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Wide-field multi-object spectroscopy with MANIFEST

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ABSTRACT

MANIFEST is a multi-object fibre facility for the Giant Magellan Telescope that uses ‘Starbug’ robots to accurately position fibre units across the telescope’s focal plane. MANIFEST, when coupled to the telescope’s planned seeing-limited instruments, offers access to larger fields of view; higher multiplex gains; versatile focal plane reformatting of the focal plane via integral-field-units; image-slicers; and in some cases higher spatial and spectral resolution. The TAIPAN instrument on the UK Schmidt Telescope is now close to science verification which will demonstrate the feasibility of the Starbug concept. We are now moving into the conceptual development phase for MANIFEST, with a focus on developing interfaces for the telescope and for the instruments.

Keywords: fibre positioner, fibre positioning systems, Starbugs, fibre robots, GMT

1. INTRODUCTION

The prototyping design phase for MANIFEST recently completed [1] focused on developing a working prototype of a Starbugs system called TAIPAN, for the UK Schmidt Telescope, which is about to commence a stellar and galaxy survey of the Southern sky [2]. The design for TAIPAN [3] incorporates 150 optical fibres (with an upgrade path to 300) situated within independently-controlled robotic Starbug positioners, allowing precise parallel positioning of every fibre, thus reducing instrument configuration time and increasing the amount of observing time relative to sequential systems.

In the MANIFEST instrument concept [4-6], Starbugs are adhered via vacuum force to a glass field plate at the telescope focal plane. Each Starbug houses a pair of microlens arrays that converts the telescope focal ratio and injects the focal plane image into optical fibres. Starbug units can either be image-slicers (to allow higher spectral resolution modes) or integral-field units (for spatially resolved spectroscopy), single fibres, or a combination. Starbug fibres will feed the G-CLEF high resolution optical spectrograph [7] and the GMACS moderate resolution multi-object spectrograph [8]. MANIFEST provides modes giving a wider field of view, a higher multiplex, and/or a higher spectral resolution than is available to these instruments in their stand-alone configuration. MANIFEST may also be used to feed future new spectrographs, or alternatively existing spectrographs that could be re-purposed for use on GMT.

For MANIFEST, we are continuing the development of the instrument conceptual design with a focus on the system optical design, the mechanisms for deployment of the Starbugs onto the glass field plate, the Starbug positioning and metrology systems, and the opto-mechanical interfaces to the telescope and instruments. We are also developing the science case and science requirements for the instrument, along with the systems engineering architecture.

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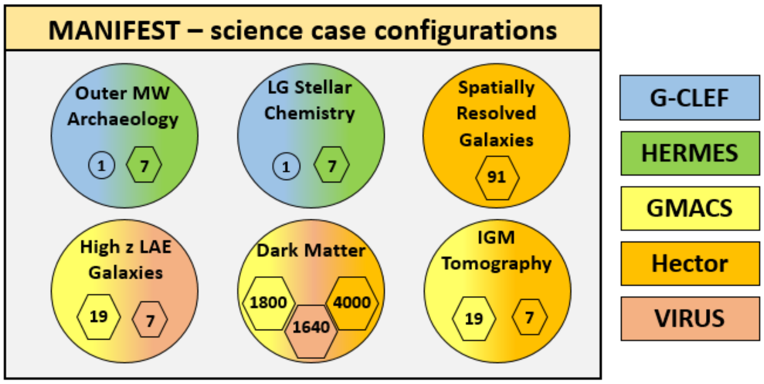
2. OBSERVING MODES

MANIFEST provides multiple possible observing modes for planned instruments (GMACS and G-CLEF) but also potential additional instruments (such as Hector [9], HERMES [10], VIRUS [11]). The versatility of MANIFEST is that it simultaneously allows observations with large IFUs, miniature IFUs, and high-multiplex single-object fibres which may feed different instruments. The multiple modes also provide for multiple spectral resolutions and bandwidths. Each observing mode can be tailored specifically to a particular science case. Figure 1 illustrates links between the science drivers and possible observing modes for a range of instruments that could be fed by MANIFEST.

Key science programs are likely to include: intergalactic medium tomography using Lyman break galaxies to reconstruct the small-scale structure of the intergalactic medium at high redshifts [12]; extending the current work of SAMI [13] and proposed work of Hector [14] to do spatially resolved galaxy studies out to z=0.05-0.1; stellar chemical abundance studies tracing the formation history of the Milky Way and nearby Local Group galaxies [15]; and archeology of the outer Milky Way disk via chemical tagging [16].



Spectrograph	# IFUs	Fibres per IFU	FOV per IFU	Resolution	Bandwidth
G-CLEF	4/40	1	0.7"	35K	550/15 nm
HERMES	56	7	1"	28K	100 nm
GMACS	60	61	1.1"	6K/20K	600/200 nm
GMACS	95	19	1.25"	3K/10K	600/200 nm
Hector	44	91	2.8"	5K	680 nm
Hector	560	7	0.75"	5K	680 nm
VIRUS	1	1640	14"	2K	630 nm
VIRUS	235	7	0.9"	2K	630 nm

Figure 1. Science cases linked to observing modes for MANIFEST.

