GRAN TELESCOPIO CANARIAS
GTC

TITULO

Report of the Gran Telescopio Canarias 2013 Instrumentation Review Panel La Palma, 17-18 July 2013

Código : GEN/DIRP/0128-L

Edición : 1.A

Fecha : 05/08/13

Nº de pág. : 17

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Report of the Gran Telescopio Canarias
2013 Instrumentation Review Panel

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La Palma, 17-18 July 2013

EXECUTIVE SUMMARY

The primary purpose of this report is to review the status and priorities of instrument development by GRANTECAN, including associated upgrades of the telescope facilities, in the context of the current (and anticipated) available resources. The development is based on the first generation instrumentation plan, essentially as laid out in the 2008 instrumentation working group report (and summarized in the Annex here). This ambitious plan from 2008 is for a total of eight on-board instruments, to be built by external consortia. GRANTECAN provides most of the funds for hardware development, while the external teams give the bulk of the manpower in exchange for guaranteed time. In addition, a significant hardware contribution is expected from GRANTECAN, with, in particular, the completion of at least three additional focal stations and the development of an adaptive optics facility.

However, since 2008, GRANTECAN's operational, financial and human resources have been severely reduced, as have, albeit to a somewhat lesser degree, the grant funding available for new instrument initiatives by the institutes involved in the instrumentation projects. As a consequence, two major instruments (MEGARA & MIRADAS) had been effectively put on hold at FDR level, and GRANTECAN cannot realistically cope with equipping the focal stations and building the GTCAO facility (to be used by the FRIDA diffraction-limited imager and integral field spectrograph), let alone provide even minimal support to overall instrument development.

This serious situation requires drastic action. The Panel has therefore worked towards producing a revised plan that is compatible with the current and foreseen resources, while trying to minimize the impact in terms of the range of science capabilities of GTC to be offered to its community.

Specifically, our main recommendations to GRANTECAN are:

- finish OSIRIS commissioning, so that it can offer its full suite of observing modes to the GTC community;

- give priority to the final testing and commissioning preparation of the multi-object NIR spectrograph EMIR, with the aim that it be put into operation as soon as possible;

- retain the current CIRCE instrument as a backup, and only undertake its final development if there are serious delays or problems that arise with EMIR;

- continue to operate the MIR CANARI-CAM instrument on GTC only until its Nasmyth focal station is required, presumably by EMIR, in early-mid 2015;

- stop the combined GTCAO/FRIDA project as currently scoped, and focus the AO team's efforts on producing a longer-term perspective of adaptive optics on GTC that is genuinely world-class;

- release funds as soon as possible in order to proceed rapidly with the MEGARA spectrograph;

- support the IAC team currently involved with the development of a high resolution optical spectrograph for GTC, provided this is their simpler HORS version, which matches well the needs of a significant segment of the GTC community;

- review carefully, as a matter of urgency, the available human and financial resources for MIRADAS, and try to find a viable strategy with the instrument team;

- repair the dome shutter problem as a top priority, once the appropriate strategy has been defined.

The Panel considers that, by focusing on the above recommendations and optimising the use of its presently limited resources, it will be challenging but certainly feasible for GRANTECAN to be able to offer its community a competitive suite of instruments by 2016.

The Panel was also tasked with analysing the likely shifts in observing capabilities for GTC to maintain its competitiveness over the next ten years. We single out the 2018 launch of the James Webb Space Telescope as the most important factor to cope with, by putting even more emphasis on covering the optical range with a large variety of observing modes, and offering both medium and high spectral resolution in the optical and near-IR.

Resources permitting, very high multiplex instruments featuring about one billion spectrographic pixels will be required, in particular in conjunction or for the follow-up of massive surveys from space (GAIA, CHEOPS, EUCLID…) and from the ground (ALMA/LMT, LOFAR/SKA, LSST…). Such scientific and observational shifts might well prove crucial beyond 2020, as the era of the Extremely Large Telescopes opens.

