Update on VLOT landscape

GAC / CATAC Tiger Team Report

Members of Tiger Team

Gregory Sivakoff (chair — GAC), Stefi Baum (CATAC), Ivana Damjanov (GAC), René Doyon (GAC), Kim Venn (CATAC), Will Percival (ex-officio — GAC), Michael Balogh (ex-officio — CATAC)

Purpose

The spirit of our charge was to provide GAC with information and guidance about the capabilities of the different VLOTs, how they align with the LRP priorities, and how this might be impacted by different modes of access. The situation is complex and in many cases uncertain. In order to provide useful advice for taking the next steps we have focused our efforts on two separate questions:

1. How well suited are the different telescope capabilities to the Long Range Plan 2020 goals?
2. What are the key considerations when comparing joining ELT-alone, or the full ESO organization?

Date

This report was compiled in the first half of 2022 and reported to the CASCA GAC (Ground-based Astronomy Committee) June 8, 2022. Some of the details in the instrument summary / comparisons could now be out of date.

Table of Contents

How well suited are the different telescopes capabilities to the Long Range Plan 2020 goals?

Assumed models

For the evaluations below we have made some assumptions, based on currently available information, about the VLOTs. These are summarized briefly below, with additional detailed information provided in the Appendices. In the case of ELT-only and GMT participation, where there is not an existing template or model, we assume a "baseline" participation that minimizes disruption to the current governance/operation of those facilities. In practice the terms of partnership would be subject to negotiation, and we use this to highlight how various elements of the participation model map to LRP requirements. In all cases except the specific question of short-term VLOT access, we evaluate the project assuming a long-term partnership or agreement.

TMT assumptions

- TMT is constructed on Maunakea in Hawaii.
- First light is no more than five years later than that of ELT.
- TMT's full complement of segments for its 30-m primary mirror (M1) aperture (655 sq m) is available at first light.
- Currently planned first-light instruments (NFIRAOS, IRIS, and WFOS) are available at first light; these include adaptive optics, imaging at visible and near-IR, and spectroscopy at visible and near-IR.
- NSF is a major (~25%) partner and Canada's share is around 10%.
- Governance model is either similar to its present form or in another form that is aligned with a commensurate Canadian share of governance.
- Canada has opportunities to contribute to construction hardware, first-light instruments, and instruments beyond first-light.

Shared ELT-ESO + ELT-only assumptions

- ELT is constructed on Cerro Amazones in Chile.
- We reference timescales to that of ELT to allow for relative timeline changes without a need for re-evaluation.
- ELT's full complement of segments for its 39-m primary mirror (M1) aperture (978 sq m) is available at first light.
- Currently planned first-light instruments [ELT-CAM (MICADO+MAORY), ELT-IFU (HARMONI), and METIS] are available at first light; these include adaptive optics, imaging at visible and near-IR, and spectroscopy at visible and near-IR.
- Canada's time share is about 9%.
- Full access to all instruments and observing modes on the ELT.

Unique ELT-ESO assumptions

- Canada is a full member of the ESO Treaty and has the same rights and responsibilities as any other ESO member state. Canadian representation on governance committees would be ~1/17 (6%).
- Canada has some opportunities to contribute to first-light instruments and instruments beyond first-light for ELT.

Unique ELT-only assumptions

- Canada has no participation in ELT governance.
- Canada has limited involvement in ELT technology development.
- Canada has some opportunities to contribute to first-light instruments and instruments beyond first-light for ELT.

GMT assumptions

- GMT is constructed on Las Campanas in Chile.
- First light is no more than 5 years later than that of ELT.
- GMT's full complement of segments for its 25.4-m primary mirror (M1) aperture (368 sq m) is available at first light
- Currently planned first-light instruments (G-CLEF, GMACS, GMTIFS, and GMTNIRS) are available at first light; these include adaptive optics, imaging at visible and near-IR, and spectroscopy at visible and near-IR.
- Canada's time share would be about 10%
- The GMT governance model remains in its present form, including its cash-based contribution model.
- The GMT operations model is similar to the current Magellan operations model. Here, partners are awarded blocks of time and operations are in queue mode within those blocks; individual partners have full control of how their time is allocated and scheduled.
- Canada has no opportunities to contribute to construction hardware or first light instruments.
- Canada has some opportunities to contribute to instruments beyond first-light.

