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CAB Contribution to HARMONI: The first light spectrograph of the E-ELT

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Abstract

HARMONI (*High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph*) is a visible and near-infrared (0.47 to 2.45 μm) integral field spectrograph selected as a first-light instrument for the *European Extremely Large Telescope* (E-ELT). With four spatial scales (60, 20, 10 and 4 mas) and a wide range of spectral resolving powers (R=3500, 7500, 20000), HARMONI will allow scientists to address many of the E-ELT science cases. The HARMONI Consortium is led by the University of Oxford, and is also formed by the UK Astronomy Technology Centre (UKATC, Edimburg, UK), Centre de Recherche Astrophysique de Lyon (CRAL), Laboratoire d'Astrophysique de Marseille (LAM), Instituto de Astrofísica de Canarias (IAC, Spain) and the Centro de Astrobiología (CAB INTA-CSIC, Spain). We summarize here the current status of the project, and describe the participation of CAB to design and manufacture two of the instrument subsystems: the calibration unit and the secondary guiding module.

1 Introduction

HARMONI (*High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph*, [4]) is the *European Extremely Large Telescope's* (E-ELT, [3]) first light optical and near-infrared spectrograph. It is foreseen to be a work-horse instrument that will allow scientist to address a wide range of programs. Design to operate with different AO flavours, i.e. Laser Tomography AO (LTAO full correction using multiple laser guide stars over most of the sky), Single Conjugate AO (SCAO, full correction using bright natural stars) and in seeing-limited conditions, it will provide integral field spectroscopic capabilities from 0.47 to 2.45 μm at a wide range of spatial scales and resolving powers. Figure 1 shows a preliminary CAD render of the instrument, located at one of the side-looking ports at one of the E-ELT Nasmyth foci.

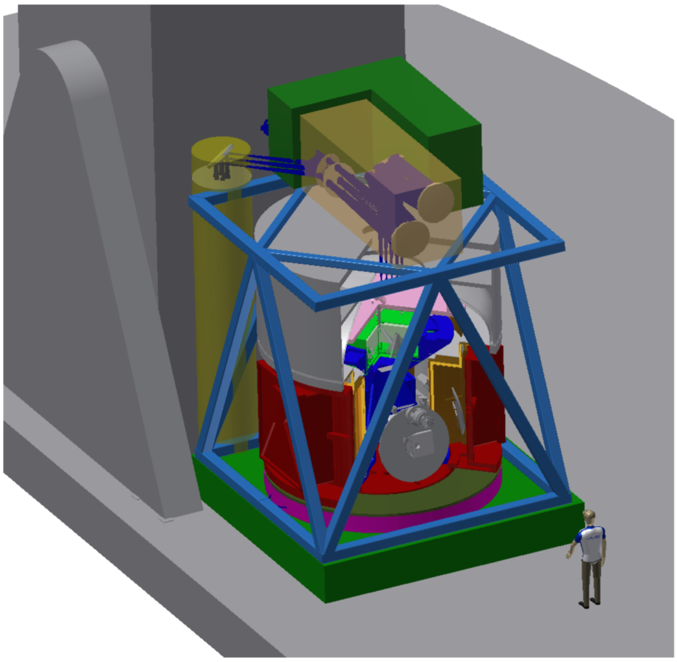

Figure 1: CAD rendering of the various sub-assemblies of HARMONI. The Nasmyth platform and the telescope pre-focal station (PFS) are shown in light and dark grey, respectively. The HARMONI IFS cryostat is shown in red, the secondary guiding is part of the wavefront sensor modules on top of the cryostat (in light grey), and the calibration module & dichroic exchange unit is shown in dark green. The LGS WFS module is represented by a vertical cylinder in yellow, the focal plane relay unit in olive green, and the support structure for it in blue.

HARMONI has four spaxel scales in its baseline design (60, 20, 10 and 4 mas), so as to optimally match the sensitivity and spatial resolution to the observing programme over an instantaneous FoV of $\sim 152 \times 214 = 32,528$ spaxels (6.42" × 9.12", 3.04" × 4.28", 1.52" × 2.14" and 0.61" × 0.86", respectively). The coarsest spaxel scale maximizes the field of view of the instrument, and is best suited for non-AO and visible observations. The 20 and 10 mas provide optimal sensitivity for extended objects and the best combination of sensitivity and spatial resolution, respectively. Finally, the finest spaxel scale is matched to the diffraction limited core of the PSF delivered by the telescope.