BACKGROUND

This 2013 Instrumentation Review has been commissioned by GRANTECAN. Its primary purpose is to review the development and operational status of the first generation GTC instrumentation Plan, including associated telescope facilities, and provide guidance to GRANTECAN for optimizing this effort in terms of human and financial cost relative to science return. Its secondary purpose is to analyse how GTC could maintain its competitiveness over the next ten years and possibly beyond.

The current Plan, largely following on from the 2008 Future Instrumentation Working Group Report (Eikenberry et al 2008), encompasses eight general-use instruments, although two of them (HORS/HORUS & CIRCE) are formally designated as "visitor instruments". This instrument suite covers a large spectral range (near-UV to mid-IR), low to medium to high spectral resolution, and many different observing modes (natural seeing & diffraction-limited imaging and spectroscopy, spectro-polarimetry, multi-object spectroscopy of various kinds, and integral field spectroscopy). Two of them are currently in operation on GTC: OSIRIS (since 2009) and CANARI-CAM (since 2012), although some of their observing modes are not yet fully commissioned.

In conjunction with instrument development, the telescope facilities are themselves not yet complete, with strong potential impact on some of the instruments currently under consideration. This work on the telescope must be considered as a crucial and integral part of the overall instrumentation effort, is largely being undertaken by GRANTECAN and includes in particular:

a) completion of M1 closed-loop active optics and M2 fast guiding,

b) design & construction of three Cassegrain focal stations, and

c) completion of the GTC-AO facility (a natural guide-star single-conjugate AO system that is essential for operation of FRIDA).

This ambitious plan is now under severe pressure, in terms of currently available and anticipated financial and manpower resources, which are affecting both the instrument consortia and GRANTECAN. A key aggravating point is that almost all GTC present or planned instruments are multi-mode: this is attractive to the user community for the wide range of observing capability that is offered, but it also hugely increases the workload not only for instrument designers and builders, but also for the subsequent commissioning, operation and data flow management. Given that GRANTECAN and the instrument teams now operate on very lean human and financial budgets, this is of major concern and might easily lead to a collection of half-completed and/or very late and quasi-obsolete instruments.

We acknowledge the extensive and creative work that GRANTECAN has done to identify and assess a range of potential solutions to cope with accommodating the anticipated range of instrumentation within the current resources. The GTC team was also very clear in presenting these alternatives and very open and straightforward in describing the current situation and their experiences in dealing

with a variety of demands and pressure.

Accordingly, we feel that in view of the severity of the situation, some difficult choices have to be made now. These actions are necessary if GTC is to be able to offer a competitive suite of instruments operating efficiently by 2016. Once the current very difficult situation has been overcome, then a re-evaluation of instrument priorities should be undertaken.

RECOMMENDATIONS

On the basis of this background to our deliberations we make the following recommendations:

1. Telescope Focal Stations

GTC has in principle seven focal stations: one at classic Cassegrain, two at Nasmyth and four at folded-Cassegrain. Of these, only the two Nasmyth foci (with OSIRIS and CANARI-CAM installed) are essentially fully functional. Two image-rotators for use at the folded Cassegrain foci have been manufactured, and one is installed. The classic Cassegrain is currently unsupported. Clearly, considerable work remains to be done in order to be able to offer full functionality at the currently unused foci.

The Panel's view is that by 2016 GTC should be equipped with a minimum of three workhorse instruments, and additionally offer a free focal station at folded-Cassegrain for innovative visiting instruments. Our recommendations and suggestions to GRANTECAN are that this should be accomplished with the minimum of instrument mounting and dismantling, as indicated below on a project-by-project basis.

2. OSIRIS

Without doubt, OSIRIS has been one of the principal successes of GTC's instrumentation program. As the only functioning instrument since 2009, virtually all of the science publications produced by GTC have come from OSIRIS, and that is from only its long-slit spectroscopy and imaging capabilities. It has the potential for high time resolution observing, and only recently has the MOS mode entered commissioning, which is clearly eagerly anticipated by the user community. The instrument has proved to be stable and reliable in operation, with now relatively low demand on technical support effort.