3. MANIFEST CONCEPT

3.1 New Features

The MANIFEST concept under development includes a number of new features compared to the previous feasibility study design. These new features have been informed by lessons learnt from the TAIPAN instrument design and development. The movable TAIPAN connector plate is replaced with a stationary assembly to enhance reliable connectivity, and this assembly comprises a series of identical modules each with a bank of Starbugs. Starbug deployment is achieved by moving the glass field plate (GFP) relative to the module assembly. Adhesion is by direct constant pneumatic pressure to individual Starbugs orthogonal to the GFP at each Starbug location. Each Starbug socket has a vacuum valve that is activated when a Starbug is removed allowing partial Starbug population. Generally optical fibres are continuous to spectrographs and push fit into the Starbugs.

3.2 Deployment and Retraction

A new concept for deployment and retraction of Starbugs is under development whereby the GFP moves down to the Starbugs that are resting in pneumatically extended cradles on the module assembly. The GFP then pushes onto the Starbugs and compresses the cradle pistons. The cone end of the Starbugs are simply supported on three spherical balls which allows the Starbugs to conform to the GFP surface and form a vacuum seal. In this system, the Starbugs are selected by switched vacuum. Once the selected Starbugs are adhered, the pneumatic pistons retract so the GFP can move along the optical axis to the focus position. Retraction requires Starbugs to return to their cradle positions. Safe mode is provided by connector plate proximity to the deployed Starbugs. Retraction of the Starbug wires, vacuum and fibre is enabled by a combination of gravity and airflow through the module assembly. If this is not sufficient for retraction, then a single retraction comb consisting of a single rod for each module can be added that is driven at half speed by the GFP movement.

A prototype pneumatic piston mounted Starbug cradle has been successfully prototyped from 3D printing (see Figure 2). Further work will develop a manifold concept to replicate this for up to 1000 Starbugs.

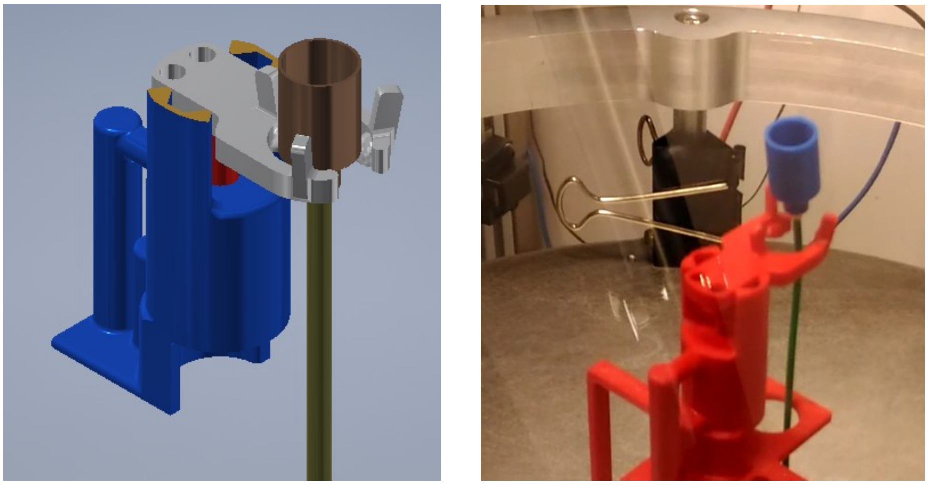


Figure 2. Design (left) and prototype test (right) for pneumatic Starbug cradle assembly with simulated Starbug.

3.3 Starbugs

Starbugs include electrical, optical, mechanical, and pneumatic interfaces. To ensure reliability for MANIFEST, each Starbug is a replaceable unit. The MANIFEST Starbug concept (see Figure 3) has a central push-fit port that accepts a ferrule on the end of a fibre into the centre of the Starbug. The cable end of a Starbug is conical in shape to interface with the support cradle on the module. Starbug diameters can range from 12 to 14.5 mm. These are larger physically than for TAIPAN to allow greater vacuum force onto the GFP, though smaller in arcsec on the sky Each Starbug has an off-centre vacuum pipe containing cabling. The fibre is routed separately from the electrical and vacuum connections.

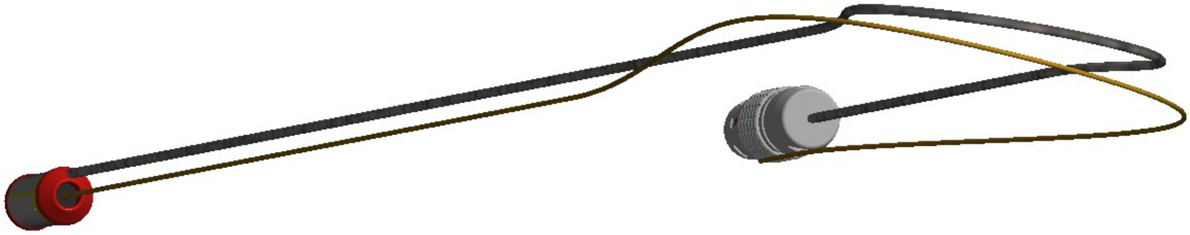


Figure 3. Starbug assembly showing Starbug (left) with vacuum tubing terminating in a COTS electrical connector. The fibre bundle runs separately.

