TOP LEVEL SCIENTIFIC AND OPERATIONAL REQUIREMENTS FOR NAOMI

wht-naomi-102

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1. Revised and extended requirements and goals

In the following specifications, *Strehl ratio* is used as a measure of image quality. This is the ratio of the central intensity of the delivered point-spread function (PSF) to that of an unaberrated image from the same telescope at the same wavelength. Where a high Strehl ratio is quoted (clause A) this means that a high proportion of the energy of the PSF will be present in a diffraction-limited core; the converse is also of great importance, that a small proportion of energy is in an extended halo. Image Full Width at Half Maximum (FWHM) is not a good indicator of adaptive optics system performance because very partial correction can produce a small diffraction-limited spike which, although it contains a very small proportion of the total image energy, has the best possible FWHM. The effect of the uncorrected seeing is expressed as the coherence length, r_0, at ? = 0.5 ?m. r_0=10 cm corresponds to 1 arcsecond seeing and r_0=20 cm corresponds to half-arcsecond seeing. All specifications in terms of seeing apply to the seeing at the zenith distance of the object.

The requirement clauses have been grouped by category. The original denotations (A, B, etc.) have been retained for compatibility with previous documents. The current ordering is therefore not monotonically alphabetical.

Upgrade routes available for extending the baseline NAOMI specifications are indicated in the same format as this paragraph. The maintenance of this upgrade potential is to be regarded as part of the baseline NAOMI specification and subject to the same change control.

1.1 Primary Scientific Requirements

1.1.1 Clause 1 (High Light Level Image Quality)

The AO system shall be capable of delivering an output Strehl ratio of at least 65% on-axis at a wavelength of 2.2 microns with guide stars of magnitude 8 or brighter when the visible (0.55 micron wavelength) atmospheric coherence length r_o is 20 cm or larger (optical (V) seeing ? 0".5). Performance at 1.25 microns shall be commensurate with the 2.2 micron performance after taking into account the additional Strehl ratio degradation introduced because of the wavelength dependence of the turbulence effects.*

* This is the clause which defines the ultimate system performance, unlimited by the number of photons detected per sub-aperture. Please see the attached samples of current modelling which predict that this level of performance will be available with much fainter reference stars.

This clause drives the following specifications:

?? system order (i.e. the number of correctable degrees of freedom of the AO system). The effect of system order is illustrated in Fig. 1 (H-band) and Fig. 2 (K-band). The figures show the effect of the seeing coherence length r_0 on Strehl ratio for various systems. The system order is expressed as the number of wavefront sensor subapertures across the diameter of an image of the WHT primary

?? tip-tilt error budget

?? uncorrectable mechanical flexure budget (i.e. those system aspects which the AO system will not self-correct)

?? uncorrectable optical error budget (The assumption is made that uncorrectable telescope aberrations will not limit performance. Data on these aberrations have been requested by the programme.)

?? the performance of the real-time control system and software and the system latency including the WFS image collection and pre-processing.

1.1.2 Clause 2 (Low Light Level Image Quality)

Minimum Requirement:

At the same science wavelength, correction wavelength and r_o as for clause A, the system should aim to achieve at least 25% Strehl ratio at the centre of the science field, with 25% sky coverage. Strehl ratio across the science field can vary according to separation from the guide star as would be predicted by standard tubulence models (being highest closest to the guide star).

Any failure to meet these specifications, for either clauses A or B, shall be due to atmospheric limitations alone. The feasibility of these clauses is predicated on models assuming atmospheric conditions equivalent to a single turbulent layer moving at 10 m/sec at 3 km above the telescope.

Goal:

At the same science wavelength, correction wavelength and r_o as for clause A, the system should aim to achieve at least 25% Strehl ratio at the centre of the science field, with 50% sky coverage. Strehl ratio across the science field can vary according to separation from the guide star as would be predicted by standard tubulence models (being highest closest to the guide star).

