Highlights of Spanish Astrophysics VIII, Proceedings of the XI Scientific Meeting of the Spanish Astronomical Society held on September 8–12, 2014, in Teruel, Spain. A. J. Cenarro, F. Figueras, C. Hernández-Monteagudo, J. Trujillo Bueno, and L. Valdivielso (eds.)

MEGARA, the new IFU and MOS for the GTC

A. Gil de Paz[1], J. Gallego[1], E. Carrasco[2], J. Iglesias-Páramo[3], F.M. Sánchez Moreno[4], J.M. Vílchez[3], M.L. García Vargas[5], X. Arrillaga[6], M. A. Carrera[6], A. Castillo-Morales[1], E. Castillo-Domínguez[2], R. Cedazo[4], M.C. Eliche-Moral[1], D. Ferrusca[2], E. González-Guardia[4], B. Lefort[5], M. Maldonado[5], R.A. Marino[1], I. Martínez-Delgado[5], I. Morales Durán[3], E. Mujica[5], G. Páez[7], S. Pascual[1], A. Pérez-Calpena[5], A. Sánchez-Penim[1], E. Sánchez-Blanco[5], S. Tulloch[5], M. Velázquez[2], J. Zamorano[1], A.L. Aguerri[8,9], D. Barrado y Naváscues[10], E. Bertone[2], N. Cardiel[1], A. Cava[11], J. Cenarro[12], M. Chávez[2], M. García[10], J. Guichard[2], R. Guzmán[13], A. Herrero[8,9], N. Huélamo[10], D. Hughes[2], J. Jiménez-Vicente[14], C. Kehrig[3], I. Márquez[3], J. Masegosa[3], Y. D. Mayya[2], J. Méndez-Abreu[15], M. Mollá[16], C. Muñoz-Tuñón[8,9], M. Peimbert[17], P.G. Pérez-González[1], E. Pérez Montero[3], M. Rodríguez[2], J.M. Rodríguez-Espinosa[8,9], L. Rodríguez-Merino[2], D. Rosa-González[2], J. Sánchez-Almeida[8,9], C. Sánchez Contreras[10], P. Sánchez- Blázquez[18], S. F. Sánchez[17], A. Sarajedini[13], S. Silich[2], S. Simón-Díaz[8,9], G. Tenorio-Tagle[2], E. Terlevich[2], R. Terlevich[2], S. Torres-Peimbert[17], I. Trujillo[8,9], Y. Tsamis[19], O. Vega[2], and V. Villar[1]

[1] Universidad Complutense de Madrid (UCM, Spain)
[2] Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE, Mexico)
[3] Instituto de Astrofísica de Andalucía (IAA-CSIC, Spain)
[4] Universidad Politécnica de Madrid (UPM, Spain)
[5] FRACTAL SLNE (Spain)
[6] AVS SL (Spain)
[7] Centro de Investigaciones en Óptica (Mexico)
[8] Instituto de Astrofísica de Canarias (Spain)
[9] Universidad de La Laguna (Spain)
[10] Centro de Astrobiología (Spain)
[1]1 Observatoire de Genève, Université de Genève (Switzerland)
[12] Centro de Estudios de Física del Cosmos de Aragón (Spain)
[13] University of Florida (USA)
[14] Universidad de Granada (Spain)
[15] University of St. Andrews (UK)
[16] CIEMAT (Spain)
[17] Universidad Autónoma de México (Mexico)
[18] Universidad Autónoma de Madrid (Spain)
[19] Open University (UK)

Abstract

MEGARA (*Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía*) is the future intermediate-resolution optical Integral-Field Unit (IFU) and Multi-Object Spectrograph (MOS) of the 10.4m GTC telescope. The instrument can be used to observe either a contiguous (100% filling factor) field-of-view of $12.5\times11.3\,\mathrm{arcsec}^2$ or 92 objects anywhere in a $3.5\times3.5\,\mathrm{arcmin}^2$ field patrolled by robotic actuactors attached to optical-fiber minibundles, respectively in its IFU and MOS modes. The MEGARA Consortium is led by the Universidad Complutense de Madrid (UCM, Spain) and also includes the Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE, Mexico), the Instituto de Astrofísica de Andalucía (IAA-CSIC, Spain) and the Universidad Politécnica de Madrid (UPM, Spain). The instrument passed its Critical Design Review (CDR) on late 2014 and is currently in construction phase with a planned date for the start of operations at GTC on early 2017. In this paper we summarize the main characteristics of the instrument and the status of the project.

