Sharp Images and Wide Fields

The scientific power of GMTIFS and MANIFEST on GMT

Lecture 3

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USP/IAG Advanced School on Astrophysics

Sao Paulo, 26 February – 2 March 2018

Structure

GMT

- ❑ Lecture 1 – Sharp Images and Wide Fields
- ❑ Lecture 2 – The GMT Integral Field Spectrograph
- ❑ Lecture 3 – The MANIFEST fibre facility

Outline of Lecture 3

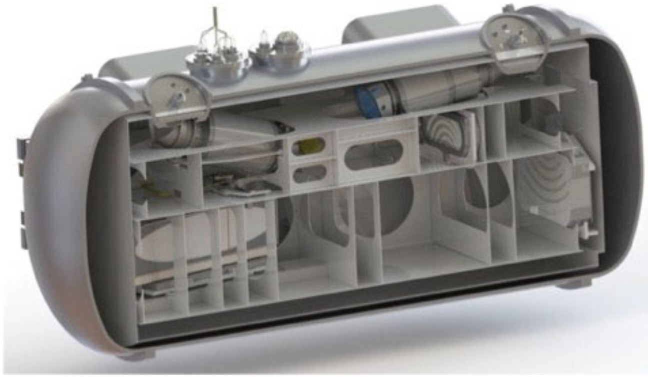
GMT

- ❑ Introduction and review
- ❑ MANIFEST – origins & timeline
- ❑ TAIPAN – a MANIFEST prototype
- ❑ MANIFEST – science & modes
- ❑ MANIFEST – instrument design
- ❑ Wide-field MOS at GMT first light
- ❑ Summary

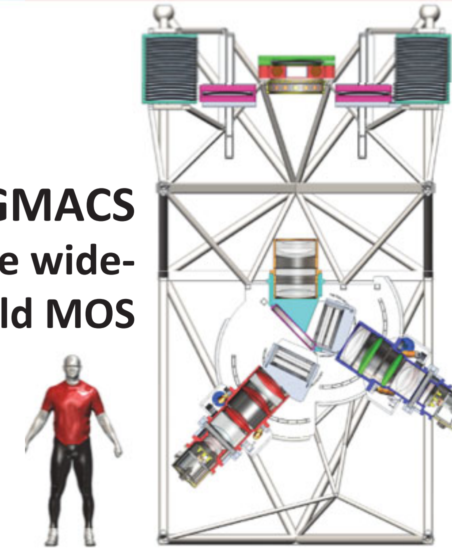
Introduction and review

First-generation GMT instruments

GMT

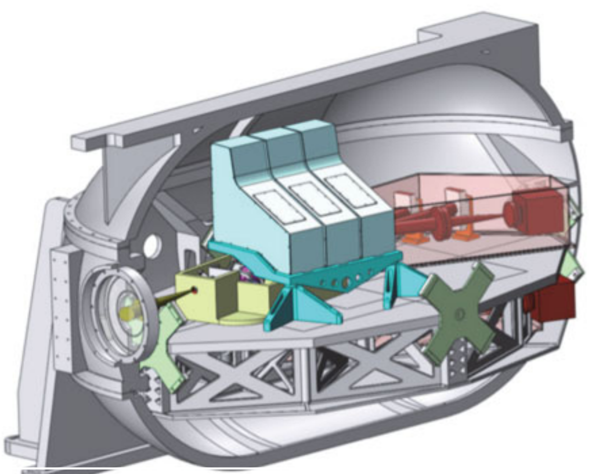


G-CLEF
high-resolution
echelle

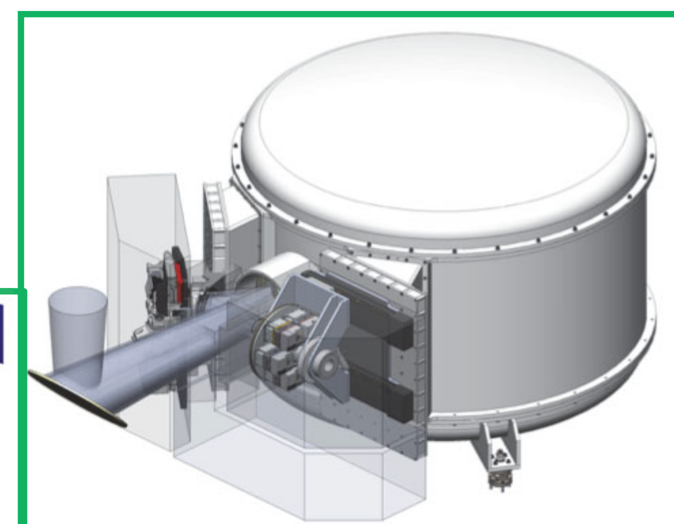


GMACS
visible wide-
field MOS

MANIFEST
facility fibre
system



GMTNIRS
AO-fed 1-5 micron echelle



GMTIFS
AO-fed IFU
spectrograph
and imager

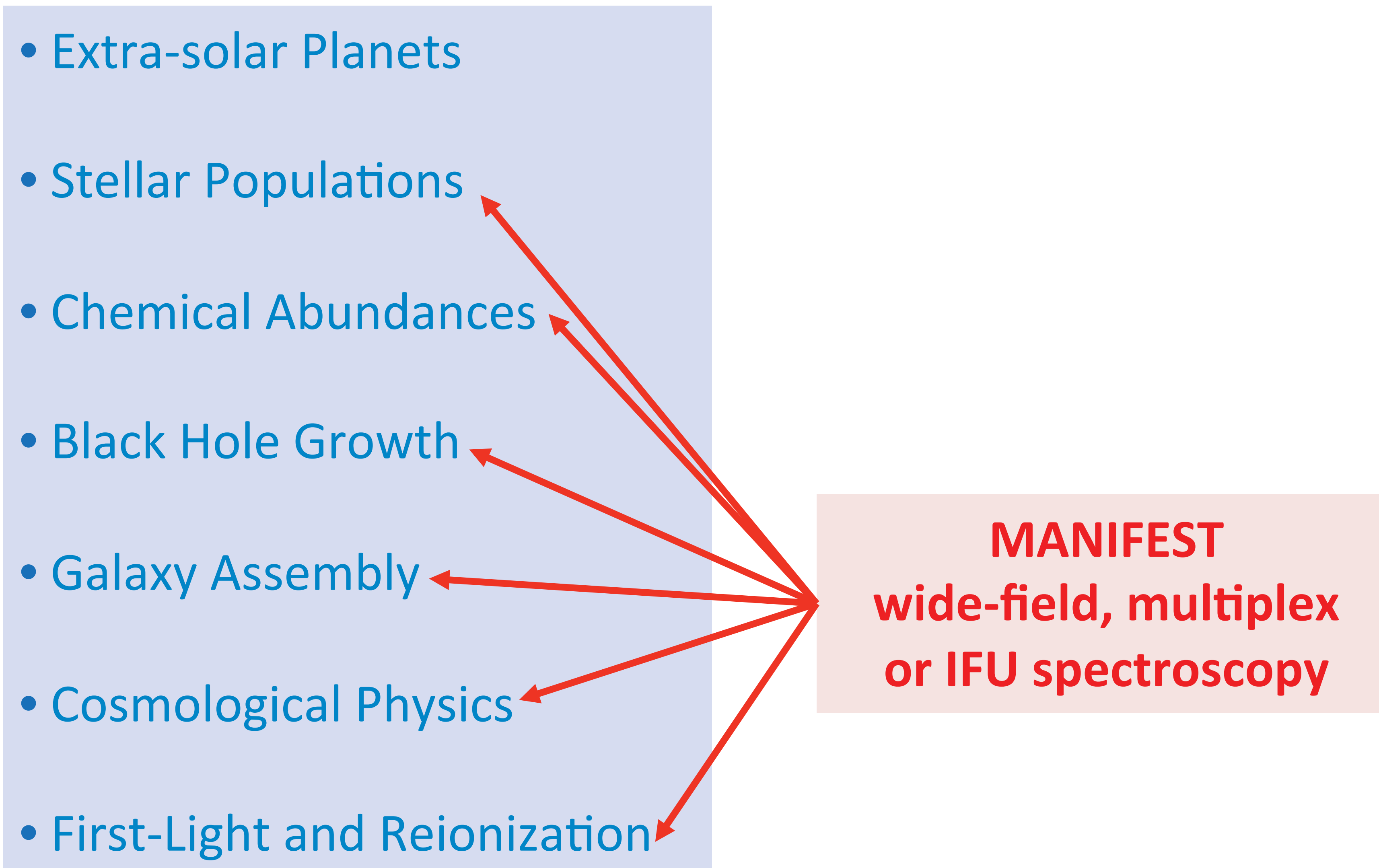
Wide fields ⇒ MOS + IFS

GMT

- MOS = Multi-Object Spectroscopy
  - Spectroscopy of many objects over a wide field of view
  - Imaging MOS images the focal plane and uses slits to isolate targets of interest
  - Fibre MOS collects light from targets of interest using optical fibres
- IFS = Integral-Field Spectroscopy
  - Spatially-resolved spectroscopy = imaging spectroscopy
  - Obtains a spectrum for each image pixel
- Multi-IFS = multi-object IFS
  - MOS with IFS of each object (likely requires MOAO)

GMT science ↔ GMT instruments

GMT



MANIFEST – origins & timeline

GMT

MANIFEST

A MANY-INSTRUMENT FIBER SYSTEM FOR GMT

Matthew Colless, AAO

GMT Instrument Workshop
14 Nov 2008

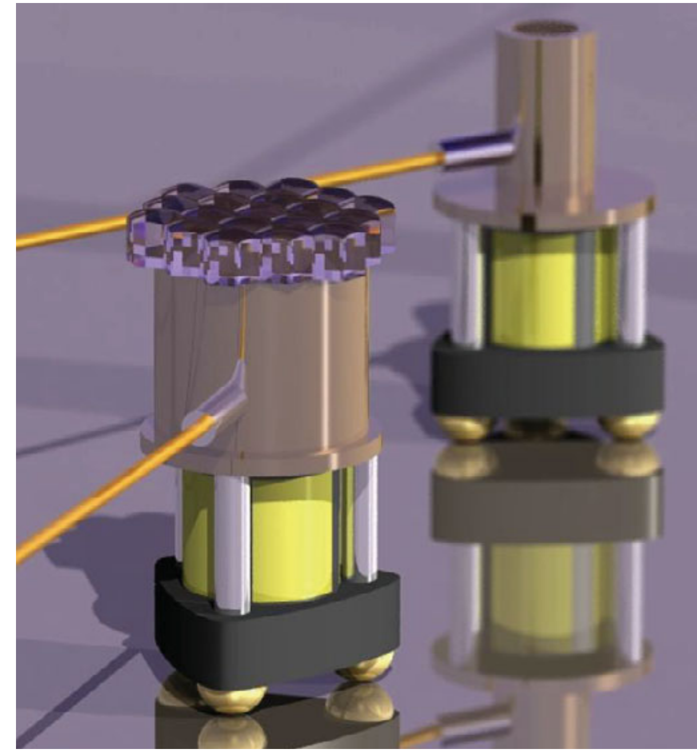
Manifesto

- GMT is the smallest ELT of those proposed (25m vs 30m vs 42m)
  - GMT=22m/25m vs TMT=30m vs E-ELT=42m
  - For Aσ or “D^4” science GMT loses by a factor of 2.5-10
- GMT has the widest field of view (20’ vs 15-20’ vs ?10’)
  - GMACS is 9’x18’=162□’ (50% of full field), NIRMOS is 5’x5’=25□’ (8%)
  - WFMOS on TMT is 4.5’x21’=92□’ (so GMACS~WFOS in terms of AΩ)
  - For AΩ science GMT wins if it uses its full 20’ field (i.e. 314□’) and TMT uses less than 14’ (160□’) and E-ELT uses less than 10’ (86□’)
- GMT should exploit its strength as the wide-field ELT by ensuring that every instrument that can benefit is able to access the full FoV <u>and</u> maximizes its potential multiplex gain
- MANIFEST: a multi-instrument fiber system for the GMT

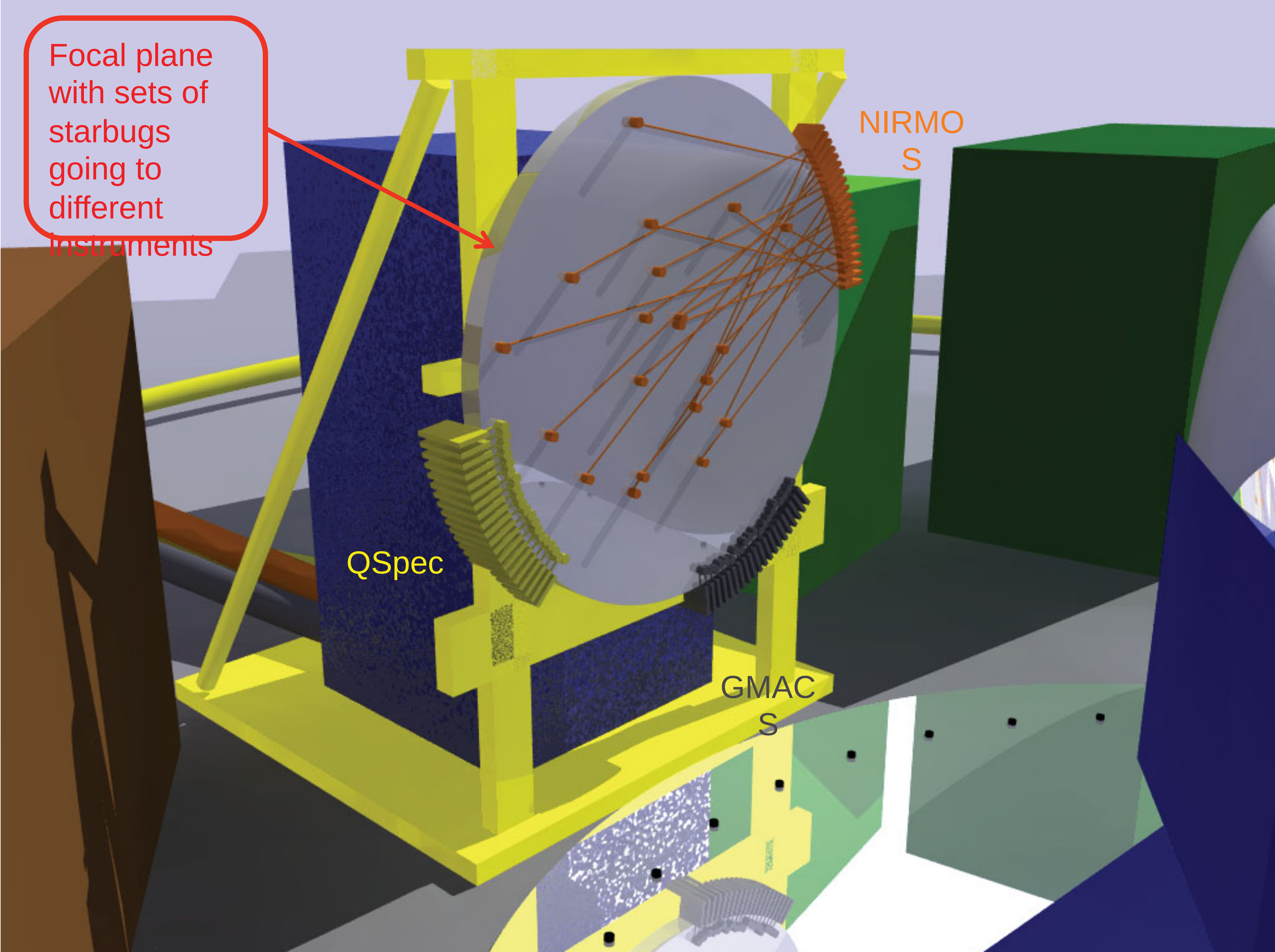
Paradigm

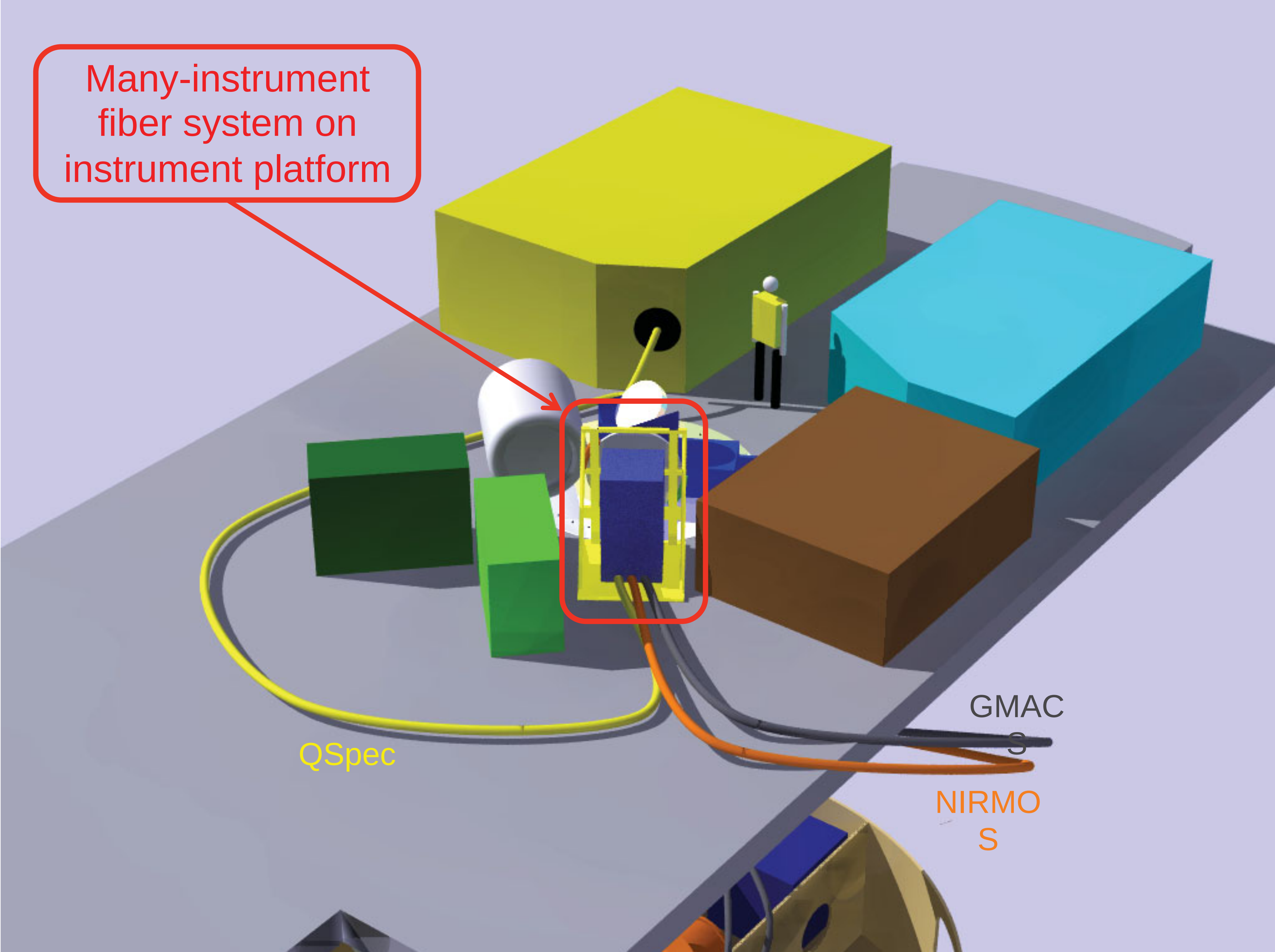
- The fundamental paradigm of this proposal is…
  - Do no harm – the system should not prevent any instrument working in its ‘native’ mode
  - Add value – the system should wherever appropriate allow instruments to access the full GMT FoV
  - Add function – the system should wherever possible provide additional functionality, over and above FoV
- This paradigm requires that the system is…
  - Switchable – can (readily) switch it into or out of operation
  - Modular – each new instrument is a (minimal) new module
  - Upgradable – offer new functionality via (minimal) upgrades
- Analogy – this system is to FoV as the AO system is to PSF

