MEGARA cryostat advanced design

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ABSTRACT

MEGARA (Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía) is an optical Integral-Field Unit and Multi-Object Spectrograph designed for the GTC (Gran Telescopio de Canarias) 10.4m telescope in La Palma. MEGARA project has already passed preliminary design review and the optics critical design review, first-light it is expected to take place at the end of 2016. MEGARA is a development under a GRANTECAN contract.

In this paper we summarize the current status of the LN2 open-cycle cryostat which has been designed by the "Astronomical Instrumentation Lab for Millimeter Wavelengths" at the Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE) and emphasize the key parts of the system that have updated since the Preliminary Design, the main activities related to acceptance, integration, fabrication and maintenance plans which fit into the overall structure of the management plan of MEGARA are also described. The cryogenic work package of MEGARA has completed all the design stages and is ready for its Critical Design Review and then proceed to fabrication.

Keywords: MEGARA, cryostat, spectrograph

1. INTRODUCTION

MEGARA (Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía)[1,2,3] is an optical Integral-Field Unit (IFU) and Multi-Object Spectrograph (MOS) designed for the GTC 10.4m telescope in La Palma. MEGARA offers two IFU-type modes with two different bundles, one covering 12.5 arcsec x 11.3 arcsec with a spaxel size of 0.62 arcsec (Large Compact Bundle; LCB, which makes use of 100 µm-core optical fibers) and another one covering 8.5 arcsec x 6.7 arcsec with a spaxel size of 0.42 arcsec (Small Compact Bundle; SCB, with 70 µm-core fibers). Both the LCB IFU and MOS capabilities of MEGARA will provide intermediate-to-high spectral resolutions (the requirement is R_{FWHM} ~ 6,000, 12,000 and 18,700, respectively for the LR, MR and HR modes; current design values, error budget included, are better than these numbers). When the SCB is used the resolving powers to be provided by MEGARA should be R_{FWHM} ~ 7,000, 13,500 and 21,500, respectively.

Regarding the sets of VPHs used by MEGARA, the instrument design includes a wheel with 11 positions so that we can simultaneously mount 6 LR gratings, 3 MR gratings (the most widely-used ones) and 2 HR gratings (LR+HR configuration). In an alternative configuration (MR+HR configuration) all 10 MR and 1 HR gratings could be mounted simultaneously yielding full optical coverage to MEGARA at $R_{(EED80)}$ = 10,000 – 17,000.

MEGARA spectrograph has a fully refractive optical system. The spectrograph is composed by a pseudo-slit, where fibers are placed simulating a long slit 119mm length and with a ROC of 1075mm. The pseudo-slits will be moved using a x-y mechanism that will allow exchanging the pseudo-slit in use between that of LCB, SCB or MOS modes, and also will be used as a focusing mechanism that will be configured in the z-axis for each mode and VPH.

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; blank diameter 160 mm). A slit shutter is placed right beyond the first collimator lens. The shutter has three positions: open, closed and the position where the order sorting 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 160 mm free diameter and it is the location for the VPH-gratings.

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Once the beam passes through the grating 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 detector.

Cryostat preliminary design has been reported previously[4, 5, 12] and describes the overall envelope of this sub-system. In this paper we report a detailed design[6] update of inside components of the main sub-subsystems of the cryogenic device as well as minor modifications that have been incorporated prior to manufacturing, other necessary activities related to assembly and integration are also described. The complete MEGARA instrument will be installed at the Nasmyth platform of the GTC at the end of 2016.

