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First results of EMIR at the GTC. Status and Short Term Plan.

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Abstract

We report the results on the EMIR (Espectrógrafo Multiobjeto Infra-Rojo) performances after two semesters of scientific operations 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 have been built by a Consortium of Spanish and French institutes led by the Instituto de Astrofísica de Canarias. EMIR is primarily designed to operated as a multi-object spectrograph 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 2.5 μm. The development and fabrication of EMIR is funded by GRANTECAN and the Plan Nacional de Astronomía y Astrofísica.
EMIR was shipped to the GTC on May 2016 for its integration at the Nasmyth platform. From June till November 2016 several commissioning periods were conducted. Then a short Science Verification phase was launched on which EMIR was offered to the community to test its capabilities on sky in image and long-slit observing modes. In March 2017, EMIR was included in the call for observing time in semester 17B and started routine scientific operations at the GTC from July 2017. In November 2017, EMIR was lifted off the Nasmyth platform for the first maintenance period and resume operations at the end of February 2018. Multi-object spectroscopy (MOS) commissioning has taken place, in two periods, starting at the beginning of March 18. At the time of this writing, the MOS commissioning and internal verification phases have been completed and the open science verification is underway. The MOS mode has been offered in the CAT19A.
This contribution summarises the results and performances of the EMIR operation at the GTC since the beginning of its routine operation at the GTC.

1 Introduction

EMIR (Espectrógrafo Multi-objeto InfraRrojo – Infrared Multiobject Spectrograph, [2] and [3]), 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. EMIR provides 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 was shipped to the GTC on May 19th, 2016; it was integrated on the Nasmyth A platform on June, 3rd, 2016; and the commissioning periods took place from June to November 2016. A short Science verification phase was run shortly after the commissioning, in the first semester of 2017 and then the instrument was offered to the community, beginning in 2017B. The results of the commissioning have been presented in [4] and [5], among other publications.

Due to the high complexity of the instrument, the tuning EMIR at the GTC has run in parallel to the scientific operations, with the participation of the scientific and technical staff of EMIR at the IAC and the UCM and the corresponding groups at GRANTECAN. Only recently, EMIR has reached a decent degree of maturity at the GTC and can be operated smoothly and efficiently. The last observing mode of the three mains, the MOS, has completed its first runs at the GTC in the last months. With this achievements, the status of EMIR at the GTC can be considered stable enough as as the team can concentrated from now on of the monitoring and improvements of its capabilities. The next sections will summarise what EMIR has already achieved at the GTC and what are the plans for the short term.

2 Calibrations and corrective actions on EMIR subsystems

2.1 Detector

From the beginning at the GTC, EMIR has suffered of two problems associated with the detector. The first one consisted in a poor orientation of the detector array with respect to the instrument focal plane which resulted in a marked loss of image quality. During the maintenance period of November 16 - February 17 on which EMIR was removed from the Nasmyth platform, this tilt was largely corrected with a residual inclination of around 4 and 2 mrad with respect to the detector X and Y axes respectively, to be compared with the previous value of 12 and 8 mrad, and currently in 0.8 arcsec seeing the increase in FWHM is at most 20% at the edge of the field as can be seen in Fig. 1. Figure 1, a composite image made using many Ks images in good seeing condition, show an alternative representation to the image quality after the correction, where the colour and circle size indicates the measured FWHM for each source in a star field. Again it is clear that there is only a slight loss if image quality in the corners of the field.

The EMIR detector also showed an irregular and somewhat erratic behaviour under low illumination conditions. This is particularly important in spectroscopy, where in between the sky lines the background is really low hence permitting a proper detection of faint signals.