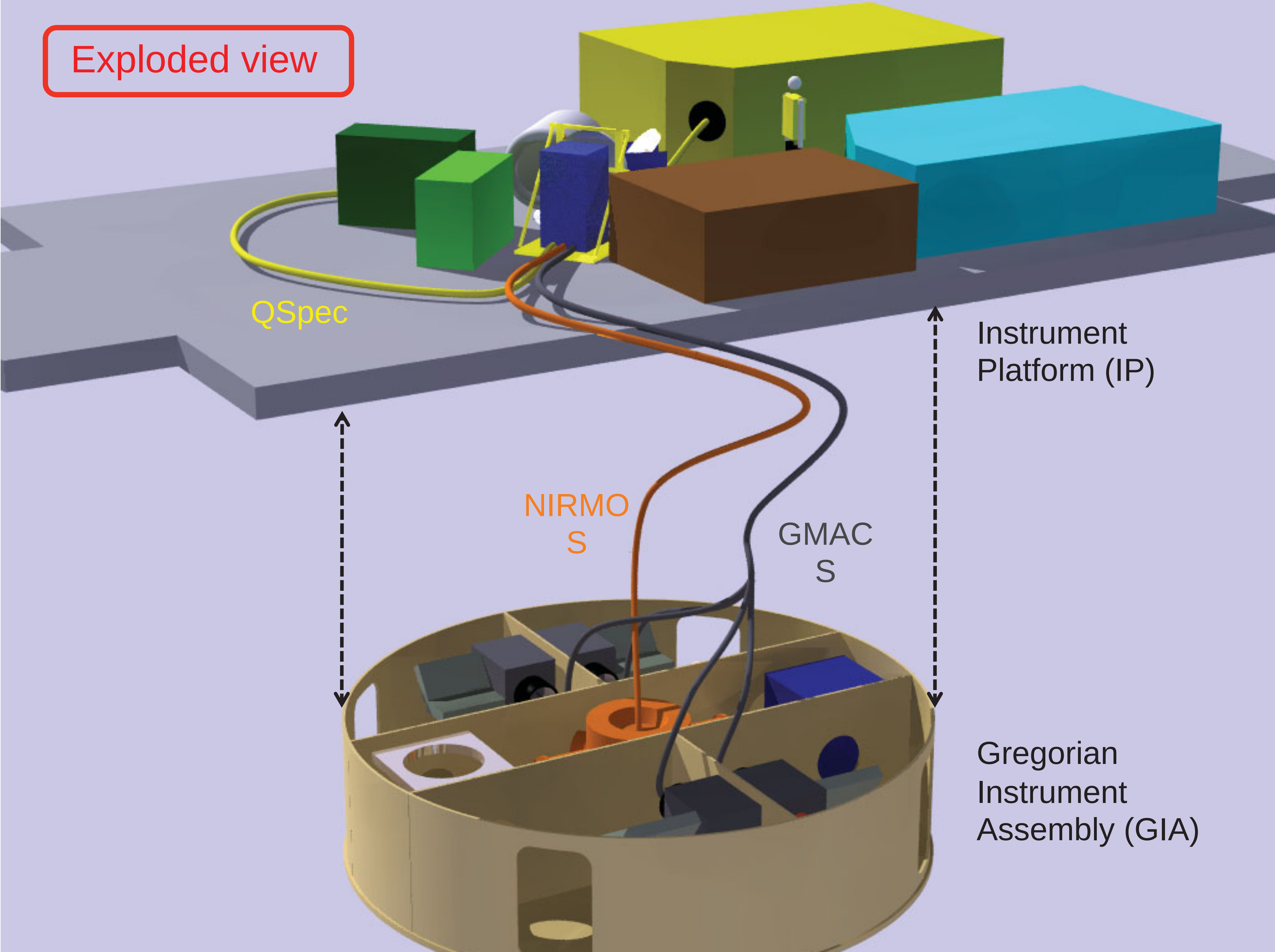
- How might this system work?
  - Flat mirror above the telescope beam focal plane to redirect beam to…
  - …a full FoV focal plane mounted on the Instrument Platform.
  - Put starbugs on focal plane to accept light over full FoV with…
  - …fore-optics on each starbug incl. ADC and f-ratio conversion



  - Fibers run from starbugs through conduits to instruments…
  - …with different sets of starbugs for different instruments, each with different types of fibers and fiber-slit mounts
  - All starbugs reside on focal plane and could be used simultaneously; manual exchange of fiber-slit mounts


Focal plane with sets of starbugs going to different instruments
NIRMOS
QSpec
GMACS


Many-instrument fiber system on instrument platform
GMAC
S
QSpec
NIRMO
S


Exploded view
QSpec
Instrument
Platform (IP)
NIRMO
S
GMAC
S
Gregorian
Instrument
Assembly (GIA)

- This concept meets the requirements of the paradigm…
  - Do no harm - the only requirement on an instrument that wants to exploit this option is that there is a way to mount a fiber slit as an alternative feed
  - Add value – any instrument accepting a fiber feed can access the full FoV and achieve a multiplex gain limited only by the number of fibers that can be accommodated on its detector
  - Add function – as well as FoV and multiplex, the fiber feed potentially allows additional functionality; for example…
    - NIRMOS: could use OH-suppression fibers to remove NIR sky lines
    - GMACS: could use hexabundle fibers as mini-IFUs
    - Qspec: could use hexabundle fibers for image-slicing
    - GLAO: small starbugs/fibers to efficiently sample full GLAO FoV

- This concept is…
  - Switchable…
    - the system can be switched in or out via a simple manual exchange of the fiber-slit mounts
    - switches between fiber feeds on different instruments can be achieved automatically by configuring different starbugs
  - Modular…
    - the system can accommodate a new instrument via a new set of starbugs & fibers with an appropriate fiber-slit mount
    - encompasses new instruments at moderate additional cost
  - Upgradable…
    - the system can be upgraded from standard single fibers to OH-suppression fibers or hexabundles
    - provides significant new functionality at moderate additional cost

Strategic advantages of this concept include…

- It enhances the scientific case for several instruments in significant ways without requiring much modification
- It can add powerful new functionality (e.g. OH-suppression and hexabundles) at modest additional cost
- It doesn't directly compete with any existing concept and extends the capabilities of several of them
- It plays to the AAO's and Australia's strengths (both technical and scientific) in wide-field spectroscopy
- It plays to GMT's strength as the wide-field ELT and opens up time-swap possibilities with other ELTs in future
- It is relatively cheap and fundamentally modular, so it can be tailored to fit the GMT instrument budget at nearly any level

MANIFEST timeline

GMT

- Feasibility Study
  - 6-month study, completed in mid-2011
- R&D Phase
  - 1-year study, completed in late 2012
- Prototyping Design Study (TAIPAN starbugs system)
  - 3-year study, commenced 2013, system running in lab by 2016
  - Commissioning on sky expected to be completed by May 2018
- Pre-Concept Study
  - 18-month study, just commencing (far less developed than GMTIFS)
- Further Phases
  - Conceptual Design, Preliminary Design, Final Design, AIT, Commissioning (details of these phases to be determined during Pre-Concept Study)
  - Aiming to have MANIFEST available in 2024, shortly after GMT first light

TAIPAN – a MANIFEST prototype

GMT

Prototyping Design Study ➡ TAIPAN

GMT

TAIPAN is a fibre spectroscopy facility for UK Schmidt Telescope

- ❑ Positioner (= MANIFEST prototype design study)
  - All 150 starbugs, the positioner assembly, metrology and A&G systems are installed in UKST and being commissioned; software effort ongoing
- ❑ Spectrograph and fibre cable
  - Spectrograph and fibre cable have been installed, aligned, and tested
  - Commissioning under way
- ❑ UK Schmidt Telescope (UKST) refurbishment
  - All major works on drives and control system complete
- ❑ TAIPAN commissioning
  - Full system testing now under way
  - Commissioning to be completed by May 2018
  - Science Verification observations to follow

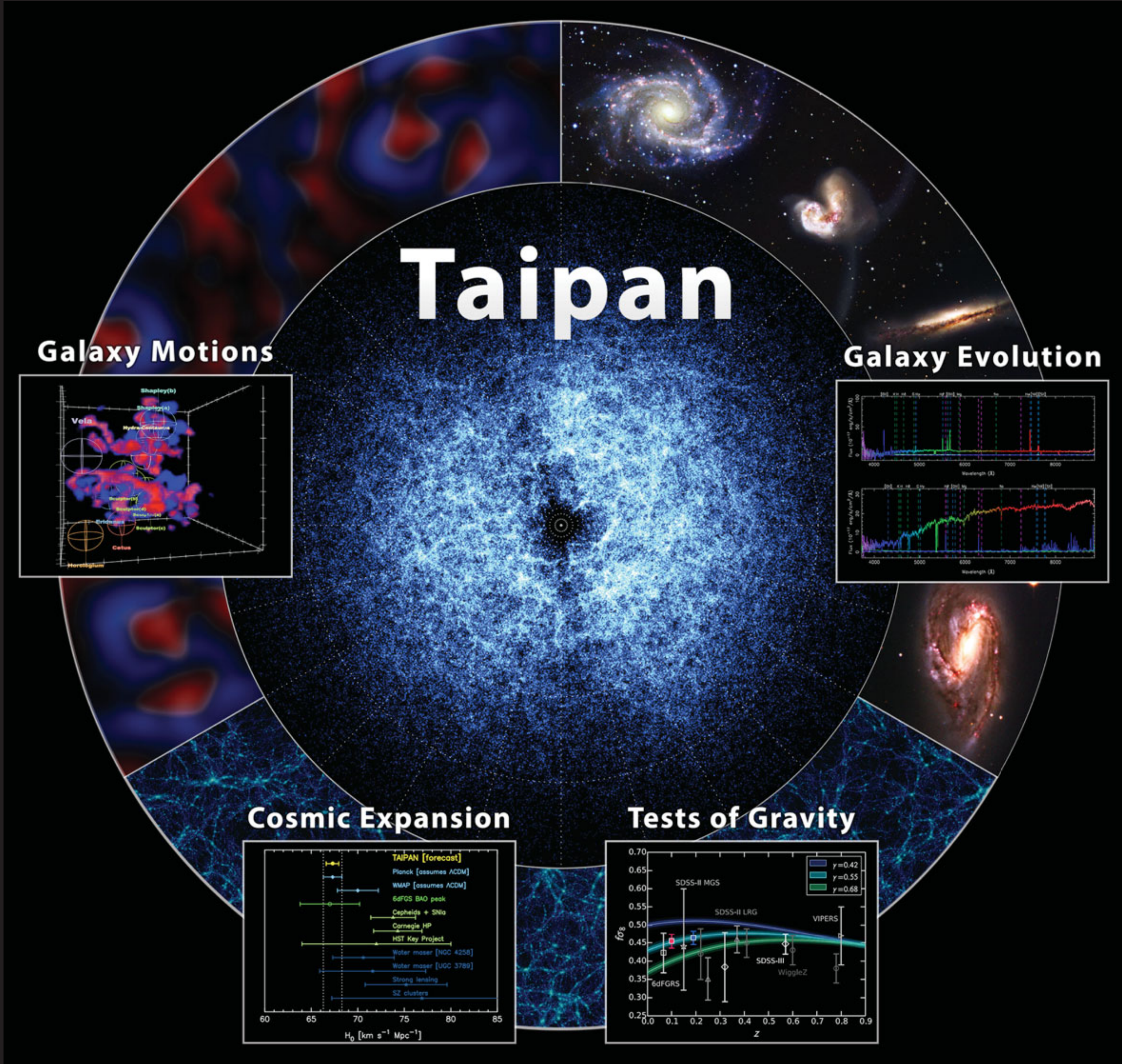
TAIPAN objectives

GMT

- **Taipan galaxy survey**
  - $1.2\text{x}10^6$ $i < 17$ galaxies + $0.8\text{x}10^6$ $i < 18$ LRGs over 20,000 deg^2 ($\delta<10^{o},b<|10^{o}|$)
  - Science: cosmology and galaxy evolution; reference survey for local galaxies
- **FunnelWeb stellar survey**
  - $3\text{x}10^6$ of southern stars (99%) in range $5<V<11$ at S/N=100
  - Science: TESS target pre-selection and stellar physics legacy
- **Working prototype for MANIFEST**
  - Demonstrate the feasibility of the starbugs technology for fibre positioning, reducing risk and cost to the MANIFEST instrument on GMT

Instrument Capabilities

- Field of view: = 6° diameter
- Multiplex = 150 objects (phase 1), 300 objects (phase 2)
- Field reconfiguration = < 5 mins (req), <2 mins (goal)
- Spatial sampling = 3.3″ fibre diameter
- Resolution = blue arm: 1960 (65 km/s); red arm: 2740 (46 km/s)
- Simultaneous wavelength coverage = 370 – 870 nm


Taipan
Galaxy Motions
Galaxy Evolution
Cosmic Expansion
Tests of Gravity
Shapley(b)
Vela
Cetus
TAIPAN [forecast]
Planck [assumes ΛCDM]
WMAP [assumes ΛCDM]
6dFGS BAO peak
Cepheids + SNIa
Carnegie HP
HST Key Project
Water maser [NGC 4258]
Water maser [UGC 3789]
Strong lensing
SZ clusters
60
65
70
75
80
85
H0 [km s−1 Mpc−1]
γ=0.42
γ=0.55
γ=0.68
SDSS-II MGS
SDSS-II LRG
VIPERS
SDSS-III
WiggleZ
6dFGRS
fσ8
z
0.70
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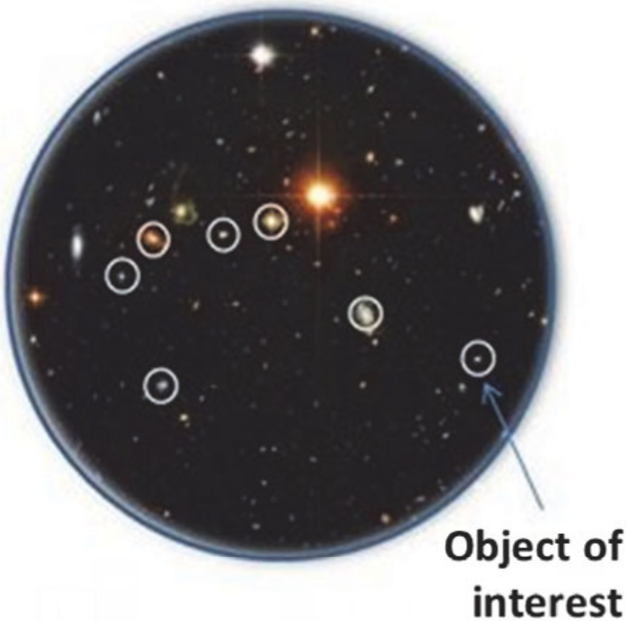
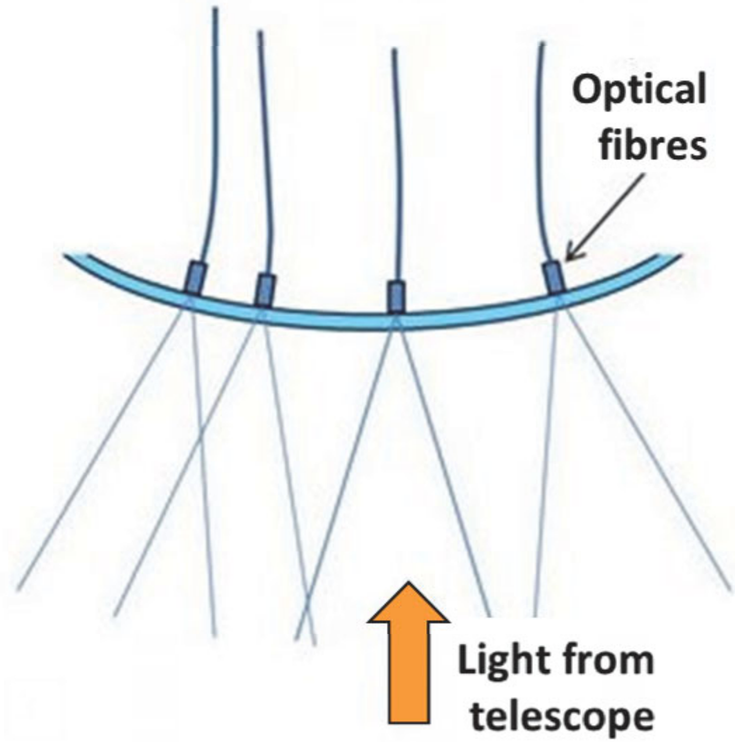
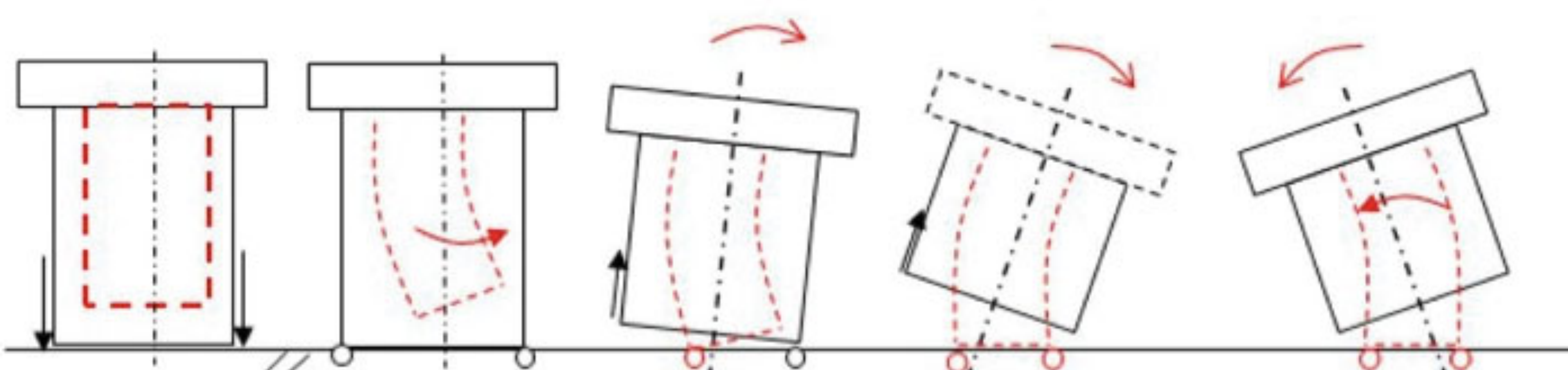
Starbug concept

GMT

Telescope ‘focal plane’:

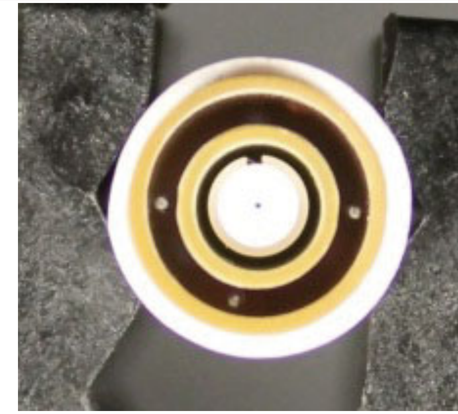


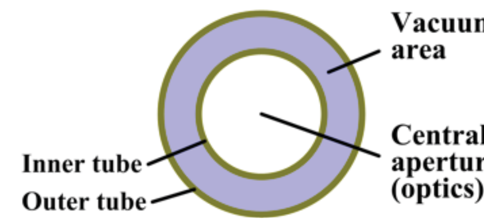


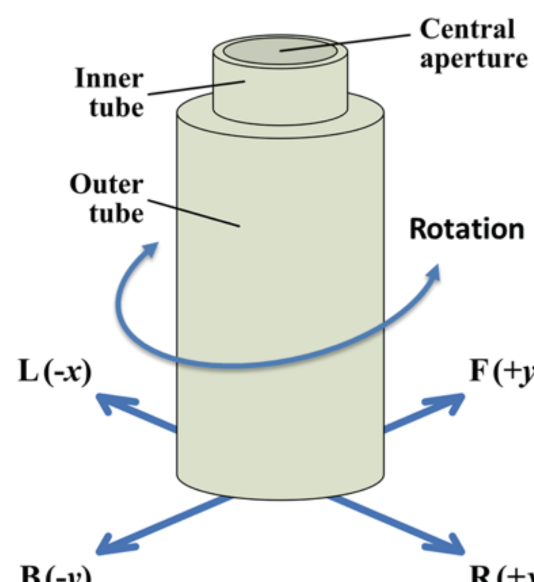


Starbug implementation

- Starbugs consist of co-axial piezoelectric tubes
- Optical payload installed at centre of inner tube
- Metrology fibres are mounted between the two tubes with LEDs mounted on each bug
- Vacuum is applied between tubes
- All services (vacuum, fibre, HV, LV) run through a single connector for each starbug
- Services distributed at connector plate

