CALIBRATION FOR THE GEMINI TELESCOPES

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ABSTRACT

It is planned that the Gemini telescopes will be allocated for a large fraction of the available time in a queue-scheduled mode. The intention is to maximise scientific throughput and take advantage of conditions of excellent seeing or transparency. To make this queue-scheduling possible, the instrument cluster will contain three major instruments, an adaptive-optics bypass that can feed any instrument, and a calibration unit. This calibration unit must support a wide range of instruments and in particular must provide the calibrations necessary to exploit the image quality which is the goal of the Gemini telescopes. We will describe this calibration unit and emphasize the demands placed on calibration by queue observing in ground-based observatories.

1. The Gemini Project

The goal of the Gemini project is to build two 8m telescopes, one in the Northern Hemisphere on Mauna Kea, Hawaii to be commissioned in 1997 and another in the Southern Hemisphere on Cerro Pachon, Chile, to be commissioned in 1999. The southern telescope is to be optimsed for optical and ultraviolet observations; its' northern twin will be optimised for observations in the infrared. (Mountain, Kurz & Oschmann 1994)

The unique capabilities of the Gemini telescopes arise from the emphasis placed on image quality and low emissivity, which are intended to take advantage of the best seeing conditions on each site. Essentially, the telescopes could be described as atmosphere limited. This is to be achieved by

- minimising the local seeing through careful enclosure design
- monitoring and control of the environment in the dome
- sensing and control of the primary mirror figure
- correction for low order atmospheric wavefront distortion
- cleaning the mirrors frequently

Since the telescope itself does not degrade the intrinsic image quality of the observation or contribute significantly to the infrared background emission, observations are more sensitive to the broad range of changing conditions; indeed exposure times may vary by a factor of ten as atmospheric conditions change. The issue of how to get the best scientific output from such a telescope has led to the decision to allocate 50% of the observing time to observations in a 'queue-scheduled' mode, responsive to the prevailing conditions. This is discussed in Section 2.

Each telescope will have up to three instruments mounted at one time, any or all of which could be used during a single night. The instruments are mounted on an instrument support structure, which also houses the acquisition and guidance unit and an adaptive optics system (Section 3).

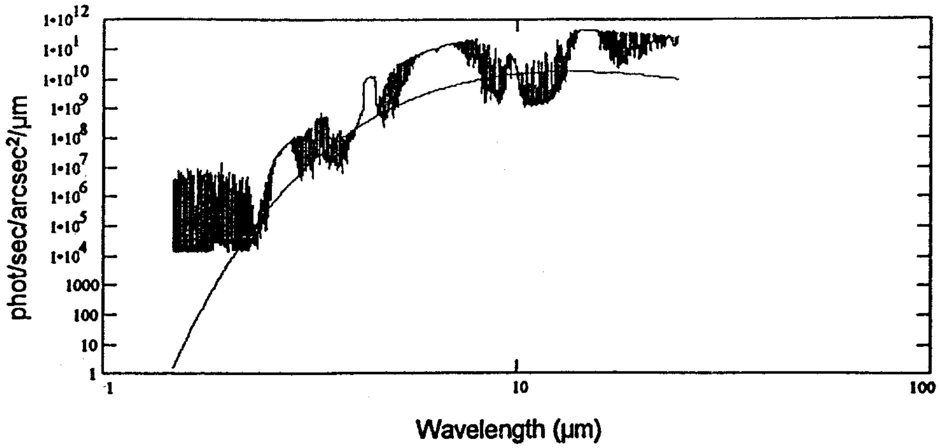


Figure 1: Thermal background emission from the atmosphere and from the Gemini Telescope.

In this paper we describe the steps which are being taken to ensure the smooth and efficient operation of such a complex telescope, and, in particular, the queue-scheduled observing. The provision of a facility calibration unit to provide high quality calibration frames for the Gemini instruments and for maintaining observing efficiency is of paramount importance. The control and data handling systems and the science driven approach to designing and developing them are discussed in Section 5.

2. Queue-Scheduled Observing

Queue scheduled observing is an extension of the decision making process that every astronomer goes through during an observing run e.g. in opting for spectroscopic observations in non-photometric conditions.

