RevMexAA (Serie de Conferencias), **16**, 13–18 (2003)

OSIRIS TUNABLE IMAGER AND SPECTROGRAPH: INSTRUMENT STATUS

Jordi Cepa,[1,2] Marta Aguiar,[1] Jonathan Bland-Hawthorn,[3] Héctor Castañeda,[1] Francisco Cobos,[4] Santiago Correa,[1] Carlos Espejo,[4] Ana Belén Fragoso,[1] Javier Fuentes,[1] José Vicente Gigante,[1] Jesús González,[4] Victor González-Escalera,[1] José Ignacio González-Serrano,[5] Enrique Joven,[1] José Carlos López,[1] Carmelo Militello,[6] Lorenzo Peraza,[1] Angeles Pérez,[1] Jaime Pérez,[1] José Luis Rasilla,[1] Beatriz Sánchez,[4] and Carlos Tejada[4]

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 bajo el punto de vista técnico, mientras en otra contribución de este mismo volumen se presentan las capacidades científicas del instrumento bajo el punto de vista del astrónomo usuario.

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 status from a technical point of view is given, while in another contribution of this proceedings, an overview of its scientific capabilities from a user point of view is given.

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

1. INTRODUCTION

1.1. *Instrument procurement*

The general philosophy for instrument procurement is to develop within OSIRIS institutions the system and subsystems specifications, the instrument error budgets, and the subsystems design up to Preliminary Design level. The subsystems Detailed Design and Fabrication, including tests, is contracted to external companies by the Instituto de Astrofísica de Canarias (IAC). This procedure allows optimization of the available engineering resources within the IAC and Instituto de Astronomía of the Universidad Nacional Autónoma de México (IA-UNAM), heavily involved in other ground-based and satellite-borne astronomical instruments, while decreasing the overall project duration. There are several exceptions to this guideline:

- The fabrication of part of camera lenses by IA-UNAM
- The masks and mask cassette, which are fully designed and manufactured at the IAC
- The instrument structure, which will be developed to Detailed Design level by the IAC to avoid interface definition by the rest of the subsystems to be attached to the structure
- The detector control (IAC)
- The instrument control (IAC)
- The instrument assembly, integration, and verification (AIV) and Commissioning (IAC and IA-UNAM).

1.2. *Instrument update*

The instrument concept (Cepa et al. 2000) was changed in June 2000 as the result of a Preliminary Design Review. According to the review results, and mainly to be able to meet the delivery date, it was decided to simplify the instrument concept. The initial proposal to use volume phase holographic gratings (VPHGs) as dispersive elements together with an articulated camera (for maximum spectroscopic performance and resolution) was discarded.

[1]Instituto de Astrofísica de Canarias, Spain.
[2]Departamento de Astrofísica. Universidad de La Laguna, Spain.
[3]Anglo–Australian Observatory, Australia.
[4]Instituto de Astronomía, Universidad Nacional Autónoma de México, México.
[5]Instituto de Física de Cantabria, Spain.
[6]Departamento de Física Fundamental y Experimental, Universidad de La Laguna, Spain.

The use of standard grisms with a fixed camera was adopted. This simplification limited the maximum spectral resolution of OSIRIS from 5000 to 2500. However, apart from schedule fulfillment, some very useful benefits were also gained from this decision regarding instrument mechanical stability. A review of the new instrument concept in April 2001 yielded certain changes to the design (mainly the collimator controlling image movement instead of the folder mirror, a a more simplified and faster mask loading mechanism, and the camera barrel concept redesign. Since then, several other improvements have been incorporated into the instrument:

- Optimization of the instrument structure
- A decoupling collimator support from instrument structure
- Compensation of temperature variations (plate scale & image quality) by passively moving one camera doublet
- Avoiding changes of temperature gradients by fully enclosing the instrument and filling it with dry air flow
- Lowering the intermediate resolution from $R = 1500$ to $R = 1100$ in order to increase the wavelength range to cover the most important optical spectral lines
- Including very low resolution ($R = 250$) grisms for nod & shuffle spectroscopy (Glazebrook & Bland-Hawthorn 2001).

1.3. *Current status*

Following the instrument procurement philosophy described above, the following subsystems or units have already been contracted:

- Collimator and folder mirror
- Filter wheels
- Tunable filters (TFs)
- Cryostat.

And the following ones are ready to be contracted before the end of 2002 or beginning of 2003:

- Camera doublets
- Broad band filters including TFs and spectroscopy order sorters
- Grisms
- Camera barrels and focussing system
- Instrument structure (fabrication)
- Data pipeline.

