EMIR: the GTC NIR multi-object imager-spectrograph

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ABSTRACT

We present the final global design and performances of EMIR, the NIR multi–object spectrograph of the GTC, as well as the plan for its early scientific exploitation. EMIR, currently in the middle of its final phase, 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 and French 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, which include imaging and spectroscopy, both long slit and multi–object, in the wavelength range 0.9 to 2.5 µm. It is equipped with two innovative subsystems: a robotic reconfigurable multi–slit mask and dispersive elements formed by the combination of high quality difraction grating and conventional prisms, both at the heart of the instrument. The present status of development, expected performances, schedule and plans for scientific exploitation are described and discussed. This project is mostly 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, multi–object spectroscopy, GTC

1. INSTRUMENT DESCRIPTION

The new generation of 10 m class optical and near-infrared telescopes currently under construction, 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. In addition, these technological challenges will establish the first steps towards the construction of instrumentation for the forthcoming 30 m+ class telescopes, now at the beginning of their conceptual design phases.

The Observatorio Roque de los Muchachos, operated by the Instituto de Astrofísica de Canarias (IAC) on the island of La Palma, is the site of the 10 meter Gran Telescopio Canarias (GTC) due for first light in 2005. GTC will be the largest aperture single dish telescope in world. Along this effort, a partnership of Spanish and French research institutions is working on the design and construction of EMIR, an advanced NIR multi–object spectrograph for GTC, which will be visited in this paper.

EMIR (*Espectrógrafo Multi–Objeto Infrarrojo*) is a common-user, wide-field camera-spectrograph operating in the near-infrared (NIR) wavelengths 0.9-2.5 µm, using cryogenic multi-slit masks as field selectors. Its expected capabilities in terms of sensitivities in the two observing modes are depicted in Figure 1.Specifications are listed in Table 1. EMIR

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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 Laboratoire d'Astrophysique de Marseille–Provence (OAMP, France). EMIR is now at the middle of its Final Design (PD) phase, and is due for first commissioning at the GTC in late 2006. This phase is being funded by GRANTECAN and the Plan Nacional de Astronomía y Astrofísica.