Observing conditions on Cerro Pachon and Mauna Kea show a wide range of natural seeing and of infrared background emission due to changing atmospheric emissivity. Values for r_o (at 550nm) vary from 0.42m in 10th percentile conditions, to 0.24m under median conditions. Emissivity varies by a few percent, due to variations in the precipitable water vapour in the atmosphere. The goal for the telescope emissivity is 2% for the northern telescope. Figure shows that for such a low emissivity, thermal emission from the atmosphere dominates the telescope emission for all wavelengths except in the 10µm window. It is predicted that the sensitivity of the telescopes will be affected by the variations in atmospheric emissivity in a way not seen with telescopes with higher emissivity. Mountain, Simons & Boroson have shown that for an telescope emissivity of 10%, typical of existing infrared telescopes, the change in the exposure time required to make an observation as the atmospheric conditions change is negligible. If the telescope emissivity is reduced to 3%, the exposure time varies by ±20%

To examine the benefits of moving to a queue-scheduled mode, Mountain, Simons & Boroson developed a model in which a 'queue' of 25 programmes of 24 observations each, and each requiring three nights of clear weather, was scheduled during a semester of typical conditions. Using 'classical' (i.e. random) scheduling, 10% of the programmes were completed; 60% were completed using queue scheduling.

The role of the instrument cluster and the calibration unit in maintaining an effective queue-scheduled observing mode is evident from the simple example of photometry vs. spectroscopy. In the Gemini model, more sophisticated decisions can be made based on information about the prevailing conditions. For example, the mid-infrared instrument, Michelle, is insensitive to poor seeing, as the image sizes are determined by diffraction effects. Conditions change on timescales of hours, so a change of instrument on this timescale may be required to optimise the observing queue. This leads on to the question of how to calibrate the different instruments during the night. To meet the observing efficiency goal of 90%, calibration observations must be automatic and infrequent. The facility should be available to carefully log the calibration observations made during the night, so that observations for which calibration frames already exist may be preferentially selected from the queue.

3. The Acquisition and Guidance Unit

The acquisition and guidance (a+g) system is key to achieving the design image quality, as it collects wavefront information for both the primary and secondary mirrors in addition to providing the means for acquiring targets and guiding the telescope. The unit also directs the telescope or calibration beam into the Instruments, including passing the beam through the adaptive optics system if required, by means of two deployable mirrors. The layout of the a+g unit is shown in Figure 3. It is organised into five separate modules containing the components which fulfill the functions outlined above. In specific cases, the acquisition and guiding functions of the a+g unit may be carried out be wavefront sensors built into the instruments. The a+g unit is seen as complementary to these sensors, and may be used in tandem with them.

Module 1 contains the high resolution wavefront sensor (HRWFS) used to determine the shape of the primary mirror and to calibrate the look-up tables needed to control the active mirror supports. After the initial calibration, the HRWFS will be used a few times a night to update these values. The wavefront sensor is a Shack Hartmann system, with 10x10 and 20x20 lenslet arrays. An acquisition camera with a $2'$ field of view is integrated in the HRWFS; modes of acquisition are discussed below.

Module 2 contains the science fold mirror, a deployable mirror able to direct either the calibration beam or the telescope beam into any of the instruments.

The peripheral wavefront sensors (PWFS, located in Modules 3 and 4) provide the guiding capability. They patrol an annulus around the science field with inner radius $3.5'$ and outer radius $6'$. There are two guide probes, each of which is capable of accessing any point in the field; two probes are need to track the field rotation (the rotation error should be less than $0.01''$, monitor, and possibly control, the telescope collimation. The current design is for two visible wavefront sensors; having two probes provides the flexibility to introduce an infrared sensor for guiding in obscured regions. Each PWFS senses tip/tilt and defocus of the telescope on timescales of 50Hz, this information is then used to control the secondary mirror. The wavefronts observed are integrated in software to provide low-order correction of the primary mirror shape (coma, astigmatism) on timescales of minutes. These wavefront sensors are low-order Shack-Hartmann sensors; three lenslet arrays from 2x2 to 8x8 are being considered to allow the PWFS to cope with conditions of worst seeing, but also to provide accurate measurements of the primary figure.

Module 4 also contains the adaptive optics fold mirror. If the adaptive optics system is to be used, it is deployed, passing the beam from the telescope into the AO unit, located on the right hand side of this diagram (Figure 3). The corrected beam is passed to the science fold mirror and then to the instrument.