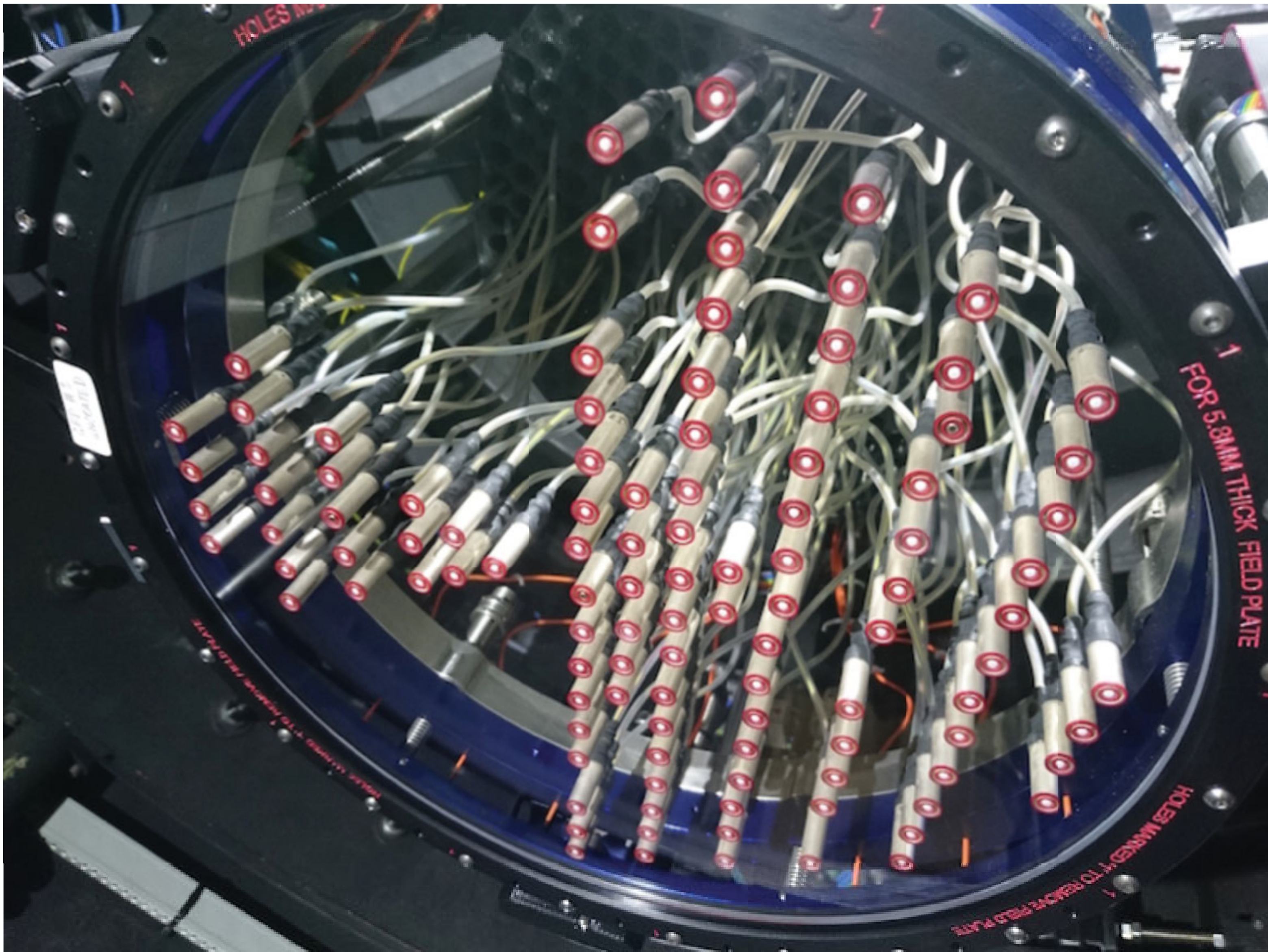






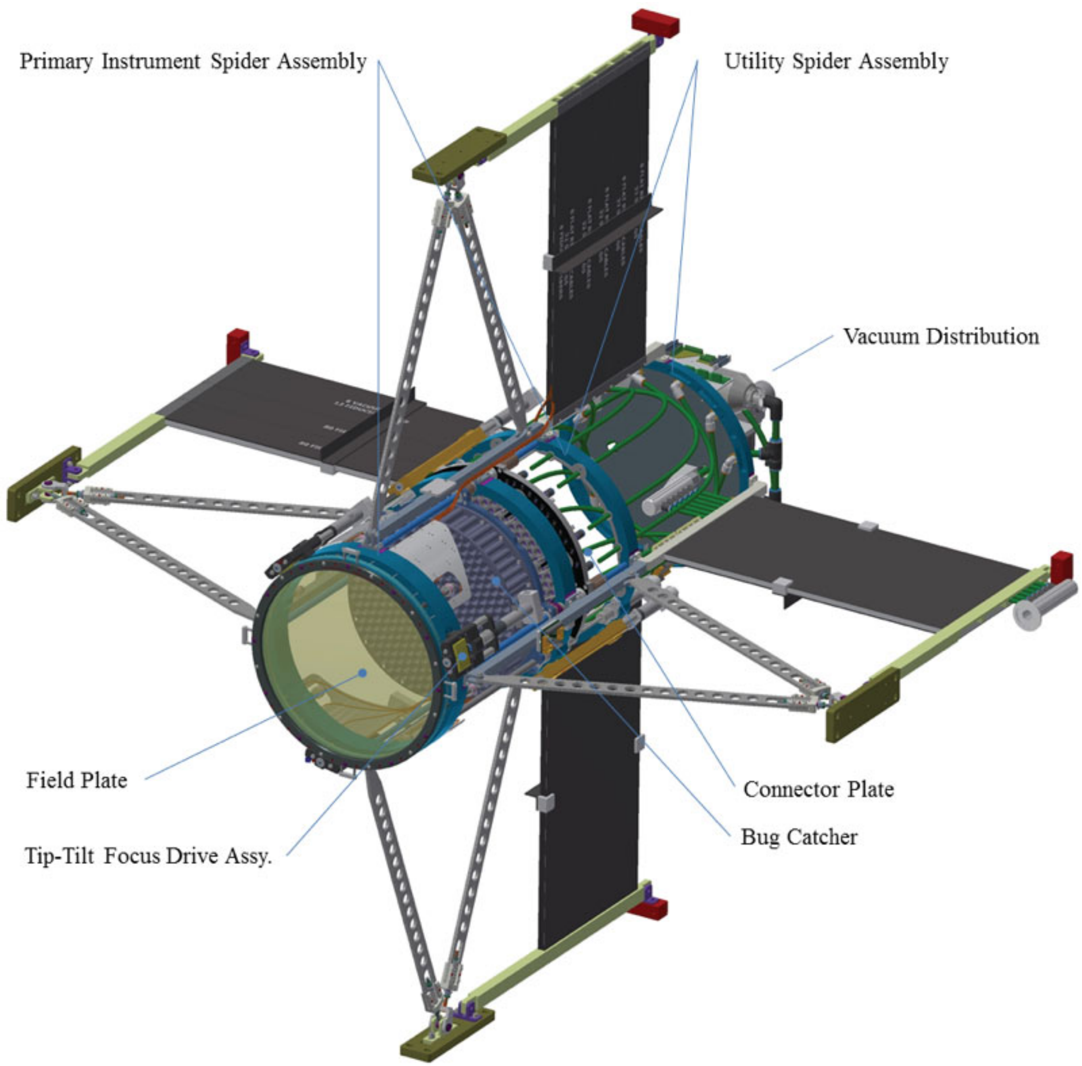
Starbugs – the movie

GMT

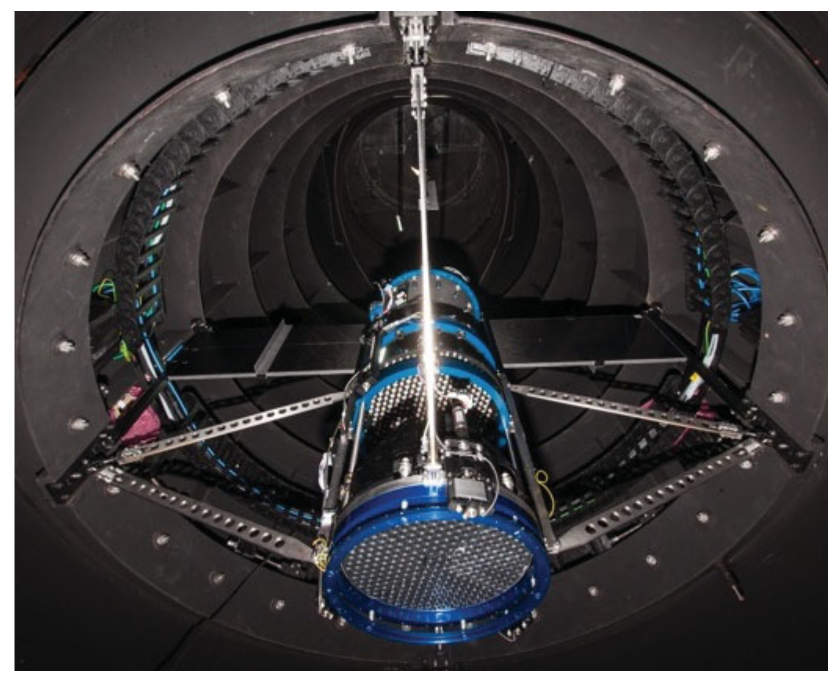


TAIPAN positioner assembly

GMT

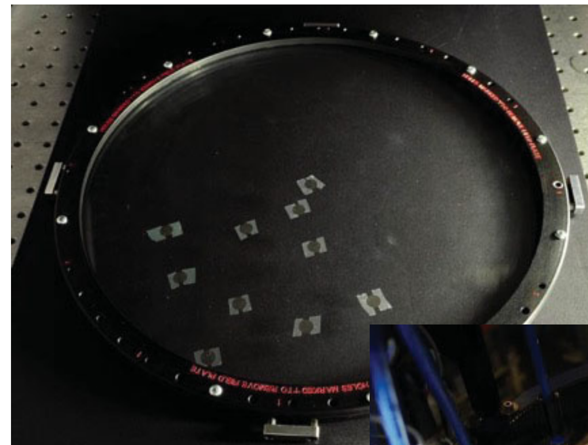
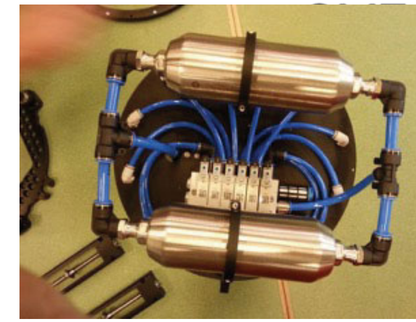
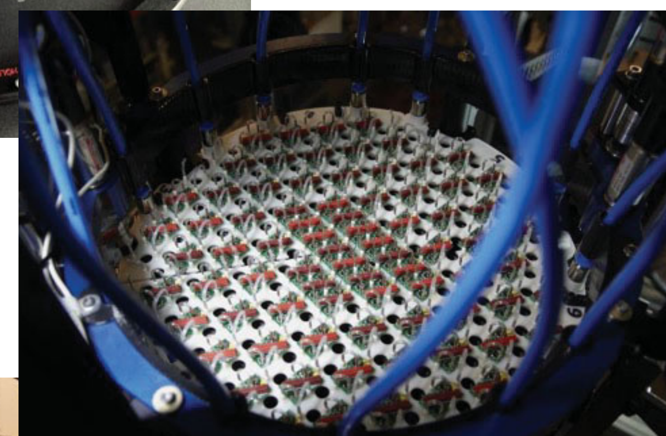
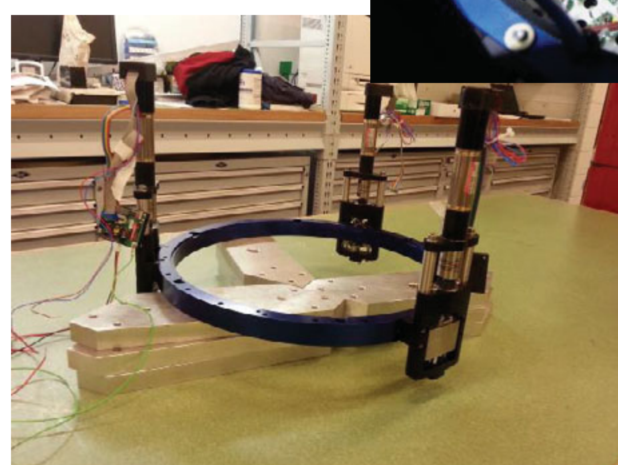
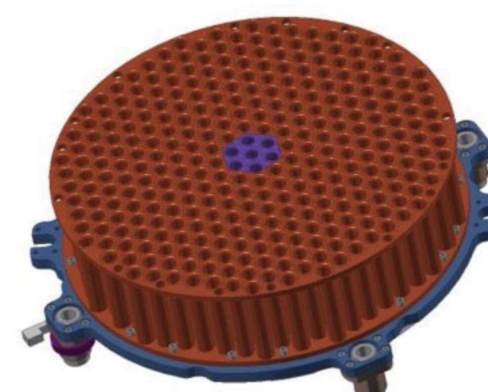


- Instrument assembly: supports glass field plate (GFP) and GFP drive, bug catcher, connector plate and vacuum manifold
- Spider assembly: mounts instrument at UKST focal plane and routes fibres & wiring



TAIPAN instrument assembly

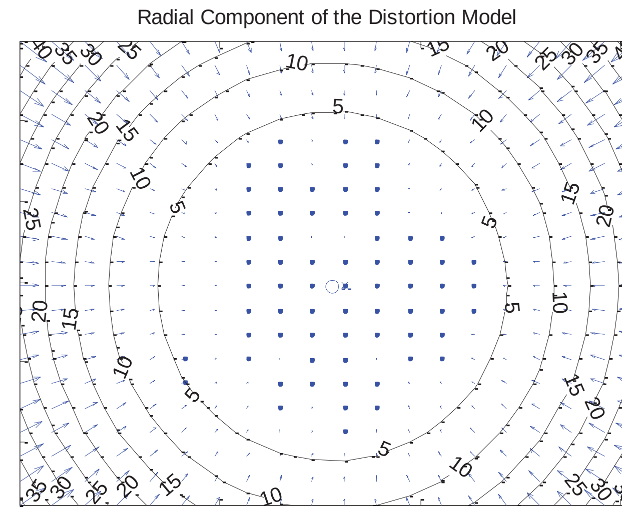
- Glass field plate (GFP) is 5 mm thick, 350 mm diameter, 3000 mm ROC N-BK7 meniscus
- Mounted with 3 linear actuators (±5mm) for GFP tip/tilt/focus
- Assembly has connector plate to distribute starbug services
- ‘Bug-catcher’ used to attach and remove starbugs from plate
- Vacuum manifold has on-telescope reservoir and off-telescope receiver tank

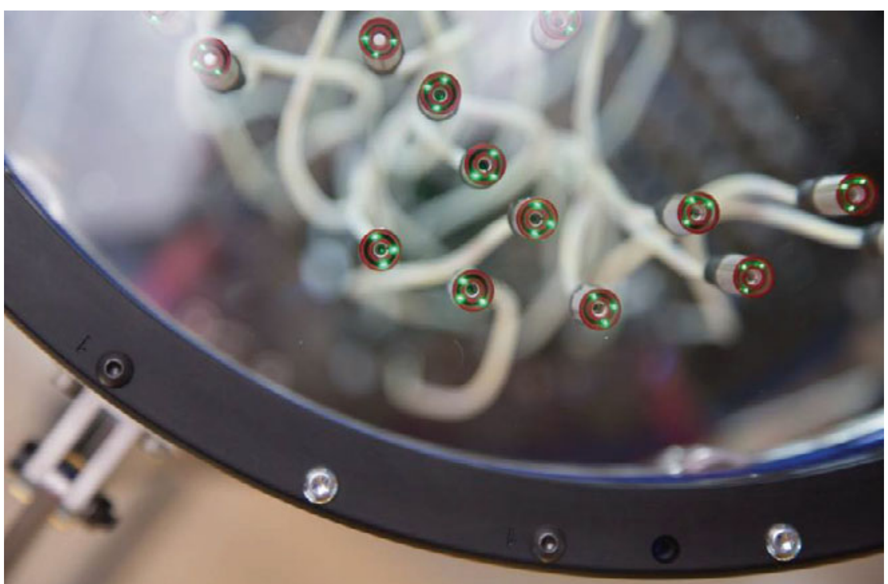






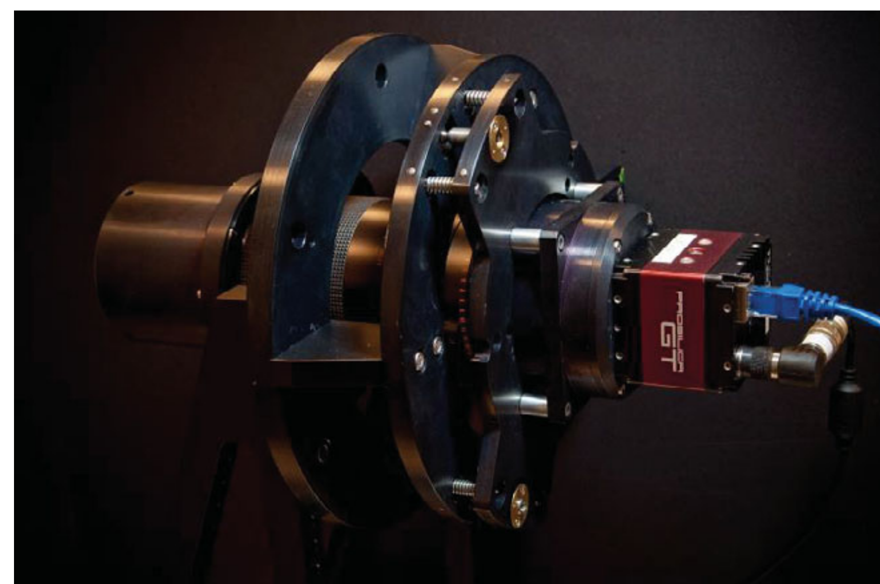
TAIPAN metrology system

GMT

- CCD: Prosilica GT6600 (6.5x4.4k array)
- Lens: 250mm f/4 Tele-Tessar + focal corrector lens
- High precision dot array used for distortion map
- Precisions requirement is 1/20th pixel, giving 5 μm location for closed loop (fibres have 50 μm core)
- Fiducials mounted around field plate exterior



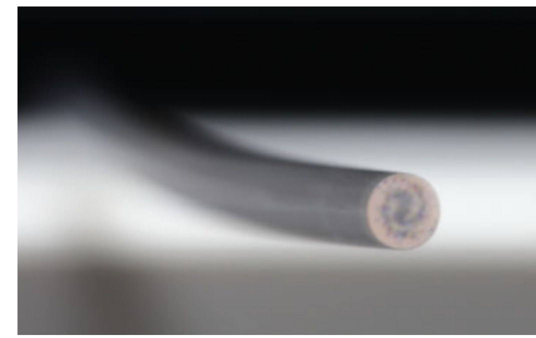


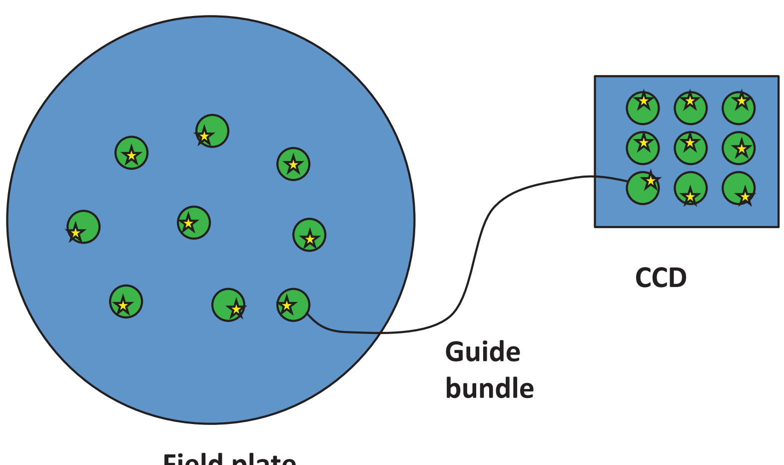


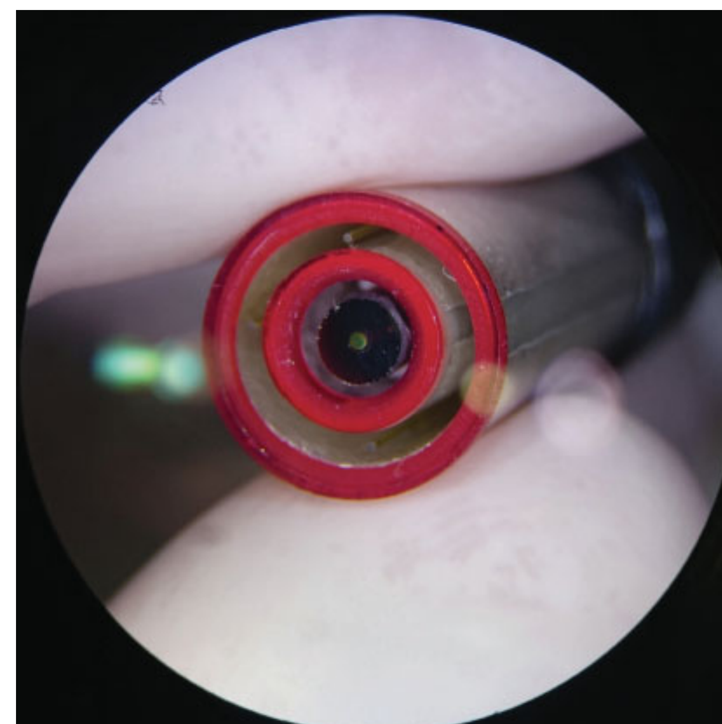
TAIPAN guide bundles

GMT

- Total of 9 coherent polymer guide bundles (7000 cores, 1.5mm diameter) are distributed in Starbugs across the field
- Back-end is reimaged onto CCD
- System provides multiple functions:
  - Field acquisition
  - Telescope guiding
  - On-sky reference frame
  - Focal plane imager
  - Field plate tip/tilt/focus measurement
  - Seeing/image-quality/extinction monitor



