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EMIR, THE GTC NIR MULTI-OBJECT IMAGER-SPECTROGRAPH

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RESUMEN

EMIR, que está actualmente cubriendo sus fases de fabricación y AIV, será uno de los primeros instrumentos de uso común en GTC el telescopio de 10m en construcción por GRANTECAN en elObservatorio del Roque de los Muchachos (Canarias, España). EMIR se construye por un consorcio de instituciones españolas y francesas, dirigido por el Instituto de Astrofísica de Canarias (IAC) y está concebido para cubrir uno de los objetivos centrales de los telescopios de la clase de 10-m, el cual es obtener un gran número de espectros de fuentes débiles simultáneamente. EMIR está diseñado para operar principalmente como MOS en la banda K, aunque ofrece un amplio rango de modos de observación que incluyen imagen y espectroscopía, tanto de rendija larga como multiobjeto, en el rango espectral de 0.9 a 2.5μm. Está equipado con dos sistema novedosos en astronomía, que constituyen el corazón del instrumento: un robot reconfigurable de multimáscaras, de un lado, y elementos dispersivos formados por combinación de redes de difracción de alta calidad y prismas convencionales. Presentamos el estado actual de desarrollo, las prestaciones previstas y los planes iniciales para su explotación científica. Los desarrollos y fabricación de EMIR están financiados por GRANTECAN y el Plan Nacional de Astronomía y Astrofísica.

ABSTRACT

EMIR, currently entering into its fabrication and AIV 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 Instituto de Astrofísica de Canarias (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 a 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 multi-object, in the wavelength range 0.9 to 2.5μm. It is equipped with two innovative subsystems: a robotic reconfigurable multi-slit mask and dispersive elements formed by the combination of high quality diffraction 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. The development and fabrication of EMIR is funded by GRANTECAN and the Plan Nacional de Astronomía y Astrofísica (National Plan for Astronomy and Astrophysics, Spain).

Key Words: **INSTRUMENTATION: SPECTROGRAPHS — TELESCOPES**

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 of 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 con-

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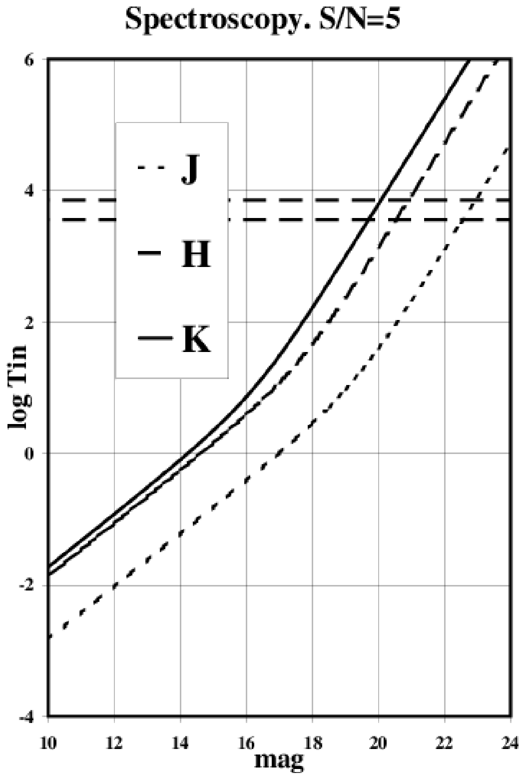

Fig. 1. Calculated sensitivities of EMIR in spectroscopic mode, using the actual figures for the optics transmission and the detector quantum efficiency. Dashed horizontal lines indicate 1 and 2 hours of integration time.

