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Jessica Zheng, Sagi Ben-Ami, Daniel Faes, Celestina S. Lacombe, Jon Lawrence, Helen McGregor, Ellie O'Brien, Luke Schmidt, Tayyaba Zafar, Ross Zhelem, "Optical interface study of MANIFEST to GMACS and GCLEF instruments," Proc. SPIE 11447, Ground-based and Airborne Instrumentation for Astronomy VIII, 114472Q (13 December 2020); doi: 10.1117/12.2561896

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Event: SPIE Astronomical Telescopes + Instrumentation, 2020, Online Only

Optical Interface Study of MANIFEST to GMACS and G-CLEF Instruments

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ABSTRACT

MANIFEST, the Many Instrument Fiber System, is a fiber-positioner facility proposed for Giant Magellen Telescope (GMT) by Australian Astronomical Optics, Macquarie University (AAO_MQ). It will use hundreds fiber robotic positioners "Starbugs" to access telescope large focal plane and provides a means for the first light instruments GMACS and G-CLEF to increase their native capabilities. Since the concept was proposed, a lot of development has been made.

In this paper, we will report the latest optical interface development between MANIFEST to GMACS and G-CLEF instrument during the pre-conceptual design study.

Keywords: optical interface,fiber positioner, MANIFEST

1. INTRODUCTION

MANIFEST is a fiber-positioner facility proposed for Giant Magellen Telescope (GMT) by AAO[1–3] . It will deploy hundreds individually controlled fiber robotic positioner known as "Starbugs"[4] to access GMT larger fields of view. With the Starbug's versatile formats of payload range from single fiber to different size of integral-field-units (IFUs) or image slicer, it offers higher multiplexing capability and high spatial and spectral resolution observation for GMT first light instruments "the Giant Magellan Telescope Multi-object Astronomical and Cosmological Spectrograph " (GMACS) and "the GMT-CfA, Carnegie, Catolica, Chicago Large Earth Finder" (G-CLEF). With MANIFEST, simultaneous observation with multiple instruments becomes possible.

Since the concept of MANIFEST was proposed, a lot of progress has been made. TAIPAN positioning system[5,6] was developed as a prototype for MANIFEST in which 150 independently controlled Starbugs (with an upgrade path to 300) was deployed. Several subsystems including 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 have been developed and tested. The whole TAIPAN system is currently commissioning on UK Schmidt Telescope (UKST) telescope.

During pre-Conceptual design phase, we developed a more detailed optical interface between MANIFEST to the GMACS and G-CLEF instrument. The progress on the post optics design for fiber slit mask between MANIFEST and GMACS and filter box between MANIFEST and G-CLEF were reported in this paper.

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Ground-based and Airborne Instrumentation for Astronomy VIII, edited by Christopher J. Evans, Julia J. Bryant, Kentaro Motohara, Proc. of SPIE Vol. 11447, 114472Q · © 2020
SPIE · CCC code: 0277-786X/20/$21 · doi: 10.1117/12.2561896

2. INSTRUMENT DESIGN CONCEPT

2.1 Science Drivers

The advancement of multi-object spectrographs and IFUs[7] during the last two decades has transformed the fields of galactic archaeology, stellar astrophysics, galaxy kinematics, formation and evolution, and cosmology. MANIFEST offers the prospect of bringing this transformative power to an ELT, with order-of-magnitude increases in sample sizes and/or sky coverage.[8]

Through collaboration with the Giant Magellan Telescope Organization (GMTO), its partners and other representatives from the scientific community, a set of principal functional requirements have been developed. A 2017 MANIFEST community workshop included more than 50 participants from GMT partner and non-partner institutions with broad scientific interests. The recommendations of this meeting were integrated into the MANIFEST scientific requirements. The key science themes for MANIFEST are as follows:

- **archaeology and stellar chemistry:** including galactic archaeology of extreme metal poor stars, the galactic stream and in the Local Group, stellar associations in open clusters, mapping the stellar halo for Galaxy assembly studies, and, potentially, polarimetry for stars, dust, and planet formation;
- **spatially resolved galaxies:** including galaxy stellar kinematic studies, the mass assembly of galaxies, and gas kinematics of faint from absorption galaxies in emission;
- **nearby galaxies:** including chemical evolution of dwarf galaxies via element abundance studies, and performing emission line mapping of the circumgalactic medium;
- **high redshift galaxies:** unveiling the reionisation epoch using Lya emitters, studying the peak of star formation to the epoch of reionisation through rest-frame UV emission of massive stars, tomography of the intergalactic medium, and studies of the first galaxies in the cosmic web; and
- **the transient universe:** transient (i.e. supernovae, asteroid, etc) follow-up, and gamma ray burst follow-up of afterglows, and host galaxies.