These modules are all located within the instrument support structure (Figure 2), onto which are mounted each of the instruments, the adaptive optics system and the calibration system. The calibration system is considered an integral part of the a+g unit (Module 5) contributing as it does to the operation of the telescope. It is described in detail in the following Section 4.

Acquiring an astronomical target with the accuracy demanded by the narrow slits of the Gemini spectrographs ($0.05''$) is non-trivial. It will be achieved using a combination of the acquisition camera, the PWFS and verification through the instruments. The preferred method will depend on the exact configuration of the instrument, and the accuracy to which the target position is known. Through-instrument acqusition undoubtedly provides the required accuracy, but the process of improving upon the pointing accuracy of the telescope ($3''$) may be time consuming, and might require re-configuration of the instrument. The location of the acquisition camera, close to the f/16 focus, makes it the most stable instrument and it is the obvious choice for acquiring objects onto instruments mounted at prime focus. For side-mounted instruments, the science fold mirror would have to be retracted to allow the acquisition camera to be used, in which case using the PWFS is convenient. The PWFS must be used if there is not a reference star within the comparatively small field of the acquisition camera ($2'$) and may be used in preference, since they are able to patrol the guide field and select a brighter offset star.

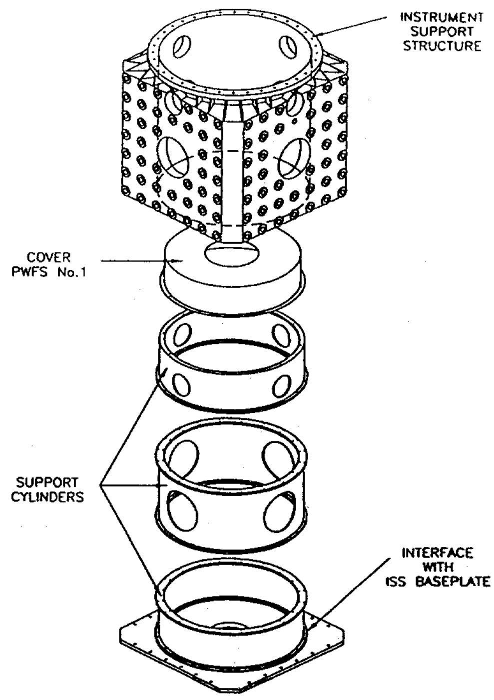


Figure 2. The instrument support structure.