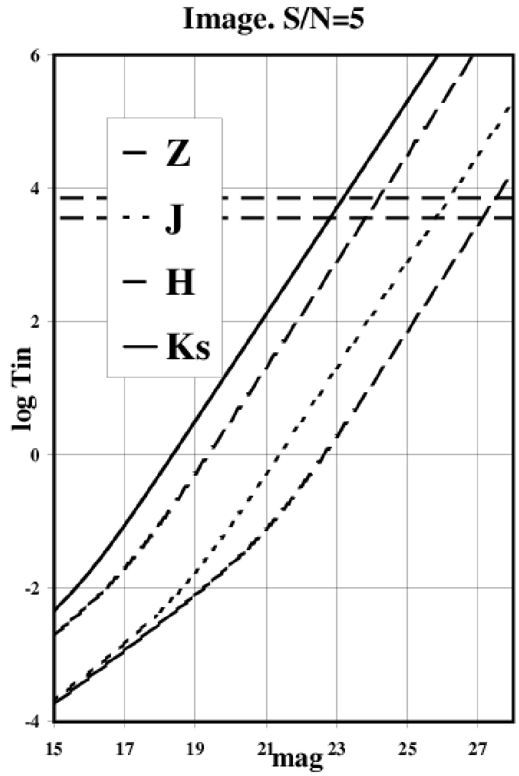

Fig. 2. Calculated sensitivities of EMIR in image mode, using the actual figures for the optics transmission and the detector quantum efficiency. Dashed horizontal lines indicate 1 and 2 hours of integration time.

struction 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 2007. 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, Garzón et al. 2003, 2004) is a common-user, wide-field camera-spectrograph operating in the near-infrared (NIR) wavelengths 0.9–2.5μm, using cryogenic multi-slit masks as field selectors. Figures 1 and 2 provide the best up to date estimate of the expected performances of EMIR in both observing modes, per spectral band. The most relevant instrumental parameter can be found in Table 1. EMIR will provide GTC with imaging, long-slit and multi-object spectroscopic capabilities. The EMIR Consortium is formed by the IAC, Universidad Complutense de Madrid (UCM, Spain), the Laboratoire d'Astrophysique des Midi Pyrénées (LAOMP, France) and the Laborato ire d'Astrophysique de Marseille-Provence (OAMP, France). EMIR is now at the beginning of its Fabrication and AIV Phase phase, and is due for first commissioning at the GTC in early 2008. This phase is being funded by GRANTECAN and the Plan Nacional de As tronomía y Astrofísica.

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

TABLE 1

TOP LEVEL SPECIFICATIONS OF EMIR

Wavelength range	0.9–2.5μm
Optimization	1.0–2.5μm
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 aperture
Spectral coverage	One observing window (Z, J, H or K) per single exposure
Array format	2048x2048 HgCdTe (Rockwell-Hawaii2)
Scale at detector	0.2″/pixel
OH suppression	In software
Image quality	$\theta_{80} < 0.3''$
	Multi-object spectroscopic mode
Slit area	$6' \times 4'$, with $\sim$ 50 slitlets of equal length and width between 0.4″ and 1″
Sensitivity	$K < 20.1$, t=2hrs, S/N=5 per FWHM (continuum)
	$F > 1.4 \times 10^{-18}$erg^{-1}s^{-1}cm^{-1}Å^{-1}, t=4hr, S/N=5 per FWHM (line)
	Image mode
FOV	$6' \times 6'$
Sensitivity	$K < 22.8$, t=1hr, S/N=5, in 0.6″ aperture

struments. Similar NIR MOS existing or planned for other telescopes are not cooled and reach out to 1.8μm only. Extending MOS capabilities to 2.2μm 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 H line, is shifted to the K band, allowing key diagnostics of the star formation history of the Universe. EMIR will allow us 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 (Guzmán 2003). 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 ranging from extragalactic and stellar bodies to interstellar medium 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 1.8μm, 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 to be available every night, suitable for GTC's intended queue observing, without warming up the spectrograph. All the aforementioned 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, which are described in full in other papers (see references). It is worth emphasizing 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 (Guzmán 2003). 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 (Ballcels 2003).

2. OPTICAL LAYOUT

The optical concept of EMIR (Manescau et al. 2003, 2004), 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.

The parameter that drives mostly the design is the size of the required FOV in both imaging and spectroscopic modes. Requirements such the spectral resolution and operation temperature of the instrument and material availability are also important and have a special role in the final design. 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 except the last one, focus the beam on to 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 EMIR optical design is specified for the use of grisms as dispersive components. 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. The complete dispersive element are formed by a combination of two refractive ZnSe prisms plus the transmission grating, which behaves like a grism as far as the light trajectory is concerned. 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.

We already ordered, and have received, 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, so called pseudogrism, which will be mounted in the Grism Wheel. This task is being performed by OAMP, and includes the acceptance testing of the grating elements and the design and construction of the mounting barrel, one for each of the three gratings.

The full set of optical components of EMIR, except the prisms for the pseudo-grisms, are now being fabricated, after the optical design was fitted to the manufacturer test plate. The camera and the collimator triplet will be delivered mounted on their barrels, with the mounting of the two bigger lenses, cryostat window and the first collimator lens, under the responsibility of the EMIR team.

