OmegaCAM – Technical Design and Performance

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ABSTRACT

The 256-Mega-Pixel imager OmegaCAM will become the wide-field camera at the VLT-Survey-Telescope of the ESO Paranal Observatory. The camera will cover 1 square-degree field of view at the 2.6-metre VST telescope with 16kx16k pixel resolution. The opto- and electro-mechanical design is the responsibility of a Dutch-German-Italian consortium whereas the cryogenic detector system is built by ESO. The design phase had been finalized with a successful Final-Design-Review in autumn 2001. Procurement and manufacturing is ongoing till the end of the year 2002 followed by an extensive testing period before Preliminary-Acceptance-in-Europe. The paper will present the camera design including the results of design analyses and performance assessments of which optical and finite-element-analyses will be emphasized. The actual design of large-format optical filters will be addressed as well. Their procurement turned out as a challenging issue.

Keywords: imager, wide-field system, survey system, optical filters

1. INTRODUCTION

OmegaCAM will become a survey instrument and a finder scope for the VLT at Paranal Observatory. The instrument will be the successor of the former Wide-Field-Imager at the 2.2m telescope of the La Silla Observatory with larger capabilities such as four times the sky coverage of WFI.

An overview about the scientific aims and the processing of the post-detection data is given in a separate paper[1] at this conference. This processing will be performed in a pipeline mode that allows the observer various choices of control. The software control of the instrument and the raw data is presented in a specific paper[2] of a separate conference which addresses the handling of the huge amount of data. A very effective control of filter exchange with a minimum of dead-time between exposures is important for the survey programs of this instrument. The 2.6m VST observing facility is also presented at this conference.[3]

This paper will address the technical design of the 1-square-degree wide-field imager as well as the performance that is expected from the design and from various analyses. It will cover opto- and electro-mechanical design issues as well.

2. DESIGN DESCRIPTION

The main structure links primarily the 1.5m large telescope flange with the central detector-cryostat system and houses the main units; two movable magazines for storing the observing filters within the instrument, the linear stage unit for exchanging the filters within the telescope beam and the 1.2m large shutter for high-precision exposures. Figure 1 gives a section-view of the final design that foresees a cylindrical housing with a spoke-like rib structure to account for the axisymmetrical loads at the Cassegrain focus of the VST telescope. Big shafts (Fig. 2) had to be build within this structure to accommodate the two magazines which will house the large format filters, each of which will support the full size of the 1-square-degree field. The storage capacity of each magazine accounts for up to six full-size filters. The total storage capacity of a dozen filters loads the instrument with about 80 kg of mounted filter optics.

Those filters will be moved on a linear stage into the beam position where they will be locked free of any play via movable notches. This ensures that intensity variations in the flat-fields due to optical imperfections (unsharply imaged dust grains etc.) will fall below the 10^{-3} level. The filter exchange unit is built in a way that it allows a synchronous exchange of the predecessor with the consecutive observing filter to account for very efficient observing. The exchange carriage will dock from either sides to the filters stored in both magazines. A separate interlock system will prevent failures and any possible damage of the expensive filters since there are several crossing moving functions. All drives are selflocking, so heat dissipating electronics can be switched off during long exposures. Those drives that faces high torques (magazines and exchange carriage) are mounted outside of the housing to avoid any source of possible internal seeing and to have them well accessible for maintenance purposes.