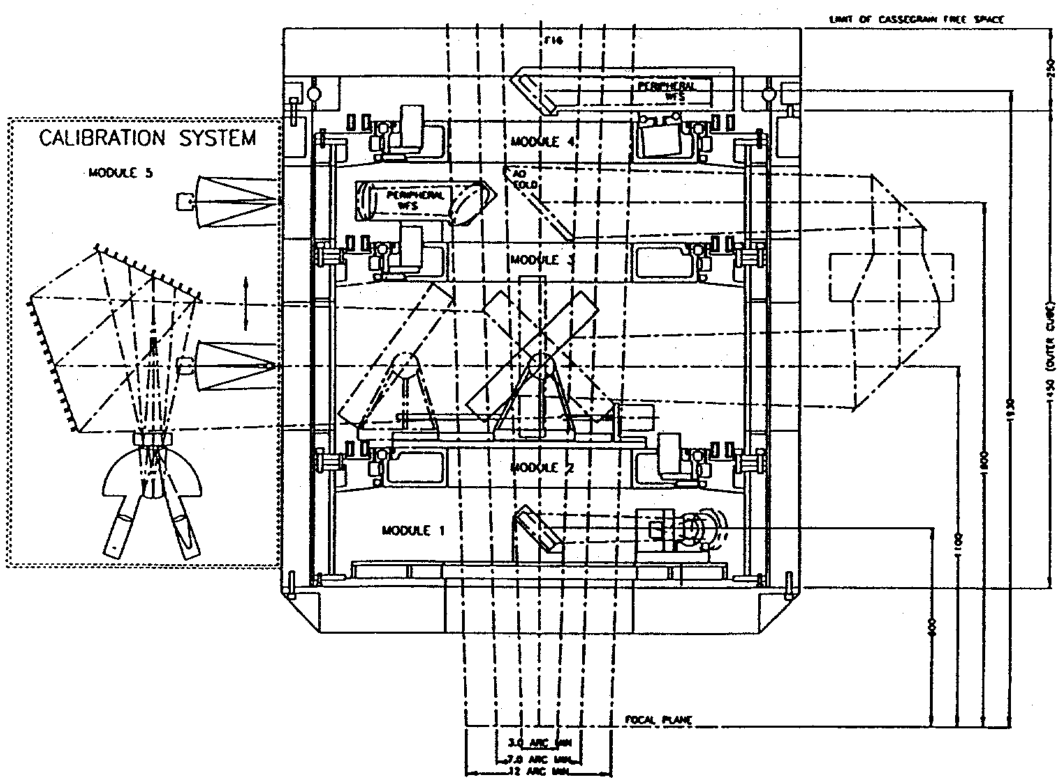


Figure 3. The Acquisition and guidance unit, showing the position of the calibration unit module.

4. The Gemini Calibration Unit

The purpose of the calibration unit is to provide flat-fielding and wavelength calibration facilities for the Gemini facility instruments, which range from an optical multi-object spectrograph to a mid-infrared imaging spectrometer. In addition, the Gemini calibration unit will contain a reference wavefront which may be fed into the adaptive optics system or used to calibrate the on-board wavefront sensors. The basic requirements on such a system are that it should simulate the f/16 telescope beam from the telescope and provide adequate flux from calibration lamps at the telescope focal plane.

Instrument	Wavelength Range	Smallest Pixel Scale	Largest Field Size
HI-Res. Optical Spectrograph (HROS)	0.4-1.1 μm	0.096″	1′
Gemini Multi-Object Spectrograph (GMOS)	0.4-1.1 μm	0.08″	7′
Near IR Imager	1-5 μm	0.02″	102″
Near IR spectrometer	1-5 μm	0.05″	150″
Mid IR Imaging- Spectrometer (Michelle)	8-27 μm	0.36″	46″

Table 1: The first light instruments

The first set of instruments planned for Gemini is summarised in Table 1. The entire wavelength range from 0.4μm to 27μm must be served by the calibration unit. The field size to be illuminated it the complete science field of 7′, though this is required only for the Gemini Multi-Object Spectrograph, the other instruments having fields of ~1′. These instruments are designed to maximise spatial and spectral resolution, taking full advantage of the image quality predicted for the telescopes; the pixel fields of view for the currently planned instruments are typically 0.05″ to 0.15″. The highest spectral resolution envisaged is 120,000 for the High Resolution Spectrograph. The high sensitivities achievable with the Gemini instruments for astronomical observations demand correspondingly good calibration frames, so that the signal/noise ratios of the observations are not degraded by the calibration. These ambitions make providing a calibration frame a considerable challenge.

A good flat-field source has uniform illumination and has sufficient flux for a high signal/noise flat to be observed in a short time. However, field uniformity and transmission place imposing constraints on the calibration unit design, which must be reconciled. The requirements on the flat-fielding accuracy for imaging is driven by the photometric accuracy required- the demands of accurate sky subtraction apply equally to imaging and spectroscopy. In the most severe cases, a uniformity of 0.1% is required over spatial scales of a few arcseconds. Arc lamps for wavelength calibration must be bright enough to provide enough photons through the narrow slits of the spectrometers. In optical astronomy, the use of dome and sky flats is widespread. The changing, spatially and spectrally structured infrared sky background makes this technique unsuitable for infrared astronomy, and the requirements for the optical instruments currently proposed for Gemini cannot be met by dome flats. This is the strongest driver for the facility calibration unit. Ideally, the flat-field must be imaged along the identical path to the astronomical field, so that it is subject to the same vignetting as the science field. To comply with this, the calibration unit will have the capability of feeding the beam directly to the instruments or through the AO unit.

All the instruments will take as a flat-field a continuum source located in the calibration unit. The etendue of commercial continuum sources is not well matched to the large field instruments (e.g. the etendue of commercial deuterium lamp is 0.12mm^{2}sr compared with 3.3mm^{2}sr for an instrument with a one arcminute field), so a diffuser or integrating sphere must be used to fill the field. Integrating spheres are also routinely used for applications where a uniform (or Lambertian) source is required. Light from the source is reflected many times on the inner surface of the sphere, designed to act as a diffuse scatterer, emerging at an output port as a uniform field. However, integrating spheres are very inefficient, and transmissions of a few percent are typical, rendering this solution is unsuitable for the Gemini calibration unit.