Two engineering-grade MAT44-82 and one MIT/LL CCID-20 have been delivered and are under evaluation. Science-grade MATs have already been delivered to GRANTECAN Project Office. The mask cassette is entering the detailed design level, and some camera lenses have already been manufactured.

In conclusion: with all the subsystems at detailed design level or fabrication by the end of 2002, and some of them already at an advanced stage, OSIRIS is matching the telescope schedule and will be ready for GTC Day One.

2. OSIRIS OPTICS

2.1. *Optical design*

The optical design (Cobos et al. 2002) is based on a reflective collimator plus refractive camera (Figure 1), with a flat mirror in between to fold the light path in order to fit the Cassegrain envelope. It has been driven by the following stringent high-level requirements (all of them accomplished more than successfully):

- To maximize the imaging field of view (FOV) and to alleviate etalon coating inhomogeneities and flatfielding irregularities, the tunable filters are to be placed at the instrument pupil. The maximum pupil diameter is then limited by the clear aperture of currently commercially available high quality TFs, such that throughput is not compromised by TF vignetting losses. As a consequence a very small pupil (less than 100 mm) relative to most instruments of 8–10 m class telescopes is required. This makes the optical design of OSIRIS a unique and challenging one.
- For the OSIRIS scientific drivers a large FOV is important since for large targets (such as clusters of galaxies and extended sources) mosaic observations produce a loss of observing efficiency. The initial goal was initially set to $8' \times 8'$ to match the telescope unvignetted FOV. The final optical design has achieved a FOV larger than this goal.
- The focal reducer must provide enough space in the collimated beam (pupil space) to accommodate two TFs, several grisms, and their necessary filters and calibration masks.

Science with the GTC 10-m Telescope (Granada, España, 5-8 febrero 2002)
Editors: José Miguel Rodríguez Espinosa, Francisco Garzón López & Verónica Melo Martín

- A red-optimized design (beyond 400 nm up to the longest possible wavelength of 1000 nm) for observing redshifted emission lines, but keeping enough blue sensitivity to observe [O II] λ 372.7 nm at zero redshift (star formation in nearby galaxies) and U imaging (365 nm, for stellar population studies). The possibility to implement two cameras (one blue- and another red-optimized) was initially considered but later rejected to stay within cost and time budgets. Our comparative throughput analysis shows that OSIRIS is comparable in the red to the most red-sensitive instrument for 8–10 m class telescopes, such as GMOS, but with a very good performance in the blue.

- Very good image quality for full exploitation of the telescope and site characteristics. The current design enables a FWHM of 1 pixel (i.e., 0.125 arcsec) to be obtained.

- A pixel size of the order of at least 1/5 (goal 1/10) of the point spread function (PSF) for good sampling to re-center images without significant spatial degradation. Detector readout noise is not an issue because TF imaging is practically sky-limited. Also, small pixel sizes alleviate cosmic ray rejection since cosmic ray hits can be better distinguished from pointlike objects. This is an important issue mainly for thick devices such as the detectors selected for OSIRIS (both the MIT/LL and the MAT options).

The behavior of the optical design under temperature changes have been reported in González et al. (2002).

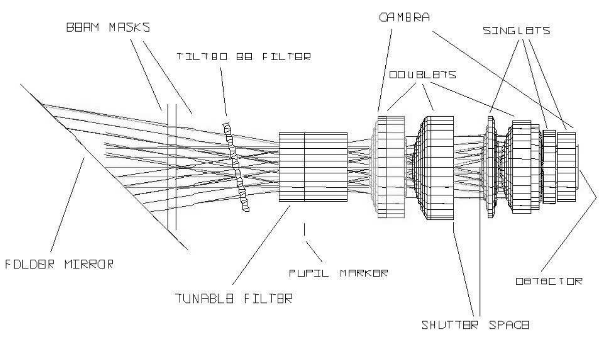

Fig. 1. OSIRIS camera layout with a tilted broad band filter and the tunable filter in the pupil space.

2.2. *Dispersive and selective optics*

2.2.1. *Imaging*

The set of broad band filters will include a *ugriz* set plus order sorters for TFs and grisms. All these filters are tilted to avoid their ghosts on the detector. Owing to the coating designs, two tunable filters (Bland-Hawthorn & Jones 1998) are needed to cover the full OSIRIS wavelength range. Both have been designed to match blue and red resolutions with relatively high contrasts and overlapping at the Hα line at zero redshift. To minimize ghost images the TFs will be wedged and the external surface of the plates AR coated. It is required that the tuned TF wavelength will be stable with a variation of less than 1/10 of the FWHM at any wavelength and mode during at least one hour of observation. This includes tuning accuracy, tuning resolution, RMS stability, and temperature variations.

