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Research Article

REM: Automatic for the People

Emilio Molinari,[1,2] Stefano Covino,[1] Francesco D'Alessio,[3] Dino Fugazza,[1] Giuseppe Malaspina,[1] Luciano Nicastro,[4] Mauro Stefanon,[5] Vincenzo Testa,[3] Gino Tosti,[6] and Fabrizio Vitali[3]

[1] *INAF-Osservatorio Astronomico di Brera, Via Bianchi 46, 23807 Merate, Italy*
[2] *INAF-Telescopio Nazionale Galileo, Rambla José Ana Fernández Pérez, 7 38712 Breña Baja, Spain*
[3] *INAF-Osservatorio Astronomico di Roma, Via di Frascati, 33 00040 Monte Porzio Catone, Italy*
[4] *INAF-IASF Bologna, Via Gobetti 101, 40129 Bologna, Italy*
[5] *Observatori Astronòmic de la Universitat de València, Edifici Instituts d'Investigació, Polígon La Coma, 46980 Paterna, València, Spain*
[6] *Dipartimento di Fisica, Facoltà di Scienze MM. FF. NN., Università degli Studi di Perugia, Via A. Pascoli, 06123 Perugia, Italy*

Correspondence should be addressed to Emilio Molinari, molinari@tng.iac.es

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We present the result of a year-long effort to think, design, build, realize, and manage the robotic, autonomous REM observatory, placed since June 2003 on the cerro La Silla, ESO Chile. The various aspects of the management and control are here surveyed, with the nice ideas and the wrong dead ends we encountered under way. Now REM is offered to the international astronomical community, a real, schedulable telescope, automatic for the People.

1. Half a World Away

REM (Rapid Eye Mount) was thought and realized in order to catch fast optical and infrared transient phenomena, correlated with high-energy events signaled by orbiting observatories, mainly GRB discovered by then recently launched Swift satellite. Its realization resulted in a workbench for various other existing and wish-list telescopes [1–3] (see also http://www.rem.inaf.it/).

The statistics of pre-Swift bright GRB optical transient led to a 60 cm diameter telescope, equipped with VIS/IR cameras, fast enough to follow Swift acrobatics and to acquire images, process them fast, and detect the transient with good accuracy to alert larger telescopes' spectrographs. We decided, in order to put it far from existing or proposed robotic telescopes, half a world apart in the southern hemisphere, on the Chilean Andes in the ESO site of La Silla.

2. Losing My Religion

In order to fulfill the requirements the telescope should have had the capabilities to react immediately to alerts, see the afterglow of the GRBs, and classify it to estimate the redshift by photometry. To this extent the mechanics of the telescope should have been robust and fast enough, the size of the mirror should have been large enough, and the photometry was needed in both visible and infrared. On the software side we should be able to control the telescope, command both cameras and analyze the images, and at the end also alert the rest of the world. Were we good at this? Unfortunately the belief that GRB afterglows were bright enough for our chosen size of 60 cm as primary mirror revealed false, and the mean, dim luminosity of the transients de facto prevented REM, as most of the other robotic telescopes of the same class, to observe a large fraction of the afterglows following Swift satellite alerts. In those early times, before we could enhance the REM pointing capabilities to observe down to 5 degrees above horizon, only 5% of the GRB alerts could be reached by REM pointing. Our lack of ability to detect precise coordinates in due time also led to abandon the finalization of the transient detection and alert software, which remained at the still remarkable level of producing automatic astrophotometry for good quality images.

Figure 1: The REM Observatory: *one dome, two telescopes, three instruments*. Under the main telescope body is the Tortora telescope with its wide field, fast photometer. On the left Nasmyth focus the are the visible (ROSS) and infrared (REMIR) cameras, partially hidden in the photo.

The robotic nature also revealed to be somewhat tricky and we had to add to our system a full self-telemetry of vital signal of the various subsystems which was also able to send SMS and e-mail to real people. A team of trained real people on-site was also required and we received the help and collaboration from ESO-La Silla technical staff, which is now able to intervene in case of need or emergency.

After we added the funded possibility to use REM as a laboratory for new technologies and finally offered the nonalert time to the astronomical community via the classical systems of call for proposals, we finally completed the REM Observatory, working regularly and autonomously every night since 4 semesters (a full photo in Figure 1).