This clause drives sky-coverage issues:

?? Wavefront Sensor (WFS) and (for the upgrade goal), Tip-Tilt Sensor (TTS) sensitivities

?? the ability to change the spatial sampling on the WFS (i.e. to reduce the system-order)

?? conjugation capability - the ability to perform correction at an image of atmospheric turbulence.

?? guide star search field

1.1.3 Clause 3 (Seeing and Wavelength Operating Conditions)

The system shall give a net gain in imaging signal-to-noise ratio (SNR) of a point source at wavelengths ranging from 1.0microns (the Ca+ triplet) to 2.5 microns (goal: 0.82 to 4.1 ? m) in atmospheric turbulence conditions as poor as ro = 8 cm (1".2 optical seeing) and with guide stars at least as faint as visual magnitude 14.

The NAOMI system alone shall have a throughput >70% to the Infrared Science Port at wavelengths > 1? m and a throughput to the wavefront sensor > 25% at wavelengths 0.9? m < ? < 1.0? m

This clause drives the following specifications:

?? science path throughput/emissivity

?? system “availability” (i.e. under what range of seeing conditions should the system be able to work).

?? the required transmission/reflectance curve of the dichroic mirror, other system surface coatings and the number of system optical surfaces.

1.1.4 Clause 4 (IR Observational Dithering)

The system should additionally be capable of producing a "dithering" offset of 18 arcseconds without shifting the pupil with respect to the science instrument and without losing lock. It shall be capable of continuously tracking objects at non-sidereal rates limited only by the guiding rate of the WHT for a self-referenced object and of 4 arcsec/sec in each co-ordinate for objects needing an independent guide star.

This clause derives from IR observational sensitivity requirements, ensuring best possible options are available for flat fielding using the sky. The clause drives the following specifications:

?? WFS and TTS pick-off methods

?? pupil imaging/conjugation optics

?? the overall control software and its interface to the telescope

1.1.5 Clause 5 (Correction Stability)

The system shall maintain loop closure between the WFS and deformable mirror for at least 60 minutes in stable conditions of single turbulent layer windspeed less than 5 m/sec and r_o > 15cm with an on-axis guide star brighter than $R=10^m$.

This clause drives or affects the following specifications:

?? electronics (camera, RTCS hardware) stability

?? mechanical stability

?? RTCS software robustness

1.1.6 Clause 6 (Observational Efficiency)

The goal of the system performance shall be to allow the astronomer to spend at least 50% of the night-time hours integrating on science targets or astronomical standards as required to calibrate the science instrument , when sky conditions are stable and photometric.

Once installed and aligned the system shall require no more than 30 minutes to optimise/confirm the alignment in any 24 hour period.

This clause drives or impinges on the following specifications:

(some specifications are not completely orthogonal to others; for example Clause F drives the degree of automation of mode switching and optimization while Clause B drives its presence in the first place).

?? automation of the calibration functions

?? automation of the moving slides, lenslets and filters in the optical chassis and WFS

?? links between the TCS and the Instrument Control System

?? level of software and tools written for visualization, modal control and optmisation, target acquisition

1.1.7 Clause 7 (IR science port)

The science field of view shall be at least sufficient to illuminate all of a 1024x1024 imaging array fully-sampled at the 1.65 micron diffraction limit with no vignetting. Also the system should have a well- defined and accessible infrared science port around which other instruments such as spectrographs and a coronagraph can be designed.

This clause drives the following specifications:

?? minimum science field-of-view and image quality specifications

?? the environment and space envelope of the corrected science focus

?? the overall control software and its interface to science instruments

1.2 Instrumentation Interface Requirements

1.2.1 Clause 8 (IR Science Instrument Optical Interface)

The output beam to the IR science instrument shall be f/16.5. The exit pupil of NAOMI in the IR science path shall be 66.7mm in diameter at a distance of 1100mm from the focal plane. The final angular image scale of the IR science instrument shall be 330? m/arcsec and its unvignetted field of view shall be at least 58 arcseconds in diameter.