2. CRYOSTAT SUB-SYSTEMS

A liquid nitrogen (LN2) wet cryostat has been selected as the container for the MEGARA scientific E2V 231-84 CCD to operate at cryogenic temperatures (150 K). Cryostat mounting is horizontal and it is designed to be kept static, as well as all the MEGARA spectrograph components. The LN2 open-cycle cryostat is a custom made product, which has been designed by the INAOE astronomical instrumentation group. The proposed cryostat offers modular stages for easy fabrication, assembly, testing and maintenance. The cryostat sub-systems can be seen in the following figure,

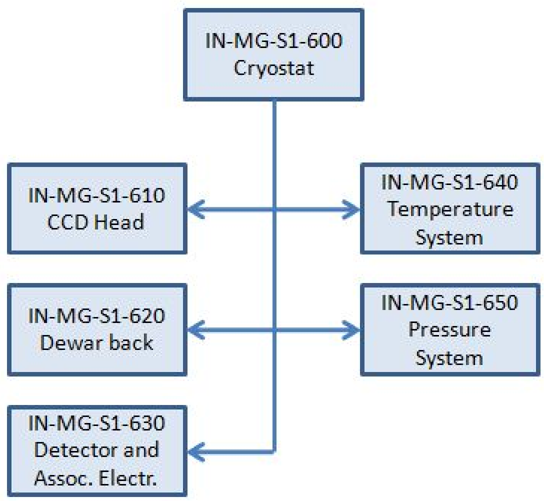

Figure 1. MEGARA cryostat product tree structure showing the sub-systems of the device.

The CCD head is assembled on top of the main body (dewar back) and contains the CCD detector and its associated electronics on a PCB. The CCD will be mounted on top of a custom made six degree kinematic mounting which allows correcting any misalignment in the linear directions as well as in the three rotation angles. A thermal isolating mounting made of aluminum and garolite will support the kinematic mounting on one side and in the other side the CCD PCB, it also has and intermediate shield to avoid any direct radiation to the detector from the PCB. The CCD will be thermally connected to the LN2 tank through a high-purity oxygen free copper strap. All these components are surrounded by an aluminum radiation shield which helps to reach the desired CCD operating temperature and improve the cryostat hold time. CCD flex cables are connected to PCB mating connectors and from here signals are taken to the outside world by connecting the wiring to one of the two hermetic connectors on the vacuum shroud, the second hermetic connector is used for temperature monitoring, the connectors used for this purpose are DT02H-24-61PN and DT02H-12-10PN from Detoronics respectively. A complete description of the CCD and its electronics can be found elsewhere[7, 8].

A front lid on the CCD-head serves to mount the cryostat into a cryostat-camera support which is attached to the main spectrograph optical table; the lid also supports the last lens of the MEGARA spectrograph, which also serves as a vacuum window. The CCD-head mechanical module is intended to be disassembled completely from the cryostat main body for easy handling, integration and verification of CCD components.

The aluminum dewar back (or main body) serves as vacuum jacket and contains the 7.3 liters liquid nitrogen tank which is surround by an aluminum radiation shield wrapped in super insulation Mylar to improve hold time (>40 hours), all

