Highlights of Spanish Astrophysics VII, Proceedings of the X Scientific Meeting of the Spanish Astronomical Society held on July 9 - 13, 2012, in Valencia, Spain. J. C. Guirado, L. M. Lara, V. Quilis, and J. Gorgas (eds.)

HEXA: a machine for spectroscopic cartography

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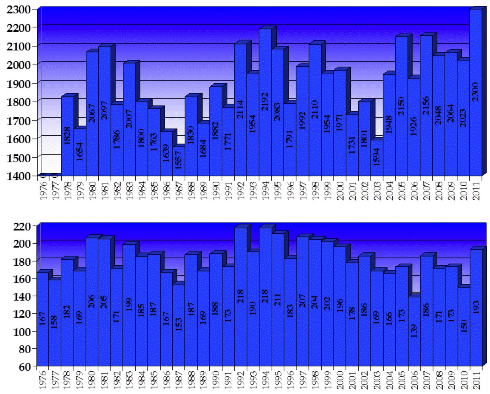
Abstract

We have performed a conceptual and viability study for HEXA, a 6.5 m aperture, wide-field telescope, with high multiplexing factor, framed in the strategic plan for the Calar Alto observatory in 2014-2018 and beyond, centred on the scientific cases arisen from the current need for wide-field spectroscopic surveys with very large multiplexing capability. The baseline design considers a field–of–view of 1.5°, multiplexing factor around or over 500 and possible spectral resolutions in the interval $R = 5000 - 50\,000$, with instruments placed on two Nasmyth platforms. Other variants are also considered, including Ritchey–Chrétien and prime-focus solutions. The telescope concept is described, together with the instruments that have already undergone, or that are still undergoing, the conceptual design process: CEO, an innovative Imaging Fourier Transform spectrograph. GEA, a *Gaia*-inspired drift-scanning slitless spectrograph. BRONTESS, a fast and simple camera for guiding and ToO work. A PMAS-based multi-IFU, highly multiplexed spectrograph. And the multi-fibre spectrograph GYGES. Some of the instrument concepts analysed are based on the versatile fiber-positioner HECATE (with a minimum of 361 positioners). Some of the fibre-based instruments would allow, too, fibres entering a battery of CAFÉ-type high-res spectrographs.

1 The observatory

The Calar Alto Observatory holds a significant number of astronomical telescopes and experiments, covering a large range of the electromagnetic domain, from gamma-ray to near-infrared. It is a very well characterized site [5, 6], with excellent logistics. The operations of the telescope is guaranteed until 2018 due to the renewal of the agreement between the partners, the Max-Planck-Gesellschaft (MPG, Germany) and the Consejo Superior de Investigaciones Científicas (CSIC, Spain). It is also an excellent site, since the number of useful hours are about 2000 per year (Fig. 1).



	2012 OPTICAL	2012 Near-infrared	2014 OPTICAL	2014 Near-Infrared
3.5m .-	**PMAS** TWIN LAICA MOSCA	**Omega2000** ~~OmegaCass~~	**PMAS** (TWIN)	**Carmenes** (PANIC)
2.2m.-	**CAFOS** BUSCA **CAFÉ (2011)**	MAGIC **PANIC (2013)**	**CAFÉ** CAFOS	**PANIC**
1.23m.-	New CCD camera		?????	
	As many changes as requested		- Two changes per month (every 15 days, from dark nights to bright and back) - 1.23m and 2.2m.- Minimum support and neutral cost	

Figure 1: *Left panel:* Total number of hours (top) and days (bottom) per year when astronomical observations were carried out (1976-2011). *Right panel:* Current and future instrumentation.

2 CAHA, current and future instrumentation

A description can be found in [2] and at the Calar Alto web page[1]. A summary is displayed in Fig. 1. The bottom-line is a reduction of the number of instruments, keeping the most competitive ones, in line with the recommendations of the European Telescopes Strategic Review Committee (ETSRC).

