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ESO Spectroscopic Facility

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Abstract. We present the concept of a novel facility dedicated to massively-multiplexed spectroscopy. The telescope has a very wide field Cassegrain focus optimised for fibre feeding. With a Field of View (FoV) of 2.5 degrees diameter and a 11.4m pupil, it will be the largest etendue telescope. The large focal plane can easily host up to 16.000 fibres. In addition, a gravity invariant focus for the central 10 arc-minutes is available to host a giant integral field unit (IFU). The 3 lenses corrector includes an ADC, and has good performance in the 360-1300 nm wavelength range. The top level science requirements were developed by a dedicated ESO working group, and one of the primary cases is high resolution spectroscopy of GAIA stars and, in general, how our Galaxy formed and evolves. The facility will therefore be equipped with both, high and low resolution spectrographs. We stress the importance of developing the telescope and instrument designs simultaneously. The most relevant R&D aspect is also briefly discussed.

Keywords. Spectroscopic Surveys, Survey facilities, Curved detectors

1. Introduction

In 2014 ESO carried out a very exhaustive poll, that involved several thousand astronomers in the European community (Primas *et al.* (2015)), from which it clearly emerged that the most requested facility, not yet available or in construction at ESO, is a wide field spectroscopic telescope. As a consequence, ESO set up a scientific working group chaired by one of us (RSE) that delivered a report, summarising the science cases, setting the main requirements, and strongly recommending ESO to continue the study of such a facility (Ellis *et al.* (2017)). In parallel, two new concepts for a spectroscopic telescope were elaborated, one suitable for fibre feeding, the other for multi-instruments and mini-IFUs (Pasquini *et al.* (2016)).

The science cases included studies of the local and high redshift universe, with a separate aspect dedicated to time transient spectroscopy and synergies with LSST. While all readers are invited to read the Ellis *et al.* (2017) report, it is worth mentioning that the main science case "the Milky way as a Model Galaxy Organism" fully embraces the science discussed in this symposium. It aims at answering fundamental questions such as how to determine the detailed shape of the galaxy potential and probe the presence of very low mass halos, to understand how stellar physics exactly works and how the elements are originated, what is the formation history and memory of a prototypical galaxy, and finally, to compare how the small mass local group companions fit into the standard model predictions.

Very large surveys, covering a good fraction of GAIA stars (e.g. 85 million stars at limiting magnitude 17), have been proposed by the WG to answer to these questions.

At the same time the quality of the answers will benefit enormously from retrieving abundances for many elements and with high precision, as the power of chemical tagging grows enormously with these two quantities. Very interesting differences already emerge amongst the Galactic subpopulations when many elements and precise abundances are available (see e.g. the presentations by R. Smiljanic or P.E. Nissen at this symposium). High precision, high resolution spectroscopy is therefore a strong (and very demanding) requirement.

The extragalactic science questions center on the evolution of the cosmic web at high redshift and how galaxies assembled, with emphasis on mapping the redshift of peak cosmic star formation and beyond. Several surveys were proposed, and key is the ability to obtain low S/N ratio spectra for millions of emission line galaxies as faint as I$\sim$ 25.8 and high quality spectra for galaxies at I$\sim$24. The added value of obtaining an integral view of the IGM with a panoramic IFU has been also emphasized.

The complementarity and follow-up of LSST will open a new domain. It is difficult to predict what the requirements will be, but it is possible to recognize that, for instance for SNae, more than 400 events will be present in the FoV at any time, even if most of them will be 'expired'. A number of fibres could therefore be dedicated in each field just for this follow-up. Most interesting, an independent NOAO study concludes that the most missing critical resource to fully exploit the LSST potential is to "Develop or obtain access to a highly multiplexed, wide-field optical multi-object spectroscopic capability on an 8m-class telescope, preferably in the Southern Hemisphere" (Najita *et al.* (2016)).

The Australian Decadal Survey sets a spectroscopic facility at high priority. The most complete and advanced effort made so-far is constituted by the excellent package developed for the Mauna Kea Spectroscopic Explorer (MSE), a proposed telescope for the dome of the CFHT, whose science cases have been compiled by McConnachie *et al.* (2016).