The order sorters to select the TF orders are requested to fulfill the following requirements:

- Allow the resolution between Hα from [N II] λ 658.4 nm

- Avoiding strong sky emission lines whenever possible

- Overlapping in wavelength when contiguous

- With higher priority for observing:
  - The zero redshift lines: Hα, Hβ, Hγ, Hδ, [O I] at λ 630.0 nm [O II] at λ 372.7 nm, [O III] at λ 436.3, λ 495.9 and λ 500.7 nm, [N II] at λ 658.4, [S II] at λ 671.7 and λ 673.1 nm, [S III] at λ 906.9 nm, the 400.0 nm break, CH λ 430.0 nm, [Fe I] λ 438.3, λ 527.0 and λ 533.5 nm, Mgb λ 517.0 nm, and CaT
  - The redshifted Hα, Hβ, [O II] λ 372.7 nm, and [O III] λ 500.7 nm.

2.2.2. *Spectroscopy*

The long slit nominal width has been chosen to match the best GTC plus best site plus best instrument image. As a general requirement the number of grisms at every resolution will cover the OSIRIS spectral range. The resolutions chosen are:

- The lowest one ($R = 250$), to shorten the spectral range increasing the MOS multiplexing capability of OSIRIS by using the nod & shuffle technique (Glazebrook & Bland-Hawthorn 2001).

- A low resolution ($R = 500$) for observing, within the same spectra, the most useful lines for diagnostics in MOS standard mode.

- A intermediate resolution ($R = 1100$) allowing observations from [O II] at λ 372.7 nm through [N II] at λ 658.4 nm, and from Hα through [S III] at λ 953.2 nm, in a single long-slit exposure.
- The higher resolutions ($R = 2000$ and 2500) for studying particular spectral lines.
- Resolutions higher than 2500 (up to 5000 or more) are currently under evaluation.

A description of the dispersive elements in OSIRIS can be found in Rasilla et al. (2002).

3. MECHANICS

The instrument mechanics (Fuentes et al. 2002a), schematically shown in Figure 2, are driven by very stringent requirements on image stability in imaging and spectroscopic modes, all of them fulfilled successfully (Fuentes et al. 2002b).

The main requirements are:

- An image movement on the detector smaller than 1/5 of the smallest FWHM (GTC plus seeing plus instrument) per hour and a spectral stability better than 10% (goal: 5%) of the nominal resolution in one hour.
- Errors due to slit fabrication and assembly, errors in spectral and focus directions due to positioning, flexures, temperature variations, etc., will not contribute to long-slit flux calibration uncertainties by more than 3.7% during a whole night.
- Overheads, intended as changes of observing mode or change of elements within the same mode, smaller than the nominal detector readout time (40 s). The largest overhead in the current design is of 24 s in the worst situation.
- The following elements should be loaded simultaneously in the instrument: SDSS filter set, order sorters for low resolution tunable imaging and spectroscopy, masks to calibrate TFs and spectrograph, low- and intermediate-resolution grisms. With the current wheel design, it is possible to accommodate all TF order sorters, all spectroscopic order sorters, the SDSS set, and the grisms for low and intermediate resolutions.

These requirements, together with the need to be able to work at Nasmyth and Cassegrain foci of the GTC, make the mechanical design quite challenging. To fulfill them, detailed error budgets using FEA models and Zeemax 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.

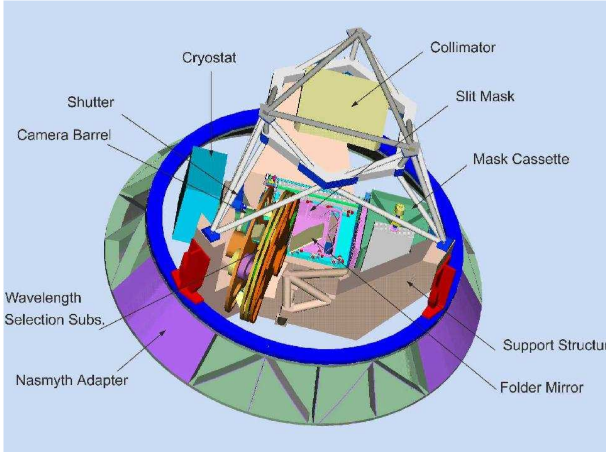

Fig. 2. OSIRIS optomechanical layout. The different subsystems are indicated. Some parts have been removed to provide a clearer view.