After 2014, the work-horses will be: For the 3.5m telescope, PMAS, one of the most efficient IFUs, and Carmenes, an optical and near-infrared high-resolution spectrograph. The 2.2m will be operated in a neutral-cost basis, with PANIC (a new wide-field, near-infrared camera), CAFOS (imager, polarimetry and low-spectral resolution spectroscopy) and CAFE (high-spectral resolution in the optical).

3 HEXA, a 6.5m telescope for spectroscopic surveys

In the survey era, a massive spectroscopic survey is supported by different scientific drivers in multiple astrophysical fields. It will provide follow-up for the different extragalactic surveys (PS1, DES, eROSITA, KIDS, LSST) allowing its photometric redshift calibration. It is complemented with the study of the evolution of galaxies and its star formation rates; and the chemical determinations for characterization of AGNs, galaxy clusters, etc. While in our Galaxy it will complete GAIA objectives of determining the structure and formation of the Milky Way and the element abundances and ages of its stars. These science objectives demand high requirements of spectral coverage (at least from 400nm to 1000nm) and a spectral resolution of 5000 or larger. And, of course, a large multiplexing. Only a large, dedicate telescope can fulfill these needs. HEXA is the proposal for Calar Alto. A more detailed description can be found in the White Book and other technical documentation

[1]https://www.caha.es/telescopes-overview-and-instruments-manuals.html

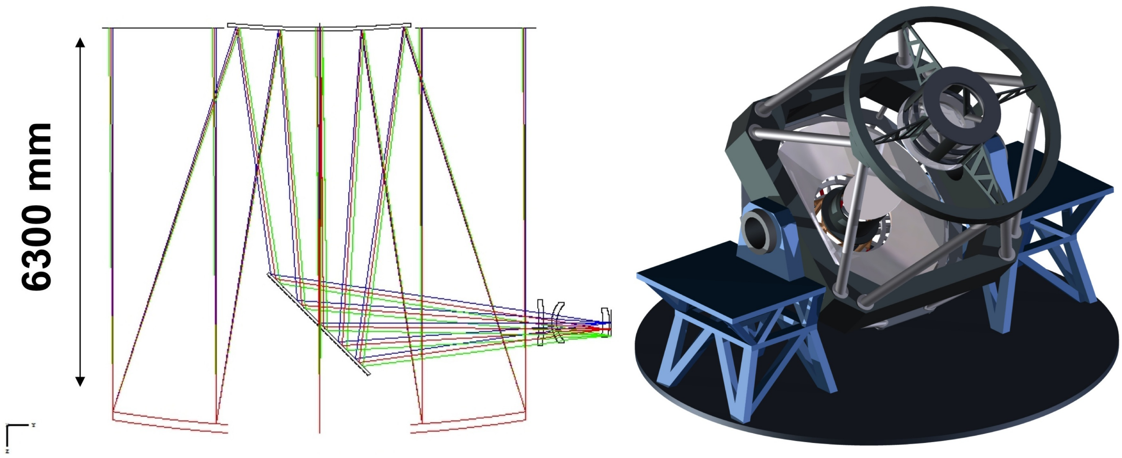


Figure 2: *Left panel:* Optical configuration for one of the HEXA design. In this case, a Richie Chretien Nasmyth configuration with a 1° field–of–view. *Right panel:* 3D model for the telescope and the two Nasmyth platforms.

already produced during the conceptual and viability design study.

3.1 The telescope concept

The base-line for the telescope was: i) aperture 6.5m, output F# number=3.6 (for the prime focus solution F#2.5 was used); ii) plate scale for 2M and 3M: 8.84 arcsec/mm (focal length 23.4m, F#3.6), and plate scale for 1M: 12.2 arcsec/mm (focal length 16.25 m, F#2.5); iii) field–of–view 1 to 2°, with image quality limited by the seeing; iv) spectral range from 3800 to 11000 Å; v) optimized for fibers, with telecentric system and flat focal plane, and multiplexing ∼500; and vi) medium to high-spectral resolution (R= 5,000 and 25,000).

The conceptual optical designed included: i) Prime focus 1°; ii) Ritchey–Chrétien Cassegrain 1° field–of–view; iii) Ritchey-Chrétien Cassegrain 2° field–of–view; iv) Ritchey-Chrétien Cassegrain 1.5° field–of–view; v) 3 Mirror solution 2° field–of–view; vi) Ritchey-Chrétien Nasmyth 1° field–of–view.