In short, OSIRIS has rapidly achieved the status of a true "workhorse" instrument on GTC that guarantees outstanding science across an enormous range of fields. It has a potentially long lifetime as part of GTC's core instrumentation suite, and is used by an extremely wide community. As such, we strongly recommend that OSIRIS remain at Nasmyth-B, and that this area not be shared with any other instrument.

Under the medium-term view spelt out in point 1, we believe that OSIRIS would be even better if operated at Cassegrain, the focal station for which it was

originally proposed. Accordingly, we recommend that funding and technical effort should be made available, so that OSIRIS can eventually be moved to Cassegrain. This would have the benefit of opening up the large area of Nasmyth-B for future developments, such as MEGARA and a revised AO system with its associated scientific instrumentation. We understand, however, that this can only be done when GRANTECAN resources permit this development without seriously impacting other critical tasks.

Furthermore, we consider that a high-dispersion scanning Fabry-Perot mode, as originally proposed, would enhance the scientific competitiveness of OSIRIS. We recommend that GRANTECAN assess carefully with its user's community the science drivers for that additional mode and the corresponding need for a bank of narrow-band interference filters and a suitable data reduction pipeline. If agreed upon, GRANTECAN should plan such an upgrade carefully for when there are sufficient resources for the appropriate commissioning of this mode, and so that it does not create undue risk for the ongoing operation of OSIRIS.

While the proposed CCD upgrade would deliver some significant improvements, these need to be carefully assessed against other priorities, and should be set by GRANTECAN. It should be noted though, that this would be a valuable long-term undertaking in any case, as GRANTECAN will need backup capacity in the event of major detector failure.

3. CANARI-CAM

The CANARI-CAM mid-IR spectro-imager has been in operation since 2012, but still requires additional commissioning of its polarimetry mode. It covers both the N and Q bands; however, the latter is severely hampered by the (too high) precipitable water vapour content at the site in summer and autumn. As with similar mid-IR ground-based facilities elsewhere, this is essentially a niche instrument, aimed at high resolution imaging at a level not yet attained from space (until JWST is in orbit). This aspect is reflected in a relatively low fraction (<20%) of telescope time allocation compared to OSIRIS.

In view of the heavy workload required to eventually move the instrument to another focal station (which has to be fully equipped for the safe operation of its cryogenics), the Panel recommends keeping CANARI-CAM in operation for the next two years or so, until the Nasmyth-A focus is needed to accommodate EMIR or possibly CIRCE (see point 3 below). This should give its community a reasonable opportunity to be able to accomplish its highest priority observations, even if admittedly some of CANARI-CAM's more exotic modes (high spectral resolution & coronography) are not yet in operation.

One potential obstacle towards this scheme is the requirement for GTC to complete the large (180-hour) ESO-GTC program for a Mid-IR Survey of Active Galaxies, with only 6 hours carried out so far. Given that the emphasis in the proposal is clearly on imaging, spectroscopy and polarimetry through fair seeing conditions in the N-band, we encourage GRANTECAN to proceed at the highest priority with the N-band observations, in order to complete this main part of the program by May 2015 at the latest (and preferably earlier). Q-band observations should be done whenever possible, but it is highly unlikely than more than a very

few sources out of the total of 34 targets could be covered in any reasonable time span. In addition, the 343-hour remaining guaranteed time observations should be completed swiftly.

4. EMIR & CIRCE

The Panel fully endorses the importance of providing the GTC community with a full set of workhorse general-use instruments covering the visible-IR range with imaging and spectroscopic (a few 100 to >20,000 spectral resolution) capabilities. In this sense, OSIRIS & EMIR (and their high spectral resolution counterparts MEGARA & MIRADAS) must continue to be top priorities, as was indeed contemplated in the original GTC instrumentation plan.