Table 1. Main instrument parameters

Filter Optics		
Dimensions	424 x 326 mm^2 mounted size	360 (270) x 270 mm^2 clear aperture
Assembly	Full-size support plate	stacked segmented filterglass
Support plate	373 x 281 mm^2 phys. dimension	$0\farcm2$ max.wedge, $\lambda/4$ surface quality
Science filter size	274 x 274 mm^2 phys. dimension	$0\farcm2$ max.wedge, $\lambda/4$ surface quality
Quality	5x10^{-6} homog.,4 fringes power irreg.	$0\farcm7$ max.wedge, B2 bubble class
Coatings	dielectric filter coatings	hard AR coatings on extern. surfaces
Passbands	Sloan u', g', r', i', z' (primary set)	B, V, $\mathrm{g'}_{broad}$, $\mathrm{i'}_{broad}$, $\mathrm{v}_{Stromgr.}$, H_α(z)
Peak transmission	85%, 94%, 93%, 96%, 96%	92%, 90%, 94%, 97%, 86%, 92%
Aver.transm.guaranteed	60%, 77%, 78%, 77%, 77%	75%, 75%, 72%, 85%, 60%, 70%
Min.transm. guaranteed	45%, 55%, 55%, 60%, 70%	55%, 55%, 55%, 65%, 50%, 60%
Off-Band blocking	$\sim 10^{-4}$	$\sim 10^{-4}$
Instrument Mechanics		
Image scale and stability	$0\farcs2/15\mu$m pixel $\Rightarrow$diff.flexure$< \pm2\mu$m	optics decenter $< \pm$ 0.5 mm
Filter position stability	3 pixel w.r.t detector within beam	1 pixel (goal)
Filter capacity	2 storage magazines	6 full-size filters per magazine
Exchange times	30 sec magazine move	40 sec filter exchange
Reliability	downtime < 1.5% observing time	10^6 expected exposures
Scattered light	max. 8 baffling levels within instrument	
Exposure Shutter		
Dimensions	370 x 292 mm^2 aperture	424 x 1 218 mm^2 phys. size
Type	linear slit shutter	CFRP slit blades
Timings	< 0.1 sec shortest possible expos.time	0.9 sec dead time
Accuracy	±0.2% homogeneity in 1sec exposures	± 0.3 msec in exposure length

The camera exposure shutter is one of the instrument's key units. The consortium votes for a linear slit