3. All the Right Friends

The companies and developers involved in the REM realization were both from the private industry and from public research institutions. Halfmann Teleskoptechnik designed together with our group the telescope body and main reflecting Zeiss optics, coated by Sagem with protected silver to enhance the performances in the infrared. The main near infrared REMIR camera [4, 5] was designed by the gOlem group of the Brera Astronomical Observatory and assembled in the US-based Infrared Lab. An engineering Hawaii I chip from Rockwell was used in its best quadrant, with 512×512 pixels on a 10×10 arcmin field of view. The visible camera and spectrograph ROSS [6], also designed by gOlem, hosts SILO optics in a mechanical assembly manufactured by Perugia University and Brera Observatory workshops. The same field of view of REMIR is imaged by means of Zaot coated dichroic with a 1 m cut on a 1 K × 1 K ALTA camera by Apogee. In Figure 2 the same field of view is observed with both cameras.

4. Daysleeper

The REM dome is positioned in the ESO La Silla premises and can profit of all the (still, at date of writing) existing infrastructures and facilities. ESO provides power, UPS, and network connections, as well as liquid nitrogen refilling every 4 days. In every assembling phase the availability of a mechanical workshop and a clean room for the infrared detector assistance proved to be essential and both time sparing and mission proved to be critical.

The dome realization was performed by ESO general services and has two sliding roof which leave completely clear the sky without the need to have any movement during the observations (see a CAD rendering in Figure 3). Notre Dome opens when the Sun is below the horizon and all the safety parameters are within the limits; otherwise the telescope room is air conditioned and telescope parked in home position. The temperature inside the dome follows nervertheless the day/night cycle and a better thermal insulation would be required. The inner relative humidity never hits the excess of outer values and no dew point conditions were so far recorded. We finally rely on ESO and local meteo measurements to define safety conditions. Humidity below 90%, wind speed lower than 17 m/s, external temperature above 0°C, and Sun below horizon are the main safety parameters, although a check on the open status of other domes in the La Silla site revealed to be a good choice, so that we will perform normal operations only when two other telescopes are observing.

5. Imitation of Life

The way REM acts is badly an imitation of autonomous machine. It needs a daily check from Italy in order to catch in with its many unforeseen situations and also, although now rare, unrecoverable stops in its sequences of jobs. In fact, we experienced some dome blockings, few main computer crashes and network halts, as well as some CCD driver timeouts. Many of these we recovered by remote commands but in some cases we had to wait for human help in La Silla.

Nevertheless its main sign of activity is the reaction to inputs. The main information flux starts from the Observing Block Scheduler which enters in the REM Observing Software (REM-OS, cfr. Stefanon et al. in this volume [7]) the sequence of targets, which is reorganized should a GRB alert or other boundary conditions occur (e.g., high airmass due to delayed observations). The flux eventually ends delivering a series of outputs: the raw data and processed photometric catalogues are immediately sent to the Bologna REM database, where PIs can retrieve their data and the general public can browse the complete observing log and retrieve all calibrations and standard stars. In the meantime a continuous cross-talk between REM-OS and the in situ internal telemetry database as well as the controls of telescope and cameras allow the images to be acquired safely.

A series of (mainly) python programs run autonomously in the various machines in the dome to get the status of the sensors, encoders, and so forth, and fill the proper SQL tables in the REM-OS machine.

(a) (b)

Figure 2: NGC3606 imaged by the REM cameras. (a) The color composite of the REMIR J, H, and K filters. (b) Photo the composition of the ROSS V, R, and I images.

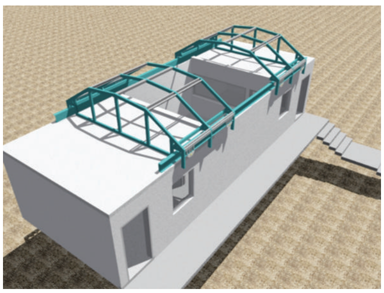


Figure 3: *Notre Dome de La Silla* as designed by ESO. A control room and a warehouse complete the REM building. An IP subnet is reserved for the REM operations and internet access is controlled by ESO internal firewalls. Its sliding roof is also used as a crane to mount and dismount instrumentation.

The control python program is the tREM-o-meter which runs every 2 minutes. The tREMometer collects the relevant data from archive, fills in the missing values, produces a public web page with the status of the telescope and all subsystems and performed observations, and, finally, checks for malfunctions and sends e-mail and SMS alerts. In case the conditions become dangerous in the infrared Dewar (the most delicate area), it is able to autonomously interrupt all IR data acquisitions. We in fact allow a small range in IR chip temperature as safe operational range: should the sensor get heated more than 105 K, the IR camera is turned off, returning to normal operations only after its temperature is lower than 100 K.