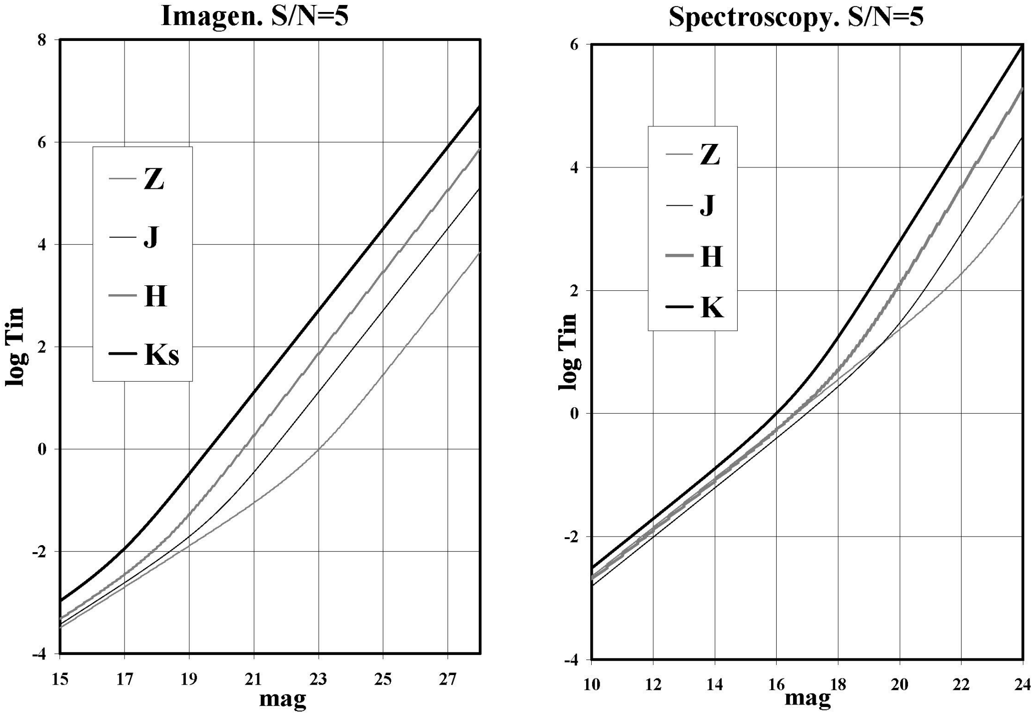

Figure 1 Calculated sensitivities of EMIR in image and spectroscopic modes, using the actual figures for the transmission and quantum efficiency.

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 able to observe in the K band at 2.2 µm without the drawback of the high instrumental background common to other conceptually similar 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, 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 James Webb Space Telescope (JWST) becomes operational late in this decade.

The EMIR design was largely determined by the requirements of its main scientific driver, the study of distant, faint galaxies, the GOYA project[1], previously known as COSMOS. 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.

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	5000,4250,4000 (JHK) for 0.6" (3-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}< 0.3 arcsec
Multi-object spectroscopic mode	
Slit area	6x4 arcmin, with approx. 50 slitlets of ~7" long and width varying between 0.4 and 1 arcsec
Sensitivity	K<21.2, t=2hrs, S/N=5 per FWHM (continuum) $F>5x10^{-19} erg^{-1} s^{-1} cm^{-1} Å^{-1}$, t=4hr, S/N=5 per FWHM (line)
Image mode	
FOV	6x6 arcmin
Sensitivity	K<23.9, t=1hr, S/N=5, in 0.6" aperture

Table 1 Top level specifications 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 GOYA 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.

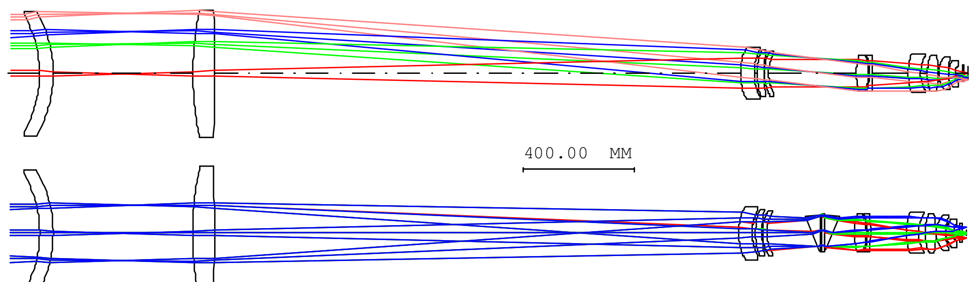

Figure 2 Layout of the optical design: top sketch for the image mode; bottom one, for the spectroscopic mode.

2. OPTICAL LAYOUT

The optical concept of EMIR has been studied from 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 (6 by 4 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.

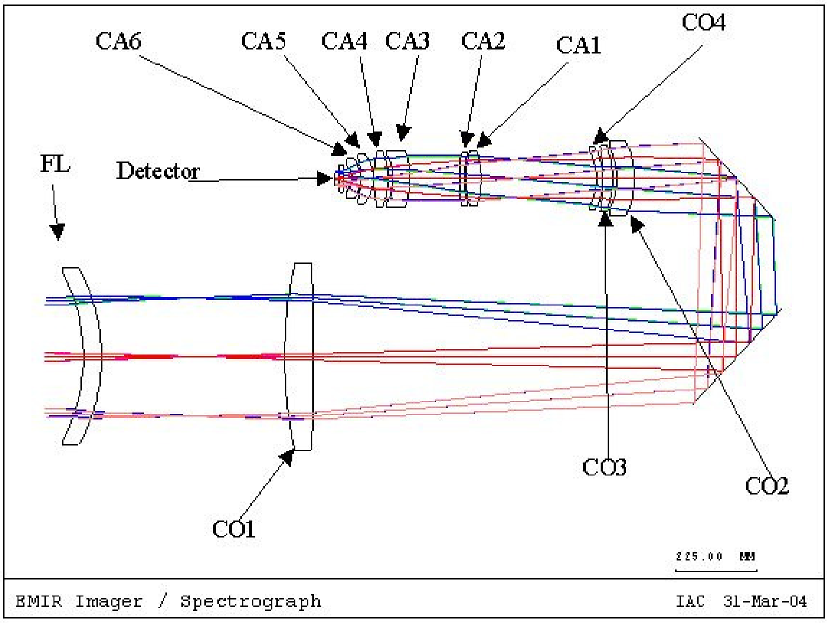

Figure 3 Optical layout as disposed in the instrument.