All these reports testify to the transformational impact of a 10m-class spectroscopic facility and the vivid interest in the community worldwide.

Before moving to a more detailed descripion, it is worth summarizing the terms of reference:

- 10m class facility dedicated uniquely to spectroscopic surveys
- a very large field
- high multiplex
- Southern hemisphere location

Why a facility and not a telescope? Past experience has shown that the well planned survey facilities can survive a long time and provide transformational science when they are flexible and conceived as an end-to-end project. In the specific case for instance, it is possible to optimize the telescope and dome by designing at the same time the instrumentation needed. In addition, the cost of the instrumentation will be comparable to that of the telescope, so it would be a major mistake not to consider and optimize the two together.

2. Top Level Requirements

Here is a summary of the top level requirements (TLRs) provided by the ESO working group:

- Telescope Parameters: 10-12 meters aperture, versatile (e.g. multi fibre and giant IFU), in the Southern hemisphere
- Field of View: $\sim$ 5 square degrees
- Multiplex: at least 5000 fibres at high spectral resolution
- Spectral Resolution: R=20-40000 for High Res, R=1000-3000 for Low Res

Table 1. Overview of etendue for several survey telescopes.

Name	**Tel. Dia.**	**Central Obs.**	**Surface (m^2)**	**$\Omega(deg^2)$**	**Etendue**
VLT VIMOS	8.0	0.97	48.75	0.043	2.08
VLT Flames	8.0	0.97	48.75	0.136	6.63
VISTA 4MOST	3.7	0.89	9.57	4.00	38.3
VLT MOONS	8.0	0.97	48.75	0.136	6.63
WEAVE	4.2	0.88	12.2	3.14	38.3
SUBARU PFS	8.0	0.97	48.75	1.33	64.7
MAYALL DESI	3.8	0.85	9.6	8	77
LSST (Imaging)	8.2	0.63	33.27	9.62	320
MSE	11.2	0.97	96.0	1.50	144
ESO Concept	11.4	0.86	87.89	4.91	431

- Wavelength range: 360-1000 nm
- Panoramic IFU: 3x3 arcmin FoV, with R$\sim$5000 and coverage in the blue down to 325 nm

In the current design phase, some additional requirements were added to the working group TLRs:

- Optimize costs: Use existing (ESO) Observatory infrastructures, use, whenever applicable, ELT technology and components (e.g. M1 segments)
- Enhance present capabilities: The spectroscopic facility shall outperform in survey power the presently planned facilities by at least one order of magnitude.
- The low resolution spectrographs shall be usable by the fibres and by the panoramic IFU
- Simultaneous observations: it shall be possible to acquire simultaneously low and high resolution observations over the whole FoV

3. A powerful telescope

The Pasquini *et al.* (2016) paper considered two potential designs. The requirement to access the largest possible focal plane with fibres, has driven to furher develop the Cassegrain fibre concept, shown in Figure 1.

The telescope pupil is 11.4 meters in diameter. The primary consists of 78 ELT primary segments, and the secondary is 4.2m in diameter, the same size of the ELT secondary. The three lens corrector (1.8 m diameter largest lens) works also as ADC and provides a corrected 2.5 degrees, 1.43m diameter focal plane at F/2.86, an excellent aperture for fibre coupling. By inserting two mirrors in front of the corrector, the central 10 arcminutes of the FoV can be directed to a coudè gravity invariant focus that can host the low resolution spectrographs and the panoramic IFU, with excellent image quality.

This telescope is very compact, it does not need extended Nasmyth platfoms, so the dome size can be kept small when compared to most telescopes of similar size. A concept of the mechanical structure is given in Figure 2. The first floor below the telescope hosts the high resolution spectrographs, sitting in a comfortable gravity invariant room, while the room below, with a rotating floor to compensate for the field rotation in the IFU, hosts the low resolution ones.

The combination of large FOV and effective diameter results in a telescope with the largest etendue ever, as shown in Table 1. Its etendue is even larger than LSST because, in spite of the huge LSST FOV, its effective area is only $\sim$40% of our concept.