6. Until the Day Is Done

The information you can see in the tREMometer well summarizes the observatory life cycle. In Figures 4 and 5 we show the tREMometer content and the capability of the REM observatory in operation.

Figure 4 at a glance gives to the human control people the instant situation of the alarm status (checking temperature and pressure in the infrared Dewar and also the telescope control hardware for failure to respond to Remos command) and the job REM is actually performing in the night. The scheduled targets are listed in the sequence they will be observed. Such schedule is continuously recomputed after every observation because the optimal conditions for the next target may be affected by some misbehavior during the last acquisition (delays, repeated frames, etc.). When the night is done, all blue dots will disappear and soon a new schedule for the next day is arranged. After every observing night every PI involved in recent observations is noticed by an automatic e-mail from the REM archive.

The monitoring of the dome opening together with shutter-open time of every acquired image is the content of Figure 5. The La Silla domes monitoring proved essential to the security of the REM operations, as we ended opening the dome only when our meteo station gives good measures, as well as the ESO one, and two other domes are open in the site. We are thus able to produce independent meteo statistics for the ESO La Silla site as well as our own efficiency rate (Figure 6).

Other plots in the tREMometer include the status of the cryostat, temperatures, and meteo data from REM meteo station. Also, the program offers a Gannt graph of the past night, allowing the REM team to check for inconsistencies in the programmed observations. The degraded, small image previews are then posted on the web site for PI and public access.

During the following morning, every PI whose observations were continued in the previous night receives a detailed e-mail directly from the database in Bologna.

Furthermore, the Remos machine produces weekly reports which are sent to a restricted set of people: first, a report on a 4-month timeline of the pressure in the REMIR Dewar and the daily consumption of the liquid nitrogen supply. These are very useful to program mid term maintenance, such as repumping the vacuum in the cryostat and in the nitrogen lines.

The last information sent by the Remos system is the status of the observing programs accepted by the Italian Time

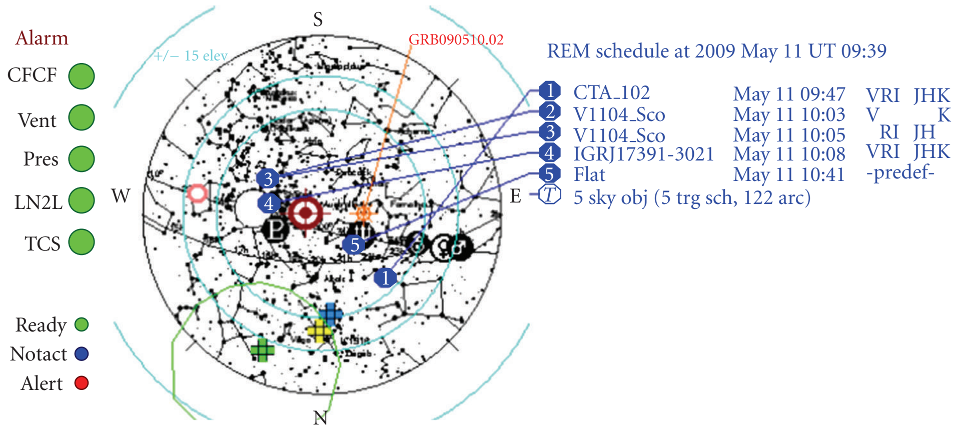


Figure 4: *tREMometer* first glance at http://www.ls.eso.org/lasilla/rem/ offers the alarm status (on the left, here all is green and working) and the working night sky over La Silla. All remaining targets for the night, listed on the right, are positioned in the sky hemisphere as blue, numbered dots. Other important information includes the actual telescope pointing, the Swift (green), INTEGRAL (yellow), and AGILE (cyan) current pointing. Also the position of the last alerted GRB (orange) is shown.