The high spatial and spectral resolutions of the spectrometers mean that the physical size of the slits is very small. Clearly, a bright calibration lamp coupled to an efficient optical train is required to provide the photon flux at the detector. Figure 4 shows the flux required for several instruments at the focal plane and the spectral radiance from some typical calibration sources. The instruments illustrated are the most demanding; the calculation is for a signal/noise ratio of 1000 in 20s. The High Resolution Optical Spectrograph and the Near Infrared Spectrograph drive the throughput- transmissions of about 40% are required to illuminate these instruments. For the Gemini calibration unit, a novel light diffuser has been designed, which netains some of the scattering properties of the integrating sphere, while seeking to increase the transmission.

4.1 The Calibration Unit Optical Design

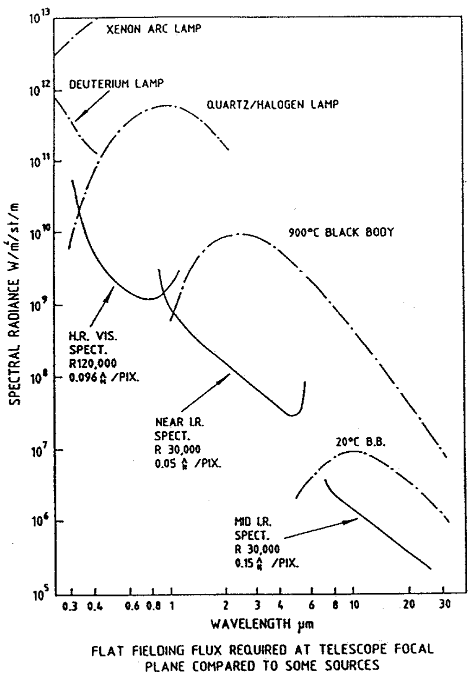


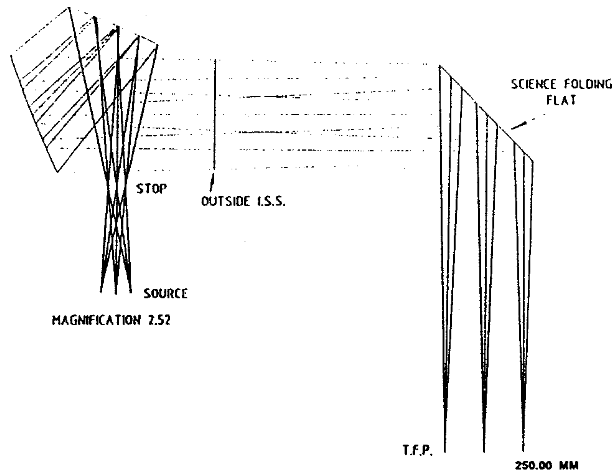
Figure 4: Flat-fielding fluxes required by the most demanding Gemini instruments.

As mentioned in Section 3, the module housing the calibration unit is part of the a+g unit; its location is shown in Figure 3, with a schematic of the calibration unit optics.

The pupil imaging optics are shown in Figure 5. Both the size of the optics (the calibration unit is 2m from the telescope focal plane, so the 7′ field has a diameter of 260mm) and the need for broad wavelength coverage impose an all-reflective design for the pupil imaging optics. The two mirror system shown has better image quality than a single mirror, although an off-axis design is required to produce a large unvignetted field. This optical design produces an exit pupil at the position of the telescope pupil.

The novel diffuser proposed for the Gemini calibration unit is shown in Figure 6. Integrating spheres have low transmission due to the large number of reflections from the walls of the sphere, but also due to the fact that light is emitted at the exit port into a hemisphere, but the amount of light entering the instrument is defined by the f/number of that instrument. This results in a geometrical reduction of the flux by factors of ~50. The essence of this diffuser is that it concentrates light into a cone with the correct etendue for the instrument, eliminating this factor.

