EMIR at the GTC: results on the first commissioning at the telescope

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ABSTRACT

We report the results on the EMIR[1] (Espectrógrafo Multiobjeto Infra-Rojo) performances after the commissioning period of the instrument at the Gran Telescopio Canarias (GTC). EMIR is one of the first common user instruments for the GTC, the 10 meter telescope operating at the Roque de los Muchachos Observatory (La Palma, 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 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 development and fabrication of EMIR is funded by GRANTECAN and the Plan Nacional de Astronomía y Astrofísica (National Plan for Astronomy and Astrophysics, Spain).

After an extensive and intensive period of system verification at the IAC, EMIR was shipped to the GTC on May 2016 for its integration at the Nasmyth platform. Once in the observatory, several tests were conducted to ensure the functionality of EMIR at the telescope, in particular that of the ECS (EMIR Control System) which has to be fully embedded into the GCS (GTC Control System) so as to become an integral part of it. During the commissioning, the main capabilities of EMIR and its combined operation with the GTC are tested and the ECS are modified to its final form. This contribution reports on the details of the EMIR operation at the GTC obtained so far, on the first commissioning period.

Keywords: EMIR, GTC, NIR spectrographs, NIR cameras, commissioning.

1. INTRODUCTION

The battery of 10 m class optical and near-infrared telescopes currently in operation, 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 in an ample range of masses, galaxies and the Universe itself. Also, they are offering, 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 in the late 80's and is still underway to allow these new infrastructures to be used to their full potential. The scientific capabilities of the new telescopes are enormous, not only because of the larger photon-collecting area, but especially because of the new instruments, which, due to major technological advances, are orders of magnitude more efficient than their counterparts built decades ago for medium size collectors. In addition, these technological challenges have established the first steps towards the construction of instrumentation for the forthcoming 30 m+ class telescopes, now at the beginning of their construction 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 10.4 metre Gran Telescopio Canarias (GTC) which started scientific operations in 2009. GTC is 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, whose performances at the GTC will be visited in this paper.

EMIR (*Espectrógrafo Multi–objeto InfraRrojo* – Infrared Multiobject Spectrograph)[1,2] 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

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field selectors. As a reminder, its main instrumental features and expected capabilities, in terms of sensitivities in the two main observing modes, are given 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 de Toulouse-Tarbes (LATT, France) and the Laboratoire d'Astrophysique de Marseille (LAM, France). EMIR will provide GTC with imaging, long-slit and multi-object spectroscopic capabilities). EMIR was shipped to the GTC on May 19th, 2016; it was integrated on the Nasmyth A platform on June, 3rd, 2016; and the first commissioning period was run from June, 13th to 23rd. This phase is being funded by GRANTECAN and the Plan Nacional de Astronomía y Astrofísica (AYA2012-33211)

Table 1 Top level specifications 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	HR:5000,4250,4000 (JHK) for 0.6" (3-pixel) wide apertures LR: 987 for 0.6" slits in HK (1st order) or YJ (2nd order)
Spectral coverage	Full window (HR) / two windows (LR) in a single exposure
Array format	2048x2048 HgCdTe (Rockwell-Hawaii2)
Scale at detector	0.2 arcsec / pixel
Image quality	θ_{80}< 0.3 arcsec
Multi-object spectroscopic mode	
Slit area	6,7x4 arcmin, with 55 slitlets of ~7" long and width varying between 0.4 and 1 arcsec
Sensitivity	K<20.1, t=2hrs, S/N=5 per FWHM (continuum) $F>1.4\times10^{-18} erg^{-1} s^{-1} cm^{-1} Å^{-1}$, t=4hr, S/N=5 per FWHM (line)
Image mode	
FOV	6,7x6,6 arcmin
Sensitivity	K<22.8, t=1hr, S/N=5, in 0.6" aperture

2. THE COMMISSIONING

The overall aim is to integrate EMIR as part of the GTC; test the performance of EMIR; learn and then optimize the operation of EMIR; and, finally, demonstrate that EMIR is ready for science operations. Let us start with a few words on the commissioning plan itself as it has been prepared and developed up to now.

