Key early science with MANIFEST on GMT

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Abstract. The MANIFEST fibre system provides a highly versatile feed for the GMACS and G-CLEF first-light spectrographs on the Giant Magellan Telescope (GMT). Combining these low- and high-resolution optical spectrographs with the wide field of view (up to 20 arcmin), high multiplex, and integral field capabilities provided by MANIFEST enables science programs that are not achievable with other extremely large telescopes. For galactic archaeology and near-field cosmology studies of Local Group galaxies, MANIFEST and G-CLEF can obtain up to 40 simultaneous high-resolution optical spectra over a wide field, and so produce detailed kinematic and chemical maps of the stellar populations out to large radius in galaxies covering a broad range of masses and morphologies. For galaxy evolution studies, MANIFEST and GMACS can combine a survey of galaxies at the epoch of peak star formation with a study of the flows of gas between galaxies and the circumgalactic medium, mapping both the emission from hot gas using integral field spectroscopy and the absorption from cold gas with multi-object spectroscopy of background sources. These programs will feature strongly in the early science goals for GMT.

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The Giant Magellan Telescopes planned first-light optical spectrographs, G-CLEF and GMACS, will produce transformative early science for users. However, the 25m GMT must provide access to its whole 20 arcmin field of view if it is to fully realise its potential $A\Omega$ advantage relative to the 30m TMT and the 39m ELT (see Figure 1). With MANIFEST, GMT can offer 3-4× performance gains for wide-field and survey spectroscopy.

GMT’s wide field corrector and atmospheric dispersion compensator (WFC/ADC) combined with the MANIFEST fibre system provides access to GMTs entire field of view for multiple spectrographs—initially the GMACS optical medium-resolution spectrograph and the G-CLEF optical high-resolution spectrograph, and in future a near-infrared medium-resolution spectrograph such as the proposed NIRMOS instrument. MANIFEST also provides a versatile set of fibre feeds, ranging from single fibres through small image-slicers to multiple integral field units. Detailed technical descriptions of MANIFEST are provided by Saunders et al. (2010), Goodwin et al. (2012), Lawrence et al. (2014), Jacoby et al. (2016) and Lawrence et al. (2016).

| Telescope + Instrument | Aperture (m²) | Field (arcmin²) | Relative $A\Omega$ |
|------------------------|--------------|-----------------|-------------------|
| GMT+GMACS              | 368          | 50.0            | 0.16              |
| TMT+WFOS               | 655          | 40.5            | 0.23              |
| ELT+MOSAIC             | 978          | 40.0            | 0.34              |
| GMT+MANIFEST            | 368          | 314.2           | 1.00              |

Figure 1. Comparison of the relative $A\Omega$ (the product of telescope aperture and instrument field of view) for various ELT+spectrograph combinations, showing the factor of 3–4 gain offered by GMT+MANIFEST.
Figure 2. Schematic showing MANIFEST’s role in linking the GMT to the available spectrographs and the applicability of specific combinations of instruments and MANIFEST fibres/IFUs to various key science cases.

Here I explore some of the early science that can be done by combining GMT with MANIFEST and either GMACS or G-CLEF. As an overview, Figure 2 provides a schematic showing some of the key science cases for MANIFEST and their mapping to specific spectrographs via various potential fibre or integral field unit (IFU) configurations. The following paragraphs briefly summarize some of the key early science that will be carried out with MANIFEST on GMT.

**Synergies with wide-field imaging surveys.** GM with MANIFEST and GMACS will reach the $5–10 \sigma$ detection limits of wide-field imaging surveys (including LSST survey fields) in practical exposure times, as shown in Figure 3. MANIFEST and GMACS can thus measure dynamics and abundances for almost any source in the LSST catalogue. The observing efficiency offered by MANIFEST’s wide field and high multiplex means GMT will excel at exploiting imaging surveys.

**Spectroscopic surveys at $z \sim 0.5$.** MANIFEST is well-suited to spatially-resolved galaxy surveys at intermediate redshifts. Currently, the SAMI multi-IFU system on the AAT 4m is surveying $10^3–10^4$ galaxies at $z = 0.05–0.1$. In future, MANIFEST and GMACS could study evolution in the resolved properties of galaxies out to $z \sim 0.5$ for similarly-sized samples. A densely-sampled, volume-limited, spatially-resolved galaxy survey can study detailed evolution over the last 5 Gyr of (i) mass and angular momentum growth; (ii) black hole feeding and feedback; (iii) stellar winds and outflows; and (iv) kinematic morphology transformations.