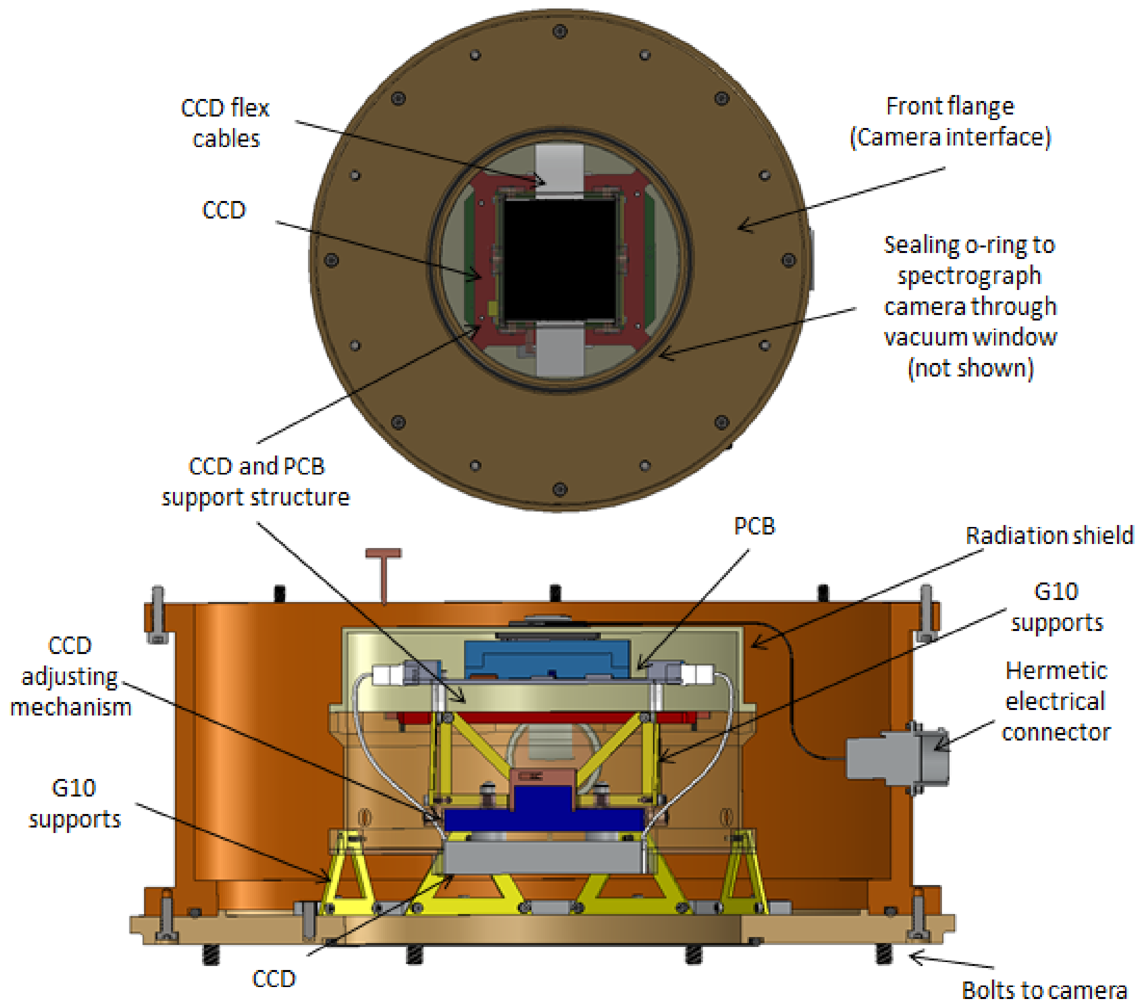

Figure 2. CCD-head cross section view, showing the thermal isolation support for CCD and PCB, all internal components are surrounded by an aluminum radiation shield. In this view only one of the two hermetic connectors on the vacuum shroud are shown.

these components are thermally isolated and mechanically supported by G10 plates and rods. On the back lid are located the pressure components, the LN2 filling tube, a pressure relief valve, the main pressure valve and a hermetic connector for temperature readout. The maximum diameter and length of the complete assembled cryogenic open-cycle system is 300 mm and 570 mm respectively. The mass of the cryostat is ~23 kg without cryogens; filling the LN2 tank (7 liters) adds 5.6 kg to the mass of the system.

The cryostat is equipped with a sorption pump installed in the dewar back, filled with activated charcoal to operate at cryogenic temperatures and has a huge surface/volume ratio (typically ~700 m^2/cm^3), this device will help to reach the ultimate vacuum level of $\leq 4x10^{-6}$ mbar and maintain it during its operation, the sorption pump can be heated out in place if necessary by using a 12-ohm resistor (PN MP820-12.0-1% from Caddock Electronics Inc.). To monitor the pressure the cryostat is equipped with a vacuum transducer 972 DualMag with KF flange from MKS which offers two sensors (Pirani/cold cathode) that enables a wide measurement range from atmosphere to 10^{-8} Torr, the controller is the MKS PDR900-1. The cryostat uses a hand operated right-angle block valve from Varian (PN L6280602) as the main vacuum valve, however we use a solenoid valve at the entrance of the turbo molecular pump in case of failure of power during pumping. The temperature is monitored by PT-103 sensors which are located on the back of the CCD mounting plate, the PCB, the LN2 tank and the LN2 filling tube, these sensors are readout and controlled by a Lakeshore 336.