There are many constrains on the overall plan and these have to be allowed for within the plan. They include:

- Limited telescope time (+expensive)
- Limited staff (both telescope and EMIR)
    - One person cannot work 24 hours a day.
    - It is pointless taking data that cannot be reduced in a timely manner. The more complex data sets, particularly those using low S/N objects may take a significant amount of time to reduce and analyse before all of the effects become obvious.
- Cannot guarantee observing conditions. Therefore, where possible there should be a number of possible tasks available at any one time so that the most suitable can be chosen in real time.

There may be other constraints such as a wish to have certain modes available in as short a time as possible where as other may take longer. This paper only deals with the on sky commissioning of EMIR and not with the integration of EMIR onto the telescope. At the beginning of the commissioning, and thanks to the excellent work of the engineering and technical teams, EMIR was integrated in full at the GTC and that the operability and functionality of all subsystems, with special attention to the ECS at the GTC, were in situ tested. All these were done in a very tight schedule as shown in the calendar of EMIR to the GTC in the last weeks, which has been the following:

- May, 20th: EMIR arrives to the GTC
- May, 23rd: integration begin
- June, 2nd: lifted to Nasmyth platform
- June, 13th: start of comm1

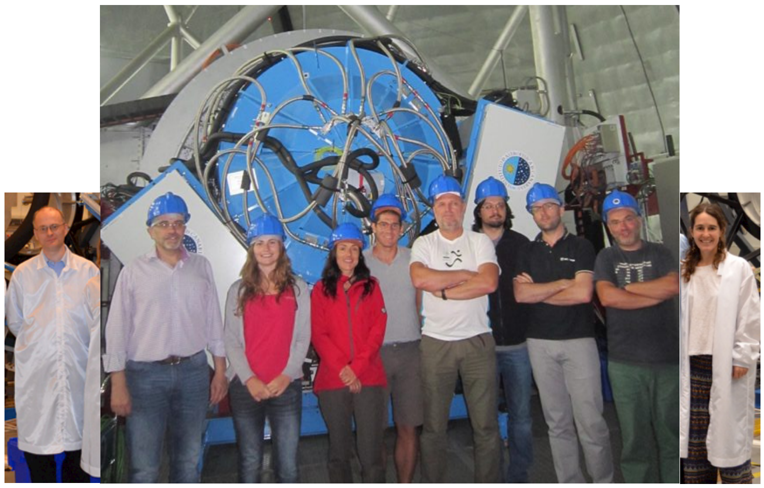


Figure 1: The commissioning team at the GTC Nasmyth A platform. Two members of the team could not come and they are shown at both sides.

2.1 The commissioning tasks

The Commissioning tasks can be broken down in a number of ways. However, a task will fall into one of the following categories.

- Basic observing steps: These are the basic operations which take place during an observation. For example, acquisition, nodding, configuring the instrument, or selecting guide stars. It is only once these steps can be performed reliably that they can be joined into a full observation.
- Calibration of systematic effects: This includes alignment of the instrument (detector) to the telescope focal plane, plate scales etc. i.e. it converts a series of counts on pixels into fluxes from specific locations on the sky.
- Performance characterization: These are the tests which demonstrate that the instrument is performing correctly. It includes image quality, magnitude limits etc.
- Full end to end observations: These tasks join the basic steps together in to a single process going from definition of the observation to reducing the final data. It is only once this has been successfully demonstrated, an observing mode can be considered to be available for science use.

2.2 The overall plan

The test plan breaks the overall commissioning into a series of logically connected tasks. Each task has an aim, a procedure and expected result. Each task also has an expected duration. This duration however will assume no significant problems and suitable observing conditions. Accounting the estimated duration of the full set of tasks, the total time for the commissioning program was initially set as 21 nights, with a maximum of 5 lost nights.

In order to make effective use of the telescope time the total time has been split into three runs: from June 13th to 23rd; from July, 9th to 15th; and from July 24th to 28th. The original goal of separating each period by at least one month cannot be achieved due to organisational constraints, so we were committed to analyse the data virtually in real time, and we are still doing. In view of the very good preliminary results of the first run, subject of this paper, we feel confident that most, if not all, the planned tasks can be successfully executed in the allocated time. It is not unexpected, however, that some specific tests would be moved to September, in a new observing period still undefined.