3.4 Module Assembly

A concept using a modular assembly for Starbug connections is under development (see Figure 4).

Here the Starbugs are installed into modules of 30 each being connectible using commercially available LEMO plugs and sockets. Switch cards for the high voltage signals are included within each module to substantially reduce connector wiring with only four common waveforms required per module (plus back plane wiring). An alternative design to be explored may consider connectors for all wires to a cooled switch card cabinet in the lower part of the instrument mounting frame. Vacuum is configurable within each module from four switched manifolds to the 30 sockets. Generally this would correspond to spectrograph fibres connected to this module, but allows individually selectable or a selectable sub-group of Starbugs.

Two fluid connectors provide eight fluidic lines with cut-off valves that can be configured for vacuum, compressed air and liquid cooling. Pneumatic Starbug cradles are not shown. A retraction rod powered from the GFP movement can be fitted along the cable loop below the Starbug sockets if required.

A module assembly sits within the instrument mounting frame which houses a frame that supports up to 30 individual modules. This assembly has three cable connections to three switch-card backplanes. The backplanes are unconventional, as they are flexible and their ten connectors are mounted in a stepped configuration. Each module position in the module assembly is supplied with four lines of switched vacuum, two switched compressed air lines for cradle deployment and retraction, and two ambient tracking chilled fluid lines.

The central hole can accommodate 3 x 39mm extra-large star bugs. The modules are removed by unplugging the two fluidic connectors and extracting the module. The module with attached flexible fibre conduits is then free to be placed on to a workstation for reconfiguration and maintenance.

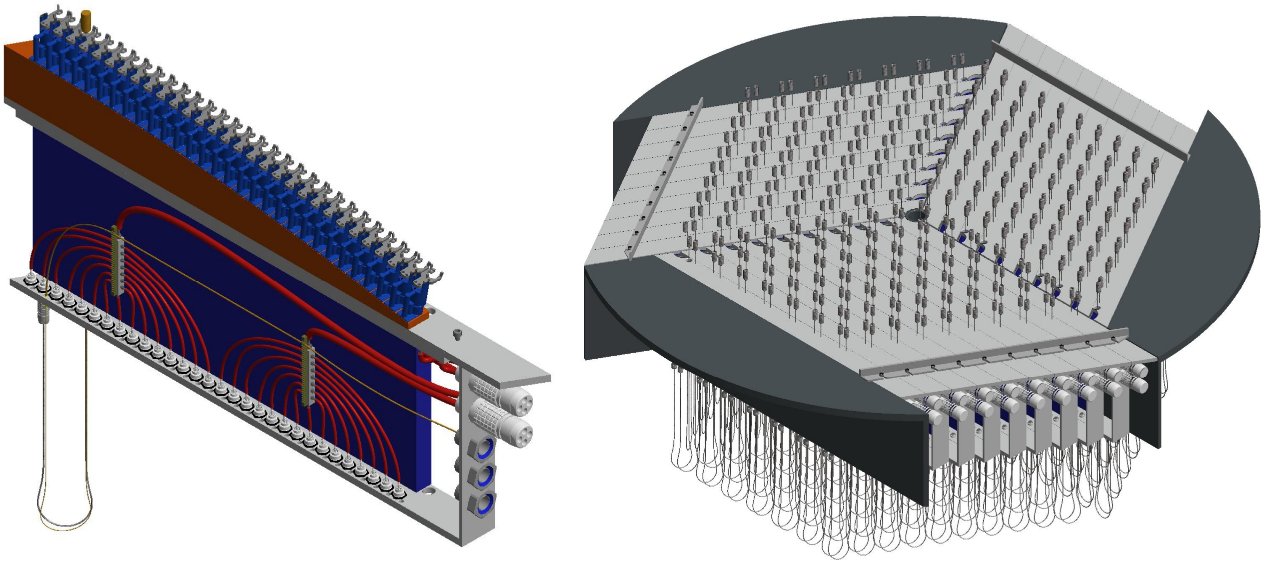


Figure 4. Starbug module (left) with 30 Starbugs. The module assembly (right) consists of a frame that supports 30 modules and their backplanes, thus providing up to 900 Starbugs across the field.

3.5 Glass Field Plate

The GFP provides a surface to support the Starbugs and is positioned so that the focal plane of the telescope is at the face of the science fibre within the Starbug. Three motorised ball screws in combination with fiducials and metrology offer micron-precise tip/tilt, and focus adjustments to the position of the GFP. Tip/tilt and focus compensates for the mounting of the instrument in the mounting frame and for variations in moving the IMF from storage.

