The REM-IR Camera: High Quality Near Infrared Imaging with a Small Robotic Telescope.

Fabrizio Vitali [a] , Filippo M. Zerbi [b], Guido Chincarini [c], Gabriele Ghisellini [b], Marcello Rodono` [d], Gino Tosti [e], Lucio A. Antonelli [a], Paolo Conconi [b], Stefano Covino [b] , Giuseppe Cutispoto [f], Emilio Molinari [b], Luciano Nicastro [g], Eliana Palazzi [h], on behalf of the REM & Ross Team

[a] INAF-Osservatorio di Roma, Via di Frascati 33, I-00040, Monte Porzio Catone – Italy

[b] INAF-Osservatorio Astronomico di Brera-Merate, Via Bianchi 46, I-23807 Merate – Italy

[c] Università di Milano Bicocca, Piazza dell'Ateneo Nuovo 1, I-20126 Milano – Italy

[d] INAF, Viale del Parco Mellini 84, I-00136 Roma – Italy

[e] Università di Perugia, Piazza Università 1, I- 06100 Perugia – Italy

[f] INAF-Osservatorio Astrofisico di Catania, Via S.Sofia 78, I-95123 Catania – Italy

[g] CNR-IFCAI, Via Ugo La Malfa 153, I-90146 Palermo – Italy

[h] CNR-IASF, via P. Gobetti 101, I -40129 Bologna – Italy

ABSTRACT

We present the near infrared camera REM-IR that will operate aboard the REM telescope, intended as a fully automated instrument to follow-up Gamma Ray Burst, triggered mainly by satellites, such as HETE II, INTEGRAL, AGILE and SWIFT. REM-IR will perform high efficiency imaging of the prompt infrared afterglow of GRB and, together with the optical spectrograph ROSS, will cover simultaneously a wide wavelength range, allowing a better understanding of the intriguing scientific case of GRB. Due to the scientific and technological requirements of the REM project, some innovative solutions has been adopted in REM-IR.

Keywords: Near Infrared Instrumentation, Cryogenics.

1. INTRODUCTION

REM (Rapid Eye Mount) is a fully robotic fast-slewing telescope primarily designed to follow the early phases of the afterglow of Gamma Ray Bursts (GRB) detected by Space-borne-alert systems such as HETE II, INTEGRAL AGILE, Swift. REM is currently in its final integration phase and will be installed at la Silla Observatory Chile by the end of year 2002. REM will host the NIR (Near Infra-Red) camera REM-IR, covering the 0.95-2.3 µm range with 4 filters (1*mic*, J, H and Ks) and ROSS (REM Optical Slitless Spectrograph), a slitless spectrograph covering the range 0.45-0.95 µm. With these instruments REM will serve as a rapid-pointing broad band spectro-photometric facility whenever prompt multi-wavelength data are needed. The overall description and the scientific rationale of the REM project can be found in Zerbi et al. 2002[1] (this conference).

REM-IR is currently in its assembling phase at the Infrared Laboratories in Tucson (Arizona, USA) and the first light at the REM telescope in the laboratories of the Astronomical Observatory of Merate (LE, Italy) is envisaged in the Fall of 2002.

2. THE OVERALL DESCRIPTION OF THE CAMERA

The REM-IR camera is standard in its basic concept but includes some innovative and particular solution due to the scientific and technological requirements:

- the REM instrument (telescope and instruments) is a complete automatic system: no human intervention is envisaged during the observations;
- the telescope should be able to move fastly to follow the trigger from the satellite;
- the instruments should be prompted for scientific exposures in the time needed to the telescope to point the object;
- the telescope has an alt-azimuth mount;
- daily maintenance should be reduced to the minimum.

These combined requirements drove the project of the REM-IR camera, leading to the adoption of some particular solution. In particular the first question arose about the cryogenics and eventually we decided to adopt a cryocooler form Leybold for its reduced dimensions and weight and for its cooling capacity: both the compressor and its electronics can be attached to the Nasmyth flange without any derotated tubes or cable but the electric power.

The cryostat houses the optics, the filters and the array. This latter is a single working quadrant HAWAII 512 x 512 pixels array from Rockwell and its position with respect to the optical axes can be changed, in case the working quadrant should lost its original efficiency and cosmetics.

In the following sections we will describe in detail the cryostat, the optics, the filters, the detector along with its electronics, and the cryogenics.

3. THE DEWAR

The project of the REM-IR camera has been designed by Infrared Laboratories, with which we experienced a very fruitful collaborative relation. The optics, the filter wheel and the array along with its onboard electronics are housed in a standard 8 inches Infrared Labs. dewar. In Figure 1 the overall scheme of the dewar is shown: one can easily recognize the optics train, the filter wheel positioned just before the pupil, the detector mounting, the compressor with the cold head that provide the 77 K to the array and to the pupil stop. Particular attention has been put to the rigidity of the system: the IR Labs SC-7X10 G10 double rigid support system has been evaluated for maximum acceleration with the dewar in both horizontal and vertical orientations, under the following conditions:

- dewar in horizontal orientation
- cold plate mass = 50lbs
- safety Factor = 3
- 0.063 inch thick G10 supports (6 places)
- two #6 SS screws securing each side of each support

In the horizontal orientation, that is the working orientation, the secondary supports provide a counter force, which greatly reduces the moment that is applied to the primary supports. The result is that the support system can withstand an acceleration of 9.5G's before failure.