Rubric definitions for Evaluation

Reviewing the LRP we have identified the following specific goals related to VLOT access:

1. Meets community's ambitions and requirements for scientific discovery.
2. Maintains a leadership role in facility governance.
3. Maintains a leadership role in overall science development.
4. Maintains a leadership role in technology development.
5. Ensures access to instruments that meet the needs of the community.
6. Canadian participation is subject to a set of guiding principles for sites used by astronomy projects, centred on consent for the use of any proposed site from Indigenous Peoples and traditional title holders.
7. Can address lack of VLOT access for Canadians due to delays in TMT construction through other arrangements.

For Goals 1–6 we define here our definitions and expectations when evaluating the suitability of each facility/model. Goal 7 is dealt with separately, later. The scale is such that yellow represents an "acceptable" match to expectations. Green exceeds that, and red is below.

Subarea			
Scientific Discovery	Provides significant opportunities for all science themes in LRP. Ability to participate in all observing modes (e.g., Large Programs, Fast turnaround etc).	Provides significant opportunities for most science themes in LRP. Access to most observing modes, though perhaps with some limitations.	Unable to provide significant opportunities for at least one science area essential to the LRP. Limitations to participate in certain observing modes significantly impacts ability to lead scientifically.
Facility Governance	Canadian role in governance at all levels is at a level minimally commensurate with our share. Governance model is compatible with Canadian rules and funding structures.	Canadian role in governance is at least marginally commensurate with our share. Some restrictions or challenges in participation may occur due to Canadian rules or funding structures.	Very limited (or no) participation in facility governance.
Science Development	Canadian participation in a Science Advisory Committee (or equivalent) and Instrument Science Teams is at a level minimally commensurate with our share. Canadians can participate in Facility-level Key Programs and Facility-level Surveys without restrictions at a level minimally commensurate with our share.	Canadian participation in a Science Advisory Committee and Instrument Science Teams is at a level nearly commensurate with our share. Participation in a Science Advisory Committee, Instrument Science Teams, Facility-level Key Programs, and Facility-level Surveys may have some restrictions.	Very limited (or no) opportunity for Canadian participation in a Science Advisory Committee, Instrument Science Teams, Facility-level Key Programs, or Facility-level Surveys.

Subarea			
Technology Development	Opportunity for Canadian participation in all present and future technology development, including construction hardware and the building of instruments. This may be competitive, but with assurance that over the long term Canada will be able to participate at a level minimally commensurate with our share.	Opportunity for Canadian participation in future technology development, including the building of instruments. Competition, governance rules, or their equivalent do not guarantee participation at a level minimally commensurate with our share over the long term. Limited or no participation in construction hardware or first-light instruments.	Very limited (or no) stable opportunities to participate in present or future technology development, including construction hardware or the building of instruments.
Instrument Access	Full access to instruments on the telescope that span the full range of parameter space that is essential to the Canadian LRP: wavelength, spectral resolution, spatial resolution, multiplexing.	Access to most instruments on the telescope or to most of the desired range of parameter space that is essential to the Canadian LRP.	Limited access to instruments or the telescope fundamentally cannot explore a critical area of parameter space that is essential to the Canadian LRP.
Guiding Principles	Has clear and unambiguous consent that meet the guiding principles that CASCA/LCRIC establish for LRP Recommendation #1.	Meets the guiding principles that CASCA/LCRIC establish for LRP Recommendation #1; however, there may still be some opposition.	Projects fails to obtain consent or does not meet the guiding principles that CASCA/LCRIC establish for LRP Recommendation #1.

Evaluation

Now we attempt to evaluate each facility/model against that rubric. Notes describe some of the key factors in reaching that decision; more detail is provided in the narrative below.

