

# 4. Top level requirements

## 4.1 Introduction

The top level requirements are derived from the science case and are a set of overall specifications for the design of the telescope, including its instrumentation, so that it can fulfil the science objectives. The science case is itself still evolving, and the top level requirements will be adapted to reflect new input until such a time when the level 1 (engineering) requirements needs to be frozen (in the preliminary design phase).

The knowledge of what can be considered technologically realistic also enters into the process of setting the requirements, and some tradeoffs between different needs are sometimes necessary.

The top level requirements are the basis from which are derived the level 1 requirements that define, at system and subsystem level, how to achieve the desired performance.

The top level requirements do not specify the details of the engineering solutions (these are spelled out in the level 1 requirements), although in some areas where it may be helpful to drive technological development (e.g. in adaptive optics), or where there are known limitations (physical, e.g. atmospheric properties, or technological) more elaborate requirements may be necessary. For example, a requirement for telescope tracking would not appear to be within the scope of the top level requirements as it is implicit in the requirements for image quality, but the effects of atmospheric refraction (that will limit the range of zenithal distances at which “wide” field observations can be carried out) need to be reflected in the top level requirements (to avoid the risk of setting stringent level 1 requirements for capabilities of the telescope that cannot be used).

## 4.2 Overall requirements

### 4.2.1 The OWL telescope

OWL will be a 100m-class, adaptive optics telescope working in the optical, infrared and, as a goal, in the sub-mm wavelength ranges. It will have a collecting area of  $\sim 7,000 \text{ m}^2$ , deliver diffraction-limited performance and be equipped with a suite of instruments able to achieve the main science goals of the project.

As the fabrication and integration of primary mirror segments may take several years, ways to use the telescope for science before the primary is completely filled shall be explored.

## 4.2.2 The Conceptual Design (Phase A)

The conceptual design of OWL will have the goal to assess the feasibility of a 100m telescope. To this end, it will be based on technical and technological solutions that are, to the maximum extent possible, proven and reliable. In particular, R&D should be limited to areas where present day technology would not suffice (e.g. in adaptive optics) or to validate options to specific solutions (e.g. alternatives to glass for the mirrors).

Options for designs of different aperture should be analyzed. A 100-m *baseline* design should be developed in detail, and its properties used as interface to subsystem studies.

Phase A should provide an indicative analysis of cost, schedule and performance variations in relation to telescope size and design.

It is to be understood that if the project goes to the next phase (preliminary design), the requirements and baseline design will be thoroughly re-assessed.

## 4.2.3 Evolution of the Top Level requirements

The present requirements apply to Phase A (Conceptual Design) and B (Preliminary and Detailed Design Phases). It is understood, however, that the conceptual design may occasionally fail to demonstrate compliance, under the proviso that plausible remedies to be undertaken in Phase B are clearly identified and planned for.

As the science case develops, requirements may be added or changed to reflect the new input. To the maximum possible extent, project phases should be planned in a way allowing requirements to be frozen at the latest reasonably possible stage. At the end of the detailed design, when comprehensive plans for assembly, integration and testing, and for operations are developed, the top level requirements may be extended to include requirements pertaining to these future stages of the project.

Should the size of the telescope need to be modified, the top level requirements will be modified as well according to the appropriate prescriptions (e.g. scaling the requirements according to their functional dependence on diameter  $D$ : none,  $\propto D$ ,  $\propto D^2$  etc).

## 4.2.4 Operational lifetime

The operational lifetime of OWL is expected to exceed 30 years and the design should be developed accordingly. During this time, OWL, its instruments, its adaptive optics, its data systems (collectively referred to as the OWL system) are expected to undergo significant upgrades and enhancements in response to the advances of technology and the evolution of the science case.

## 4.2.5 Location of OWL

The search of a site for OWL will continue until the moment the site properties need to be incorporated in the final design. The choice of the site will be the result of a thorough trade off analysis of atmospheric, logistical, seismic and ground properties, and of astronomical considerations (e.g. available fraction of the sky). Low cloud coverage, low precipitable water vapour, moderate ground-level wind, adequate turbulence characteristics (turbulence profile, amplitude, and coherence time) will be major selection criteria. The site should ideally be suited to observations also in the mid to far (sub-mm) infrared.

