GROND Commissioned at the 2.2-m MPI Telescope on La Silla

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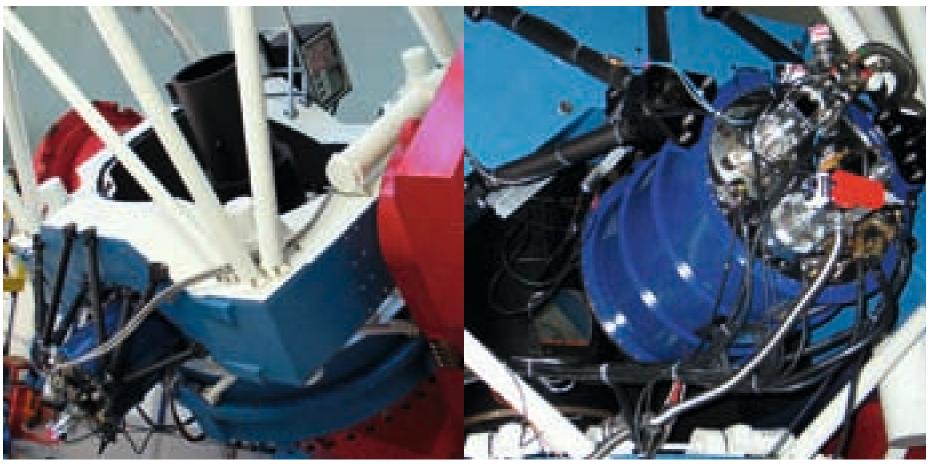
An imaging system capable of operating in seven colours simultaneously, has been designed, built, and recently commissioned at the 2.2-m MPI/ESO telescope on La Silla. This instrument is called GROND, for Gamma-Ray Burst Optical and Near-Infrared Detector. GROND has been designed for rapid observations of gamma-ray burst afterglows. The seven bands from Sloan *gr$\tilde{i}$z* to near-infrared *JHK* allow an immediate photometric redshift determination for bursts at $z \geq 3.5$. In addition, the unique capability of simultaneous multi-band imaging allows for many other scientific applications.

Why imaging in more than one band?

Simultaneous imaging in different filterbands is interesting in a variety of astrophysical areas. It primarily aims at measuring the spectral energy distribution, or its variations in variable objects, in order to uncover the underlying emission mechanism. Examples are, among others: (1) monitoring of all kinds of variable stars (flare stars, cataclysmic variables, X-ray binaries) to determine the outburst mechanisms and differentiate between physical-state changes and changes induced by geometrical variations, like eclipses; (2) monitoring of AGN to understand the physical origin of the observed variability; (3) mapping of galaxies to study the stellar population; (4) photometric redshift surveys; (5) observations of extrasolar planets; and (6) mapping of reflectivity inhomogeneities of Solar System bodies as a function of their rotation to map their surface chemical composition.

A new need arose with the observation of a large number of gamma-ray burst (GRB) afterglows with the *Swift* satellite. With its much more sensitive instruments, *Swift* detects GRBs over a very wide redshift range at a rate of about one hundred per year. Since high-resolution spectroscopy to measure the physical conditions of the burst environment is constrained to the first few hours after a GRB explosion, a rapid determination of the redshift becomes important. This is best done with multi-band photometry (until integral field units have grown to several arcmin field of view) and deriving a photometric redshift based on the Lyα break. There are currently few instruments with simultaneous multi-channel imaging, but those combine less than four channels and typically are operated on small telescopes.

Figure 1: The GROND instrument at the 2.2-m telescope. Left: View of the 2.2-m telescope with GROND to the lower left, the light baffle on top of M3 in the middle, and the main electronics rack at the rear top. Right: Detailed view of the GROND vessel and its various connections.



Instrument Design

GROND was developed for implementation on the MPI-owned 2.2-m telescope, operated by ESO at La Silla. This f/8 Ritchey-Chretien telescope hosts, at its Cassegrain focus, the Wide Field Imager (WFI; *www.ls.eso.org/lasilla/sciops/2p2/E2p2M/WFI/*) and the echelle spectrograph FEROS (*www.ls.eso.org/lasilla/sciops/2p2/E2p2M/FEROS/*). GROND therefore has been placed in a Coudé-like position at the centre piece of the telescope (Figure 1). A special folding mirror was built which can be swept into position within 20 sec and deflects the light into the GROND camera (Figure 2).