The GFP has three positions; focus, deploy and safe-home. Deploy is a position which is half way between the Starbugs mounted in their cradles and the 10 mm travel of the pneumatic cradle piston. Starbugs return to their deployment locations for retraction. The safe-home position is one Starbug body length above the cradle when the pneumatic piston is fully extended. This is a safe position for a configured field of Starbugs when the vacuum system is compromised.

The instrument is designed for encapsulation as a clean room environment for the Starbugs. The glass field plate will incorporate a circumferential baffle that seals to the cylindrical enclosure as it moves up and down the frame. The module assembly is also designed for complete baffling to the instrument frame. Filtered compressed air is bled into the enclosure and vents through the modules acting as a coolant for both the Starbugs and the switch cards.

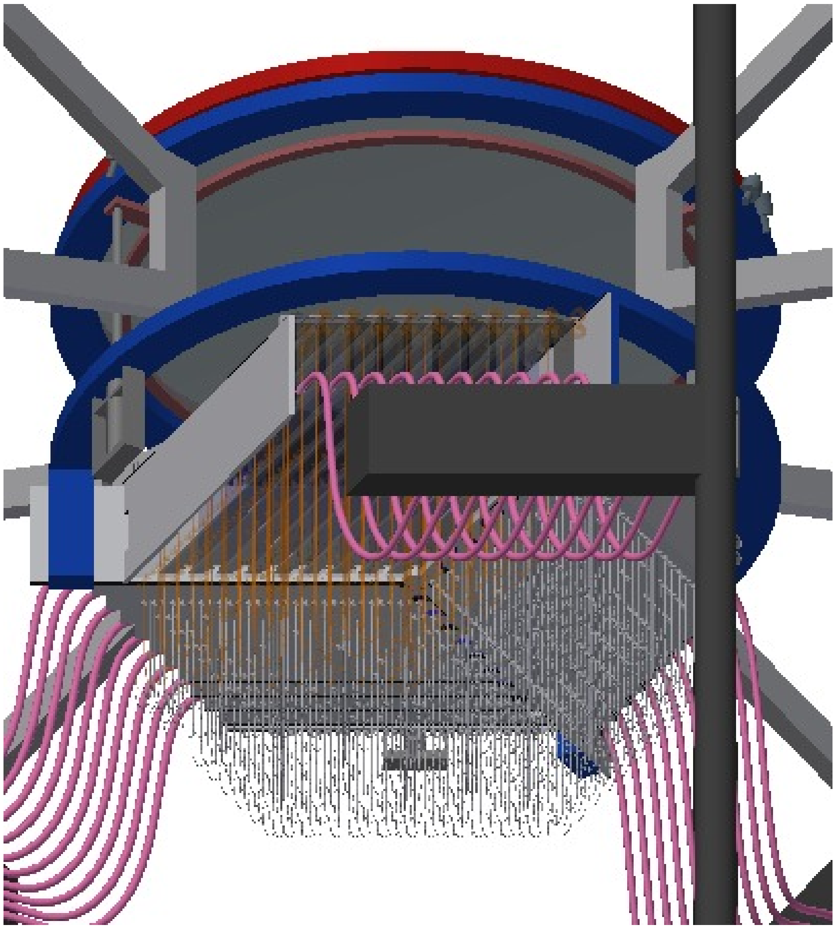


Figure 5. Glass field plate at focus and instrument central assembly.

4. TELESCOPE INTERFACES

4.1 WFC/ADC

The two-mirror GMT Gregorian design provides a useful uncorrected field of view of ~10’ diameter. The addition of corrector lenses allows a larger field-of-view, the possibility of an ADC action, and a telecentric focal surface. A baseline design exists for the wide-field-corrector/atmospheric dispersion compensator (WFC/ADC), which consists of 6 elements, of BK7, LLF1 and fused silica [17]. It allows a 20’ FoV and an ADC action. The ADC action is generated by zero-deviation Risley prisms. A trade-off study is currently being conducted to explore other options for the WFC/ADC to determine if there is a simpler and cheaper design.

An alternative concept being considered is the 3-lens fused silica CLADC (Compensating Lateral ADC) design with 20’ FoV [18]. This design achieves ADC action by moving the second lens laterally, moving the third lens in rotation and translation, tilting the GFP, and adding a small motion to the telescope M2. The throughput and image quality are superior to the baseline design but the CLADC design requires some changes in the way the telescope is used.

Finally, a minimal design is considered, with just two lenses close to the focal surface. These lenses produce telecentricity and provide some increase in useful FoV, to 12’. However, there is no ADC action which is a limitation to the target observations allowed.