## 4.2.6 Optical design

The optical design of OWL will provide diffraction-limited performance in a 2 arcmin (diameter) field of view in the K band (goal 3 arcmin), and in a 0.5 arcmin field of view in the V band (goal 1 arcmin). The total field of view, i.e. scientific plus technical, will be 8 arcmin or more. The final

focal ratio will provide a focal plane such that the optical beam is transmitted to the instruments without auxiliary optics. The design will have the means to transfer the focus to at least 4 focal stations where instruments can be mounted.

#### **4.2.7 Maintenance**

Once operational, the OWL facility will be maintained in such a way that allows the top level requirements to be preserved during operations, with a technical downtime of less than 3% (goal 2%). The OWL design will include maintenance concepts from the conceptual design phase in order to simplify technical activities and to reduce the operational costs of the facility.

#### **4.2.8 Instrumentation**

OWL will have a number of fixed, semi-permanently mounted instruments. These will be modified, upgraded or replaced at well announced times after an approved program to do so has been executed and documented. Some instruments will be general-use observatory facilities; others might be specialized experiments with a well-defined finite life program. A number of concept designs will be developed during the design phase of the telescope, with a choice of those to enter Preliminary and Final design to be taken about two years into the telescope Phase B.

#### **4.2.9 Coating optimization**

The coating of OWL shall cover the wavelength range from 0.5 to 25 $\mu$ m, with blue-UV and sub-mm microwave reflectivity as a goal. Every effort to achieve the highest possible reflectivity shall be made. During the conceptual design phase, protected Ag coating as developed recently by the Gemini Observatory will be assumed. Studies about the feasibility of extending its blue-UV reflectivity will be performed during Phase B.

#### **4.2.10 Astronomical site monitor**

An astronomical site monitor will be part of the OWL observatory and will provide means to characterize the atmospheric conditions above the observatory as well as monitor meteorological conditions. It will be defined and designed in Phase B. Options to have multiple monitors at various distances from the site in order to predict/foresee changes in atmospheric conditions shall be explored.

#### **4.2.11 Safety**

Safety during construction and operations will be a driver of the design. Concepts will be developed during Phases A and B so that guaranteeing the safety (human resources and hardware) can be achieved in a simple, verifiable and logical way.

### **4.3 Performance requirements**

This section defines the minimum acceptable performance capabilities of the OWL facility as required by the science case.

### 4.3.1 Telescope transmission

The telescope shall have freshly coated reflectivity (per surface) of 98% (goal 99%) from 1 to 25  $\mu\text{m}$ , 95% (goal 98%) from 0.5 to 1  $\mu\text{m}$ , and > 90% (TBC) to 1mm. Blue-UV sensitive coatings shall be a goal. Coating reflectivity shall not degrade by more than 1% during operations.

### 4.3.2 Emissivity

The telescope shall be designed so that its total emissivity at wavelengths above 2 $\mu\text{m}$  will not exceed  $(1-\eta)^n$  with  $\eta(\lambda)$  the reflectivity per mirror and  $n$  the number of mirrors<sup>36</sup>, and in any case be less than 15% (telescope only, goal 8%). Baffling will be included in the design to avoid direct view of the sky or of any part of the structure.

### 4.3.3 Sky coverage

The fraction of the sky accessible to OWL will depend on the site selection. This parameter shall be included in the site selection trade-off.

The telescope shall operate at zenith distances from 1 to 60 degrees (goal 0.5 to 70 degrees). Ways to counter the zenith distance limitations imposed by atmospheric refraction to observations in “wide” field (0.5 arcmin in V, 2 arcmin in K, see 4.3.6) shall be explored in Phase B. These will include as a minimum post-processing, active optical elements and appropriate operational strategies.