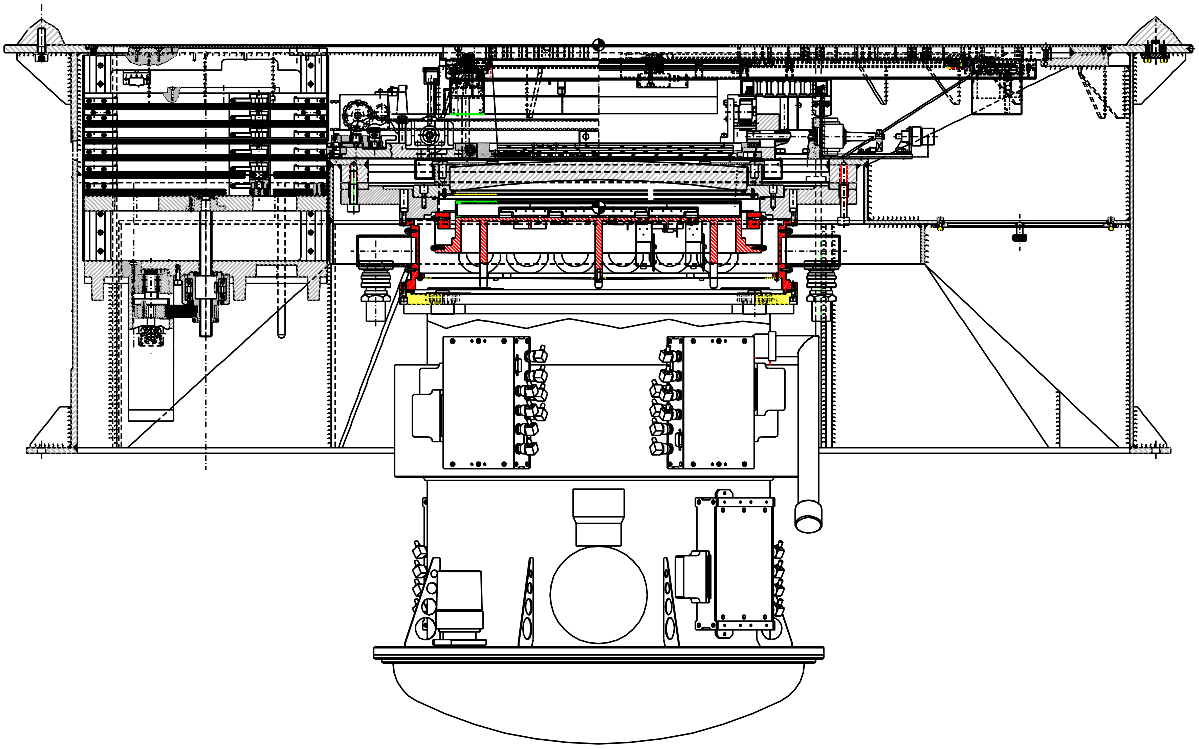

Figure 1. General drawing of the OmegaCAM instrument. Two sections through the inner part are visible; one of the magazines with drive to the left, the exposure shutter and the filter exchange unit to the right. The instrument view is dominated by the cryogenic cooling system (with pre-amplifiers, vacuum nozzles etc. attached on the outside) and the detector head on top of it (containing the CCD mosaic in section view).

type shutter to avoid the excessive dimension and dynamical load of rotary stages at that field size which are experienced with much smaller devices such as the one in FORS. The moving blades of this shutter are controlled via micro-stepper motors all along its traveling path. This guarantees that each of the two blades moves with identical motion profiles thus allowing a very smooth movement without any high acceleration that form a slit in case of short exposures. Due to the controlled profiles, each individual pixel 'sees' the preceding and following edge of the two blades with identical delay time. A proper design of electro-mechanics and control hardware leads to an accuracy on sub-milli-second level[4] for a shutter of 1.2m physical size (see Fig. 3).

3. PERFORMANCE ASSESSMENT

Table 1 lists the primary instrument parameters. All of them are met by the design and are checked in a formal Final-Design-Review. Those which are crucial for the functional performance are verified in separate analyses (also covered by FDR) which are listed in Tab. 2.

3.1. Static and Modal Finite-Element-Analysis

Instrumental flexure is crucial for the performance of this Cassegrain instrument. A static and dynamic analysis is therefore performed to verify the design goals. The field lens is the entrance window of the cryostat and part of the telescope optical system. The requirements on its position accuracy relative to the optical beam within sub-arcminutes and a few microns (due to the error budget) are rather tight. All the optical specifications could be met with the design (cf Tab. 2).

The more sensitive PSF deterioration due to image motion on the detector is determined by differential motion of the individual CCDs on the mosaic's mounting plate since the autoguider signal is gained from two separate auxiliary CCDs that are mounted next to the science array on the same base plate. Instrumental flexure will therefore not affect image quality via image motion. The CCD mosaic base plate is analyzed with a static and a thermal computer model[5] which ensures that all motions within to the detector mosaic will fall within the ± 2μm limit for the 15μm pixel of the Marconi 2kx4k CCDs.

Two additional auxiliary CCDs are mounted onto the base plate which can tune the telescope optics. Each of these two CCDs is mounted 2mm off from the focal plane, one in front, the other behind the plane. The primary imaging aberrations will be derived from those defocused images which can be applied for an active correction of the telescope mirrors. This kind of aberration detection is similar to the so-called *curvature sensing*, well known from adaptive optics.

The modal analysis was done in respect of dynamical excitation due to earthquakes at the Chilean site or other sources. The structural design turned out such stiff that the lowest eigenfrequencies start around 124 Hz which is far from any possible exciting source at the observatory. The earthquakes at the Paranal site have no frequency overlap and are therefore dynamically un-coupled that only static load factors of 3–5 in the maximum had to be applied which raise no concern for the stiff housing structure.

Table 2. Performance values, estimated from design analysis or hardware testing.