Those science cases will drive the science requirements for MANIFEST and they are representative of the science requirements for the MANIFEST instrument design at this stage.

2.2 Instrument Functions

Figure 1 shows MANIFEST optical system flow chart from the focal plane of wide field corrector of GMT to GMACS and G-CLEF instrument with different operational modes.

The top-level function of the fibre feed system is to efficiently route the light from the astronomical targets at the telescope focal plane to the instruments. The essential functions of the fibre feed are outlined in the graph and key components are the fibre cable, fore optics, connectors, spectrograph slits, fibre mode scrambler, strain relief, cable de-rotator unit and fibre coupler etc. Figure 2 shows the functional diagram of the fibre system.

MANIFEST will consist of several hundred Starbug robots that patrol the (ideally) 20' field of view of the GMT and will be fed to current planned optical spectrographs (presently high resolution G-CLEF and medium resolution GMACS) and future spectrographs (possibly including infrared spectrographs). MANIFEST will provide fibre feeds that will range from single fibres to multiple integral-field units. The MANIFEST instrument aims to enhance the functionality of the GMT spectrograph by offering capabilities such as:

- increasing the field of view;
- providing a moderate to a high degree of multiplex capability;
- multiple deplorable IFUs;
- increased spectral resolution and/or wavelength coverage via image-slicing;