In the vertical orientation, the secondary supports provide no counter force. The results show that this is the weakest orientation because the primary supports have to hold all forces due to acceleration: nevertheless, the system can withstand 2.8G's in this orientation.

One area of concern was the strength of the stainless steel screws that secure the ends of the supports. The calculations show that the screws are 2.81 times stronger than the supports. The result is that the G10 support will be the first point of failure.

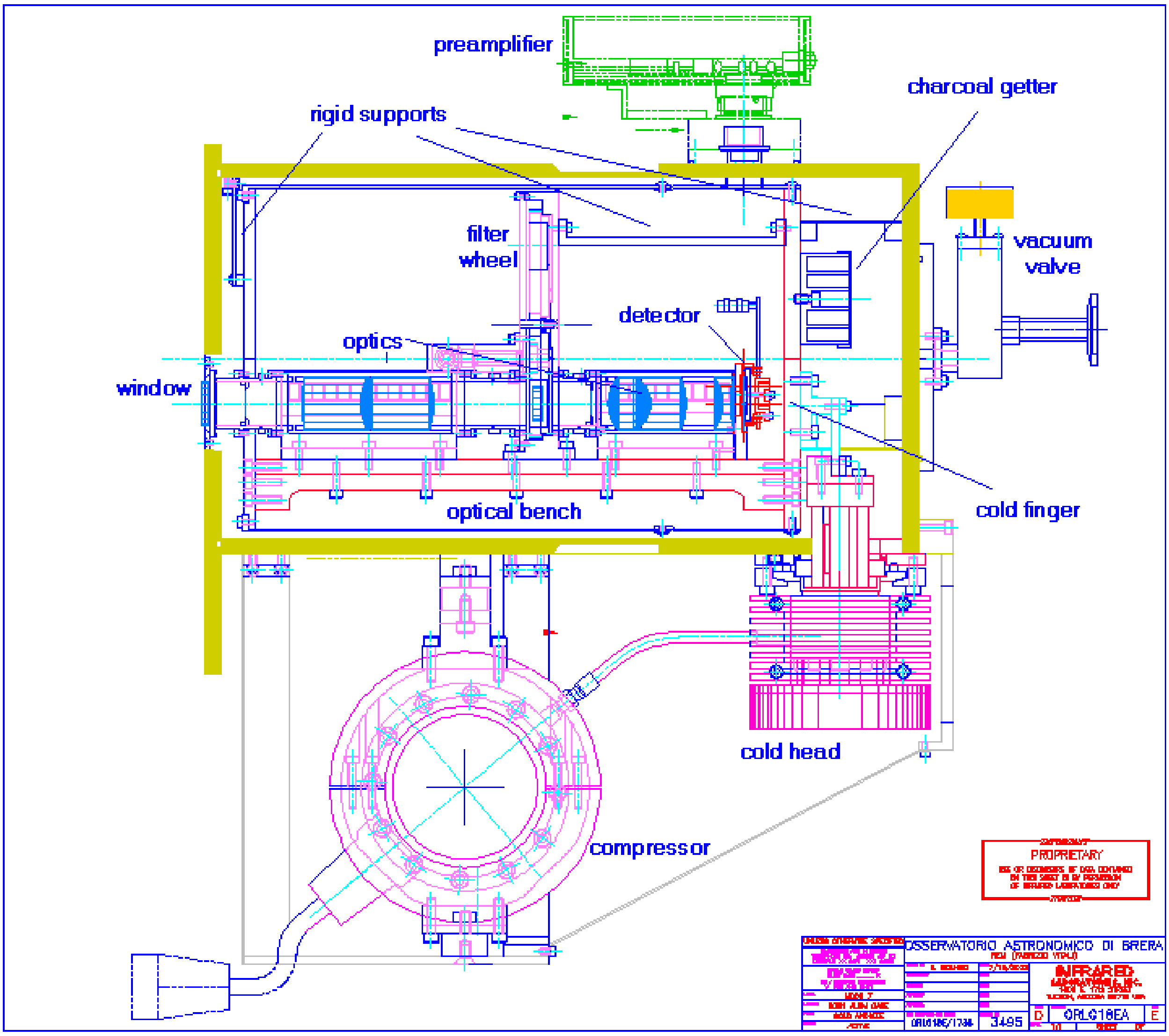


Figure 1. Schematics of the REM-IR cryo-mechanical system (courtesy of IRLabs).

The limited cooling power provided by the Leybold cryocooler suggested to differentiate the working temperature for the array and Lyot stop with respect to the optics and filters: in fact, these latter will work at a slightly higher temperature with respect to the 77 K of the array, probably around 100 K. Moreover, to reduce the amount of matter to cool, we have adopted a particular lens tube holding system: in Figures 2 and 3a,b 3D details of the optical bench are shown, where the particular solution for the lens tubes is illustrated: it is placed in a V-shaped groove and some *finger* strips hold on the tube.