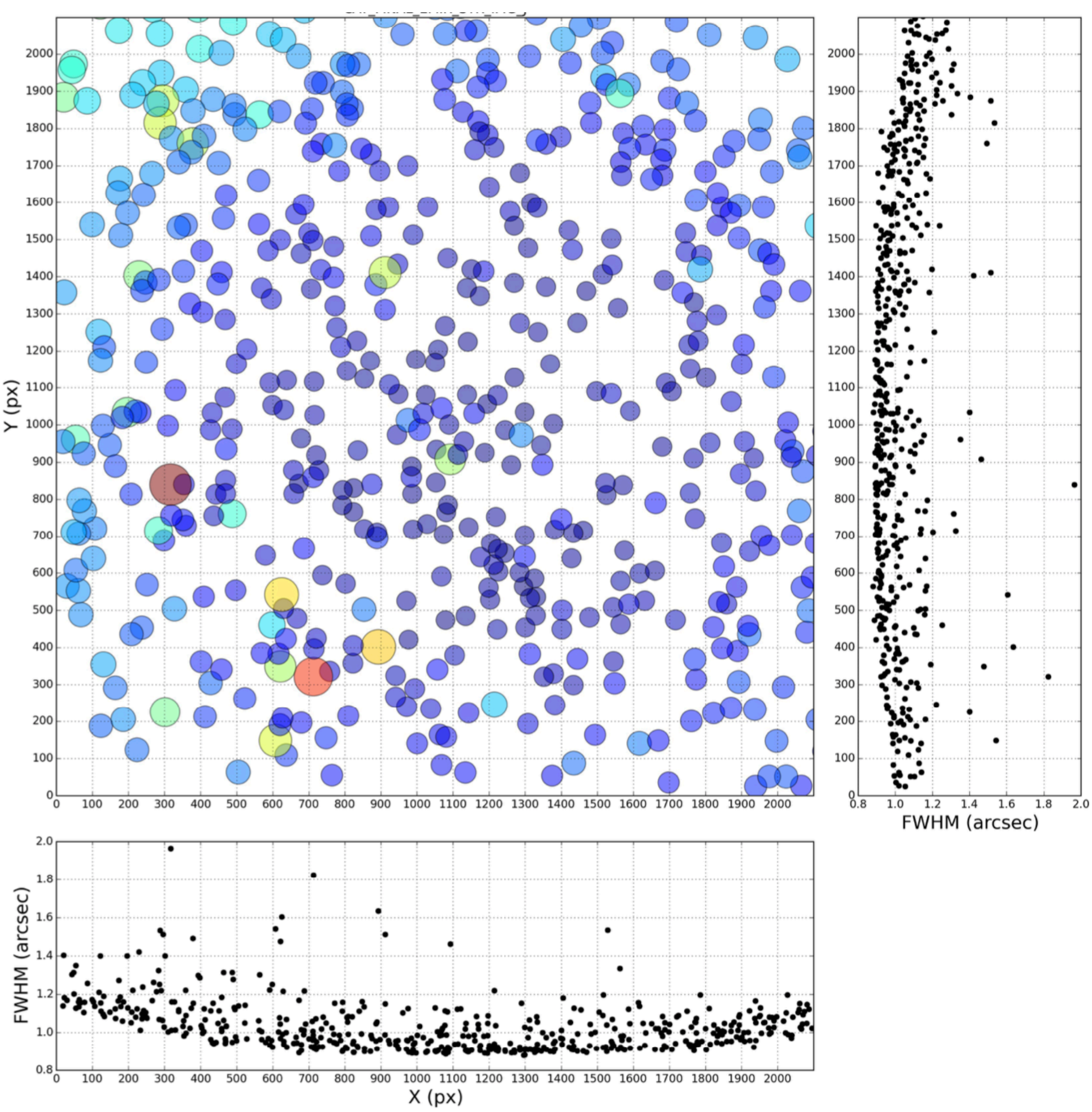

Figure 1: PSF sizes of the images on the detector. The sizes of the circles are proportional to the PSF size. The two small panels show the variation of the PSF with respect to the X and Y pixels at the detector.

