

Grantecan
Instituto de Astrofísica de Canarias
Vía Láctea s/n,
E-38200 La Laguna
Tenerife
Spain
pedro.alvarez@gtc.iac.es

- 1. *Introducción***
- 2. *The GTC's First Generation instruments***
- 2.1 *OSIRIS***
- 2.2 *CANARICAM***
- 3. *The GTC's Second Generation instruments***
- 3.1 *CIRCE***
- 3.2 *EMIR***
- 3.3 *FRIDA***
- 3.4 *UES***
- 3.5 *Optical medium-resolution spectrograph***
- 3.6 *NIR seeing-limited medium-resolution spectrograph***
- 3.7 *Feasibility studies towards new AO capabilities***
- 4. *The GTC and the new large facilities ALMA, JWST and ELTs***
- 5. *References***

Pedro Álvarez



Gran Telescopio CANARIAS - GTC

The GTC instrumentation plan

Abstract

The Gran Telescopio Canarias (GTC) started its regular science operation activity in March 2009. I present here the development plan for the science instruments for this telescope to provide the GTC community with novel and competitive observing modes in the era of large new observing facilities such as ALMA, JWST and the ELTs.

1. Introduction

The GTC is a 10.4 m segmented primary mirror telescope sited at the Observatorio del Roque de los Muchachos, on the Spanish Island of La Palma. It is a partnership between Spain, México and the University of Florida. GTC science operations started in March 2009 with OSIRIS, one of its two first generation instruments.

The GTC primarily serves a specific user community in Spain, México and the University of Florida. This community is broad-based in its scientific interests so that its instrumentation needs are also diverse. The GTC will play an essential role for a large fraction of this community since it will provide prime large telescope access to the northern skies.

It will be no easy task for the GTC to excel among the other large aperture observatories. It can only be made competitive through a judicious combination of its slightly larger aperture with a suite of carefully chosen instruments and telescope capabilities matched to the properties, strengths and plans for growth of the scientific community it has been built to serve.

The GTC's first generation instruments are OSIRIS, now in operation at the GTC, and CanariCam, which is completed and waiting to be installed and commissioned in the coming months.



The GTC inside its dome

Science
with the
8-10m
telescopes
in the era
of the ELTs
and the
JWST

235

Here, I present the GTC instruments currently under development and the plans for future instruments. I also describe second generation instruments that are at various stages of advancement. Of particular interest are CIRCE, a near-infrared camera, planned to be commissioned on the GTC at the end of 2010; EMIR, a wide field multi-object near-infrared spectrograph, which will be starting its assembly phase in autumn; and FRIDA, the Adaptive Optics-fed near-IR integral field unit spectrograph being built in México. FRIDA has undergone its preliminary design review and is now well into its final design phase.

A plan for the further development of new science instruments and telescopic capabilities has been prepared, intensively discussed and finally approved, and is now fully supported. This plan includes the development of two medium resolution MOS spectrographs, one working in the visible and the other one in the near IR. High dispersion optical spectroscopic capabilities could soon be available using the Utrecht Echelle Spectrograph (UES).

2. The GTC's First Generation instruments

2.1 OSIRIS

OSIRIS is a powerful multi-purpose workhorse instrument for imaging and low-resolution spectroscopy operating in the optical waveband (0.36-1.0 μm). It was specifically designed for narrow-band tunable-filter imaging, a uniquely competitive niche among 8-10 m class telescopes. OSIRIS also provides a full set of additional observational modes, including long-slit and multi-object spectroscopy ($R < \sim 5000$), fast photometry and spectroscopy, as well as powerful CCD-transfer modes like fast photometry and fast spectrophotometry, or bracketing line emission frames with continuum frames and subtracting before a read out and reset takes place. The optical design allows for a sizeable field of view (7×7 arcmin² unvignetted) with a proper oversampling of good ORM seeing conditions. Narrow-band imaging can be continuously tuned from 365 to 1000 nm (FWHM from 12 to 40 Å). Spectroscopically, it samples $R = \lambda/\Delta\lambda$ resolutions from 300 to ~ 5000 (0.6'' slit width), and in MOS mode can accommodate from 40 to several hundred object spectra in fields that depend somewhat on the chosen resolution. OSIRIS delivers a competitive field of view in its spectroscopic modes that is considerably larger than similar instruments of its class, such as GMOS (Gemini) and LRIS (Keck).