Figure 3. Survey area and sensitivity ($5\sigma$ depth) of imaging surveys expected to be complete or underway at GMT first light, together with the corresponding spectroscopic limits ($5\sigma$ continuum $I$-band detection) in 20 hours on a 4m, 8-10m and GMT. [Bernstein et al. (2018), Fig.1-10]
Spectroscopic surveys at $z > 6$. GMT’s large aperture and wide field are well-suited to studying faint, high-redshift galaxies. MANIFEST and GMACS provide an efficient way to follow up $z > 6$ galaxies with large surveys. A single deep ($H_{AB} = 27$ mag) WFIRST pointing will include of order 1000 $z > 6$ galaxies—see Bernstein et al. (2018). MANIFEST and GMACS can detect Lyα in all $z \sim 6–7$ galaxies with line fluxes $> 3 \times 10^{-17}$ erg s$^{-1}$ cm$^{-2}$ with $S/N > 5$ in a 10-hour integration. As Figure 4 shows, MANIFEST’s 20 arcmin field of view can cover almost all of a WFIRST field in just 3 shots.

IGM/CGM absorption-line surveys. MANIFEST and GMACS will be able to perform tomography on the intergalactic medium (IGM) and circumgalactic medium (CGM) using Lyman-break galaxies. The aim is to reconstruct the 3D small-scale structure of the IGM and CGM at high redshifts by very densely sampling the Lyα forest over large areas of sky. GMT can see the Lyα forest in the spectra from faint (and therefore dense) Lyman-break galaxy samples at $2 < z < 3.5$ (0.36–0.56 $\mu$m). Using MANIFEST will double the object multiplex and spectral resolution relative to GMACS alone, and provide sub-Mpc spatial sampling of the IGM along each line of sight.

Circumgalactic medium in emission. With a large-field optical IFU, MANIFEST and GMACS will enable studies of the CGM in emission around not only QSOs but also inactive galaxies, where the ionizing flux is much lower than in the vicinity of QSOs. Cosmological surface brightness dimming means the sensitivity needed to detect faint Lyα flows varies strongly with redshift; with a blue-sensitive CCD, MANIFEST and GMACS will be able to target Lyα emission in and around galaxies at $z \sim 2$. The virial radius of a typical star-forming galaxy at $z \sim 2$ is about 90 kpc, corresponding to an angular extent of 11 arcsec, so a large optical IFU is ideal for these studies.

Stellar chemistry and Galactic archaeology. Using MANIFEST in combination with G-CLEF allows the study of stellar chemical abundances in Local Group galaxies, and these abundances can be used to trace the formation history of the Milky Way itself and nearby Local Group galaxies, including the LMC, SMC, and about 40 dwarf galaxies within about 1 Mpc. A survey of 2000 stellar spectra at $S/N \sim 30$ sampling 100 red giant branch stars in each of 20 Local Group galaxies would take about 30 nights on GMT with MANIFEST and G-CLEF. This combination can also study the Galactic archaeology of the outer Milky Way disk via chemical tagging and enable a faint extension of the current
GALAH survey on the AAT 4m, which is using chemical abundances for a million bright stars to chemically tag coeval stellar associations in the inner disk and bulge. With GMT, it should be possible to extend such surveys to the outer disk and even the inner halo.

In summary, by allowing GMT to exploit its full 20 arcmin field of view, MANIFEST will make GMT the ‘wide-field ELT’, with a $3-4 \times A\Omega$ advantage over other ELTs. It will also provide versatile high-multiplex/multi-IFU feeds for the GMACS and G-CLEF first-light spectrographs. For galaxy evolution, MANIFEST and GMACS can combine a survey of galaxies at the peak star formation epoch with studies of gas flows between galaxies and the circumgalactic medium, mapping both the emission from hot gas using integral field spectroscopy and the absorption from cold gas with multi-object spectroscopy of background sources. For galactic archaeology and near-field cosmology using Local Group galaxies, MANIFEST and G-CLEF can obtain up to 40 simultaneous high-resolution optical spectra over a wide field, and so produce detailed kinematic and chemical maps of the stellar populations out to large radii in galaxies covering a broad range of masses and morphologies. Consequently, MANIFEST should be a key element of the early science programs carried out with GMT.

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Discussion
R. Egeland: We heard about systems with 150 and 300 fibres (‘starbugs’). What is setting the limit for the number of starbugs one can implement?

M. Colless: The systems with 150 to 300 starbugs are single-fibre prototypes. MANIFEST will probably have hundreds of IFU starbugs and over 1000 fibres.

B. Weiner: Is there a tension between the fibre diameters needed to do integrated high-throughput spectroscopy of galaxies/stars, and that need for IFU spatially-resolved spectra? Are different fore-optics needed?

M. Colless: MANIFEST will have image-slicers for high-throughput integrated spectroscopy and IFUs for spatially-resolved spectroscopy. We expect to provide a variety of starbugs offering different feeds for different applications and different instruments.

G. Bono: Is the limiting magnitude you mentioned for MANIFEST for seeing-limited or AO-assisted observations?

M. Colless: The limits mentioned apply to seeing-limited observations.