### 4.3.4 Image quality

Image quality is as much a driver as collecting power for almost all the science objectives of OWL. If highly improved energy concentration down to the diffraction limit cannot be achieved, much of the *raison d'être* of OWL would disappear. Therefore this section goes into a somewhat more detailed discussion.

#### 4.3.4.1 Telescope

The image quality delivered by the telescope design will be such that the corresponding correction carried out by adaptive optics to reach the diffraction limit performance will be kept at a minimum.

#### 4.3.4.2 Adaptive Optics

Adaptive Optics is probably the most demanding technological development to achieve the science goals of OWL. In a very concrete sense we consider it as a *go/no-go* milestone for the project. To allow maximum development time, AO will be developed in successive stages, with a progressive increase of capabilities.

Science “first light” (whether or not with a partially filled primary) will provide at least single conjugate AO correction in the near infrared.

The requirements for Adaptive Optics are set according to the following:

- The first generation of AO correction is required to achieve at least 80% of the stated requirements. It is not required that the first generation include the most demanding techniques (e.g. extreme AO).
- The requirements are intended for observations within 30 degrees of zenith. Larger zenith distance degradation (due both to the atmospheric behaviour and to the allowed zenith-dependent performance of the telescope) is acceptable.

<sup>36</sup> If the reflectivity is different for different mirrors this becomes  $\prod(1-\eta_i)$ ,  $i=1,n$

- For the purpose of simulations before the final site characteristics are defined, all atmospheric parameters and statistics shall be those of Paranal.
- When a requirement is given at only one wavelength or band, it is understood that the instrumental realization will provide correction at adjacent bands.
- For ground layer AO, the requirements are set as ensquared energy (EE) rather than Strehl
- An attempt at taking into account seeing and reference star magnitude is made for some modes. If at instrument design level it is found that the relationship between these has a different behaviour, the most stringent requirement shall be the driver.
- Sky coverage will be driven by the individual science cases. However, for the purpose of this chapter, the following should be assumed for the first generation of instruments:
  - Exoplanets: all available stars ( $V < 10$ ) within the zenith limitation
  - Cosmology: sky coverage provided by NGS (~20% at K at galactic poles, MCAO)
  - In the long term, the sky coverage for cosmology should reach 80% at K at GPs.
- Field of view values are intended as diameter of a circular field of view unless expressed otherwise (e.g.  $2 \times 2$  arcsec<sup>2</sup> is a square field of view)

#### 4.3.4.2.1 Telescope AO

The telescope will include in its optics adaptive mirrors that will provide “system” AO correction. They either provide the full correction in certain modes (e.g. IR SCAO, IR GLAO, dual conjugate IR AO), or represent a first stage of a complex AO system, with other stages probably integrated in an instrument.

The requirements for SCAO, MCAO and GLAO are to be understood as requirements for the system-delivered AO correction.

#### 4.3.4.2.2 Single Conjugate AO

SCAO will be used in a variety of conditions. Its range of application will be 1 to 5  $\mu\text{m}$ . The field of view will be  $> 30''$ . Requirements are given at J and K band, with usual extrapolation to other wavelengths assumed. Values are the on axis correction.

Star mag	Seeing	Strehl (J)	Strehl (K)
13.5	0.4	0.45	0.75
	0.6	0.35	0.65
	0.8	0.25	0.55
	1.2	0.10	0.40
15.5	0.4	0.15	0.45
	0.6	0.10	0.35
	0.8	0.05	0.25

Table 4-1. Single conjugate AO requirements.

#### 4.3.4.2.3 Multi Conjugate AO

MCAO will operate between 1 and 2.5  $\mu\text{m}$ , over a field of view of at least  $2 \times 2$  arc minutes<sup>2</sup>, in a variety of observing conditions. The star magnitude is to be intended as the integrated magnitude of the multiple reference stars. A  $\pm 10\%$  departure from the mean of the PSF across the field of view will be acceptable.

Star mag	Seeing (arc secs)	Strehl		
		J	H	K
13.5	0.4	0.20	0.35	0.45
	0.6	0.15	0.30	0.40
	0.8	0.10	0.25	0.35

Table 4-2. Multi-conjugate AO requirements.