To optimize the performance of the EMIR team, the first commissioning run has been carried out during half nights. Hence, there is time to look at the results and make changes before the next night. This is particularly true for the ECS and the on line reduction pipeline (DRP), which have been fine tuned virtually every day. The same format will also be adopted for the second period, while we will use full nights on the third and last run.

Table 2 List and short description of the tests planned for the first commissioning.

Ref.	Group	Task
EM002	Before Sky	Check that the instrument can be rotated.
EM003	Before Sky	Check the instrument temperature.
EM001	Before Sky	Basic communication test
EM004	Before Sky	Check Detector noise and detector calibrations.
EM005	Before Sky	Check operation and calibrations of the DTU, GRISM and filter wheels.
EM008	Before Sky	Check operation and calibration of CSU.
EM009	Before Sky	Focus detector onto CSU
EM006	Before Sky	Obtain dome flats in all modes.
EM007	Before Sky	Obtain arc images with the ICM in all bands
EM010	Before Sky	Run sample sequences
EM102	Getting Started	Pointing
EM103	Getting Started	Initial Focus
EM104	Getting Started	Initial Instrument orientation on sky
EM105	Getting Started	Initial Instrument plate scale
EM106	Getting Started	Orientation of image on Screen
EM107	Getting Started	Find initial centre of Rotation
EM306	Sky calibration	Find centre of Rotation and calibrate offset to GP
EM101	Getting Started	Measure the sky flat
EM108	Getting Started	Zero points
EM109	Getting Started	Saturation magnitude
EM110	Getting Started	Check Alignment/initial image quality
EM201	Opt. Quality	Fine Focus
EM202	Opt. Quality	Variation of Focus Across Field of View
EM203	Opt. Quality	Variation of PFS Across Field of View
EM204	Opt. Quality	Alignment of the pupil.
EM301	Sky calibration	Photometric Calibration
EM302	Sky calibration	Plate scale, distortion and orientation
EM303	Sky calibration	Backgrounds
EM304	Sky calibration	Stray light from bright stars
EM305	Sky calibration	Persistence.
EM401	Operations	Guiding accuracy when using fast and slow guiding
EM402	Operations	Offsetting accuracy over 1 to 30” (short distances)
EM403	Operations	Offsetting accuracy over 30” to 30‘ (longer distances)
EM404	Operations	Long term guiding accuracy
EM405	Operations	Main offsetting patterns Dither, Mosaic, Beam switch etc. Calculate accuracy and overheads.
EM406	Operations	Use of point origin offsets
EM407	Operations	Non-Sidereal Guiding
EM601	Obs. Opt.	Imaging of single point sources
EM602	Obs. Opt.	Imaging of star fields
EM603	Obs. Opt.	Imaging of extended sources
EM501_0	Spectroscopy	Source acquisition for long slit
EM502_0	Spectroscopy	Source acquisition for MOS
EM503_0	Spectroscopy	Zero point and saturation levels for each grating
EM504_0	Spectroscopy	Percentage flux/spectral resolution with slit width.
EM505_0	Spectroscopy	Using narrow (2 or 1 pixel slits) with over sampling using the DTU

