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THE OSIRIS TUNABLE IMAGER AND SPECTROGRAPH: A 2004 STATUS REPORT

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RESUMEN

OSIRIS (Optical System for Imaging and low Resolution Integrated Spectroscopy) constituye el instrumento óptico de Día Uno del GTC y el único instrumento de Día Uno español. Dado que los calendarios del telescopio y del instrumento van paralelos y sincronizados, OSIRIS estará disponible en cuanto el GTC esté preparado para empezar su operación científica. En el presente artículo se pasa revista al estado del instrumento a mediados de 2004.

ABSTRACT

OSIRIS (Optical System for Imaging and low Resolution Integrated Spectroscopy) is the optical Day one instrument for the GTC and the only Spanish Day One instrument. With both instrument and telescope schedules matched, OSIRIS will be available as soon as the GTC is scientifically operational. In this contribution an overview of the instrument at the middle of 2004 is given.

Key Words: **INSTRUMENTATION: SPECTROGRAPHS — METHODS: OBSERVATIONAL**

1. INTRODUCTION

OSIRIS is an imaging system and a low-resolution long-slit and multi-object spectrograph for the Gran Telescopio Canarias (GTC), covering the wavelength range 365–1000 nm with an unvignetted field of view of 8.53'x8.53' and 8.0'x5.2' in direct imaging and low-resolution spectroscopy respectively. It will be the first instrument for telescopes of the class 8-10 meters that includes the concept of tunable filters. It is designed to allow multi-object spectroscopy combined with charge shuffling on the CCD detectors to improve continuum and sky subtraction. The fundamental observing modes will be: broad band imaging, narrow band imaging using tunable filters, long slit and multi-object spectroscopy, and fast spectrophotometry. OSIRIS will be installed on Day One in the Nasmyth-B focus, although will be designed to work also at the Cassegrain focus (Cepa 1998; Cepa *et al.* 2003).

OSIRIS is a joint endeavour of the Instituto de Astrofísica de Canarias (IAC) and the Instituto de Astronomía of the Universidad Nacional Autónoma de México (IA-UNAM). The IA-UNAM is in charge of the optical design, the manufacture of some camera lenses, the design of the camera barrel, and the management of the external contracts for the rest of the camera lenses, coatings, and camera barrel fabrication. The IAC retains the overall instrument responsibility and all the other tasks: instrument structure, mask loader, collimator and folder, mirror, wheels, tunable filters, filters, grisms, camera specifications, control software and hardware, and pipeline for data reduction.

2. INSTRUMENT STRUCTURE

The instrument mechanics are driven by very stringent requirements on image stability in imaging and spectroscopic modes. In the imaging mode, the movement of a point source on the detector must be smaller that 1/5 of the smallest FWHM (GTC plus seeing plus intrument) per hour and a spectral stability better than 10% (with a goal of 5%) of the nominal resolution in one hour. The errors due to slit fabrication and assembly, errors in spectral and focus directions due to positioning, flexures, and temperature variations should not contribute to long-slit flux calibration uncertainties by more than 3.7% during a whole night.

The requirements, coupled with the need to be able to work at the Nasmyth and Cassegrain foci of the GTC, make the mechanical design quite challenging. To fullfill them, detailed error budgets using

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TABLE 1

MAIN OSIRIS PARAMETERS

Field of View (Imaging)	8.53' x 8.53'
Field of View (Low Resolution Spectroscopy)	8.0' x 5.2'
Plate Scale	0.125"/pixel
Detector	e2v CCD 44-82
Conventional Filters	21 positions (SDSS set plus order sorters)
Blue Tunable Filter	Covers 365–670 nm
Red Tunable Filter	Covers 620–1000 nm
Charge Shuffling	1/3 central FOV mask
Fast Photometry	3" long slit
Spectroscopy Resolution	250 through 2500
Long Slit Spectroscopy	Fixed with, from 0.4 to 5.0 arcsec
Slit Mask Loader	13 masks
Multi-object spectroscopy (conventional)	40-60 targets
Multi-object spectroscopy (microslit)	$\sim$ 1000 targets

