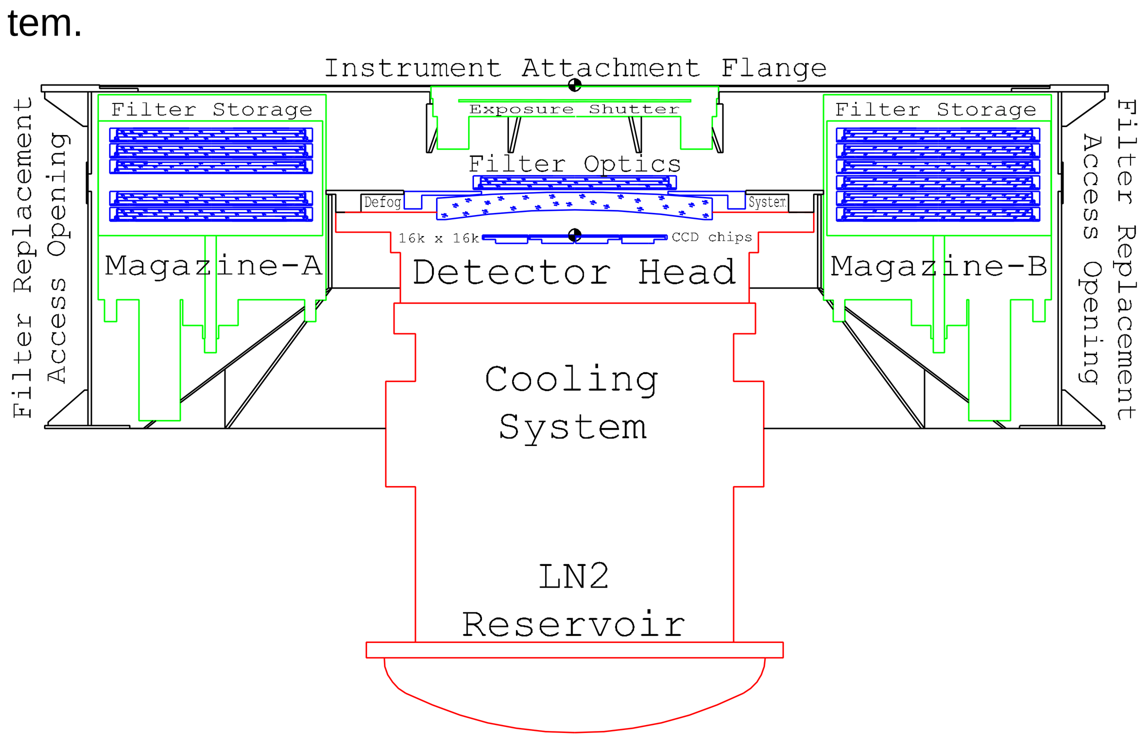

Figure 2: *Schematic view of the instrument. Key components are labeled.*

Figure 2 gives a section view of the final design that foresees a cylindrical housing with a spoke-like rib structure to support the axisymmetrical loads at the Cassegrain focus. The real housing with integrated shutter and magazines can be seen in Fig. 3. The filters are stored in two magazines which can move up and down, either side of the focal plane, through large shafts in the housing. A linear stage slides filters into the beam, where they are locked into place by means of movable notches. The total number of motors used in the filter exchange and positioning mechanism is 7. High precision filter positioning ensures that intensity variations in the flat fields due to optical imperfections in the filters (dust grains, etc.) are less than 0.1%. The filter exchange unit is built in such a way that it allows one filter to be pulled into the beam while the previous one is pushed out, allowing efficient observing in spite of the rather large distance the filters have to travel. Filter exchange time depends on how far the magazines need to move and whether the incoming and outgoing filter belong to the same magazine or not. Provisions for increasing the efficiency of observations are made in software and planned for instrument operations (e.g. optimized distribution of filter in magazines).