For the preliminary design, we have selected the last option, which includes two foci and different sets of instrumental concepts.

Nasmyth A (Hekatonkheires+Cyclops): A1) HECATE (HExa CArTographic Element), a fiber positioner; A2) GYGES (GaYa GrEat Spectrograph), a multifiber spectrograph; A3) High-spectral resolution based on CAFÉ; A4) At least one PMAS/PPAK-like IFU; A5) BRONTESS, a fast imager.

Nasmyth B (Titans): B1) GEA, a slitless spectrograph based on Gaia; B2) CEO, a Wide Field IFU based on Fourier interferometry.

We will briefly describe some of these concepts.

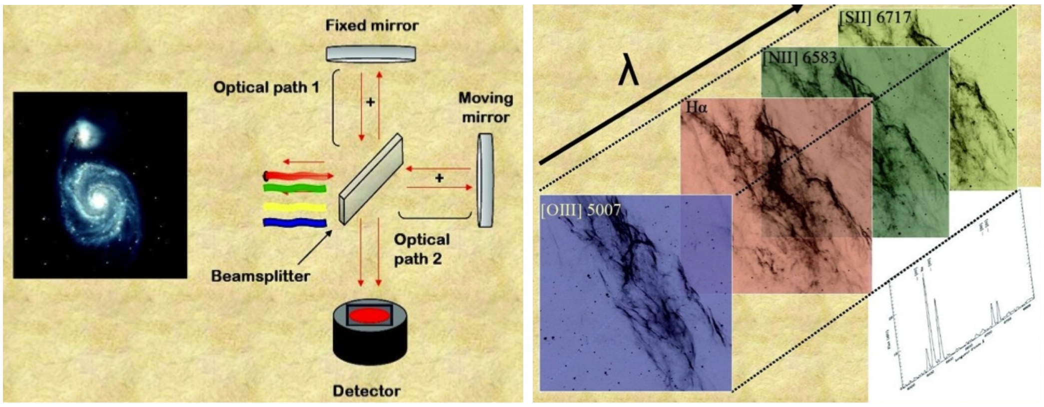


Figure 3: *Left panel:* Representation of a Michelson interferometer. *Right panel:* emission line maps resulting from an observation of a nebula with an IFTS.

3.2 Instruments (I): CEO, fourier transform spectrograph

CEO would be an Imaging Fourier Transform Spectrometer (IFTS) working at optical wavelengths ($3500\AA < \lambda < 10000\AA$) like SpIOMM [3], the one already working at the 1.5m telescope at Mont Mégantic, or SITELLE, starting early 2013 at CFHT3.6m.

CEO is intended to have a wide field–of–view (between 20 and 30 arcmin diameter) with a pixel size of ≈0.33", in order to properly sample the average seeing at Calar Alto (0.8 arcsec). The resolving power would be variable between $1 < R < 20000$ and easily selected by the user just before the observation. This instrument is based in a Michelson interferometer with two mirrors: a fixed mirror and a moving one. The result of a standard observation is a 3D cube in (α, δ, OPD), where OPD is the optical path difference of the moving mirror with respect to the fixed one, that is converted into a more conventional 3D cube in (α, δ, λ) after the inverse Fourier Transform is performed for each pixel. Figure 3 shows the scheme of a Michelson interferometer (left) and an example of the typical emission line maps that can result after a proper reduction of the data (right).

The large field–of–view covered by CEO will make possible to perform proper studies of the evolution of galaxies in clusters with a 100% spatial coverage, which will provide information not only on the individual cluster galaxies but also on stellar/gaseous features often found in the intra-cluster medium and never exhaustively explored till the date. In addition, the proposed spatial resolution (i.e. that of the seeing) of CEO will allow to resolve the centers of the stellar clusters where the crowding prevents it with classical long-slit and fiber-fed spectrographs. Summarizing, CEO will be an optical spectrograph with flexible spectral resolution and high spatial resolution conceived for wide-field Astrophysics.