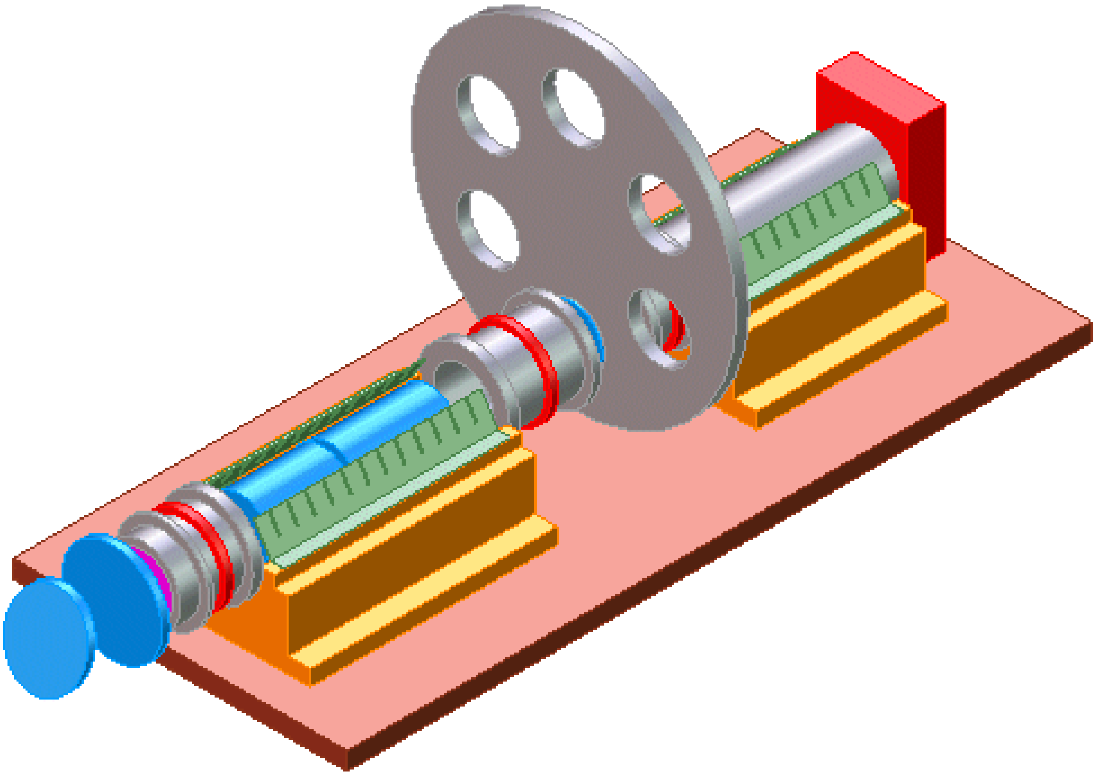


Figure2. The optical bench inside the dewar.

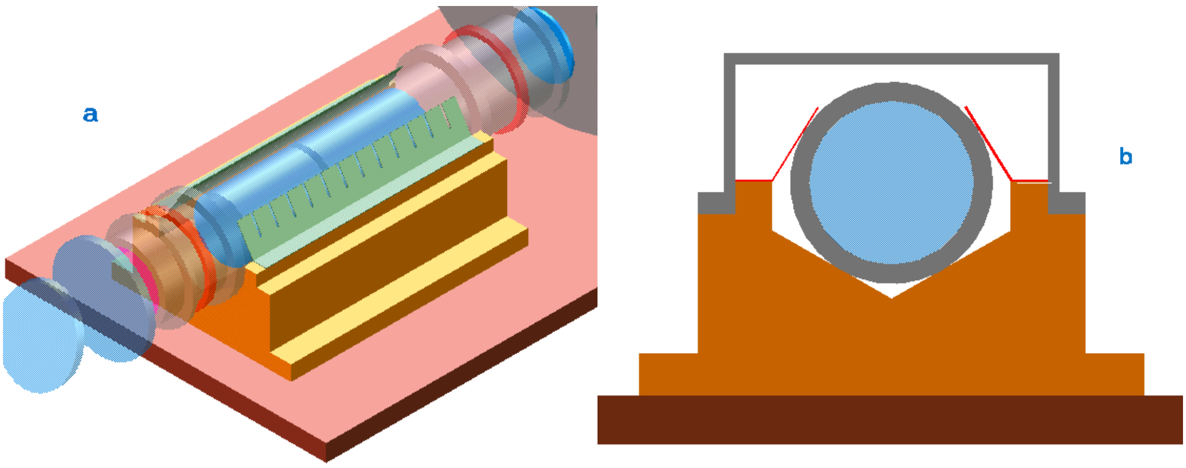


Figure3. Details of the lens mounting on the internal optical bench.

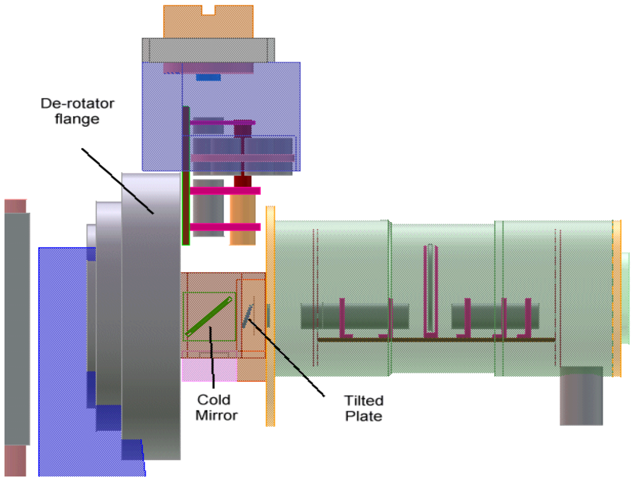


Figure 4. The derotator flange of the REM telescope with the ROSS spectrograph (up) and the REM-IR camera (right).