Regarding the NIR instrumentation, the GRANTECAN should concentrate on the optimal preparation and technical support required so as to receive and commission EMIR efficiently and effectively. EMIR should be installed at Nasmyth-A as planned.

CIRCE should still be under consideration, but only as a temporary backup instrument (with no multi-object capability) in case EMIR suffers serious problems and/or delays. CIRCE was developed in order to provide prompt NIR access for the GTC community, so GRANTECAN must urgently press for a reliable delivery date for CIRCE. If this is not forthcoming, or major delays ensue, then the instrument should be discarded once EMIR's readiness is positively assessed. It is then extremely important that GRANTECAN concentrates on working closely with the EMIR instrument team on strict readiness tests during summer 2013, and review with them a suitably detailed commissioning plan.

By late 2013 it will be known how well EMIR has passed its critical operational tests, at which point GRANTECAN will know whether or not to prepare for CIRCE. In the unfortunate circumstance of EMIR's failure or serious delays, then we recommend that the completion of the folded-Cassegrain focal station be accelerated, and that CIRCE be installed there until EMIR arrives. Once EMIR is available, then GRANTECAN should consider carefully the future use and necessary support for maintaining CIRCE.

5. HORS/HORUS

We recommend that GRANTECAN prioritise the high-resolution capability of HORS, as against the extremely high radial velocity accuracy of HORUS. We fear that the vacuum chamber and spectral comb unit required for a planet searcher will greatly complicate the operation of HORUS as well as its associated demands on the telescope and its environment. This will lead to serious technical and operational requirements, as well as making it significantly more expensive. Furthermore, we fear that it might not be fully competitive in the planet search field, as it has not been specifically designed for this in the way that other instruments have, and would severely compromise a more general purpose high-resolution mode. We suggest that HORS is fed from the folded Cassegrain focus if it is ready and available.

6. GTCAO/FRIDA

The GTCAO/FRIDA combination is proposed to offer diffraction-limited imaging, as well as low to medium resolution integral field spectroscopy, based on natural guide-star single-conjugate AO correction. The workload on GRANTECAN just to complete the GTCAO facility is very significant, at the level of at least 7 man-years, conflicting severely with other urgent priorities, and focus preparation will be anything but trivial.

However, the most basic problem with GTCAO is its very low sky coverage, especially as similar instruments on other 8-10m-class facilities have already covered many of the best observable targets, e.g. the Galactic Centre, nearby star-forming regions and the handful of accessible globular clusters. FRIDA imaging capability is at least one generation behind the GeMs MCAO/multi-lasers Imager/MOS spectrometer at Gemini-South; similarly for its integral field spectroscopic mode compared to the forthcoming OSIRIS at Keck and ERIS at the VLT. Its sole competitive niche would be for medium resolution integral field spectroscopy of a limited number of bright enough resolved targets and the polarimetric mode. This first step approach in the AO arena, that was recommended by the 2008 Instrumentation Working Group and selected for GTC, was entirely defensible in an era of adequate resources; it is unfortunately more and more untenable as the GTC operational budget is increasingly and severely squeezed.

In view of the large impact on GTC and even more of the decreasing competitiveness of the present GTCAO/FRIDA, the Panel strongly recommends not to proceed with the project as currently conceived. The Panel recognizes and fully regrets the hardship imposed on the FRIDA team that has so far developed the instrument in a most professional way, but does not see any responsible way to continue along the present plan. FRIDA is completely dependent on the GTCAO system and its situation should be re-evaluated together with a new medium-term AO plan for the telescope.

We therefore encourage GRANTECAN, possibly in collaboration with the FRIDA team, to completely rethink and redevelop its long-term AO plan for GTC, with the goal to move towards what will ultimately be a fully competitive AO facility. There are various possible approaches for this, ranging from a relatively low-cost development such as AO-assisted speckle holography in the visible, to a much larger (and costlier) endeavour such as laser-assisted Multi-Conjugate or even Multi-Object AO. We note that this could be an opportunity to attract outside collaborations, e.g. from the United Kingdom, or even new partners.