The instrument throughput is remarkably competitive. Its optical transmission (excluding dispersive elements and detector) is significantly better at all wavelengths than similar instruments like FORS (VLT), GMOS (GEMINI) and LRIS (Keck). Overall, OSIRIS is a competitive instrument within its class, with the extra advantage of tunable imaging, thus making it quite a competitive and adaptable workhorse optical instrument for broad- and narrow-band imaging and low-to-intermediate ($R < \sim 5000$) spectroscopy.

OSIRIS's optical design employs a reflective active collimator and a refractive camera. A flat mirror folds the light beam in order to fit it within the Cassegrain envelope. OSIRIS carries two wide format (2048 x 2048) Marconi-EEC detector arrays. Preserving blue sensitiveness has been a constant goal for OSIRIS. U band (365 nm) imaging will therefore be possible for stellar population studies. The array detector sensitivity in the red is also fairly high, thus making OSIRIS ideal for observations of the redshifted Universe, for instance through the study of the [OII] $\lambda 372.7$ nm line at high redshift. Further details of OSIRIS can be found at <http://www.gtc.iac.es/en/pages/instrumentation/osiris.php>.

2.2 CANARICAM

CanariCam is the second first generation instrument for GTC and will serve as the facility's mid-infrared instrument. CanariCam is designed for observations in the 8.0–24.0 μm wavelength range. It was built at the University of Florida and represents an evolution of the successful instrument design of T-ReCS, the Gemini South mid-IR imager/spectrometer. CanariCam can perform broad- and narrow-band imaging, long slit spectroscopy, dual beam polarimetry and coronagraphy. The coronagraphy option is, to the best of our knowledge, the first to be made available in the mid-IR on a large ground-based telescope. The detector is a blocked-impurity-band (BIB) arsenic-doped silicon array from Raytheon, with 240 x 320 pixels, 0.08" each on the sky, hence providing a field of view of 19" x 26". CanariCam is designed to get diffraction-limited images across its FOV. CanariCam carries for its imaging mode a large set of broad and narrow-band filters. The coronagraphy mode is selected by inserting an occulting spot in the telescope's focal plane and one of several Lyot stops in the pupil plane. The baseline coronagraphy mode is for the 10 μm window only. In polarimetric mode CanariCam allows polarimetry in the 10 μm atmospheric window. Both the ordinary and the extraordinary rays are observable simultaneously on the detector array, thus allowing much better accuracy even through thin clouds. A Wollaston prism is inserted into the beam after the collimator separates the orthogonally polarized components of the light, which are then imaged separately onto the detector.

Slit-spectroscopy is implemented by inserting a slit in the image plane and one of the four gratings into the pupil plane. There are two gratings for 10 μm spectroscopy, at low ($R=100$) and High ($R=1300$) resolution respectively, and another two for low ($R=60$) and High ($R=700$) resolution spectroscopy in the 20 μm atmospheric window. Together, the low-resolution gratings span the entire 10 μm (8-14 μm) and 20 μm (approximately 16-25 μm) windows. Both high-resolution gratings can be positioned to select the required wavelength within the 10 μm and 20 μm windows respectively. Two basic slit widths are available: a narrow slit for diffraction-limited observations and a wide slit for twice the diffraction limit.