3.1. *The Corrector & Positioner*

The working principle of the corrector is inspired by those proposed for NTT, VISTA & MSE (Grupp *et al.* (2012), Gillingham & Saunders (2014), Saunders & Gillingham

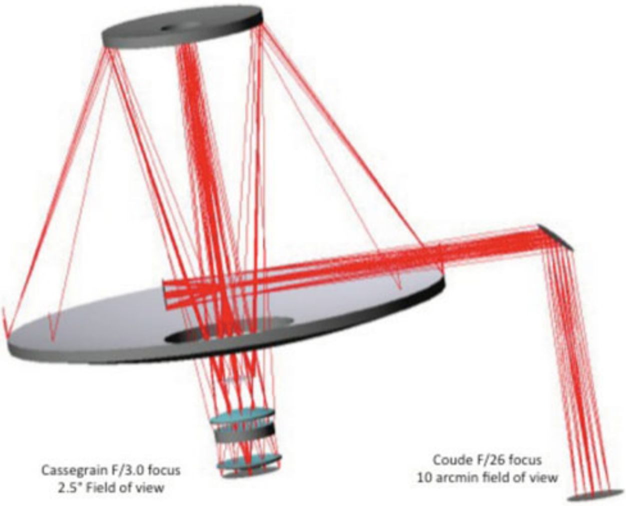

Figure 1. Optical concept of the telescope, with Cassegrain fibre focus and coudè for panoramic IFU.

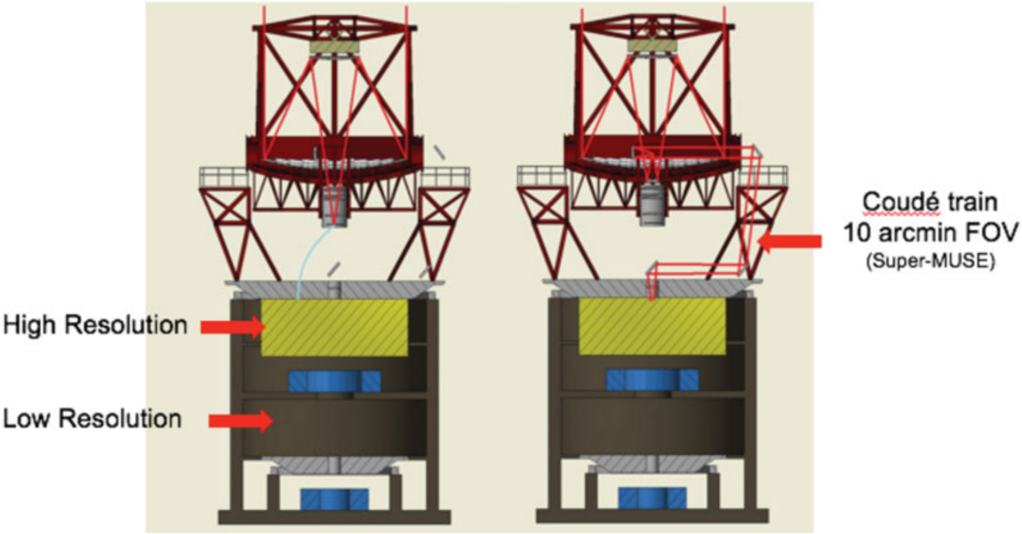

Figure 2. Telescope with main structure.

(2016)); the last two lenses and the focal plane tilt around a circle of 5m radius to compensate for the changing atmospheric dispersion, as described in Figure 3. The tilt introduces coma, that is corrected by simultaneously translating the secondary. The correction is good up to airmass ~1.8, and in the 360-1300 nm interval. The corrector has only three aspheric surfaces (each lens has one aspheric surface). The glass is silica. The 1.8m aspheric lenses would probably be the largest ever produced, larger, but comparable to the LSST corrector ones.