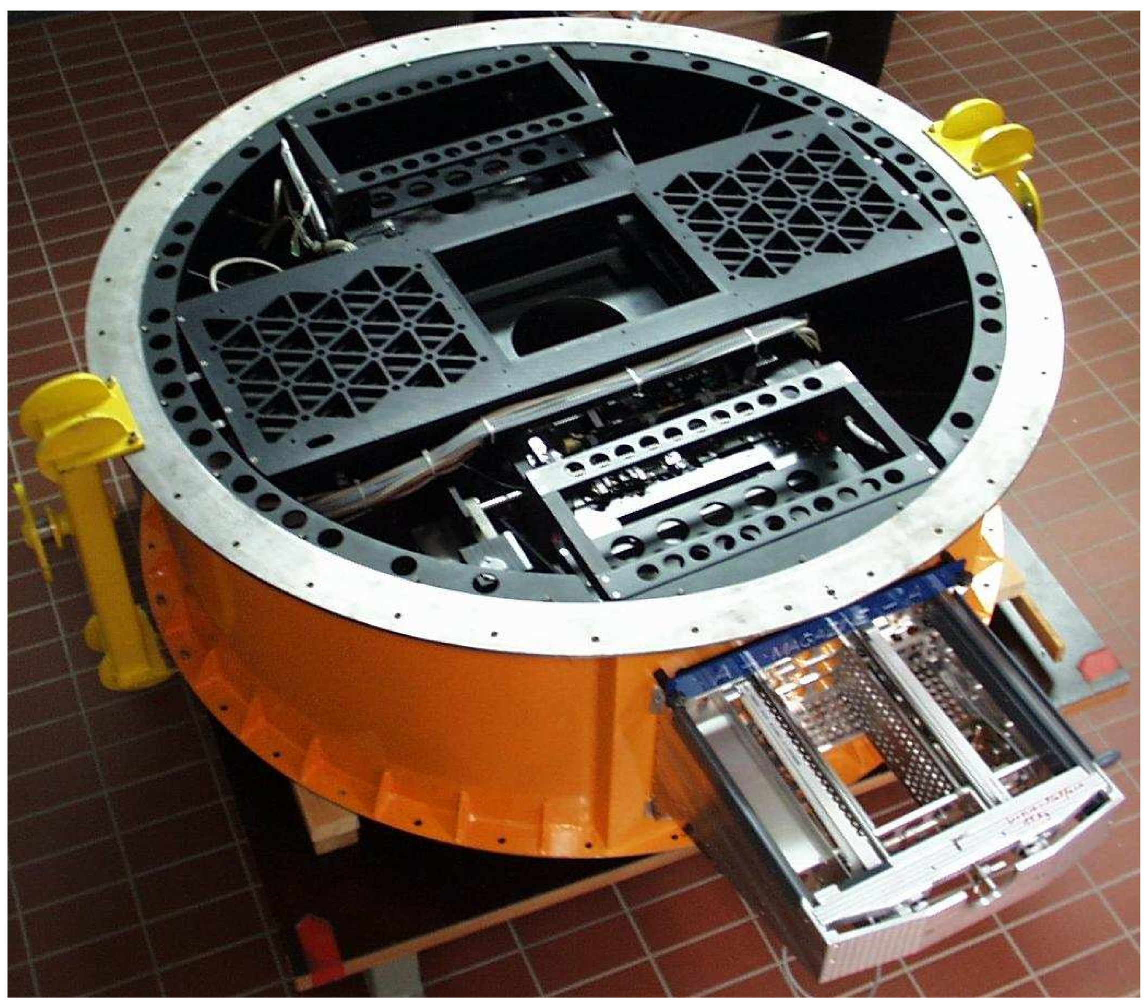

Figure 3: *The 1.5 m diameter housing structure with integrated shutter (structure going from left to right) and storage magazines for filters (upper and lower part. The filter loading platform is attached to the housing. Each magazine can be filled with up to 6 filters which are large and heavy: when fully loaded with 12 filters, the instrument will contain 40 kg of filter glass alone! During the filter exchange process about 17kg are moved (mass of 2 filters and the carriage).*

The exposure shutter is one of the key units of OmegaCAM. It consists of two carbon fiber blades which open and close the light path. They are driven by 2 micro-stepper motors and move smoothly on linear motion guides. These movements are controlled such that each individual CCD pixel 'sees' the opening edge of the one blade and the closing edge of the other blade with an identical time difference, even if the blades are still accelerating–this provides an impact-free, high-accuracy photometric shutter. Tests of the shutter have shown that the performance is much better than the specifications: for an exposure time as short as 1 second, deviations from a homogeneous exposure are well below $\pm$0.2% over the whole field of view. The exposure delay for individual image columns resulting from the finite blade speed can be exactly predicted.

The OmegaCAM instrument control electronics follows the well established ESO standards. To facilitate the user interface, coordination, testing and maintenance of the instrument a UNIX based workstation with high level control SW communicates via LAN to a Local Control Unit (LCU). This LCU is based on a VME system equipped with a Motorola CPU board running under the real time operating system VxWorks as well as a set of specialized control and interface boards. A dedicated calibration system provides the user with reliable data. The instrument control hardware is fully embedded into the observatory alarming system thus facilitating effective and reliable operations.

2.3 Optics

The VST telescope will work in two configurations, which can be selected remotely. In the standard configuration, foreseen for work at small zenith distances, a two-lens field corrector is used. The second configuration replaces this corrector with one including an Atmospheric Dispersion Corrector (ADC), consisting of one lens and two counter-rotating prism pairs. The operating wavelength ranges are 320–1014nm and 365–1014nm for the two-lens corrector and corrector + ADC respectively.