We have undertaken an intensive campaign for exploring different ways of configuring the detector readout modes using dark current measurements as a proxy for this purpose. The objective has been to achieve a more regular pattern of the detector reads that permit the calibration and on-line removal of this effect. Figure 2 shows the results of this campaign. A single panel on Fig. 2 represents the average of a section of 5k pixels on the centre of each of the 32 detector channels. Only four of these segments are shown. It can be seen how the trend of the detector reads in 10 consecutive ramps is markedly more regular on the right side

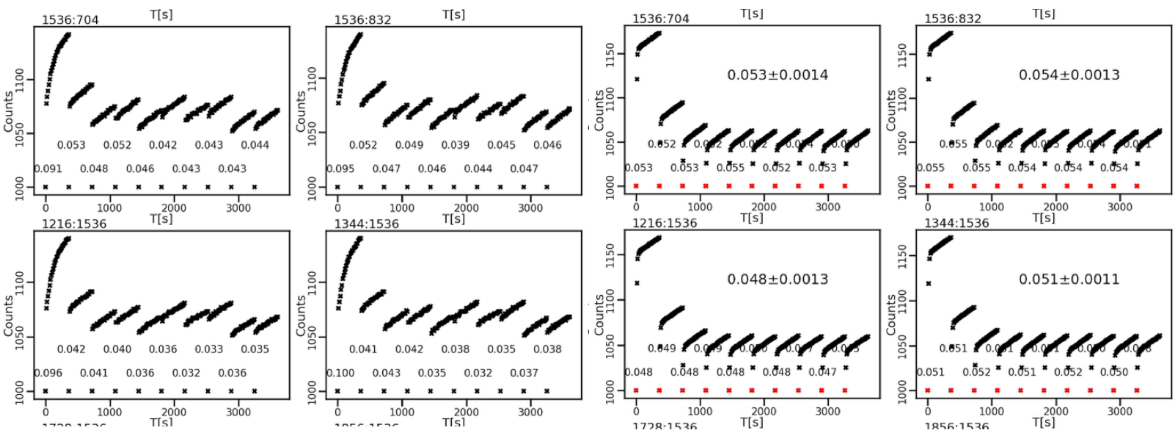

Figure 2: DC level in 10 consecutive ramps, 360s of integration time each. The 4 panels on the left correspond to the old read modes and the ones in the right, to the new modes. See text.

panels compared to the left ones. These calibrated DC measurements, a sequence of 10 series for each of the permitted single integration times, are loaded by the Emir Control System (ECS) at the GTC and removed from the detector reads before saving the data to disk. Hence, a large fraction of the non-uniformities in the detector frame series are not present in the final data. A point to be taken into account for those users interested in reaching the very faint limit of EMIR, is the fact that this removal has the unavoidable effect of adding the noise of the DC calibration, which is a small fraction of that in the object frames, but might be not negligible. It is always possible to revert the effect of the DC and detector drift calibration using simple scripts that can be made available to the interested users.

2.2 Cold Slit Unit (CSU)

The CSU is a system that lies in the heart of EMIR as its spectroscopic capabilities, both in long slit and in MOS, relies on its proper functioning. During the maintenance period mentioned before, we replaced a significant fraction of the cryogenic piezo set, which are the motors of the actuators that control the the bar motion, that have shown signs of degradation, by new ones with better specs in cryogenic conditions. After this, a long calibration campaign took place, again during day time, which have resulted in a control of the position of each sliding bar with accuracy better than 0.15 px in the worst cases. Figure 3 shows the accuracy over the whole length of a long slit 0.6 arcsec wide measured in terms of the flux variation over the slit under uniform illumination conditions.

