EMIR: the GTC NIR multi-object imager-spectrograph

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ABSTRACT

In this contribution we review the overall features of EMIR, the NIR multiobject spectrograph of the GTC. EMIR is at present in the middle of the PD phase and will be one of the first common user instruments for the GTC, the 10 meter telescope under construction by GRANTECAN at the Roque de los Muchachos Observatory (Canary Islands, Spain). EMIR is being built by a Consortium of Spanish, French and British institutes led by the IAC. EMIR is designed to realize one of the central goals of 10m class telescopes, allowing observers to obtain spectra for large numbers of faint sources in an time-efficient manner. EMIR is primarily designed to be operated as a MOS in the K band, but offers a wide range of observing modes, including imaging and spectroscopy, both long slit and multiobject, in the wavelength range 0.9 to 2.5 μm. The present status of development, expected performances and schedule are described and discussed. This project is funded by GRANTECAN and the Plan Nacional de Astronomía y Astrofísica (National Plan for Astronomy and Astrophysics, Spain).

Keywords: Ground base astronomical instruments**,** Infrared spectrograph, multiobject spectroscopy, GTC

1. INSTRUMENT DESCRIPTION

The new generation of 10 meter class optical and near-infrared telescopes currently under construction, or in the early phases of its lives, by European and American countries, by sounding ever deeper into the Universe, hold the promise of providing, for the first time, a direct view of the processes that shaped the formation stars, galaxies and the Universe itself. Also, they will provide, again for the first time, the capability of detecting and isolating extragalactic stars and star forming regions with unprecedented sensitivity and resolving power, both spatial and spectral. A collective instrumentation effort is underway to allow these new infrastructures to be used to their full potential. The scientific capabilities of the new telescopes are thought to be enormous, not only because of the larger photon-collecting area, but especially because of the new instruments, which, due to major technological advances, are expected to be orders of magnitude more efficient than their current-day counterparts.

The Observatorio Roque de los Muchachos, operated by the Instituto de Astrofísica de Canarias (IAC) on the island of La Palma, will be the site of the 10 meter Gran Telescopio Canarias (GTC) due for first light in 2003. GTC will be the largest aperture European telescope in the Northern Hemisphere. Since mid-1998, a partnership of Spanish, French and British research institutions is working on the design and construction of EMIR, an advanced NIR multiobject spectrograph for GTC, which will be visited in this contribution.

EMIR (*Espectrógrafo Multiobjeto Infrarrojo*) is a common-user, wide-field, near-infrared camera-spectrograph operating in the near-infrared (NIR) wavelengths 0.9-2.5 μm, using cryogenic multi-slit masks. Specifications are listed in Table 1. EMIR will provide GTC with imaging, long-slit and multi-object spectroscopic capabilities. The EMIR consortium is formed by the IAC and Universidad Complutense de Madrid (UCM, Spain), the Laboratoire d'Astrophysique des Midi Pyrénées (LAOMP, France) and the University of Durham (UD, UK). EMIR is now at the middle of its Preliminary Design (PD) phase, which is due for February, 2003. This phase is being funded by GRANTECAN and the Plan Nacional de Astronomía y Astrofísica.

EMIR will provide the GTC user community with key new observing capabilities. It is expected that it will be the first fully cryogenic multi-object spectrograph (MOS) on a 10m class telescope, hence it will be able to observe in the K band at 2.2 μm without the drawback of the high instrumental background common to other conceptually similar

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instruments. Similar NIR MOS existing or planned for other telescopes are not cooled and reach out to 1.8 µm only. Extending MOS capabilities to 2.2 µm is the natural next step in MOS design. EMIR will open, for the first time, the study of the nature of galaxies at redshifts beyond z=2 with unprecedented depth and field of view. At these redshifts, the well-studied visible rest-frame of galaxies, in particular the strong Hα line, is shifted to the K band (see Figure 1), allowing key diagnostics of the star formation history of the Universe. EMIR will allow to bridge between the extensive studies at lower redshifts carried out in the nineties on 4m class telescopes and those above z=6 planned for the near future using the far infrared and millimetre wavelengths. EMIR will also provide a link between current spectroscopic capabilities and those that will become available when the Next Generation Space Telescope (NGST) becomes operational late in this decade.