<table>
<tr><th>Subarea</th><th>TMT</th><th>ELT-ESO</th><th>ELT-only</th><th>GMT</th></tr>
<tr><td rowspan="2">Scientific Discovery</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">The TMT scientific discovery is already integrated into the LRP.
The ELT has the largest collecting area and is furthest along in construction of both the telescope and its instrumentation.
Neither the ELT nor the GMT provide access to Northern skies.
The GMT has reduced sensitivity / astrometric capacity compared to the TMT and the ELT, but is the best facility for wide-field science.
mid-IR science will be more challenging on both the GMT and the ELT given their respective sites. Access to >5μm is especially difficult for the GMT and there are currently no instrumentation plans for this wavelength range.</td></tr>
<tr><td rowspan="2">Facility Governance</td><td></td><td></td><td></td><td>Unresolved</td></tr>
<tr><td colspan="4">The TMT will be dominated by United States institutions. Familiarity and history may provide opportunities for leadership despite our small share and the lopsided distribution.
The ESO is not dominated by any single partner. The ESO has demonstrated stability.
The ELT-only governance model is unknown and we assume a minimal governance model.
The GMT currently has a largely institution-based governance model; any negotiations should ensure Canadian access to appropriate levels of governance.</td></tr>
<tr><td rowspan="2">Science Development</td><td></td><td></td><td></td><td>Unresolved</td></tr>
<tr><td colspan="4">The TMT science development potential is already integrated into the LRP.
The ESO (and thus the ELT-ESO) option has clear rules on commensurate access to science development teams.
Even without ELT membership, Canadians have been able to participate in the science and technical development of MAORY and ANDES. In the ELT-only model, presumably such opportunities would continue, though at a smaller scale and with less assurance than an ESO partnership would provide.
The GMT has an instrument development model that is driven by single institute leads; any negotiations should ensure Canadian access to appropriate science development teams.</td></tr>
</table>

<table>
<tr><th>Subarea</th><th>TMT</th><th>ELT-ESO</th><th>ELT-only</th><th>GMT</th></tr>
<tr><td rowspan="2">Technology Development</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">The TMT technology development potential is already integrated into the LRP.
In both the ESO-ELT and GMT options, capacity for technology development would be dominated by instruments past first-light, with limited opportunity to contribute to construction or first-light instruments.
The ELT-only technology development model is unknown, but we assume participation in ELT-only would not provide access to significant technology development opportunities. However, even now, there is some Canadian participation in MAORY and ANDES. While there may always be some opportunity to contribute to instrumentation in a limited way, they are without any guarantees and are only acceptable as a short term stop-gap solution.
It is not clear if the mechanism for funding and building instrumentation in Canada will enable us to be competitive with GMT partners under the current model.</td></tr>
<tr><td rowspan="2">Instrument Access</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">All telescopes provide good coverage of the desired parameter space, with the exception of GMT in the mid-infrared. GMT has no plans for instrumentation operating beyond 5 microns, though in principle they could go up to 14 microns. Coupled with the smaller M1 diameter of GMT, this is likely to impact some high-impact science (biosignature searches).</td></tr>
<tr><td rowspan="2">Guiding Principles</td><td>Unresolved</td><td>Unresolved</td><td>Unresolved</td><td>Unresolved</td></tr>
<tr><td colspan="4">No VLOT has demonstrated that it has achieved consent (even considering consent that is granted after the project has “begun”). The Canadian community has not yet developed the processes needed to ensure Canadian support (especially over long timescales in international partnerships) via alignment with the LRP.</td></tr>
<tr><td rowspan="2">Short-term VLOT access for Canadians</td><td>N/A</td><td>N/A</td><td>Potential</td><td>Potential</td></tr>
<tr><td colspan="4">TMT and ELT-ESO are not considered as a short-term solution for VLOT access while awaiting construction of the TMT.
ELT-only and GMT provide potential routes for short-term VLOT access for Canadians. ELT is currently scheduled to be the first completed.
It is unclear how ESO or GMT would react to a Canadian request for temporary access to their facilities by Canada.</td></tr>
</table>

Evaluation Summary:

1. We support the statement in the LRP that TMT remains our best opportunity to achieve the goals set out in that document. Alignment with the guiding principles, via appropriate site selection, remains the main risk and challenge.
    a. The assumed 10% share provides reduced opportunities relative to earlier ambitions of 15% and higher. It is still at an acceptable level (and comparable to what we could expect in ESO or assume for GMT), but should not drop much further. A higher level of participation would be preferable and would very likely see a corresponding (or greater) increase in scientific output and industrial participation. There is undoubtedly sufficient demand in Canada to warrant a share >10%.
    b. Significant descopes in capability/instrumentation, or delays that push first light much later than 5 years after ELT, will compromise Scientific Discovery with TMT and shift its evaluation from green to yellow.
2. If participation in TMT is impossible, joining ELT via ESO also provides an excellent way to satisfy our VLOT ambitions. The implications for the rest of Canadian astronomy need to be considered.
3. Participation in ELT-only or GMT would provide sufficient scientific capability to Canadians. There remain important unresolved questions and uncertainties around governance, science, and technology development that would need to be addressed. This makes these options riskier and less desirable.
4. In addition to the problems raised in the previous point, GMT is the smallest telescope, is on a low-altitude site that compromises MIR observations, and has incomplete access to the Northern Sky. It is therefore the least desirable VLOT, though we note it would still provide an acceptable way to achieve most of our scientific ambitions if the challenges in Point 3 could be addressed.
5. If Canadian astronomy wishes to pursue short-term VLOT access prior to completion of TMT construction, then ELT-only and GMT access have the potential to meet that need.
    a. A route to national short term access to ELT is less clear, although ongoing access for individual groups based in Canada through contributions to instrumentation could be provided with additional support.
    b. Short term access to GMT would be a point for negotiation in some scenarios. However, this interim solution is being evaluated in the context where there is still a definite route to TMT construction that is not significantly delayed. Scenarios counter to this would require careful consideration, depending on the scale of the potential delay.

6. In the above analyses, the VLOT Tiger Team assumed that access to the full northern sky and mid-IR spectral range are desirable, but not critically essential features of VLOT access. This is consistent with earlier CATAC reports on TMT sites. Under this assumption, neither observing mode “significantly impacts [Canadian] ability to lead scientifically” or is part of the “parameter space that is essential to the Canadian LRP”. A significant change to this prioritization would affect not only GMT and ELT rankings in this assessment, but also the assessment of TMT on sites other than Maunakea.
    a. Full northern sky access is only consistent with TMT, either on Maunakea or its alternative site Observatorio del Roque de Los Muchachos (ORM), in La Palma, on the Canary Islands (Spain).
    b. Access to the mid-IR spectral range is difficult from the ground. TMT on Maunakea has the best mid-IR access, and may be the only available option at wavelengths longer than 14 microns. The number of good mid-IR nights for ELT on Cerro Armazones is less than for TMT on Maunakea. Access to the mid-IR from TMT on ORM or GMT are more strongly compromised.

Appendices

Acronyms

- ACURA: Association of Canadian Universities for Research in Astronomy
- ALMA: (United States / European / East Asian) Atacama Large Millimeter/submillimeter Array
- AO: Adaptive Optics
- ANDES: ArmazoNes high Dispersion Echelle Spectrograph on ELT (formerly HIRES)
- CASCA: Canadian Astronomical Society
- CATAC: CASCA/ACURA TMT Advisory Committee
- CCAT-p: Cerro Chajnantor Atacama Telescope prime (now FYST)
- CFHT: Canada France Hawaii Telescope
- CHIME: Canadian Hydrogen Intensity Mapping Experiment
- CHORD: Canadian Hydrogen Observatory and Radio-transient Detector
- DAO: Dominion Astrophysical Observatory
- DRAO: Dominion Radio Astrophysical Observatory
- ELT: (European) Extremely Large Telescope
- ESO: European Southern Observatory
- FoV: Field of View
- FYST: Fred Young Submillimeter Telescope (formerly CCAT-p)
- Gemini-N/Gemini-S: (United States-led) Gemini North / Gemini South Telescopes
- G-CLEF: GMT-Consortium Large Earth Finder
- GMACS: GMT Multi-object Astronomical and Cosmological Spectrograph
- GMT: Giant Magellan Telescope
- GMTIFS: GMT Integral-Field Spectrograph
- GMTNIRS: GMT Near Infrared Spectrograph
- GAC: (Canadian Astronomical Society) Ground-based Astronomy Committee
- HARMONI: High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph
- HIRES: HIgh Resolution Echelle Spectrograph on ELT (now ANDES)
- IFS: Integral Field Spectrograph
- IFU: Integral Field Unit
- IRIS: InfraRed Imaging Spectrograph on TMT
- JCMT: James Clerk Maxwell Telescope
- LRP: (2020 Canadian Astronomy) Long Range Plan
- LSST: Legacy Survey of Space and Time on (United States) Rubin Observatory
- M1: Primary mirror
- MAORY: Multi-conjugate Adaptive Optics RelaY on ELT
- MICADO: Multi-AO Imaging Camera for Deep Observations
- mid-IR: mid-infrared
- MSE: Maunakea Spectroscopic Explorer