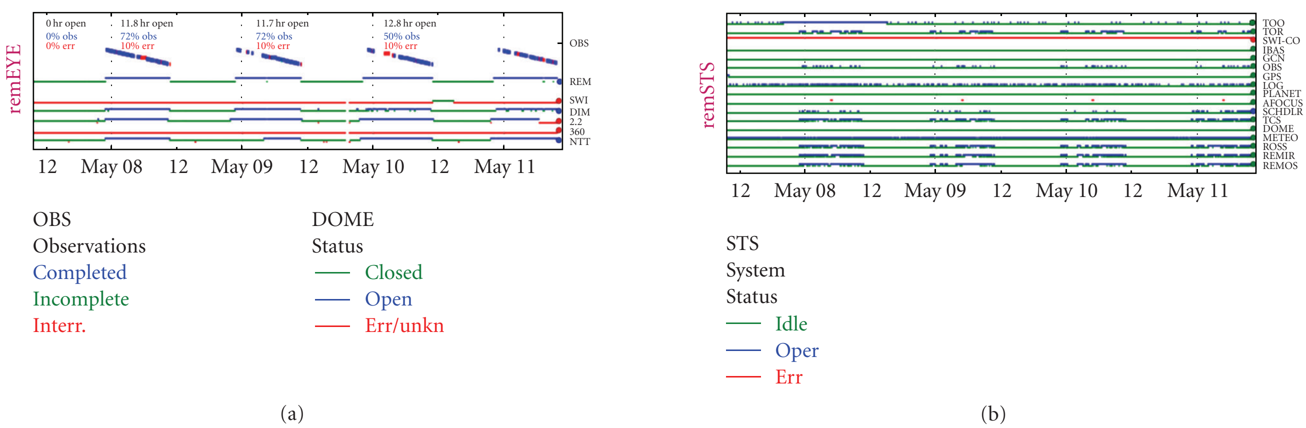


Figure 5: (a) The status of every dome in La Silla is monitored and is used as one of the safety parameters we include in our opening decision algorithm. Also an automatic statistics is computed after each night in order to keep track of real night length (useful for meteo + technical downtime statistics) as well as the effective use of the open time. Percentages report shutter-open time in the night. Errors (in red) are noncompleted observing blocks that need to be repeated. (b) The log of every subsystem status.

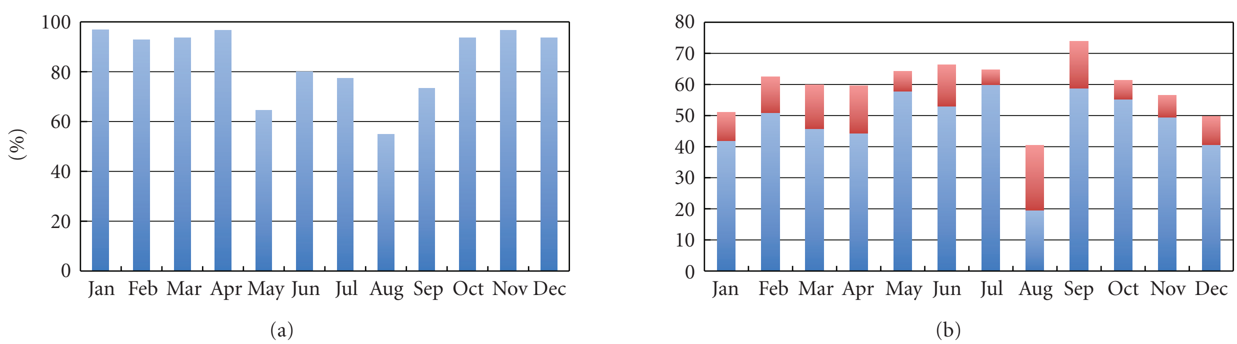
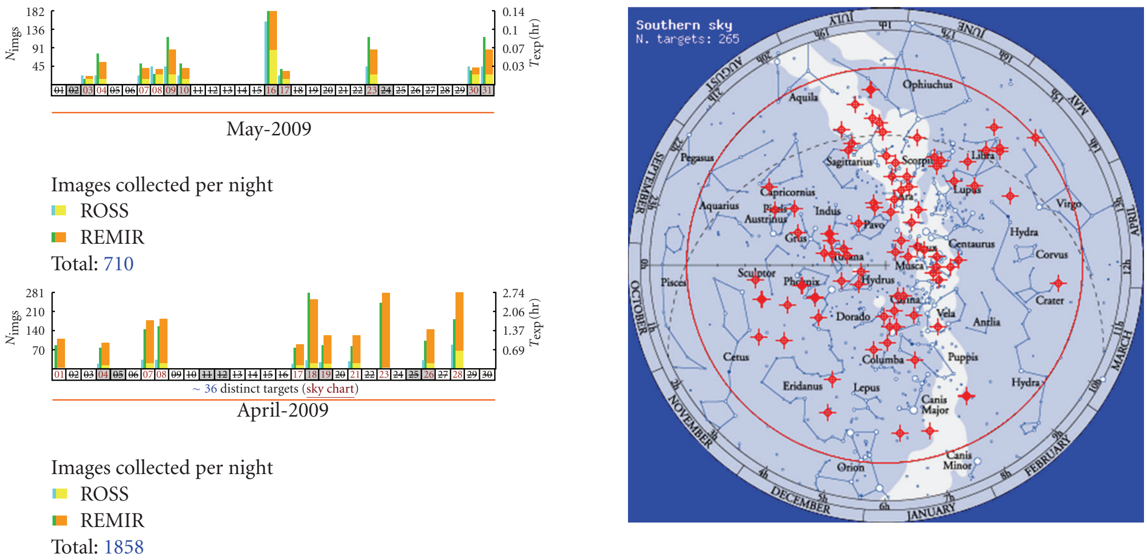