The only optical parts located in the instrument are the filters, and the entrance window to the cryostat, which doubles as a field lens. The primary filter set of OmegaCAM will be a set of Sloan u', g', r', i' and z' filters. In addition, there will be Johnson B and V filters for stellar work and for cross-calibrating the photometric systems, a Strömgren v filter, an Hα filter consisting of 4 segments with redshifts of up to 10000km/sec, and a segmented ugri filter for efficient photometric monitoring of the sky.

Filters are being manufactured by SAGEM in Paris, and by Barr Associates in Massachusetts, and consist of 3-layer sandwiches of coloured or coated glass plates. The expected throughputs of the Sloan filters are very high (Fig. 5). The first filter (r', see Fig. 4) is being actually (May 2004) tested.

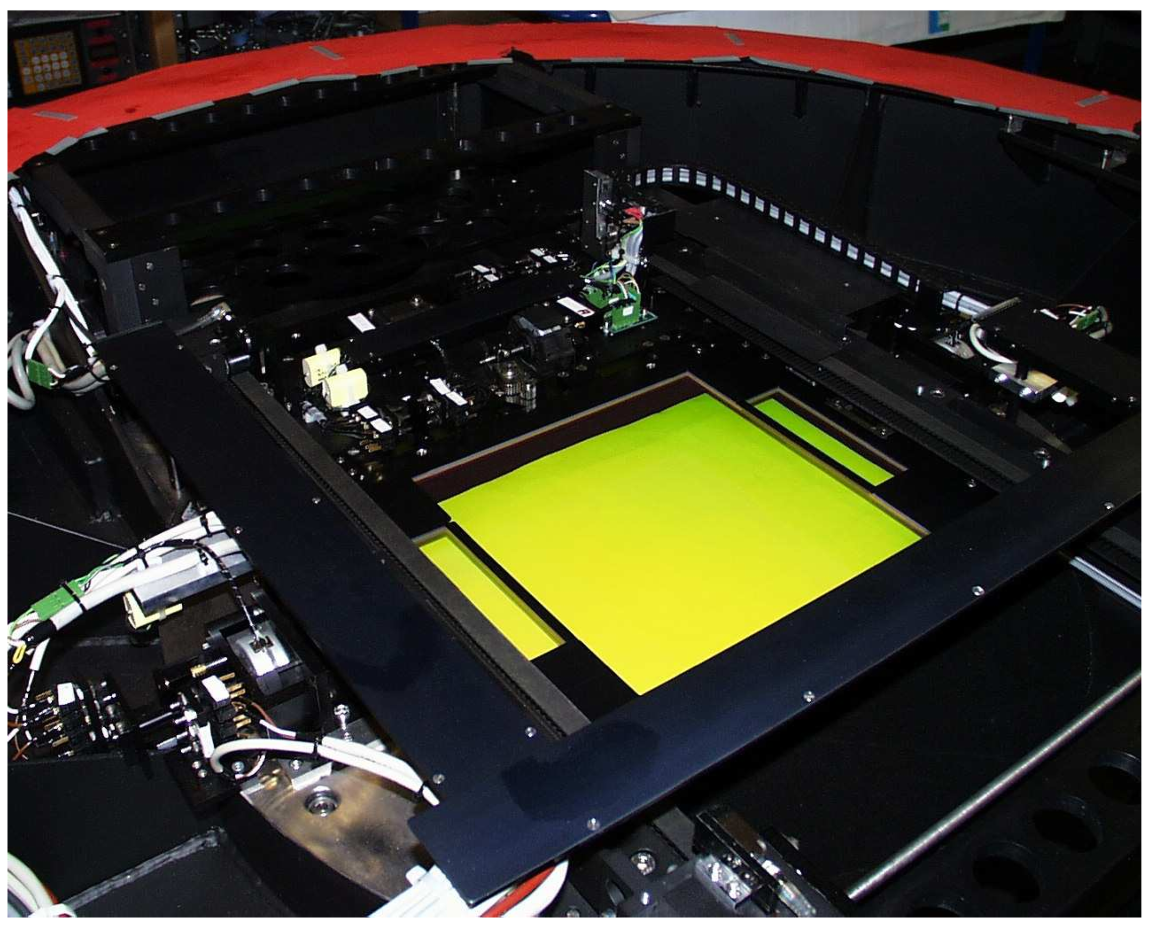

Figure 4: The r' filter in the light path (main field of view 268×268 mm). On the right and left side of the science filter the auxiliary filters for guiding and image analysis are visible. The total mass of the filter including frame is 6kg. Note that the shutter was not mounted when the picture was taken.