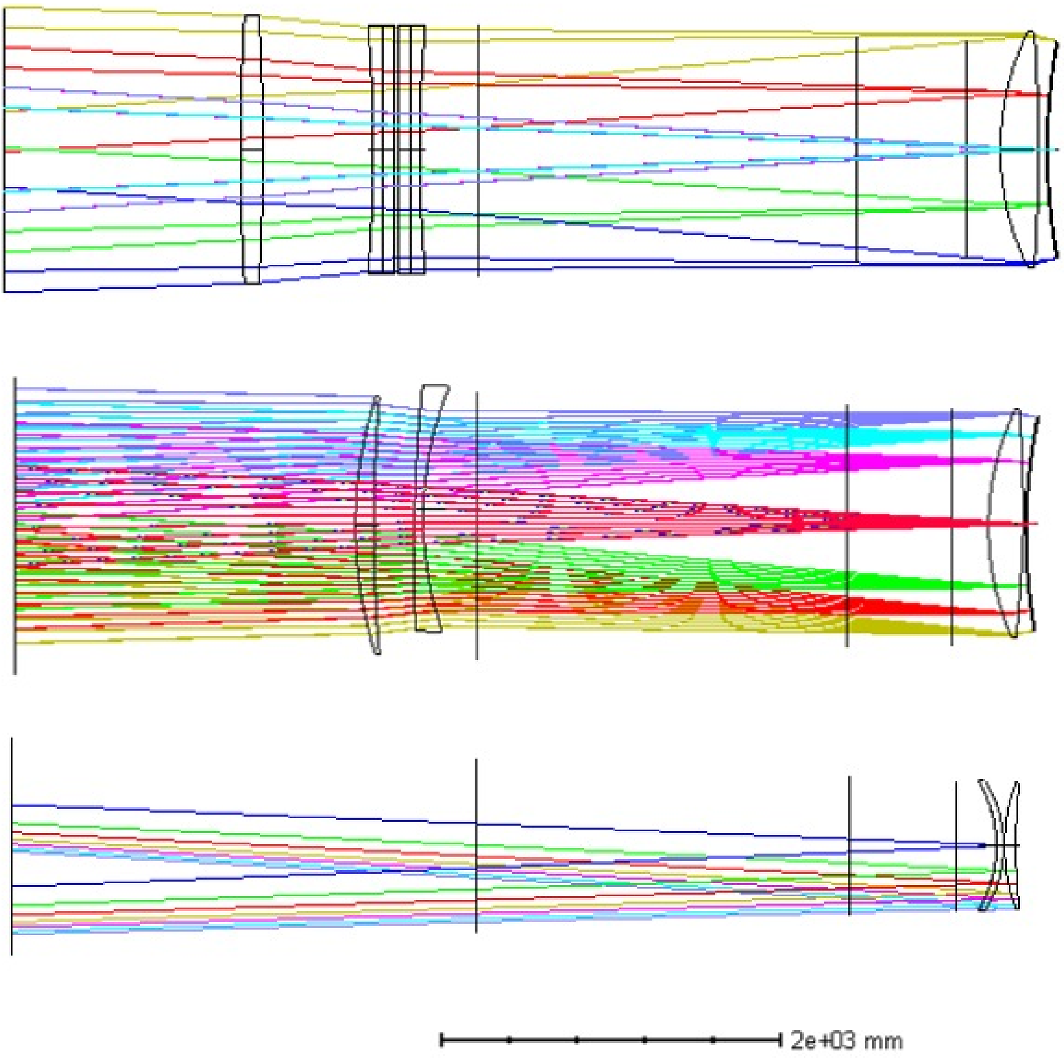


Figure 6. Three options for the design of the WFC-ADC: the baseline design (top), CLADC design (middle), and limited field option (bottom).

5. INSTRUMENT INTERFACES

5.1 G-CLEF

The GMT-Consortium Large Earth Finder (G-CLEF) is a fibre-fed, high-resolution Echelle spectrograph for the GMT. G-CLEF [7] will be the first major instrument to go on the GMT. G-CLEF covers a wide wavelength range, from 350-950nm, and implements an asymmetric white pupil design. Large format CCDs and a dichroic, which separate the dispersed beam into two channels, blue (350-540nm) and red (540-950nm), allow G-CLEF to cover its entire wavelength range in a single exposure.

The G-CLEF spectrograph is mounted inside a thermally stabilized vacuum chamber, located on a gravity invariant platform of the GMT. It is fed by a novel fibre-slit that comes with several modes: two high-resolution pupil-sliced modes with precision radial velocity measurements capabilities (R = 108,000), each using seven 100 μm core fibers; a medium resolution mode (R = 35,000) using 300 μm core fibers; a high throughput mode (R = 19,000) using 450 μm core fibers, and a multi-object mode using MANIFEST.