The large corrected focal plane, combined with a ~ 160 micron/arcsecond plate scale, is very comfortable for installing fibre positioners. For instance, by using the positioner mechanism adopted by the DESI survey, more than 15000 positioners can be hosted, just using existing technology. By adopting a slightly different arm design, like the one chosen

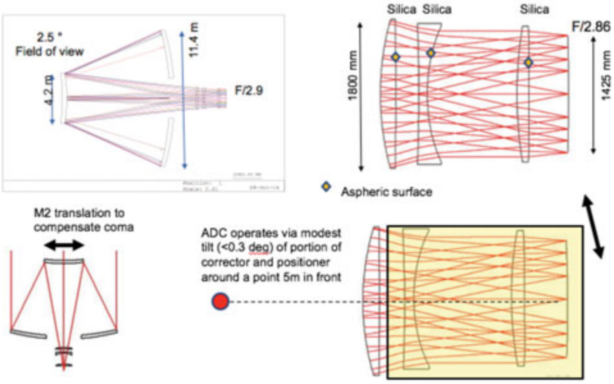

Figure 3. The Cassegrain corrector design and ADC concept. The last two lenses and the focal plane tilt around a point 5m away to compensate for atmospheric dispersion. The coma introduced is compensated by translating the secondary.

by MOONS, each point of the focal plane can be reached by three fibres. This would allow a very convenient ratio of 2:1 between the High resolution and the Low resolution fibres, and each point of the FOV is reachable by at least one high resolution fibre and two low resolution ones. With a reference number of 15000 fibres, 5000 objects could be observed at high resolution and 10000 at low resolution simultaneously.

With such a huge multiplex and etendue, this facility will have a survey power (etendue× number of objects) more than 10 times higher than any other spectroscopic facility either in construction or in design.

4. The spectrographs

So many objects, on the other hand, will require a large number of spectrographs. The challenges in building the spectrographs for this facility are to find a reasonable design that can contain the costs. In order to fully exploit the telescope diameter, in fact, it is needed to produce quite fast cameras (around F/1) for pixel matching. Another challenge is to find a suitable design for the high resolution spectrographs, which will need a large pupil in order to obtain the required resolution.

In order to procure efficient, fast and cheap cameras, suitable for multi-spectrographs solution, we think that it is imperative to use curved detectors. Curved CCDs have been produced and tested in the past (Iwert *et al.* 2012) and a lot of effort is presently ongoing on CMOS devices with very good results (Hugot *et al.* (2016), Guenter *et al.* 2017) so having them available for this facility carries a very limited risk. Curved detectors allow very simple, therefore efficient, cameras, that do not require exotic glasses, therefore cheap. The optical design of a low resolution spectrograph is shown in Figure 4 and the F/1.1 cameras are made by just 4 lenses glued in two groups. The spectrograph has two arms (Blue and Red), with a separation around 680 nm, and each uses a 4K×4K detector. With an F/1.1 camera, the scale is of 0.25 arcseconds/pixel and each spectrograph can host $\sim$ 600 one arcsecond fibres. Less than 20 such spectrographs will suffice to cover all low-res fibres, while 65 of them will be needed to provide a 3x3 arcminutes panoramic IFU.

As for the high resolution spectrographs, their design is pending, likely the principle will be similar to those developed for 4MOST, with the novelty of using also for these spectrographs the fast cameras allowed by the curved detectors.

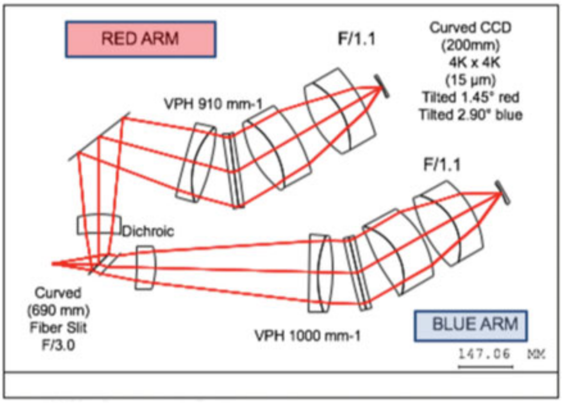

Figure 4. Optical design of the low resolution spectrographs. The two arm design covers the 380-100 nm range. It provides a resolving power of ∼2600 with 1 arcsecond fibres, and the double for the panoramic IFU. It accomodates ∼ 600 spectra on a 4Kx4K curved detector.

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