<table>
<tr><td colspan="4">Detector flange displacement (w.r.t the telescope beam)</td></tr>
<tr><td>Horizon.load (1g$_x$)</td><td>dx = 3 μm</td><td>dy = 1 μm</td><td>tilt = ±1 μm</td></tr>
<tr><td>Horizon.load (1g$_y$)</td><td>dx = 1 μm</td><td>dy = 3 μm</td><td>tilt = ±6 μm</td></tr>
<tr><td>Vertical load (1g$_z$)</td><td>dx = 1 μm</td><td>dy = 1 μm</td><td>dz = 1 μm</td></tr>
<tr><td colspan="4">Modal analysis</td></tr>
<tr><td>Lowest eigenfrequencies</td><td>1st = 124 Hz</td><td>2nd = 150 Hz</td><td>3rd = 200 Hz</td></tr>
<tr><td colspan="4">Filter and field lens stability (deformation and strain)with change in radius of curvature</td></tr>
<tr><td>Filter deformation (1g$_z$)</td><td>dz$_{max} < 16$ μm</td><td>$\sigma_{max} < 0.5$ MPa</td><td>r$_{bending} \simeq 10^3$ m</td></tr>
<tr><td>Field lens deformation (1g$_z$)</td><td>dz$_{max} < 98$ μm</td><td>$\sigma_{max} < 6$ MPa</td><td>r$_{bending} \sim 10^2$ m</td></tr>
<tr><td colspan="4">Exposure shutter (test results)</td></tr>
<tr><td>Shutter performance</td><td>1 msec min. exposure</td><td colspan="2">± 0.3 msec homogeneity at 0.1 sec exposures</td></tr>
<tr><td>Reliability</td><td>10^6 operations expected</td><td colspan="2">10^7 operations tested with prototype</td></tr>
</table>

3.2. Filter optics deformation

Possible PSF broadening had to be excluded from the bending under its own weight due to the large format of the filter optics. The analysis took the load of the filter support plate by the assembled science filter sandwiches into account. The maximum deformation is below 16μm at the centre leading to a curvature radius of some 10^3m which is negligible for the plane-parallel plates without refractive power. The tensile strain is at least by a factor of 20 below the critical value for the breakage of glass (Tab. 2).

3.3. Field lens deformation

The mechanical stability of the vacuum-tight field lens can affect the instrument two fold. First, it seals the CCD array against contamination from the outside and would destruct the array in case of breakage. Second, it could deteriorate image quality with broadening the PSF by bending under atmospheric pressure. Both can be excluded from the analysis which simulates the lens as a plane-parallel plate. The induced curvature is of the order of 10^2m for a plane plate and the tensile strain about 10 times below critical value (cf Tab. 2). Both will improve in reality due to the positive curvature of the field lens meniscus of about 1–2 m curvature radius.

Figure 2. The 1.5m diameter housing structure during a test assembly of the main units: the two storage magazines (to be inserted into the big shaft at left and hidden right), the filter exchange unit with the exchange carriage and a 420x320mm^2 dummy-filter (at bottom left).

Figure 3. The camera exposure shutter of 1.2 metre dimension due to its linear slit type. The laptop covers (for scale) the operating aperture of 370x290 mm^2. The typical timing accuracy of this shutter is better than 1 milli-second.

4. LARGE FORMAT FILTERS

The procurement of large format filters of the required $(300\text{mm})^2$ size turned into a challenging task. Only one manufacturer of plane optics did send an offer on producing the OmegaCAM filters without segmenting them. Even raw colored glass is hardly available at that size. Therefore, multiple-layer coating of up to five surfaces will produce the passbands. Since more than two glass surfaces are necessary for the large number of coatings, the science and the auxiliary filters have to be stacked and glued together (Fig.4). All three sandwiches of a single filter will be cemented onto a large homogeneous support plate because the transmission curves of science and auxiliary filter are not necessarily identical.

The glass assembly of support plate with the cemented filter sandwiches is mounted into a stiff aluminum frame for handling, transportation as well as for docking and sliding into the optical beam with the exchange unit. The total weight of a single filter amounts to more than 6 kg. Special devices for transport and inserting the filters safely into the instrument magazines had to be built. Those handling tools and procedures will protect the valuable filter optics against damaging and dust grains. The latter is important for the flat-field i.e. for the data quality and the long-term stability. This is one reason to over-pressurize the instrument slightly with the dry and clean nitrogen gas, vaporized from the cryogenic cooling system for defogging the cool field lens.

Table 1 lists the main characteristics that are in the contract with the optics manufacturer. The primary filter set that is ordered can be seen in the first column. The set in the next column is in discussion for the more specific observing programs of the consortium. The transmission parameters, that are guaranteed by the manufacturer over the full width, are fabulous and the rising and falling edges will be extremely steep due to the specific interference properties leading to excellent passbands.