In conclusion, we fully recognise the significant work undertaken in bringing GTCAO/FRIDA to its current state. However, AO based on natural guide stars is no longer competitive at a facility such as GTC, and it is important to plan for a medium-term more effective system now, hopefully to be implemented under less financial hardship. We therefore encourage the formation of a new collaboration to build on the GTCAO/FRIDA efforts so far and consider the development of a more significant, longer-term instrument for exploiting a more extensive AO facility at GTC, although we also recognise the current competing demands for

resources to accomplish such preparatory work.

7. MEGARA

The need for a medium-resolution (R~10,000-30,000) multiplexed spectrograph in the optical band has been a top priority since the earliest days of GRANTECAN. This was fully endorsed in the 2008 Report by Eikenberry et al., which recommended an optical, medium resolution, multi-object spectrograph as one of the top GTC priorities for additional instruments. Accordingly, we strongly recommend that MEGARA should be the first priority for GTC once EMIR becomes operational.

MEGARA is a multi-purpose instrument with a large multiplexing capability, it has very strong support within the GTC user community, has recently passed PDR and at present there are no serious risks or delays envisaged. We suggest that MEGARA is placed at Nasmyth-B, after moving OSIRIS to Cassegrain. Alternatively, should the Cassegrain focus not be ready, it could be installed at a folded-Cassegrain focal station.

8. MIRADAS

The 2008 Report on Future GTC Instrumentation identifies a near-IR, medium resolution spectrograph (R~20,000) with multiplexing capabilities as one of the top priorities for GTC additional instruments. We agree with this view and emphasize the importance for GTC to have such an instrument as one of the components of its instrument suite. We find that such a facility should be a priority for GTC immediately following MEGARA, and ideally be operational by the time JWST is launched (2018-19) and as soon as possible after Gaia databases become available, circa 2018.

MIRADAS is a very promising, but demanding, instrument, whose 5-arm version fulfils the interests of an important part of the GTC community, and its spectro-polarimetric capability would be unique. However, we note that GRANTECAN cannot afford the costs and additional manpower at the present time without compromising the more urgent, current developments outlined above. Delaying the project further might not be an option as the instrument team is likely to dissolve quickly, should the project continue to be put on hold. We therefore recommend that GRANTECAN re-evaluate, as a matter of urgency, its interest and capacity to undertake MIRADAS, and, if needed, agree a viability plan with the instrument team.

9. Focal station priorities

In concurrence with our recommendations above,

(a) we strongly encourage GRANTECAN to proceed with the completion of the main Cassegrain focal station whenever adequate resources are available;

(b) (at lower priority) offer a folded-Cassegrain focal station to suitably assessed visiting instruments.

10. Dome shutter repair

We are impressed with the procedures that have been followed in identifying how to deal with the current dome shutter constraints (which are having significant impact on observations). This is important work and we strongly support the GRANTECAN approach of careful preparation and assessment. Once this is ready to be undertaken it should have over-riding priority.

11. Future strategy for instrument acceptance and commissioning

A common factor in both GTC instruments currently in use is the extended interval over which commissioning has taken place. It is perfectly understandable how this has happened, since almost all modern large telescope instruments are complex and offer multiple observing modes that require extended periods of time to properly commission and characterise (and some modes are even deliberately left unused for an unspecified future date due to their complexity). Yet it is equally important to put these instruments into full operation as quickly as possible, as substantial delays can lead to a loss of scientific potential and competitiveness.