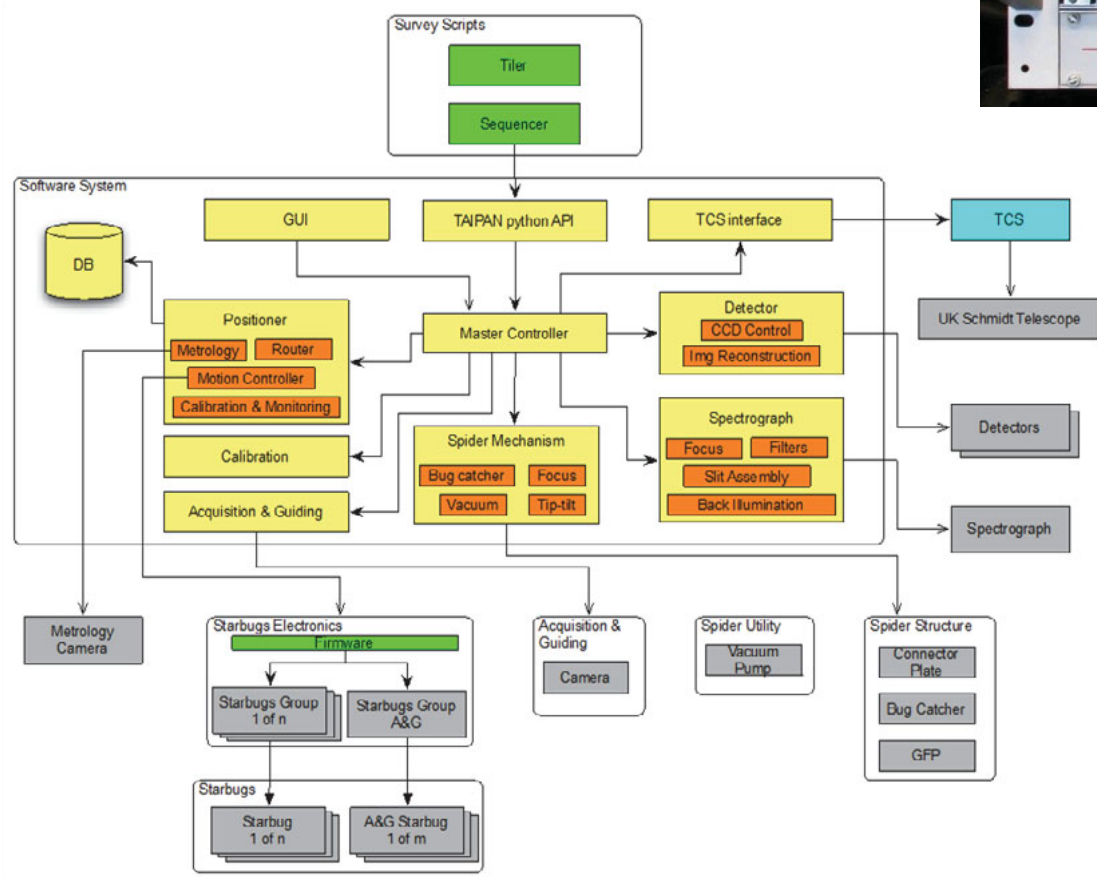




TAIPAN electronics & software

GMT

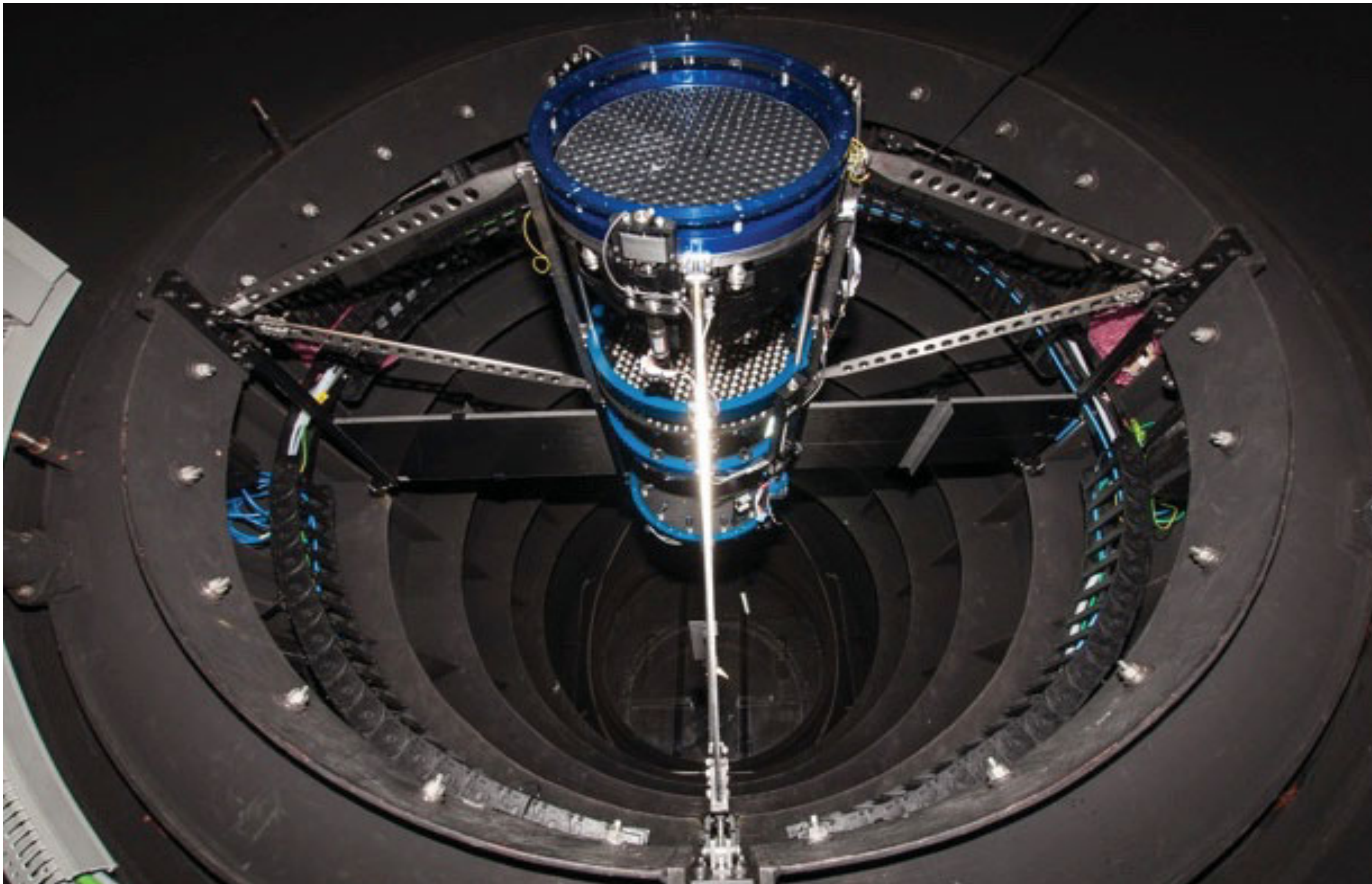
- 80 starbugs per chassis (power supply, HV DC, network/waveform, power amplifier & relay switching)



- Blocks use ARM 32-bit processors with CAN bus communications
- Separate modules for positioner, spider mechanism, detector, spectrograph, A&G, calibration & TCS under a master controller
- Written in C++, using AAO's DRAMA for middleware layer, MongoDB for database

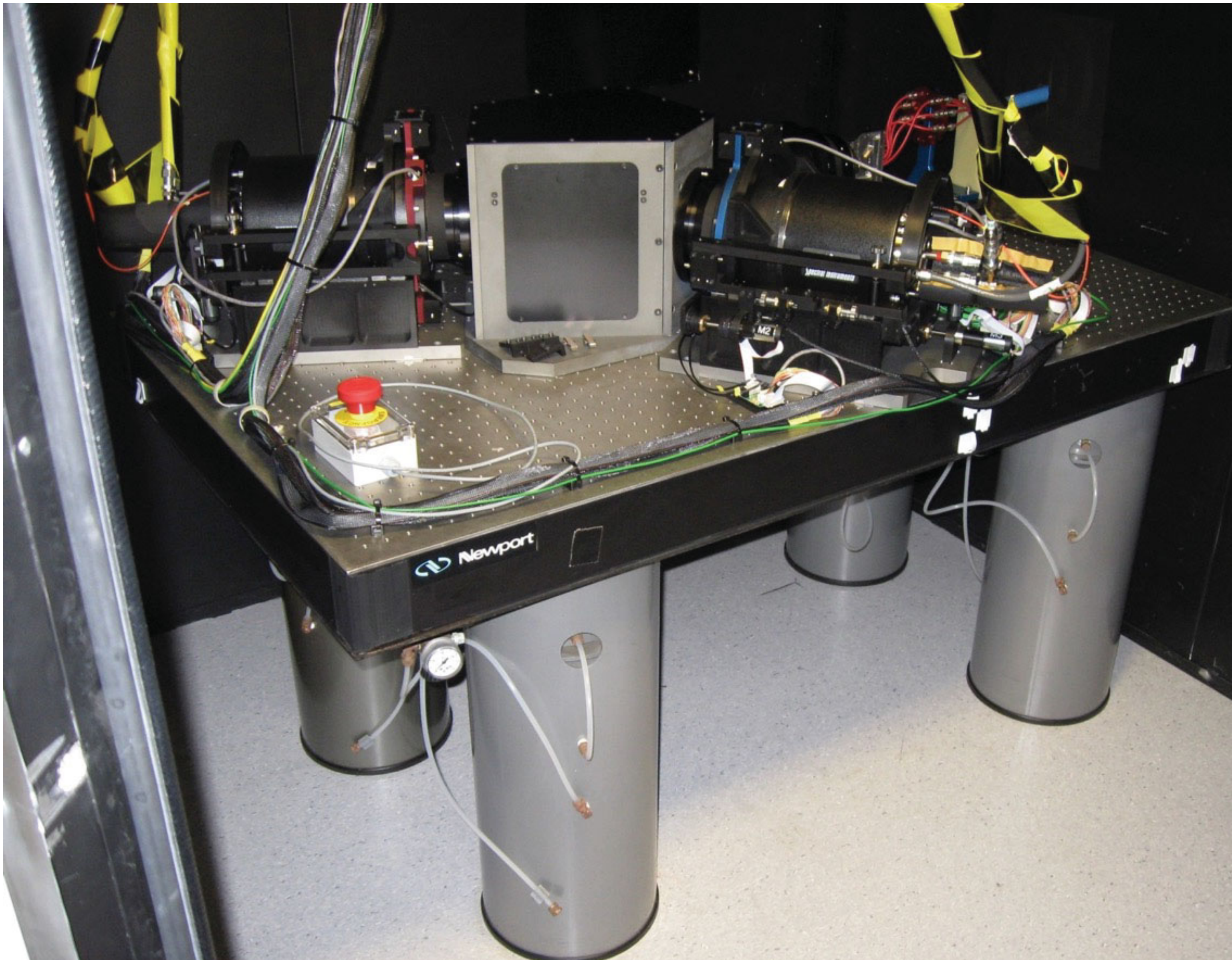
TAIPAN on the UKST

GMT



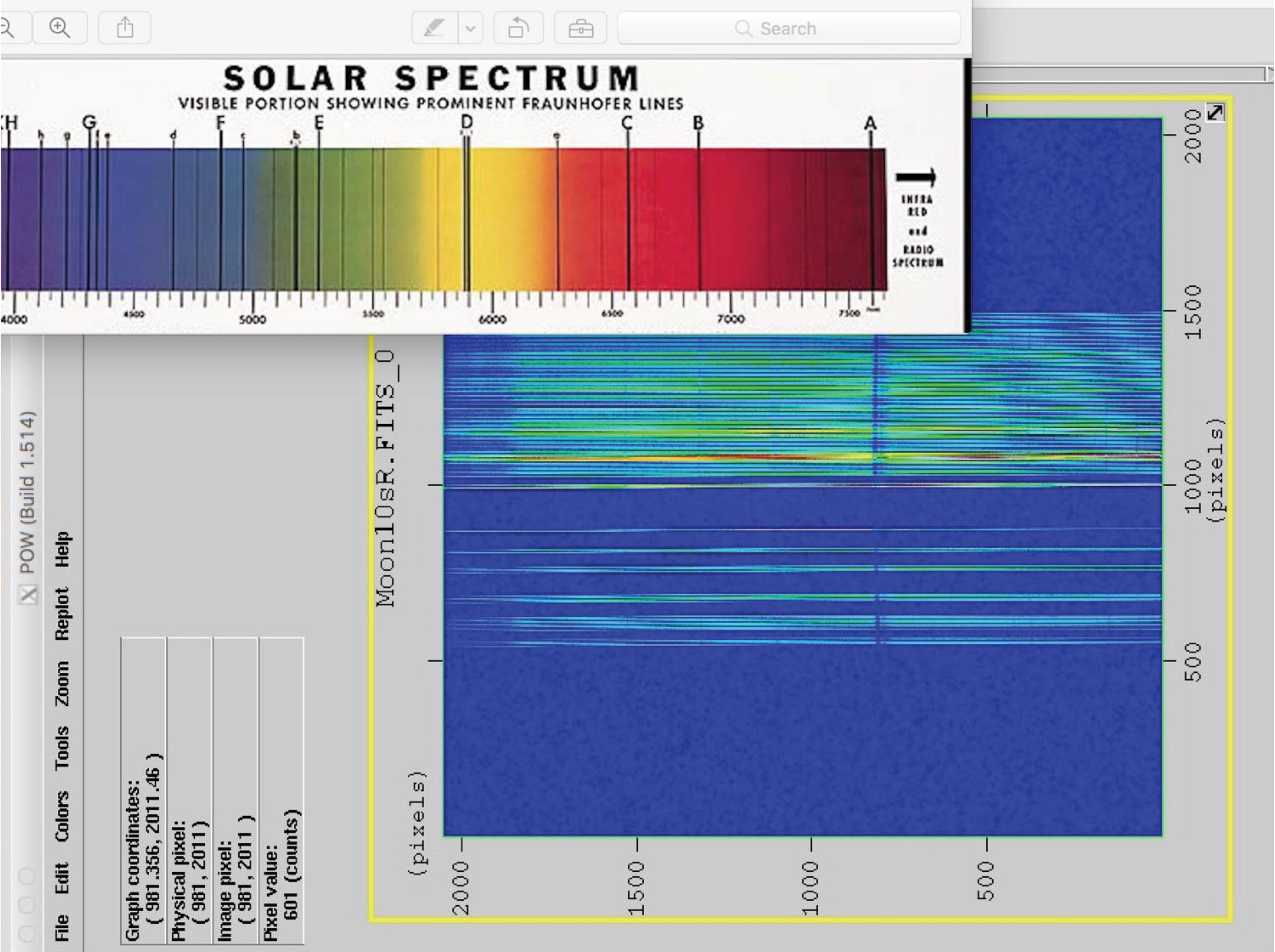
TAIPAN spectrograph

GMT



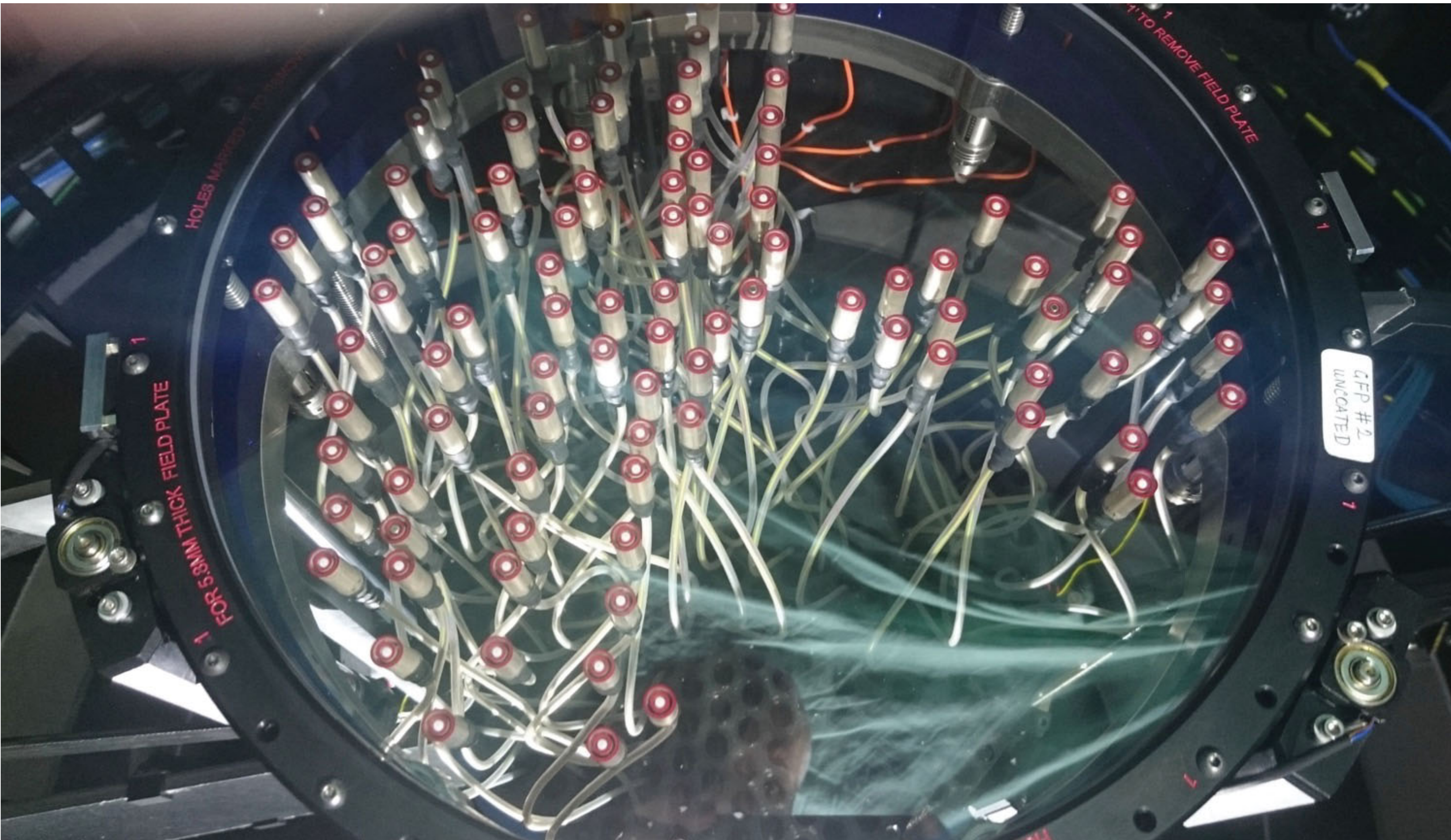
TAIPAN opening

GMT


Search
SOLAR SPECTRUM
VISIBLE PORTION SHOWING PROMINENT FRAUNHOFER LINES
H G F E D C B A
4000 4500 5000 5500 6000 6500 7000 7500
INFRA RED and RADIO SPECTRUM
POW (Build 1.514)
File Edit Colors Tools Zoom Replot Help
Graph coordinates: (981.356, 2011.46)
Physical pixel: (981, 2011)
Image pixel: (981, 2011)
Pixel value: 601 (counts)
Moon10sR.FITS_0
(pixels)
2000 1500 1000 500
(pixels)
2000 1500 1000 500

TAIPAN ➡ MANIFEST

GMT



TAIPAN ➡ MANIFEST

GMT

Changes & challenges going from TAIPAN to MANIFEST

- ❑ Starbug inverted operation
  - ▶ Adhesion + motion *against* gravity (starbug safety)
  - ▶ Atmospheric pressure at GMT vs UKST
  - ▶ Test setup under development at AAO
- ❑ Off-axis metrology
  - ▶ S/W to be adapted
  - ▶ Camera placement study underway
    - ▹ GMT optical elements in the way?

MANIFEST – science & modes

GMT

GMT+MANIFEST = full-field MOS/IFS

GMT

- MANIFEST is a versatile fibre positioner and feed for *all* of GMT's natural-seeing or GLAO spectrographs, offering…

  ① increased fields of view for all instruments

  ② multiple deployable IFUs in a variety of sizes

  ③ increased spectral resolution (factor 3-8) via image-slicing

  ④ efficient detector packing, both spectrally and spatially

  ⑤ feed narrow spectrograph field from fibres with wide FOV

  ⑥ simultaneous observations with multiple instruments

  ⑦ feed spectrographs at gravity-invariant locations

  ⑧ OH sky-line suppression in the near-infrared

MANIFEST motivations

GMT

Field of View

- WFC provides access to full field of (20 arcmin); important for low to moderate density sources and for science cases that need to cover large areas/volumes

Multiplex

- More efficient detector packing increases multiplex gain (x2 GMACS, x4-40 GCLEF)

Spectral resolution and wavelength coverage

- Image slicing an oversampled detector, so no detector noise penalty from higher spectral resolution (x2-3 for GMACS); or can use for greater wavelength coverage

Simultaneous Observations

- GMACS and G-CLEF can operate simultaneously (if they have targets in same field)

Efficiency

- Throughput reduced when fibres are added, but compensated by increased efficiency of spectrograph and small IFUs capturing all of target's light
- For many science cases, multiplex or field of view is just as (or more) important

Sky subtraction

- For very long duration exposures, using PCA sky subtraction achieves a precision close to the Poisson limit down to ~0.3% of sky [Sharp 2010].
- Depends on number of sky fibres, nod and shuffle mode, source brightness, etc.