2.3 On-line and off-line Data Reduction Pipeline

Since day one of EMIR at the GTC, much efforts have been devoted to, first tune an operative pipeline at the telescope that permits a real time monitoring of the observations, and then

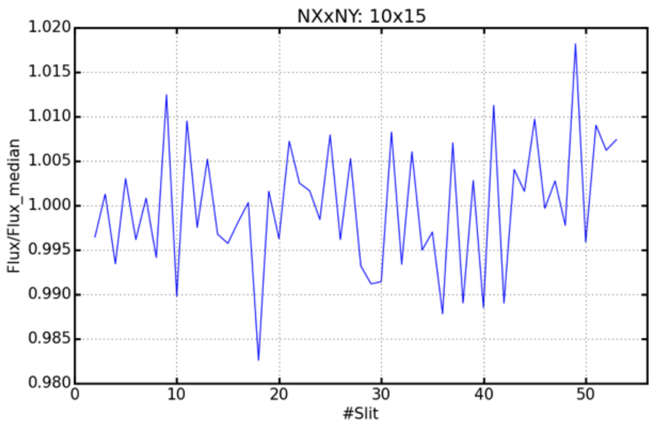

Figure 3: Ratio of the flux measured in a box of NX×NY pixels centred on each slitlet with respect to the median flux over the whole long slit.

to build a stand-alone system which will do the full reduction of the EMIR data till the level on which the scientific analysis can start. The first of these task is of outmost importance to make it possible the EMIR observations at the GTC, as the on-line DRP is providing a quick look of the data taken for initial configuration of the instrument and telescope, in one hand, and then of the observation products as they are being taken. The EMIR group at the UCM, together with software engineers of the teams at the IAC and and GRANTECAN, is coping with this task, that has to develop in the framework of the GTC Control System (GCS) which is updated frequently to accommodate new features and/or remove bugs and inefficiencies in the performances. After many interventions, the EMIR on-line DRP is now capable to deal with the run of the observations in an efficient way and it can be considered on its final status except, maybe, for minor adjustments dictated by upgrades in the GCS. The current version of the on-line pipeline includes the automatic wavelength calibration of data taken in spectroscopic modes, as described in [1] and in Cardiel et al. (*Reducing EMIR spectroscopic data with Python*, these proceedings).

Many of the capabilities of the on-line pipeline can be found also in the off-line version (*pyemir*), which can be downloaded from (https://github.com/guaix-ucm/pyemir). There are still some features which are missing in the current version of *pyemir*, for example the spectral flat fielding correction, but the team is working to be able to accommodate the needed capabilities in the short term.

3 Science observations with EMIR

In this section a brief sketch of some results obtained from observations with EMIR will be given. Some are not yet published but all together can provide a picture of the present day capabilities of the instrument. During the last observing campaign of the commissioning of the MOS mode, several scientific programmes were used as test beds to verify the performances of EMIR in MOS mode, and some preliminary results from them will also be shown here.

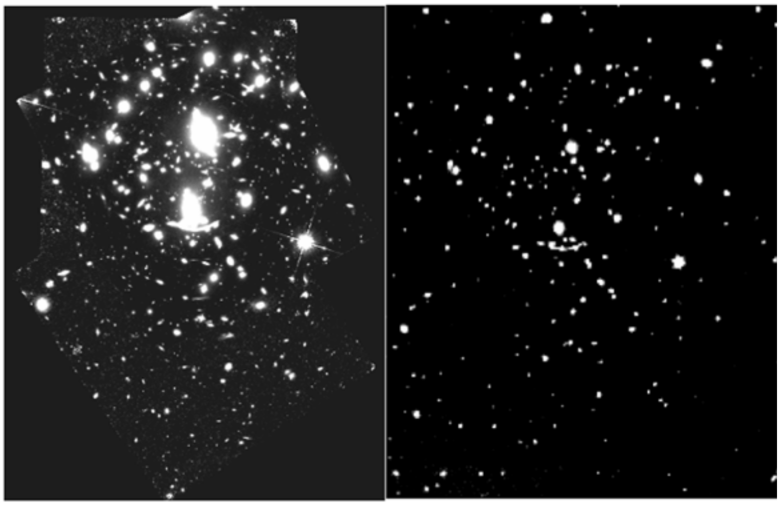

Figure 4: A370 images from HST in FW160 filter, left, and from EMIR in K_s.