The REM-IR camera is interfaced with the REM telescope through a derotated hexagonal instrument flange, as shown in Figure 4 (see Zerbi et al. 2002[1] for more details). The NIR camera is mounted along the optical path and shares the telescope beam with the ROSS spectrograph through a high efficiency dichroic.

Between the dichroic and the dewar window, a dithering wedge is mounted to provide the dithering during the infrared observations: it consists simply in a tilted parallel slab that can rotate between each observation: this new solution for the dithering guarantees an easy, fast and precise dithering of the image on the detector focal plane.

4. THE OPTICS

The REM-IR camera follows a focal reducer design in order to reform a white pupil in a cold environment for Lyot stop positioning (see Figure 5). A filter wheel with 8 positions is located at the reformed pupil allowing one to insert filters and grisms for slit-less spectroscopy or polarimeters in a parallel beam. The camera changes the focal ratio from f/8 to f/5.3 providing a plate-scale of 64.4 arcsec/mm that allows one to position a 9.9 x 9.9 arcmin FOV on a 512x512 (18.5 µm pitch) HgCdTe chip produced by Rockwell.

The REM-IR lenses have been designed in house (gOlem laboratories, Merate Italy) and manufactured by Gestione SILO (Florence, Italy). Both collimator and camera are made of a Silica-CaF2 doublet (the latter reverse-mounted) with the peculiarity of being more thick than large. Other optical elements are the Cryostat window lens and a field corrector lens near the FPA, that ensures a very low field distortion, less than 0.3 %. The total thickness of the optical design is 345 mm.

Given the size of the Airy disk, the quality of the image has been designed to fit onto a square of 2 x 2 pixels, as can be seen on the spot diagram (Figure 6) derived for the worst case in which the dithering wedge is parallel to the dichroic, situation in which the astigmatisms add . Nevertheless, in a radius of 18.5 µm we have an encircled energy from 96 to 82 % with respect to the diffraction limit (see Figure 6).