The separation of the different photometric bands has been achieved using dichroics (Figure 3), whereby the short wavelength part of the light is always reflected off the dichroic, while the long-wavelength part passes through (see Figure 4 for the wavelength ranges of the seven bands). The dichroics were designed such that the combination of their cut-off wavelengths defines bands as close as possible to the Sloan system, with the exception of the *i*-band. Since in the Sloan system, *riz* the bands overlap at their ~ 70% transmission values, we decided to compromise the *i*-band in favour of standard width *r* and *z* bands (therefore calling it $\tilde{i}$). For the infrared part, a focal reducer system was devel-

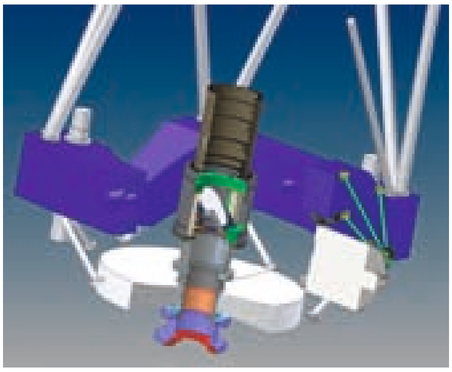


Figure 2: Cutaway view of GROND on the 2.2-m telescope with the new folding mirror M3 within the light baffle (centre).

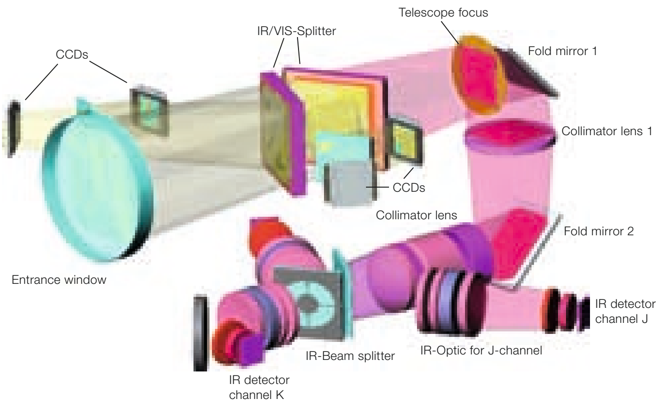


Figure 3: 3D structure of the optical beam of GROND with most of the components labeled.

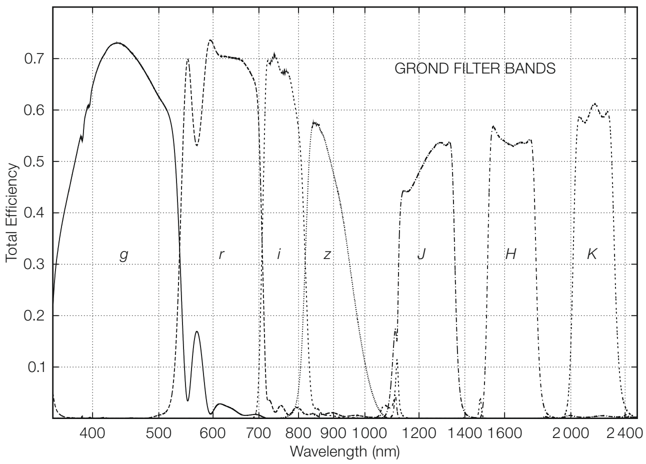


Figure 4: Filter curves of GROND showing the total efficiency of the instrument including the telescope mirrors, GROND-internal optics, and detectors.

oped in order to enlarge the field of view to 10 arcmin, thus ensuring coverage of the full error circles of gamma-ray burst positions provided by the BAT/Swift, SuperAGILE or GLAST/LAT instruments (typically a few arcmin radius). Two stationary folding mirrors are introduced to reduce the overall instrument size. The entire system has been designed for a working temperature of 80 K in vacuum, because deviations from the nominal temperature by more than 20 degrees would already lead to refractive index changes large enough to cause noticeable image quality degradation.

Best possible efficiency was a driver in many decisions during the development of GROND, and included special selection of the four CCDs for maximum sensitivity in their respective wavelength bands (see Table 1), silver (rather than aluminium) coatings for the various mirrors, and very high transmission requirements of the dichroics and anti-reflection coatings. The total efficiency in the visual bands is at the 70% level (except *z*-band), and still above 50% for the three NIR bands.

Table 1: Detector details of GROND

Optical part:	
Detector	4 × 2048 × 2048 E2V
Field of view	5.3 arcmin
Pixel size	0.″16
Infrared part	
Detector	3 × 1024 × 1024 HAWAII
Field of view	10 arcmin
Pixel size	0.″6

A few noteworthy features of the GROND instrument include:

(1) IR detector focusing motors. Since the depth of focus in the infrared part is only 25 μm (as opposed to 60–120 μm in the visual channels), each IR detector unit involves a focusing stage by an independent stepper motor. Each motor allows relative movements to an accuracy of 0.4 μm over a range of ±2 mm around the nominal focus position

(2) Lens housings. The focal reducer contains five lenses in the collimator, and 6 lenses in each of the camera objectives. In order to keep the lenses properly centred during the cool-down to 80 K, a special spring mount was developed which allows lenses to be held in groups of two to four

(3) *K*-band dither mirror. Since the readout speed in the optical channels prevents frequent telescope dithering, the *K*-band channel was equipped with a dither mirror

(4) CCD operation in 80 K environment. Since all channels and detectors are located in the same cryostat, the shutters for the CCDs have to operate at 80 K. Also, the CCD detectors are mounted with special thermal insulation and are kept at their nominal operating temperature of 165 K by 0.2 W counter-heaters.