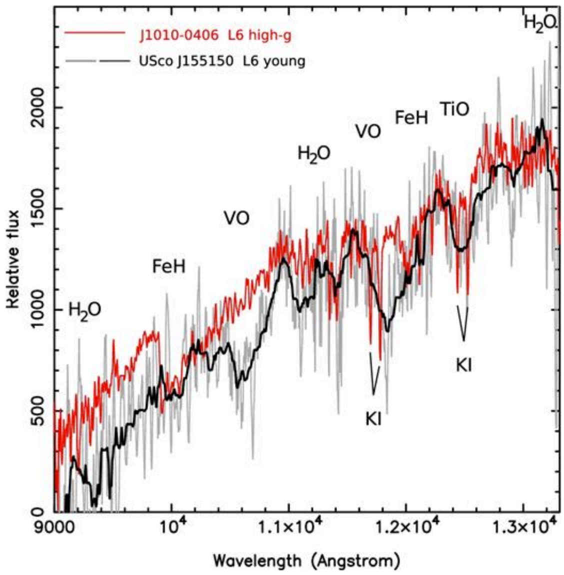

Figure 5: EMIR spectra of 2MASS 10101480-0406499 (red) and USco J155150.2-213457.

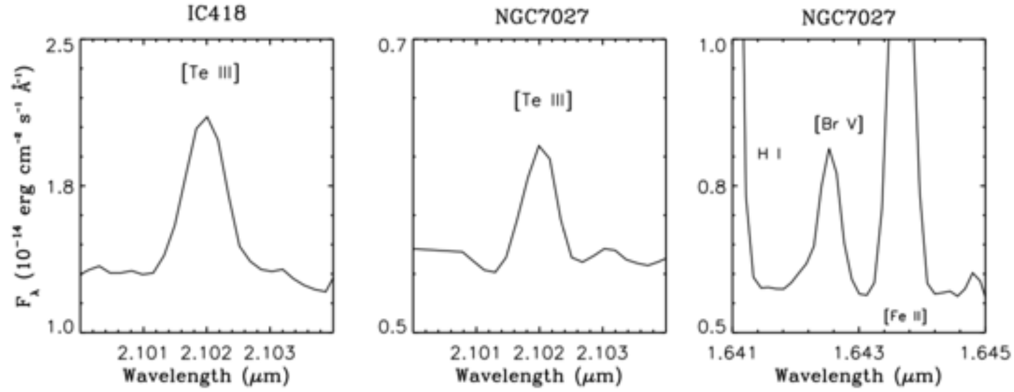

Figure 6: EMIR spectra of the newly detected PNe emission lines.

During the initial science verification after the first commissioning runs, a deep image of the Abell 370 galaxy cluster in K_s was taken and is shown in Fig. 4, together with the corresponding HST image of the same field.The image is the result of the co-adding of many individual frames of 3s exposure time each, totalling 1470s, with average PSF FWHM of 0.8 arcsec. The limiting magnitude at SNR=3 is 20.17. The HST image of A370, covering roughly the same area, is shown in Fig. 4 for comparison. That has a total integration time of 75788s with pixels size of 60 mas after drizzling.

[6] was the first in publishing an infrared spectrum taken with EMIR, which is shown in Fig. 5. These are a couple of L6 dwarfs of young planetary-mass in the Upper Scorpius association.

In [7] two new near-infrared emission lines, [Te III] 2.1019 μm and [Br V]] 1.6429 μm, in the spectra of planetary nebulae (PNe) arising from heavy elements produced by neutron capture reactions were identified in two PNe, NGC 7027 and IC 418. [Te III] was detected in both PNe, while [Br V] was seen in NGC 7027 only. The emission lines are shown in Fig. 6.