- ngVLA: Next Generation Very Large Array
- NFIRAOS: Narrow Field InfraRed Adaptive Optics System on TMT
- NOIRLab: (United States) National Optical-Infrared Astronomy Research Laboratory
- NSF: (United States) National Science Foundation
- ORM: Observatorio del Roque de Los Muchachos
- PFS:Prime Focus Spectrograph on (Japanese) Subaru Telescope
- *R*: Spectral Resolution
- SKA: Square Kilometre Array
- TMT: Thirty Meter Telescope
- US: United States (of America)
- VLOT: Very Large Optical Telescope
- VLT: (European) Very Large Telescope
- WFOS: Wide Field Optical Spectrograph on TMT
- WST: (European) Wide-Field Spectroscopic Telescope (formerly SpecTel)

Additional Facility Details

Additional TMT Details

- TMT on Maunakea would be located at 4050 m above sea level.
- There is no publicly available first light / start of science operations date. The earliest possible first light would be 2032, with science operations starting 1 years later, 2033.
- 492 mirror segments will provide a collecting area of 655 sq m, equivalent to an unobstructed 28.9m diameter primary, with the resolving power of a 30m diameter primary.
- NFIRAOS, IRIS, and WFOS instruments available at first light (see Instrument Summary / Comparisons for more detail)
    - NFIRAOS: Multi-Conjugate Adaptive Optics system (near-IR)
    - IRIS: imaging+integral field spectroscopy (near-IR)
    - WFOS: seeing-limited imaging+multi-slit spectroscopy (visible)
- TMT governance is managed via the TMT International Observatory, a not-for-profit corporation in Hawaii, with guidance from a Science Advisory Committee.
    - Canada currently has representatives on the TMT governance structures, and those representatives have the opportunity to ensure that Canadian access to governance remains commensurate with our share.

Additional ELT Details

- ELT is located 3046 m above sea level on Cerro Amazones in Chile.
- Technical first light for ELT is 2027, with science operations starting (3 instruments commissioned) 3 years later, 2030.

- 798 mirror segments will provide a collecting area of 986 sq m, equivalent to an unobstructed 35.4m diameter primary, with the resolving power of a 39m diameter primary.
- MAORY, HARMONI, MICADO, HARMONI, and METIS are available at first light (see Instrument Summary / Comparisons for more detail).
  - MAORY: Multi-Conjugate Adaptive Optics system (near-IR)
  - MICADO: imaging+long slit spectroscopy (near-IR)
  - HARMONI: integral field spectroscopy with Adaptive Optics (visible/near-IR)
  - METIS: imaging and integral field spectroscopy (mid-IR)

Additional ESO Details

- Since Canada's time share will be determined based on our GDP, we estimate the time share is about 9% (from last assessment). As of 2017, member states and time shares are here: https://www.eso.org/public/about-eso/memberstates/
- Current ESO governance is managed via the ESO Council and European Science Advisory Committee, with no facility-specific governance bodies. Canada would be the 17th member state and our representation on governance committees would be ~1/17 (6%), regardless of time share. The following dictates the precise shares in ESO governance structures.
  - ESO Council: Two delegates from each Member State
  - ESO Finance Committee: One delegate from each Member State
  - ESO Scientific Technical Committee: One delegate from each Member State and one member from Chile plus up to six members-at-large who may be from non-member states
  - ESO Users Committee: One delegate from each Member State and one member from Chile
  - ESO Observing Programmes Committee: By appointment, with no preset quota
- Australia's Strategic Partnership with ESO has only recently been amended to include participation in the Technology Development Program. We assume this type of participation is not included in a "baseline" ELT-only participation, though the Australian example demonstrates that this issue has precedence for contention during negotiations.