Three different resolving powers are foreseen for the instrument, i.e. R∼3500, 7500 and 20000, and an additional fourth high resolution grating is planned to be specified by the end of the Preliminary Design Phase (PDR). The wavelength coverage of the various settings are set to match the atmospheric transmission windows in the near-infrared, wherever appropriate. The resolving powers and wavelength coverage of the different settings are defined in Table 1.

The Centro de Astrobiología (CAB INTA-CSIC) has actively participated in the HARMONI project since its beginnings in 2007. The main responsibilities of the CAB are the design, manufacture, integration and test of two of the sub-systems of the instrument, i.e.

Table 1: HARMONI resolving powers and wavelength coverage

Band	R	$\Delta\lambda$ [μm]
V+R	3000	0.5–0.8
IzJ	3000	0.83–1.35
HK	3000	1.45–2.4 (goal 2.45)
Iz	7000	0.83–1.05
J	7000	1.05–1.32
H	7000	1.45–1.8
K	7000	1.97–2.40
J_{high}	20000±2000	1.19–1.30 (TBC)
H_{high}	20000±2000	1.54–1.67 (TBC)
K_{high}	20000±2000	2.10–2.28 (TBC)

the calibration and the secondary guiding sub-systems, and to elaborate and develop the calibration plan of the instrument.

The CAB also participates in two of the main science cases driving the high-level design requirements of the instrument: The high-z ULIRGs [2], [1], and the black holes and AGN [5].

2 Status of the project

In October 2015, the contract to design, build, test and commission HARMONI was signed between the European Southern Observatory (ESO) and the UK Science and Technology Facilities Council. Following this signature, the project started its PDR phase, that will continue until October 2017. The next two years, until 2019, will be dedicated to finish the detailed design of the instrument, and after five years of manufacturing, assembly and tests, HARMONI is expected to arrive at the telescope by mid 2024.

During the first year of PDR, the baseline architecture of the instrument was defined, after different trade-off studies. In particular, we opted for one of the designs developed during the Phase A and the Interim Study of the project, that consists on a gravity invariant cryostat, rotating about a vertical axis to compensate for field rotation (see Figure 2). The primary driver was the stability of the calibrations, particularly the wavelength calibration at high spectral resolving power. This is paramount for a successful sky subtraction in the near-IR to a high degree of accuracy.

In addition, since HARMONI is expected to achieve an adequate sky coverage ($\geq$50% on average) under AO operations, and almost complete ($\sim$99%) under seeing-limited conditions, we adopted a cold optical relay optics as a solution rather than an optical de-rotator (K-mirror), to maximize the field of view of the technical field available at the relayed focal plane. This will allow us to patrol a circular field of $\sim$2 arcmin diameter for guiding sources for the LTAO and secondary guiding sub-systems.