Science gains & opportunities

GMT

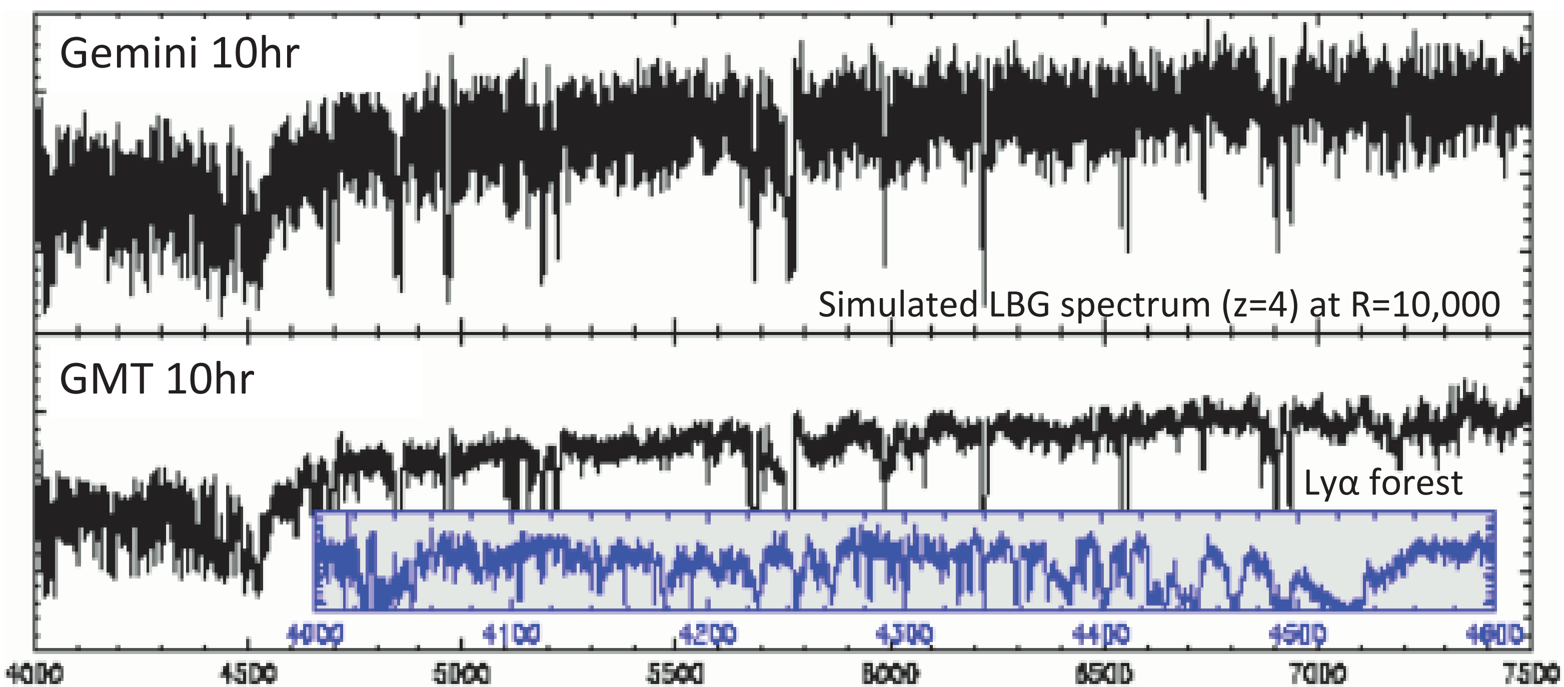
- What science can *only* be done (or done *better*) with MANIFEST?
  - First light/epoch of reionization
  - Redshift surveys (esp. calibrating photometric redshifts)
  - Dwarf galaxy dynamics (near-field cosmology)
- Wide field (etendue = 2-3 x TMT/ELT) + multiplex advantages
  - Transients
  - Redshift surveys
  - Extended targets
- Can offer IFUs with different N_{fibres} depending on science case (e.g. 250 @ 7 fibres, 95 @ 19 fibres or 60 @ 61 fibres)
- Simultaneous operation of GMACS + GCLEF
- Doesn't preclude future GMT instruments (NIRMOS, GMT-MOS)

MANIFEST + GMACS science

GMT

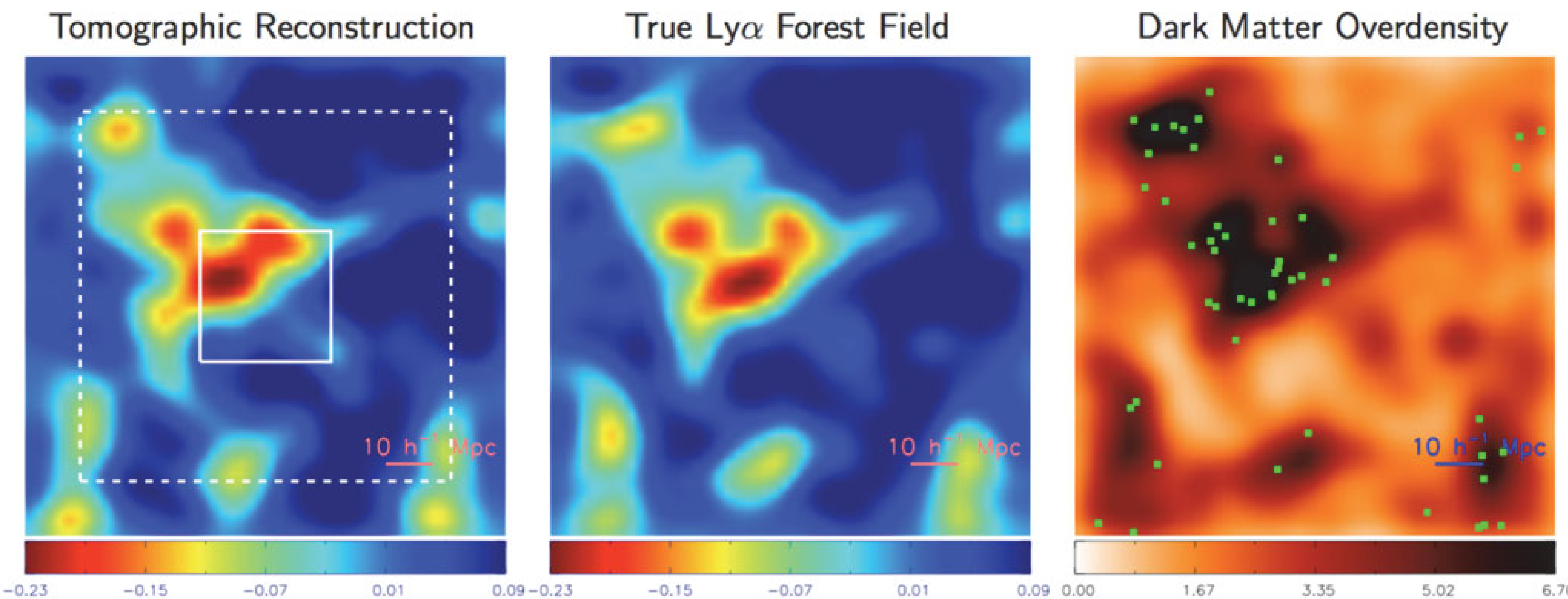
Intergalactic medium tomography using Lyman break galaxies

- Aim to reconstruct the 3D small-scale structure of the intergalactic medium (IGM) at high redshifts by very densely sampling the Lyα forest over large areas of sky
- GMT can see Lyα forest in faint (⇒ dense) LBG samples at $2<z<3.5$ (0.36-0.56μm)
- Relative to GMACS with standard grating, MANIFEST doubles the number of objects and the resolution (giving sub-Mpc sampling of IGM along line of sight)



Lyman-α tomography simulation

GMT



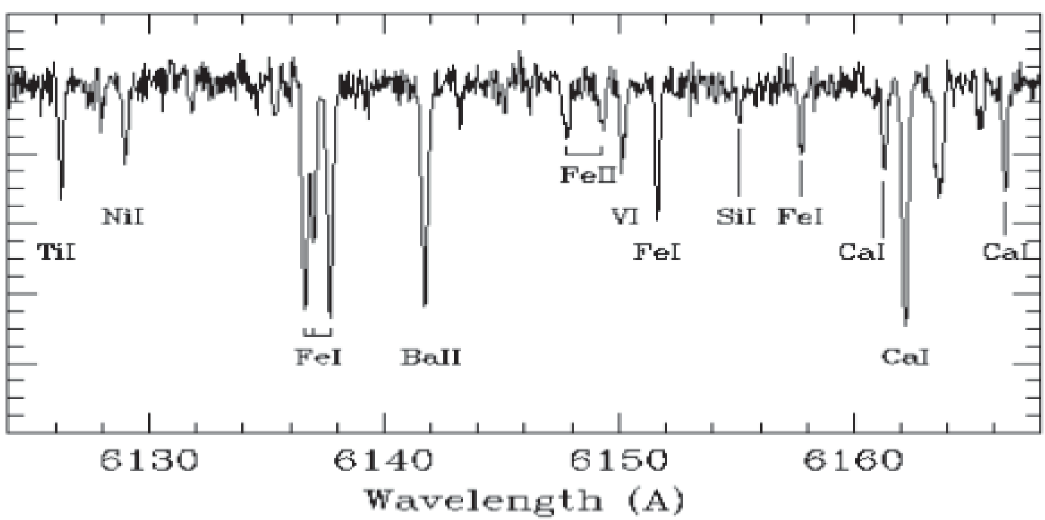
Left: Tomographic reconstruction from simulated Lyα forest absorption sightlines of sources down to m_{AB} = 24.5, with spectral S/N assuming Reddy et al. (2008) LBG luminosity function. **Center:** True underlying 3D Lyα absorption field. **Right:** Underlying dark-matter overdensity. The center and right panels are smoothed with 3.5 h^{-1} Mpc Gaussian to match reconstructed map. These sightlines have dimensions 2 x 2 x 100 h^{-1} Mpc. Green dots on the DM field show R ≤ 25.5 galaxies coeval with the Lyα forest, obtained from halo abundance matching; dashed rectangle on the left panel shows an area of 1 deg^2. *[TMT science case 2015; image adapted from Leed et al. 2014]*

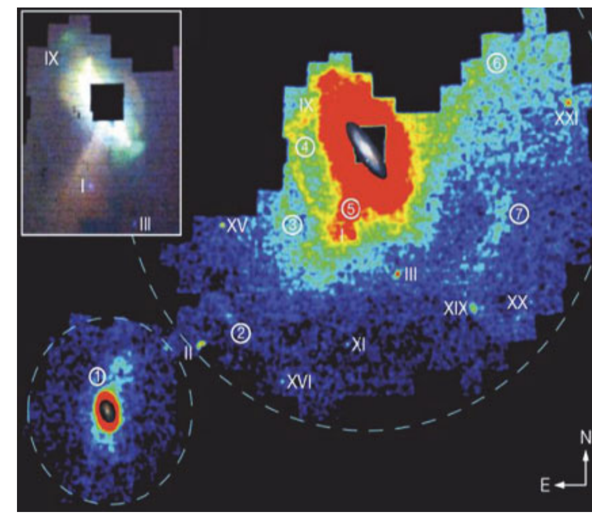
MANIFEST + G-CLEF science

GMT

Stellar chemical abundances in Local Group galaxies

- ❑ Use chemical abundances to trace the formation history of the Milky Way and nearby Local Group galaxies (LMC, SMC and 40 dwarfs within ~1 Mpc)
- ❑ A survey of 2000 stellar spectra at S/N~30, sampling ~100 RGB stars in each of 20 LG galaxies, would take ~30 nights





RGB stars around M31 from PAndAS

Archaeology of the outer Milky Way disk via chemical tagging

- ❑ Faint extension of GALAH survey that is getting detailed abundances for 10^6 bright stars to chemically tag coeval stellar associations in the inner disk/bulge
- ❑ GMT can extend this program to the outer disk and even the inner halo

MANIFEST – basic requirements

GMT

- Number of starbugs: at least 500
- Number of starbugs for A&G: 25
- Number of fibres in starbugs: 1, 7, 19, 61 (+ 2100 in fixed IFU)
- Throughput for given exposure time (incl. FRD): 15-30%
- Wavelength coverage/resolution: matching instruments
- Image slicing available if desired
- FoV (instrument): 20 arcmin given WFC (10 arcmin otherwise)
- FoV (fibre/IFU): 3 arcsec for single fibre, various for IFUs
- Positioning accuracy: <0.3 arcsec
- Starbug (re)configuration time: <5 minutes (goal: 2 minutes)
- Starbug lifetime (for maintenance/replacement): 5 years

MANIFEST science & technical reqs

GMT

GMACS
Mode a = visible, single fibers or IFU bundles, low resolution spectroscopy

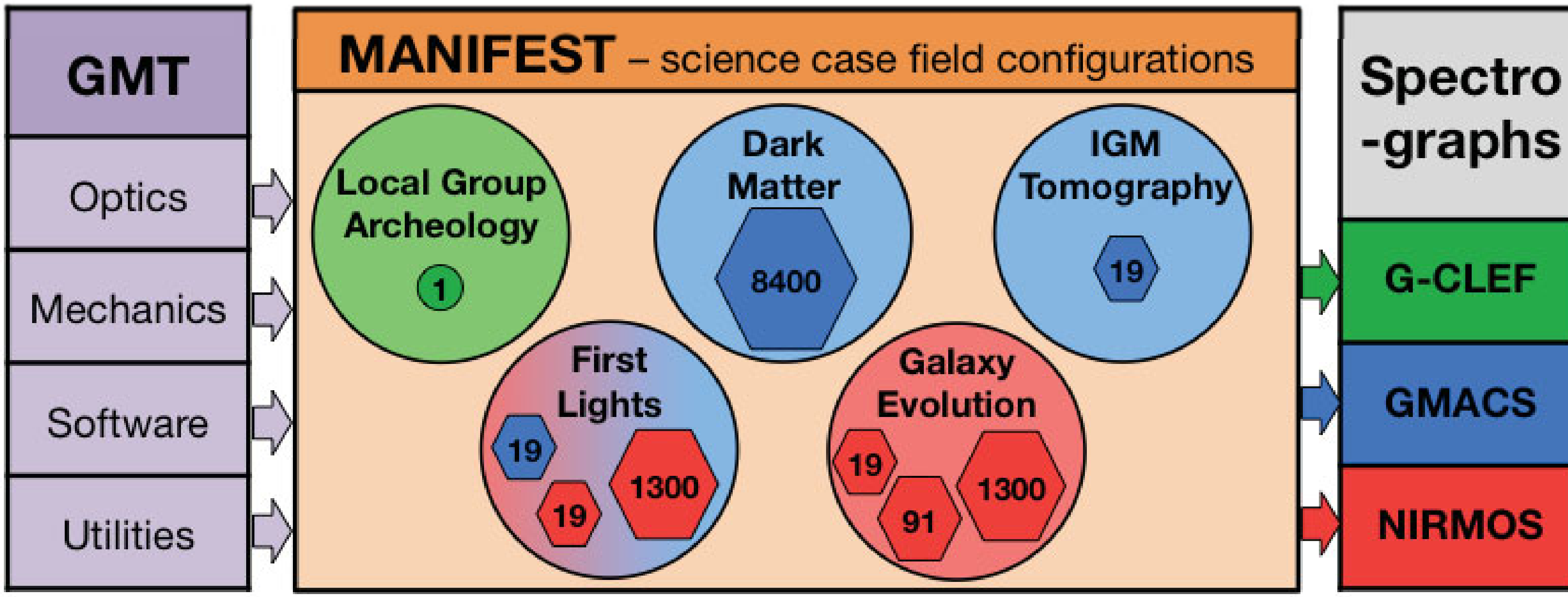
NIRMOS
Mode b = NIR, single fibers, low resolution spectroscopy

G-CLEF
Mode c = visible, single fibers, high-resolution spectroscopy

Science Application	λ range	λ/Δλ	Mode	Notes
Star formation and chemical evolution in galaxies	400-1000 μm	~2000	a, b	Abundances, stellar populations and ages, star formation rates
Massive galaxy assembly	500-1000 μm	~3000	b	Stellar ages, stellar populations, velocity dispersions, rotation curves
Chemical tagging of Milky Way structures	320-1000 μm	~50000	c	Abundance and kinematic studies of tidal streams
Dark matter distributions	400-800 μm	~5000	a	Dynamics of clusters, planetary nebulae, resolved stellar populations
Evolution of galaxy clustering	400-900 μm	~2000	a	Large-scale galaxy surveys
Tomography of the IGM	400-900 μm	~2000 & ~10000	a, c	Galaxy surveys and IGM tomography with faint background sources
Technical Parameter	**Requirement**	**Goal**	**Notes**	
Wavelength range	400-900 nm	320-1100 nm 1-1.6 μm	Two sets of fibers may be needed to address visible and near-IR	
Patrol field	20' diameter	–	Should reach full extent of corrected field	
Positioning accuracy	0.1" RMS	–		
Setup time	≤ 8 min	–	Should not add more than 25% overhead to observation for most applications	
Throughput	≥ 60%	≥ 80%	Includes coupling and transmission losses; excludes input losses, telescope and atmosphere	
Multiplex factor	> 150	–	Feed for optical low-resolution spectrograph	
Multiplex factor	> 10	–	Feed for optical high-resolution spectrograph	
Multiplex factor	> 100	–	Feed for near-IR spectrograph	

MANIFEST science - original modes

GMT



spectro -graph	# starbugs/IFUs in configuration	# fibres per starbug or IFU	field of view of starbug/IFU
G-CLEF	43/4	1	0.7”
GMACS	420	19	1.0”
GMACS	1	8400	23”
NIRMOS	65	19	1.25”
NIRMOS	14	91	2.75”
NIRMOS	1	1300	9”

Initial available configurations (G-CLEF and GMACS rows)

Potential additional configurations (NIRMOS rows)

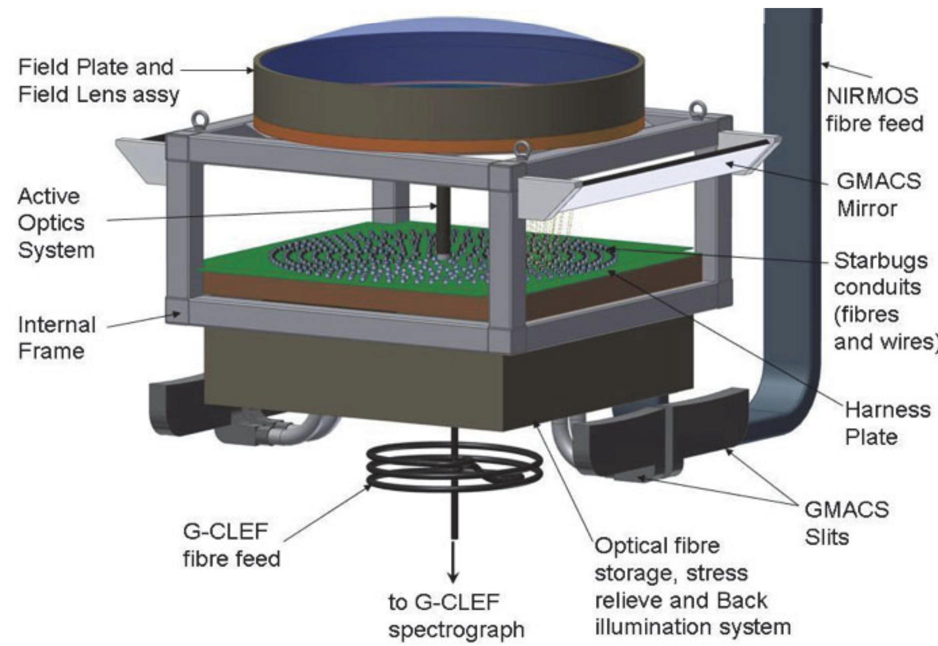
MANIFEST – instrument design

GMT

MANIFEST – instrument concept

GMT

- GMT's MANIFEST fibre facility feeds…
  - GMACS (Texas A&M): low resolution imaging optical spectrograph
  - G-CLEF (Harvard/SAO): high resolution white pupil echelle spectrograph
  - Also potential new spectrographs (e.g. NIRMOS) or repurposed spectrographs (HERMES, Hector, VIRUS – see later)