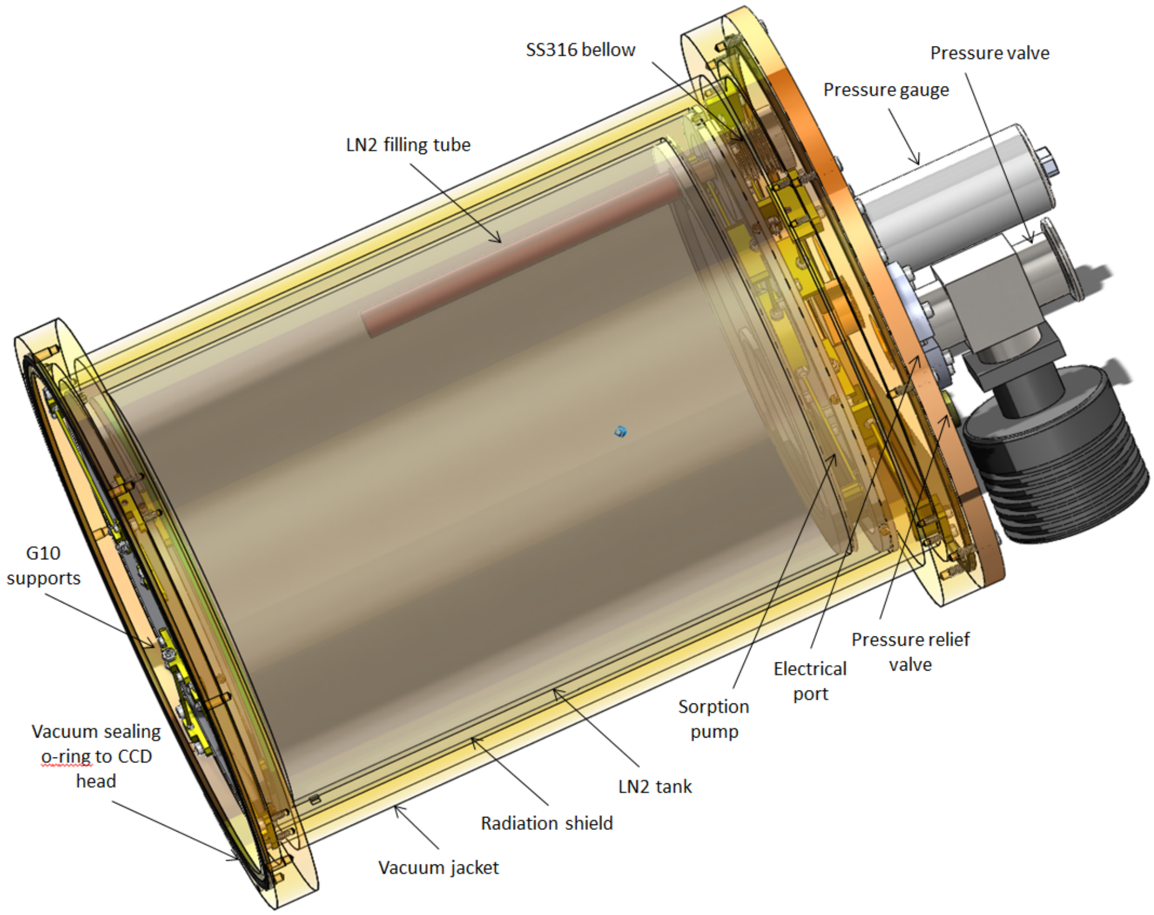

Figure 3. View of MEGARA cryostat dewar back. The vacuum valve and vacuum sensor (pressure relief valve is not visible) are visible on the back; on the central part is the radiation shield and LN2 tank with filling tube; on the front part are the cold-plate and radiation shield held by G10 supports, from this side the dewar back is coupled to the CCD-head.