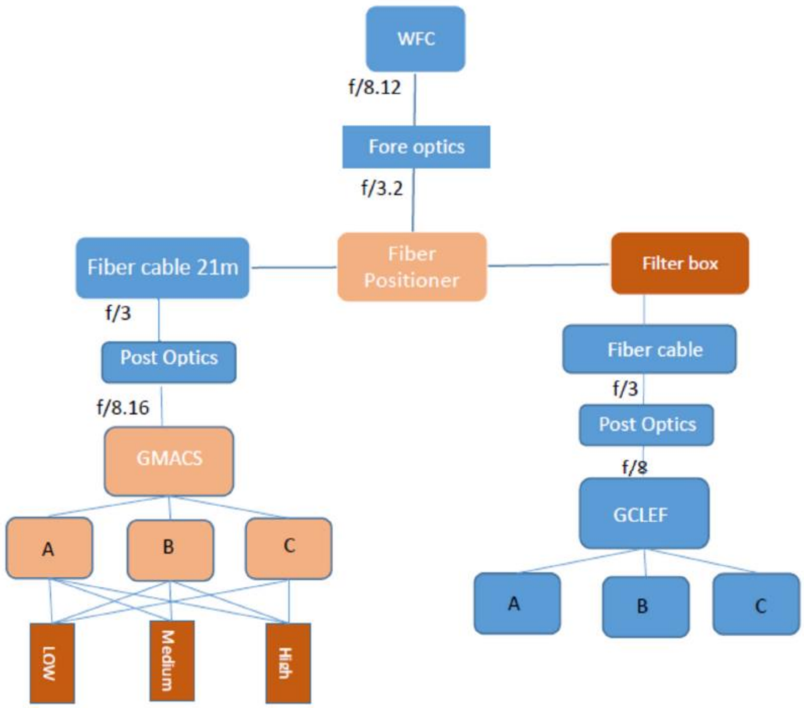


Figure 1. Flow Chart of MANIFEST optical system

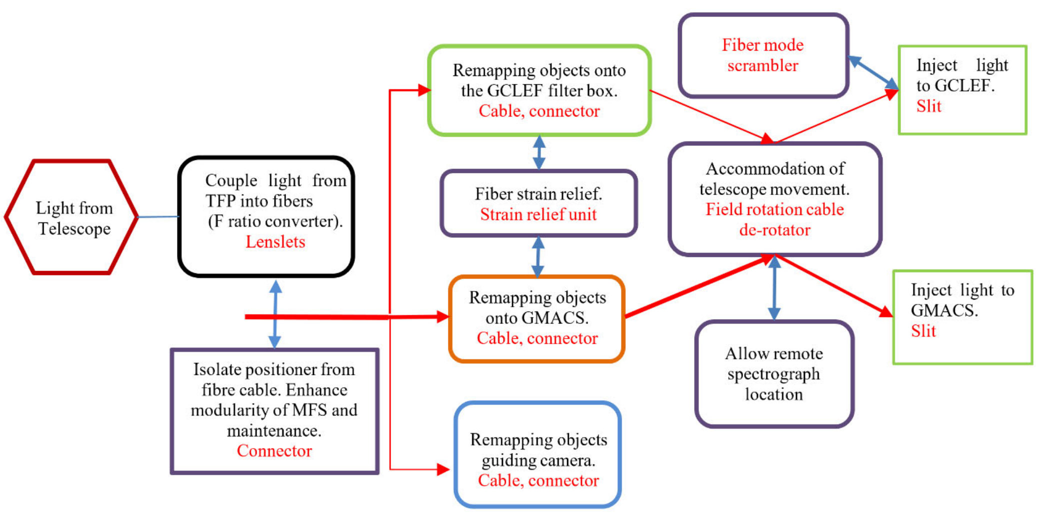


Figure 2. Fiber feed subsystem essential functions block diagram

Figure 3. Samples of MFS IFUs for MANIFEST

- the opportunity for simultaneous observation with multiple instruments;
- the possibility of a gravity-invariant spectrograph mounting;
- the potential for OH suppression via fibre systems in the near-infrared;
- the versatility of adding new instruments in the future.

3. OPTICAL INTERFACE

MANIFEST interfaces with several subsystems of GMT. There are a few papers in this conference reporting the latest interface study between MANIFEST to GMT and GMACS and G-CLEF.[9,10] Here we only focus on optical interfaces study.

3.1 Fore-optics for MANIFEST

The native GMT Gregorian design provides a useful uncorrected field of view of 10' diameter. To achieve wide field operation up to 20', a wide field corrector (WFC) and a possible atmospheric dispersion corrector (ADC) needs to be designed. The detailed design study about this has been published in references.[11] The corrected Gregorian focus of the GMT is F/8.12. Its plate scale is about 1mm/arcsec and it is curved with about 3m in radius. An input focal ratio conversion optics (fore optics) needs to be designed to convert f/8.12 telescope beam to f/3.2 beam for efficient fiber coupling and reducing the fiber focal ratio degradation (FRD). The optics needs to have a magnification factor of 3.2/8.12. In the previous feasibility study, the concept of fore optics has been developed with large IFUs (1000) in which large scale customized of microlens array has been designed and manufactured.[12]

MANIFEST will have different operation modes, each has its own size of IFUs. Figure 3 shows samples of MANIFEST IFUs for GMACS and G-CLEF, in which either single or different size of IFUs will be used depending on different science.

In the next phase of the study, we will prototype the integration of the fore optics into Starbugs and investigate its optical performance under the Starbug's operation and their long term optical and mechanical stability.

3.2 GMACS

GMACS is a multi-object, slit-mask, wide field optical spectrograph currently being developed for the Giant Magellan Telescope (GMT).[13,14] Its current concept includes ≥ 20 interchangeable multi-object slit masks which are placed at the focal plane of the GMT. The instrument (see Figure 4 is mounted within a single bay of the GMT GIR. 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. The cassette, mounted on one side of the focal plane, position and automatically exchange slit masks into the holder. The f/8.16 beam from telescope Gregorian focal plane first passes through the slit mask and a field lens. A dichroic mirror splits the beam to two collimating lens groups deliver light via to two separate cameras optimized for each band.