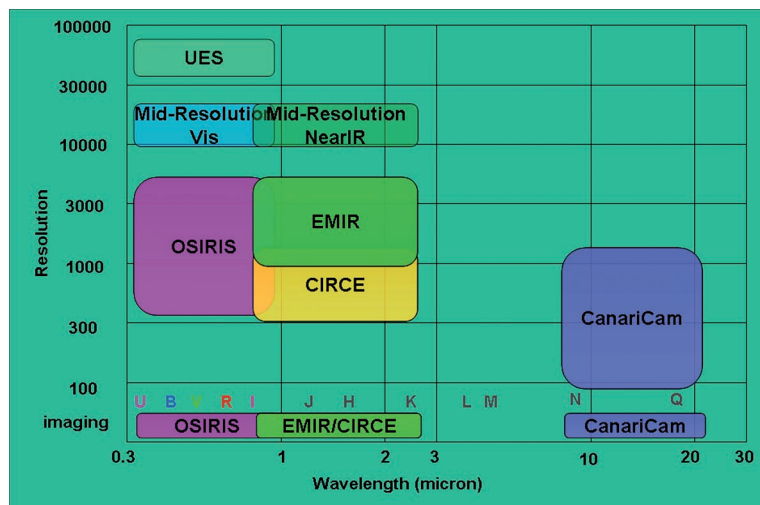
CanariCam has been delivered to the Observatory and will be installed on the GTC in the coming months to start its commissioning. Its use for science observations is expected to be initiated during semester 2010A. Further information on CanariCam and its scientific programmes are available at <http://www.gtc.iac.es/pages/instrumentacion/canaricam.php>.

3. The GTC's Second Generation instruments

3.1 CIRCE

The Canarias InfraRed Camera Experiment (CIRCE) is a near-infrared (1-2.5 micron) instrument. CIRCE will fill the near-IR gap between the first generation facility instruments OSIRIS and CanariCam. The optics and detector array of CIRCE will provide a pixel scale (0.10 arcsec/pixel), fine enough to sample adequately the excellent images provided by GTC, while at the same time providing a near-IR field of view (3.4x3.4-arcmin) comparable to any currently available on the world's largest telescopes (a real FOV ~25 times larger than NIRC on Keck, and ~3 times larger than NIRI on Gemini).

CIRCE will employ two gratings to provide spectroscopy with two different resolutions. The first grating allows the J, H and K bands to be covered in a single frame at roughly a resolution of $R=550$ (for a 3-pixel slit). The second grating will cover a single band instantaneously at a resolution of $R\sim 1500$ (3-pixel slit) in its 3rd order (K-band), 4th order (Hband) and 5th order (J-band). CIRCE will also have a polarimetric mode with the use of a Wollaston prism. It also offers a sub-framing readout mode, for high-speed imaging photometry in any filter (broad or narrow band). The control electronics supports continuous frame rates faster than 1 Hz over fields of view exceeding 1×1 arcmin².



GTC Instrumentation coverage of spectral resolution versus wavelength parameter space. FRIDA is not included in order to simplify the picture. It will cover the area covered by CIRCE, EMIR and the Mid-Resolution Near-IR instrument but with a small FOV as it will work in AO mode only with an IFU.

After the delivery of EMIR to the GTC, CIRCE will continue in scientific use on the GTC, where its high imaging quality and resolution, polarimetric capability, high time-resolution readout and lower spectral resolution (useful for very faint targets) will complement the capabilities of EMIR. CIRCE will be a visiting instrument provided to the GTC by the University of Florida. It is expected to be installed and commissioned on the GTC by the end of 2010. Further information on CIRCE and its science drivers are available at <http://www.astro.ufl.edu/circe/>.

3.2 EMIR

EMIR is a cryogenically cooled wide-field, near-infrared (0.9–2.5 μm) imager and multi-object spectrograph. EMIR is being developed by a consortium of institutes, led by the IAC and including the Universidad Complutense de Madrid (UCM, Spain), the Laboratoire d'Astrophysique des Midi Pyrénées (LAOMP, France) and the Laboratoire d'Astrophysique de Marseille–Provence (OAMP, France). EMIR's optical design allows for a plate scale of 0.2 arcsec/pixel on a Rockwell-Hawaii-2 2Kx2K HgCdTe detector with 18 μm pixels. This results in a 6' x 6' field of view.