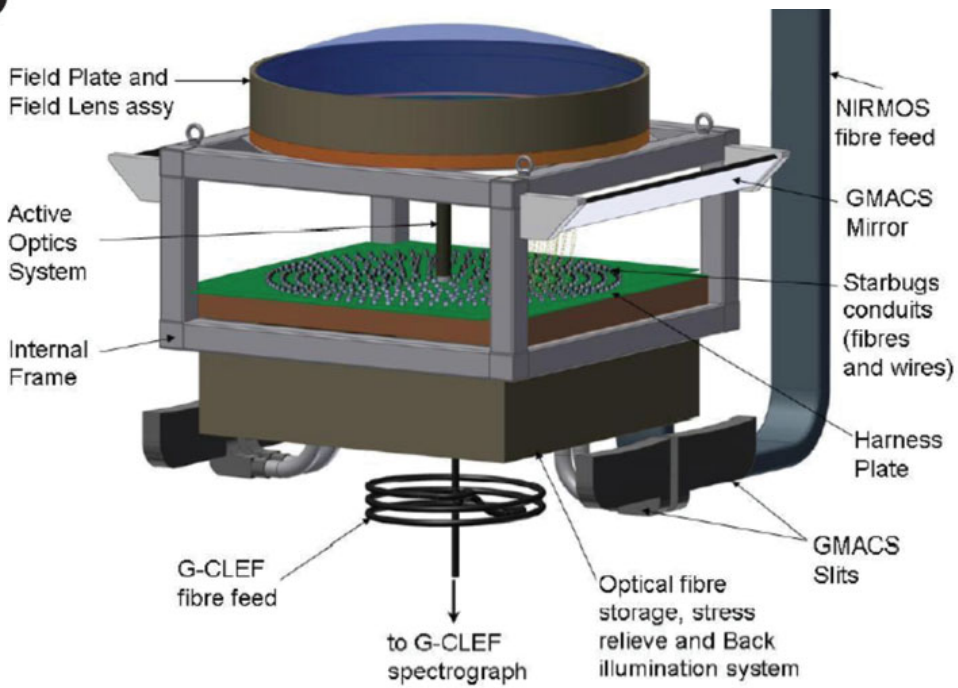


	TAIPAN	MANIFEST
# starbugs	150-300	200-4000
# fibres	150-300	1000s
Field of view	6 deg	20 arcmin
Field ROC	3 m	3.3 m
Field diameter	330 mm	1300 mm
Starbug pitch	8 mm ➡ 10'	~50 mm ➡ ~1'
Focal ratio	F/2.5	F/8
Payload	single fibre	single & IFU
Telescope	Schmidt	Gregorian
Instrument	Fixed	Deployable

- Other modes possible (MOAO, GLAO)
- Provides high resolution, wide FOV, high multiplex, versatile, and flexible
- Feasibility Study and Prototyping Design Study complete
- Pre-Concept Study commencing

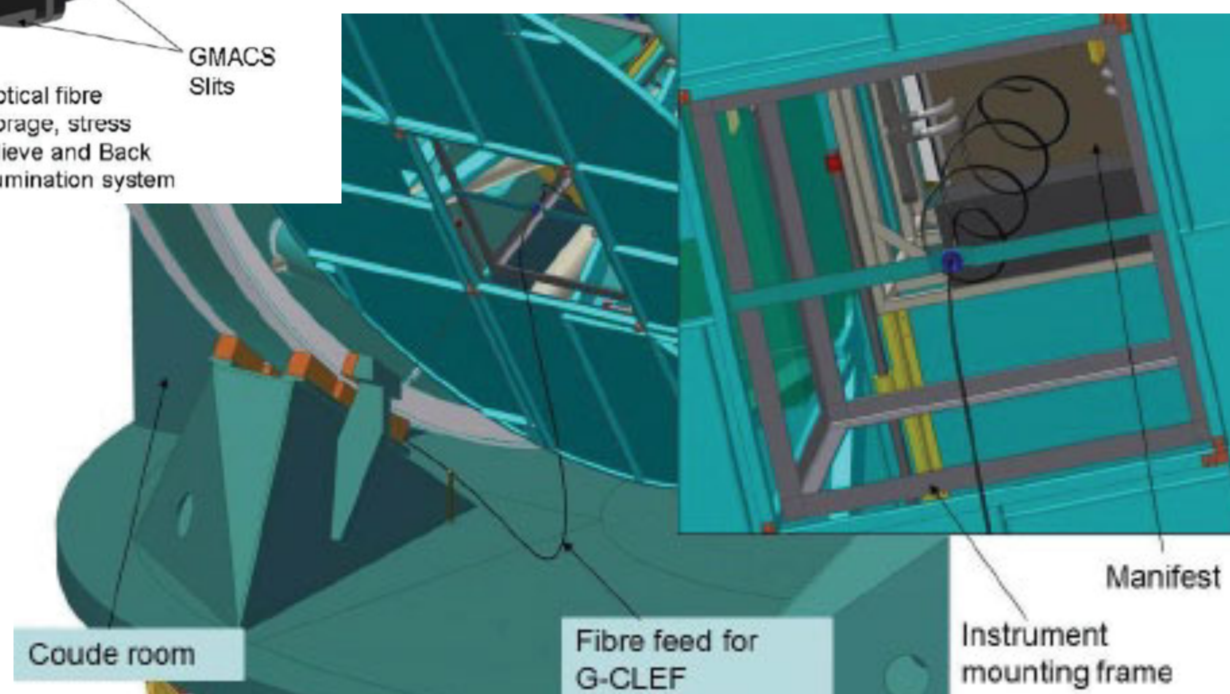
Fibre routes

GMT



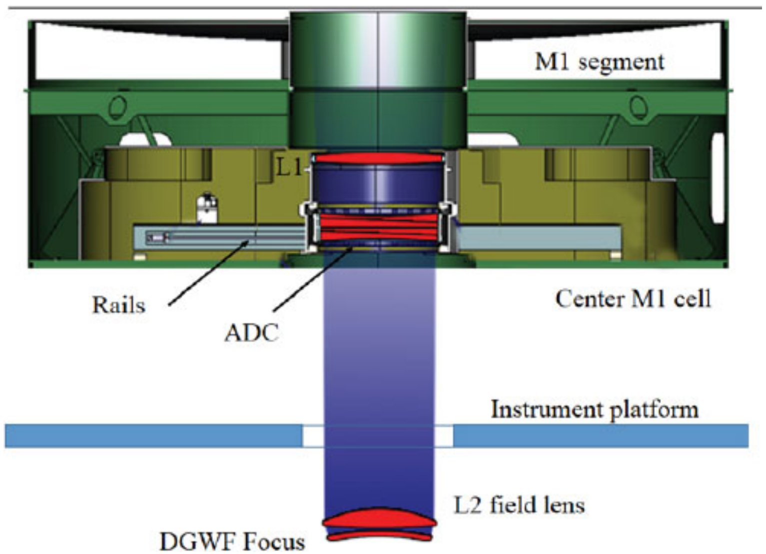
- ❑ For GMACS, feasibility study had a short fibre run leading to GMACS slit mounted beside MANIFEST while GMACS stored in instrument bay
- ❑ New location of GMACS requires re-routing

- ❑ For G-CLEF, feasibility study had a 25m fibre cable from MANIFEST to instrument at azimuth platform with helical coil for storage



WFC/ADC

GMT



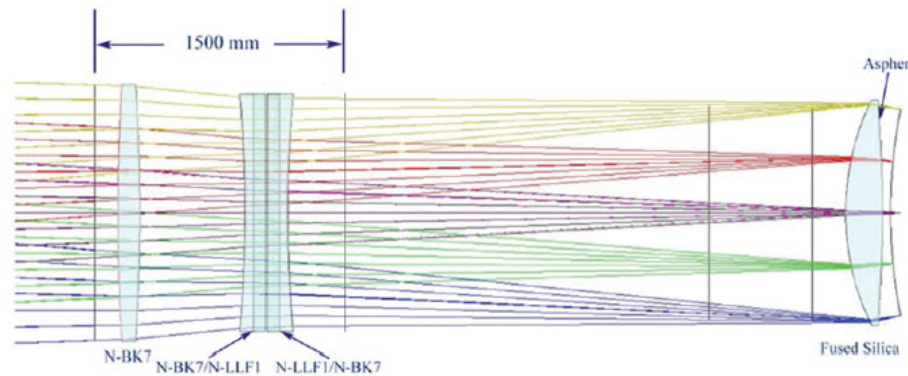
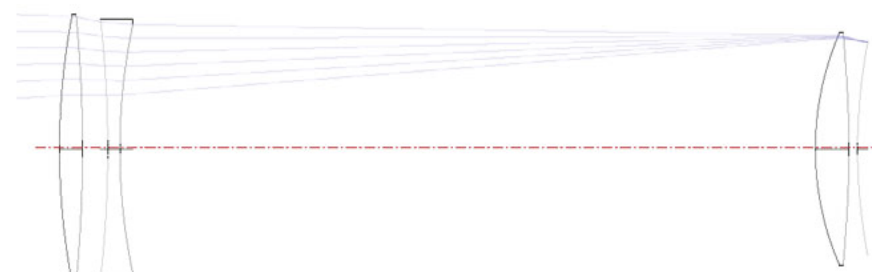
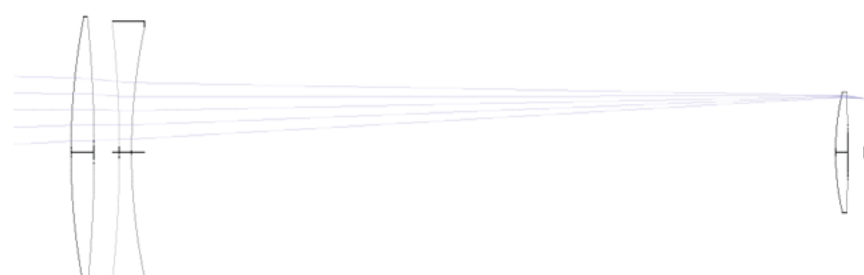


Figure 6-347. Layout of the Baseline Corrector-ADC Optics

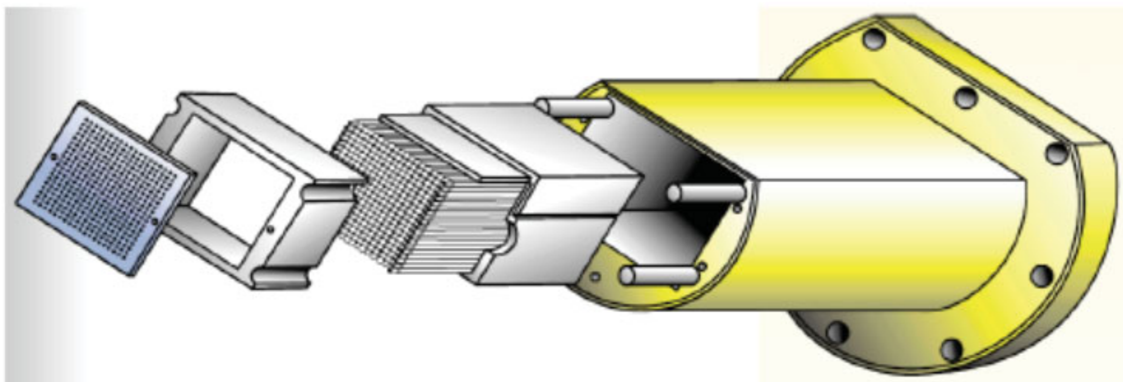


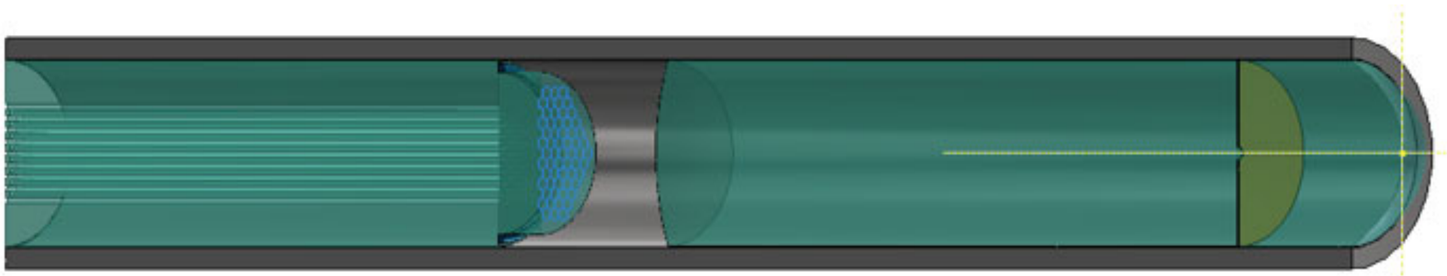


- Baseline WFC/ADC design exists that corrects full 20' FOV – but expensive!
- However GMT baseline does not include the WFC/ADC at first light (comes later)
- AAO proposed cheaper variant with less glass, though it has some other issues
- GMTO have said they will consider other options but plans are currently unclear

MANIFEST – starbugs

GMT

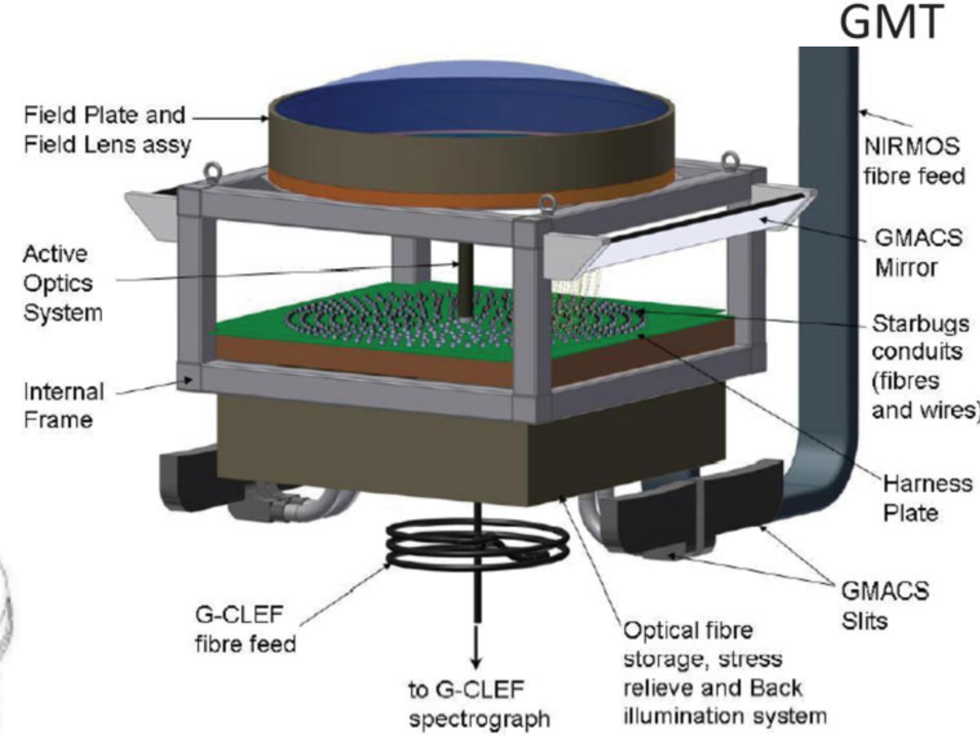


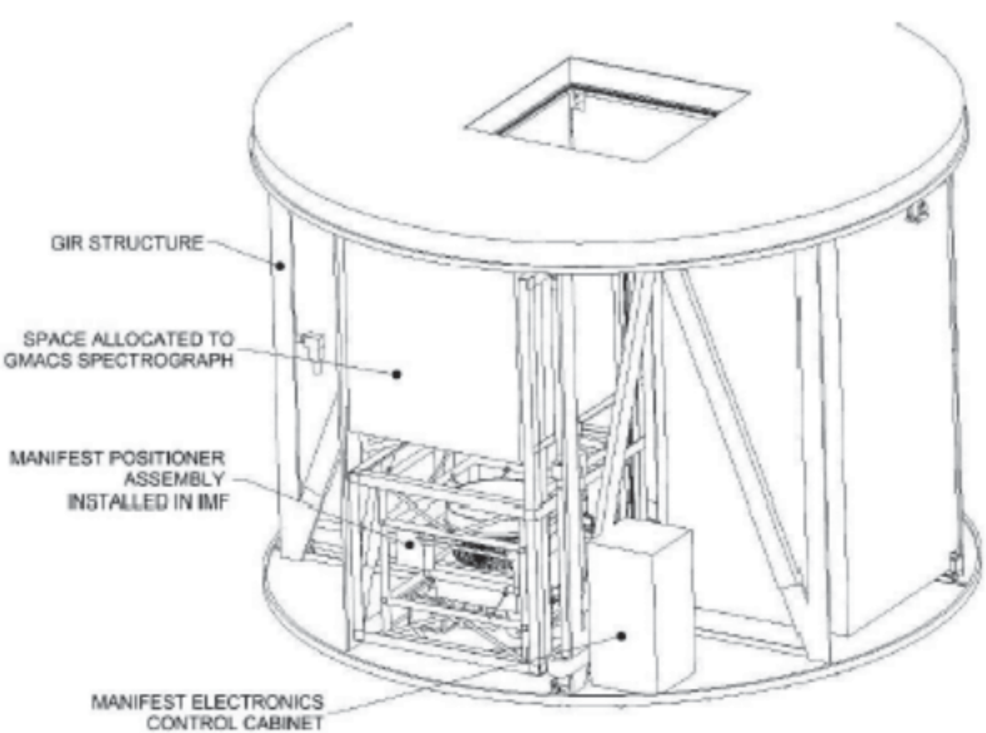


- Further effort is required to develop the various multi-fibre (IFU) starbugs with fore-optics
- But broadly similar systems have already been developed at AAO for other instruments
- Work also required on the connector plate to function with multi-pole fibre connectors

MANIFEST – positioner

- In original concept MANIFEST was stowed under GMACS in a half-size instrument bay
- MANIFEST deployed to centre of GIR; short fibre run to GMACS slit in front of fold mirrors



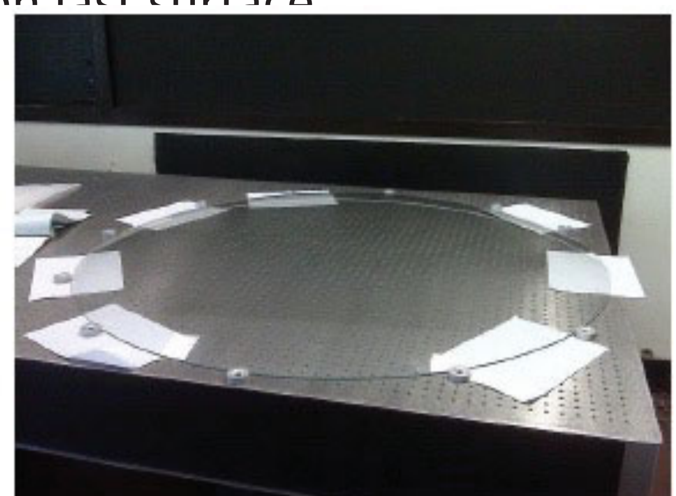


- Changes to starbugs, GMACS, and instrument bay mean MANIFEST storage and deployment concept needs to be reworked
- Deployment to be fully automated

MANIFEST – GFP + WFC

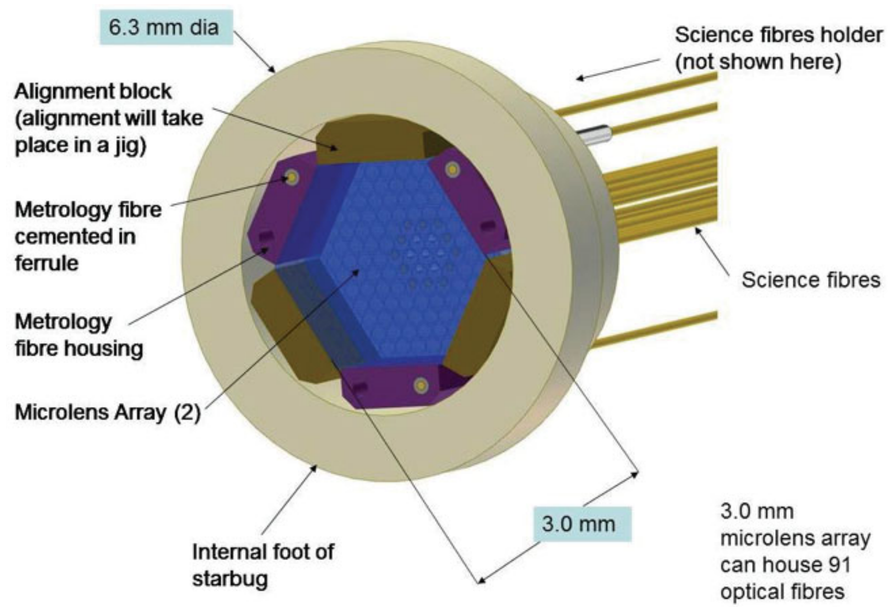
GMT

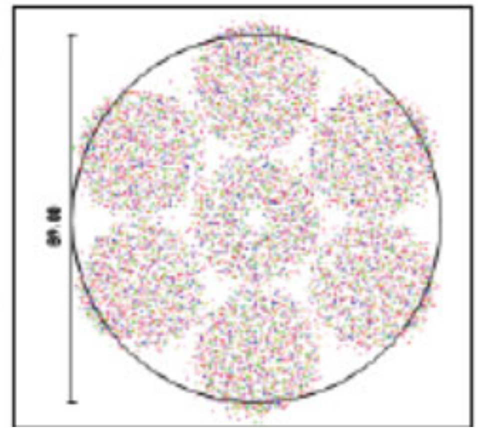
- TAIPAN glass field plate is 330 mm diameter, 5 mm thick, and can be fabricated via conventional techniques
- MANIFEST glass field plate is nominally 1300 mm diameter, 5 mm thick, and has a significant manufacturing risk (and hence cost)
- Considering a large increase in thickness so it is more like a conventional large lens (to reduce risk); but must consider impact on WFC/ADC design
- Would like thick last element for MANIFEST (first surface can be powered)
- Would like flat face on last surface