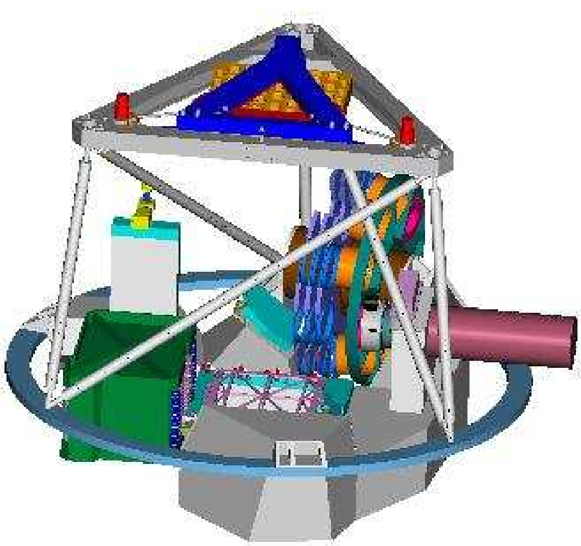

Fig. 1. 3D model of the OSIRIS structure.

finite element analysis (FEA) and Zeemax software models for analysis have been developed to control the contribution of each component to the image movement and considering the collimator as compensator of flexure residuals in open loop.

The instrument support structure has been awarded to TTM (Spain). The contract has been signed and the work has already started.

3. WAVELENGTH SELECTION

The wavelength selection consists on a structure formed by a hollow tubular shaft where four filter wheels are mounted. These wheels can rotate around the shaft and can be positioned independently by the user to select the appropriate filter to be used. Each wheel is driven by a motor via a geared transmission and a timing belt. An incremental encoder situated on the motor axis allows to identify the optical element positioned in the optical beam.the mechanical interface with the support structure (Rasilla *et al.* 2003).

Following the optical path from the telescope to the detectors (see Figure 1) conventional Filters are installed in wheels 1 and 2; Wheel 3 can accommodate both conventional filters and collimated beam masks, while the two tunable filters and grisms are located in Wheel 4 (the closest to the camera). Wheels 1 to 3 are aluminium disks 20 mm thick and of 15 kg mass each one. Wheel 4 is made of steel. Wheels external diameter is large, near one meter in diameter. In total, the system allows the simultaneous loading of the two tunable filters (blue and red), 6 grisms and 24 filters. Conventional filters include order sorters for the tunable filters and a set of the Sloan Digital Sky Survey (SDSS) broad band system (Fukugita *et al.* 1996).

The filter wheels, manufactured by NTE (Spain), entered fabrication phase in November 2003, with an expected delivery by middle of 2004. The holders for the tunable filters, the filters and the grisms have started fabrication at the IAC mechanical workshop.

3.1. *Grisms*

For the spectroscopic modes grisms are used as dispersive elements. Grisms are a combination of transmission gratings and prims, manufactured in a way that the central wavelength of the first order spectrum is passed without deviation. The maximum guaranteed resolution will be R = 2500, and the minimun resolution will be R = 250. The higher dispersion grisms (R = 2500 and 5000) are based on Volume Phased Holographic Gratings (VPH). Peak efficiencies are higher than 80% for R = 2500 and 60% for R = 5000.

The low resolution grisms (250, 500, 1000) were manufactured by Spectra-Physics (Rochester, New York, USA). The design of the intermediate resolution ones (R=2500) has finished and manufacture will start by mid 2004. The high resolution ones (R = 5000) are being designed and their manufacture will start before end 2004.

On March 2004 six grisms made for low and intermediate resolution were received in the IAC.

3.2. *Tunable Filters*

An important aspect of OSIRIS is the use of tunable filters (TF) for narrow band imaging. The tunable filters are conventional Fabry-Perot etalons in that the cavity thickness, defined by high reflectance plates separation, can be adjusted in a wide thickness range with high accuracy. In this way, the filters allows selecting a wide range of resolving powers. Tunable imaging allows obtaining line fluxes: (i) simultaneously for all objects within OSIRIS FOV, (ii) avoiding sky emission lines, (iii) at an arbitrary selected wavelength compatible with the etalon configuration.