1 Introduction

MEGARA (*Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía*) is an optical Integral-Field Unit (IFU) and Multi-Object Spectrograph (MOS) designed for the Spanish 10.4m GTC telescope in La Palma. MEGARA offers one IFU bundle covering 12.5 arcsec × 11.3 arcsec with a spaxel size of 0.62 arcsec (Large Compact Bundle; LCB, which makes use of 100μm-core optical fibers). The MEGARA MOS mode will allow observing up to 92 objects in a region of 3.5 arcmin × 3.5 arcmin around the two IFU bundles. Eight additional bundles will be devoted to the determination of the sky during the observation with the LCB IFU. Both the LCB IFU and MOS capabilities of MEGARA will provide intermediate-to-high spectral resolutions (the requirement is $\mathrm{R_{FWHM}}\sim$6,000, 12,000 and 18,700, respectively for the LR, MR and HR modes) using a total of 18 Volume-Phased Holographic (VPH) gratings. The IFU and Fiber-MOS subsystems are placed on the Folded-Cassegraing focus of GTC while the MEGARA spectrograph is located on the Nasmyth platform. In Section 2 below we briefly describe the scientific objectives that define the instrument requirements. Section 3 describes the Folded-Cassegrain subsystems while Section 4 provides a summary of the main characteristics of the MEGARA spectrograph. The status of the project and a brief description of the major future milestones of the project is given in Section 5.

2 MEGARA science

In this section we briefly summarize the scientific objectives that have driven the design of the MEGARA instrument, as put together by the MEGARA Science Team. These scientific interests can be grouped in two broad categories, (1) the study of nebular objects, both in the Milky Way and beyond, and (2) the study of compact (point or close-to-point) sources with intermediate-to-high surface densities. Among the former these interests include the study of Planetary Nebulae, nearby galaxies, and the high-redshift IGM and among the latter Galactic open stellar clusters, resolved stellar populations in Local Group galaxies, intermediate-redshift dwarf and starburst galaxies, and high-redshift cluster galaxies are the main subject of our research activities. Deep imaging of both resolved stellar populations and cosmological fields (including those in clusters such as the Frontier fields) will be a major objective of current and coming imaging facilities (such as LSST or JWST). MEGARA will be the tool for spectroscopically following-up these fields and will fill a niche that is poorly covered by current-day instrumentation, especially within 10m-class telescopes.

The MEGARA Science Team encompasses researchers with a broad range of scientific interests belonging to institutions of all members of the GTC community (Spain, Mexico and University of Florida). This guarantees that, as a facility instrument, MEGARA will also successfully serve to the interests of the entire astronomical communities of the GTC Consortium members.

What is common to all the scientific interests of the MEGARA Science Team is the need for intermediate-to-high spectral resolution optical spectroscopy in the range R=6,000-20,000. In some of the cases this need is a mere consequence of velocity resolution (kinematics) but in many cases is given by the need of reducing line blending, either directly when lines from different elements ought to be measured in stars or via a reduction in the degeneracy of the properties of composite stellar populations.

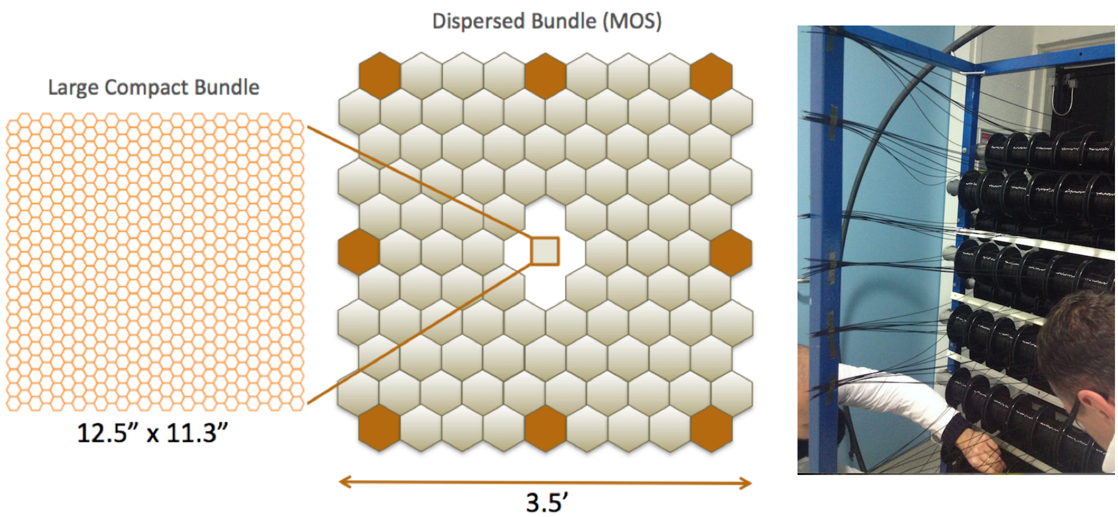

Figure 1: Left: Layout of the MEGARA Large Compact (LCB) and Dispersed fiber bundles (MOS). Right: Photograph of the LCB fiber bundle being mounted.