Light from the calibration lamp is focussed on a mirror at the position of the aperture stop and reflected to fill a reflective diffuser. The beam is then scattered in the direction of the stop; light which does not pass through the stop (into the pupil imaging optics) is returned by an oblate spheroid mirror to the diffuser. Ray tracing of this arrangement has shown that transmissions of 40% are achievable. Unlike a traditional integrating sphere, however,



TWO MIRROR ARRANGEMENT PUPIL IMAGING OPTICS

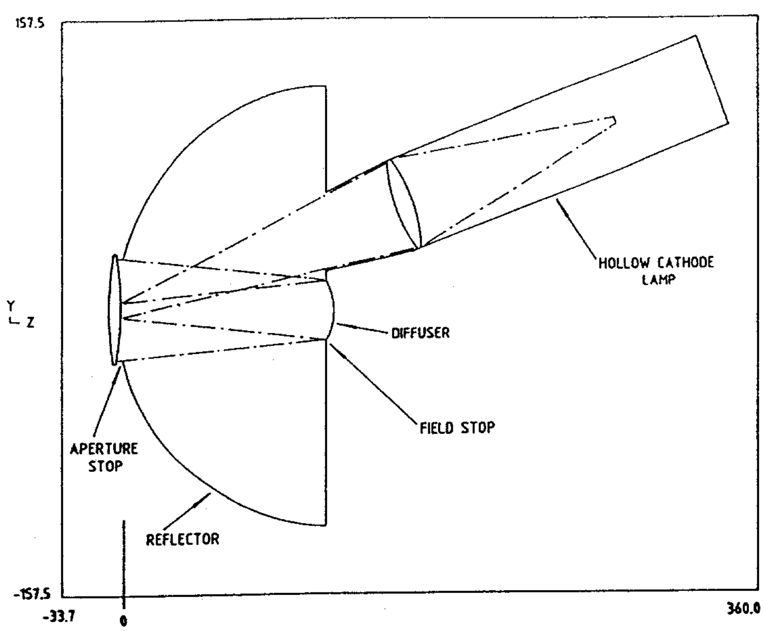
Figure 5: The pupil imaging optics for the Gemini calibration unit

multiple reflections by the diffuser do not increase the uniformity of illumination at the telescope focal plane, which then becomes dependent on the uniformity of the source.

More than one diffusing system will be required to produce the different field sizes required of the instruments. Each diffuser can be optimised for the wavelength range of the instrument using appropriate reflecting coatings to increase the transmission. This is most important, as diffusing surfaces which effectively scatter optical light are not suitable for use in the infrared.

The reference wavefront for calibrating the adaptive optics system is a simple pinhole, which produces a spherical wavefront. The optical image quality of the reflective optics passing the beam to the telescope focal plane is of great importance; the present design gives a 14$\hat{''}$ field with a Strehl ratio of 0.99 at the edge (λ=900nm). The optical design also allows for known aberrations to be introduced in the wavefront if required.

5. Managing the Queue



SCIENCE FIELD ILLUMINATED BY HOLLOW CATHODE LAMP

Figure 6: The diffusing optics for the Gemini calibration unit

Successful operation of the queue-scheduled mode will depend on the ability of the astronomer at the telescope to return from a night of observing with a complete set of calibration frames for the observations carried out. This requirement holds for 'classical' observing, at any telescope, and is a skill all observational astronomers must have. However, the complexity of the calibrations required for the Gemini telescopes, which may include taking into account the idiosyncracies of the principle investigator if the observations are carried out by a staff astronomer, requires careful monitoring of the data flow through the telescope sub-systems.

To devise a control and data handling system with no redundancy and yet which copes with the operation of the telescope and its many subsystems, a science driven approach to the design has been adopted using 'observational scenarios'. These scenarios are thought experiments, in which observations from the simplest (e.g. taking a bias frame) to the most complex (creating a spectral map of an extended region) are 'carried out' by the Observatory Control System (OCS) and the Data Handling System (DHS).

5.1 The Data Handling concepts

The control system for the Gemini Telescope is designed around four cooperating principal systems:

- The Observatory Control System (OCS) has responsibility for the operational user interfaces, science planning, scheduling, and execution, including the sequencing of the principal systems during execution of an observation.
- The Data Handling System (DHS) is responsible for data transport, organization, storage, and presentation.
- The Instrument Control Systems (ICS) have the responsibility for managing the control of the indivi 'dual instruments for data collection.
- The Telescope Control System (TCS) manages the telescope and enclosure to provide the best possible conditions for data collection by the instruments.