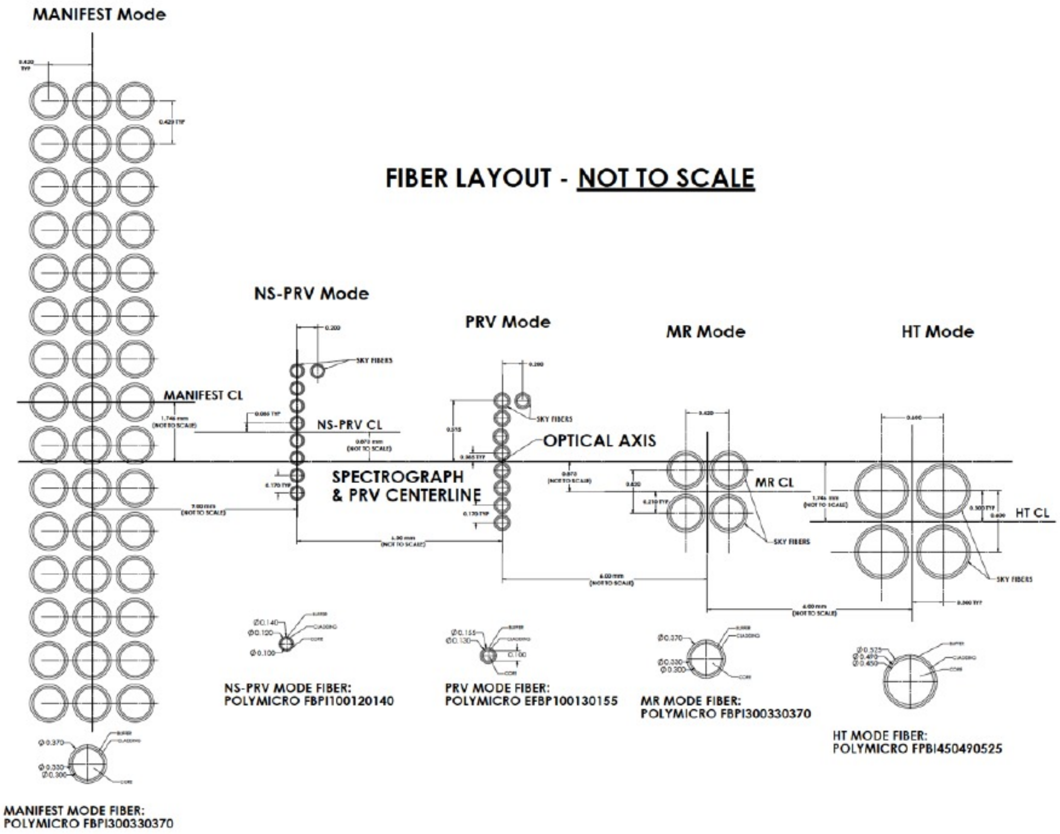


Figure 7. G-CLEF slit layout. The MANIFEST slit shows three rows of 15 fibres. The feasibility to accommodate 4 rows of 40 fibres is now being explored.

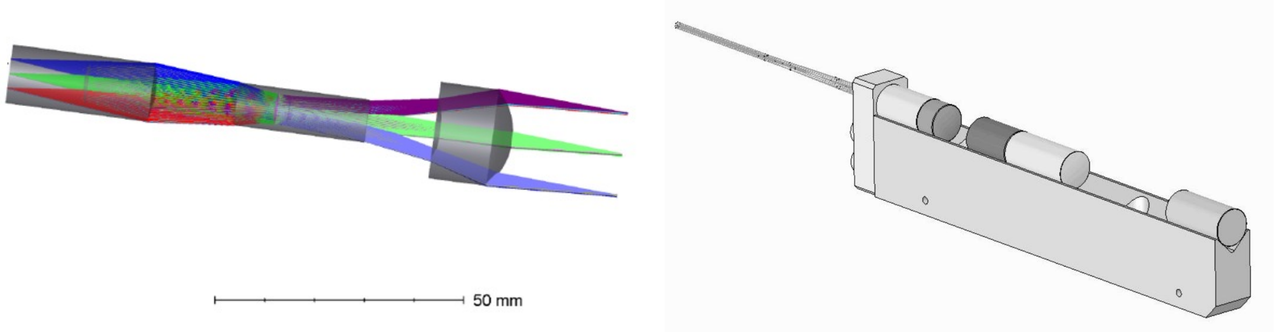


Figure 8. Concept for MANIFEST injection module. Optical layout is shown in figure left. The mechanical concept is shown in figure right.

The current concept for the G-CLEF MANIFEST mode consists of a series of rows of fibres mounted beside the G-CLEF fibres inside the instrument cryostat (see Figure 7). Each fibre is fed by a single-fibre Starbug unit from the MANIFEST glass field plate. With all but the central 4 probes output masked on the spectrograph entrance slit, a multi-order spectrum is obtained for 4 objects at once over the full instrument wavelength range. With all probes and a wedged Fabry-Perot filter, a series of well-separated chunks of spectra are obtained, tunable in the sense that the whole series can be shifted up and down in wavelength. Any desired echelle order can be selected, along with sections of other orders. This gives a higher multiplex, but at the expense of spectral coverage.

The G-CLEF spectrograph accepts an f/8 beam. To minimize focal ratio degradation, the fibres are fed close to f/3. Thus focal reducers are required for all input fibres. For the internal G-CLEF observing modes, focal ratio conversion is achieved using a bi-telecentric lens system. A similar approach is proposed for the MANIFEST slit. The object space of the injection system is the fibre slit which is cemented to the back of a plano-convex lens. The fibre faces are imaged at f/8 onto the quasi-slit of the spectrograph. The injection optics is therefore a macroscopic bi-telecentric magnifier (Figure 8). The current design is appropriate to accommodate 3 rows of 15 fibres. It appears feasible to increase this to 4 rows of 40 fibres.