The optical train, all in transmission, is composed, from end to end, by a cryostat window, acting as a field lens and powered for flattening the GTC focal surface, where the Cold Mask Unit is located. Then a multiple spherical lens collimator, combining a single lens and a triplet forms the image of the GTC secondary at the pupil plane, where the dispersive elements and Lyot stops can be inserted and removed from the beam. A six element camera, all of them spherical, focus the beam onto the detector after crossing the filter wheel situated between the last camera lens and the detector, mounted on a XYZ movement table. All lenses, including the field lens will be AR coated in the two surfaces. The prescriptions of the optical elements, sketched in Figure 3, are given in Table 2 (figures are in mm).

Element	**Material**	**Thickness**	**Clear Ap.**	**Element**	**Material**	**Thickness**	**Clear Ap.**
FL	InfraSil	50	440	CA2	IRG2	10	134
CO1	InfraSil	80	464	CA3	InfraSil	48	144
CO2	InfraSil	50	188	CA4	BaF_2	40	140
CO3	BaF_2	26	168	CA5	IRG2	35	126
CO4	IRG2	18	160	CA6	Zne	25	100
CA1	BaF_2	44	138				

Table 2 Specifications of the optical design of EMIR.

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 have already completed such a development during the PD phase, where a demonstration programme was launched to produce a test sample functional in the K band. This was done in a collaborative effort with the OAMP and the grating manufacturer Jobin Yvon. The complete dispersive element are formed by a combination of two refractive ZnSe prisms plus the transmission grating, as can be seen in Figure 4, which behaves like a grism as far as the light trajectory is concerned.

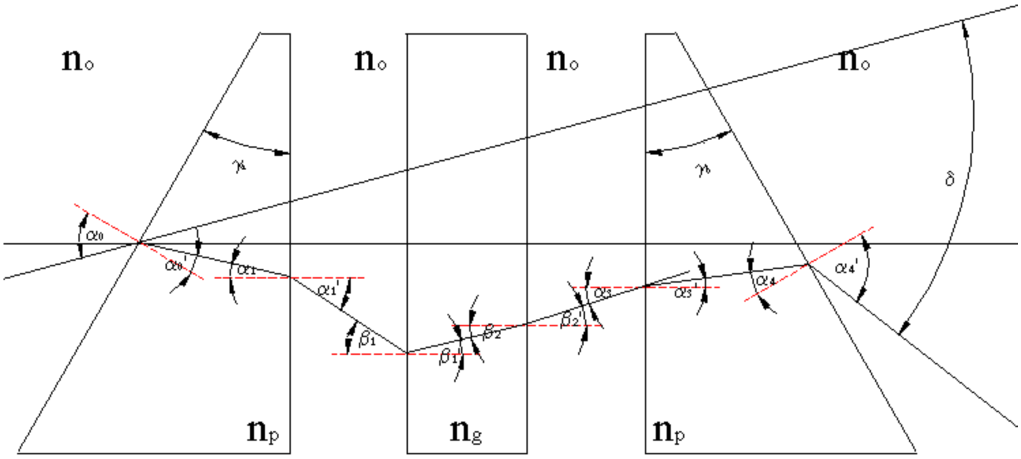

Figure 4 Sketch of the design for the dispersive component.

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 Jobin Yvon is possible to achieve high transmission rates in the ruled material as it is shown in Figure 5.