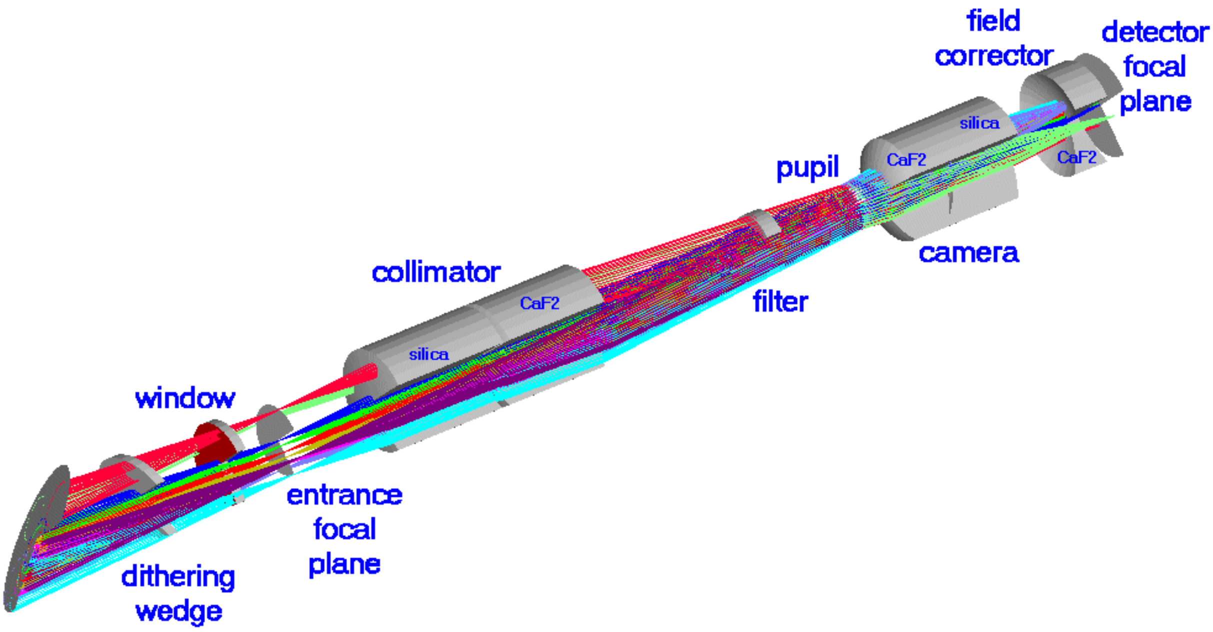


Figure 5: REM-IR Optical train

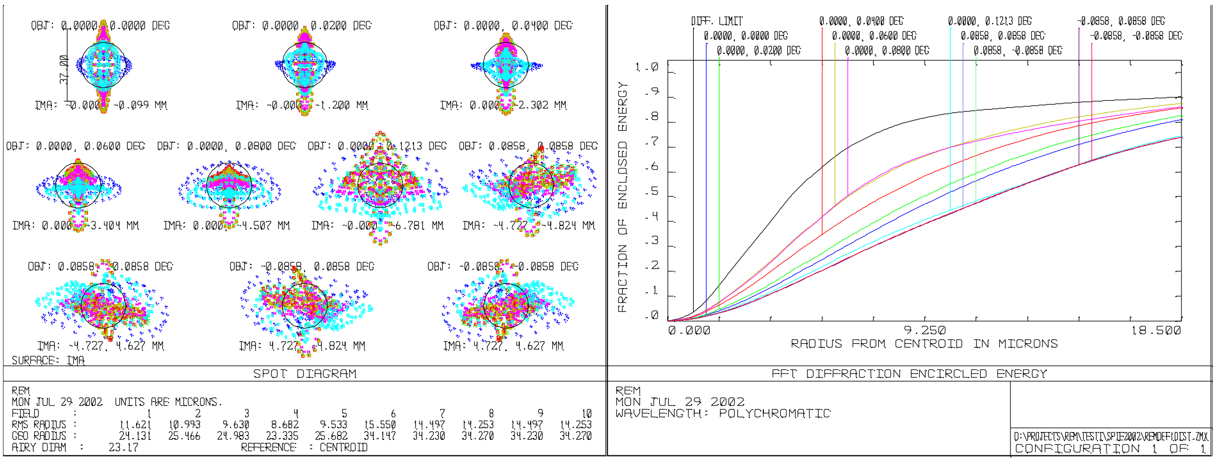


Figure 6: REM-IR spot diagram and encircled energy.

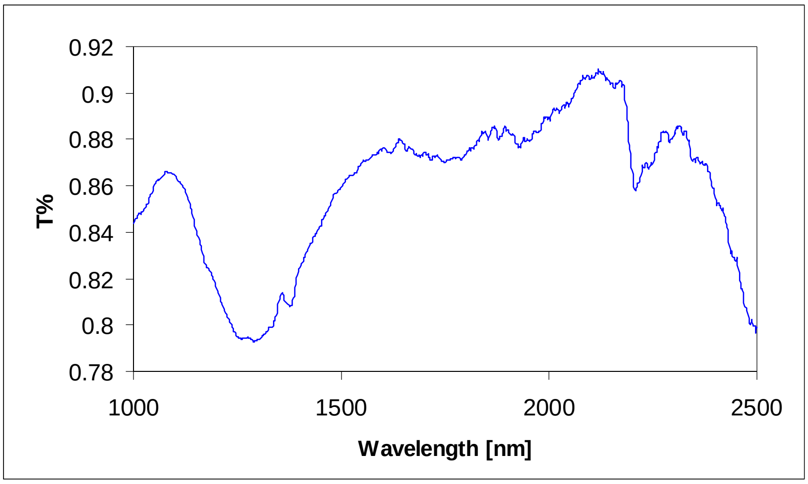


Figure 7. Measured efficiency of the REM optical train (10 surfaces)

Particular attention has been put to the efficiency of the optics, through custom AR coatings made by Gestione SILO (Fi) and the measured total efficiency of the optical train is shown in Figure 7: as can be seen, with ten surfaces, we obtained an average efficiency of about 84 %, with a minimum at 1.3 µm of about 79 % and a maximum of about 91 % at 2.1 µm.

5. THE FILTERS

The filters for the REM-IR camera are standard high performance IR filters. The J, H and Ks units have been ordered to Barr Associates Inc. in the framework of the International Consortium led by University of Hawaii (PI A. Tokunaga). These filters are high performance filters for astronomy manufactured with a special set-up. In Table 1 a list of the requirements for these filters is shown.

Table 1. The main characteristics of the REM-IR filters.

Item	**J**	**H**	**Ks**
CWL [µm]	1.250	1.635	2.150
Cut-on 50%T(HP) [µm]	1.170	1.490	1.990
Cut-off 50%T(HP) [µm]	1.330	1.780	2.310
Substrate Material	Quartz *	Quartz *	GE124*

Common Specifications	
Diameter [mm]	25.4± 0.1
Thickness	3.0mm +/- 0.2mm
TWF	λ/4 at 633nm, P-V
Clear Aperture	1.5 mm uncoated edge, maximum
Parallelism	≤ 10 arcseconds ***(before coating)***
S/D	60/40
Operating Temperature	From 77K to 100 K
AOI [degrees]	5
Ripple	less than ± 5% of average transmission
Out of Band Transmission	e-4 from 0.2 – 3.0 µm
Slope **:	≤ 2.5%

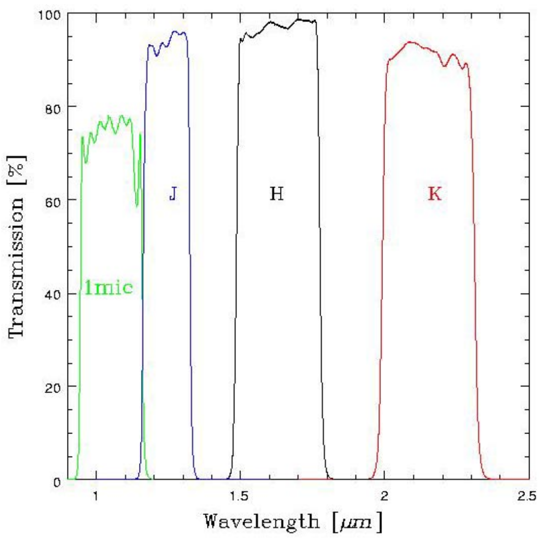
Note: * Substrate of the test sample. In alternative the filters could be B-270 (J and H) and B-270 or Infrasil (K);
** %slope = $\{abs[(\lambda_{90}-\lambda_{10})/\lambda_{10}]\}*100$ where $\lambda_{90} = 0.9*T_{peak}$ and $\lambda_{10} = 0.1*T_{peak}$

All these filters will be made on a single substrate with no radioactive coatings materials. At the date of the present proceedings the filters have not yet been all delivered but BARR has very recently provided the transmission curves of some sample derived from the filter batches (see Figure 8, courtesy of Dale L'Hussier).