Wavelength range	0.9-2.5 µm
Optimization	1.0-2.5 µm
Observing modes	Multi-object spectroscopy Wide-field Imaging
Top priority mode	K band Multi-object spectroscopy
Spectral resolution	4000 for 0.6" (3-pixel) wide apertures 6000 for 0.4" (2-pixel) wide apertures
Spectral coverage	One observing window (Z, J, H or K) per single exposure
Array format	2048x2048 HgCdTe (Rockwell-Hawaii2)
Scale at detector	0.2 arcsec / pixel
OH suppression	In software
Image quality	θ_{80}< 0.6 arcsec
Multi-object mode	
Slit area	6' x 4', minimum of 20 slitlets (~0.6"x8")
Sensitivity	K>20.2, t=4hrs, S/N=5 per FWHM (continuum) F>5x10^{-18}erg^{-1}s^{-1}cm^{-1}Å^{-1}, t=4hr, S/N=6 per FWHM (line)
Imaging mode	
FOV	6'x6'
Sensitivity	K>23.5, t=4hr, S/N=5, in 0".65 aperture

Table 1 Top level instrument specifications of EMIR.

The EMIR design was largely determined by the requirements of its main scientific driver, the study of distant, faint galaxies, the COSMOS project[1]. Being a common-user instrument, however, it has been designed to meet many of the broader astronomical community. It is therefore a versatile instrument that will accomplish a wide variety of scientific projects in extragalactic, stellar and Solar System astronomy.

The construction of EMIR pushes the challenges of large-telescope instrumentation to new limits. The GTC 10m aperture translates into a physically large focal surface. Matching the images given by the telescope to the small size of current detectors requires large optics with fast cameras. Large, heavy optics need advanced mechanical design and modelling to bring flexure down to acceptable levels. To work in the region beyond 1.8 µm, the EMIR optical system and mechanical structure will be cooled down to cryogenic temperatures. Temperature stability and cycle-time requirements pose stringent demands on the design and performance of the instrument's cryogenic system. A key module of EMIR is a cryogenic mask unit to allow several different configurations of multi-sit masks being available every night, suitable for GTC's intended queue observing, without warming up the spectrograph. All the afore mentioned aspects need development effort, as the technology is not available or it is not scalable from existing solutions. Finally, we are seeking the development of a documented, robust processing pipeline as an integral part of the instrument and are including such software effort in the developments needed for a successful operation of EMIR.

In the subsequent sections we will briefly review the different technical aspects of the EMIR design effort. It is worth to emphasize again that EMIR is a science driven instrumental project, being its top level design requirements taken directly from the main goals of the COSMOS project[1]. But, at the same time, it is conceived as a powerful and flexible common-user instrument which will open new windows to the community to which it serves. It is also planned to extend the present day EMIR scientific team, mostly focused on COSMOS, at the end of the PD phase, permitting the coverage and early preparation of a wider list of scientific topics.

2. EMIR AND THE COSMOS PROJECT

The instrumental concept of EMIR is closely related with the principal objectives of the COSMOS project[1]. In summary, COSMOS is intended to build a rather complete census of the population of the Compact Blue Luminous Emission Line galaxies, at redshifts in the range 1–2, an epoch of great enhancement of the stellar formation rate in the history of the Universe. To this end, a large collecting aperture telescope, e.g. the GTC, is needed due to the intrinsic faintness of the sources.

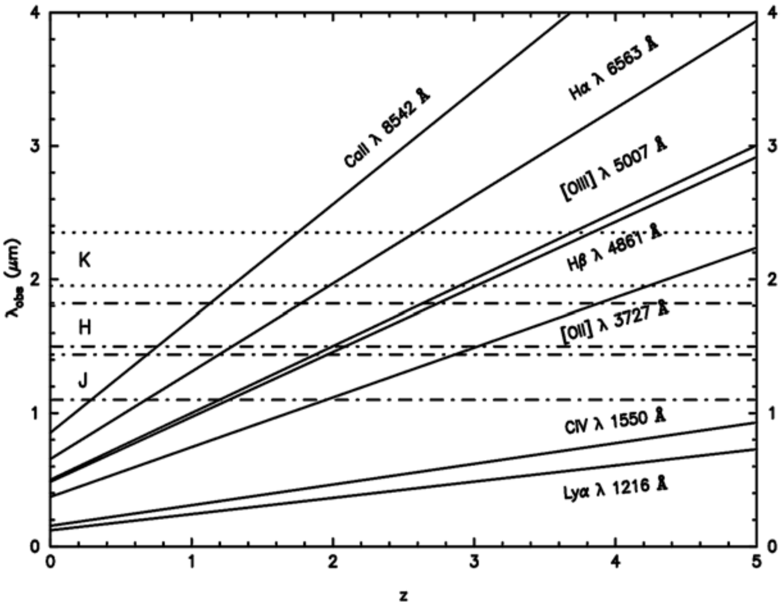


Figure 1 Observed wavelengths of the most representative emission and absorption lines in normal galaxy spectra at various redshifts.