3.3 Instruments (II): GEA slitless spectrograph

The GEA (Gaia on EArth) concept aims to reproduce ESAs *Gaia* spectroscopic capabilities on the ground, to complete *Gaia* spectral survey down to much fainter limiting magnitudes (approaching $V = 21$ mag). The instrumental design would be kept as close as possible to *Gaia* features [8]: $R = 11\,500$, spectral range 8470-8740 Å, slitless and drift-scan (DTI) operation, 20×20 arcmin field–of–view. Keeping the same methods, spectral range, assumptions and techniques as *Gaia* would provide coherence, reduced systematics, synergies, overlap and cross-check. The main difficulties to implement this concept arise from the focal ratio difference among the *Gaia* and HEXA telescopes (f/41 vs. f/3.5 or so), and from the data processing challenges posed by source crowding [7], due both to the deep limiting magnitude and to the wide, seeing-dominated PSF.

3.4 Instruments (III): BRONTESS, the eye on the sky

BRONTESS (monitor of BuRsts in the Optical aNd Transient Events in the Solar System) is a simple camera with a small field–of–view (about 2 arcmin), based on a EMCCD detector or similar device and equipped with a filter wheel. It can work as an autoguider and should be able to respond to unexpected events.

3.5 Instruments (IV): PMAS-like IFU

The expertise of CAHA in the IFU field is well recognized world-wide. Since its instalation, the 3.5m IFU (PMAS), has been one of the most demanded instruments with ∼35% of the telescope time, and produced about ∼50% of the publications. This instrument offers one of the wider field IFU, PPAK, which covers more than 1 arcmin^2 field–of–view. This expertise put the observatory in great competitive position compared to other paces around the world. This adventageous position has leaded to the developing of CALIFA, the Calar Alto Legacy Integral Field Area survey, the major IFS surveys ever performed (see the first data release at Husemann et al. 2012).

In the new future, IFS surveys have moved from single object modes, to multi-IFU ones (e.g., MaNGA at SDSS and SAMI at AAO). For being competitive in the field it is required a new concept of multi-IFU optical spectrograph (3600–10.000Å range), with higher spectroscopic resolution than PMAS (R ∼2500), and larger field–of–view of the current proposed competitors (∼0.3 arcmin^2), together with a Wide-IFU mode (∼4 arcmin^2). With this instrument it would be possible to (1) cover the 10.000 accesible galaxies from the north hemisphere up to $z < 0.03$, (2) sample all the known galaxy clusters in z <0.1, (3) study high-redshift galaxy lenses around nearby clusters, and (4) perform blind Lyman-α statistics at high redshift. All these measurements would be of a fundamental importance in the understanding of both the cosmological evolution of galaxies, the estimation of the SFR at different redshift and even the understanding the cosmological parameters. These are our requirement for IFU attached to the telescope.

3.6 Instruments (V): high resolution spectroscopy

CAFE [1], a high-resolution optical spectrograph ($R \approx 60,000$), has been developed at CAHA and it has gone beyond the specifications (stability, throughput, efficiency). One possibility

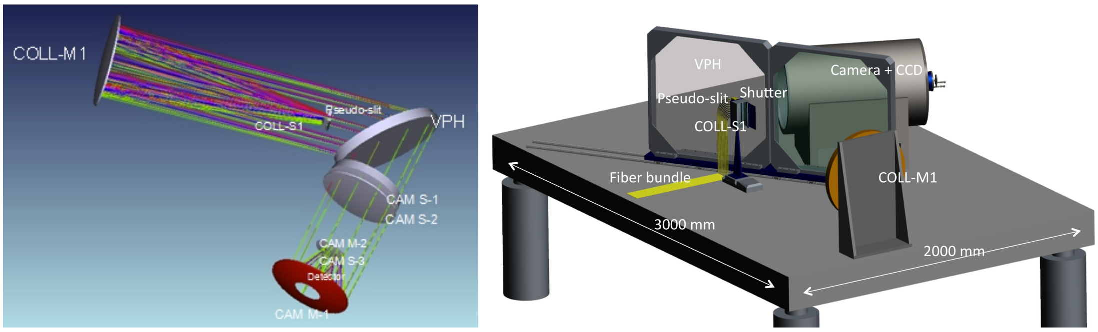


Figure 4: *Left panel:* 3D optical layout for GYGES, the medium-resolution multiobject spectrograph *Right panel:* 3D view on GYGES spectrograph of the optical bench.

is to connect several dozens of this fast track, unexpensive instrument, to the the Nashmyth focal plane. Thus, a moderate multiplexing can be provided at a low cost.