To achieve this, we strongly recommend that GRANTECAN adopts a more proactive role in its dealings with instrument teams than has happened so far. Such interactions, especially in the instrument verification phase and even more for commissioning preparation and execution, are essential for completing commissioning successfully and efficiently. Indeed, it is crucial that the primary commissioning, characterisation and any fault-finding activities be led by the instrument teams themselves, but with involvement of appropriate GRANTECAN staff as part of the eventual "handover" procedures. Such "handover" should not occur until GRANTECAN has formally "accepted" the instrument (implying that it has met its performance specifications). We are fully aware of the resource limitations (both financial and manpower) of GRANTECAN, and so our main recommendations above have partly been made in order to help GRANTECAN be able to invest much more in the support of instrument building than the relatively meagre involvement that has been possible so far.

12. Community assistance with GTC instrumentation

While it is important to establish clear responsibilities for the Observatory staff with regard to establishing, monitoring, enhancing and understanding the instrumentation suite at GTC, we feel very strongly that this process could be greatly enhanced by harnessing the efforts, expertise and experience that exist

within the GTC astronomical user community. Until now there appears to have been an almost invisible "barrier" in place which has prevented this from happening. We believe that such involvement greatly extends the capacity to quickly understand and improve instrument performance, as well as bringing the users to a greater knowledge of the Observatory's capabilities, which of course can enhance their own scientific exploitation of GTC. This approach has been used elsewhere to great effect, and can be encouraged with appropriate allocations of Director's Discretionary Time.

In the same vein, we recommend that GRANTECAN consider a policy to restore a larger fraction of “classic” visitor mode observing, as compared to the current, almost 100% queue mode observing. While we agree that queue mode should continue to be the dominant observing route, we would suggest that this be no greater than say 75% of the total (ESO's VLT has a maximum of 65% for queue mode). We believe that this will not only increase and improve communications with the GTC community, but also the ability of observers to properly appreciate the range of capabilities of GTC and its instrumentation. Furthermore, this will help observers in being able to more fully exploit their GTC data and also reduce the considerable resources necessary for tasks such as data quality control.

More generally, we take the opportunity of commenting on the currently less than ideal level of communications that appear to be in place between GRANTECAN and its community of users. We feel that it is important to keep the community aware of progress, both positive and negative, in terms of what is happening at GTC, as well as what is planned on semester-scale intervals.

13. Pipeline processing of GTC data

Acquisition and data reduction pipelines are a vital component of every instrument on GTC. In the current situation, pipelines are in principle developed by the instrument teams and eventually offered to the users. Whilst this is an essential starting point for the delivery and commissioning of the instrument, it is almost certain that it will develop and evolve rapidly as experience is gained with the actual performance characteristics and idiosyncrasies of the instrument. Consequently, if there is no software upgrade support, nor guaranteed long-term maintenance, then serious problems are almost certain to occur.

In the short term, in order to mitigate this risk, GRANTECAN is encouraged to negotiate with the relevant instrument team institutes at an early stage of the projects in order to obtain an acceptable level of long-term support, e.g. from a team astronomer deeply involved in exploiting the instrument. Where relevant, it is suggested that such an activity be rewarded with an appropriate amount of GTC guaranteed time. On a longer-term perspective, we hope that GRANTECAN will be able to free the resources needed to internalize this vital activity.

GTC: THE NEXT 10 YEARS

As a result of the recommendations above, the Panel foresees that GTC will carry a powerful suite of general-purpose instruments (OSIRIS, EMIR, HORS and MEGARA) by 2016, and with the possible addition of MIRADAS circa 2018.

At the turn of the decade, ground-based optical-IR telescopes are expected to encounter severe competition from the James Webb Space Telescope (JWST). It is indeed foreseen that they will be all but wiped out of some of their currently most important observing fields. In particular, this includes low spectral resolution (1,200-2,700) spectroscopy of faint targets in the huge 1.7-28 micron range, with lesser but still strong competition down to 0.7 micron. Equally severely hit will be deep, diffraction-limited, small field (a few arc minute square) imaging in the same spectral domains. JWST in addition features small field integral field units in the NIR and MIR that will provide low spectral resolution, high sensitivity, diffraction-limited data cubes. But in the red to near-UV region, GTC and the other 8-10m class telescopes will retain their dominance until the era of the Extremely Large Telescopes begins.