In addition, an spectrograph working in the NIR is mandatory for the project since at those redshifts the diagnostic lines used to delineate the stellar formation, e.g. Hα, lies in the NIR (see Figure 1). Finally, the multi-object capability is needed due to the large number density of objects to be measured and the need of an efficient way to do so.

3. OPTICAL LAYOUT

The optical concept of EMIR has been studied in many approaches in order to have a good balance between the performance of the instrument, the technical risks and the global price. The EMIR requirements make the optical concept extremely challenging, and the design approaches have tried to minimize the trade off between requirements and technical solutions. Details about the optical layout of EMIR have to be found elsewhere in these proceedings[2].

The parameter that drives mostly the design is the size of the required FOV in both imaging (6 by 6 arcmin) and spectroscopic (at least 6 by 3 arcmin) modes. Requirements such the spectral resolution and operation temperature of the instrument and material availability are also important and have special role in the final design.

The EMIR optical design is specified for the use of grisms as dispersive components[2,3]. This option appears to be the most feasible approach, with the strong caveat of the unavailability of such grisms in the market. Technical developments to procure large grisms with high refractive index materials are needed, but no only in the EMIR project, and we are currently envisaging a collaborative effort with the Laboratoire d'Astrophysique de Marseille and the grating manufacturer Jovin Ybon to develop such a component. Strictly speaking, they are formed by a combination of two refractive ZnSe prisms plus the transmission grating, as can be seen in Figure 2, which behaves like a grism as far as the light trajectory is concerned.

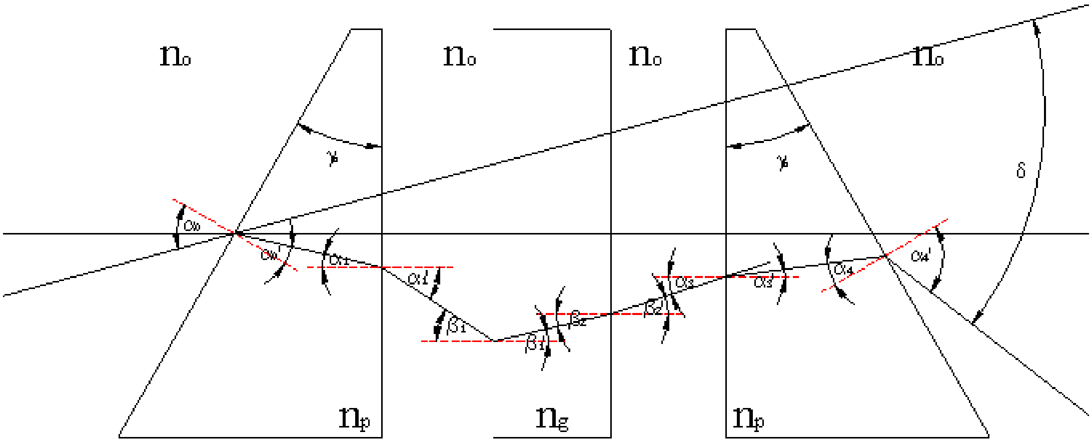


Figure 2 Sketch of the design for the dispersive component.

One key aspect in the development of such a *pseudo–grism* is the technical quality of the gratings grooves, much deeper in the NIR than in the optical. With the etching technique recently developed by Jovin Ybon is possible to achieve high transmission rates in the ruled material as it is shown in Figure 3.