3 Folded-Cassegrain subsystems

MEGARA Folded-Cassegrain subsystems include all components that collect and conduct the light from the Folded-Cassegrain focal plane to the spectrograph, which is located at the GTC Nasmyth platform. These include: (i) a Field Lens to correct from lack of telecentricity providing a telecentric focal plane for the microlens arrays, (ii) the cover that allows obtaining very low cross-talk observations in half the FOV of the MEGARA default mode, (iii) the microlenses that change the focal number of the telescope allowing a good coupling with the fibers (including those of the IFU and the Fiber-MOS minibundles), (iv) the fiber bundles themselves, and (v) the Fiber-MOS subsystem (including the 92 robotic positioners that allow positioning the 92 minibundles −and their 92×7=644 optical fibers− in specific areas of the Folded-Cassegrain flat and unvignetted focal plane). We will focus here on describing the main characteristics of the IFU and MOS microlens arrays and fiber bundles.

The MEGARA Instrument is composed of two modes, the Integral Field Unit (IFU) mode and the multi-object spectrograph (MOS) mode, that correspond to the Large Compact (LCB) and Dispersed fiber bundles (MOS mode), respectively. The 567 fibers that constitute the LCB (100μm in size) are arranged on a square microlens array that projects on the sky a field of 12.5 arcsec × 11.3 arcsec in size centered at the optical axis of the instrument. The 644 fibers (in groups of seven) belonging to the dispersed bundle (also 100μm in core diameter) can be positioned anywhere in the central 3.5 arcmin × 3.5 arcmin around the LCB IFU bundle thanks to the instrument 92 robotic positioners (see Figure 1). Additionally, 56 fibers from 8 static robotic positioners (orange hexagons in Figure 1) in the outer edge of the instrument FOV are used for measuring the sky background simultaneously with the observations with the LCB. The layout of the hexagonally-packed (and shaped) microlens array of the LCB IFU is also shown. Each microlens, both for the IFU and MOS modes, is an hexagon with a circumdiameter of 0.62 arcsec projected in the sky.

4 MEGARA spectrograph

The MEGARA spectrograph is a fully refractive optical system. The optical fibers of the LCB IFU and MOS are arranged on two 119mm-long pseudo-slits at the entrance of the spectrograph. These pseudo-slits are moved using two translation stages mounted on X-Y that will allow exchanging the pseudo-slit in use between that of LCB or MOS modes, and also will be used as a focusing mechanism in the z axis. Following the light path we find then the collimator, which is composed by 5 lenses (1 singlet and two doublets). The first lens of the collimator is the only aspherical surface of the instrument, which also one of the smallest lenses in the system (140mm diameter). A slit shutter is placed right beyond the first collimator lens. The shutter has three positions: open, closed and filter, position where the order-sorting (OS) filter is placed in the optical path. This latter position will be selected to reject the blue end of the spectrum during the observation with the reddest disperser elements. The pupil has 160mm free diameter and it is the location for the MEGARA Volume-Phased Holographic (VPH) gratings (see Table 1). The use of VPHs and the resulting high efficiency they yield is unprecedented in instruments working at these resolutions in 10m-class telescopes.