The slit mechanism is also subject to spectral stability and repeatability requirements:

- Contribution of the slits to the flux error budget within the allocated value
- Contribution of the slits to the spectral stability error budget within the allocated value
- Slit repeatability to avoid acquiring slit position during observations.
- A number of masks suitable to carry on a long slit, a MOS, or a long slit plus MOS observing program (thus easing queue observations) during the same night without changing masks

These requirements are achieved with a cassette with space to store as many as 13 multislit and longslit masks. A mechanism of two degrees of freedom allows the selection of one of the masks by removing it from the cassette and positioning it in the telescope focal plane with the required repeatability. The complete design of the mechanism, including an analysis of the predicted performances and a 3D model used to check the geometry and mass properties, is presented by Peraza et al. (2002).

4. DETECTOR AND DETECTOR CONTROL

The detector mosaic is composed of two 2k $\times$ 4k CCDs abutted to give a total of 4k $\times$ 4k pixels (15 micron/pixel, 0.125$''$ plate scale). Day One arrays will be MAT44-82s from Marconi, although

Science with the GTC 10-m Telescope (Granada, España, 5-8 febrero 2002)
Editors: José Miguel Rodríguez Espinosa, Francisco Garzón López & Verónica Melo Martín

these will probably be upgraded to MIT/LL CCID-20 blue-enhanced ones afterwards. The detectors have been chosen to have a maximum quantum efficiency (QE) in the red but to be blue-sensitive and with minimum fringing. The Detector Control System performance parameters (such as readout noise or speed) will be driven only by those of the above mentioned CCDs. To handle the mosaic some minor hardware modifications have been made to a classical ARC-GenII controller, together with major software DSP programming, to run any of the complex OSIRIS observing modes (Joven, Gigante, & Beigbeder 2002). Some tests of the above configuration with a couple of MAT engineering-grade devices at room temperature have been performed successfully (Figure 3). Readout modes include charge shuffling up and down, continuous readout, and reading windows. Readout speeds will be at least slowest possible, intermediate (nominal), and fastest possible. Frame transfer is also contemplated with both devices for fast spectroscopy modes.

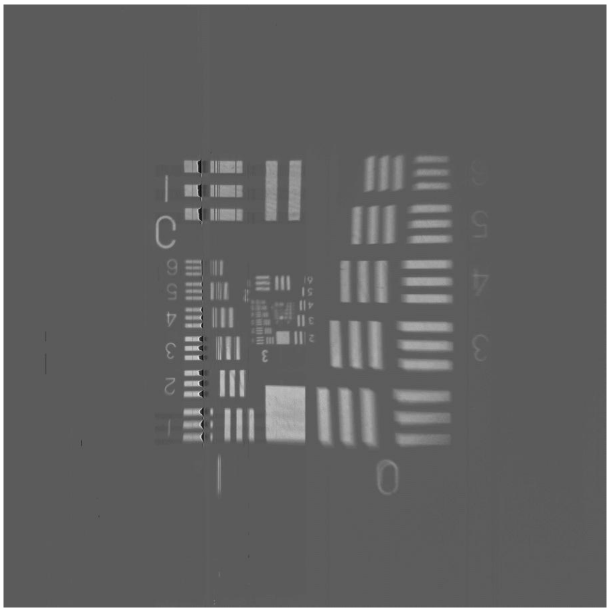

Fig. 3. First image taken with the full engineering-grade 4096 × 4096 pixel MAT mosaic. The image corresponds to a test exposure of 100 ms using a LED to illuminate a test pattern. The four channels (two for each CCD) have been read at 800 kpix/channel, giving a total readout time of 5 s for the full frame, using the SDSU-genII plus VxWorks. A dark frame has been subtracted.

5. INSTRUMENT UPGRADES

Since OSIRIS has been designed as a multipurpose, flexible instrument, several very interesting upgrades are possible, depending on available budget and human resources. In this section the possible upgrades are briefly described.

5.1. *Upgrades for Day One*

Day One upgrades are already under development and will hopefully be available on Day One or shortly afterwards and have been selected according to the criterion of not affecting the instrument design or schedule:

- Solutions for achieving higher resolution spectroscopy, up to 5000 or more, have been studied at the IAC. The feasible options have already been selected, funds are to be requested, and the gratings will probably be tested during instrument AIV.
- Fabry–Pèrot spectroscopy will be implemented in a collaboration between IA-UNAM (Mexico) and the IAC (Spain) to allow 2D spectroscopy at high resolution to be performed over the OSIRIS FOV. This mode opens up a completely new window in 8–10 m class telescopes.
- Coronography is currently under study at IA-UNAM. This possibility opens up the new observing mode of tunable coronography, unavailable on other large telescopes. It will allow the observation of emission lines of host QSOs and galactic nebulae with bright stars embedded, among other applications.