The fibres will enter the G-GLEF cryostat through a vacuum flange with fibre feedthroughs. A mechanism external to the cryostat will allow light from unused fibres to be blocked in low-multiplex MANIFEST mode or for G-CLEF stand-alone operation. A mechanized filter system external to the cryostat will be used to prevent overlapping orders in the MANIFEST high multiplex mode. The details for the filter and mask system are currently under development.

5.2 GMACS

GMACS is a multi-object slit-mask spectrograph that covers a relatively wide field (at least 7.5 arcmins) with a wide wavelength coverage [8]. The instrument has two cameras optimized over single octave band-passes. The full instrument will deliver moderate resolution (R =1000-6000) spectroscopy from the near UV out to ~1000 nm. The instrument (see Figure 9) is mounted within a single bay of the GMT Gregorian instrument rotator. In the top section of the instrument frame is the slit mask holder which sits at the telescope focal plane when the instrument is deployed. A cassette, mounted on one side of the focal plane, positions and automatically exchanges slit masks into the holder. A field lens sits beyond the focal plane, followed by a dichroic that splits the beam into two wavelength channels. Each channel then has another collimating lens group, followed by a volume phase holographic grating. The gratings and camera barrels for each arm are articulating, and gratings can be swapped in and out to provide variable spectral resolution.

MANIFEST brings significant benefits to the GMACS stand-alone modes. It provides improvement to multiplex via efficient detector packing and spectral resolution via image-slicing, and provides access to integral field unit modes. For the baseline design, two sets of fibre probes are envisioned; the table in Figure 1 illustrates a possible fibre configuration for these modes. Further refinement of the operating modes will await more detailed development of the MANIFEST science case. It is likely that a large single object IFU positioned at field centre would be one of the modes.

For operation with MANIFEST, GMACS must be in its stowed position in the Gregorian instrument rotator. The MANIFEST fibre slit is required to be inserted into the entrance aperture of the spectrograph (mimicking the telescope feed). We have developed a concept to achieve this as shown in Figure 10. Here the MANIFEST fibre slit is attached to a plate that matches the dimensions and interfaces as for the standard GMACS slit masks. A replica of the standard slit grabber/actuator mechanism can then be used to drag the MANIFEST fibre slit into position to the required tolerance.

Other details of the GMACS/MANIFEST mechanical interface are to be determined. One issue currently being addressed is that it is likely that one arm of the GMACS spectrograph will intrude into the MANIFEST IMF when GMACS needs to be operated from its stowed position. A clearance has been allowed in the MANIFEST IMF to account for this intrusion.