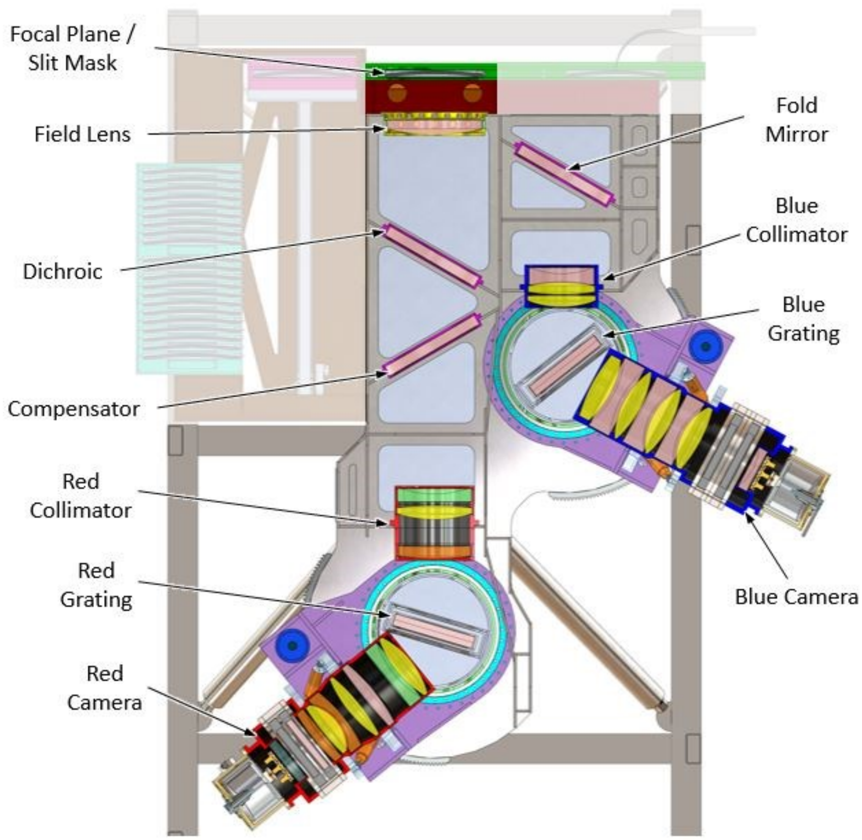


Figure 4. Layout of GMACS instrument

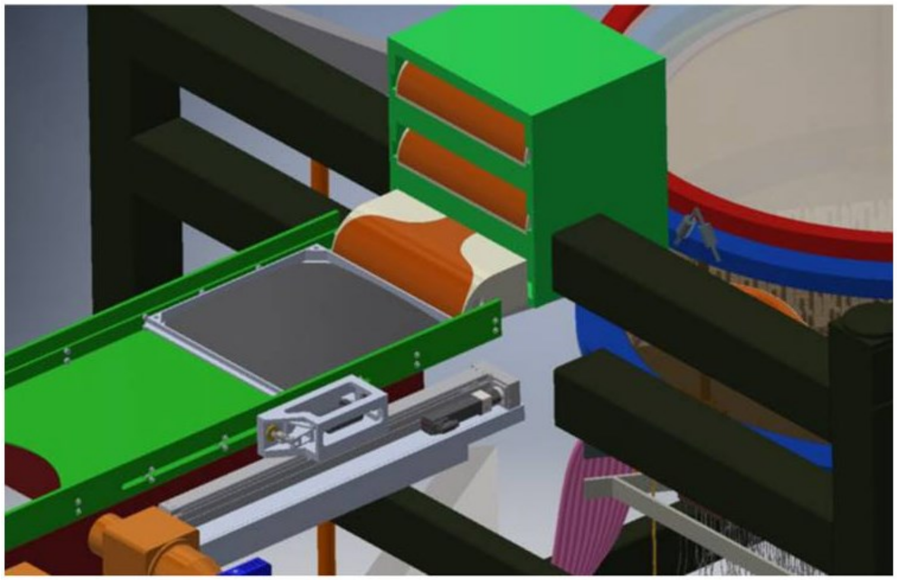


Figure 5. MANIFEST slit selector mechanism

Table 1. MANIFEST GMACS Modes

No. Starbugs	FoV Size	No.Fibers per IFU	Fore optics	Fiber core(µm)	Size of fore optics(mm)	Slit to Spectrograph	Post optics
380 Mask A	0.75”	1	Single lens	~300/330/370	Ø5*15	32 slit/450mm 12 fiber/slitlet Fiber pitch: 1.25fiber core	Post optics : f/3~8.16 for each slitlet. (Size: 15*15*60, 5 optical elements) Folding prism for each slitlet. 3 Slit masks located horizontally.
100 Mask B	1.5”	7	Microlens array(2)	~160/190/250	Ø3*15	31 slit/450mm 23 fibers/slitlet Fiber pitch: 1.25fiber core	
19 Mask C	3”	37	Microlens array(2)	~160/190/250	Ø3*15	31 slit/450mm 23 fibers/slitlet Fiber pitch: 1.25fiber core	