Figure 6: La Silla good nights of year 2008. (a) The percentage of nights with more than 6 hours of opening for REM dome: it may be considered very close to good weather nights in La Silla. (b) The shutter-open time percentage for REM cameras: red portions are the Observing Blocks ending with some error status which are to be repeated. No overheads have been included in this plot. The month of August included a two-week maintenance mission which makes those data inconsistent.



(a) (b)

Figure 7: The REM archive browser allows PI and general public to select and retrieve observed targets. A limited statistical analysis can be performed on the fly: on the upper part of (a) all the flat field frames in the month of May 09, in the lower part of (a) the GRB observations during April 09. The sky chart on (b) the position in the southern hemisphere of all GRBs in the year 2008.

Allocation Committee, allowing to follow the completion of the requested observations. In the last completed call (AOT18) all programs were well above 80%, not counting the ToO which did not use all their time.

7. 1 000 000

The final repository for all the REM images is the REM Archive in Bologna. After an image is written on disk in Chile by the cameras, it is processed for quick astrophotometry and then sent to the database together with other data. In May 2009 the number of entries in the archive overcame 1 000 000. The archive web browser allows identified users to use a password layer to access their private data as well as all the public calibration frames.

Various preset types of query can be used to select and then retrieve the wanted images, and as well a custom SQL WHERE clause may be entered by the user.

It is also possible to perform basic on-line analysis on the observations, grouping by date or type, and showing the object position on the sky as shown in Figure 7.

Among the 1 million images many have found their place in high ranked scientific papers, both in GRB science [8] and in other topics such as blazars [9]. In fact, even if GRBs are fainter than thought, the fast reaction time of REM allowed us to observe the onset of the infrared afterglow, leading to the measure of the expansion velocity of the fireball. The mean elapsed time for REM observing after a satellite alert is 30 seconds as shown in [7] and the time resolution can be as fast as 1 second when the afterglow is bright enough.

8. Everybody Hurts

Even the most exciting project comes to a regime cycle that can hurt the creativity of a research group. REM Team to avoid becoming a managing and maintenance unit for yet another telescope turned the REM observatory into a working laboratory for experimenting new devices.

The first was the change in cooling system for the REMIR camera. The on-board Stirling cryocooler by Leibold Vacuum presented a series of problems ending in a serious instability of the system. The main problem was the underdimensioned power for our heat removal needs, but the Leibold company itself admitted that the maintenance of such cryocooler was so difficult that at the end they dismissed the production. Thus we adopted an ad hoc modified Continuous Flow Cryostat, a cryogenics system developed by ESO and extensively used in ESO instrumentation, whose main characteristic is that the LN2 vessel is separated from the cryostat, allowing a greater LN2 tank, then really improving the hold time [10]. We are now able to run continuously the telescope with one LN2 tank change every 4/5 days. In normal conditions this is the only human intervention REM needs to work.

A completely new experiment was also conceived in collaboration with IASF-Bologna, University of Bologna and SAO (Russia). TORTORA [11, 12] is a separated telescope hosted in parallel to REM, mechanically fixed in the same mount (see Figure 1). The aim was to study short stochastic optical flares of different objects (GRBs, SNs, etc.) of unknown localization. To this purpose it is necessary to monitor large regions of sky with high time resolution and we developed a wide-field camera (FOW is 400–600 sq.deg.) using TV-CCD with time resolution of 0.13 second to record and classify optical transients. The photometer can reach mag 10.5 in one single 0.13 second exposure. Together with REM cameras it forms the telescope complex TORTOREM, operated from May 2006 by the joint teams of REM and SAO. The main result was the serendipitous observation of