Not entirely by coincidence, the GTC 2008 Instrumentation Plan emphasis on medium resolution spectroscopy (~ 25,000) with first MEGARA, then hopefully a MIRADAS-like instrument, as well as high spectral resolution with HORS, will leave GTC with substantial observing domains essentially free from JWST competition, even in the NIR. OSIRIS will maintain an edge for wavelengths shorter than 0.7 micron, as well as when using either the blue or red tunable filters. EMIR, which addresses a subset of the JWST NIRSpec multi-slit spectrometer observing range, will be the hardest hit. We therefore recommend that it be given higher observing priority in order to complete its most important science drivers by the end of the decade.

The putative competition from JWST must be carefully accommodated when embarking on the next generation of GTC instruments. This will be important when revising GTC's AO plans, as again near diffraction-limited JWST imaging and low spectral resolution spectroscopic modes are expected to be all but unbeatable above 0.7 micron. However, that still leaves a number of competitive options such as speckle holography imaging in the visible, and multi-object spectroscopy with deployable integral field units as well as medium spectral resolution (~ 25,000) spectroscopic coverage (as featured in the FRIDA concept).

For future GTC instrumentation, one way to better compete with JWST could be to take advantage of the capability of ground-based facilities to feature instruments with a huge number of pixels, much more than e.g. the meager 2k x 4k pixels for the JWST 0.7-5 micron NIRSpec spectrometer. Indeed, the next few years will see the deployment on 8-10 meter telescopes of survey-type optical spectrometers with huge spectroscopic arrays of up to half a billion pixels: that includes the 2-degree diameter patrol-field, low spectral resolution multi-object (2,400 targets) prime focus spectrograph (PFS) on Subaru and two integral field low spectral resolution spectrographs, VIRUS on HET with a ~ 3’ x 3’ field and MUSE on the VLT with a 1’ x 1’ field. As no present or planned GTC instrument features more than 4k x 4k pixels, this approach would require drastically different next

generation instruments.

Science emphasis on PFS – as on the many similar instruments currently being built for 3-4m telescopes – is to derive the Dark Energy equation of state through observation of baryon oscillations; such as the study of galaxy building blocks at low redshift ($z<2.8$) on VIRUS, and at high redshift ($z>2.8$) on MUSE. GTC cannot compete with the Subaru PFS multi-object spectroscopic facility for lack of a similarly wide field, but the integral field approach, perhaps with a medium spectral resolution mode for e.g. follow-up of the GAIA one billion star survey in dense stellar fields, might be considered. Here a close collaboration with the Isaac Newton Group and its WEAVE optical multi-object spectrometer project could be particularly fruitful.

We also note that 100-million pixels or more IR multi-object spectrometers are currently being built or planned, like the PFS NIR arm on Subaru and MOONS on the VLT, with respectively 2,400 and 1,000 simultaneous targets. They will likely give them an edge over the JWST 100-target NIRSpec instrument, except for the most distant objects, where JWST superior sensitivity cannot be even approached from the ground, because of strong night-sky emission in the J and H bands and thermal background in the K band. GTC next generation instrumentation might also invest into that field.

Finally, the possible installation of CTA North at Teide Observatory would offer GTC a new window for follow-up of interesting high-energy sources emitting in the gamma-ray domain, as it would be ideally positioned to exploit such opportunities. Fast, time-resolved spectroscopy in the optical (already foreseen as an option by OSIRIS) would be another possible direction for future instrumentation developments.