When MANIFEST feeds GMACS, the MANIFEST fibre slit mask is deployed to feed light into its optical system. Figure 5 shows its mechanical layout.[9] The mask have fibres aligned in three different rows into the GMACS input slit plane.[9] The proposed MANIFEST GMACS modes as shown in Table 1 are: (a) a monolithis IFU. Both fiber ends will have 0.75” aperture as GMACS standalone slit width. (b) multiple 7-fiber image-slicers, each fiber of sampling of 0.25” and (c) multiple 37-fiber image slicer, each fiber of sampling of 0.25”. The three operation modes will correspond to different science case. With this arrangements, when it works at mode B and C, it allows a three-fold increase in the spectral resolution of the spectrograph over GMACS standalone use. Using MANIFEST Starbug’s fibre positioning system, GMACS can be quickly reconfigured to observe new targets over the full telescope field of view.

Since GMACS spectrograph is designed with input optics of F/8.16, the light from the fibers of MANIFEST is of f/3.2, it must be converted to F/8.16 at the slit mask plane. The MANIFEST- GMACS slit post optics shall be designed to meet this requirement. There are two options for the geometry of the optical interface between MANIFEST and GMACS slits.

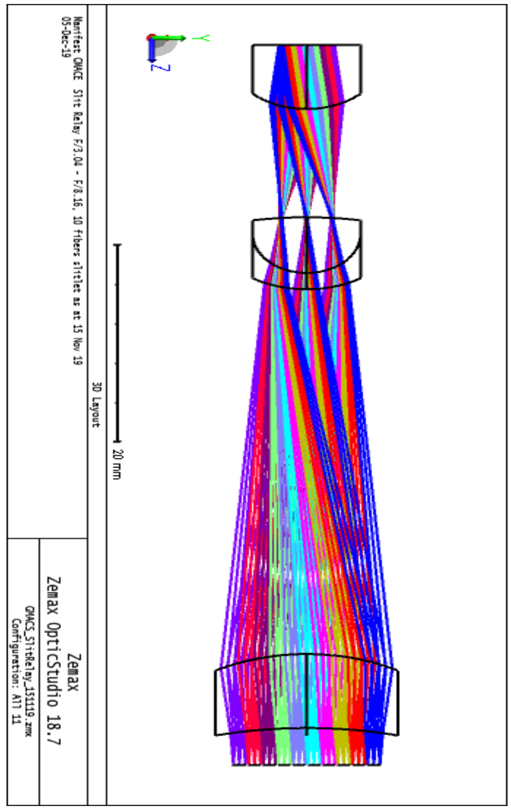


Figure 6. Optical layout of post-optics for GMACS. Option 1

3.2.1 Fiber slit masks mounting vertically

Figure 6 shows the optics layout where the post optics and fiber slit masks are located vertically relative to the GMACS slit plane. The fiber slitlet exit image plane is coincidence with the GMACS slit mask position. With this option, the fibre cable will be routed vertically. If the MANIFEST slit masks (corresponding to different operation mode) stacks vertically which is similar to GMACS nature slit masks, the space between masks would be quite large. This option will need a large space between MANIFEST slit mask planes.

The post optics converts the focal ratio by grouping 10 fibers together. Figure 6 shows this concept . It is assumed that the fiber core is 0.33mm and fiber pitch is 0.42mm and each slitlet contains 10 fibers. The maximum diameter of the collimating lens in each slitlet would be 13mm. The total slit length to GMACS is 450mm which sets the limit of the fiber number in one fiber slit mask. The optics will create a similar focal plane as GMACS native GMT Gregorian focal plane.

3.2.2 Fiber slit masks side mounting

The second option is shown in figure 7. The post optics in the fiber slit mask shall include a folding prism which will fold the converted f/8.12 plane towards GMACS input focal plane. The three different slit masks can be arranged in the similar way as native GMACS's arrangement of slit mask magazine. The mechanical design shall be able to pickup the proper slit masks and put into the GMACS slit mask place. This will be a more favorable option.