Besides these standards NIR band we envisaged in REM-IR a *1micron* filter already used in instruments such as NICS at the Galileo National Telescope, manufactured by Omega. In Table 2 the main characteristics of this filter are shown, whereas in Figure 8 the transmission curve is depicted.

Table 2. The main characteristics of the *1 micron* filter.

Item	**1 micron**
CWL [µm]	1.050
Cut-on 50%T(HP) [µm]	0.950
Cut-off 50%T(HP) [µm]	1.150
Diameter [mm]	25.4
Thickness	5.0mm
Clear Aperture	22 mm
Surface quality	E/F scratch/dig per mil-C-48497
Out of Band Transmission	e-4 from 0.8 – 2.6 µm
Operating Temperature	From 77K to 100 K



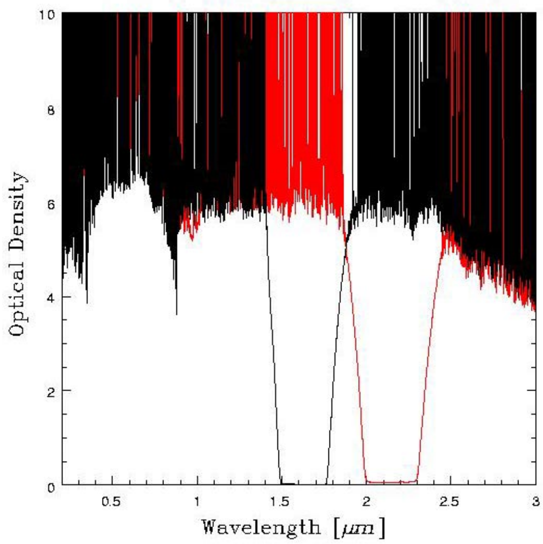


Figure 8. left) The transmission curves of the REM-IR filters (courtesy of Omega and BARR), and right) the optical density for the H and K filters.

As can be seen in Figure 8, the transmission of the filters are all in specifications: it is worth to note the high efficiency of the J, H and Ks filters, all above 90 % of average transmission and the high optical density, almost always above 5 (available only for the H and K filters).

6. THE DETECTOR

The optics of REM-IR have been designed to feed a 512 x 512 pixel IR array, with pixel pitch of 18.5 µm, that is a Rockwell HAWAII 1024 x 1024 with 1 working quadrant. Following our order, Rockwell delivered an HAWAII array with 3 out of four quadrant working. Therefore, we changed the holder of the array to preserve the possibility to change the working quadrant once the performances degradation of the one in use will no longer be acceptable. The main characteristic of the array are depicted in Figure 9 where the quantum efficiency histogram and a map of the array are shown: as can be seen, each quadrant has one or two major defects (bad pixels bunches or bad columns) but the overall cosmetic quality is enough to work with. Only the quadrant with the two bad columns does not meet Science Grade specifications. As can be seen in Figure 9, this array seems to be very good in term of QE, with a surprising median value of about 85 % and with a very flat QE map.

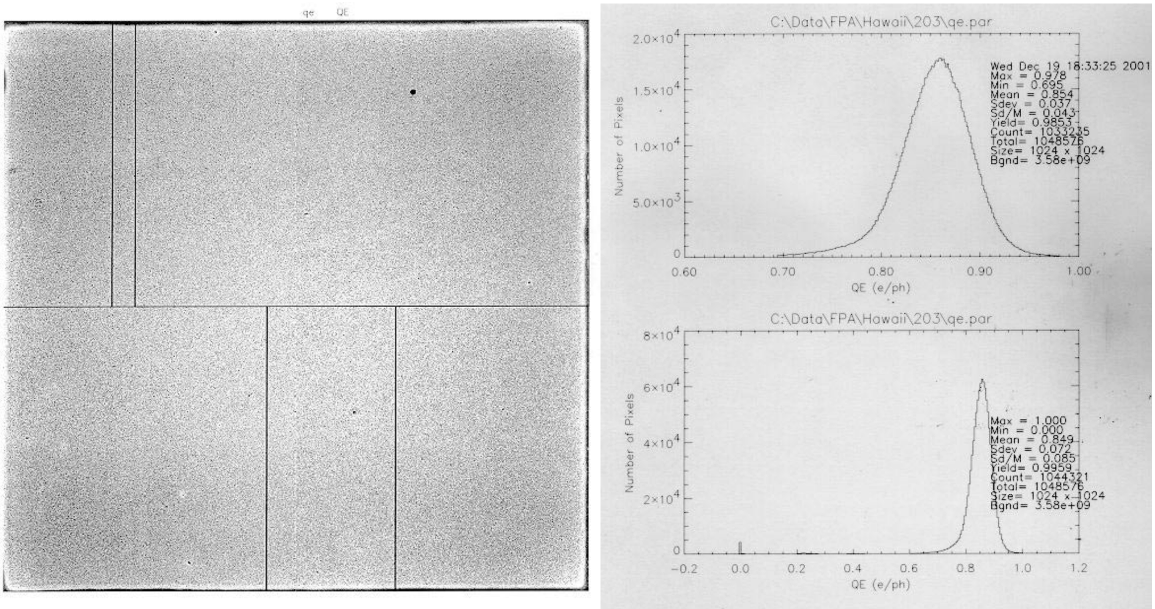


Figure 9. The QE map and histogram of the REM-IR NIR detector.