3. THE FIRST RUN

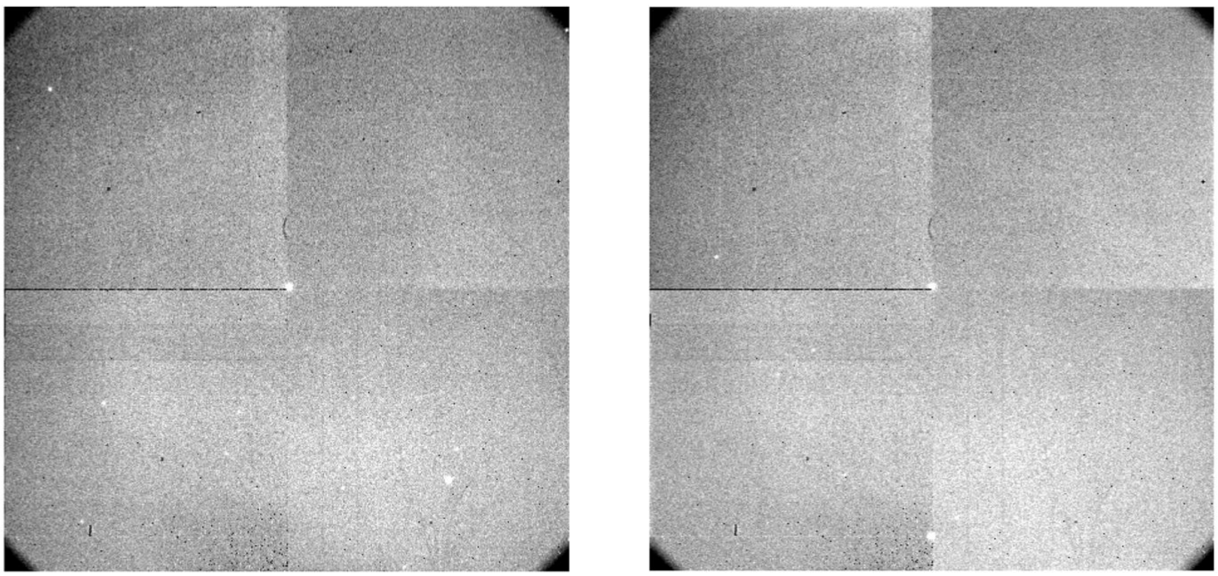
In this first run, a series of tasks were performed several days ahead of the start of the night work. Most of them aim at calibrating different aspects of the instrument and take benefit of the ability of operating EMIR with the external cover closed and multislit pattern in the CSU, which then forms an artificial sky. All but the last three were successfully performed. The list of task is given in table 2.

In the following sections, we are giving a short summary of the results obtained so far. All together, they give an impression of the performances of EMIR at the GTC. Judging them, one must bear in mind that the results depicted here are from the very first run of the commissioning and that period just happened, so only light analyses have been conducted. Given the technical complexity of EMIR and its many configurations attainable, it is easily foreseeing that the instrument will necessitate a much longer period to reach its routine operations. In our view, the sooner the instrument will be used by the community, in shared risk mode, the better so as the assessment from many groups external to the instrument team could be used to fine tune the instrument operations. This goal is one of the main drivers of the commissioning being executed in this very compact format.

4. SOME RESULTS

4.1 The first image

On Monday June 13th, the first day of the commissioning, we opened EMIR to the sky and took the images depicted in figure 2.



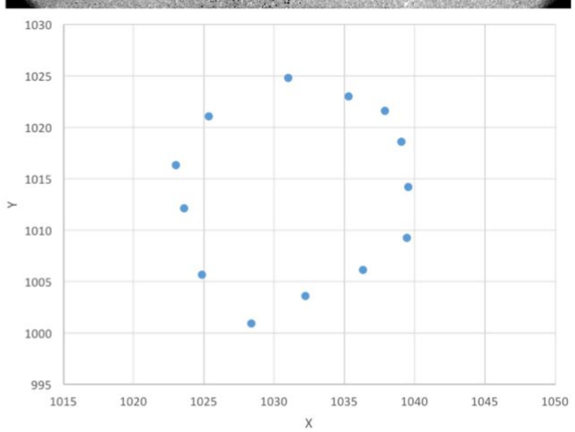


Figure 2: Top left: the very first image of EMIR, with the test star right on the centre. Top right: second image, with the instrument rotated by 30º showing the very good alignment of the centre of rotation with the centre of the detector. Bottom left: raw results of test EM107 (see list on table 2) shown as image motion in detector pixels during a full rotation of the instrument; the internal flexure correction with the DTU was not in place.

4.2 Calibration of the DTU

The Detector Translation Unit (DTU) lies on the heart of EMIR. It consists in a 3D motion system which can move the detector along the optical axis for focusing and in a plane perpendicular to that axis. The latter is used to freeze the sky image on the detector as the instrument rotates during tracking, which causes internal flexures of the instrument. Should these flexures be not corrected it would result in image wander of as much of 6 detector pixels in a complete turn of the instrument. Figure 3 shows the result of the calibration of the DTU motion against the point sources on the sky using only a short exposure image on each position. With this, the image can be stabilized at the detector within a fraction of the pixel size. It is expected to further improve that calibration in the next commissioning taking several images per position to improve the SNR and hence the positional accuracy.

