Smart Focal Plane Technologies for VLT Instruments

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1 Introduction

As we move towards the era of ELTs, it is timely to think about the future role of the 8-m class telescopes. Under the OPTICON programme novel technologies have been developed that are intended for use in multi-object and integral-field spectrographs. To date, these have been targeted at instrument concepts for the European ELT, but there are also significant possibilities for their inclusion in new VLT instruments, ensuring the continued success and productivity of these unique telescopes.

2 ‘Smart Focal Planes’

A smart focal plane is a system that maximises the use of the telescope focal plane for science observations. Examples range from wide-field, multi-object spectrometers and multiple integral field units (IFUs), to future systems such as robotically-fed, photonic spectrometers. Under the Framework Six OPTICON programme\(^1\), a wide range of novel systems has been developed by a team from eight European countries \([1]\), providing a toolkit for instrument designers including:

- Replicated image slicers to enable more economic production of multiple IFUs \([2]\).
- ‘Starbugs’ – miniature robots that carry fibres or pick-off mirrors to any given place in the focal plane, potentially at cryogenic temperatures \([3]\).
- ‘Starpicker’ – an alternative cryogenic, robotic positioner to place pick-off mirrors on a potentially curved, dual focal-plane that is tumbled into its observing position \([4]\).

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Active correction mirrors used to correct for aberrations caused by the movement of a pick-off mirror across the focal plane [5].

Micro-mirror arrays fabricated in silicon that can be used to form multi-object slitlets with high densities of objects [6].

## 3 Wide-field options for the VLTs

In the era of ELTs, an obvious role for an 8-m telescope could be for wide-field imaging surveys, in the same manner that CFHT and UKIRT have been very productive in the 8-m era. However, the VLTs were never designed for wide-field operation and there are severe optomechanical and operational constraints on providing a wide-field facility at any of the VLT focal stations. It will be very difficult and expensive to extend the VLT focal plane to beyond one degree [7]. Indeed, wide-field imaging in the near-IR is not competitive unless a field of at least one degree can be accessed; at visible wavelengths even this would not be competitive with Pan-STARRS and LSST.

A number of presentations at this workshop have made a clear case for spectroscopy of a large number of sources over a field of a degree of more, e.g. unprecedented galaxy redshift surveys to map large-scale structure, or wide-area stellar surveys to trace the mass-assembly history of the Milky Way. Smart focal plane technologies can now deal with the physical size, and possible curvature, of such a field-of-view, even if cooled to cryogenic temperatures. However, the technical and cost problems relating to modification of the telescope itself are severe. The classical option for wide-field astronomy is at prime focus, but the VLTs have significant mass, space and systems limitations. For instance, the secondary mirrors are part of the active telescope system, and carry out real time tip-tilt and focus correction at up to 50Hz. Any prime focus system would need to provide similar functionality.

With the notable exception of Subaru, decisions taken in the early design stages of the 8-m class telescopes have made prime focus options difficult. In principle, Gemini has the option for a replaceable top-end to allow conversion to a wide-field mode, but this has never been implemented; replacing the top end with a carbon-fibre structure has been proposed to allow an increased mass at the prime focus [8], but using such a solution on one of the VLTs would be very expensive. It would also be necessary to provide correcting optics – a non-trivial challenge for an 8-m telescope. For instance, the Subaru corrector for the 30' FMOS field (optimized from 0.9 to 1.8 µm) requires three elements of up to 600 mm diameter in BSM51Y glass [9]. Other options, such as the forward-Cassegrain arrangement used to convert UKIRT to a wide-field mode for WFCAM [10], would likely be even more challenging for the VLT.
4 Cladistics & natural selection

It can be argued that technology selection for astronomical instruments follows a similar process to natural selection in nature. Selection pressures have analogies in terms of resources, competition and even predation – although it is hard to see where sexual selection takes a role! Many ideas follow an evolutionary path with ideas splitting-off from an original concept, through an almost cladistic mapping, as illustrated by the example of wide-field spectroscopy (Figure 1), where most systems can be traced back to Medusa, the first fibre plug-plate system at Steward Observatory [11].

![Cladistic map for multi-object spectroscopy. Adapted from [12].](image-url)
It is noteworthy how evolution has led to significant novelty in an isolated continent like Australia. Similarly, the team at the Anglo-Australian Observatory (AAO) have been responsible for many innovations! A recent example is the Echidna positioner developed for FMOS, that deals with dense packing of targets within a physically small field, in which traditional pick-and-place devices are not feasible [9]. A similar design to the Echidna positioner has been proposed for Gemini/Subaru-WFMOS, while an alternative concept uses small field lenses to select sub-fields which are then fed by miniature pick-offs to a fixed grid of fibres. A further concept proposed at this workshop is an update of the traditional fibre plug-plate, using robotics to assemble replaceable fibre modules [13].

5 Multi-slit spectroscopy

The science case for slit spectroscopy remains strong, particularly in cases where both a high multiplex and good throughput are required for point-like sources with known positions. New technologies are now becoming available to replace slit masks with configurable slit-arrays, that can also operate at cryogenic temperatures. The slitlet mechanism developed for the European Space Agency by CSEM under the OPTICON smart focal planes programme is now being incorporated into the Keck MOSFIRE instrument [14]. Moreover, devices such as micro-mirror arrays [6] and the shutter arrays in the JWST NIRSPEC instrument [15] offer potential arrays of up to 10,000 slitlets. These could be used in concepts such as the proposed VLT-MegaMOS [16].

6 IFU spectroscopy

In many cases, such as attempts to disentangle observations of merging galaxies, we require three-dimensional imaging spectroscopy. In this instance, image slicers offer significant advantages over slits. Precision manufacturing techniques such as diamond machining, stacked-element glass slicers and electroformed replication could provide a larger number of channels, or larger field-of-view, than the capabilities of KMOS or MUSE. When combined with new OPTICON pick-off technologies (e.g. Starbugs and Starpicker) instruments can be foreseen that combine a relatively wide patrol field, with high spatial resolution (i.e. fed by future AO systems).

7 Miniature spectrometers

In the longer-term, new technologies from the photonics industry could result in integrated, miniature spectrometers. For instance, array waveguide devices could be used if the problems of efficient light-coupling and bandwidth can
be solved [17]. There are also integrated devices under development for fluorescence spectroscopy that are based on bulk optics and holographic gratings, yielding spectral resolutions of up to 400 at visible wavelengths from a device that can fit within a 1 cm cube [18]. These concepts may be useful in a highly-multiplexed instrument, in which a swarm of miniature spectrometers are self-propelled around the focal plane by autonomous robotic carriers.

The ultimate miniature imaging-spectrometer would be an energy sensitive detector. Unfortunately, current devices such as superconducting tunnel junction arrays, or transition edge superconductors, do not offer large pixel-densities, nor useful spectral resolution. However, it is possible that such components could revolutionise spectrometer design in the future, possibly in conjunction with photonic feed devices.

8 Conclusions

In summary, there are considerable technical challenges in developing a wide-field spectrograph for the VLT, particularly when one considers the available resources within ESO and of its partners; a wide-field prime focus instrument would also lead to operational problems for VLTI. Future smart focal plane and photonics technologies may enable a lighter, more compact, prime focus (or forward-Cassegrain) instrument, but current technology readiness levels suggest that a compromise would be to exploit the maximum field available at the Nasmyth foci, e.g. Super-Giraffe [19]. Meanwhile, technology development for ELT instrument concepts such as EAGLE, and through the next Framework Programme, should be supported to help break the existing paradigm.

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