The OSIRIS TFs have been designed for covering a range of resolutions from R = 300 to R = 1000. In order to improve the coating reflectivity, two TFs will be used. A blue TF optimized from 365 to 670 nm with a reflectivity of 91%, and a red TF with a reflectivity of 94% covering from 620 to 1000 nm.

The blue and red Tunable filters have been manufactured by IC Optical Systems Ltd (U.K) Each one has a diameter of 20 cm and 11 cm of heigh. Acceptance tests, including environmental ones, and modifications are being performed at the factory. Were the results satisfactory, the acceptance of the blue and red TFs is expected for June 2004. As soon as the tunable filters are accepted and characterized at the IAC optical laboratory, the order sorter filters will be purchased. There is only one supplier (Barr Associates, Inc., USA) that can provide interference filters of the size (19 cm diameter) and quality required. However, the filters are very expensive and only part of the optical spectra will be covered within current budget.

4. MASK LOADER

Some observing modes (i.e. multi-object spectroscopy, or tunable filter imaging with change shuffling) will require that some parts of the field of view coming from the telescope must be blocked.

The masks (build in aluminium) are situated together in a mask cassette, and a mechanism select one mask and remove it from the cassette to place it on the GTC focal plane. A slit loader with capacity for up to 13 masks allows to insert and remove slits masks to and from the telescope focal plane. In addition to user-customized masks for multi-object spectroscopy, a number of fixed width long slit masks will be available. One extra mask for point-like fast photometry and another for charge-shuffled continuum subtraction will be available as well (Peraza *et al.* 2003). A two degrees-of-freedom mechanism allows selecting one of the masks, removing it from the cassette and positioning it in the telescope focal plane with the required repeatibility, providing spectral stability better than 10% of nominal resolution per hour (including contributions from all instrument subsystems). The long slit flux calibration uncertainties will be less than 4% during the night.

The slit subsystem can carry out three functions: mask storage and identification, mask selection and mask positioning in the focal plane. The changing time (currently 24 seconds) is smaller thant the detector readout time. Masks will be stored in the cassette. The masks can be exchanged through individual doors. The masks are automatically identified within the instrument by a bar-coded reader mounted beside the cassette. When a new mask is placed in the instrument, the contents of the cassette are read and recorded automatically. In the long slit mask the slit length is 8.5'. The multi-object spectroscopy masks cover a field of view of 8.5' x 5.2'.

The masks and mask loader are fully designed and manufactured at the IAC. The mask loader has entered the fabrication phase after passing the Detailed Design. A mask prototype has been fabricated at IAC mechanical workshop, its size of around 60x40 cm.

5. INSTRUMENT OPTICS

The instrument optics is designed around the classical concept of collimator and camera. The Collimator consists of an off-axis ellipsoid mirror attached to a cell that support it mechanically (Cobos *et al.* 2003). A Folder Mirror has been added to fit the instrument envelope. The Camera unit consists of the Camera Barrel, the Shutter and the Detector Unit (two CCDs mounted inside a liquid nitrogen cryostat).

5.1. *Collimator and Folder*

The Collimator Subsystem consist of the Collimator Mirror, the Positioning mechanism to tilt the mirror and the Cell that supports the system and allows to attach it to the instrument main structure. The Collimator is an off-axis ellipsoid having an optical clear aperture of 533 x 431 mm. A lightweight substrate having an aspect ratio of 6:1 and a minimun mass reduction of 40% has been used to fullfil the mass requirements.

The folding mirror design was assumed by SESO (France). The mirror is made of zerodur, characterized for its very low expansion thermal coefficient and its long term stability. The mirror fixed via 3 metallic flexures to a triangular base made of steel, that insures the fixation interface onto the OSIRIS support frame. The collimator unit design and manufacturing was shared between SESO and CSEM (Switzerland). The collimator mirror is made of zerodur, and the total weight of the collimator system is around 150 kg.