EMIR is a very versatile near-IR instrument that will become a workhorse for near-IR imaging and multi-object spectroscopy. Apart from its primary mode, which is K-band multi-object spectroscopy with up to 55 slitlets in a 6' x 4' field of view, EMIR is designed to perform broad- and narrow-band imaging. The expected limiting magnitude in the K-band is 23.9 mag in a 1 hour exposure (S/N= 5) within a 0.6" aperture. As for spectroscopy, EMIR is expected to reach 21.2 mag in K-band spectroscopy for a 2 hr exposure (S/N= 5). The Spectroscopic resolution provided by pseudo-grism dispersers ranges from $R \sim 5,000$ in the K-band to $R \sim 4,000$ in the J-band, allowing observing between the OH telluric lines for better sensitivity to faint objects.

EMIR is a complex instrument. The very wide field of view, relatively high spectral resolution and multi-object capability all add to its overall intricacy. The configuration of slit masks will be performed with a cryogenically cooled robot. EMIR is a general-purpose instrument with a wide range of capabilities and a design optimized for multi-object spectroscopy of high-redshift galaxies in the K-band. Further details on EMIR can be found in the EMIR web page at <http://www.ucm.es/info/EMIR/>. The current plan is to install EMIR at the GTC at the end of 2012.

3.3 FRIDA

FRIDA and the GTC Adaptive Optics systems (GTCAO) will provide near-diffraction-limited imaging and integral field spectroscopy over the 0.9-2.5 micron band-pass on the GTC. GTCAO will initially provide natural-guide-star correction over the isoplanatic patch with Strehl ratios as high as $\sim 65\%$ in the K-band. A later upgrade of GTCAO will provide a laser guide star with a similar Strehl ratio and dramatically improved sky coverage.

FRIDA uses an image slicer to produce the Integral Field Unit configuration and is based on the successful FISICA design from the University of Florida. FRIDA offers 3D spectroscopy in the 1 to 2.5 micron range, allowing simultaneous imaging and spectroscopy of its field of view. It will therefore deliver data cubes from which images in selected bands can be retrieved. FRIDA employs a Rockwell 2k x 2k Hg-Cd-Te Hawaii II array. Two different plate scales, 0.010"/px and 0.020"/px, will be available for imaging to produce 20.48" x 20.48" and 40.96" x 40.96" fields of view respectively. In spectroscopy three spaxel ratios produce 0.010"/px x 0.020"/slice, 0.020"/px x 0.040"/slice and 0.040"/px x 0.080"/slice respectively. These give a fine scale field of view of 0.66" x 0.66", a medium scale field of 1.32" x 1.20" and a coarse scale field of view of 1.64" x 2.40" respectively. As for spectral resolution, there is a low-resolution mode (R=1500) covering the H and K windows, an intermediate resolution (R= 4000) that allows OH suppression and gives the J, H and K bands independently. Finally, a high-resolution mode (R=30000) can cover selected spectral regions in the H and K bands. This high-resolution mode is a unique feature in FRIDA.

FRIDA is being built at the Institute of Astronomy of the Universidad Nacional Autónoma de México, which leads a large consortium. The other participating institutes are the University of Florida, the IAC and the Universidad Complutense de Madrid (UCM). FRIDA is planned to reach the telescope in 2012. More info on FRIDA can be found in the FRIDA web pages http://www.astroscu.unam.mx/ia_cu/proyectos/frida/index.html.en

3.4 UES

High resolution spectroscopy requires a large number of photons. Except for specific projects, only the largest telescopes at any moment can be really competitive. Therefore, high-resolution spectroscopy is one of the fields in which GTC will be very competitive owing to its large collecting area.

The Utrecht Echelle Spectrograph (UES) is being refurbished so that it can be fibre-linked to the OSIRIS mount on the Nasmyth platform of the GTC. The UES will provide the GTC with high optical spectral resolution (R ~ 50000). The former UES, an echelle cross-dispersed spectrograph, had been successfully used for years in one of the Nasmyth focal stations of the WHT. The UES had been decommissioned to free the Nasmyth platform for the ING AO programme. This is a collaborative project between the Isaac Newton Group (ING), owner of the William Herschel and other telescopes on La Palma, and the Instituto de Astrofísica de Canarias.