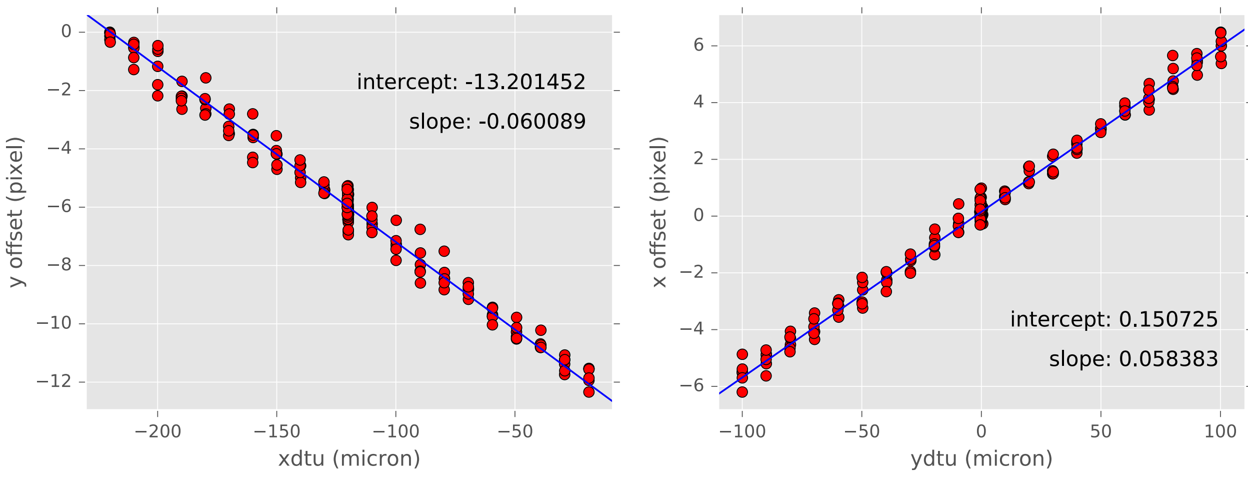
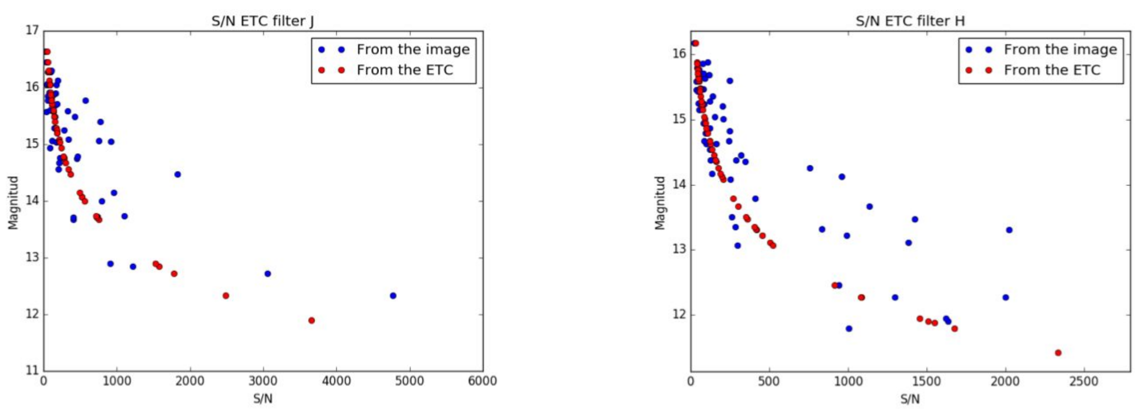


Figure 3: Calibration of the DTU motion, in the XY plane, with respect to the shift of the source images on the detector