To end with this short review of EMIR results, some fresh observations of two programmes in MOS mode are presented. The first one correspond to a MOS mask of the GALEP project. GALEP aims at using EMIR to obtain near IR spectroscopy of many thousands sources, the vast majority of which are located in the inner Galaxy. Its main aim is to accurately classify the sources to tackle ambiguities in the interpretation of structures in the inner Galaxy. Figure 7 depicts several spectra of GALEP sources in the K band taken in a single shot with a MOS mask designed for the field, using the mask designer tool (OSP) developed at LATT. The spectra in Fig. 7 will be analysed by the Ferre code used in the APOGEE, for which it is necessary to develop a sort of *interface* to conform to the APOGEE prescriptions. This work is underway.

A second programme, with obvious areas in common with GALEP, deals with the search and characterisation of red supergiants in the Galaxy. In Fig. 8 the spectra in the J band are of 9 RSG candidates in the Young Massive Cluster RSGC01, which contains a very rich population of RSG stars. The goal is to provide metallicity estimates, for the first

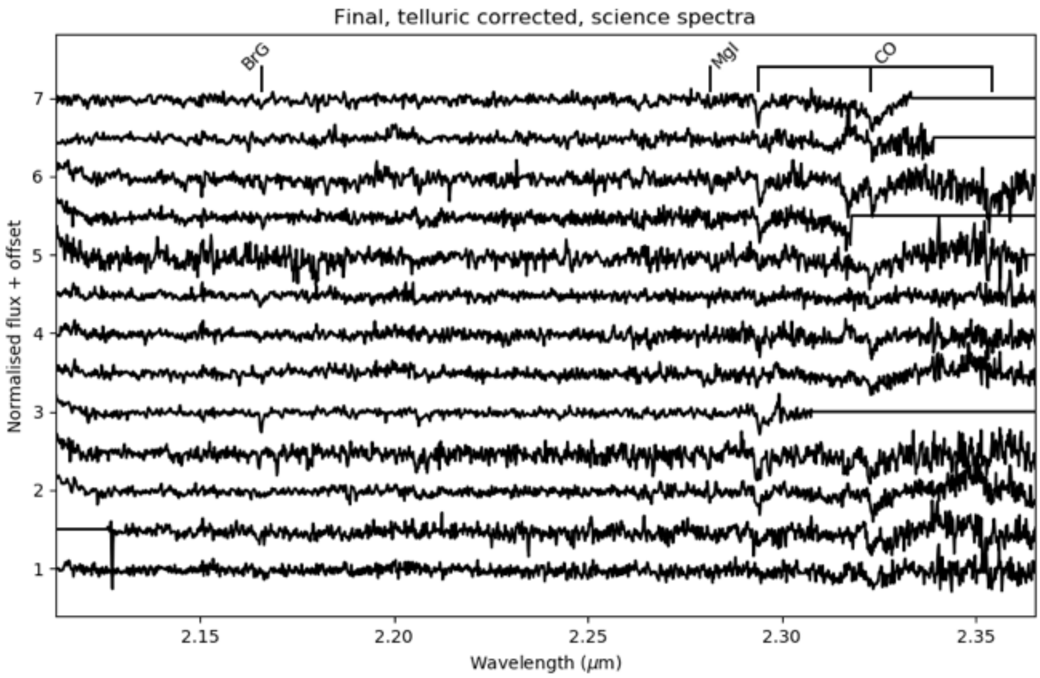

Figure 7: EMIR spectra of GALEP sources in the K band taken with a single MOS mask.

time, for this cluster. This will be done using a narrow spectral window in the J-band where elemental features arising from Fe, Mg, Si, Ti dominate the spectral appearance.