6.1. The electronics

The chip is controlled by a Leach Controller and read-out at 1.5 microsecond per pixel, this in order to achieve the speed needed for the primary science case (see Zerbi et al. 2002[1])

The block diagram in Figure 10 illustrates the major components of the camera control electronics and its associated control computer. The detector is mounted on a Printed Circuit Board inside a cryogenic dewar. The Focal Plane Array printed circuit board incorporates electrical filtering and decoupling elements to ensure low noise performance. A JFET transistor for the video signal is also included. This transistor is used as an alternative buffer to the on-chip buffer transistor located on the detector, which can be a source of electro-luminescence and local heating inside the detector itself. The video signal is fed to an external Pre Amplifier located in an enclosure outside of the dewar, which further buffers the video signal and provides a low impedance drive to the Readout Electronics. This arrangement further enhances the low noise characteristic of the Video signal.

The Readout and Control Electronics consists of four printed circuit boards. A Video Processor Board, a Timing Board, a Clock Driver Board and a Power Control Board. All four boards are mounted on a VME bus type back plane motherboard which routes the signal, ground and power lines through DIN96 pin printed circuit board connectors. The whole assembly is mounted inside a heavy aluminum enclosure mounted in close proximity to the dewar.

The buffered video signal is fed to the Video Processor Board, which consists of a pre amplifier with input offset to remove the bias on the incoming array signal. This is followed by an inverter and integrating amplifier. The gain of this processing chain provides a 0 V dark to + 10V full well capacity video signal to a sample and hold switch and 16 bit analog to digital converter operating at 300 Khz. The resultant 16 bit image data is routed across the VME bus backplane to the timing board that incorporates a parallel to serial converter, which transmits the image data and synchronizing clock signals through a 30-meter long fibre optic link to a DSP interface on a PC board located in the host computer.

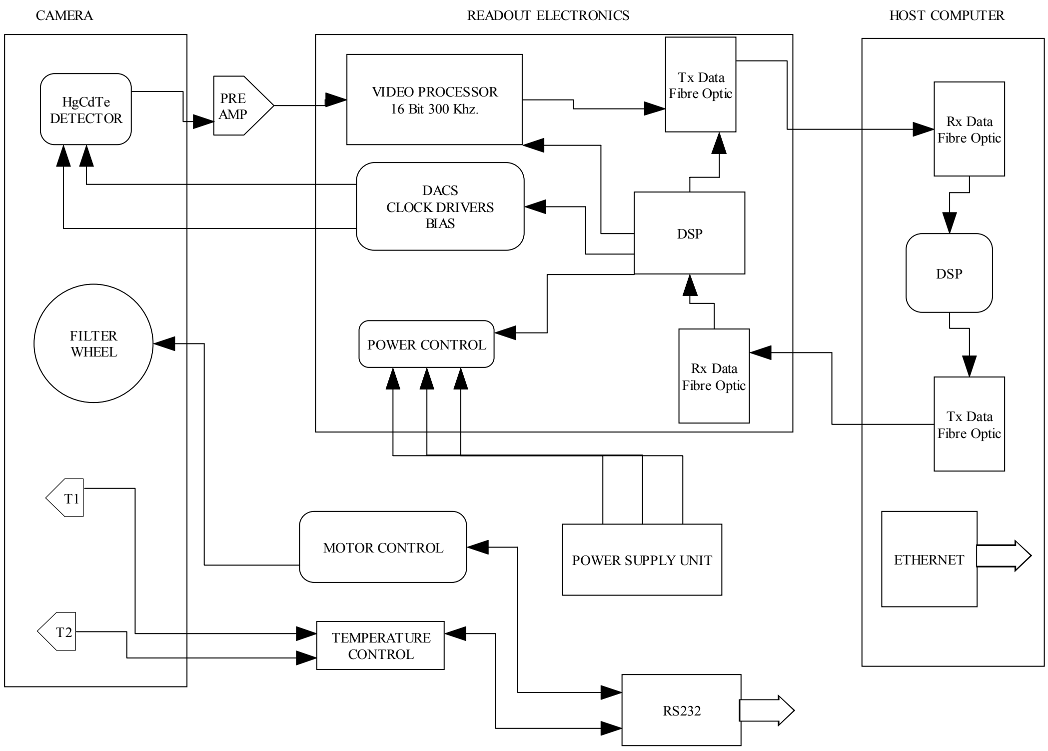


Figure 10. The block diagram for the REM-IR readout electronics.

The Digital Timing Board controls all of the functions of the Readout Electronics. A Motorola DSP56002 processor controls the system. This is a 24bit data word, 16 bit address space 40 nanosecond ALU with RISC architecture digital signal processor. Basically the system functions as a timing generator by writing 24 bit data words from memory to its external bus. These data words are written to the back plane for decoding on the Clock Driver Board for generating the appropriate waveforms for controlling and driving the detector array and the Video Processing Board for controlling the ADC and synchronizing the serial data interface to the host computer. The array clocking and readout are under DSP control, which offers different readout schemes depending upon the selected sampling method. Available sampling methods are straight single readout, correlated double sampling or multi sampling, i.e. co-add/co-subtract multiple frames. On Power Up or Reset the DSP embedded programme writes the data containing the readout parameters, the array timing waveforms and the voltage data for all of the Digital to Analog Converters in the system. Communication with the host computer is by fast fibre optic link.