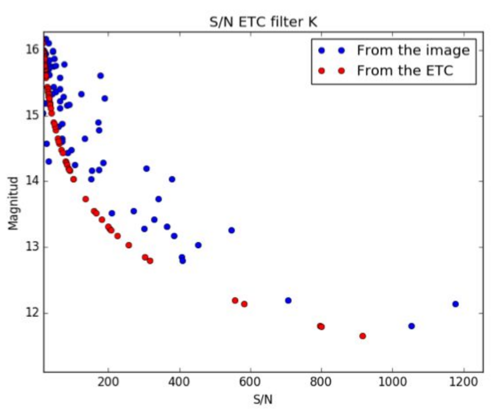


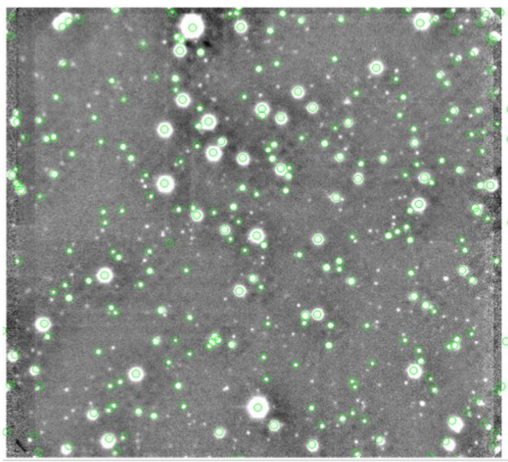
Figure 4: SNR estimates from the ETC in JHKs bands and those measured in the images, after basic reduction with the DRP.

4.3 ETC estimates vs. real data

EMIR will offer to the users a complete suite of observing tools. Between the most demanded is the Exposure Time Calculator (ETC), which is available at the instrument web site: http://www.iac.es/proyecto/emir. During the first commissioning we have analysed every image with point-like sources taken in broad band filters, mostly from NGC5053 and NGC6811, to compare with the ETC predictions. The results so far are quite good, see figure 4, while there is room for improvement. It has to be noted that sky subtraction, one of the trickiest treatment on NIR images, has been performed with the online data reduction pipeline (DRP), which has been continuously fine-tuned during the observations in this particular aspect. Hence, part of the spread on the figure is due to this fact.

4.4 Astrometry

The images from the two clusters used along the commissioning, NGC5053 and NGC6811, have been cross correlated with the 2MASS Point Source Catalogue[3], which offers a standard reference for astrometry at the accuracy level intended in this first commissioning. Some results are depicted in figure 5. The initial guess, left panel, is quite good, without additional correction, except in the corners. As can be seen, right panel, the geometrical distortion can be modelled using the radial distance from the centre of the image as independent variable. A 5^{th} order polynomial can then be fitted to the data, in fact to the median points of each radial bin. This information is since then stored in the header of each frame and so can be corrected. The maximum distortion measured at the edges is at 1.5% level, well within specifications.



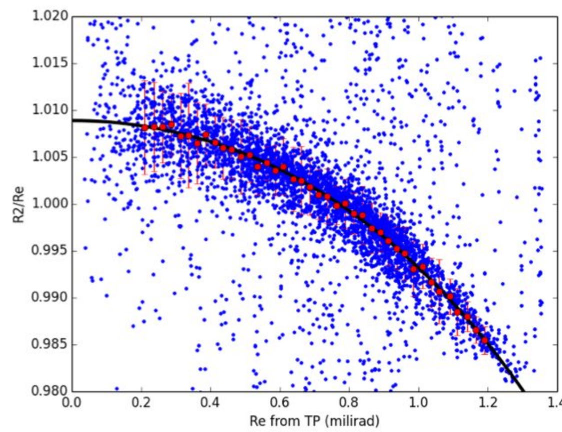


Figure 5: Left panel: cross matches between EMIR images and 2MASS. Right panel: radial fit of the distortion.

4.5 Photometry: zero points and noise parameters

We have compiled, using a large set of stellar objects, the zero points of the EMIR broad band photometrical system. The same caution on sky subtraction mentioned before, apply here, so one could expect some improvement in the near future. Anyhow, the zero points show clearly the potential of EMIR for deep images in the NIR.

- ZP_J=25,25±0,08
- ZP_H=25,50±0,31
- ZP_{Ks}=25,04±0,14

Also, we have characterized the detector noise in real conditions at the observatory. The figures are:

- GAIN: 4±0.47 e-/adu
- RON: 5.23 adu, in single read, which translate to 14.66 e- using a ramp with 10 reads.
- DC: 0.09 adu/s, or 0.36 e-/s

4.6 Images of extended objects

We have commissioned one of the standard observing modes of EMIR which is the dithered and stare images with and without separate sky measurements interleave with the object frames. The DRP is able to accumulate the sky frames, masking the stellar objects which could be present on them; accumulate stare images in the same pointing and subtract the closest sky frame; and, finally, combined the intermediate results of each of the dither pointing. Some true colour images combining J, H and Ks dithered images are shown in figure 6.