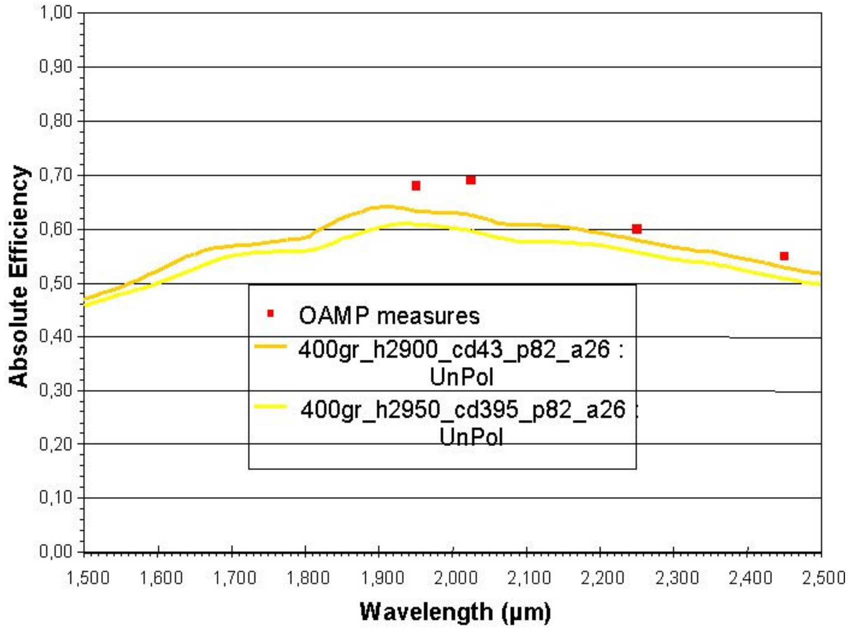

Figure 5 Measured and computed transmission of the ruled grating in the K band. The lines represent the calculated transmission, for TE and TM unpolarized light, and the solid dots, actual measurements in the demonstration sample.

We have already ordered one grating specified for each of the atmospheric windows JHK, following the successful results of the previous phase. These components will be sandwiched between two standard ZnSe prisms to form the dispersive element (see Figure 4), so called pseudogrism, which will be mounted in the Grism Wheel. The remaining optical elements are now fully specified and will be ordered in the next months.

3. 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 final set of specifications has been obtained to feed the detailed design. We are at present entering into a prototyping phase in which the most critical aspects of the mechanical concept will be tested and qualified. The full details of the mechanical design are published in this proceedings[7,8,9].