3.7 Instruments (VI): GYGES

The baseline requirements for GYGES spectrograph is to allow the multi-object configuration (to be used in combination with the fibers) having at least 300 fibers for objects at the pseudo-slit entrance (with the goal of 500). The spectral resolution has to be R = 25,000 (in EED80) or higher for the specified wavelength range (between 5500Å and 9500Å). The resolution element shall be considered in the minimum number of pixels possible in order to maximize the spectral coverage (4 or 5 pixels per resolution element could be considered in case of need of the optical design). The instrument shall use a 4K x 4K Si detector with $15\mu m \times 15\mu m$ pixel size and the distance between two adjacent fibers shall be at least 2 pixels in order to avoid cross-talk.

GYGES spectrograph is located on the Nasmyth platform. It is composed of the following elements: the beam from the fibers comes from the pseudo-slit position at the entrance of the focal plane. Then the collimator, composed by a singlet (a lens) and a mirror. The collimated beam goes to the pupil position where a VPH is placed. Finally, the light goes to the camera, also catadioptric, composed by two singlets, two mirrors (labelled as CAM M-1 and CAM M-2 in the figures) and another singlet (CAM S-3), which is the cryostat window where the CCD detector is placed. See Fig. 4.

GYGES mechanical 3D is shown in Fig. 4. The current dimension of the optical bench for this configuration is 3000mm x 2000mm. The dimensions could be considerably reduced if a single VPH is used each night and it is changed during daytime. Nevertheless, once the final requirements and concept will be settled up a more detailed mechanical study should be done in the next phases in order to optimize the instrument envelope and mass. Current dimensions (both in the large and small format) are fully compatible with the installation on one of the Nasmyth platform of HEXA telescope.

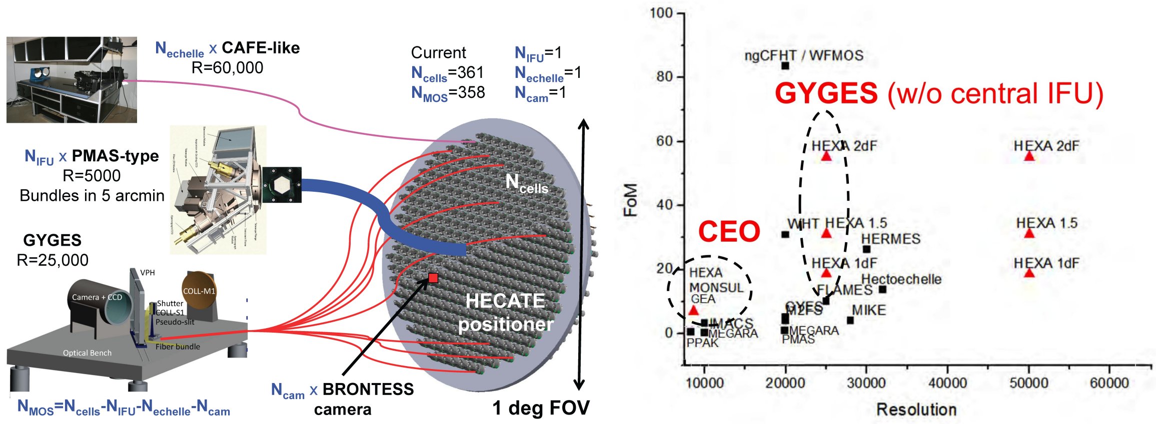


Figure 5: *Left panel:* The diagram shows how several instruments (GYGES, one or several IFUs (PMAS-like), several high-resolution spectrographs (CAFE-like) and the camera BRONTESS can be attached to HECATE, the fiber positioner. *Right panel:* Figure of Merit for several current and planned instrument at different telescopes. The ones proposed for HEXA clearly stand out because of their efficiency.