#### 4.3.4.2.4 Ground Layer AO

GLAO is intended to provide reduced-seeing images, formally with a Strehl Ratio of a few percent. The performance values are expressed in Ensquared Energy (EE), and represent the improvement with respect to seeing within a 50 mas pixel. GLAO will operate between 1 and 2.5  $\mu\text{m}$ , over a field of view of at least 3 arc minutes. A  $\pm 5\%$  variation from the mean of the PSF across the field of view will be acceptable.

Star mag	Seeing (arc secs)	EE gain		
		J	H	K
13.5	0.6	2.5	3.0	3.5
	1.2	2.0	2.5	3.0

Table 4-3. Ground-layer AO requirements.

#### 4.3.4.2.5 Multi-Object AO

Multi-Object AO (also called Distributed AO) aims to provide a higher level of energy concentration in an even larger field of view by performing pseudo closed-loop SCAO corrections on a number ( $\sim 10$ -20) of selected objects in the field. Minimum specifications are given in the Table below, with a goal 4 times higher.

Star mag	Seeing (arc secs)	EE gain		
		J	H	K
13.5	0.6	40	60	80
	1.2	10	15	20

Table 4-4 Multi Object AO requirements

#### 4.3.4.2.6 Extreme AO

It is understood that this is the most demanding technique, driven by the exoplanets science case. It is envisaged that the best (10%) seeing conditions will be available for such science case.

Star mag	Seeing (arc secs)	Strehl Ratio			
		V	J	H	K
< 10	< 0.6	0.40	0.87	0.92	0.96

Table 4-5. Extreme AO requirements.

#### 4.3.4.2.7 AO at optical wavelengths

It shall be the ultimate goal of OWL to provide diffraction-limited images at optical wavelengths. It is conceivable that the first step in this direction will be the adaptation of Extreme AO technology developed for the IR to SCAO for the Optical domain.

The star magnitude is intended as the magnitude of a single reference star or the integrated magnitude of multiple reference stars, whether natural or artificial.

Star mag	Seeing (arc secs)	Strehl Ratio		
		V	R	I
< 10	0.4	0.4	0.5	0.6
	0.6	0.3	0.4	0.5
	0.8	0.2	0.3	0.4

Table 4-6. AO requirements at optical wavelengths (provisional).

#### 4.3.4.2.8 Laser Guide Stars

Single and multiple laser guide star systems will be necessary to either/both extend the sky coverage and/or to provide sufficient flux to perform the wavefront analysis. Detailed feasibility of LGS systems will be studied in Phase B, as will ways to counter the limitations imposed by the out-of-focus nature of LGS images at ~ 90 km altitude (e.g. pulsed lasers, readout gating, extra optics etc).

### 4.3.5 Atmospheric dispersion compensation

Atmospheric dispersion will be corrected, either at telescope level or, if too difficult, at instrument level. Ways should be explored in Phase B to assess feasibility of using atmospheric dispersion as a dispersive element of some instrument (e.g. with partial correction so that it is kept constant over some range of zenith distance).

The compensation shall be such that the residual dispersion will be less than 0.2 pixels of the relevant instrument at the relevant wavelength. The transmission of the compensator should exceed 97%.

At the spatial resolution scale of OWL, active closed loop compensations may be necessary.

### 4.3.6 Atmospheric refraction

In diffraction-limited observations and for fields of view larger than several arc seconds, the differential position displacement at different locations due to refraction may prevent long exposures. Unless the readout noise of detectors is extremely low (so that short exposure can be co-added after geometrical alignment), or techniques to reformat the focal plane can be developed (e.g. with active cylindrical optical elements), this may represent a problem for a 100m telescope.

The effect in the K band at the edges of a 2-arcmin field between meridian and one hour after (or before) is summarized in Table 4-7 for various values of the declination. The effect is computed for two stars separated by 1 arcmin in right ascension (RA) or declination (DEC) for the K band (i.e. for a total field of view of 2 arcmin as the center of the FoV can be kept fixed by the control system), and for stars separated by 30 and 15 arcsec in the V band (FoV of 1 and 0.5 arcmin respectively). The observatory parameters are those of Paranal.