Additional GMT Details

- GMT is located 2516 m above sea level on Las Campanas in Chile.
- Technically-paced first light for GMT is 2031, with shared-risk science starting late that year.
- 7 mirror segments will provide a collecting area of 368 sq m, equivalent to an unobstructed 21.6m diameter primary, with the resolving power of a 24.5m diameter primary.
- G-CLEF, GMACS, GMTIFS, and GMTNIRS are available at first light (see Instrument Summary / Comparisons for more detail). .

    - G-CLEF: high-resolution echelle spectroscopy (visible)
    - GMACS: medium-resolution multi-object spectroscopy (visible)
    - GMTIFS: diffraction-limited integral field spectroscopy (near-IR)
    - GMTNIRS: single-object echelle spectroscopy (near-IR to mid-IR)
- Current GMT partners are all institutes, not nations. It is not 100% clear how national participation would work. One model might be the current Canadian participation in Euclid or LSST, which are not national but are broad and inclusive enough to include most interested Canadians. Another model is that all of Canada would be considered the equivalent of an institute.
- In the current Magellan operations model, partners are awarded blocks of time. Operations are in queue mode within those blocks. Individual partners have full control of how their time is allocated and scheduled.

Instrument Summary / Comparisons

- TMT
    - NFIRAOS: Multi-Conjugate Adaptive Optics system providing diffraction-limited coverage in 0.8-5 micron band over 34”x 34” Field of View (FoV)
    - IRIS: imager+IFU with the 0.84-2.4 micron coverage and diffraction-limited performance > 1micron; spectral resolution *R*=4000-10000; FoV = 34”x 34” in imaging mode; up to 2.25”x4.4” in slicer IFU mode
    - WFOS: seeing-limited imager+multi-slit spectrograph covering the 0.31-1 micron range and the FoV of 8.3’x3’; spectral resolution *R*=1500-3500 (with 0.75” slits).
- ELT
    - MAORY: Multi-Conjugate Adaptive Optics module
    - HARMONI: single field near-IR IFS with AO with up to 10’’x5’’ FoV covering 0.5-2.45 micron range)
    - MICADO (near-IR imager+long slit spectroscopy, 0.8-2.5 micron range, up to 50’’x50’’ FoV)
    - METIS (mid-IR imager and spectrograph covering 3-13 micron range (imagining) and 3-5 micron range for high-res IFU spectroscopy and with the 10” FoV (~1” for IFU)
- GMT
    - G-CLEF: high-res spectrograph (*R*=19,000-100,000) covering 0.35-0.95 micron range and with 300 arcmin^2 FoV
    - GMACS: medium-res (*R*=1,000-6,000) multi-object spectrograph with 300 arcmin^2 FoV covering 0.32-1 micron range
    - GMTIFS: diffraction-limited IFU (*R*=5,000-10,000) with the FoV of 20’’x20’’ covering wavelength range 0.9-2.5 micron
    - GMTNIRS: single-object near-to-mid IR echelle spectrograph with R=65,000-85,000 covering 1.1-5.4 micron range

First light	Shortly (<5 years) after first light	Subsequent instrumentation

	Type of Instrument	TMT	GMT	E-ELT
AO system		NFIRAOS	Deformable M2	MAORY
Optical	Multi-Object Spectrometer	WFOS Preliminary Design	GMACS Preliminary Design	MOSAIC
	High-resolution Spectrometer	HROS	G-CLEF Fabrication	ANDES Phase A
Near-IR	AO-assisted Imager	IRIS Final design	GMTIFS Preliminary Design	MICADO Final design
	IFU spectroscopy			HARMONI Final design
	AO-assisted Echelle Spectrometer	MODHIS Conceptual design	GMTNIRS Preliminary Design	ANDES Phase A
Mid-IR	AO-assisted Echelle Spectrometer	b-MICHI		METIS Final design
	Extreme AO	PSI	G-AOX	PCS