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. After finalising a prototyping phase in which the most critical aspects of the mechanical concept have being tested and qualified, EMIR is now entering into the fabrication and AIV phase. The full details of the mechanical design can be found in Fuentes et al. (2004), Correa et al. (2004), Barrera et al. (2004) and Sánchez et al. (2006).

The EMIR mechanical design relies 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 run with an industrial partner during the conceptual design phase to accommodate the EMIR needs to feasible technologies, either already existing or due for development in the short term. After the finalisation of that contract, and prior to the launch of the call for the procurement of the final component, we have additionally run a demonstration programme with a different industrial partner devoted to identify the most critical aspects in the mechanism, both in the mechanical and electronics areas. A functional prototype has been produced as a result of this contract. At the IAC we will now intensively and extensively test the prototype, at both room temperature and in cryogenic working conditions, before issuing the definitive call for tenders for the final system.

The current status of the mechanical development is described in Sánchez et al. (2006). It is worth to mention that the project has recently reviewed the results of the prototype test in an Advanced Review Meeting which has concluded successfully. Part of the mechanical items are already being fabricated. In the next months the EMIR project will launch calls for proposals to fabricate the cold bench, the vacuum vessel and the EMIR CSU. These contracts will close all the pending components in the EMIR mechanical supply.

4. CONTROL SYSTEM

The EMIR software and control system (López-Ruiz et al. 2002, 2004) 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, 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 (Gago et al. 2004), 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 (Richard et al. 2004) 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 (Gallego et al. 2002), 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 which will driven by a controller based on a SDSU architecture. A second science grade FPA has been tested and accepted at the IAC, 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 campaign16 in that array, which are summarised as follows:

- Gain: $3.03 \pm 0.12e{-}^{-}/\mathrm{ADU}$
- Readout noise: $6.5e^{-}$
- Well depth: $126,000 \pm 500e^{-}$, up to 2% deviation from linearity.
- Dark current 0.03/0.15 e^{-}/s @ 77 K.
- Maximum pixel rate per channel 140 kHz.

All the tests have been performed using a basic version of the final Data Acquisition System to be used in EMIR. The design adopts the final hardware components and architecture and the main software components. The inclusion of auxiliary software capabilities and the system integration is planned for a next phase.

To speed up software development a prototype to mimic an observing mode is been developed. This prototype is based as much as possible in standard hardware and software components already available. Coordination of actions required to perform the observing mode, data filters, detector control and data acquisition are aspects covered by this development.

5. SCHEDULE

EMIR is now running its fabrication and AIV phase, on which all the EMIR components are in fabrication, or already available to the EMIR team; following this, verification and integration and at component, subsystem and system level will result in the final instrument ready to be mounted at the IAC premises ready to be qualified prior to shipping to the GTC. The work is proceeding as expected, with some delays which have been accumulated since the beginning of the project, being the major challenges the procurement of the pseudogrisms needed for the light dispersion and the multi-slit mask subsystem, as described above. With the current development contracts being well underway, or close to be assigned, we are not expecting major impacts on the instrument schedule to completion. Most of the present day uncertainties in the calendar will be fixed before or around the summer 2006, after the signatures of the pending procurement contracts.

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

- The start of the AIV at component and subsystem level by mid/late 2006.
- The start of the AIV at system level by mid 2007.
- The beginning of the commissioning at the GTC by early 2008.
- EMIR first light in mid 2008.

6. SCIENTIFIC EXPLOITATION

As mentioned in Sec. 1, EMIR is a science driven project. Two teams are at present working in the early preparation of the scientific exploitation of EMIR (Ballcels 2003). The GOYA team, aimed at producing at complete census of galaxies in the early Universe, in an epoch of enhanced star formation and the EAST, recently formed, which will cope the non-GOYA topics to conform a coherent Central Program to be developed during the first phases of the instrument at the GTC, by the use of the Guaranteed Time.

In addition to the above mentioned efforts, and closely related to them, the EMIR team is going to undertake and intensive and extensive astronomical calibration campaign, cooperating with the GTC team, which will permit to overcome the many problems associated with the more classical ad hoc approach, on which the target measurements are directly compared with data taken on standard stars in more or less similar observing conditions. The spatial astronomical missions have, since long ago, accepted the caveats of such calibration procedures and are developing specific calibration tools which increases the value of the date archives. This calibration problem is particularly important in the queue observing scheme adopted by GTC, which needs the setup of clear and systematic procedures.

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