3.8 Instruments (VII): HECATE, versatility in one Nasmyth focus

HECATE is a fiber positioner located in one of the Nasmyth foci. It covers a 1 degree field in diameter and includes a minimum of 361 positioners (500 when optimized). A single fiber or a bundle is located in each positioner. Single fibers could go either to GYGES (the medium-resolution spectrograph) or to a battery of CAFÉ-like instruments). The fiber bundle (several bundles plus several mini-bundles) would serve an IFU (or several), covering several arcminutes and making this instrument one of the most competitive IFUs world-wide. In addition, one cell can fit the BRONTESS imager (fast response and cadence camera for Target of Opportunity science). Figure 6 provides an sketch of HECATE and how different instruments can be attached to it. All these instruments could be implemented simultaneously, or by stages, depending on the number of spectroscopic surveys to be carried out.

Thus, HECATE is an extraordinary and polivalent part of the HEXA concept, and allows to carry out simultaneous spectroscopic observations at very different resolutions, with a very high multiplexing capability (see Fig. 6).

Additional information can be found in the documentation already produced:
- HEXA: A 6.5m telescope for Calar Alto observatory. White book, v1.0, 2012
- HEXA/TEC/001: Market Analysis for the construction of a 6.5m telescope at CAHA Observatory
- HEXA/TEC/002 HEXA: Trade-off analysis for an optical concept of the telescope
- HEXA/TEC/003 HEXA: Project Management Plan
- HEXA/TEC/004 HEXA: System Engineering Plan
- HEXA/TEC/006 HEXA: Fiber Positioner System Conceptual Design
- HEXA/TEC/007 HEXA: Fiber System Conceptual Design

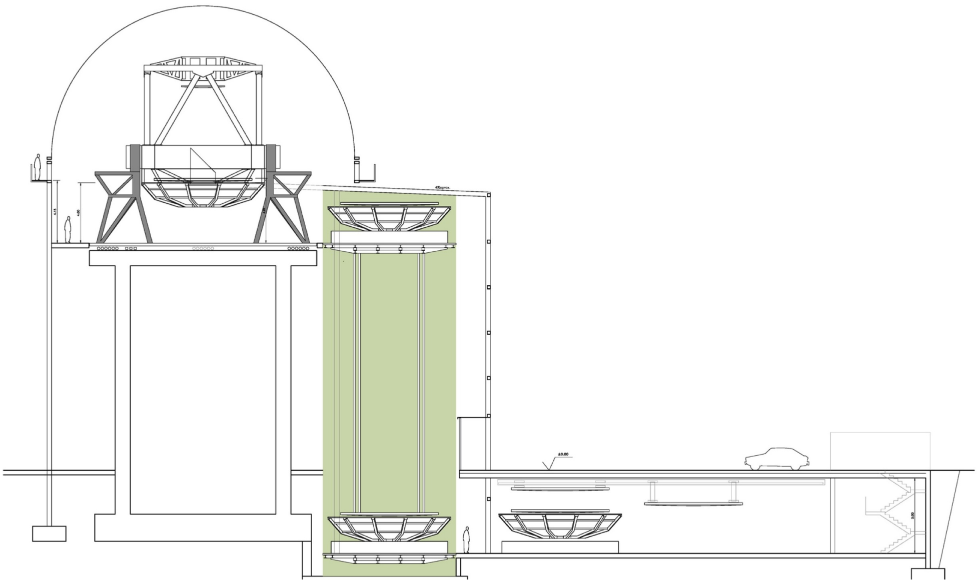


Figure 6: The Dome, the telescope and the service module.

Acknowledgments

This study has been financed by the Spanish "Ministerio de Economía y Competitividad, Plan Nacional de Astronomía", "Acción Complementaria" AYA2010-11308-E. Some parts have been developed in collaboration with FRACTAL SLNE.

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