In the next phase study, we will prototype the post optics and work closely with GMACS team to exam their optical performance.

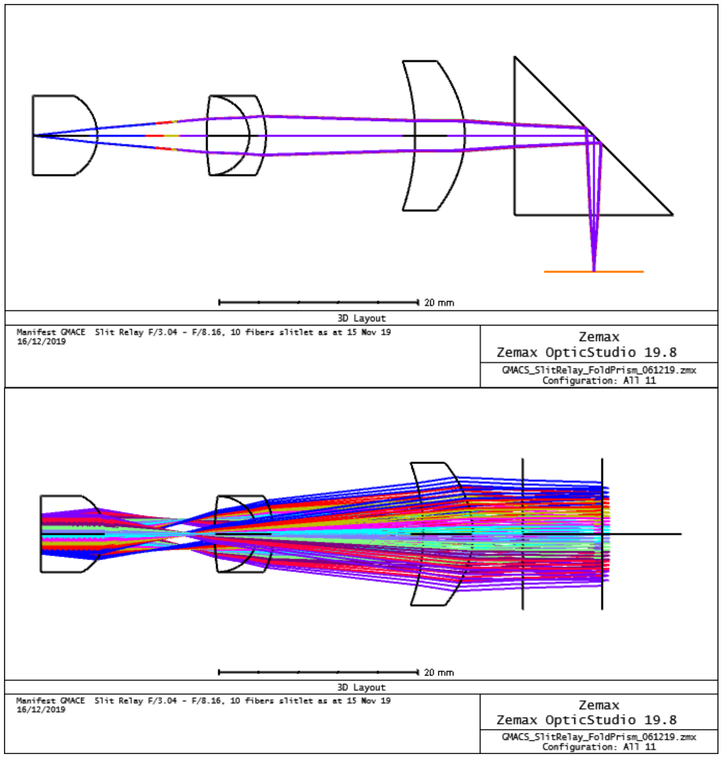


Figure 7. Optical layout of post-optics for GMACS. Option 2

3.3 G-CLEF

G-CLEF is a fibre-fed, high-resolution Echelle spectrograph that was selected as the first light instrument of GMT.[15,16] It is mounted on the gravity-invariant azimuth disk of the telescope, inside a thermally stabilized vacuum chamber. It is an ultra-stable and versatile high resolution spectrograph operating over a wide wavelength range, from 350-950nm. 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 100μm core fibers; a medium resolution (MF) 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.

While the G-CLEF spectrograph input fibers are fed at F/3 to minimize FRD, to keep a reasonable spectrograph size, an F/8 spectrograph design was chosen. A focal ratio converter is required for any input fibers. The details of the injection optics including optics for MANIFEST fiber input slit can be found in reference.[16]

3.3.1 MANIFEST G-CLEF Slit Configuration

When MANIFEST feed G-CLEF instrument, the general design goal is to use the spectrograph efficiently. The simplest method for doing this is to put as many seeing-limited fibers close-packed on the slit as the inter-order separation allows or get all orders for all targets The proposed MANIFEST G-CLEF will use 300/330/370μm (core/cladding/buffer) fibres, similar to the G-CLEF baseline MF fibres. It is also assumed that the fibre pitch are 420μm in both column and row direction. Figure 8 shows the schematic layout of MANIFEST G-CLEF slit plane to the spectrograph.

3.3.2 MANIFEST G-CLEF Operating modes

With the baseline design of G-CLEF Echelle spectrograph, the average inter-order spacing on the imaged echellogram is 1mm,[16] this sets the maximum objects (size of 0.8") to be observed with a full spectrum with MANI-

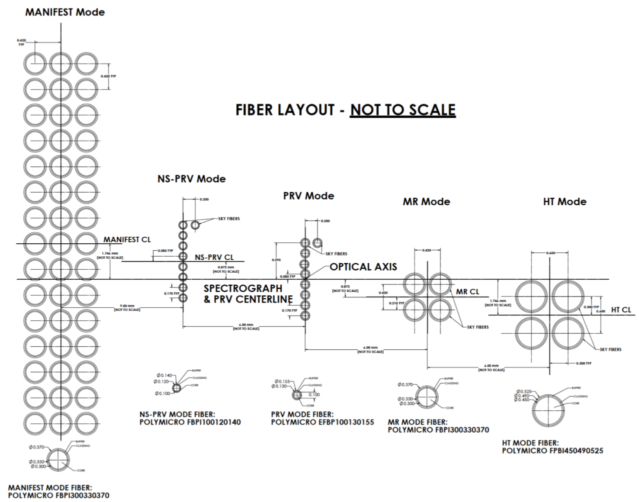


Figure 8. GCLEF slit plane with MANIFEST slit on the left (adapted from SAO-INST-DOC-00194).