Detailed specifications

TMT

more detail at https://www.tmt.org/page/instrument-overview

Instrument	**Field of view/ slit length/ pixel scale**	**Spectral resolution**	**Wavelength range (μm)**
IRIS Final Design	IFU 0.45x0.51”@0.004”/pix to 2.25”x4.4”@0.050”/pix	4000-8000	0.84-2.4
	Imager 34”x34”@0.004”/pix	J, H, K+ narrow bands	
WFOS Preliminary Design	25.5 (8.3x3) arcmin^2, >500” total slit length (~58 targets with 8” slits, 0.5" gaps), 0.05”/pixel	1500-3500 @0.75" slits	0.31-1.0 Full spectral coverage @R=1500
MODHIS Conceptual Design	Four (goal of eight) 0.1”x0.1”collectors, @0.02” spatial sampling, 5” diameter field of regard	100,000	0.95-2.4

GMT

Instruments Available Within Five Years of First Light					
Function/Name	Δλ(μm)	λ/δλ	FoV	Science Drivers	Current Development Stage and Planned Design Milestones
Multi-Object Spectrograph GMACS	0.31 – 1.0	1,000 – 6,000	7′ x 6′	Surveys, Time Domain, Cosmology	Preliminary Design (PDR 12/2023) (FDR 12/2027)
High-Resolution Spectrograph G-CLEF	0.35 – 0.95	50,000 – 200,000	1″ fiber	Exoplanets, ISM, IGM, Stellar Abundances	Fabrication (FDR Spec 12/2018)
High-Resolution Spectrograph GMTNIRS	1.1 – 5.5	65,000 – 85,000	3″ long slit	Stars, Exoplanets, Debris Disks	Preliminary Design (PDR 6/2023) (FDR 9/2025)
IFU & Imager GMTIFS	1.0 – 2.5	5,000 & 10,000	4″/20″	Galaxies, Black Holes, Exoplanets, Star Formation	Preliminary Design (PDR 10/2023) (FDR 7/2026)
MANIFEST	Facility fiber feed system for seeing-limited spectrographs			Surveys, Galaxies, Stars, Cosmology, Exoplanets	Conceptual Design (PDR 2/2026) (FDR 9/2027)

ELT

Ramsay et al. (2021) update. Note public information about first science observations is Sept 2027 (6 months after technical first light). https://www.eso.org/public/announcements/ann21008/

Instrument	Main specifications			Schedule				
	Field of view/slit length/ pixel scale	Spectral resolution	Wavelength coverage (µm)	Phase A	Project start	PDR	FDR	First light
MICADO	Imager (with coronagraph) 50.5′ × 50.5′ at 4 mas/pix 19′ × 19′ at 1.5 mas/pix	*I, Z, Y, J, H, K* + narrowbands	0.8–2.45	2010	2015	2019		
	Single slit	*R* ~ 20000						
MAORY	AO Module SCAO – MCAO		0.8–2.45	2010	2015			
HARMONI + LTAO	IFU 4 spaxel scales from: 0.8″ × 0.6″ at 4 mas/pix to 6.1″ × 9.1″ at 30 × 60 mas/pix (with coronagraph)	*R* ~ 3200 *R* ~ 7100 *R* ~ 17000	0.47–2.45	2010	2015	2018		
METIS	Imager (with coronagraph) 10.5″ × 10.5″ at 5 mas/pix in *L, M* 13.5″ × 13.5″ at 7 mas/pix in *N*	*L, M, N* + narrowbands	3–13	2010	2015	2019		
	Single slit	*R* ~ 1400 in *L* *R* ~ 1900 in *M* *R* ~ 400 in *N*						
	IFU 0.6″ × 0.9″ at 8 mas/pix (with coronagraph)	*L, M* bands *R* ~ 100000						
HIRES	Single object	*R* ~ 100000	0.4–1.8 simultaneously	2018				
	IFU (SCAO)							
	Multi object (TBC)	*R* ~ 10000						
MOSAIC	~ 7-arcminute FoV ~ 200 objects (TBC)	*R* ~ 5000–20000	0.45–1.8 (TBC)	2018				
	~ 8 IFUs (TBC)	*R* ~ 5000–20000	0.8–1.8 (TBC)					
PCS	Extreme AO camera and spectrograph	TBC	TBC					

1 milliarcsecond (mas) = 0.001″