3.5 Optical medium-resolution spectrograph

A mid-resolution optical spectrograph (R=10000-20000) is planned for the GTC by 2015. An announcement of opportunity has been issued to initiate its development. It is required as a multi-purpose workhorse instrument aimed at giving support to a

large number of projects. It will need significant multiplexing capability not only to take advantage of large surveys but also because in current research many results have been reached only after analysing a large number of objects. Possible references (and competitors) would be FLAMES-GIRAFFE and MUSE on the VLT or WFMOS on Subaru. At present, there is no such instrument operating in the northern hemisphere, and only GMOS, with limited resolution, would be a competitor in the blue (DEIMOS at Keck II is also a competitor in the red).

3.6 NIR seeing-limited medium-resolution spectrograph

To fill the gap in near-IR, medium-resolution (10000-20000) spectroscopy, and multiplexing capability over a large field of view an announcement of opportunity has been made to develop a new spectrograph to reach the telescope by 2016. FRIDA provides such spectral resolution in this wavelength range but it is an adaptive-optics instrument and its field of view is consequently limited. No such instrument is yet available or planned for any other 8 to 10 m telescope.

3.7 Feasibility studies towards new AO capabilities

New capabilities need to be developed in the field of high spatial resolution and this will require the upgrading of the GTC AO system.

Feasibility studies for multi-conjugate adaptive optics and ground layer adaptive optics capabilities, and their related instrumentation, need to be initiated to identify new capabilities to be made available on-sky by 2018.

Such capabilities are closely tied to knowledge of the turbulence scale height at the ORM. The GTC will therefore perform a study to provide high-resolution measurements of the ground layer properties and the turbulence scale height at the ORM

4. The GTC and the new large facilities ALMA, JWST and ELTs

From 2012 onwards, new millimeter and sub-millimeter observatories will be operational: ALMA in the southern hemisphere and Large Millimeter Telescope in the northern hemisphere. The GTC will not be the best candidate for ALMA follow-up surveys, but can be a useful tool in dealing with selected samples mostly through NIR spectroscopy and narrow- and broad-band imaging in the optical, NIR and mid-IR. For galactic objects, the GTC can help with AO observations of the closest cool objects detected before the ELTs become fully operational.

The LMT is a better option as it has the same sky coverage as the GTC. Synergies between both instruments can be easily addressed as INAOE is a partner in the GTC and there is an agreement on exchange of observing time and the development of joint programmes around both instruments between the communities.

The James Web Space Telescope (JWST) will be operational from 2014 or 2015 and for a lifetime of 5 to 10 years. It will be an unprecedented step forward in observing the sky, especially in the infrared part of the spectrum. But major ground-based telescopes will complement its observations on studies requiring higher spectral resolution than its limit at $R \sim 3000$; or at shorter wavelengths than its cutoff around 0.6 microns, which will be particularly important after the HST is decommissioned; or when the higher spatial resolution using AO, in the mid infrared, in good seeing conditions are required. The GTC, like other ground-based telescopes, can benefit from its larger FoV, above the JWST limit of about 3×3 arcmin. Multi-IFU capabilities can also be complementary as they are not available at the space telescope. Finally, the upgradability and versatility of the ground-based GTC should be an advantage with respect to the limited flexibility of space facilities to improve and adapt their instrumentation.

After 2018, or probably some years later, the ELTs will become the new unbeatable observing facilities. At that time the 8 to 10 metre telescopes have to adapt to their new roles in the way that 2 to 4 metre telescopes have had to do after the present generation of larger telescopes were built. But there will be fewer ELTs than 8 to 10 metre telescopes. That difference could mean that telescopes like the GTC will play an important role for a longer period of time in complementing the ELTs. By that time the GTC will need to be well equipped with AO observing capabilities as this will be the main observing mode of the ELTs.

In the longer-term it is difficult to identify the best role for the GTC. We need to be open to fundamentally re-assessing our objectives and mission in a time led by multiple ground-based ELTs.



The GTC buildings at the Roque de Los Muchachos Observatory (ORM)

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