4 Plans for the short term

As mentioned before, at the time of this writing the MOS commissioning and internal verification phases have been completed and the open science verification is underway, and the MOS mode has been offered in the CAT19A. The plan for further actions on EMIR includes several tasks to maintain and improve whenever possible the performances of the instrument. The foreseen actions act in three main areas of the instrument: the ECS and software in general, including both on-line and off-line pipelines; the EMIR hardware subsystems; and the EMIR observing modes.

The plan for the ECS aims at a complete refactoring of the software, once the desired capabilities of the control system have been achieved. The ever changing environment of the GCS is imposing this action. That will include the interfaces between the ECS and the on-line DRP, which has to be modified accordingly. This upgrade will have very little, if any, influence in the observation results but will make the EMIR operations at the GTC more efficient, reliable and robust. An important aspect of the EMIR general software upgrades, and with a high impact in the user community, is the evolution of the off-line DRP to include the missing capabilities and permit a more complete data treatment.

As per the actions in the EMIR hardware, the current plan includes a maintenance stop during 2019 or 2020, yet to be decided, to remove the residual tilt of the EMIR detector,

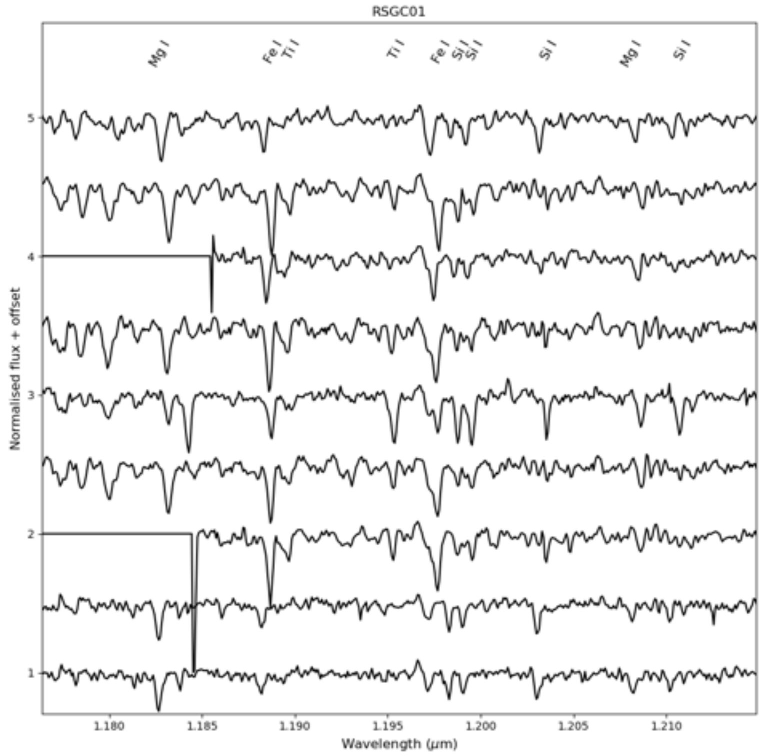

Figure 8: EMIR spectra of RSG in the J band taken with a single MOS mask.

commented in section 2.1. During this stop, the remaining set of old model CSU piezos will be replaced by the new ones.

Finally, the plans to improve the EMIR performances also contemplates the tuning of the detector read modes design to get rid of as many artefacts as possible. That will need a close monitoring of the data taken in different modes by the user community to first identify the spurious effects and then design and test ways of treating them.

Acknowledgments

EMIR is being operated at the GTC by a dedicated team composed by scientist engineers and technicians of the IAC, in close collaboration with the GTC astronomical and technical staff. All of them deserves special thanks for an extremely professional job executed under pressing conditions and with excellent results. EMIR is supported by the Spanish Ministry of Economy and Competitiveness (MINECO) under the grant AYA2015-66506-P; the Canarian Agency for Research, Innovation and Society of Information (ACIISI) under the grant ProID2017010117; GRANTECAN, S.A., via a development contract, and the EMIR partnership institutions, in alphabetical order, IAC, LAM, LATT and UCM.

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