FEST to 3 without Echelle grating order blending.

To make use of G-CLEF 40” full slit length and the G-CLEF spectrograph efficiently when it is fed by MANIFEST, We did a series investigation based on the G-CLEF slit and its spectrograph[16] design. Three operating modes are proposed as:

- 3 single objects (Starbugs) with full wavelength coverage;
- 21 single objects (Starbugs) with dual passband coverage;
- 2 sets of 27 single objects (Starbugs) with single-order narrowband coverage.

To realize those operating modes, a filter box needs to be designed to be placed between MANIFEST and G-CLEF instrument. It will separate the spectrum from multiple objects to avoid order blending or maximize the number of objects observed on both camera.

The first two modes share one filter wheel. The third mode requires two separate filter wheels. Note that 27 is the maximum number of the fiber that G-CLEF input slit can support when it is observed with one Echelle order on both cameras.

Figure 9 shows the proposed first two operation modes. Among the 24 input fibers connected to the first column, the top 3 fibers are dedicated to the MANIFEST Starbugs carrying three individual objects and feed to the clear filter which won’t block any wavelengths. It shall work under the condition when the filter wheel rotates to the position where it blocks all light from the rest of Starbugs in the same column. in this mode, G-CLEF will work as its native operation mode where a full spectrum on both cameras can be observed without any order blending. When it is not in observation, the filter wheel shall be designed to block the light from this clear path.

For mode B, the rest of 21 fibres from the first column are arranged in groups of 3. Each group shall be routed to different fibre arrays. The last set of 3 fibres is not used in the first slit. light from each group will pass a dual band-pass filter and will be re-imaged to the output fibre arrays accordingly. The maximum number of fibres that one filter shall support is limited to 3 to avoid order blending in G-CLEF spectrograph. Each of these filters shall have two pass-band with one band in the blue camera wavelength range and one in the red camera. The input and output fibre arrays shall be very similar and their positions shall remain the same without any