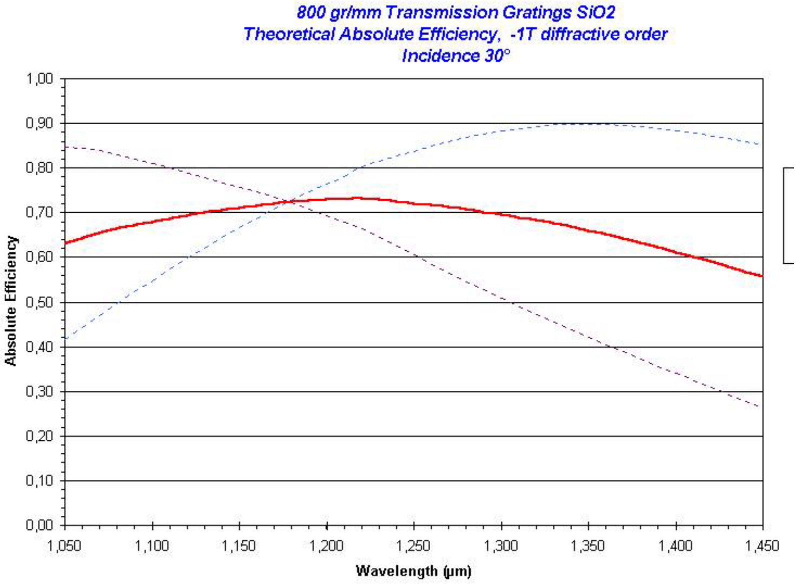


Figure 3 Theoretical transmission of the ruled grating in the J band. Dashed lines are transmission for TE and TM polarized lights and the solid one, the average of the other two, for unpolarized light.

We have already ordered one grating specified for the K band which should be ready to be tested by the beginning of 2003, right on time for the EMIR PDR, where a final decision has to made on this crucial component. Since this is the most difficult spectral band, success in this development will ensure availability of gratings for the rest of bluer bands on which EMIR will operate.

In view of the high risk of not having this critical component in time, we have evaluated the performances of the optical design using an existing lower resolving power grism element. The results are very satisfactory from the point of view of general image quality, so this approach can now be considered as a fall-back solution for EMIR in the meanwhile until the optimum grism(s) is(are) available. And, in any case, provisions have been made in the design of the grism wheel to insert such an element in all cases to permit the coverage of the full spectral range (1–2.5 µm) in a single exposure.

4. MECHANICAL CONCEPT

EMIR will be attached to the mechanical rotator of the Nasmyth-B focus. The mechanical layout of the instrument has been derived from the optical design, taking into account the Nasmyth space envelope. Two flats have been added to bend the beam and a cold bench has been optimized to fulfil the image stability error budget. A mechanical concept has been developed for each subsystem, and a first draft of the specifications has been obtained to feed the preliminary design. Trade-off studies are under development to homogenize as much as possible the technical solutions adopted for the cold mechanisms.

The current EMIR mechanical desing[4] is split into two different, but with as many similarities as possible, concepts due to the project decision of developing in parallel two solutions for the slit mask unit. The first concept for this subsystem is a classical mask wheel, plus a decker wheel, being developed by a joint collaboration between the University of Durham and the IAC, and which is referred to as the CMU. That would result into a mechanical main structure, the cold bench, and instrument layout which are shown in Figure 4. The more severe drawback of such a system is the limited number of masks that will be available to the user each observing night, and the increasing operational effort and related instrumental risks associated to the day-time replacement of the slit mask. That will imply to fully cycling the cryostat on around 12 hours, which is one of the most stringent requirements of the CMU subsystem. To avoid unnecessary risks to the rest of the instrument, the cryostat is divided into two vacuum spaces by the mounting flange, which requires an additional separation window between the two spaces.