The collimator and folder mirror supports are finished. The mirror polishing was finished in January 2004 and the high quality protected silver coatings are being done at SESO. The collimator actuators (the ones that will actively correct for image movement by moving the collimator) are finished and undergoing tests at CSEM, for an expected delivery date of October 2004.

5.2. *Camera*

The Camera barrel includes a barrel for the first -focusing- doublet, and second barrel for two singlet and two-doublet lenses. The last camera lens is mounted to the detector unit as a cryostat window. The Camera barrel is formed by two units: a focusing mechanism, using the first doublet as an image quality compensator, and a passive athermalization system, using some of the other lenses, for keeping the focal distance and image quality almost constan under temperature variations.

The all-refractive OSIRIS camera consists on 9 lenses defining 6 optical elements, all spherical surfaces. The last lens is the dewar window. The camera effective focal length of 181 mm provides the required detector scale (0.125arcsec/pixel) on a flat focal plane tilted 1.83 degrees. With the present element apertures, the camera does not vignette a telescope FOV of at least 11 arcmin in diameter. The first doublet is allowed to move to focus the camera for all combinations of pupil optics and for assembly and integration purposes.

The camera lenses that are manufactured at IA-UNAM optical workshop are finished. The camera lenses that are manufactured in FISBA (Switzerland) are being polished and will be delivered in May 2004. The camera barrel (that holds the lenses together at the specified distances, tilts and tolerances) will start fabrication very soon (design by IA-UNAM, fabrication by CIDESI, Querétaro, México).

5.3. *Detector and Detector Control*

The detector mosaic is composed of two 2k x 4k CCDs abutted, with a plate scale of 0.125"/pixel (15 microns/pixel). The Day One arrays will be a set of two e2v CCD44-82, although these will be probably be upgraded to MIT/LL CCID-20 blue-enhanced ones afterwards. The detectors have been chosen to have a maximun quantum efficiency in the red but to be blue-sensitive (MIT ones) and with minimun fringing. Readout modes include chage shuffling up and down, continuous readout, and reading windows. Readout speeds will be at least the slowest possible, intermediate (nominal), and the fastest possible. Frame transfer is also contemplated with both devices for fast spectroscopic modes.

The detector controller will be a commercial SDSU-2 controller, using a timing board with parallel cable linked to a commercial digital PMC frame grabber. The CCD controller will allow to synchronized the TF switching frequency (up to over 100 Hz) with charge motion over large areas of the detector The software architecture allows to run any of the complex observing modes, that involves coordination and synchronization of critical operations (as charge shuffling and wavelength tuning) with real time constraints. (Joven, Gigante & Beigbeder 2004).

The strict requirements for photometry decided the project to select a Bonn shutter, manufactured by Bonn University. The design is based in slit type shutter with two independent carbon fiber blades driven by stepper motor over a rectangular aperture. The shutter blades are made of carbor fiber material. The three main components (mechanics, control electronics hardware and control electronics software) play together to achieve a photometric accuracy of the order of 1% at an exposure time of 0.1sec (i.e. timing accuracy of 1msec) at any position across the aperture.

6. SOFTWARE

The OSIRIS control software will be deployed on different machines executing both, conventional and Real Time Operating System (RTOS). These machines will be connected to the GTC Control System (GCS) through different networks, mainly ATM. An Ethernet (10/100 Mb/s) is also used for enginnering purposes, and are also available serial and CAN type field buses. The OSIRIS Control Software is being developed using a Use Case Method for requirements capture, and using a Distributed Object Oriented Approach which is integrated into a major framework, the above mentioned GTC Control System. The RUP (Rational Unified Process) has been used as software process framework (Lopez-Ruiz *et al.* 2002).

Two specific software packages are being written for science operations, the OSIRIS Data Factory Pipeline (OSIRISDFP) and the OSIRIS Mask Designer. Both packages were developed by GMV S.A. (Spain). The OSIRISDFP controls an automatic set of procedures that will be available to process the data acquired from standard OSIRIS observing modes. At least (a) standard imaging, (b) long-slit spectroscopy, (c) charge shuffling imaging and (d) fast photometry observing modes will be processed using the pipeline. The OSIRIS Mask Designer is a utility prepared to define the exact positions and shapes of slits in a focal plane mask in order to perform multiobject spectroscopy. The Mask Designer can be run either by using a list of values presenting equatorial coordinates or by defining slit positions with a mouse and an input FITS format image.