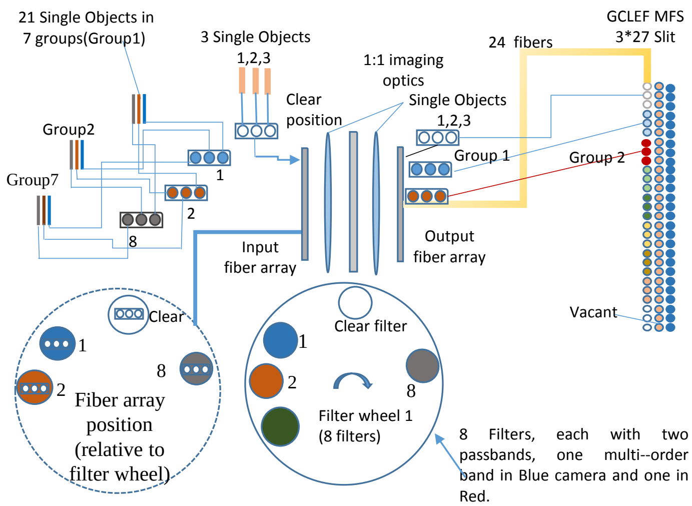


Figure 9. Filter configuration for the first two operation modes

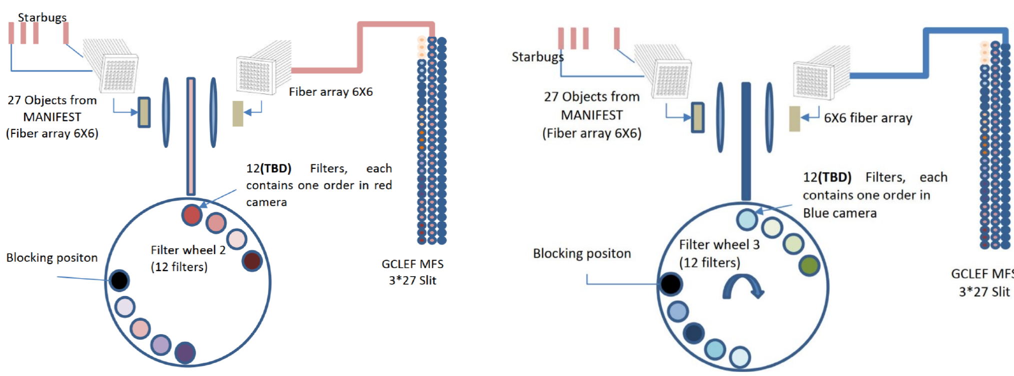


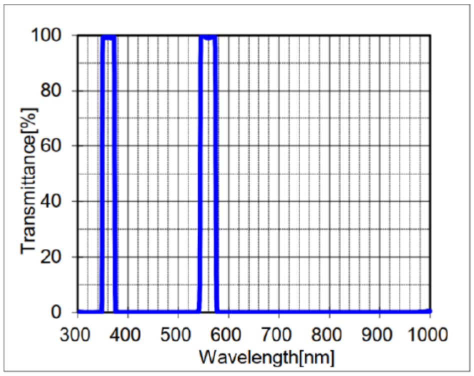
Figure 10. Filter configuration for the third operation mode

movement. To change the observation wavelength range, the filter wheel needs to be rotated. When these two modes are not in operation, the filter wheel shall be able to block all light from all Starbugs.

Figure 10 shows the third operation mode C. In this mode, two filter wheels shall be designed to dedicate to multi-object observation with very narrow band filters (one order of the Echelle grating within G-CLEF Red or Blue camera wavelength range). Figure 10 (Left) shows its operation in the red camera, where its output fibres feed to G-CLEF MANIFEST slit second column. Figure 10 (Right) shows the similar operation in blue camera, where its output fibres feed to G-CLEF MANIFEST slit third column. By doing this, 54 single objects from MANIFEST can be observed simultaneously in G-CLEF spectrograph. Those two filter wheels both shall reserve one position where when they are not in use, they can block the light to G-CLEF spectrograph.

All three filter wheels shall be able to control and re-position individually and they shall be designed to reserve a blocking position so that when MANIFEST is not in use, no light from any optical path can be transmitted through MANIFEST G-CLEF slit to the spectrograph and affect its native operation.

The three filter wheels and their relative input and output fiber arrays, imaging optics shall be assembled in



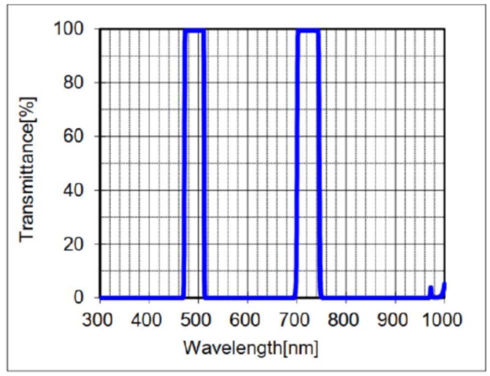


Figure 11. Dual bandpass filter sample design

one box. There is no limitation on their relative position. The routing of the output fibers have to be designed so that fibers from one filter wheel shall feed to the same column of the G-CLEF MANIFEST slit. The filter box will be attached to MANIFEST mainframe and free of any vibration.

The filter wavelength and bandwidth are critical for MANIFEST to be used with G-CLEF. These filters need to be designed with either one order of Echelle grating pass-band or two pass bands (multi-orders) with one pass band in blue and another one in red camera spectrum range. Figure 11 shows the transmission of two sampled filter designs from one commercial filter vendor. The exact center wavelength and bandwidth of the filter has to be designed with the science case and the observation plan. Detail about this is beyond the discussion of this paper.

In the next development phase, we will develop the filter box optical design in detail. Filter configuration will also be investigated with more matured MANIFEST G-CLEF science requirements.

4. CONCLUSIONS

The pre-Conceptual design study for MANIFEST has recently finished. During this phase, the optical interface architecture between MANIFEST and GMACS and G-CLEF has been investigated and presented in the paper. MANIFEST is currently moving to the next design phase and we will continue the development of the key instrument interfaces in more details.

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