If one assumes that the maximum acceptable differential displacement per single exposure is 10% of the diffraction limit, the maximum exposure time is indicated for the V and K bands. The time limit is set by the smaller of the two exposure times in RA and DEC. This effect is only very mildly wavelength dependent, so extrapolation at other bands is straightforward.

A diffraction-limited field of view of 2 arcmin in the V band is not at present a science requirement (and given that the exposure times computed for K have to be divided by  $\sim 4$  to apply to the V band it may prove a very challenging goal, matched only by the challenge of paving such a field with 0.7 mas pixels). For the V band the effect is computed both for 1 and 0.5 arcmin FoV. The latter is the present science requirement. The required readout noise so that the short exposures can be background-limited (to allow geometrical correction before co-addition) should be  $\text{RON}^2 < 0.2 \times \text{background/pixel}$ , and is well within the capabilities of present day detector technology in the IR. For the V band, where the background is  $\sim 1$  photon per minute per half-PSF pixel, post-processing alone may not be the solution to the problem (especially is the field is  $\geq 1$  arcmin and at substantial zenith distance). The other options mentioned above may be the only recourse.

Decl	Effect in 2' FoV, K band				Effect in 1' FoV, V band				Effect in 0.5' FoV, V band			
	Sep in RA		Sep in DEC		Sep in RA		Sep in DEC		Sep in RA		Sep in DEC	
	Displ [mas]	$\Delta T$ [min]	Displ [mas]	$\Delta T$ [min]	Displ [mas]	$\Delta T$ [min]	Displ [mas]	$\Delta T$ [min]	Displ [mas]	$\Delta T$ [min]	Displ [mas]	$\Delta T$ [min]
35	-2.88	12	-2.15	15	-1.46	6	-1.09	8	-0.73	11	-0.55	15
25	-1.75	19	-0.92	36	-0.89	9	-0.47	18	-0.44	19	-0.24	35
15	-1.24	27	-0.48	> 60	-0.63	13	-0.24	34	-0.31	26	-0.12	> 60
5	-0.97	34	-0.27	> 60	-0.50	17	-0.14	> 60	-0.25	34	-0.07	> 60
-5	-0.83	40	-0.16	> 60	-0.42	20	-0.08	> 60	-0.21	39	-0.04	> 60
-15	-0.76	44	-0.08	> 60	-0.38	22	-0.04	> 60	-0.19	43	-0.02	> 60
-25	-0.73	45	-0.02	> 60	-0.37	22	-0.01	> 60	-0.19	45	-0.01	> 60
-35	-0.75	44	0.04	> 60	-0.38	22	0.02	> 60	-0.19	44	0.01	> 60
-45	-0.81	41	0.11	> 60	-0.41	20	0.06	> 60	-0.21	40	0.03	> 60
-55	-0.95	35	0.23	> 60	-0.48	17	0.12	> 60	-0.24	34	0.06	> 60
-65	-1.20	28	0.45	> 60	-0.61	14	0.23	37	-0.30	27	0.11	> 60
-75	-1.68	20	0.91	36	-0.85	10	0.46	18	-0.43	19	0.23	36
-85	-2.76	12	2.18	15	-1.39	6	1.11	7	-0.70	12	0.56	15

Table 4-7. Effect of differential displacement due to atmospheric refraction between meridian and one hour from meridian. RA and DEC are right ascension and declination, Sep is the separation between the stars, Displ is the relative differential displacement in milliarcsec at one hour from meridian, and  $\Delta T$  is the maximum exposure time in minutes to have a displacement  $< 10\%$  of the diffraction peak.

It is clear that higher latitude sites would suffer less from this effect, but a choice of site at moderately low latitude guarantees access to a larger fraction of the sky, so higher latitudes may not be the solution.

This effect should be considered in instrumentation using similar or larger fields of view, e.g. multi-object spectrographs using mini IFUs, as these may need to be repositioned in the FoV to maintain the objects properly centered.