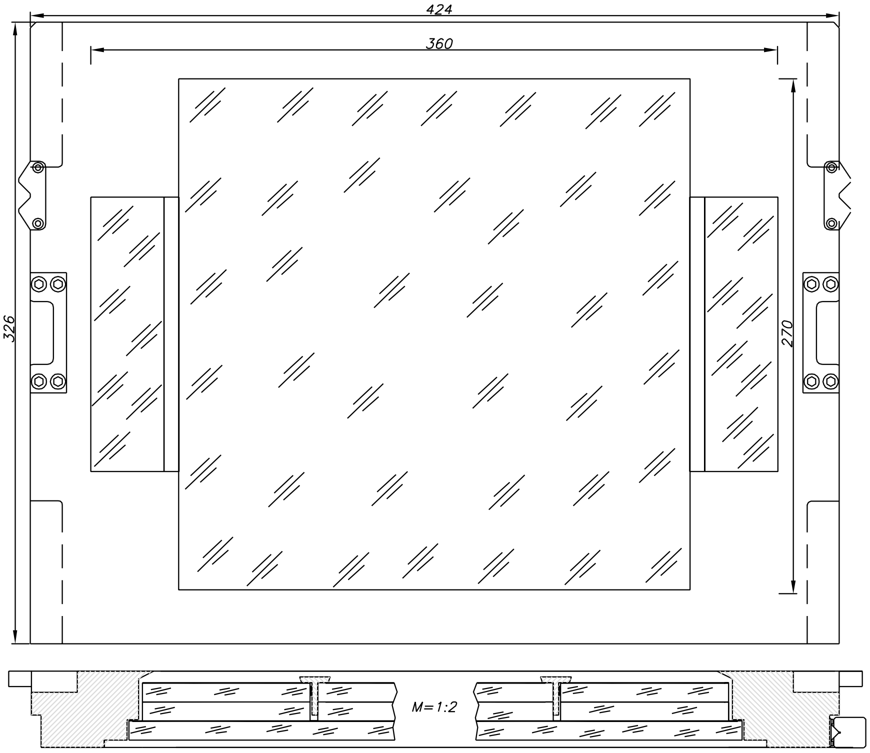

Figure 4. Schematic sketch of the OmegaCAM large format filters. Clearly visible are the glass assembly of the full-size support plate with three filter sandwiches (the central science and the two auxiliary fields), the aluminum frame and the mechanical items for docking, guiding and locking.

Due to the mosaic configuration of the CCD assembly with its bonding gaps etc., the use of a segmented H_α-Filter is foreseen in which each of the four quadrants will filter the Balmer line at different redshifts in one single shot. This could raise the efficiency for cosmological observing programs.

5. VST CONSTRAINTS

The procedures and attachments of the instrument at the VST telescope are determined by loads and spatial constraints. In avoiding overloading the telescope's instrument flange, all electronic control cabinets will be mounted to a separate co-rotating flange. This is dominated by the numerous electronic items necessary for controlling the 256 million pixel. The instrument flange carries the sheer camera hardware with the detector system.

Specific transport, handling and mounting carts have been built for the different groups. The one that carries the camera had become quite complex due to multiple purposes. This instrument cart supports all procedures on and off from the telescope in very different hardware configurations, such as camera testing and last minute detector checking before attachment, within the given spatial constraints.

6. SUMMARY

Manufacturing and procurement is running towards its finalization including the efforts that had been carried out by the optical detector team at ESO. The design and assembly of the detector and cryogenic parts[6] have been a central part of the project – similar to handling and processing the huge amount of scientific data – which pushes it to a real success.

At the end of the year 2002, the pre-integration and testing phase in Europe will follow. Thus, the original schedule of the project can be met that foresees the integration and commissioning of the instrument at the VLT Survey Telescope on the Paranal site for second half of 2003.

Preliminary test results indicate that all specifications will be fulfilled. Provided that commissioning confirms that instrument performance, the European community will get access to a most modern and powerful survey tool. This facility will nevertheless enhance the capabilities of the much larger Unit Telescopes of the VLT.

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