3. CRYOSTAT SYSTEM ENGINEERING

Systems engineering provides the methodology for developing a complex system, like MEGARA, in a structured and orderly manner and, therefore, helps to ensure that the whole instrument is correctly developed from the beginning, minimizing risks and anticipating problems that may arise.

The main tasks that are carried out by the system engineering plan and have been addressed by the cryostat work package are summarized as follows:

- Implement the requirements engineering, which aims to: ensure that the initial requirements are correctly interpreting user needs.
- Perform system analysis, resolve requirement conflicts, carry out trade-off, develop and use simulation models, analyze project risks and perform RAMS analysis.
- Define and maintain system configuration (define Product Tree and Interface Table).
- Prepare and execute the Integration and Verification Plan.
- Develop the Operation and Maintenance Plan

Activities such as requirement, definition and fulfillment verification, technical budgets, analysis and designs at different levels have been described before [5, 6], thus here we briefly describe the main cryostat system acceptance activities.

Cryostat system engineering plan[8] was developed for the complete system life cycle, from conceptual design to the final instrument acceptance at GTC. The activities that are being performed during the detailed design have as objective to complete the design reaching the point to be able to manufacture or acquire the subsystems.

The summarized milestones in the overall plan to proceed to cryostat fabrication are:

- Receive funding at INAOE
- Purchase process of raw materials
- Purchase process of instrumentation equipment
- Laboratory setup for assembly, testing and characterization at INAOE
- Fabrication process of the cryostat
    - Fabrication process of CCD-head components
    - Fabrication process of dewar-back components
- Assembly process of the cryostat
- Temperature and vacuum setup of cryostat
- Vacuum and cryogenic testing and full characterization
- Packing and shipping to UCM-LICA

System Acceptance includes all activities that will be performed to ensure that the final system meets the initial high-level requirements and can therefore provide the performance and services required by the Scientific Team and GRANTECAN.

System and subsystems acceptance should be carried out at different levels. It means, the subsystems as well as the complete instrument shall be firstly accepted at factory (or in the case of cryostat at INAOE) and, then, at Laboratory for Advanced Scientific Instrumentation (LICA) at UCM, to finally proceed to telescope installation and commissioning.

In order to accept each component, the component requirements must be analyzed to identify how each requirement is going to be verified at each level of the project. It means, the verification matrix of each component shall be prepared and the required acceptance activities included in the acceptance plan of the component.

3.1 Integration and verification

The Integration and Verification Plan will include the scheduling of all required activities to integrate the system and subsystems and verify that they fulfill the initial requirements. At detailed level, a procedure must be defined for each activity, where the required tools, manpower, conditions to execute the activity, the execution environment and any other relevant information that must be identified to execute the procedure will be included. The Integration and Verification Plan of the MEGARA instrument is summarized in the MEGARA Integration and Verification Plan document[9].

As shown in figure 1 the cryostat is integrated by five sub-systems, where the CCD head and the dewar back are the main ones. All the integration tasks associated with an open cryostat must be carried out in a clean room and with all the usual anti-static precautions. All metallic components such as lids, supports and flanges (CFF or KF) must be cleaned of any contaminants that can increase the outgassing rate and affect the vacuum performance. An ultrasonic bath with soft detergent solution is typically used to clean all metallic components, then they can be left to dry on lint-free absorbent material in the clean room. Once these components are dry then they can be immersed in a solution of acetone and isopropyl alcohol and dried in a vacuum oven to remove any out-gassing material. Although components have been chosen to minimize outgassing, some of its parts such as connectors unavoidably contain volatile elements. Placing these components in an oven at 50°C and at reduced pressure, over a weekend, will minimize the material that is subsequently outgassed.