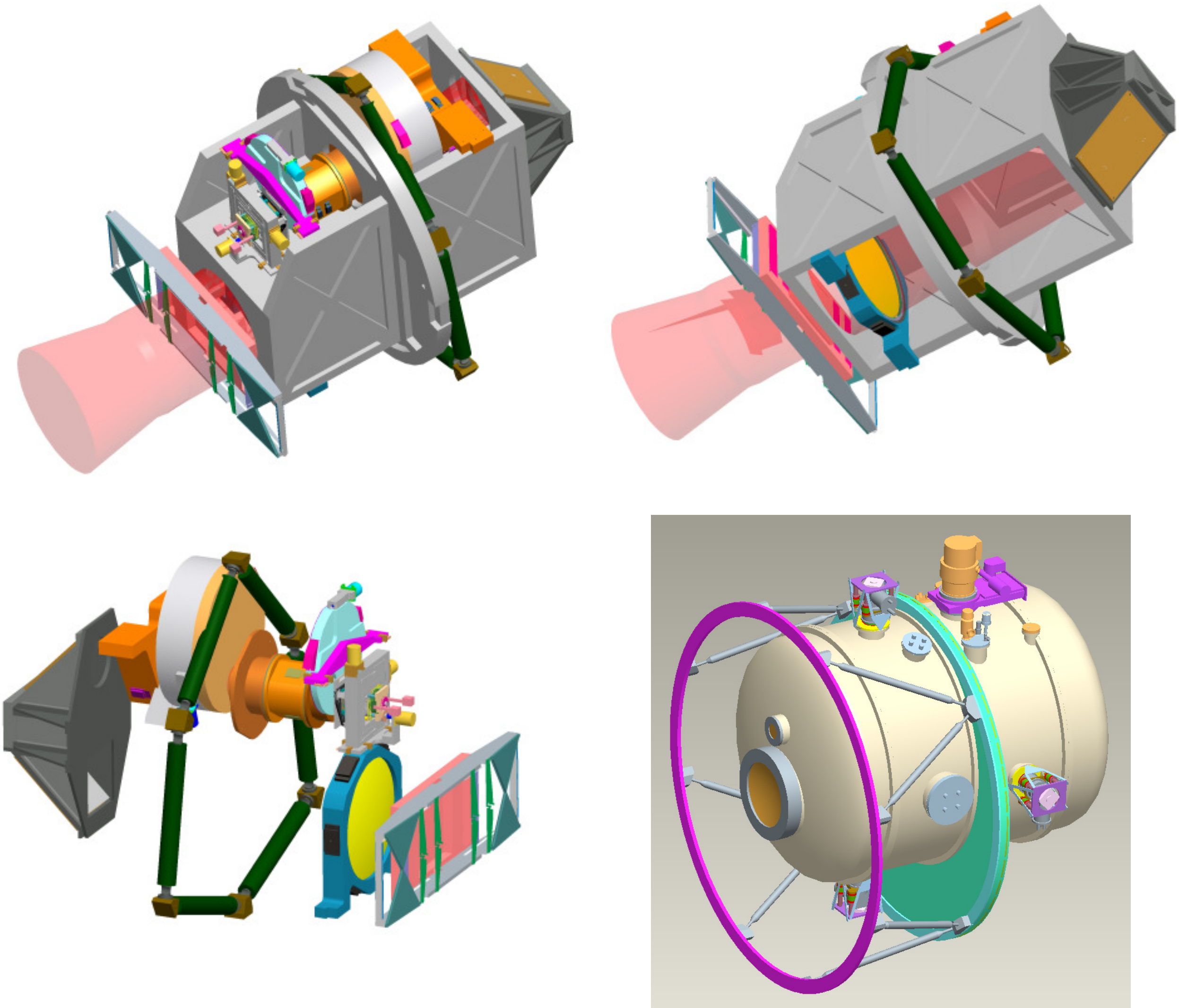

Figure 6 Different views of the EMIR cold bench. Top left: upper view showing the CSU, periscope, second collimator barrel, grism wheel, camera barrel, filter wheels and the detector mount table. Top right: view from the bottom on which the CSU, first collimator barrel and the periscope are seeing. Bottom left: schematic of the different subsystems positioned along the incoming beam, without the cold bench. The support trusses are also shown. Bottom right: the EMIR cryostat ready to be attached to the Nasmyth focus

The EMIR mechanical desing[4] relays on the development of a fully cryogenic robotic system which can be remotely reconfigured to form the multi–slit pattern in the instrument focal plane, and which is referred to as CSU along this paper. To this end, a development contract was signed with the Swiss firm CSEM to complete a conceptual design during the PD phase. The final contract for the procurement of the functional unit is at present on the process of public tendering. The cold bench and instrument layout are displayed in Figure 6.

Two main mechanisms have being developed in the course of the design phase: the wheels for the grisms and filters. Also we are preparing the specifications of an XYZ motorized positioning bench for the detector, which will be subject of a separate development and procurement contract. This 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.

It is worth to mention that the project will review the results of the prototype test in an Adavanced Review Meeting (ADR) to be held late this year, and after which the detailed design of the remaining parts of the instrument will proceed.

4. 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. EMIR Control is based on a distributed architecture where every subsystem has a self contained objective. The instrument core takes control, synchronizes and triggers all the tasks to carry out a sequence of actions which configure an observation. here are four main aspects in the control system that have been considered as integral part of the instruments from the beginning:

- 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 is equipped with a Rockwell Hawaii 2 FPA. A second science grade FPA is currently being tested at the IAC[10], using our 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 already completed the first test campaign in that array, which are summarised as follows:

- Readout noise: 12e^-
- Well depth: (80.000–100.000) e^-, up to 2% deviation from perfect linearity.
- Dark current 0.03/0.15 e^-/sec @ 77 K. Some
- Maximum pixel rate per channel 140 kHz.