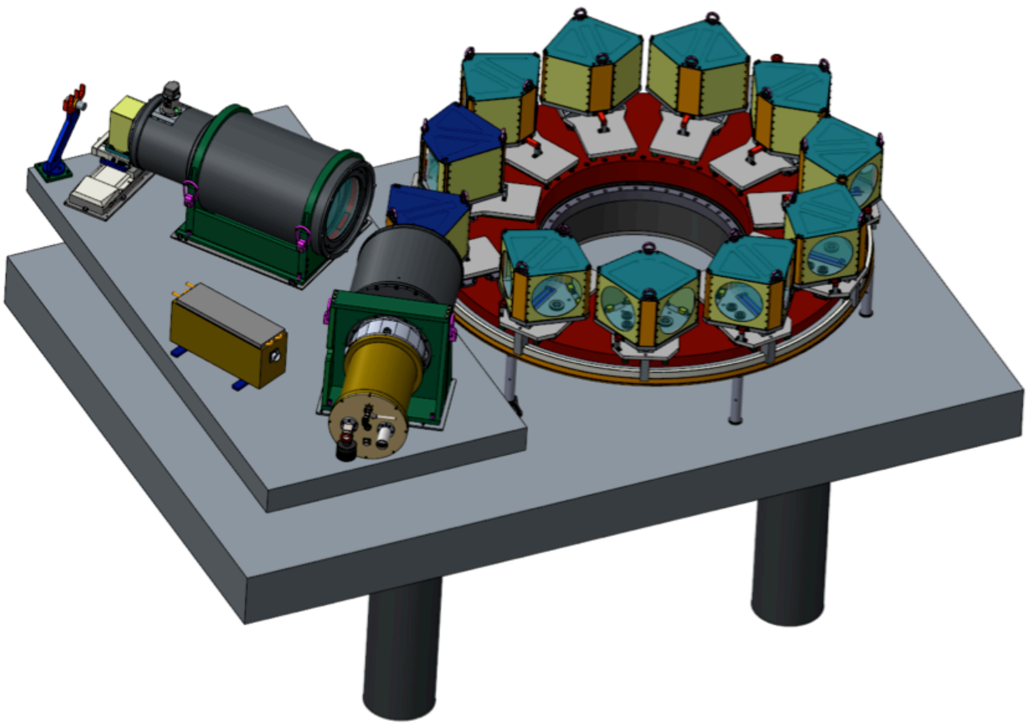

Figure 2: 3D view of the MEGARA spectrograph detailed design.

Once the beam passes through the VPH it goes to the camera (composed by two doublets and 3 singlets, being the last lens also the cryostat window) that focuses the light onto the MEGARA detector, a E2V CCD model 231-84.

5 Status of the project

The MEGARA instrument passed its Optical Critical Design Review on May 2013 and the fabrication of the optical elements started on summer of that year coinciding in time with the endorsement of the "GTC future instrumentation" review panel report. MEGARA succesfully completed and passed the Critical Design Review (CDR) for the rest of subsystems and for the instrument as a whole on late 2014.

On February 2015 MEGARA should go through the Laboratory Pre-aceptance milestone, while on February 2016 the instrument is expected to be fully accepted at the UCM LICA (*Laboratorio de Instrumentación Científica Avanzada*) laboratory. According to the terms of the MEGARA Construction Contract between GRANTECAN S.A. and the UCM the instrument should be delivered at GTC before December 1st 2016 and installed and commissioned at the telescope before the end of 2016. That should allow the GTC community to make use of the instrument on the first half of 2017. The instrument is fully funded until the end of its commissioning at the telescope.

Table 1: Main characteristics of the MEGARA VPHs, namely spectral resolution, wavelength coverage, central wavelength, velocity resolution and reciprocal dispersion [the spectral resolution, $R_{FWHM}=\lambda/\Delta\lambda_{FWHM}$, is derived from the FWHM ($\Delta\lambda_{FWHM}$) of the 1D spectra].

VPH Name	Setup	R_{FWHM}	λ_1-λ_2 (Å)	λ_c (Å)	$\Delta\lambda$ (at λ_c) (Å)	Δv (km s^{-1})	lin. res. (Å pix^{-1})
Low-Resolution VPH gratings							
VPH405-LR	LR-U	6028	3653-4386	4051	0.672	50	0.17
VPH480-LR	LR-B	6059	4332-5196	4800	0.792	49	0.20
VPH570-LR	LR-V	6080	5143-6164	5695	0.937	49	0.23
VPH675-LR	LR-R	6099	6094-7300	6747	1.106	49	0.28
VPH799-LR	LR-I	6110	7220-8646	7991	1.308	49	0.33
VPH890-LR	LR-Z	6117	8043-9630	8900	1.455	49	0.36
Medium-Resolution VPH gratings							
VPH410-MR	MR-U	12602	3917-4277	4104	0.326	24	0.08
VPH443-MR	MR-UB	12370	4225-4621	4431	0.358	24	0.09
VPH481-MR	MR-B	12178	4586-5024	4814	0.395	25	0.10
VPH521-MR	MR-G	12035	4963-5443	5213	0.433	25	0.11
VPH567-MR	MR-V	11916	5393-5919	5667	0.476	25	0.11
VPH617-MR	MR-VR	11825	5869-6447	6170	0.522	25	0.13
VPH656-MR	MR-R	11768	6241-6859	6563	0.558	25	0.14
VPH712-MR	MR-RI	11707	6764-7437	7115	0.608	26	0.15
VPH777-MR	MR-I	11654	7382-8120	7767	0.666	26	0.17
VPH926-MR	MR-Z	11638	8800-9686	9262	0.796	26	0.20
High-Resolution VPH gratings							
VPH665-HR	HR-R	18700	6445-6837	6646	0.355	16	0.09
VPH863-HR	HR-I	18701	8372-8882	8634	0.462	16	0.12

Acknowledgments

The MEGARA team would like to acknowledge financial support from GRANTECAN S.A. and from the MEGARA Consortium institutions. This project is also partly financed by the Spanish Ministry of Economy and Competitiveness research projects AYA2012-30717 and AYA2013-46724-P.