The likely shift, outlined above, towards survey-type instrumentation, could not bear fruit without big changes in the GTC mode of operation, as a massive legacy-type survey would require taking out a large fraction of total telescope time over typically 3 to 5 years. It is expected that their science drivers will largely come from follow-up of all-sky space missions, like GAIA in 2013 (1 billion galactic star positions), CHEOPS in 2017 (transiting exoplanets) and EUCLID in 2022 (100 million galaxy spectra), although the latter will only be launched as the era of the next generation of Extremely Large Telescopes (ELTs) begins. GTC will also be in an excellent position for optical-NIR follow-up of the two northern-based radio observatories LMT and LOFAR, as well as a substantial fraction of the sky accessible to the SKA.

The advent of the Large Synoptic Survey Telescope (LSST), possibly by the turn of the decade, is expected to revolutionize astrophysics in the time domain, through the detection of a huge number of transient objects. Spectroscopic follow-up with large telescopes is expected to have become a cottage industry by then. However, the GTC site is poorly situated with respect to the LSST's Chilean site, both with its northern latitude (severely limiting the fraction of observable targets) and its eastern longitude (preventing very rapid follow-up of fast transients). On the other hand, even a small fraction of LSST sources could easily saturate GTC's available observing time. In instrumentation terms, follow-up might require a multi-arm single object spectrograph, like the X-shooter on the VLT, covering three octaves, from the atmospheric UV cutoff to the edge of the K band.

GTC, like most of the present 8-10m telescopes, must soon start developing a vision of its future role in the forthcoming era of ELTs. One rare silver lining out of the current financial difficulties encountered by most present telescope operations is that all three current ELT projects are suffering in a similar way, and the need for a drastic change of tack in GTC science directions is likely to be pushed well into the next decade. Should past history of the 3-6m telescopes versus the rise of the next generation 8-10m telescopes be a reliable guide, this would mean even more reliance on massive survey type instruments on the wide-field smaller aperture telescopes. Wide-field AO-based imagery and spectroscopy might also constitute an interesting avenue, as similar facilities on ELTs are expected to be exceedingly difficult and expensive to build.

Annex: GTC 2008 Instrumentation Plan

Name	Date/P.I.	λ	Modes	N_{px}
OSIRIS	**2009** IAC	**O**	7.8' x 7.8' Imaging; 7.8' x 5.2' Spectra Blue & Red Tunable Filter $\Re \sim 500$ Long & Multi-slit $\Re$ 300-2500	4k x 4k
CANARI-CAM	**2012** U. Florida	**MIR**	19" x 26" field Imaging/Polarimetry Long-Slit Spectrograph ($\Re \sim 3.10^3$)	320 x 240
EMIR	**2014+** IAC	**NIR**	6' x 6' Imaging; 6' x 4' Spectra: LSS & 50 cryogenic multi -slits; $\Re$ 4,000	2k x 2k
FRIDA	**2015** UNAM	**NIR**	NGS/SCAO diffraction-limited 40" x 40" Imaging 2.4" x 2.4" Integral Field; $\Re$ up to 3.10^4	2k x 2k
MEGARA	**2016** UCM	**O**	100-target MOS – 3.5' x 3.5' patrol Fiber IFU – 14" x 12" & 10" x 8" field $\Re$ 6 x 10^3-1.9 x 10^4 & 9 x 10^3-2.5 x 10^4	4k x 4k
MIRADAS	**2017** U. Florida	**NIR**	1-5-20 cryogenic d-IFU (4" x 1.2") 5' dia. patrol field; $\Re$ 2.10^4 Echelle	2k x 4k
HORS/HORUS	**2014/2016** IAC	***O***	$\Re$ 40,000 fiber-fed X-dispersed echelle (High-stability HORUS version)	4k x 4k
CIRCE	**2014** U. Florida	***NIR***	3.4' x 3.4' Imaging (0.1"/pixel) Long-Slit Spectrograph $\Re$ 400-700 (spectro)-polarimetry	2k x 2k

(d)-IFU: (deployable)-Integral Field Unit; LSS: Long Slit Spectrograph;
MOS: Multi-Object Spectrograph; NGS: Natural Guide Star
SCAO: Single Conjugate Adaptive Optics