5. SCHEDULE

EMIR is now running its final phase, on which the final detailed design of all subsystems have to be completed, the fabrication and/or procurement of all parts shall occur and the integration and verification at component, subsystem and system level will result in the final instrument ready to be mounted at the GTC. The work is proceeding as expected, being the major challenges the procurement of the psuedogrisms needed for the light dispersion and the multi–slit 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 7, and which have still some uncertainties on it. Most of these uncertainties will be fixed before or around the ADR.

Id	Task Name	Start	End
1	Project Science	01/04/03	22/01/07
3	Project Management	01/04/03	22/01/07
64	Advanced Design Review	16/07/04	16/07/04
65	System Detailed Design	23/06/03	20/09/04
113	Optics Design & Fabrication	01/04/03	03/06/05
155	Mechanical Design & Fabrication	01/04/03	22/12/05
156	Advanced Design	01/04/03	13/10/04
278	Mechanics Detailed Design	22/07/04	24/03/05
306	Mechanics Fabrication	22/12/04	22/12/05
333	CSU Development	01/04/03	30/11/05
348	DetectorTranslation Unit Development	01/03/04	14/12/05
355	Control Design & Fabrication	07/04/03	16/09/05
356	Software & Control	02/02/04	22/07/05
363	Electronics Design	07/04/03	16/03/05
400	Electronics Fabrication & Procurement	16/03/05	16/09/05
404	AIV: Subsystems	24/04/05	28/05/06
405	Structural Assemblies	04/07/05	22/01/06
412	Cryogenics Assembly	24/04/05	22/01/06
419	Lens Barrels Subsystems	22/06/05	22/12/05
433	Other Assemblies	22/05/05	20/12/05
438	Cold Mechanisms	30/11/05	28/05/06
443	Electronics Subsystems	30/11/05	28/04/06
448	AIV: System	22/01/06	20/10/06
449	Commissioning at GTC	20/10/06	20/01/07
450	EMIR first light	20/01/07	20/01/07

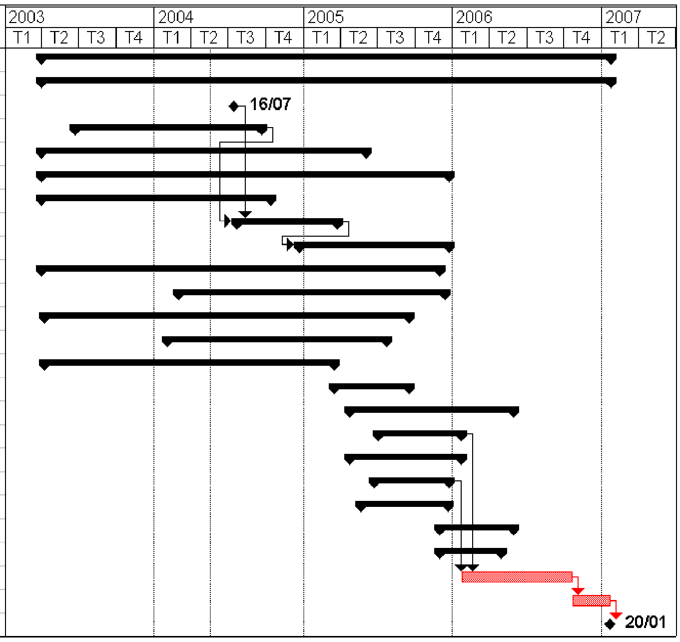

Figure 7 Overall schedule of the EMIR project

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

- An external review of the prototyping of the mechanical design, which will take place by the end of 2004
- The start of the AIV at component and subsystem level by mid 2005.
- The beginning of the commissioning at the GTC by early/mid 2006.
- EMIR at the GTC ready to operate by early 2007.

6. SCIENTIFIC EXPLOITATION

GOYA and EAST
CALIBRACION

ACKNOWLEDGEMENTS

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