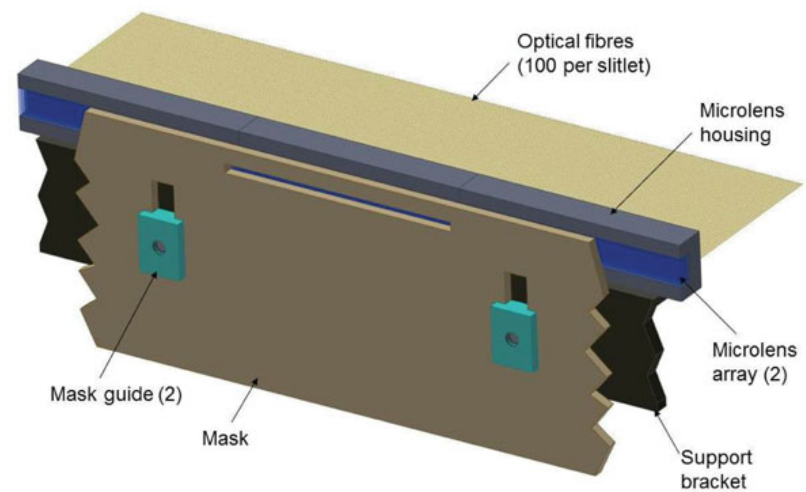

GMACS – interfaces

GMT





- ❑ Pupil of telescope fed into fibre and reimaged onto spectrograph grating rather than slit (other configurations are possible)
- ❑ Overfilled by 7%



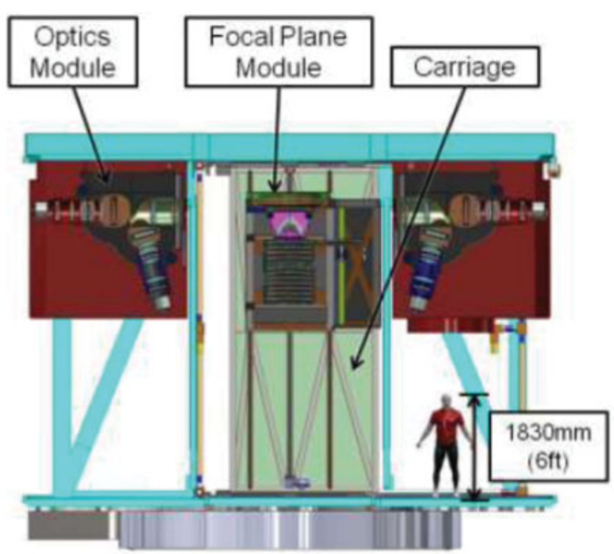
- ❑ GMACS front-end optics have dual microlens arrays feeding fibre bundle
  - ▶ Mode 1: 420 x 19 fibre (1”)
  - ▶ Mode 2: 1 x 8400 fibre (1”)
- ❑ Other configurations possible
- ❑ Based on original GMACS slit length and design

- ❑ At GMACS feed a fibre silt is formed
- ❑ Slides & slit mask offer multiple configurations

GMACS – interfaces

GMT

- At feasibility, GMACS had tent mirrors with deployable focal plane module with fixed spectrograph, so MANIFEST slit could be fixed with respect to the fold mirror
- Now GMACS is fully deployable: would remove slit mask and move MANIFEST slit unit into the centre of the slit mask holder
- Whether MANIFEST slit unit fixed to GMACS or MANIFEST or GMT depends on location of GMACS and sort of mechanisms used



G-CLEF – interfaces

GMT

- Interface control documents drafted
- No internal mechanisms in G-CLEF
- External splice, switch & filters

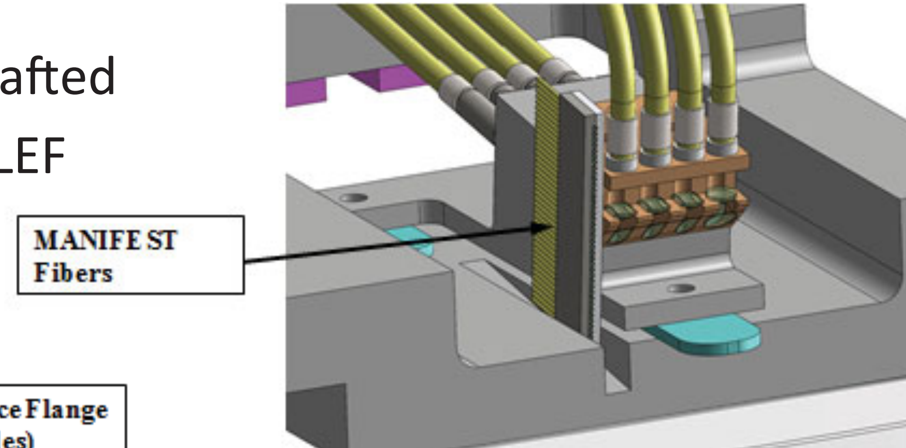


Figure 4: Fiber Injection Assembly – Close Up

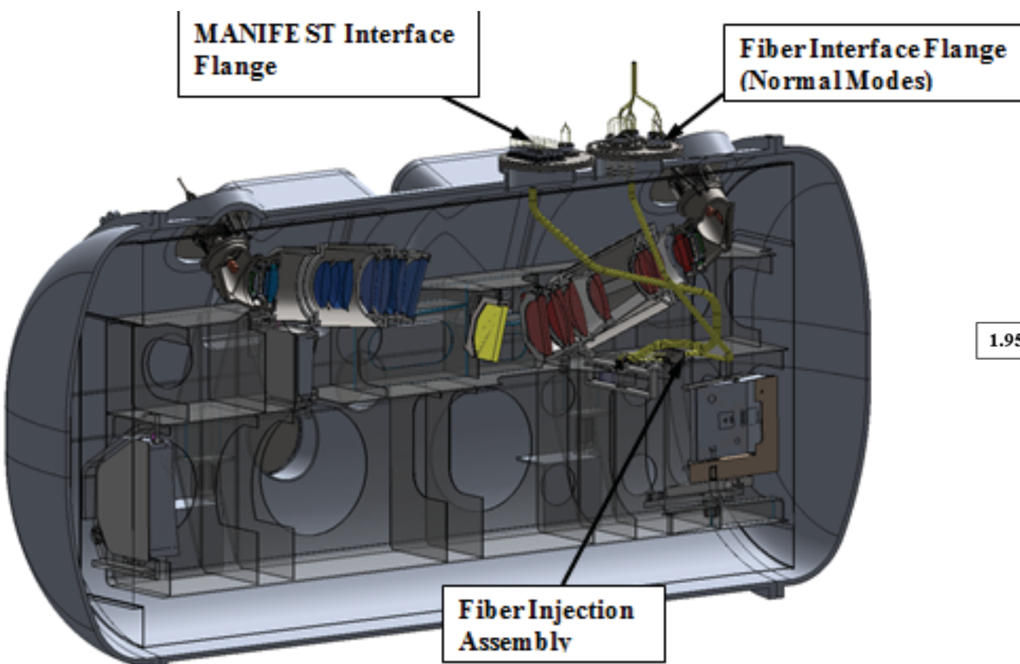


Figure 2 - Spectrograph in Vacuum Chamber (Section View)

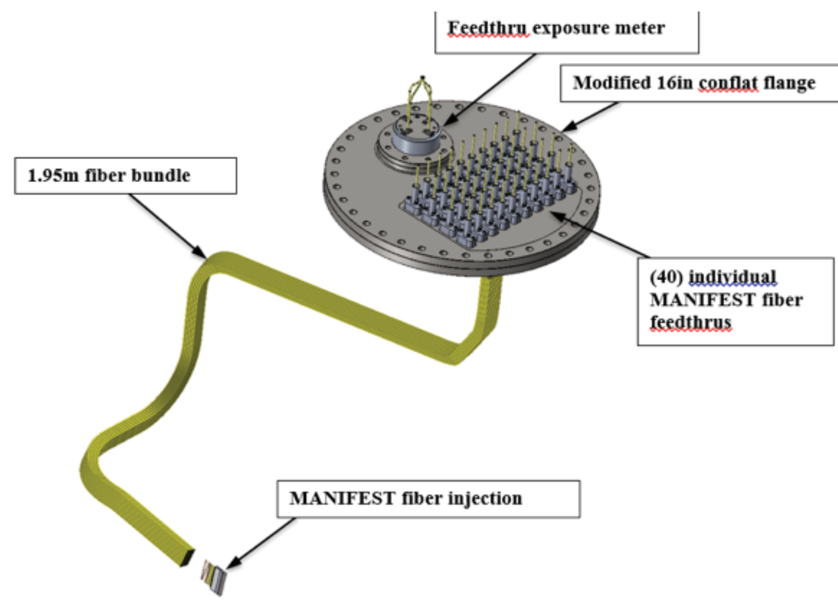
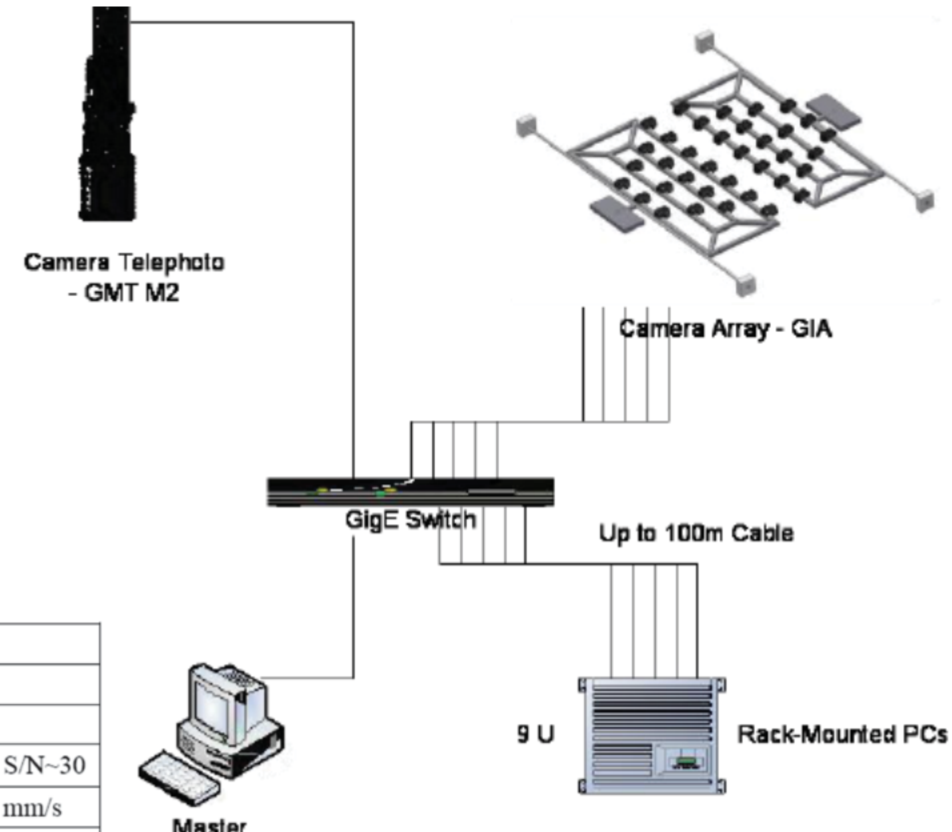


Figure 13 - MANIFEST Fiber Assembly

MANIFEST – metrology

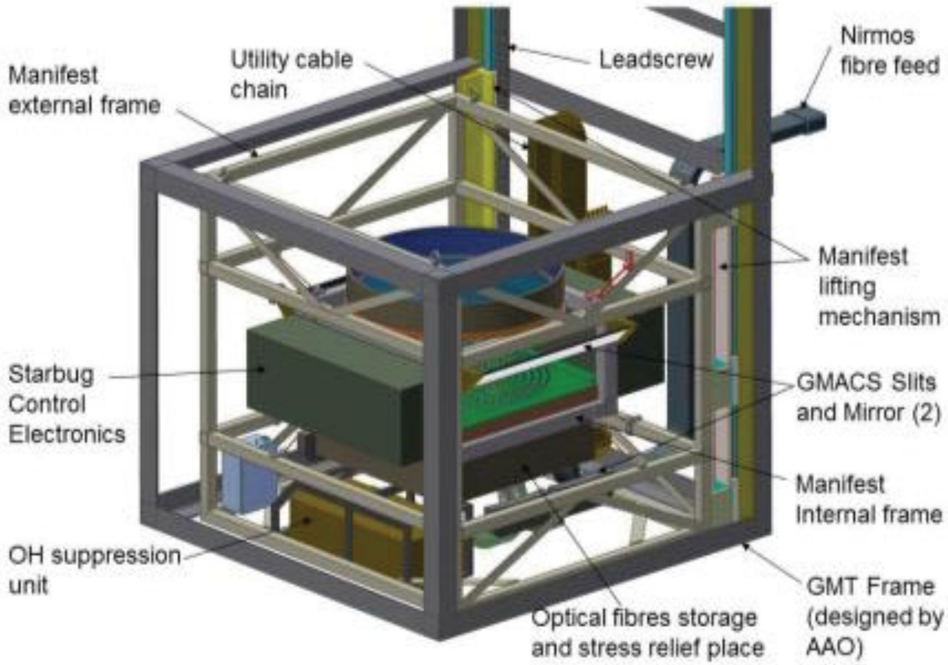
GMT

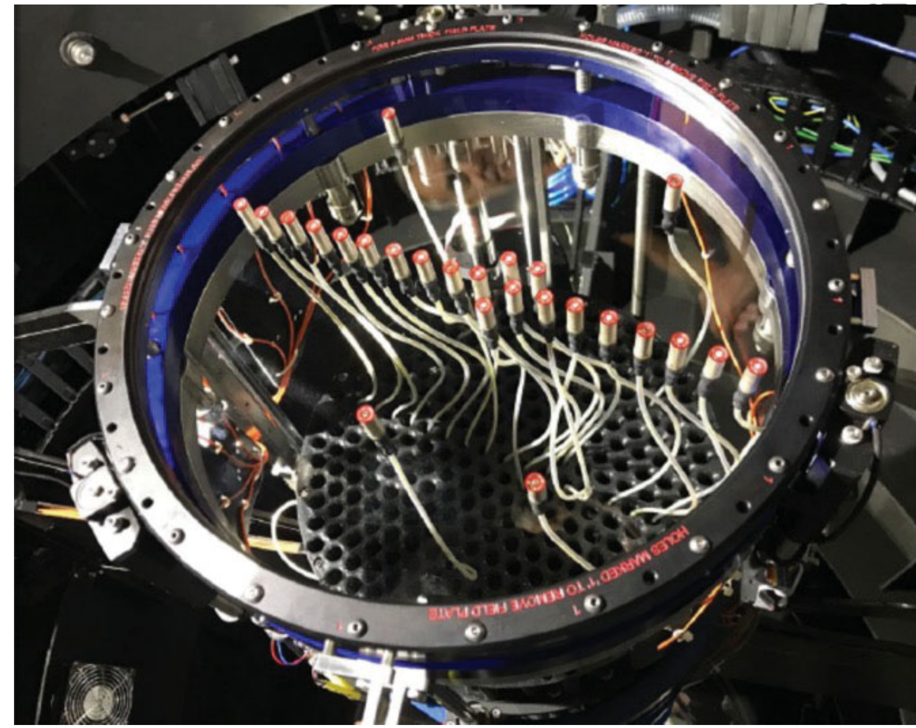
- In feasibility study, MANIFEST required 4 CCDs at M2 with single COTS lens
- Now would likely use single CCD with custom lens assembly (of similar size)
- Uses a larger array close to GFP for engineering off-sky
- Other locations will be explored

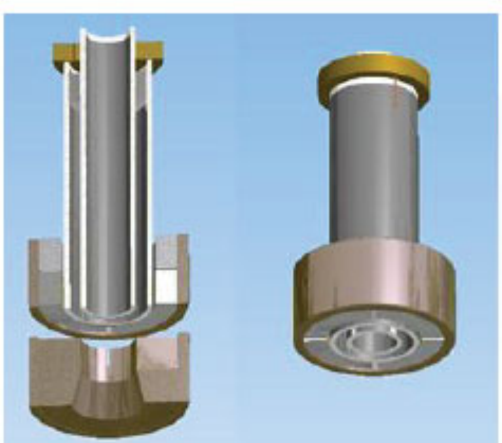


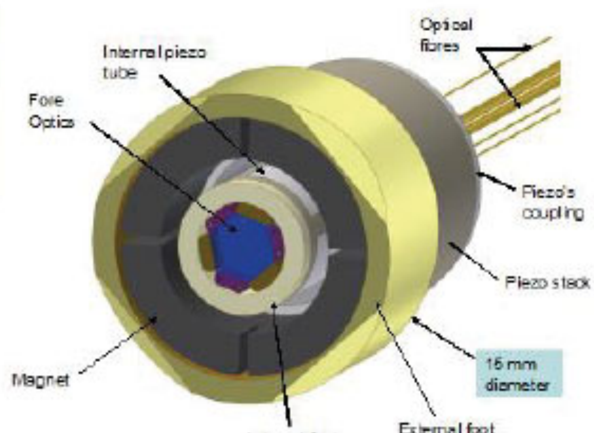
Specification	Value	Description
Location	M2 (20m above F/8 focus)	clear view of full field plate
Field sampling	4000 x 4000 pixels	requires 4 off the shelf cameras
Pixel scale	315 μm at F/8 focus	centroid accuracy 1/20 pixel for S/N~30
Frame rate	> 15 fps	Starbug motion tracking up to 7 mm/s
Exposure	< 10 ms	mitigate differential motions
Imaging	Telephoto F/5.6 Lens	400mm focal length for 6μm CCD pixel
Interface	GigE Ethernet	standard interface; up to 100m cable run
Unit size	150 x 150 x 500 mm	minimal impact of mounting on M2
Cameras	4 x Prosilca GE2040 4 x Canon 400mm EFL F/5.6	2040 x 2040, 6 μm pixel, 15 fps, CCD 20% field overlap