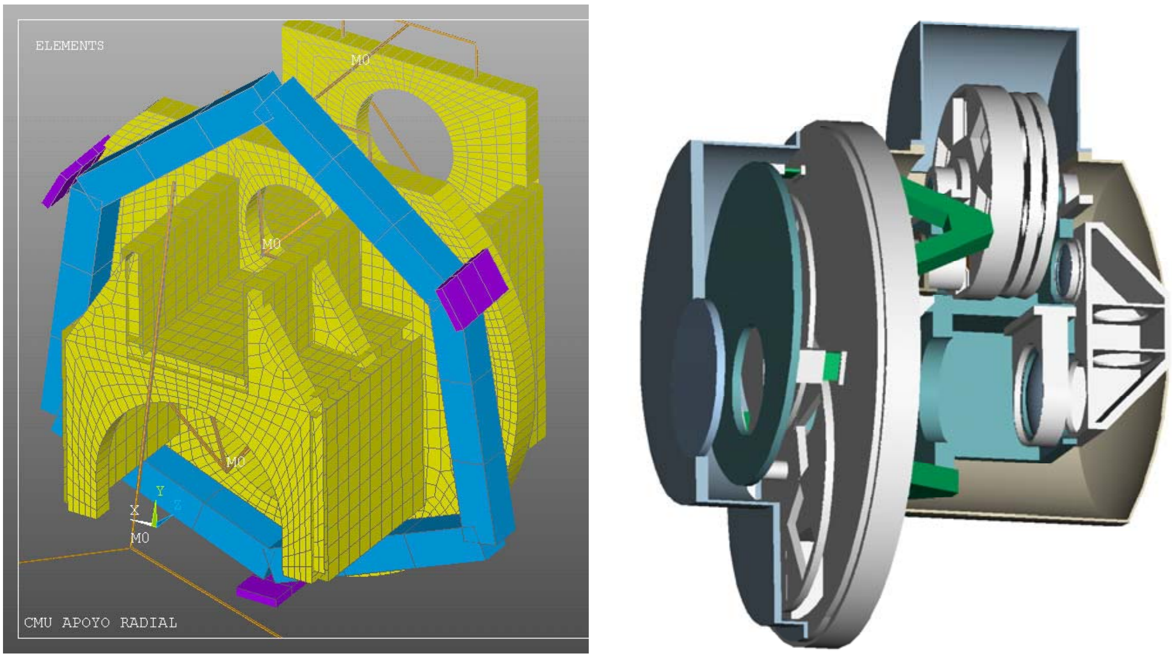


Figure 4 Main mechanical structure and global layout for the CMU concept

The second concept relays on the development of a fully cryogenic robotic system which can be remotely reconfigured to form the multislit pattern in the instrument focal plane, and which will be referred to as CSU along this paper. To this end, a development contract has been already signed with the Swiss firm CSEM. The preliminary design, whose sketch is shown in Figure 5, is in a well advanced status and its completion is due for October 2002, after some functional tests in cold conditions have been performed with a prototype with a limited number of multislit bars. This subsystem has obvious functional and operational advantages with respect to the CMU at the cost of involving much higher number of cryo–actuators and so increasing the risk of failures and bad functioning. The resulting cold bench and instrument layout are displayed in Figure 6. In this case there is no need for the separation window in the support flange, since there will be only a single vacuum space for the whole instrument.

At the time of the PDR the project will evaluate the status of both CMU and CSU, in terms of design specifications, compliance of the EMIR requirements, robustness and feasibility and will make a decision about the concept to be fully developed. That implies that during this preliminary design phase, the EMIR mechanical design has to maintain compatibility with these two subsystems, being that of the CMU the baseline for the preliminary design till PDR.

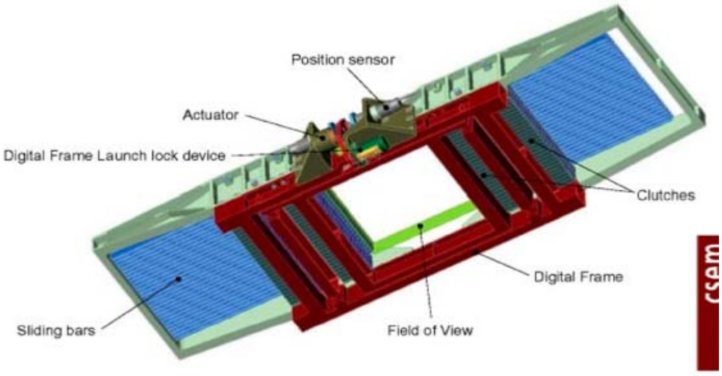


Figure 5 Layout of the CSU concept

We have also started recently to tackle the design of the opto–mechanics. Being EMIR a big instrument with large FOV, the main difficulty is the secure support of heavy lenses in cold while maintaining the stringent requirements of stability and accuracy in geometrical position and orientation. There is very little, if any, previous experience in this field which could be applied to EMIR which implies an extra cost in design effort for the mechanical team.