1.2.2 Clause 9 (Optical Port: Acquisition)

The NAOMI system shall have an optical wavelength port with field of view 2.9 arcmin in diameter and with throughput > 58% between 0.5 and 0.8? m, which may be used for acquisition. The focal ratio of this optical beam shall be f/16.8.

1.2.3 Clause 10 (Optical Port: Science)

The optical beam specified in Clause H shall also be available for optical science provided that this does not in any way compromise infrared science.

1.2.4 Clause 11 (Network Interface)

Any NAOMI interface to the telescope or any instrument control system shall be via DRAMA and shall conform to ING networking standards.

1.2.5 Clause 12 (IR Science Instrument Control Interface)

The interface to the IR science instrument shall, as a minimum, permit the AO system to inititiate a windowed or non-windowed exposure, to confirm the completion of the exposure and to obtain the data. This entire sequence should complete in no longer than ?? seconds for a 128x128?? pixel window.

The science instrument shall as a minimum be able to command the AO system to open or close the control loops and to perform a specified closed-loop offset.

1.3 Support Requirements

1.3.1 Clause 13 (Preparation, Installation, Removal)

It should be possible to carry out pre-use alignment, calibration and testing off the telescope. A suitable off-telescope mounting base shall be supplied with NAOMI.

It shall be possible for on-island staff to install and align the equipment within 8 hours and to remove it to a WHT storage point in 4 hours.

All these operations should be such that they may be carried out safely by a maximum of two people.

1.3.2 Clause 14 (Documentation)

Documentation shall include, as a minimum, a User's Manual, full system (optics, mechanical, electronics, software architecture) engineering diagrams as built, maintenance procedures and trouble-shooting guidelines. The documentation approach shall be to recognize that the system must be supported by staff who have good appropriate mechanical, electronics and software engineering skill but who did not build the system.

1.3.3 Clause 15 (User Interface)

The User Interface to NAOMI shall allow operation by a trained telescope operator.

The NAOMI system shall provide optional automatic adjustment of the number of corrected modes and of the operational bandwidth. This adjustment process shall adapt to changing atmospheric conditions. A manual override of these operating parameters shall be provided. Information to support the manual choice shall be provided to the operator. This information shall include as a minimum the values of r_0 *and the Greenwood frequency.*

1.3.4 Clause 16 (Operational Lifetime)

The operational lifetime of any tip-tilt mirror and WFS camera shall be > 10000 hours. The deformable mirror shall have an operational lifetime of >3000 hours subject to one actuator failure and replacement.

1.3.5 Clause 17 (Temperature and Humidity)

The NAOMI system shall operate fully over a temperature range from -10^oC *to* 25^oC*, in relative humidity from 10% to 90%, at 8000ft. The system shall be able to survive relative humidity of 100%.*

1.3.6 Clause 18 (EMC)

NAOMI should be designed to conform to good EMC practices. The NAOMI project shall consult with the ING in mutually establishing these practices..

1.3.7 Clause 19 (Standard Components, Spares)

Where appropriate, the same type of electronics components should be used as are already in use at the ING, as defined by the ING. Where other components are used a minimum of one spare for each type shall be supplied. Any exceptions (for example the Deformable mirror) shall be subject to a specific agreement with ING. (In practice 2 weeks written or email notice of the adoption of a card-level component should be given to the on-island project manager before freezing the specification)

VxWorks should be used as the operating system for non-specialised (i.e. AO-specific) local control processors.

1.3.8 Clause 20 (Software Standards)

NAOMI software shall be written to standards agreed with the ING

1.4 Additional requirements

1.4.1 Clause 21 (Thermal Output)

The NAOMI system shall not, by its own thermal power input, degrade the uncorrected local seeing conditions at GHRIL by more than 0".1. The goal shall be for no detectable seeing degradation due to NAOMI's presence.

This clause drives the following specifications:

?? the thermal control of electronics on bench and in attached racks.

1.4.2 Clause 22 (User Software)

IRAF should be assumed as the offline astronomical data analysis environment (i.e. any application provided should not require the existence of some other complete astronomical data reduction environment).

The FINAL archival format should be DISKFITS.