Subsequent treatments of the images off the DRP have been performed to improve the final results. Bad pixels rejection and object masking in the sky frames are the aspects on which we have to keep pushing.

Figure 6: Left to right and top to bottom: true colour JHK_S images of NGC6811; M51 and M57-Lyra.

4.7 Some spectra

While not in the initial task list of this first commissioning, we have used part of the day time to take arc spectra in several predefined multislit patterns. This was done mostly to prepare the extraction of the stellar spectra and their preliminary wavelength calibration at the DRP, which will be tested and configured in the second commissioning period. In figure 7 are shown the K band spectra taking with a slit pattern in which opened and closed slits are interleaved to permit a better spectrum identification and extraction, together with the wavelength calibrated result produced by the DRP. This is in the form of an image frame with each spectrum corrected from curvature and filled with a convenient number of zeros on each side to rebin them into the same wavelength calibrated scale.

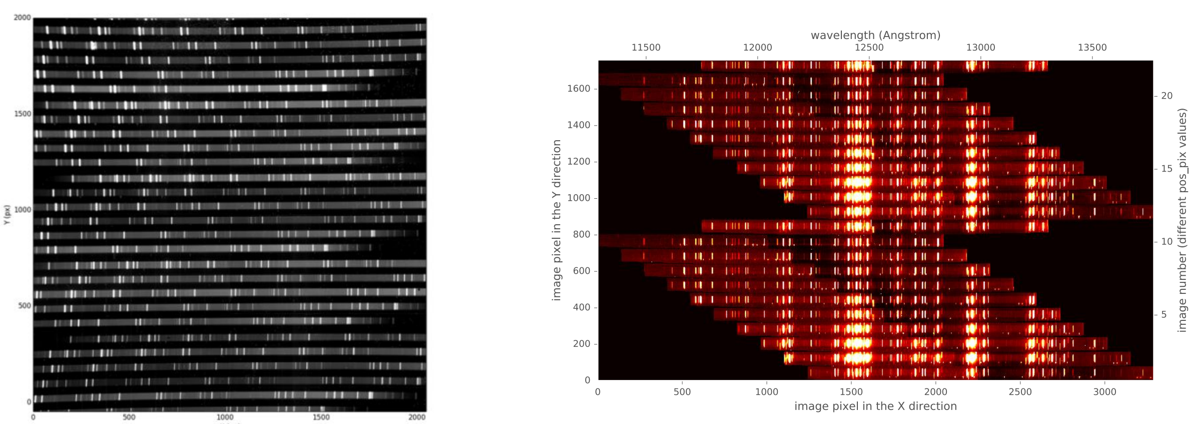


Figure 7: Left panel: raw image of arc spectra in the K band. Right panel: example of reduced arc observations in the J band, where two particular slits were placed in 11 different locations in the focal plane.

5. SHORT TERM PLAN

As commented in section 2.2, we are about to start the second commissioning period, set to July 9th till 15th, which will be mostly devoted to test the spectral performances of EMIR and configured the observing strategies for the early times. If we succeed, then a third period is now booked for July 24th till 28th, aimed at final testing of the observing sequences and of the instrument control system, together with the training of the GTC staff. The goal is that the instrument can be offered to the community as early as possible.

We are tentatively seeking the launch of an initial call of proposals in share risk mode in the final quarter of 2016, with the instrument being delivered to the GTC TAC for the semester 2017A.

6. ACKNOWLEDGMENTS

The commissioning of EMIR is being performed at the Gran Telescopio Canarias as the final part of the development of the EMIR. EMIR was integrated by a dedicated team composed by engineers and technicians of the IAC, in close collaboration with the GTC technical staff. All of them deserves special thanks for an extremely professional job executed in very short time under pressing conditions and with excellent results. EMIR is supported by the Spanish Ministry of Economy and Competitiveness (MINECO) under the grant AYA2012-33211, GRANTECAN, S.A., via a development contract, and the EMIR partnership institutions, in alphabetical order, IAC, LAM, LATT and UCM.

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