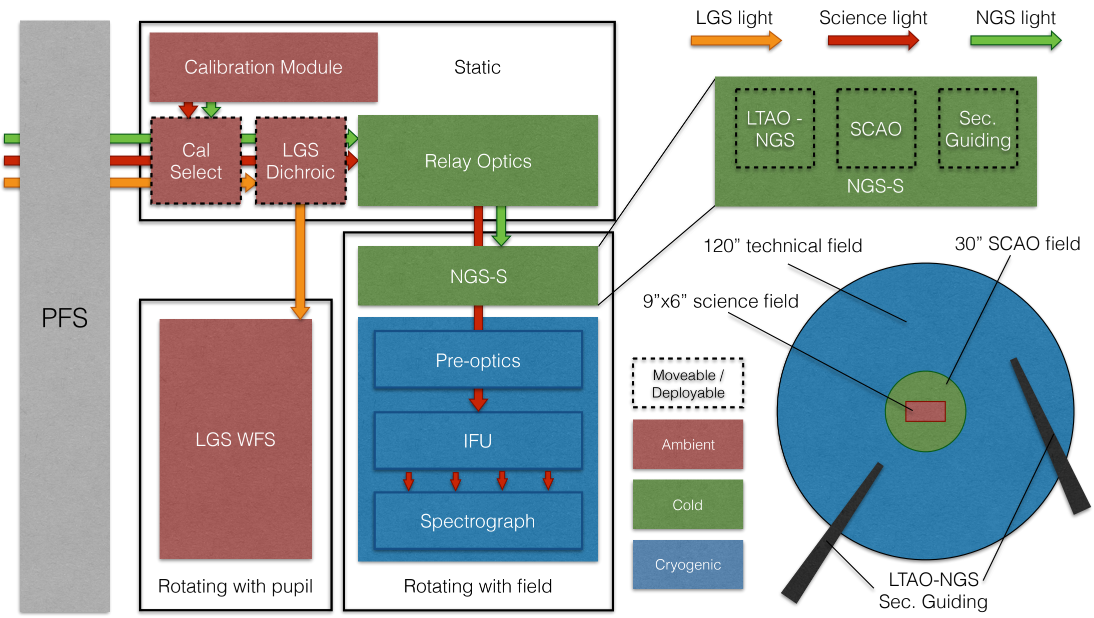

Figure 2: Top-level block diagram of HARMONI, including the H-LTAO system, showing the thermal environment of each component. In the bottom right corner there is a sketch of a zenithal view of the NGS-S technical field, showing two of the WFS patrolling probes.

3 Calibration Module

The calibration module will simulate the optical output of the telescope generating an exit pupil with the same size and position as the one delivered by the telescope. It will also provide the functionality needed to illuminate the focal plane with an exit beam that mimics the telescope focal-ratio of F/17.718, offering a uniform illumination of 1% at the focal plane over the science field (∼12 arcsec diameter). This involves wavelength calibrations, flat fields, well-known geometrical patterns and point-like sources for calibrating the IFS, together with the ability to calibrate the LTAO natural star low order wavefront sensors, the SCAO wavefront sensor and the secondary guiding sensor.

The main functional requirements of the calibration module are:

- Provide illumination to allow spaxel-to-spaxel (or pixel-to-pixel) sensitivity calibration.
- Provide illumination necessary to transform detector pixel coordinates to x, y, λ coordinates in the input field (i.e. wavelength calibration, geometrical distortion, etc)
- Provide illumination to characterize the instrument spectral and spatial PSF.
- Provide the ability to measure the location of focal plane masks (e.g. coronagraphic spot)

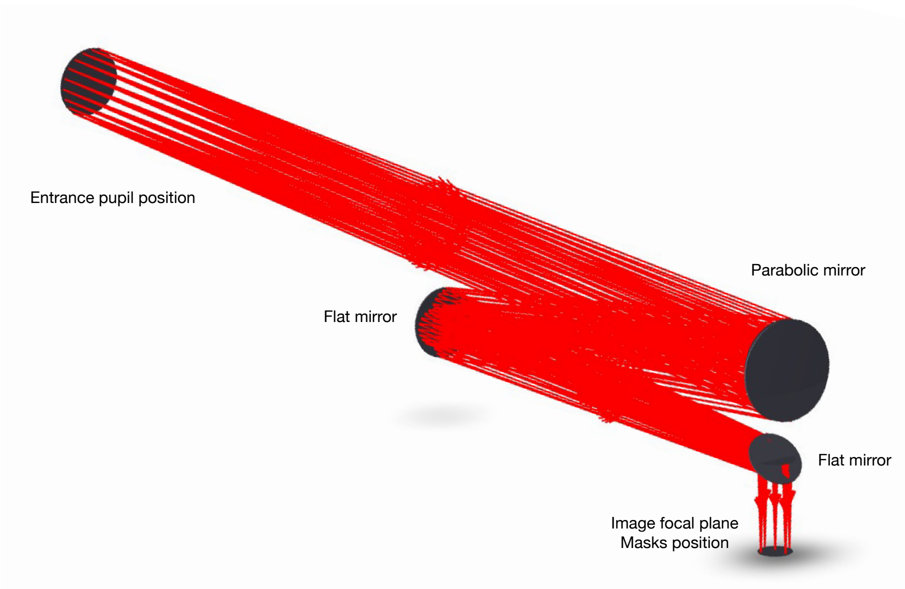

Figure 3: Calibration module preliminary optical layout.

Some of these functionalities will be implemented via a focal plane mask wheel carrying field stops and calibration masks, the cold pupil stop and pupil imaging optics to calibrate the IFS and SCAO field of view. In addition, a set of optical fibres is foreseen to deliver a well-known grid of point-like sources over the technical field.