Software

The GROND Pipeline (GP) system is a software package designed and written specifically for GROND. Its prime objective is to schedule rapid GRB afterglow observations and determine the redshift as quickly as possible. The architecture of the GP is based on an asynchronous framework to provide speed and the degree of freedom necessary to apply different analysis strategies. The GP mainly consists of two layers, the system layer and the GRB analysis layer (see Table 2). The system layer consists of the processes that receive the GRB alerts, decide whether to follow that burst or not, schedule and reschedule observations and conduct the observations by initiating, continuing, interrupting or ending them. Furthermore, the main system process controls all processes including the analysis processes, and coordinates the interprocess communication. The GRB analysis layer contains pre-processing of the images, photometric analysis, identifying the GRB afterglow, spectral energy distribution (SED) analysis and photometric redshift determination.

First light

GROND was mounted at the 2.2-m telescope in April 2007, and saw first sky light on April 30. During the following months most of the commissioning steps have been successfully conducted, including the derivation of zero points for all seven bands, checks for vignetting, determination of the focus formula, verification of the effect of the *K*-band dither mirror, and tuning of the exposure and read-out timings in the different channels. Also, the Rapid-Response Mode (*http://www.eso.org/observing/p2pp/rrm.html*) has been implemented in order to allow rapid (few minutes) start of observations after a GRB or transient alert.

All of the various checks have proven the full functionality of the instrument. Two examples of science demonstration results are shown in Figures 5 and 6, each based on just 3-min and 4-min exposure time in the visual and infrared channels respectively!

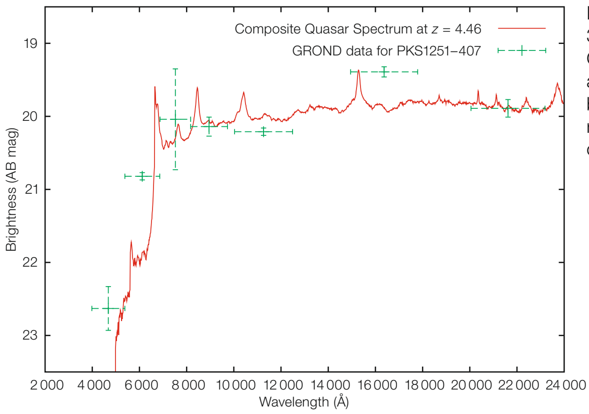


Figure 5: First-light result from April 30, 2007: green crosses are the GROND camera photometric estimates as derived from a 4-min observation block of the quasar PKS 1251-407 at a redshift of $z = 4.46$. The red line is the composite quasar spectrum.

Figure 6: A science demonstration image taken in early May 2007, showing a *JHK* colour composite of the Omega nebula M17. The colour-coding has been chosen to mimic what the human eye sees; namely, hot and massive stars appear bluish-white, while dust reddens the light. The thick dust lanes at the North (top) and West (right) rims absorb even the 2.4 μm wavelengths. The image is 10 arcmin across, and has an effective exposure time of 4 min (twenty-four 60-sec images in each of the three bands).

Table 2: The duties of the software system and the GRB analysis layers of the GROND Pipeline

System – Observation Control Layer	GRB Analysis Layer
Receiving GRB alerts	Pre-processing the images
Deciding whether to observe the target	Photometric analysis of 7-band data
Calculating visibility of the target	Constructing the SED of the objects
Scheduling of the observations	Identifying the GRB afterglow
Triggering/continuing/stopping observations	Determining the photometric redshift
Providing web-interface for user interaction	Evaluating the accuracy of the redshift

Fine-tuning of the operations strategy as well as scheduling and analysis software is expected to bring GROND into complete operational conditions, thus allowing to start full science operations. We are looking forward to an exciting time not only for GRB follow-up observations, but also to many other applications of this unique instrument.

The instrument is operated by the Max-Planck Institute for Extraterrestrial Physics, Garching, under a mutual agreement with ESO, and available to astronomers from the Max-Planck Society. More details about the instrument can be found in Greiner et al 2008.

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References

Greiner J. et al. 2008, PASP (in press)