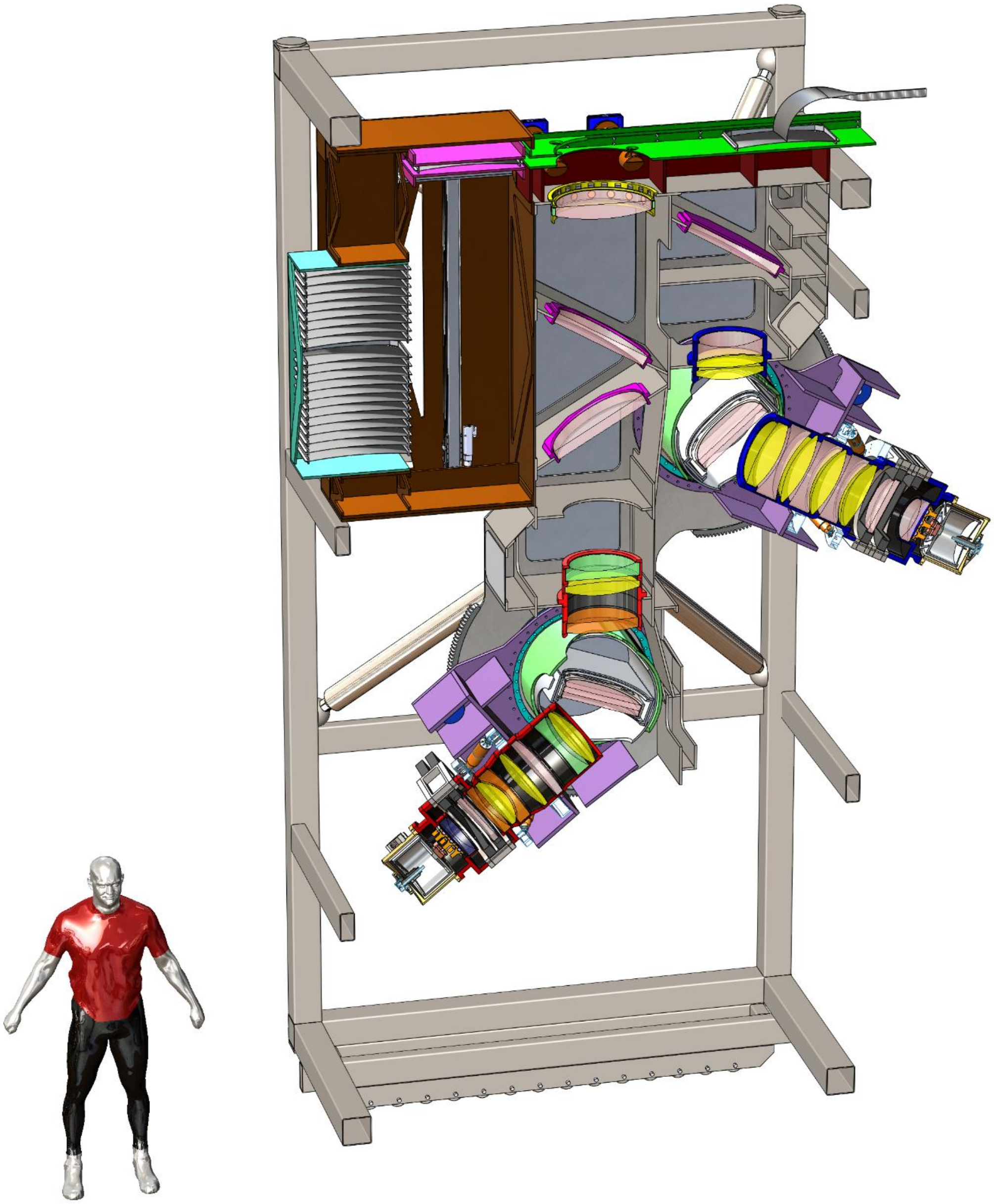


Figure 9. Concept model for the GMACS spectrograph, showing slit-exchange unit feeding collimator optics with two-deployable camera arms.

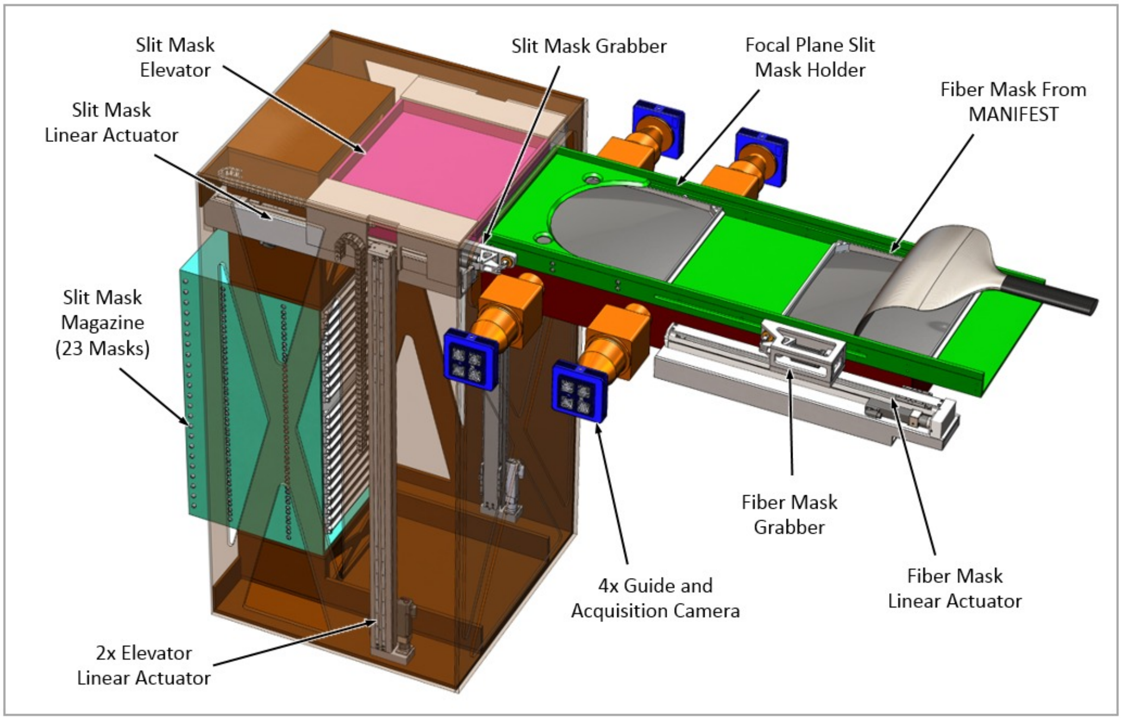


Figure 10. Concept for the MANIFEST fibre mask exchange mechanism into GMACS.

6. SUMMARY

The Pre-Conceptual Design Study for MANIFEST has recently commenced. During this phase, work will focus on the instrument interfaces. These include interfaces with the telescope, such as the metrology system, the wide-field-corrector, and the instrument assembly within the telescope GIR; and interfaces with the instruments, GMACS and G-CLEF. In addition, the high level systems engineering for the instrument will be addressed via the development of the science case and instrument requirements. Progress has already been made on all aspects of the study.

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