MANIFEST – design status



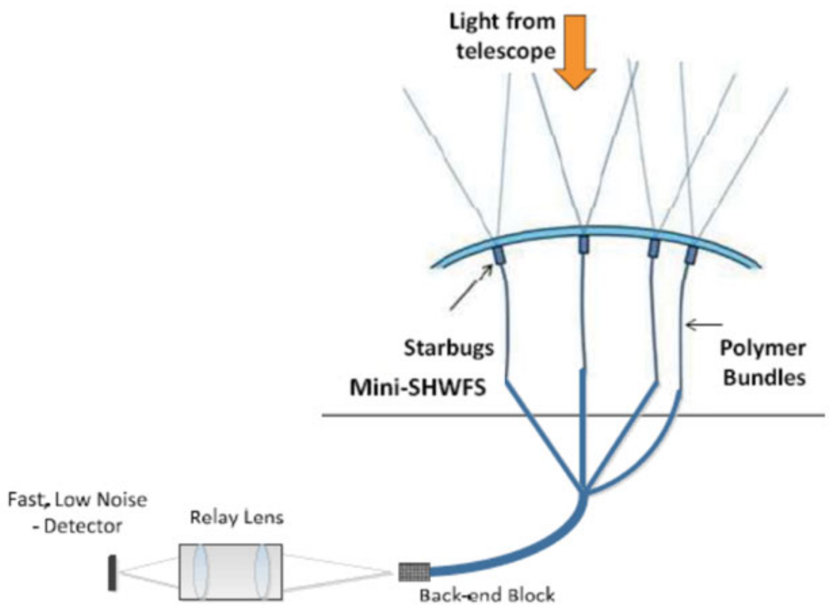


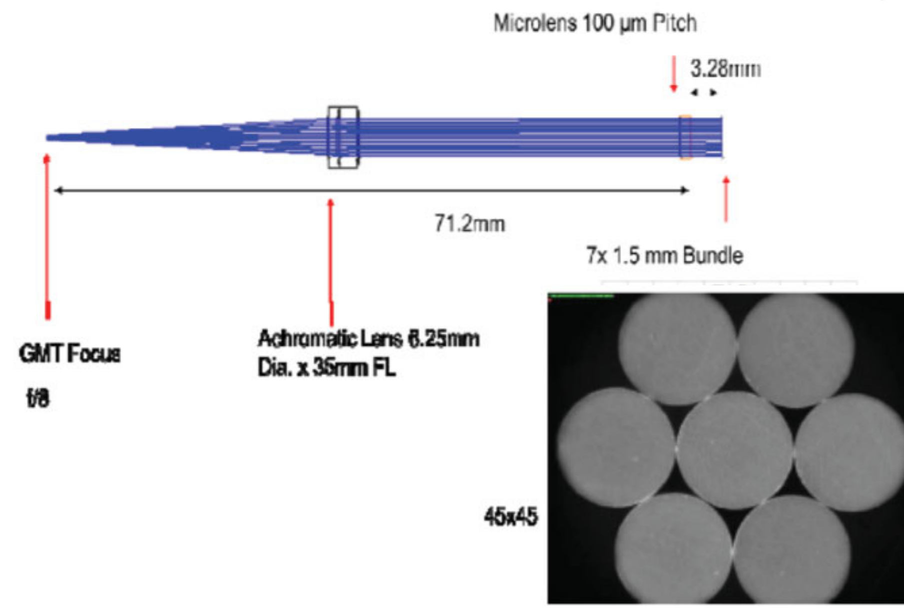




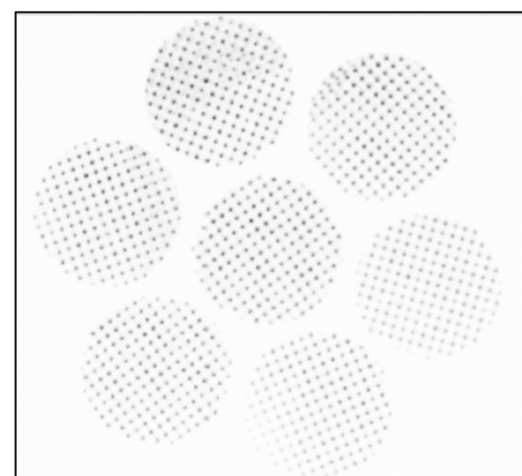
MANIFEST – MOAO mode

GMT



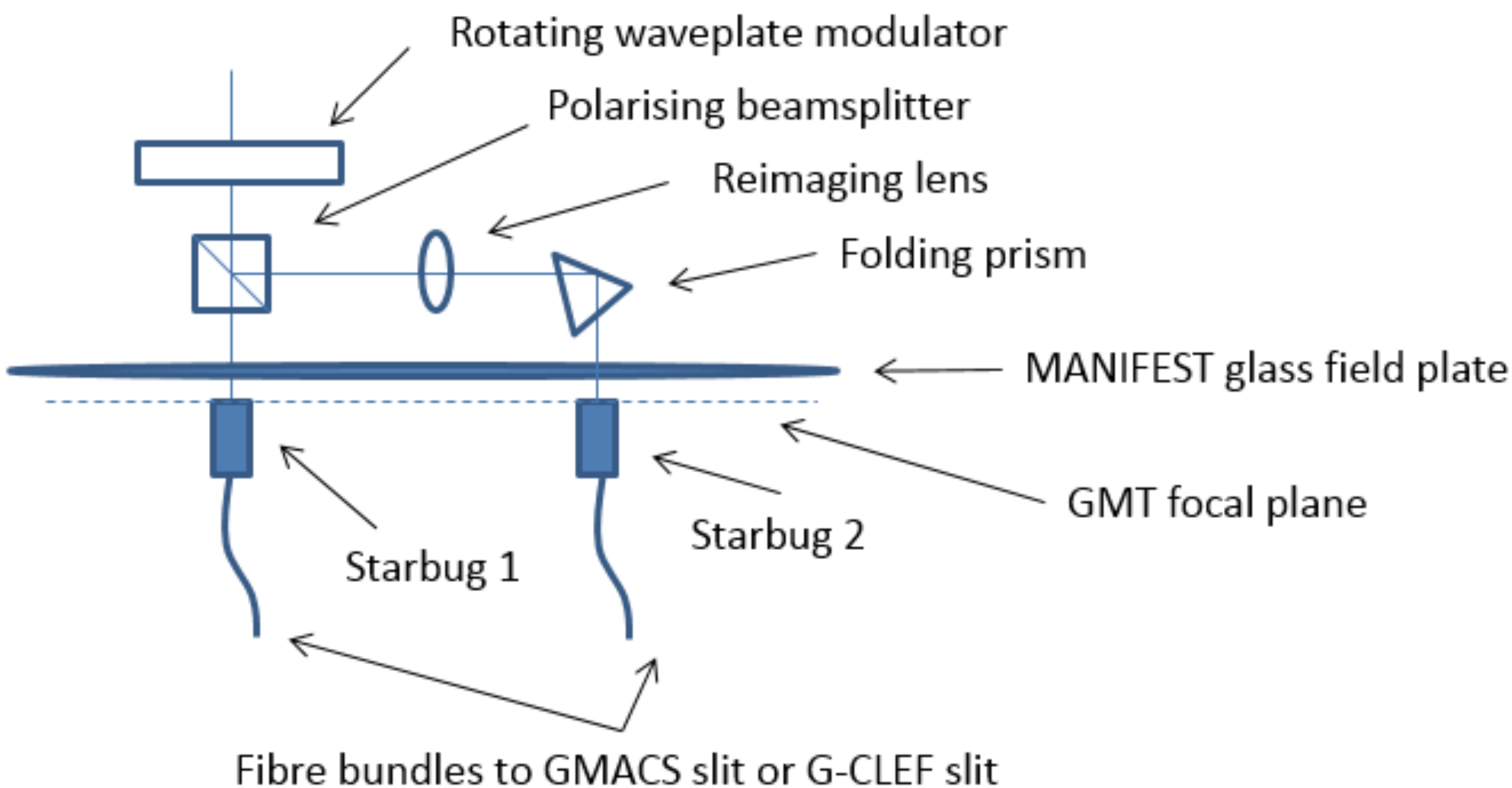


- Miniature WFS under development can be incorporated into starbugs to serve as sensor component of MOAO system
- Further development required for miniature deformable mirror system for correction component of MOAO system



MANIFEST – spectropolarimetry

GMT



Wide-field MOS at GMT first light

GMT

Wide-field MOS at GMT first light

GMT

- GMT’s planned first-light multi-object optical spectrograph, GMACS, can produce transformative early science for users
- Long-term, however, GMT needs to fully exploit its wide field to have a unique competitive advantage w.r.t. other ELTs
- GMT’s baseline plan includes a wide field corrector and atmospheric dispersion compensator (WFC/ADC) and the MANIFEST fibre positioner, which together provide access to GMT’s <u>full</u> field for <u>multiple</u> spectrographs
- But the WFC/ADC & MANIFEST are planned for Phase 3, so initially GMT has no full-field MOS
- What are the potential pathways to providing wide or full-field multi-object and IFU spectroscopy for GMT in Phase 1 (i.e. at or near first light) at very low cost to GMTO?

Wide-field MOS requirements

GMT

- There are three critical components required in order to implement wide-field MOS on GMT:
  1. a wide field corrector (with or without ADC)
  2. a fibre positioner
  3. one or more spectrographs
- There are various low-cost options for implementing each of these components so as to provide GMT, around first light, with wide-field (even full-field) MOS and/or multi-IFU spectroscopy at low-to-medium spectral resolution

WFC/ADC options

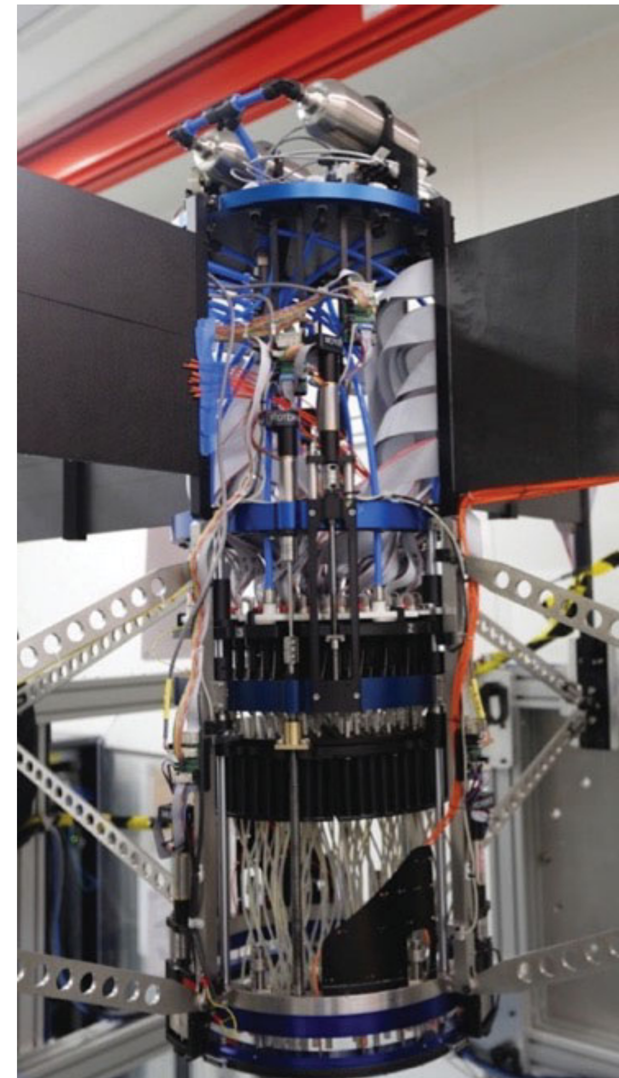
GMT

- Full-field WFC/ADC must ultimately be implemented to ensure that GMT has one clear advantage over other ELTs
- Full WFC/ADC solution is already included in GMT Phase 3 baseline, but that design is expected to cost ~$10M; that could be brought forward, or there are low-cost alternatives
- Option 1.1: ~10 arcmin 'native' GMT field
  - The 'native' GMT field is available from first light
  - However, for MOS, it still requires telecentricity correction via a field lens and/or the MANIFEST glass field plate
- Option 1.2: ~20 arcmin corrected field with ~2/3 fill factor
  - The AWACS concept might provides this capability at a cost of ~$1M, and could be independently funded

Positioner options

GMT

- The MANIFEST fibre positioner is part of the Phase 3 baseline GMT system (cost ~$10M, funded by GMTO)
- Option 2.1 – MANIFEST in Phase 1
  - One option is simply to bring MANIFEST forward by finding independent funding and making it (fully or partially) an in-kind contribution for Phase 1
- Option 2.2 – Alternative positioner
  - Independently fund an alternative (less capable, maybe cheaper) positioner in Phase 1, and then build MANIFEST in Phase 3 (as per the GMT baseline)
  - *More design risk & greater total cost* (so not the preferred approach!)



Spectrograph options

GMT

- If G-CLEF and GMACS are built for first light (or soon after) then the WFC and fibre positioner options above can, and should, feed these baseline facility instruments
- However if GMACS is not built by first light due to funding constraints, it would be highly desirable to have one or more alternative low-medium resolution spectrographs
- Absent further funding, the lowest-cost options involve re-purposing suitable existing spectrographs
- Due to the scaling between 4m-class telescopes on poor-seeing sites and GMT on a good-seeing site, and with the flexibility afforded by fibre image-slicing, it emerges that there are some high-capability spectrographs that could be re-purposed to give GMT first-light MOS capabilities

Spectrograph options

GMT

- Option 3.1 – **HERMES**
  - Now operating on the AAT; available for GMT first light
  - R~28,000, 4 bands over 471-789nm, 392 fibres
- Option 3.1 – **VIRUS2**
  - Funded to be built for McDonald 2.7m; expected to be on-sky in 2020; available for GMT in 2024
  - R~2000, λλ=370-1000nm, 1600 fibres fed by single large IFU or deployable IFUs
- Option 3.2 – **Hector**
  - Replacement for SAMI on AAT; now seeking funding; aim to build by 2021, and available for GMT in 2024
  - R~5000, 370-1000nm, 4000 fibres, fed by deployable IFUs or single large IFU

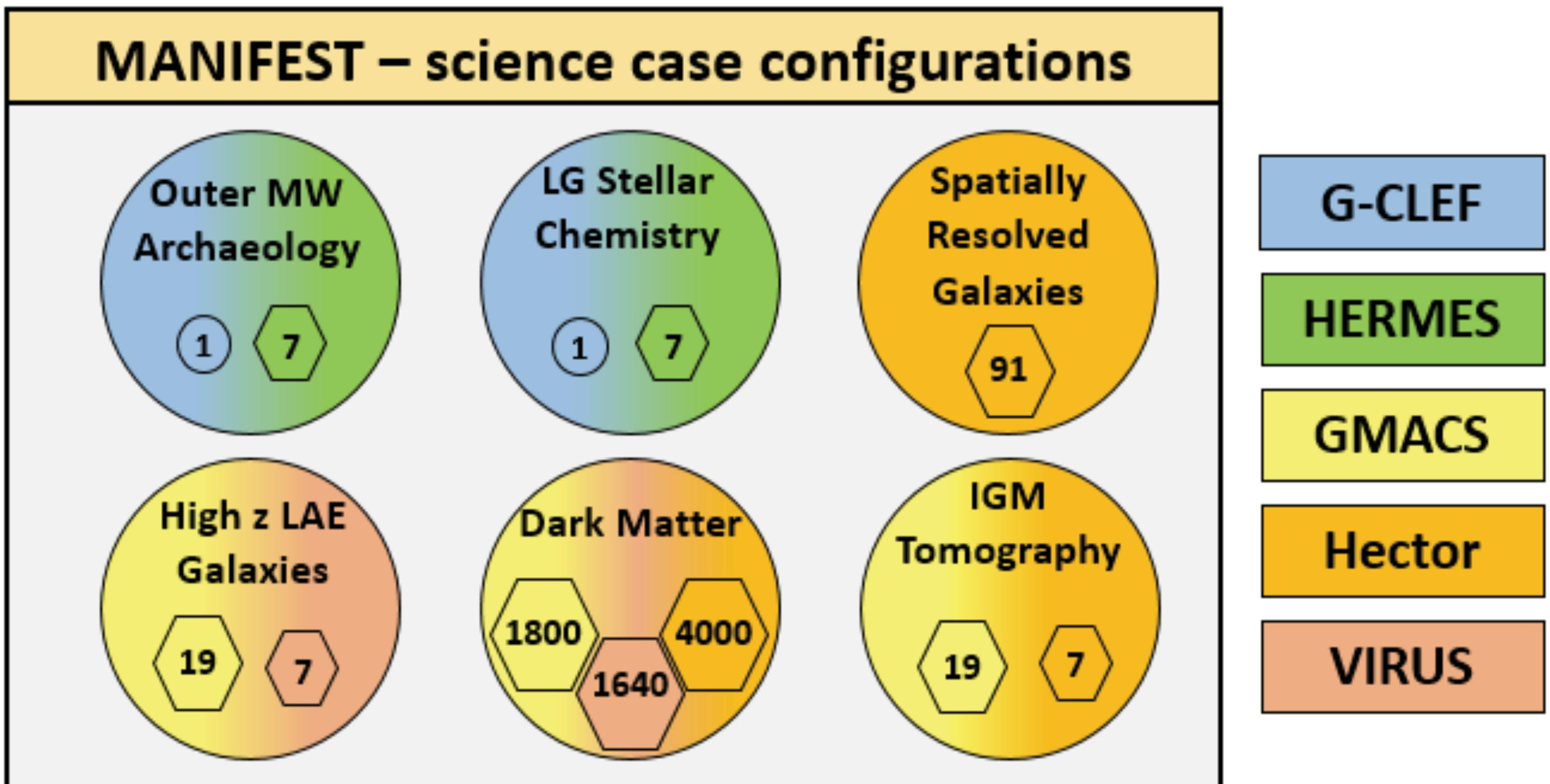
GMT MOS first-light options

GMT

Spectrograph	# IFUs	Fibres per IFU	FOV per IFU	Resolution	Bandwidth (nm)	Range (nm)
G-CLEF	4/40	1	0.7”	35K	550/15	350-900
HERMES	56	7	1”	28K	100	471-789
GMACS	60	61	1.1”	6K/20K	600/200	350-950
GMACS	95	19	1.25”	3K/10K	600/200	350-950
Hector	44	91	2.8”	5K	680	370-1050
Hector	560	7	0.75”	5K	680	370-1050
VIRUS	1	1640	14”	2K	630	370-1000
VIRUS	235	7	0.9”	2K	630	370-1000

GMT+MANIFEST+MOS science

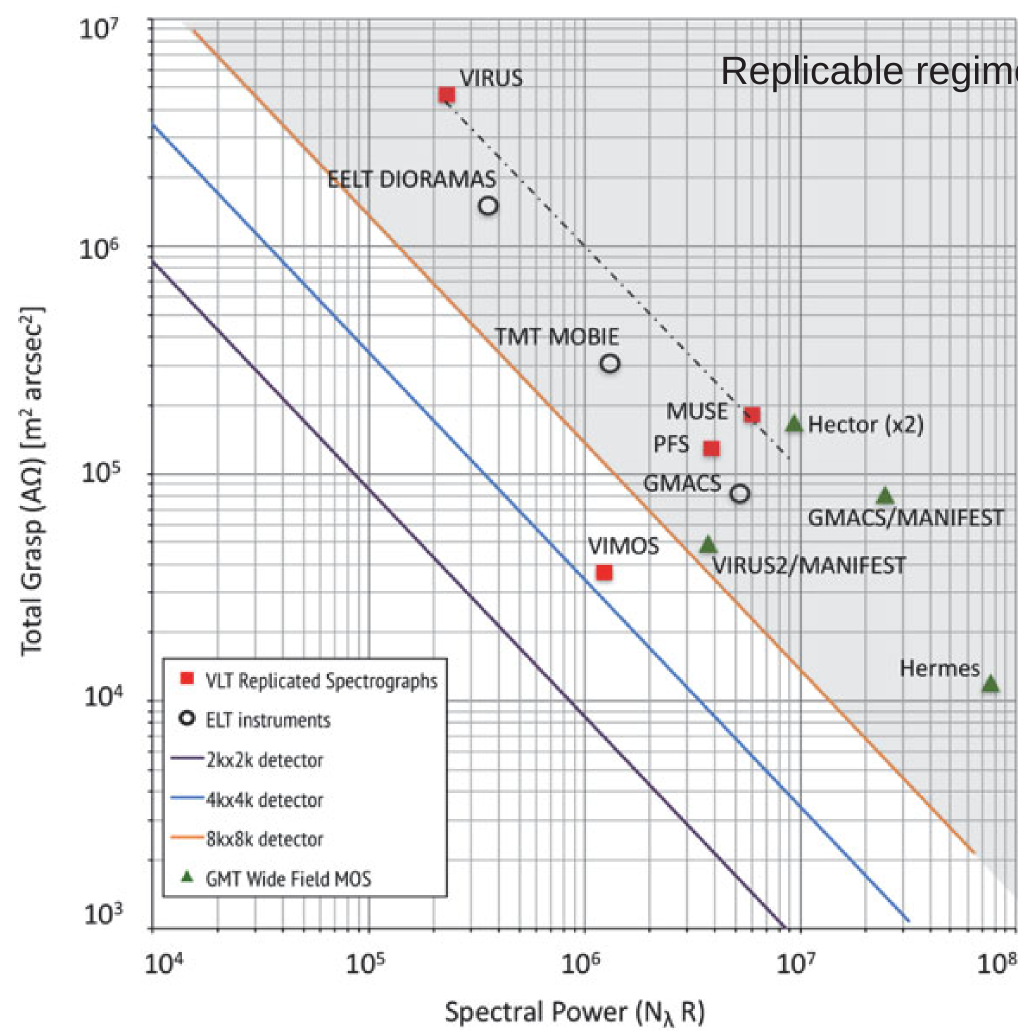
GMT



GMT MOS/IF instrument suite

GMT

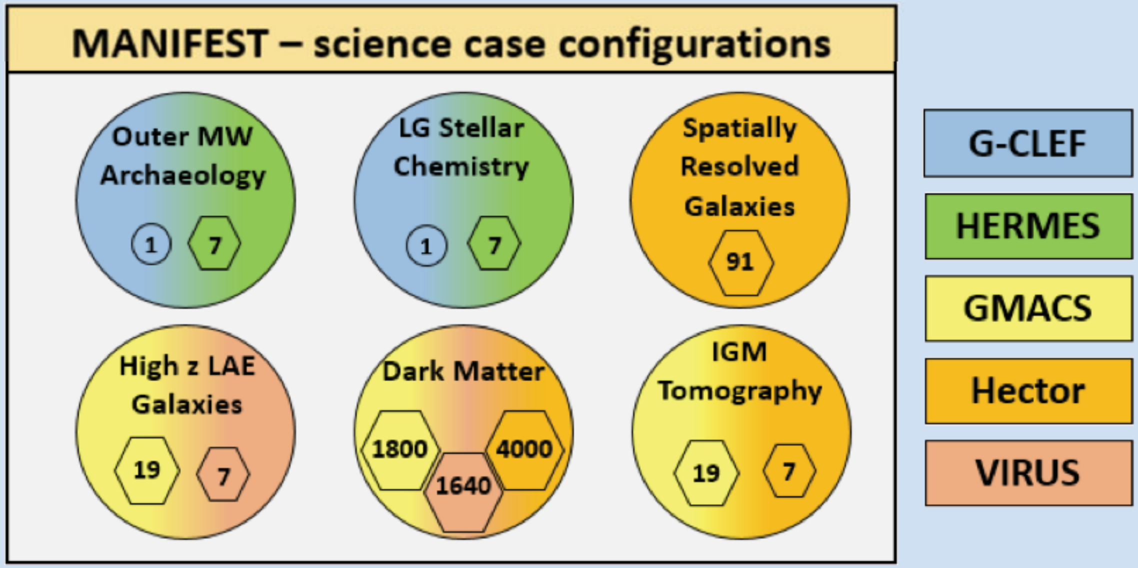
- Potential wide-field, optical MOS instruments for GMT first light:
  - GMACS – GMT baseline; under design
  - HERMES – now built and in operation on AAT
  - VIRUS2 – designed and funded for UT's McDonald Observatory
  - Hector – in design, to be funded for AAT
- MANIFEST allows full-field access and a variety of MOS/IFS modes, ensuring GMT is competitive with TMT & E-ELT and versatile enough for future science needs



Based on: Hill, "Replicated Spectrographs in Astronomy," AOT, Vol 3, Issue 3, 265 (2014)

Summary

GMT



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