Mounting the dewar back radiation shield to the LN2 tank and the vacuum shroud are one of the major tasks during the integration process. For this purpose LN2 tank has incorporated G10 supports at the top and bottom parts which allows installing the radiation shield around the LN2 tank. Once the LN2 tank and radiation shield are fully assembled then it is possible to start the assembly of the vacuum shroud, which again is secured by another set of G10 supports (bottom and top) keeping the whole assembly concentrically. The filling tube is welded at the LN2 tank back lid and then interfaced to a stainless steel bellow which is screw tighten at the radiation shield stage on one side and to the vacuum lid on the other side. Finally, vacuum port, pressure gauge, hand valve and relief valve are installed in the vacuum back lid. Temperature sensors are installed and carefully wired during the intermediate stages of the assembly.

The CCD-head lid and the CCD-head body are the other major pieces to assembly during the integration of the cryostat. As first step, the radiation shield aluminum main support (square shaped) has to be assembled to allow proper placing of the CCD mounting plate and the PCB and then the radiation shield body and back cover are installed to proceed to attach the complete unit to the CCD-head vacuum lid. Finally, the vacuum shroud is mounted and at the same time the connectors of the PCB and temperature sensors have to be attached from the hermetic connector to its other end. CCD and its cables are installed during the intermediate steps of the procedure[10].

The thermal link between the CCD base plate and LN2 needs to be attached before the cryostat is closed up. After closing the cryostat it should be pumped to below 10^{-3} mbar to remove any absorbed water vapor. Finally, the cryostat should be pumped to below 10^{-5} mbar and mounted on the test-bench in its operational orientation to conduct subsequent test with the other components of the spectrograph. It is necessary to conduct a series of iterations with the kinematic mounting in warm and cold conditions in order to find the final position of the CCD.

Cryostat will be first time tested after its fabrication at INAOE facilities to look for vacuum leaks, thus all o-rings and seals will also be verified prior to other tests. A thermal characterization will also be provided by the Astrophysics Instrumentation team from INAOE. A first cool down should be performed in order to test operation performance. The cryostat is filled with LN2 and the Lakeshore 336 controller is used to monitor the cool-down and to measure the final equilibrium temperature with zero heater power. As part of the verification tasks a CCD dummy (or engineering CCD) will be used. The cooling down time, cryogens consumption and hold time are registered for future reference. The heater power applied to the CCD dummy to place it at 158K provides also important data in the characterization procedure.

The MEGARA Maintenance Plan shall describe in detail all the activities that must be performed in order to ensure that the instrument is maintained in good working conditions and is ready to be used during the night observations. The MEGARA Maintenance Plan shall be generated in agreement with the GTC Maintenance Plan, following the maintenance policy stated by GRANTECAN. The complete instrument maintenance plan will be prepared in the following phase of the project, however during the preliminary phase a list of activities has been prepared as outcome of the RAMS analysis performed. In particular the cryostat and data acquisition system (DAS) maintenance activities have been documented[11] including preventive and predictive maintenance activities for the cryostat, the CCD controller and the DAS control system; corrective and operative maintenance activities are also considered.

4. CONCLUSIONS

MEGARA cryostat has fulfilled conceptual and preliminary designs, and as a result from external committee's evaluations some minor modifications and revisions have been addressed in order to provide a better and robust device to harbor the scientific CCD of the spectrograph.

During the second half of 2014 MEGARA will have its final revision at a Critical Design Review (CDR). The cryogenic work package of MEGARA includes the following deliverables to Gran Telescopio de Canarias for CDR: technical design documentation, mechanical and thermal simulations to validate the design, manufacturing drawings, detailed product tree of the system which includes all and every of the pieces (with project and telescope code) necessary to fabricate and assembly the system including replacements, fabrication plan, assembly, verification and maintenance documentation are also part of the deliverables.

MEGARA cryostat has completed all the design stages required by GTC and will be CDR reviewed in the following months to then finally proceed to fabrication leaded by the INAOE instrumentation group in Mexico.

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