The OCS and DHS must work together to ensure that calibration data is associated with the proper science data processing, and to avoid expending resources on unnecessary calibrations. Wherever possible, calibrations are shared between observations. To this end, the DHS maintains a database of data and calibrations in a form suitable for rapid searching, retrieval and examination. The OCS provides support for attaching calibrations from this database to observations.

Each instrument that is in use has a data storage server running as part of the DHS to collected both image and header information from the instrument. The storage server is responsible for inserting t is information into the database. In addition, the DHS provides 'quick-look' display servers capable of quickly providing partially reduced data to the observers during an observation. These servers allow the observer to make qualitative assessments on the success of an observation in a timely fashion.

A flow chart showing the progress of a typical observation submitted to the observing queue is presented in Figure 7. An astronomer with an accepted observing proposal defines the programme of observations to be carried out. This programme may consist of many observations, with one or more instruments, including the calibration frames required (e.g. bias, dark, flat-field). The astronomer also specifies the instrumental configuration, provides notes on acquiring the object (e.g. through the instrument) and subsequent guiding (e.g. position of guide stars) and the requirements on the observing conditions (acceptable values of r_o). Once this is completed, the observation is submitted to the queue, where it resides in the Observing Database, a database containing both 'submitted' to 'completed' observations. The astronomer can gain access to this database to check on the status of the observation or examine that data if it is completed.

During the night of observing, the queue is assembled and maintained by an operator at the telescope. In deciding which submitted observations ' to select from the Observing Database, several pieces of information are relevant: the grade of the programme, the coordinates of the object, the observing conditions, the availability of the instrument and whether the required calibration frames are already available in the database of observations. Once an observation has been selected and observed, any calibration frames taken are stored in the database where they may be used for the next programme. The observations are reduced using pipelined reduction software, so that the operator and observer can assess the data quality. This also provides information to update the observing conditions. Finally, a completed observation is both submitted to the Observations Database (this time labelled 'completed') and to the Gemini Data Archive.

The scenarios are also used to test the Operational Concept Definitions (OCDs), which detail the behaviour of each of the subsystems and verify that the necessary interfaces between exist and that the flow of data through them is well understood. Figure 8 shows a schematic of this process.

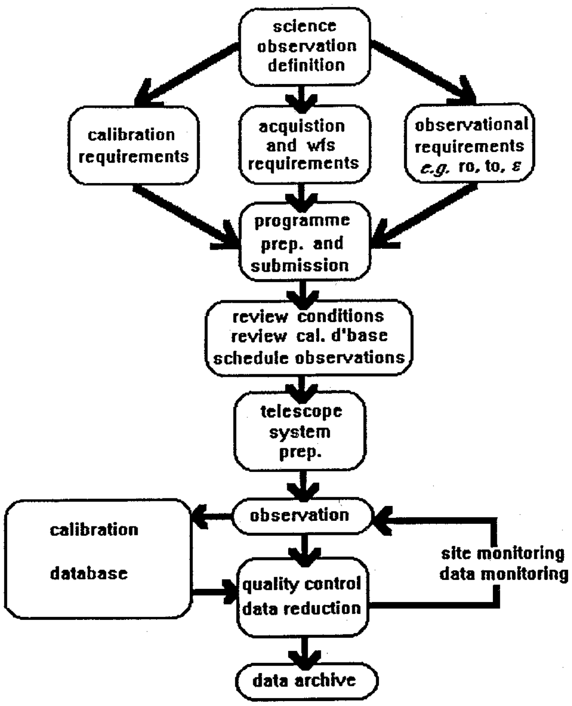


Figure 7: The progress of a typical observation

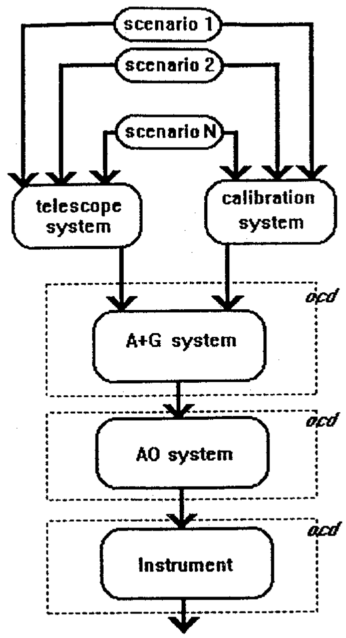


Figure 8: The scenarios test the OCD

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