The GUI shall be Motif- or Tk-based. The scripting language shall be Tcl. These are rapidly deveolping areas and these requirements may be revised by mutual agreement with ING.

1.4.3 Clause 23 (Deformable Mirror Removal)

The deformable mirror and its electronics shall be supplied with its own carrying and tranpsort case. It shall be possible to remove and re-install the DM safely, including its electronics, in less than an hour and without dismantling the rest of the NAOMI system. Only minor further optical alignment should be required after re-installation.

1.4.4 Clause 24 (Minimization of emissivity)

An upper limit to the emissivity at 2.2 microns and longer wavelengths of the total optical path to the cryostat window excluding the telescope shall be 20%, with a goal of ? 16%..

These numbers derive from assuming reasonable emissivities (e.g. optimum coatings but not necessarily freshly cleaned) for the minimum practical number of surfaces commensurate with an off-axis paraboloid design (two OAPs, a segmented DM and a dichroic coating compromised to give good throughput to the WFS.

?? This implies the use of a minimum number of surfaces which are, so far as possible, all reflective and drives the choice of coatings of these surfaces.

?? Including a predicted telescope emissivity budget for the WHT at Nasmyth focus the above specification gives a total system emissivity of ?45% with a goal of ?35%.

1.4.5 Clause 25 (Laser beacon upgrade)

The system shall be designed to permit an upgrade to Na laser beacon operation so that the sky coverage over which high Strehl ratios at K can be obtained is limited only by the availability of tip-tilt guide stars when used with wavefront and tip-tilt sensing detectors of at least the sensitivity required by clause C.

Note: this does not mean FULLY EXPLOIT a Na laser beacon - (that is for a generation-2 WHT AO system).

This clause drives the leaving upgrade of an upgrade path to install a separate tip-tilt sensor

2. Relationship between the Science Clauses and Astronomical Projects

A summary table is given below which associates important high spatial resolution astronomical projects with particular clauses.

A number of detailed astronomical cases have been made for AO. A new Gemini document, “Science Drivers for Adaptive Optics on Gemini-North” (1996) by Simon Morris et al. (DAO), is a particularly helpful source of material which distinguishes between high resolution observations most appropriate for 4m AO, 8m AO and HST. The reader is also referred to the AO internal document AOP/SCI/GG/1.0/09/95 from which many of the examples in the summary table below are drawn. Readers are also referred to the Gemini Adaptive Optics Working Group Report (Ellerbroek et al, Racine Chair, October 1993) and to the article by James Beletic in “Future of Space Imaging” (1994), the initial case for the HST Advanced Camera.. The latter, in particular, points out the importance of corrected PSF contrast (or core/halo ratio) when doing imaging or high-spatial resolution spectroscopy in the presence of a diffuse background or a very bright nearby source. Partial adaptive optics (Clause 2) leaves a high proportion of PSF intensity in an extended halo which can seriously affect contrast in many projects. It is for this reason many of the projects in the summary table below have been ascribed to Clause1.

As a general point, the use of the WHT NGS system (in Clause 1) will permit the imaging of any fainter point sources. (1 magnitude deeper in K despite the higher emissivity and reduced throughput inevitably introduced by the AO system optics).

Clause	**Section**	**Specification**	**Astronomical Examples (near-IR)**
1	2.1	Image quality	AGNs and starbursts, Stellar populations (in crowded fields and when seen against extended sources such as external galaxies and galactic nebulae), Young and evolved stars. Extragalactic distance scale (surface brightness fluctuations). Planetary Nebulae.
2	2.2	Sky coverage	Galactic Cores, High-redshift Galaxies, unbiased surveys in general. The ability to get improved resn and/or higher snr obs, on a wide range of unique or one-off type sources (i.e. a reasonable probability of being able to observe a specific target.)
3	2.3	?/seeing range	Faint stellar spectroscopy.
4	2.4	Dithering	To obtain best flat-fielding on IR array, beam switching along a slit. Gives ability to observe a moving object.
5	2.5	Instrumentation	Imaging, spectroscopy, coronography.