During this first year of PDR, the optical design of the calibration module is being carried out in collaboration with the Durham University. As shown in Fig. 2, the calibration module will be located as early in the optical path as possible, to provide maximum common path with the science light, and to be able to calibrate the deployable dichroic mirror for LTAO. A preliminary optical design of the module is outlined in Fig. 3.

4 Secondary Guiding Module

The secondary guiding subsystem basic requirement is to provide knowledge (relative and absolute) of the location of the science focal plane on timescales of a few seconds and longer (up to months) during seeing-limited observations, to compensate from movements of the Nasmyth platform. To maintain the image quality during observations, the position of the science focal plane has to be well-known with an accuracy of at least $\leq$25% of the seeing FWHM.

To achieve this, the secondary guiding will be able to patrol the 2 arcmin diameter technical field of HARMONI to track the position of a guiding source (star or galaxy) during observations (see Fig. 2). The subsystem will measure the position of the guiding source on its detector on timescales of $\sim$1 s to stabilize the science field during the expositions, conserving as much as possible the image quality.

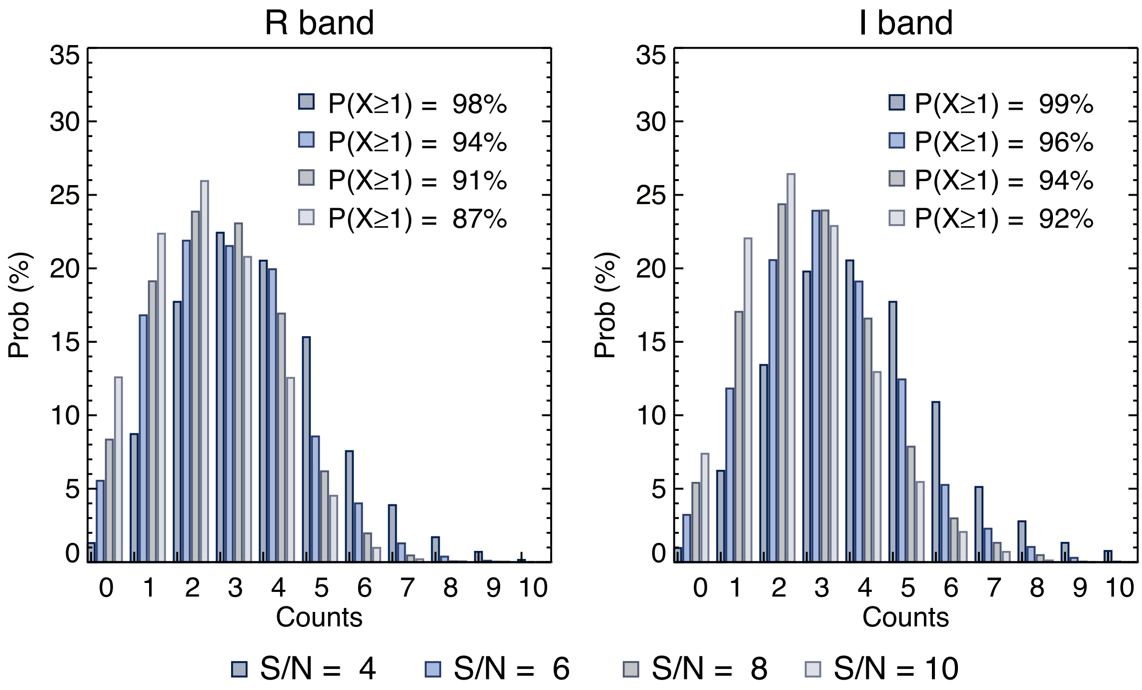

Figure 4: Probability distributions for finding at least one suitable guiding source on the HARMONI technical field on the R and I bands, respectively, for different values of the peak S/N.

Guiding will be performed on the I-band, which maximizes the probability of finding at least one guiding star on the technical field without being much affected by differential atmospheric refraction. Figure 4 shows the probability distribution for finding suitable sources for guiding on the R and I bands. To simulate the sources distributions, we considered a realistic scenario of a typical cosmological field, in terms of low star surface density and a galaxy surface density similar to the GOODS-South field. This assures a sky coverage for HARMONI of nearly the 99% of the sky during seeing-limited observations.

Acknowledgments

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