The Clock Driver Board electronics translates the data from the Digital Timing Board to drive the 12 bit DACS, which generate the bias potentials and waveforms to control and clock the detector. The output of each DAC is monitored by the power control board, which will detect any out of range voltage swing and activate an analog switch placed at the output of each clock driver to protect the array against damage due to over voltages.

The Power Control Board conditions the +/- 15V and +5V from an external Power Supply Unit and applies the supply voltages in a controlled manner to protect the electronics and particularly the detector array from high voltage transients on Power On/Off. Power to the DACs, Video Processor Board and the detector is only applied after digital supply has stabilized and the DSP software has been loaded from the EPROM. A bank of comparators continuously monitors the analog and digital supply voltages. In the event of an out of range voltage condition or power supply failure the analog voltages will be switched off.

After an exposure period the image readout sequence is initiated and 16 bit image data is passed from the timing board through the serial interface to the host computer via the fibre optic link. A whole frame is read out in 0.865 Seconds. During the readout sequence, the host computer PCI board interprets data from the timing board as image data. On board software writes the images to disk in FITS format. Once the raw images are hosted in the computer, a dedicated software AQUA (see Di Paola et al. 2002[2], this conference) will preprocess the raw images to get science images, on which automatic routines will run to detect the triggered GRB and to set the subsequent observations.

7. THE CRYOGENICS

The requirements of a fast and precise slewing telescope led to the choice of an alt-azimuth mount for the telescope and consequently the derotation of the focal plane instruments was a primary issue. Moreover, economic and logistic conditions led to a lack of daily human assistance at the telescope. All the above forced us to avoid a liquid nitrogen cooling system for the dewar and to adopt cryocoolers. Among others, we found a very small, light and compact cooling unit made by Leybold, the linear Stirling cryocooler POLAR SC-7 COM: in Figure 11 the system is shown during the recent integration phase at the Infrared Laboratories.

Figure 11. The POLAR SC-7 COM cryocooler on the Infrared Labs bench during the recent integration phase: the cold head (left) with the cold finger on the upper part is linked through the helium line to the compressor (right). On both the cold head and compressor some cooling fins will be added to avoid overheating (Courtesy of Infrared Labs.).

All the system (cold head, compressor and electronics) will be mounted at the derotator flange of the telescope, with the only derotated cable being the power supply. With a cooling capacity of 6 W @ 77 K we will be able to cool down the array and the Lyot stop, with the remaining optics and filters at a slightly higher temperature, around 100 K.

An electronic control unit is needed to operate the linear cooler: the POLAR DRIVE D provides to the Stirling cooler the necessary AC supply voltage of about 40 V and control the temperature at the cold finger within the range of 35 to 300 K. The electronics of both units are preset to 77 K control temperature and may be easily driven via the RS 232 C interface.

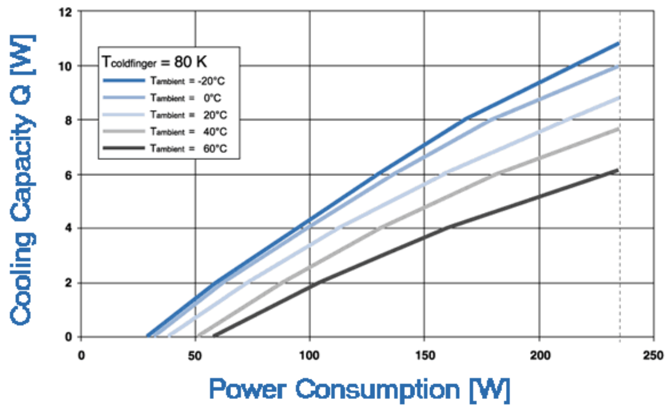


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Figure 12. The Cooling capacity as a function of the Power consumption.

Operation of this new and more efficient cryocooler is based on the thermodynamic Stirling cycle in which helium is used as the working gas. Here the copper end piece of the cold finger is cooled down to cryogenic temperatures down to 35 K. At a cooling capacity of 6 W at 77 K, power consumption of the cryocooler is only 180 W. In Figure12 the cooling capacity of the POLAR SC-7 COM as a function of the power consumption is shown, for a cold finger temperature of 80 K. In Table 3 the main characteristics of the Leybold cryocooler are shown.

Table 3. The main characteristics of the Leybold POLAR SC-7 COM cryocooler (adopted from Leybold WEB site).

Helium filling at room temperature at 50/60 Hz	Bar Mpa	< 30 < 3.0
Cooling capacity (nominal) at an ambient temperature of 23 ºC		6 W @ 77 K
Cool down time, from T=23 ºC to 70 K (30 g Cu mass)	min	< 10
Temperature stability (regulated),approx.	K	+/- 0.1 K
Power consumption	W	250 max. / 180 nominal
Admissible ambient temperature	ºC	-40 to +65
Weight	Kg	8.0
Vacuum requirements (cold finger)	mbar	< 1 x 10-4
LN2 - condensation rate, theoretical, approx.	ml/h	40
Noise (according to DIN 45635)	dB(a)	48

REFERENCES

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2. Di Paola A. et al., 2002, SPIE 4847-55 (this conference)