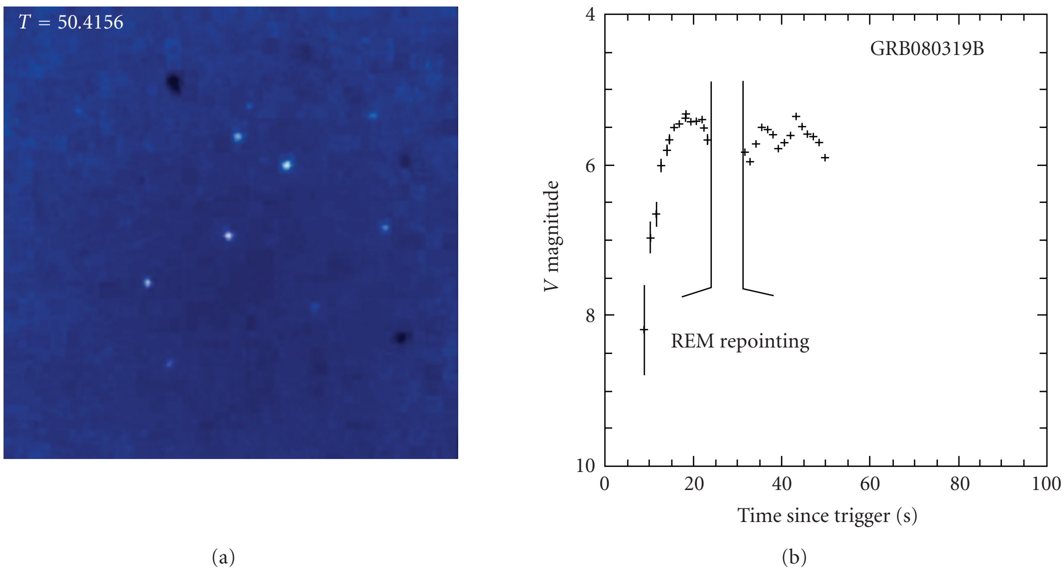


Figure 8: (a) A subframe of the wide field image centered on the optical transient 50 seconds after Swift trigger. The light curve (b) of GRB080319B measured by the TORTORA camera.

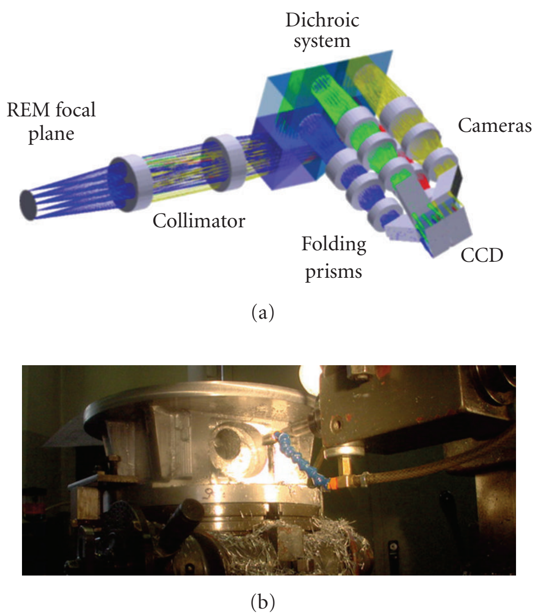


Figure 9: (a) ROSS2 visible camera optical layout: 4 separated images in four passbands will be recorded on a single 2 K × 2 K CCD. (b) The manufacturing of the mechanical interface for ROSS2 and REMIR.

GRB080319B, a naked-eye burst whose light curve could be monitored in high time frequencies [13] as reported in Figure 8.

The future step of the REM lab will be the complete replacement of the optical camera ROSS. ROSS2 will have better optical quality which revealed not being optimized in the present camera and will produce 4 simultaneous images in the Sloan passbands g′, r′, i′, and z′. Figure 9 sketches the optical design which makes heavy use of dichroics.

9. The Great Beyond

The experience of this project will not be lost. Our team is now deeply involved in the conceptual design of a 4-meter class telescope which will have a simultaneous camera like ROSS2 which extends into the infrared up to K′ band. Its response time after alerts will be comparable with REMs, aiming to the target within well under one minute [14]. Its capabilities will be coupled with a battery of wide field, fast photometer telescopes which in principle should cover the whole sky or a great portion of it and be able to generate alerts instead of reacting to satellites.

Acknowledgments

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