5.2. *Upgrades after Day One*

After Day One, a set of possibilities, requiring major instrument changes, are possible:

- Changing the CCD for a near infrared-sensitive device allows the use of a tunable filter in the nonthermal near infrared to observe Hα up to redshift 2 or more
- A post-focal insertion unit will allow the implementing of:
  - Polarimetry
  - Very high resolution Fabry–Pèrot spectroscopy
  - IFU spectroscopy

6. CONCLUSIONS

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 easily upgradable and is multipurpose. Since it is optimized for line flux determination, OSIRIS can be designated as a Star Formation

Science with the GTC 10-m Telescope (Granada, España, 5-8 febrero 2002)
Editors: José Miguel Rodríguez Espinosa, Francisco Garzón López & Verónica Melo Martín

Machine. With all subsystems at the detailed design level or in fabrication before the end of 2002, some of them at an advanced stage. OSIRIS is matching the telescope schedule and will be ready for Day One.

The Web site http://www.iac.es/project/OSIRIS provides the updates on the project.

OSIRIS instrument is funded by GRANTECAN S.A., by the Spanish Ministerio de Ciencia y Tecnología project AYA2000-0333-P4-02, and by the Instituto de Astrofísica de Canarias.

REFERENCES

Bland-Hawthorn, J., & Jones D. H. 1998, SPIE, 3355, 855

Cepa, J., Aguiar, M., González-Escalera, V., González-Serrano, J. I., Joven, E., Peraza, L., Rasilla, J. L., & Rodríguez, L. F. 2000, SPIE, 4008, 623

Cobos, F. J., González, J., Tejada, C., Rasilla, J. L., Cepa, J., Sánchez, B., Pérez, A., Espejo, C., Garfias, F., Chapa, O., & Pérez, F. 2002, SPIE, in press

Fuentes, J., Militello, C., Correa, S., Peraza, L., Hernández, B., Cepa, J., Pérez, A., Ballester Lluch, J. A., & Pérez-Espinos, J., 2002a, SPIE, in press

Fuentes, F., Militello, C., Rasilla J. L., Correa, S., González, J., Peraza, L., & Hernández, B. 2002b, SPIE, in press

Glazebrook, K., & Bland-Hawthorn, J. 2001, PASP, 113, 197

González, J., Tejada C., Rasilla, J. L., & Fuentes F. 2002, SPIE, in press

Joven, E., Gigante, J. V., & Beigbeder, F. 2002, in ASSL, Optical Detectors for Astronomy II, ed. Paola Amico & James W. Beletic (Dordrecht: Kluwer), in press

Peraza, L., Fuentes, F., Militello, C., Correa, S., & Pérez-Espinos, J. 2002, SPIE, in press

Rasilla, J. L., Cepa, J., Fragoso-López, A. B., González, J., & Bland-Hawthorn, J. 2002, SPIE, in press

J. Cepa, Marta Aguiar, H. O. Castañeda, Santiago Correa, Ana Belén Fragoso, Javier Fuentes, José Vicente Gigante, Victor González-Escalera, Enrique Joven, José Carlos López, Lorenzo Peraza, Angeles Pérez, Jaime Pérez and José Luis Rasilla: Instituto de Astrofísica de Canarias, E-38205 La Laguna, Tenerife, Spain (jcn, mag, hcastane, scorrea, afragoso, fjf, gigante, vgonzal, eja, jlopez, lpc, mperez, jperez, jlr@ll.iac.es)

J. Cepa: Departamento de Astrofísica, Facultad de Física, Universidad de La Laguna, E-38071 La Laguna, Tenerife, Spain (jcn@ll.iac.es)

J. Bland-Hawthorn: Anglo–Australian Observatory, P.O. Box 296, 167 Vimiera Road, Epping, NSW 2121, Australia (jbh@aaoepp.aao.gov.au)

F. Cobos, C. Espejo, J.J. González, B. Sánchez and C. Tejada: Instituto de Astronomía, Universidad Nacional Autńoma de México, Apartado Postal 70–264, México, D.F., México 04510 (cobos, espejo, jesus, beatriz, tejada@astroscu.unam.mx)

I. González-Serrano: Instituto de Física de Cantabria (CSIC–Universidad de Cantabria), E–39005 Santander, Spain (gserrano@ifca.unican.es)

C. Militello: Departamento de Física Fundamental y Experimental, Facultad de Física, Universidad de La Laguna, E–38071 La Laguna, Tenerife, Spain (cmilite@ull.es)