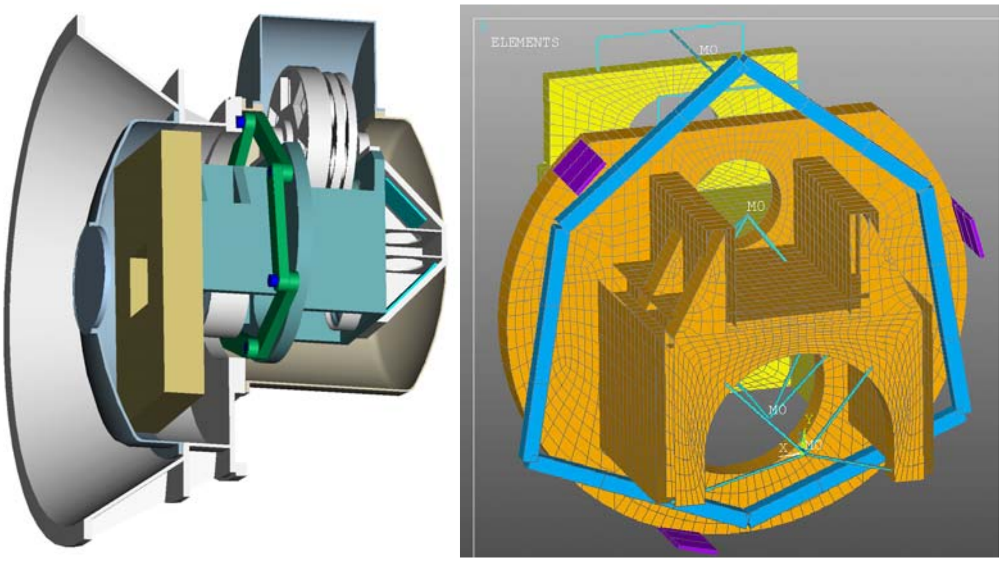


Figure 6 Main mechanical structure and global layout for the CSU concept

Finally, three main mechanisms are being developed: the wheels for the grisms and filters and the detector focus mechanisms. Also we have made space provision to include later along the PD phase an XY motorized positioning bench for the detector. The latter will permit active compensation of the internal flexures of the instrument, attached to the Nasmyth rotator and could also be used to implement advanced features in the observing strategy.

5. CONTROL SYSTEM

The EMIR software and control system[5] is being developed by a multi-institutional group formed by scientist and engineers from IAC, UCM and LAOMP, under the coordination of the IAC. It follows strictly the prescriptions of GRANTECAN for the development of instrument software, in view of the subsequent integration on the global GTC Control System. There are four main aspects in the control system that have been considered as integral part of the instruments from the beginning:

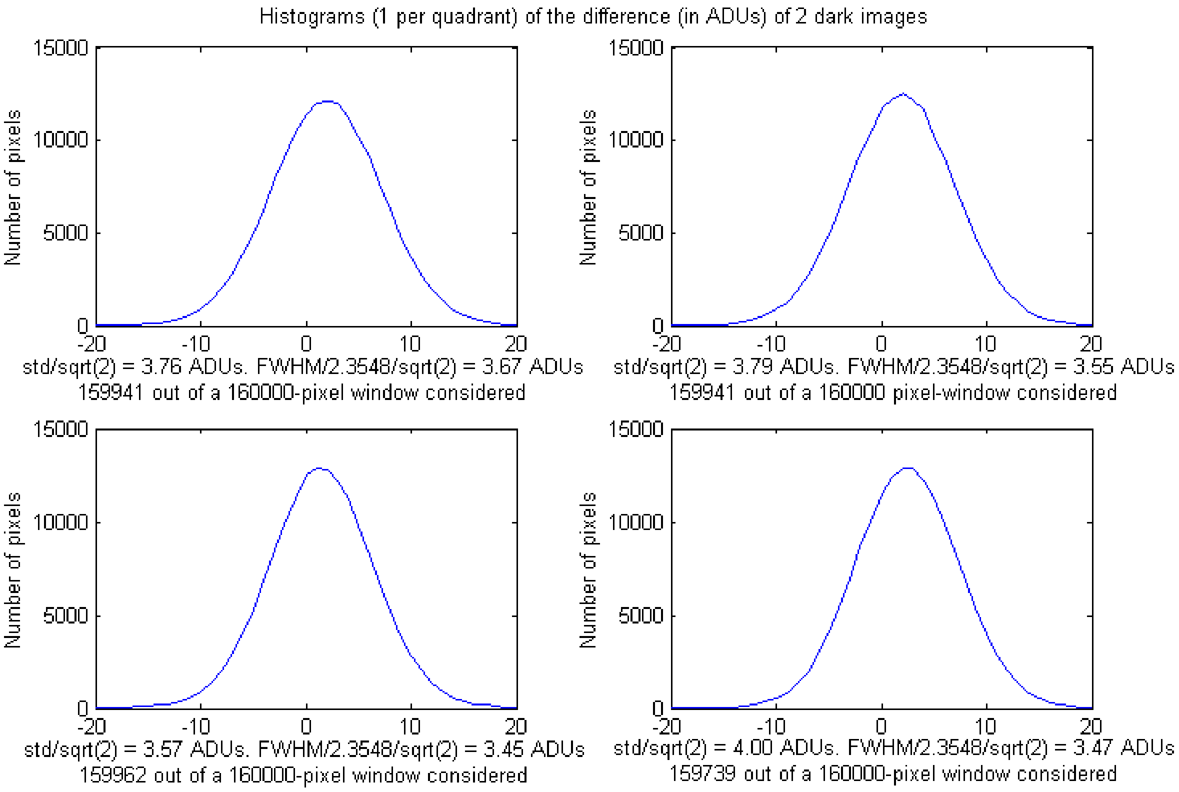


Figure 7 Read-out noise distribution of the engineering array.