The Mask Designer passed the Final Advanced Review at the IAC in the beginning of December 2003 and the first release is expected by June 2004. The first release of the Pipeline for data reduction is also expected by the same date.

7. SCIENCE WITH OSIRIS

While some instruments for the 8-10m class of telescopes are conceived as *Redshift Machines*, the main scientific motivation for OSIRIS is to be a *Star Formation Machine*, unique to provide an homogeneous and consistent mapping of star formation indicators in nearby and back to the furthest observable galaxies with GTC.

In particular, star formation in galaxies as a function of redshift is a classical topic and one main objective of several current projects of instruments for large telescopes both, ground based and aboard satellites. These projects are mainly aimed to moderately large redshifted galaxies, via the near-infrared study of their optical emission lines, or to higher redshifts by means of far-infrared SEDs and lines. Objectives of highest priority for OSIRIS are two main areas left relatively untouched by these other programs: star formation rates in field and cluster galaxies at intermediate redshifts, and the UV emission spectra of large redshift galaxies. This field, widely developed in relatively small telescopes and currently pursued by 8-10m class telescopes, is an area were important contributions are expected, using specially tuned spectral indicators (for age, abundances and initial mass function determinations) based on absorption lines and synthesis techniques. Together with the nebular study of star formation in nearby galaxies, OSIRIS plans to make a consistent connection among the observations of local, intermediate and hopefully distant galaxies.

In order to accomplish the maximun scientific return in the use of the instrument, the Instituto de Astrofísica de Canarias decided to open its share of guaranteed time (GT) to the astronomical community, with its administration in charge of the OSIRIS PI. A first Call for Proposals was made public to the OSIRIS Science Group, with a deadline by October 31, 2001, as part of the scientific preparation required for an optimal OSIRIS exploitation. Proposals were evaluated and comments sent to the proponents for the preparation of the second round.

The second call for GT proposals will be issued by winter 2004. Before that a workshop will be held in Madrid to evaluate the proposals technically. The received proposal will be examined, and after evaluation of their ratings and rankings, the Core Group will recommend the OSIRIS Principal Investigator which proposals shall receive guaranteed time and with which amount. A Committee composed by the Principal Investigator, the Head of the IAC Scientific Division and the Head of the IAC Technological Division will supervise the distribution of the observing time (Castañeda & Cepa 2003).

8. INSTRUMENT UPGRADES

Day One upgrades are already under development.

Solutions for achieving higher resolution spectroscopy, up to 5000 or more, have been studied at the IAC. An *Accion Especial del Ministerio de Ciencia y Tecnología* for implementation of higher spectral resolution in OSIRIS using VPHs has been approved. We plan to reach R = 5000, with expected peak efficiency of around 60%. We are studying to implement Fabry-Perot spectroscopy in a collaboration between the IA-UNAM and the IAC, to allow 2D spectroscopy at high resolution to be performed over the instrument FOV. This mode should open a completely new window in 8-10 m class telescopes. Finally, coronography is currently under study at the IA-UNAM. It will allow the observation of emission lines of host QSOs and galactic nebulae with bright stars embedded, among other applications.

9. FINAL REMARKS

OSIRIS is a Day One instrument for the GTC of wide field of view, high efficiency, and cost competitiveness, for imaging and low resolution spectroscopy. It is easy upgradable and is multipurpose. Since it is optimized for line flux determination, OSIRIS can be designated as a Star Formation Machine.

All external contracts done and already in fabrications phase (except structure, that will begin fabrication in June 2004). All purchases done except: VPHs for R = 2500 and TF order sorters that will be done by mid 2004. The full instrument assembly and laboratory tests at IAC will start by winter 2004. The Web site *http://www.iac.es/project/OSIRIS* will provide continuus updates of the project status.

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