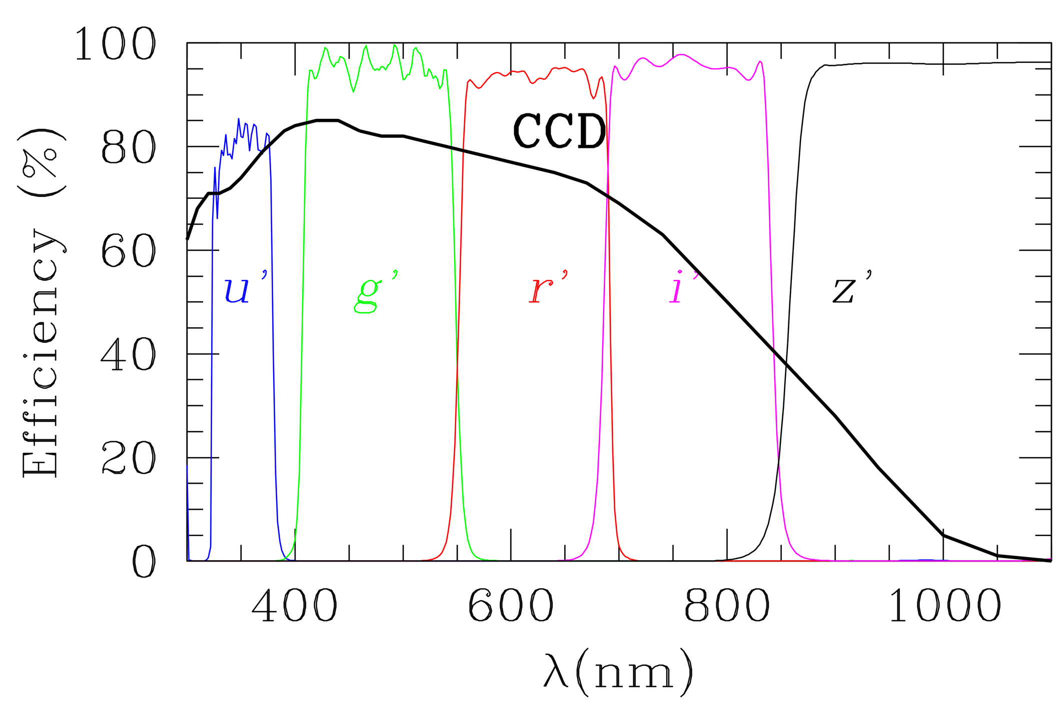

Figure 5: *Theoretical throughput curves from SAGEM for the SDSS filter set, and measured quantum efficiency of one of the OmegaCAM CCDs.*

2.4 Control Software

All instrument functions (filter exchange, shutter, detector readout, as well as monitoring the instrument state) are controlled in software. The programming environment is defined and provided by ESO through the releases of the VLT Common Software which has to be used as the basis for design and development. The partitioning of the OmegaCAM Instrument Software (OmegaCAM INS) into software subsystems follows also the VLT standards. Further, a new software algorithm was developed to extract optical aberration coefficients from the out-of-focus images recorded on the Image Analysis CCDs. On the detector software side, particular attention had to be paid to the coordination of the readouts by the different FIERA's, and to the efficient storage of the data on disk.

3 Calibration and Data Reduction Software

The amount of data produced by OmegaCAM will be truly huge. We estimate that there will be over 15 Terabyte of raw data per year. This raw data volume contains roughly 5 Terabyte of calibration data and 10 Terabyte of raw science data. Data processing will then produce another 10 Terabyte of reduced science data and may create, with about 100000 astronomical objects per OmegaCAM field, enormous catalogues. To efficiently handle this data volume the data acquisition, calibrations and the pipeline reductions are strictly procedurized, a key aim being to maintain the *instrument*, not individual data sets, calibrated at all times. ESO will operate the instrument in service mode, optimizing the observing programme to ambient conditions, and routinely taking calibration data. Thus each night the instrument's overall responsivity and also the transmission of the atmosphere will be monitored in the u', g', r' and i' bands irrespective of the schedule of science observations. Data reduction recipes, run in ESO's DFS, will provide a continuous characterization of the behavior of the instrument in these *key* bands. When other filters are used, the calibration plan foresees a cross calibration of these filters versus these key bands.

4 Current status

Extensive hardware (filter exchange and positioning mechanism, exposure shutter, safety measures) and software (control, maintenance, observation, calibration and data reduction) tests of the instrument have been made in the past months. Presently the acceptance tests for the 'non detector' part of the instrument are being finished. The detector system is about to be integrated into its final configuration. After testing, it will be integrated with the rest of the instrument for final system tests. Shipping to Paranal is foreseen for the February 2005.