- The EMIR Coordinated Operations (ECOs), which includes the control of the instrument global configuration related with observations and calibrations. These might have to interact with the GTC control system. It is being built in cooperation by IAC and LAOMP.
- The EMIR Data Acquisition System (DAS), which drives the different detector read-out modes and controls the flow of data. It is being developed by IAC, based on a SDSU controller.
- The EMIR Observing Programme Management Subsystem (EOPMS, formerly EOPMT), which is the master programme which monitors the EMIR performances and will ensure an adequate use of the EMIR instrument by the regular astronomers. LAOMP is undergoing its design.
- The Data Reduction Pipeline (DRP), which includes specific filters and reduction packages for each observing mode. It is under the responsibility of the UCM.

EMIR will be equipped with a Rockwell Hawaii 2 FPA which is being tested at the IAC with the use of testing equipment (cryostat plus detector controller) specifically designed and built to this end by the EMIR team at the IAC.

The controller is a home made design around the SDSU. We have now completed the first test campaign in the engineering grade array, some of whose results are depicted in Figure 7, and will proceed immediately with the science class array which has been delivered a few months ago. During this first test campaign we have obtained promising results of the features of the engineering array, whose cosmetic can be appreciated in Figure 8.A brief summary of this first results follows:

- Readout noise: $11e^-$
- Gain: $3e^-$/ADU
- Well depth 150.000 e^-
- Dark current 0.02 e^-/sec @ 77 K
- Maximum pixel rate per channel 140 kHz.

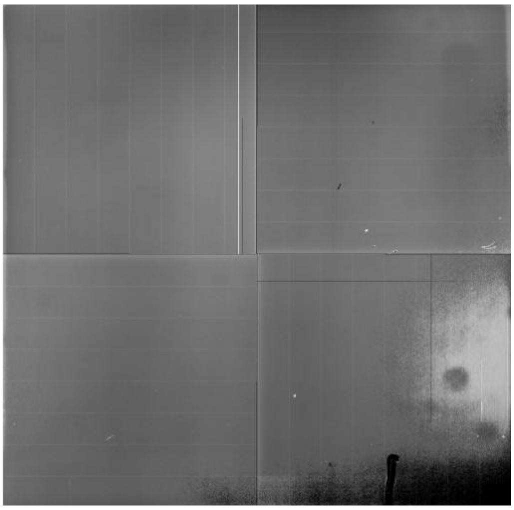


Figure 8 Sample image taken with the EMIR engineering detector array

One of the important remaining tasks in this area is the characterisation of the detector controller, currently built around a SDSU system, to check the compliance of the EMIR requirements, mostly in terms of data taking rate. We are not excluding an approach based on a different architecture.

6. EMIR SCHEDULE

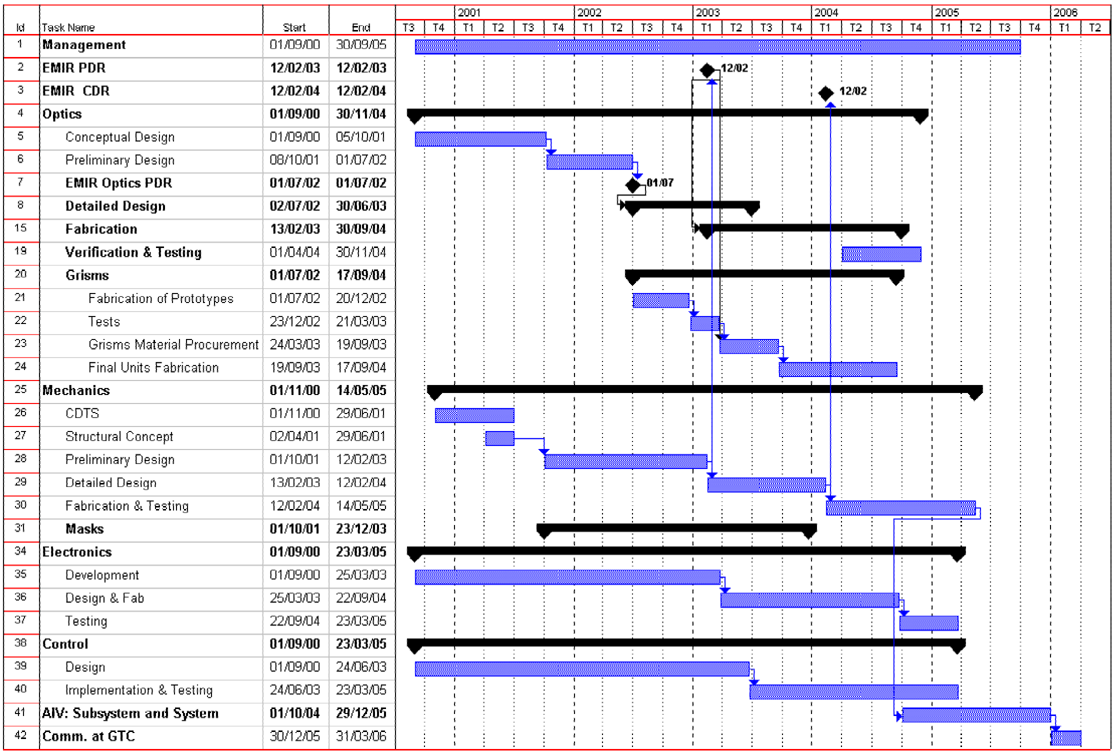
As mentioned in §1, EMIR is now running its PD phase. The work is proceeding as expected, being the major challenges the procurement of the large size grism(s) needed for the light dispersion and the multislit mask subsystem, whose specificities have been described above. With the current development contracts being well underway we are not expecting major impacts on the instrument schedule to completion, which is shown in Figure 9, and which have still many uncertainties on it. Most of these uncertainties will be fixed along the PD phase.

With all the above in mind, we are now facing an schedule to PDR which contemplates three major milestones:

- An internal review of the optical design, which took place in July 1st, 2002.
- An official (run by GRANTECAN) Mid Term Review, by October/November, 2002.
- The PDR which will be help by February, 2003.

7. ACKNOWLEDGEMENTS

The design effort of EMIR along this Preliminary Design Phase is supported by the Plan Nacional de Astronomía y Astrofísica, throughout the project AYA-2001-1656, the GRANTECAN Project Office, via a dedicated contract, and the EMIR partners institutions: IAC, LAOMP, UCM and UD.



Id	Task Name	Start	End
1	**Management**	01/09/00	30/09/05
2	**EMIR PDR**	**12/02/03**	**12/02/03**
3	**EMIR CDR**	**12/02/04**	**12/02/04**
4	**Optics**	**01/09/00**	**30/11/04**
5	Conceptual Design	01/09/00	05/10/01
6	Preliminary Design	08/10/01	01/07/02
7	**EMIR Optics PDR**	**01/07/02**	**01/07/02**
8	**Detailed Design**	**02/07/02**	**30/06/03**
15	**Fabrication**	**13/02/03**	**30/09/04**
19	**Verification & Testing**	01/04/04	30/11/04
20	**Grisms**	**01/07/02**	**17/09/04**
21	Fabrication of Prototypes	01/07/02	20/12/02
22	Tests	23/12/02	21/03/03
23	Grisms Material Procurement	24/03/03	19/09/03
24	Final Units Fabrication	19/09/03	17/09/04
25	**Mechanics**	**01/11/00**	**14/05/05**
26	CDTS	01/11/00	29/06/01
27	Structural Concept	02/04/01	29/06/01
28	Preliminary Design	01/10/01	12/02/03
29	Detailed Design	13/02/03	12/02/04
30	Fabrication & Testing	12/02/04	14/05/05
31	**Masks**	**01/10/01**	**23/12/03**
34	**Electronics**	**01/09/00**	**23/03/05**
35	Development	01/09/00	25/03/03
36	Design & Fab	25/03/03	22/09/04
37	Testing	22/09/04	23/03/05
38	**Control**	**01/09/00**	**23/03/05**
39	Design	01/09/00	24/06/03
40	Implementation & Testing	24/06/03	23/03/05
41	**AIV: Subsystem and System**	**01/10/04**	**29/12/05**
42	**Comm. at GTC**	30/12/05	31/03/06

Figure 9 EMIR schedule to completion, as it is today.

8. REFERENCES

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